STUDIES ON THE MORPHOLOGY OF JAPANESE SEA-STARS[1]

I. Anatomy of *Henricia sanguinolenta* var. *ohshimai* n. var.

BY

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(*With 1 Plate and 30 Text-figures*)

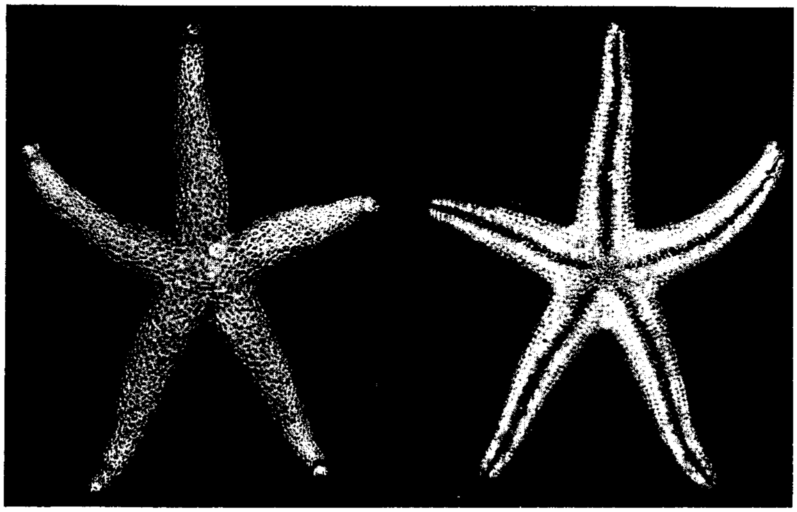
In comparison with reports concerning the external anatomy of sea-stars, those about their internal anatomy are very meagre. In the classification of the Asteroidea, external characters are chiefly discussed by recent workers. The writer, therefore, at the suggestion of Prof. Tohru UCHIDA, is engaged in studies on the comparative anatomy of Japanese sea-stars in order to investigate the relations between their external and internal characters. The present paper is a report on the anatomy of a sea-star belonging to *Henricia*. Materials used in this research were collected by the writer in the vicinity of the Amakusa Marine Biological Station, during his sojourn from April to October, 1933.

The writer must express his cordial thanks to Prof. Tohru UCHIDA for his kind guidance and is also indebted to Prof. Hiroshi OHSHIMA, director of the Amakusa Marine Biological Station, for giving him much valuable advice and permission to use his well-equipped library. The writer's hearty thanks must be extended to Messers. K. BABA and H. IKEDA, who showed great kindness in various ways during his sojourn at the Marine Biological Station.

1) Contribution No. 83 from the Zoological Institute, Faculty of Science, Hokkaido Imperial University.

External Aspect

Rays five, moderately long, thick at the base and generally recurved at the extremity. Disc moderately swollen (Text-fig. 1).

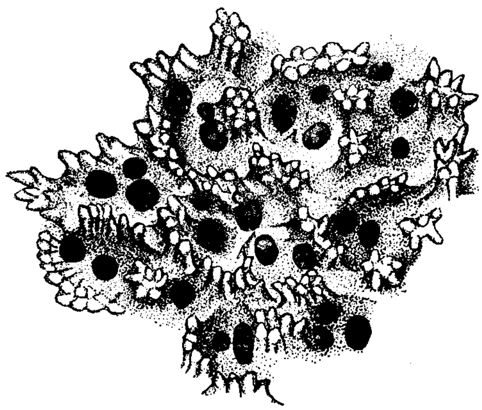


Text-fig. 1. Normal specimen, viewed from abactinal and actinal sides, about natural size.

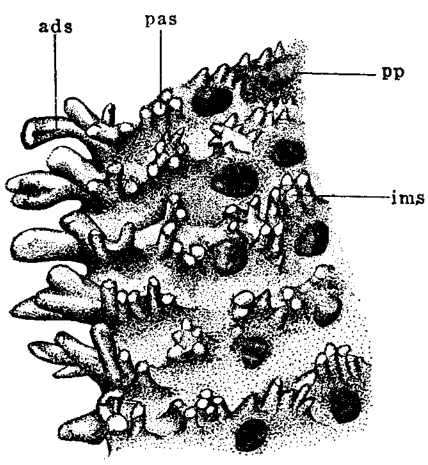
Measurements made from 22 specimens are as follows:

Specimen No.	R (mm)	r (mm)	R : r	arm base (mm)
1	19	6	3.1	7
2	22	7	3.1	8
3	24	7	3.4	8
4	27	7	3.8	8
5	29	7	4.1	8
6	29	7	4.1	8
7	30	7	4.2	8
8	31	7	4.4	8
9	31	8	3.8	9
10	34	8	4.2	9
11	34	8	4.2	9
12	34	8	4.2	9
13	35	9	3.9	9
14	35	9	3.9	10
15	36	9	4.0	10
16	36	9	4.0	11
17	38	10	3.8	11
18	38	9	4.2	11
19	40	9	4.4	10
20	40	10	4.0	11
21	40	11	3.6	12
22	43	10	4.3	11

Abactinal skeleton composed of a great number of small ossicles in various forms, which are united endwise into a fine-meshed reticulated skeleton. No carinal row observable. These ossicles are covered with small, slender, rough-tipped spines, 4–13 spines making groups, generally arranged in a single or double rows. Papular areas, surrounded by spine groups, fairly large, deeply sunken, each with 1–4 papulae. These areas are often more or less divided by skeletal pieces bearing one or two small spines (Text-fig. 2). Inferomarginal plates arranged in a regular longitudinal series, transversally elongated and each with 6–12 small slender spines. Superomarginal plates scarcely distinguishable from other dorso-lateral plates. When distinguishable, they are arranged in a longitudinal series, each with 5–10 spines and are not so elongated as in inferomarginals. Distally both marginals converge and are arranged in parallel, but in the proximal portion of the ray they gradually diverge; and in large specimens two inter-marginal rows are interpolated, one of them extending beyond the half length of the ray. The marginals and intermarginals are

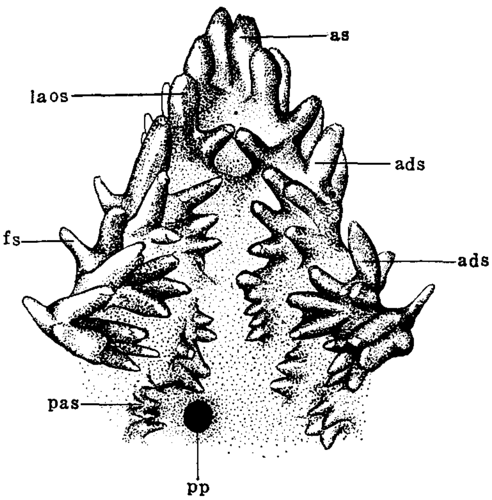


Text-fig. 2. Abactinal surface of middle portion of ray. ×15.

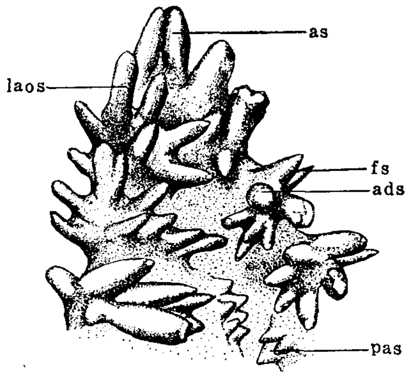


Text-fig. 3. Actinal surface at middle length of ray. ×15; ads adambulacral spine, ims inferomarginal spine, pas peractinal spine, pp papular pore.

separated from each other by a longitudinal series of papular areas, each containing a papula. Adambulacral plates carry about 5–8 large spines, generally arranged in a zig-zag or two irregular transverse rows, decreasing in size from the inner towards the external one. They are often arranged in two parallel transverse rows or in one transverse series. The larger spines are usually compressed, blunt at the tip, sometimes clavated or bifid. The innermost one, the furrow spine, arranged in a longitudinal series from the base to the tip of the ray, is directed somewhat obliquely across the furrow. Peractinal plates, each with small, slender, rough headed spines (3–7) arranged in a distinct longitudinal row, opposite in position to each adambulacral, much smaller than inferomarginals and disappeared near the tip. Between peractinals and inferomarginals there is a distinct row of papular areas, each with a papula (Text-fig. 3). Along the proximal half length of the ray a series of the second row of interactinals is present. Apical or peroral spines, two or three in number, are larger than any other spines (Text-figs. 4, 5).

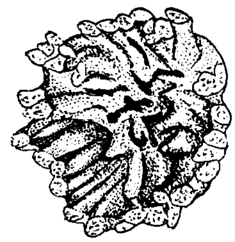


Text-fig. 4. Jaw and adjacent parts. ×15; ads adambulacral spine, as apical spine, fs furrow spine, laos lateral adoral spine, pas peractinal spine, pp papular pore.



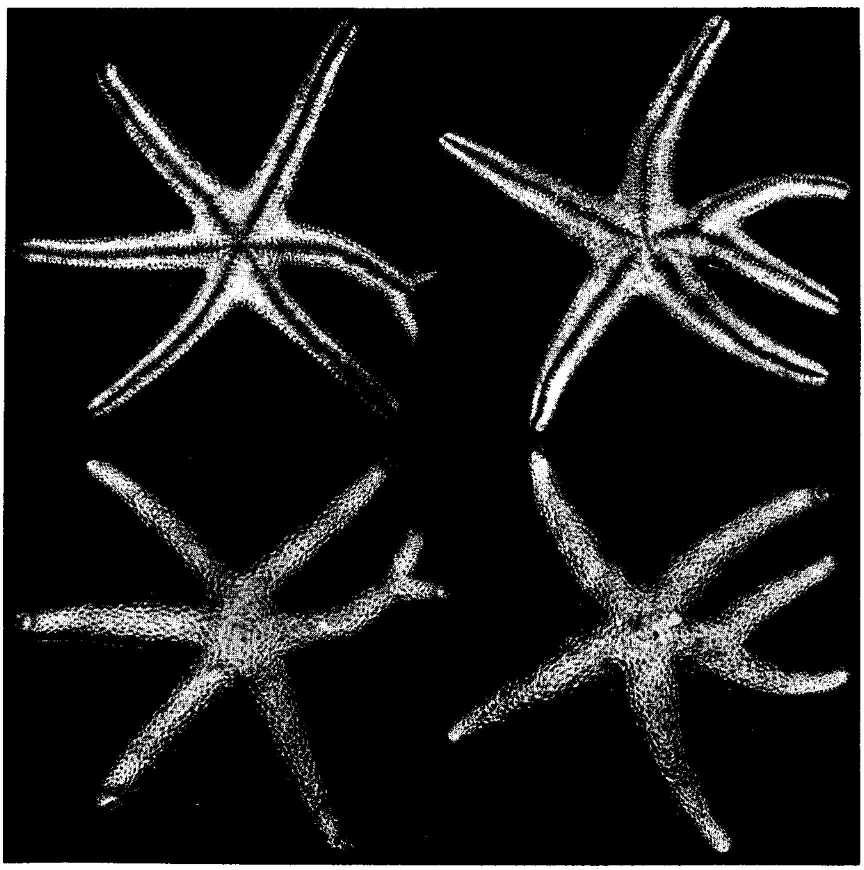
Text-fig. 5. Jaw and adjacent parts. ×15; ads adambulacral spine, as apical spine, fs furrow spine, laos lateral adoral spine, pas peractinal spine.

Madreporite, with spines, placed nearer the centre than the margin of the disc, circular or oval in outline, with external surface flat or concave (Text-fig. 6). Anal pore distinct and guarded with small incurved spines. Colour in life, orange yellow with large brown patterns.



Text-fig. 6. Madreporite. ×15.

Among specimens collected by the writer two are abnormal, with a bipartite ray. One of them, R 32 mm and r 8 mm, with five rays, and another, R 34 mm and r 6–8 mm, with six rays (Text-fig. 7). Four-rayed specimens rarely occur.

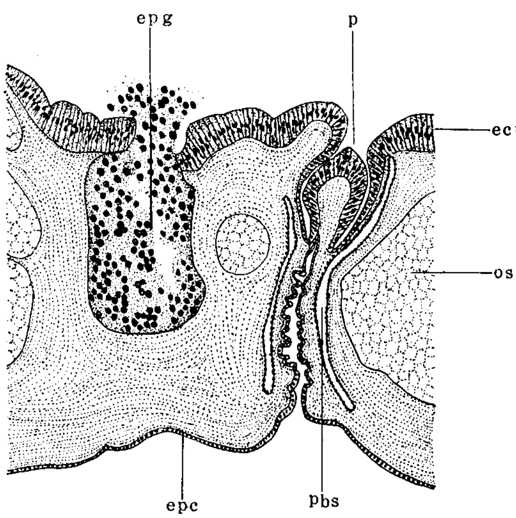


Text-fig. 7. Abnormal specimens, viewed from abactinal and actinal sides, about natural size.

From the characters mentioned above, the Japanese *Henricia* is identified with *Henricia sanguinolenta* in which several varieties are included. Among the varieties, the sea-star most resembles the type species, but differs from it in the following point: In the Japanese specimens papular areas are fairly large and abactinal spinulation is rather similar to that of *leviuscula* var. *annectens*, and smaller in size and different in colour. Marginals, especially in inferomarginals, are conspicuous, forming a regular series as in *sanguinolenta* var. *esschrichtii*. Adambulacral spines are fewer than in *sanguinolenta* and various in arrangement. Some of them are arranged in one zigzag or two irregular transverse series as in *sanguinolenta* var. *esschrichtii*, some in a transverse series as in *aspera*, and some in two paralleled transverse rows as in the type species. The Japanese sea-star, therefore, seems to be referable to a new variety of *H. sanguinolenta*, and the writer takes pleasure of naming the species in honour of Prof. H. OHSHIMA.

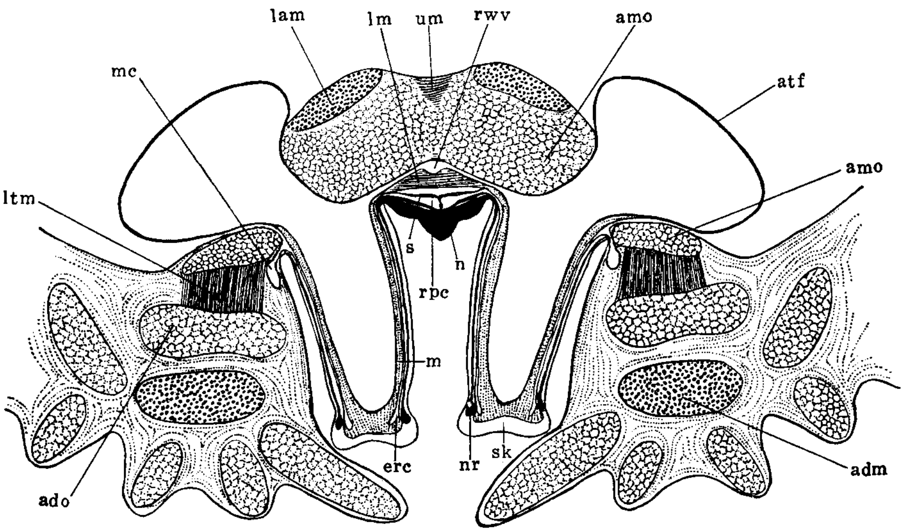
Internal Anatomy

Body wall. The body surface is completely covered with a layer of ciliated ectoderm, which also wraps the spines. It consists of a single layer of elongated columnar cells, containing numerous gland cells scattered amongst them. The greater part of the body wall is composed of so-called cutis and calcareous ossicles. In the abactinal wall of the disc and ray, numerous large glands are found amongst the cutis and ossicles. They are cy-



Text-fig. 8. Vertical section of abactinal wall of disc. ×75; ect ectoderm, epc epithelium of perivisceral cavity, epg epithelial gland, os ossicle, p papula, pbs peribranchial sinus.

lindrical in form and filled with numerous small rounded granula which are probably deformed epithelial cells. Each gland opens to the exterior through a small aperture (Text-fig. 8). According to the writer's observation, the sea-star in the living state secretes a sticky mucus-like substance from the abactinal surface, especially in an unfavourable condition. The glands have been reported in the abactinal wall of *Echinaster sepositus* (CUÉNOT, 1888) and *Henricia sanguinolenta* (ac-



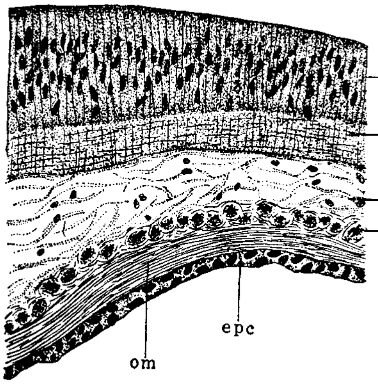
Text-fig. 9. Schema of transverse section of ray, near its proximal end. adm adambulacral longitudinal muscle, ado adambulacral ossicle, amo ambulacral ossicle, atf ampula of tube-foot, erc extention of radial perihaemal canal, lam longitudinal ambulacral muscle, lm lower transverse muscle of ambulacral ossicle, ltm lateral transverse ambulacral muscle, m longitudinal muscle of tube-foot, mc marginal canal, n radial nerve cord, nr nerve ring of tube-foot, rpc radial perihaemal canal, rwv radial water vessel, s septum, sk sucker of tube-foot, um upper transverse muscle of ambulacral ossicle.

cording to MORTENSEN and LIEBERKIND, 1928). The apical longitudinal muscles are greatly thickened along the mid-abactinal line of rays and are visible to the naked eye. The muscle cords of all the rays unite near the centre of the disc. In addition to the apical muscles there are found five kinds of muscles in the actinal wall of the body. They are

(1) the upper and (2) lower transverse muscles along the median line of the ambulacral ossicles; (3) a pair of well developed longitudinal muscles of the ambulacral ossicles which are not divided into two muscle bundles; (4) a pair of lateral transverse ambulacral muscles and (5) paired longitudinal adambulacral muscles (Text-fig. 9). By virtue of these muscles movement is made. The papulae are hollow processes of the body wall and devoid of calcareous deposits. At the base of each papula the peribranchial sinus is found (Text-fig. 8). The tube-foot will be described under the heading of the watervascular system.

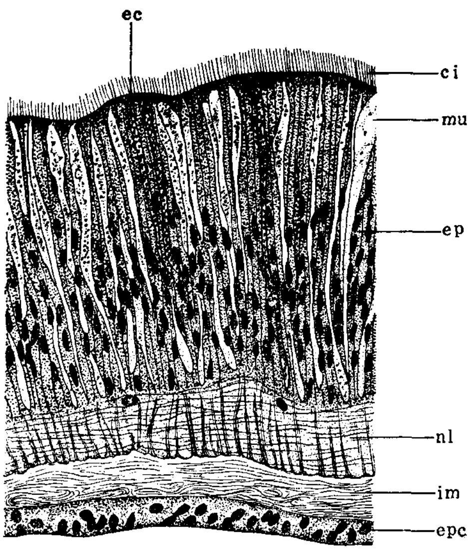
Digestive system. The system is composed of the mouth part, the stomach, the hepatic caeca, the intestine, the rectal sac and the rectum. At the centre of the actinal surface of the disc is situated a soft circular membraneous peristome which is surrounded by ossicles of bases of rays and is armed with peroral and adoral spines. In the centre of the peristome opens the mouth which is extensible according to the contractivity of the muscles surrounding it (Pl. I, fig. 2). The oesophagus is a short cylindrical passage and is connected with the stomach. In this species the stomach is rudimental and is furnished with five pairs of retractor muscles which originate, one pair in each ray, along the sides of the axial ridge (Pl. I, fig. 2). Differing from those of *Asterias rollestoni*, etc., which form thin fibrillated membraneous bands, these muscles are represented by considerable thick muscular bands and inserted in the lateral wall of the stomach. In the aboral view, the cardiac portion of the stomach is completely hidden by the hepatic caeca, rectal sac, etc. The cardiac stomach of following species, *Patiria pectinifera, Certonardoa semiregularis, Astropecten polyacanthus* and *Asterias rollestoni*, etc., is found to occupy almost all the oral portion of the disc cavity and is projected radially into the cavities of the rays, forming deeply folded cardiac pouches. In this species, however, the pyloric portion of the stomach is comparatively large, and is continuous with the proximal ends of the hepatic caeca (Pl. I, fig. 3). It is not of a flat pentagonal form in the aboral view, as is found in *Astropecten polyacanthus* and *Asterias rollestoni*, etc. When a ray is cut off, a pair of the diverticulated hepatic caeca are observed on the sides of the median line of the ray. They are suspended in the cavity of the ray by two mesenteries attached to the inner surface of the aboral wall, extending throughout the base to the tip of the ray (Pl. I, fig. 3). Their colour, in life, is reddish yellow. Each caecum has a spacious median canal which is elongated dorso-ventrally in cross-section, and the wall is thin and folded. From both dorso-lateral sides of the median canal branch out a large number of diverticula, which are beset with secondary and tertiary lobes and communicate with the median canal through the slit-like aperture (Pl. I, fig. 1). Near the base of the ray these diverticula are not found, each caecum being separately led into the pyloric portion of the stomach and not by a common duct, as is observed in *Asterias rollestoni* and *Astropecten polyacanthus*, etc. The proximal portion of the median canal, which is destitute of the diverticulum, is widened and at once connected with the pyloric portion of the stomach. This portion of the stomach is constricted horizontally in the central part of its aboral surface. This constriction is much more marked than that between the pyloric and cardiac portions of the stomach, and is a rudimentary intestine, through which the pyloric stomach leads into the rectal sac. The rectal sac is composed of lobular caeca radially disposed, some of them giving off two or three branches. The cavity of each caecum communicates with the others in the central portion of the rectal sac. The colour of this organ is yellowish brown. According to the individual the number and size of the caeca vary considerably. Near the centre, the rectal sac leads into the rectum (Pl. I, figs. 3, 4). The rectum is a short and narrow tube. Through it the rectal sac ends in the anus, which lies near the centre of the disc and is guarded by several incurved spines on the abactinal surface.

The integument of the peristome is not calcified, composed of ectoderm cells which are much longer than those of the general body surface. Beneath the ectoderm layer are present delicate nerve fibres which are continuous with the circumoral nerve ring on the periphery of the peristome (Text-fig. 26). Under the nerve layer is situated a connective tissue, fibres of which form a spongy network. This tissue is thickest around the mouth and becomes gradually thinner towards the periphery of the membrane. Next come two layers of muscular fibres, the inner concentric around the mouth and the outer radial. Both muscle layers are thickest around the mouth, like the connective tissue. The outer muscular layer is in contact with the epithelium formed by a single layer of cubical cells and lining the body cavity (Text-fig. 10).



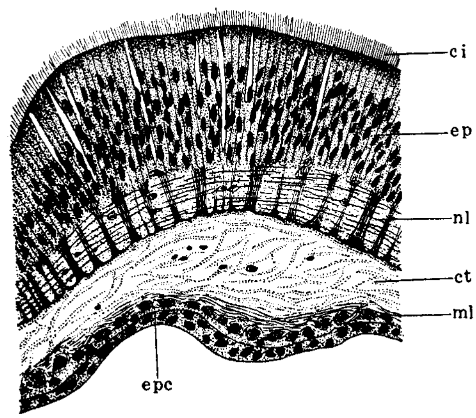
Text-fig. 10. Vertical section of peristome. ×200; ct connective tissue layer, ect ectoderm, epc epithelium of perivisceral cavity, im inner muscular layer, nl nerve layer, om outer muscular layer.

The epithelium of the peristome near the oesophagus is distinctly ciliated and contains long mucous cells. The connective tissue and the two muscular layers, especially the inner one, are thin. In the cardiac portion of the stomach the epithelium becomes thick and is slightly folded. Among the columnar cells of the epithelium are found numerous large mucous cells and a large number of granulated gland cells well-stained by eosin. These cells are spindle-like or elongated rod-like in form. Towards the pyloric portion of the stomach, the mucous cells become fewer and gradually disappear, and the epithelium is less folded. Under the epithelium



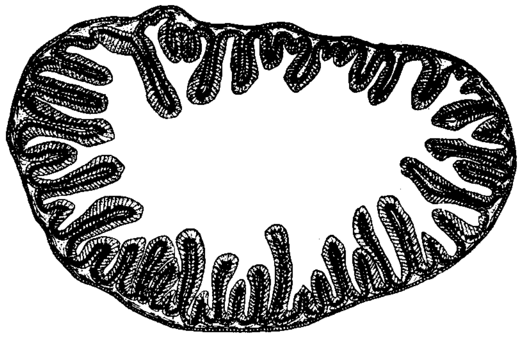
Text-fig. 11. Vertical section of cardiac stomach. ×550; ci cilia, ec eosinophilic gland cell, ep epithelium, epc epithelium of perivisceral cavity, im inner muscular layer, mu mucous cell, nl nerve layer.

is situated a nerve layer which is perpendicularly traversed by many fibres arising from the lower end of the epithelial cells and bounded together in bundles. Under the nerve layer only the inner muscular layer of uniform thickness is present. In the epithelium of the cardiac stomach neither connective tissue nor an outer muscular layer are found. The inner muscular layer is in contact with the epithelium of the perivisceral cavity (Text-fig. 11). The pyloric portion of the stomach resembles in general the cardiac portion, but differs in having a weak muscular layer, the granulated eosinophilic gland cell suddenly increased, and fewer mucous cells. In the intestine, a connective tissue is well developed under the nerve layer. There are two layers of muscular fibres: the outer circular and the inner longitudinal. A large number of mucous cells may also be observed. The nerve layer is apparently similar to that of the stomach. The outer muscular layer is in contact with the epithelial lining of the perivisceral cavity (Text-fig. 12). According to CHADWICK (1923), however, the muscular fibres are not found in the intestine of *Asterias rubens*, and, moreover, in his figure (Pl. IV, fig. 37) of the longitudinal section of this organ the nerve layer is not shown. In the rectal sac the epithelial lining is strongly folded into the lumen of the rectal sac (Text-fig. 13). Near the intestine a number of mucous cells are present. Though the two muscular layers are present, in some places it is difficult to distinguish these two layers, the fibres being irregularly arranged. The outer layer seems to be circular or oblique, while the inner layer is longitudinal or oblique. The connective tissue is weakly developed,

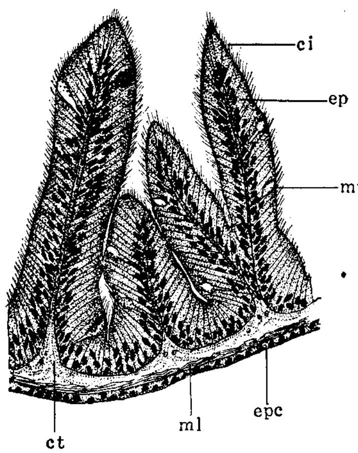


Text-fig. 12. Longitudinal section of intestine. ×200; ci cilia, ct connective tissue, ep epithelium, epc epithelium of perivisceral cavity, ml muscular layer, nl nerve layer.

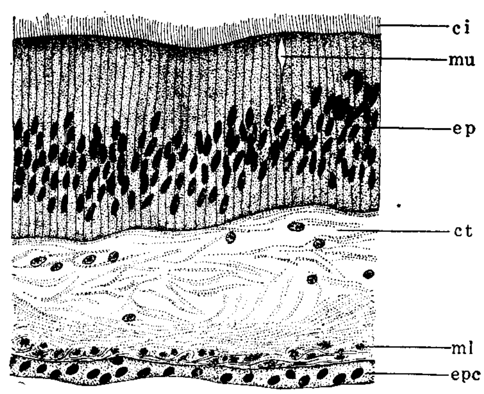
and the nerve layer is scarcely recognizable (Text-fig. 14). In the rectum the connective tissue is as well developed as in the intestine. Under the connective tissue is situated a longitudinal fibrous layer, and next comes the circular muscular layer which is in contact with the epithelium of the perivisceral cavity. In the epithelium are contained a number of mucous cells, but the nerve layer is as barely recognizable here as in the rectal sac



Text-fig. 13. Transverse section of lobe of rectal sac. ×50.

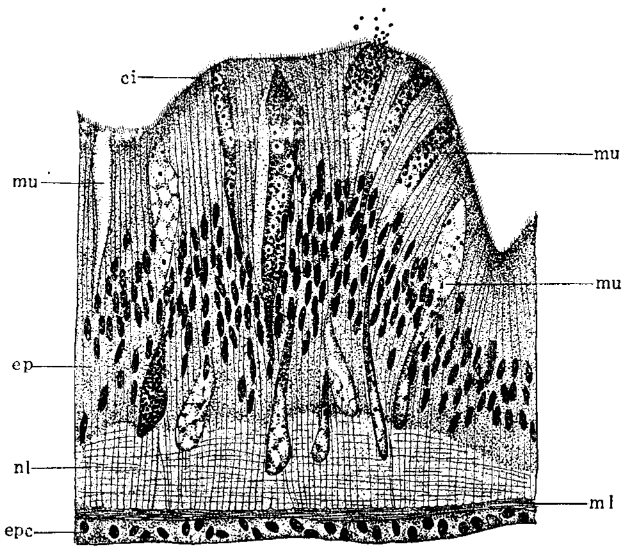


Text-fig. 14. Transverse section of rectal sac. ×200; ci cilia, ct connective tissue, ep epithelium, epc epithelium of perivisceral cavity, ml muscular layer, mu mucous cell.



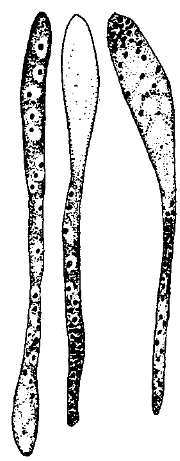
Text-fig. 15. Longitudinal section of rectum. ×550; ci cilia, ct connective tissue, ep epithelium, epc epithelium of perivisceral cavity, ml muscular layer, mu mucous cell.

(Text-fig. 15). The ciliated epithelial cells are continuous with that of the abactinal surface. In the hepatic caecum (Text-fig. 16) the thickness of the wall is almost due to the epithelium. Along the wall of the median canal there is a thin layer of muscular fibres, but on the wall of



Text-fig. 16. Transverse section of hepatic caecum, near free end of median canal. ×550; ci cilia, ep epithelium, epc epithelium of perivisceral cavity, ml muscular layer, mu mucous cell, nl nerve layer.

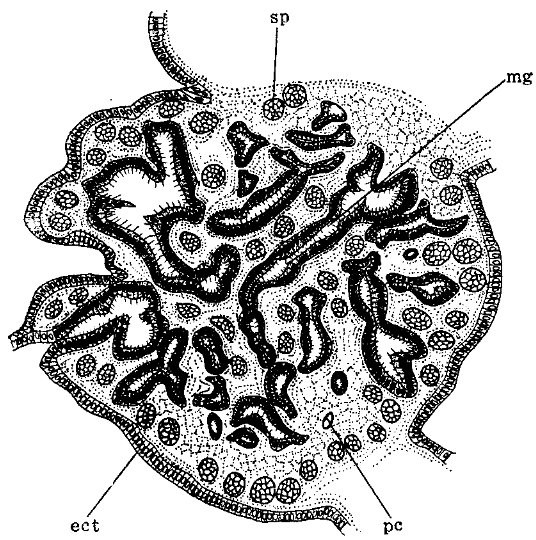
the diverticula no muscular fibres are found, the epithelial cells being directly fused with those of the perivisceral cavity. The epithelial cells are very slender and bear powerful cilia, especially in the median canal, except at the free end. The nuclei of the cells in the median canal are more densely crowded than those of the diverticula and are arranged in a thick row. The fibres arising from the epithelial cells are merged into the nerve layer. Among the epithelial cells are scattered numerous mucous cells, especially in the median canal (Text-fig. 17). On both the lateral walls of the median canal cell-masses are generally found paired, which are composed of several



Text-fig. 17. Mucous cells in median canal of hepatic caecum. ×550.

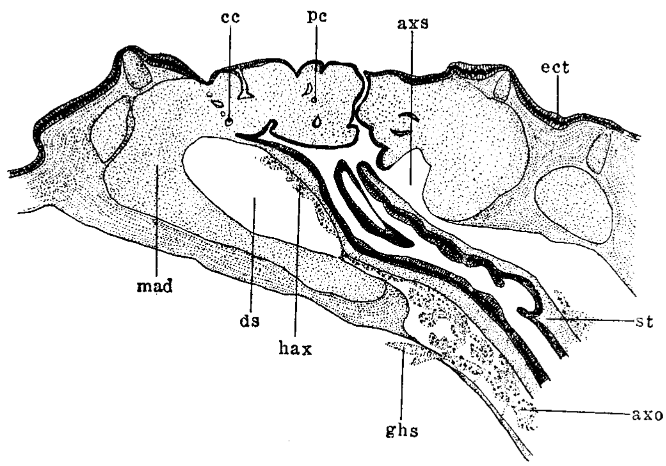
large mucous cells of hyaline or of a net-work appearance. In the free end of the canal the ciliation becomes weak, and many large mucous cells are often found to be crowded. These cells are thickly granulated, deeply stained by haematoxylin, net-work, or hyaline. In the epithelial cells of lateral diverticula a large number of granulated eosinophilic gland cells are also found, together with the mucous cells mentioned above. CHADWICK (1923) reported of *Asterias rubens* as follows : " many mucus cells of two kinds, the one large and rounded and so closely crowded together as to give sections a vacuolated appearance under a low power ; the other of much smaller size, oval form and present in smaller numbers." In this species, however, the mucous cells are very large and exceedingly elongated, showing hyaline, net-work or thickly granulated appearance. So far as the writer observed in the Japanese species, all the mucous cells are of one kind, since their appearances are changeable according to secretions.

Watervascular system. This system consists of various organs. The ring canal, nearly circular, forms the central portion of this system. It is placed on the aboral (inner) sides of the peristome, encircling the mouth part. From the ring canal issue tubular radial canals, one for each radius. The canals run in the space, formed by ambulacral plates and their lower transverse muscles (Text-fig. 9). Each radial canal ends in the lumen of an unpaired azygous tentacle at the tip of the ray. This tentacle is pointed at its distal end and elastic (Text-fig. 28). From the radial canal a large number of very narrow lateral canals branch out. Each lateral canal leads into the axis of the tube-foot (Text-fig. 9). The tube-feet are arranged in two rows along the median line of the ray. They are soft, of cylindrical in form and furnished with a suctorial disc which is absent in the terminal tentacle. At the base of each tube-foot, there is a small thin-walled vesicle, the ampulla of the tube-foot. The ampullae are arranged on each lateral side of the ambulacral plates in a series (Pl. I, fig. 2). On the inner wall of the ring canal, there are paired small brownish-coloured bodies in each interradius,—TIEDEMANN's bodies. It is noticeable that TIEDEMANN's bodies occur always in pairs in the interradius on both sides of the stone canal (Pl. I, fig. 2). The Polian vesicle is absent, as in *Asterias rollestoni*, *Lysastrosoma anthosticta*, etc. The ring canal connects with the stone canal in the madreporic interradius. The stone canal lodged in the axial sinus runs upwards and communicates with the madreporite. Throughout its length, the canal has a ridge projected into its lumen. The ridge arises from the opposite side to that in which the stone canal is attached to the axial organ, and is two-lobed in cross-section (Text-fig. 23). The ridge gradually diminishes towards the mouth and finally disappears at the junction of the stone canal with the ring canal. The same structure of the stone canal is already known in *Asterina gibbosa* and *Cribrella oculata* = *Henricia sanguinolenta*. In this species, the stone canal is attached to one of the free ends of the axial organ, and in its aboral portion is supported by mesenteries extended from the roof of the dorsal sac of the madreporite. The madreporite of this species is simple compared with that of *Asterias rubens* reported by CHADWICK (1923). The madreporite bears about 10–15 small spines on its concave external surface and is irregularly traversed by grooves, some of these grooves being continuous from the centre to the margin (Text-fig. 18). The number of the madreporic grooves is not so numerous as that in *Asterias*, *Patiria*, *Luidia* and *Certonardoa*, etc. When the madreporite is sectioned horizontally,



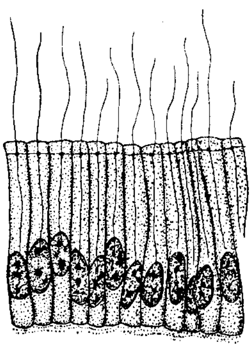
Text-fig. 18. Horizontal section of madreporite. ×30; ect ectoderm of body surface, mg madreporic groove, pc pore canal, sp spine.

many minute pores are recognized at the bottom of the grooves. They are the external openings of the minute pore canals. As the madreporite is not thick, the pore canals are very short and open directly into the collecting canals (Text-fig. 19), which run irregularly through the madreporite horizontally. The collecting canals open into the funnel-like aperture of the stone canal, and in this place, through a minute pore, the stone canal also communicates with the axial sinus (Text-fig. 19). The madreporite encloses a large lumen, the dorsal sac, in which the head process of the axial organ is situated. But so far as the

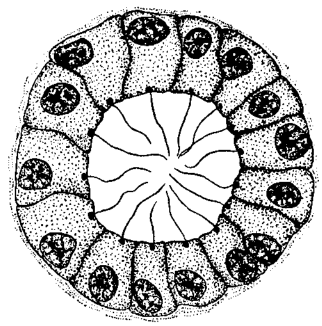


Text-fig. 19. Vertical section of madreporite and stone canal. ×30; axo axial organ, axs axial sinus, cc collecting canal, ds dorsal sac, ect ectoderm, ghs gastric haemal strand, hax head process of axial organ, mad madreporite, pc pore canal, st stone canal.

author's observation goes, the ampulla of the stone canal could not be recognized. The external surface of the madreporic groove is covered with columnar ciliated cells. Their nuclei, situated near the basal end, are more closely set than those of the general ectoderm, and are stained sharply with haematoxylin. Each cell has a long cilium with a basal granule near the periphery of the cell; from the granule issues a cilia-rootlet towards the basal line (Text-fig. 20). The ciliated cells of the pore canal are cubical and have rounded nuclei (Text-fig. 21). The histological nature of the collecting canals is closely similar to that of the pore canal. Into the stone canal the cells are again also columnar

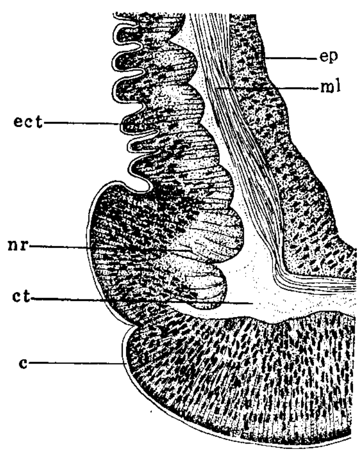


Text-fig. 20. Vertical section of epithelium of madreporic groove. ×1100.



Text-fig. 21. Horizontal section of pore canal. ×1100.

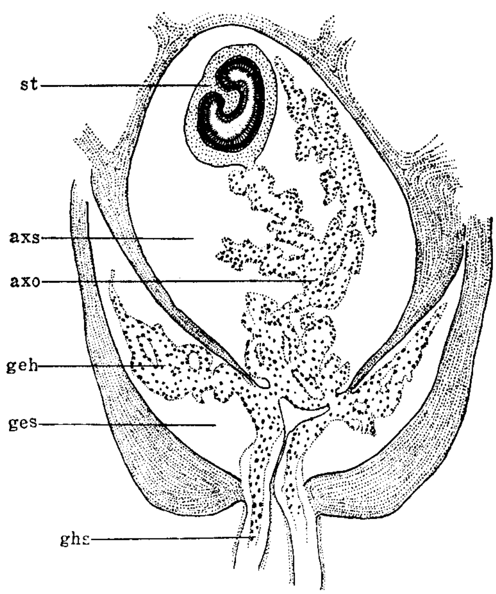
and contain elongated nuclei. These cells resemble those covering the madreporic grooves. The cells on the free edge of the ridge are considerably short and their ciliation is slightly weak. The TIEDEMANN's bodies are tubular, folded in cross-section and communicate with the ring canal (Text-fig. 26). In the tube-feet the ectoderm is covered by a thin cuticular layer. The nerve layer is well developed and can be traced in sections from the radial nerve cord towards the terminal sucker. The nerve layer is very thick and forms a well-marked ring near the terminal sucker. The longitudinal muscular fibres are well developed, and at the distal end of the tube-foot they



Text-fig. 22. Longitudinal section of free end of tube-foot. ×200; c cuticula, ct connective tissue, ect ectoderm, ep epithelium of tube-foot cavity, ml longitudinal muscular layer, nr nerve ring.

converge towards the centre of the disc. Near the sucker the connective tissue intervenes between the muscular layer and the ectoderm (Text-fig. 22). The muscular fibres of the ampulla are arranged perpendicularly to the perivisceral epithelium.

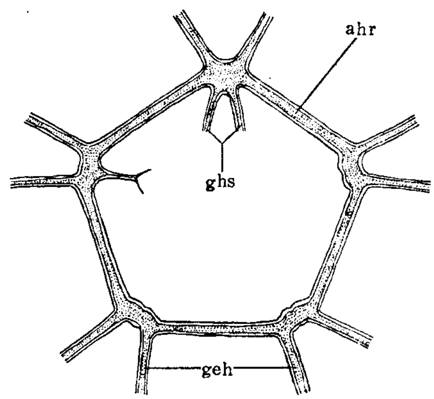
Perihaemal spaces. As already noticed, the axial sinus contains the stone canal and axial organ (Text-fig. 23). At its aboral end the stone canal communicates with the collecting canals of the madreporite and also through a pore with the axial sinus. At its oral end the sinus opens into a circular space known as the inner circumoral perihaemal canal. This canal, surrounding the mouth, is separated by a oblique septum from a larger outer circumoral perihaemal canal (Text-fig. 26). From this septum the vertical septum inserts into each radial perihaemal canal. The septum is T- or Y-shaped and has two lateral free ends (Text-fig. 27). In the place where the radial water vessel communicates with the tube-feet through the lateral branches, the free ends of the vertical septum extend laterally and also attach to both lateral margins of horizontal septum, the radial perihaemal canal being there divided into three parts (Text-fig. 9). The radial perihaemal canal invades each tube-foot as a lamellar sinus between the nerve and muscular layer of the tube-foot. These sini are connected with the marginal canal running along the margin of the ambulacral furrow. In the places corresponding to the



Text-fig. 23. Horizontal section of madreporic interradius, near its aboral end. ×30; axo axial organ, axs axial sinus, geh genital haemal strand, ges genital perihaemal sinus, ghs gastric haemal strand, st stone canal.

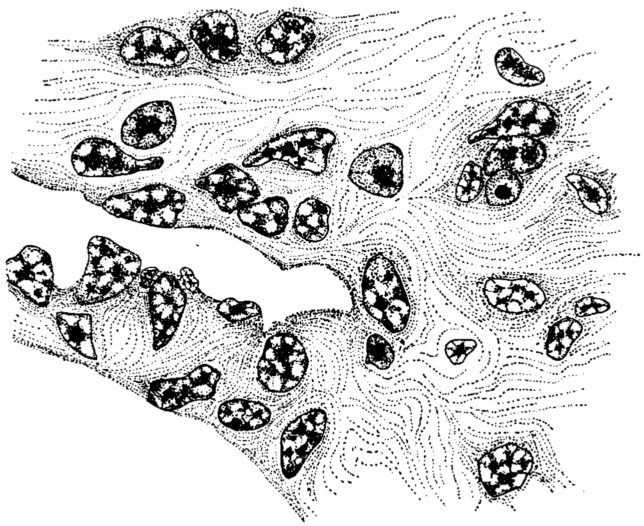
tube-feet, the marginal canal always communicates with the periviscera cavity through small canals. The aboral perihaemal sinus is a pentagonal space, from which paired genital sini are given off one into each ray (Text-fig. 23). In the madreporic interradius, no communication was found between the axial and the aboral sinus. The perihaemal spaces enclose the haemal tissues.

Haemal system. This is known as the blood vascular or lacunar system and has been studied by many investigators. The axial organ is a fold projecting from the wall of the axial sinus. By means of a mesenteric fold the axial organ is attached to the wall of the axial sinus. It is a remarkable gland-like organ, and has been called under various names by several investigators. Near its aboral end it extends into the head process, projecting across the cavity of the dorsal sac (Text-fig. 19). The axial organ is continuous near its aboral end with a subpentagonal haemal tissue which is called as the aboral haemal ring. The ring is placed in the muscular tissue of the inner surface of the body wall. From each corner of the ring, two strands are given off to the adjacent rays, with their extremities merged into the gonads (Text-figs. 23, 24). Very close to its junction with the axial organ it gives off two axial strands (Text-figs. 23, 24) which are the "gastric haemal tufts" of GEMMILL (1914) or the "gastric strands" of DURHAM (1892). It was confirmed for *Asterias rubens* by GEMMILL (1914) and CHADWICK (1923) that they penetrate the wall of the axial sinus, project into the perivisceral cavity and come in contact with the wall of the cardiac portion of the stomach. In this species, however, the fact could not be observed. The strands are



Text-fig. 24. Schema of aboral haemal ring. ahr aboral haemal ring, geh genital haemal strands, ghs gastric haemal strands.

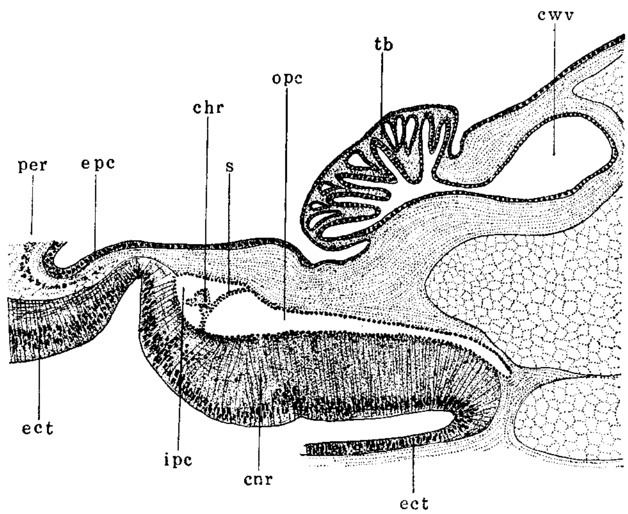
in contact with the inner surface of the body wall and are not conspicuously tuft-like, as figured (Pl. II, fig. 22) by CHADWICK (1923). It is also observed that from one corner of the aboral haemal ring only one strand is set off to the opposite side to the genital strands. The axial organ is broad in the aboral portion and gradually becomes narrow towards its oral end. The colour, in life, is pale brown. It consists of tubular anastomosed strands, its wall being composed of an exceedingly



Text-fig. 25. Transverse section of a part of axial organ. ×2500.

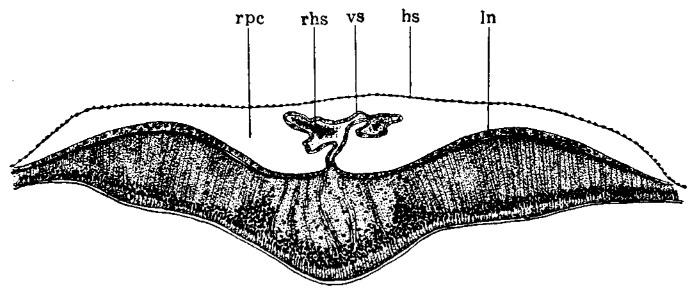
thin membrane. The organ is crowded with wandering cells, some of them having the appearance of leucocyte (Text-fig. 25). From vertical sections of the mouth part, the oral end of the axial organ is continuous with the circumoral haemal tissue which rests upon the oblique septum separating the outer circumoral perihaemal canal from the inner one (Text-fig. 26). The radial haemal tissue is the extension of the circumoral haemal tissue. It rests upon the vertical septum in the radial perihaemal canal (Text-fig. 27).

Nervous system. The nervous system is generally divisible into three systems, the ambulacral, the deep-oral and the apical nervous systems. MEYER, who (1904) described in detail the structure of the nervous system of *Asterias rubens*, denied the presence of the apical nervous system. So far as the author's observation goes, the apical system could not be found in this Japanese species. The nerve ring of the ambulacral system is situated in the circumference of the peristome, forming a pentagonal thickened ridge. From the nerve



Text-fig. 23. Vertical section of mouth part. ×100; chr circumoral haemal ring, cnr circumoral nerve ring, cwv circumoral water vessel, ect ectoderm, epc epithelium of perivisceral cavity, ipc inner circumoral perihaemal canal, opc outer circumoral perihaemal canal, per peristome, s septum, tb TIEDEMANN's body.

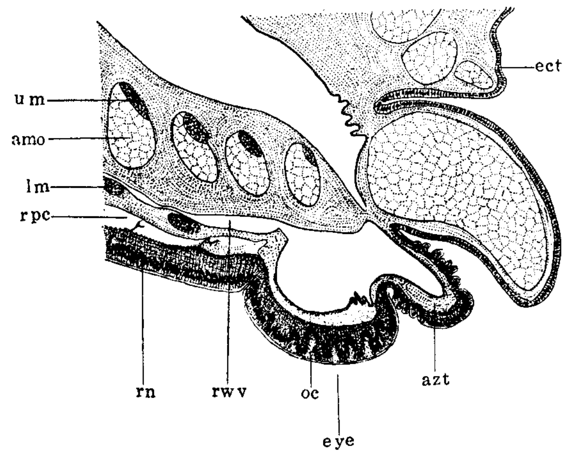
ring radiate the radial nerve cords, one for each ray. Between the rows of the tube-feet, along the roof of the ambulacral furrow, each radial nerve cord runs the entire length of the ray. At the distal part of the ray each cord ends in a red-pigmented optic cushion, the so-called eye-spot, which is found just below the azygous tentacle (Text-fig. 28). The transverse section of the mouth part shows that the body wall made of ectoderm cells suddenly becomes at first thick and folded, and again gradually thinner towards the peristome. The thickened portion corresponds to the circumoral nerve ring (Text-fig. 26). The transverse section of the ray shows that the paired ambulacral ossicles are fused to a plate by the upper and lower transverse muscular layers, and horizontal septum. The radial nerve cord is represented by a triangular thickening of the ectoderm at the proximal portion, and gradually becomes thin towards the tip of the ray. From the nerve cord issue nerve fibres into the ectoderm of the ambulacral groove and of the tube-feet. The radial perihaemal canal is enclosed by the horizontal septum and the radial nerve cord. The ectoderm cells found in the nerve cord are exceedingly columnar, covered with a thin cuticular layer, and have nuclei situated near the external surface.



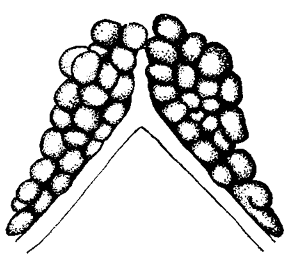
Text-fig. 27. Transverse section of radial nerve cord, about at middle length of ray. ×100 ; hs horizontal septum, ln LANGE's nerve, rhs radial haemal strand, rpc radial perihaemal canal, vs vertical septum.

The fibres of these cells extend into the underlying nerve layer (Text-fig. 27). In the sagittal section of the eye-spot the ectoderm layer corresponding to foldings forms several optic cups. At the opening of the optic cups a lens-like structure is observable (Text-fig. 28). The deep-oral system, LANGE's nerve, consists of a thickening of the oral wall of the perihaemal canal, and is separated from the radial nerve cord by a thin connective tissue-like layer. The nerve layer of the alimentary canal and the tube-feet have already been described.

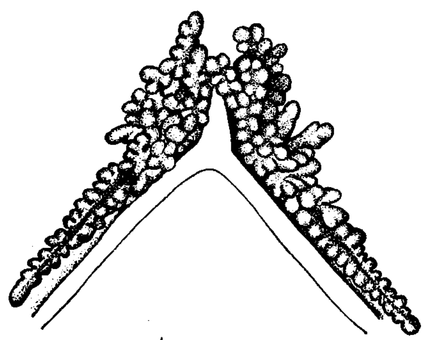
Reproductive system. Sexual difference is not distinct externally. A pair of gonads are found in each ray. The ovaries are distinguished from the testes by form and colour (Text-figs. 29, 30); the ovaries



Text-fig. 28. Longitudinal section of tip of ray. ×50; amo ambulacral ossicle, azt azygous tentacle, ect ectoderm, eye eye spot, lm lower transverse muscle of ambulacral ossicle, oc optic cup, rn radial nerve cord, rpc radial perihaemal canal, rwv radial water vessel, um upper transverse muscle.



Text-fig. 29. Ovaries in August. ×3.



Text-fig. 30. Testes in August. ×7.

reddish yellow and the testes uncoloured. Each gonad is attached to the dorso-lateral body wall in the interradius and opens to the exterior through a ciliated canal.

The internal character of the species may be summarized as follows. Cardiac portion of the stomach rudimental. Pyloric portion of the stomach continuous with the proximal portion of the hepatic caeca. Hepatic caecum with a spacious median canal, leading directly to the pyloric portion. Rectal sac comparatively large, simple in form, and composed of several radial lobes. Intestine rudimental. Anus present. The epithelium of alimentary canal and its appendages are ciliated, containing numerous gland cells. In the dorsal wall numerous epithelial glands are found. Polian vesicle absent. TIEDEMANN's bodies situated in pairs in each interradius. Madreporite simple in structure, collecting canals running irregularly through the madreporite horizontally. At the junction point of the stone canal with the collecting canals, the former communicates with the axial sinus through a minute pore. Ampulla of stone canal could not be found. Each tube-foot with an ampulla. Stone canal resembling in structure that of *Asterina gibbosa* and *Cribrella oculata = Henricia sanguinolenta*. The gastric haemal strands seem not to be connected with the cardiac portion of the stomach. Vertical septum has two free ends which extend to the lateral margins of the horizontal septum at the place of the tube-feet and dividing the radial perihaemal canal into three lumina. Radial perihaemal canal communicating with marginal canals which lead into the perivisceral cavity through small canals. The existence of the apical nervous system could not be proved. Ambulacral nervous system well developed.

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Plate I

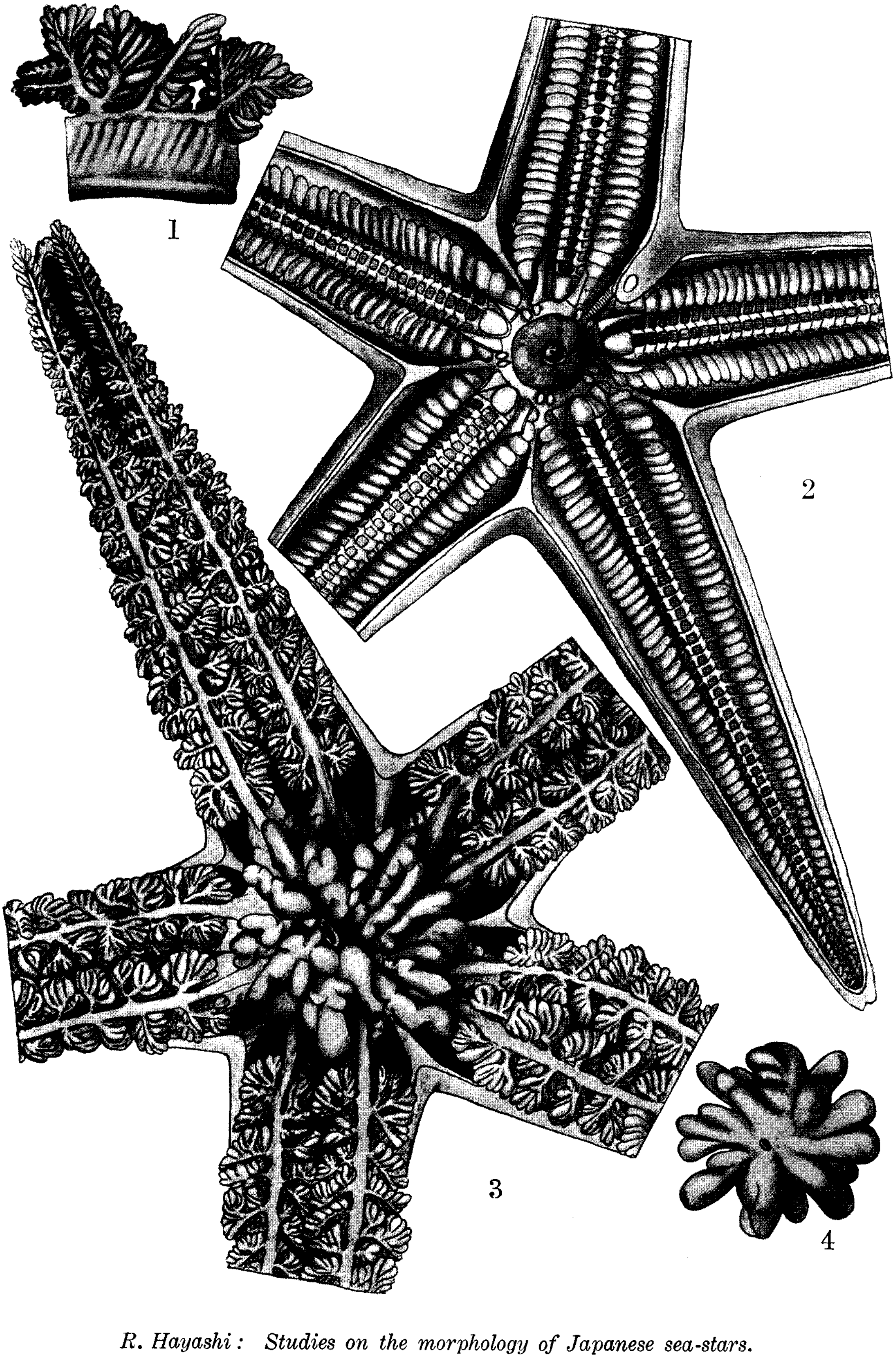
Explanation of Plate I

1. A part of hepatic caecum of *Henricia sanguinolenta* var. *ohshimai* n. var., viewed from lateral side. ×5.

2. Dissection of *Henricia sanguinolenta* var. *ohshimai* n. var. showing watervascular system. ×3.5.

3. Dissection of *Henricia sanguinolenta* var. *ohshimai* n. var. showing digestive system. ×4.

4. Rectal sac of *Henricia sanguinolenta* var. *ohshimai* n. var. ×5.



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