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

II. Internal anatomy of two short-rayed sea-stars, *Patiria pectinifera* (MÜLLER & TROSCHEL) and *Asterina batheri* GOTO

BY

Ryoji HAYASHI

(*With 1 Plate and 12 Text-figures*)

The two species, both pentagonal in form and widely distributed in Japan, closely resemble each other in their external forms in young specimens. So far as the writer's observation goes, these species are generally in agreement in the adult with each other concerning internal characters. They are, however, different from the genera such as *Asterias, Leptasterias* and *Lysastrosoma* belonging to the Forcipulosa and also from *Luidia* and *Astropecten*, both belonging to the Phanerozonia. They are also distinguished from *Henricia*, which belongs to the common order Spinulosa, especially in respect to the watervascular system and in some points of the digestive system. As for the external characters of these two species, S. GOTO (1914) has given a detailed description, so in this paper only the internal characters will be described.

The writer must express his cordial thanks to Prof. Tohru UCHIDA for his kind guidance and indebtedness to Prof. Hiroshi OHSHIMA and Messrs. K. BABA and H. IKEDA for giving him much valuable advice and great kindness in various ways during his sojourn at the Amakusa Marine Biological Station from April to October, 1933.

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Material

Patiria pectinifera examined by the writer were collected in the vicinity of the Amakusa and Oshoro Marine Biological Stations. The examples of *Asterina batheri* used in this study were collected in Amakusa. The former is generally found on sandy or rocky shores, while the latter dwells under stones near the tidal line.

Internal Anatomy

Body wall. The body surface of the two sea-stars is covered with a single layer of ciliated ectodermal columnar cells. Among them are scattered numerous mucous cells and eosinophilic granulated cells (Fig. 1), but no epithelial gland such as is found in *Henricia sanguinolenta* has been observed. The longitudinal muscles on the abactinal wall of the body are well developed. In each ray three muscle cords are visible to the naked eye on the inner side of the abactinal wall, meeting with others at the centre of the disc. One of them lies along the abactinal carinal line of the ray, and the other two run above the median canals of hepatic caeca. In the two species are present five kinds of muscles in the actinal side of the body as in *Henricia sanguinolenta* var. *ohshimai*; (1) the upper and (2) lower transverse muscles of the ambulacral ossicles, (3) a pair of longitudinal muscles of the ambulacral ossicles, (4) a pair of lateral

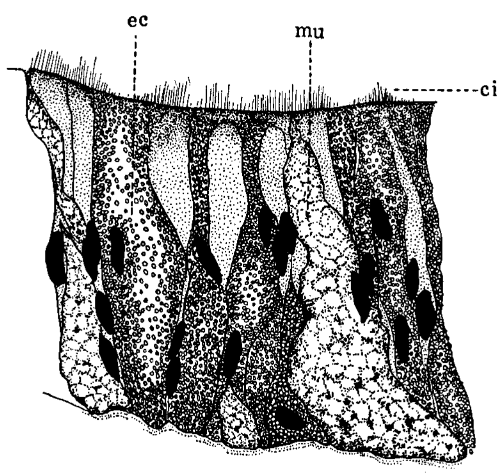

Fig. 1. *Patiria pectinifera*; abactinal ectoderm in vertical section. ×1300; ci cilia, ec eosinophilic granulated cell, mu mucous cell.

ambulacral transverse muscles and (5) paired longitudinal adambulacral muscles. The structure of papulae and tube-feet is quite similar to that found in *Henricia sanguinolenta* var. *ohshimai* and *Asterias rubens.*

Digestive system. The peristome of both the species is nearly pentagonal in form (Pl. IX, fig. 1), the cardiac portion of the stomach being well developed and occupying almost all the oral portion of the disc cavity. The cardiac portion projects radially into the proximal portion of the ray cavities, forming five deeply folded cardiac pouches, though that of *Henricia sanguinolenta* var. *ohshimai* is rudimental. Each cardiac pouch is furnished with a pair of very elastic retractor muscles which originate from the sides of the axial ridge (Pl. IX, fig. 2). By virtue of these muscles the cardiac portion of the stomach in everted condition is retracted through the mouth. The pyloric portion of the stomach is of a small flat pentagonal form in the two species and is relatively smaller than in *Astropecten* and *Asterias,* etc. (Pl. IX, fig. 5). From each corner of the pyloric portion of the stomach a pair of hepatic caeca issues separately, not having a common duct, into each ray cavity. They are suspended from the inner surface of the aboral wall by two mesenteries along both sides of the carinal line of ray. The hepatic caecum is similar in structure to that of *Henricia sanguinolenta* var. *ohshimai,* having a spacious median canal in both the species (Pl. IX, figs. 2, 4, 5), and is pale brown in colour in life. The intestine of the two species is rudimental. The rectal sac of *Patiria pectinifera* is composed of five botryoidal caeca interradially placed (Pl. IX, figs. 2, 3). The rectal sac of *Asterina batheri,* simpler than those of *Patiria pectinifera,* is composed of five interradially disposed lobular caeca, each with short lobular branches (Pl. IX, fig. 6). In both the species the lumen of the sac is conveyed outside through the rudimentary rectum and anus. The anus is situated near the centre of the disc.

Among the ciliated ectoderm cells are found eosinophilic granulated cells which are numerous in *Patiria pectinifera,* but few in *Asterina batheri.* Beneath the ectoderm layer is found the nerve layer composed of delicate nerve fibres which are continuous with those of the circumoral nerve ring situated on the periphery of the peristome. Under the nerve layer is situated a connective tissue, of which fibres do not display a spongy net-work as in *Henricia sanguinolenta* var. *ohshimai*. They are exceedingly muscular. In *Asterina batheri* the connective tissue is thickest around the mouth, becoming thin towards the periphery of the peristome, while in *Patiria pectinifera* it is not so thick around the mouth. In both the species here considered the connective tissue becomes thin towards the stomach. Beneath the tissue come two muscular layers; the inner concentric one around the mouth and the outer radial. The outer muscular layer is in contact with the epithelium lining the body cavity. The epithelium of the peristome becomes exceedingly thick towards the oesophageal region and is folded. The ciliated epithelium of the cardiac stomach is folded many times, containing numerous elongated mucous cells and a large number of eosinophilic cells. Under the epithelium is situated the nerve layer, traversed by numerous fibres arising from the lower end of the epithelial cells. The connective tissue is slightly recognizable in places. The muscles are in two layers, the inner one seemingly longitudinal and the outer circular. The latter is in contact with the epithelium of the perivisceral cavity. Towards the pyloric portion of the stomach the epithelium becomes gradually thin and less folded. It resembles in general the cardiac portion, but the muscular layer is weak and contains numerous granulated eosinophilic cells. The epithelium of the intestine is densely crowded with nuclei, having a large number of gland cells. The nerve layer is well developed. The connective tissue is also well developed, showing a spongy net-work which is better developed in *Patiria pectinifera* than in *Asterina batheri*. There are two layers of muscle fibres; the outer circular and the inner longitudinal. The outer muscular layer is in contact with the epithelial lining on the perivisceral cavity. Though the rectal sacs of the two species differ in external form, their internal structure is quite similar, resembling in general that of *Henricia sanguinolenta* var. *ohshimai*. In the rectum the connective tissue is comparatively well developed, the epithelium thin and containing a large number of gland cells. The muscular layers of this organ are divided into two; the inner longitudinal and the outer circular. There is also observed a weakly developed nerve layer continuous with that of the abactinal surface. Though the internal structure of the hepatic caecum resembles in general that of *Henricia sanguinolenta* var. *ohshimai,* there are not found any paired gland cell-masses on the wall of the median canal.

Watervascular system. The arrangement of the organ is similar to that of *Henricia sanguinolenta* var. *ohshimai.* The ring canal is pentagonal encircling the mouth part (in *Henricia sanguinolenta* and *Asterias amurensis* it is nearly circular), and the radial canals end each in the lumen of the azygous tentacle, running in the space formed by ambulacral plates and their lower transverse muscles. The radial canals communicate each with a tube-foot through a narrow lateral canal. The tube-feet, each with a suctorial disc, are arranged in two rows and have two ampullae, arranged in two series on lateral sides of the ambulacral plates (Pl. IX, figs. 1, 2). The Polian vesicles always occur one in each interradius except the madreporic one. The Tiedemann's bodies are situated in pairs in each interradius (Pl. IX, Fig. 1).

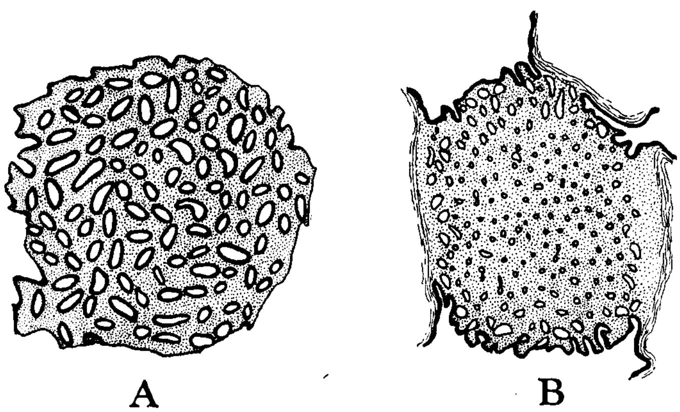

Fig. 2. *Asterina batheri*; horizontal section of madreporite showing the arrangement of madreporic grooves (A) and pore canals (B). ×40 (A), ×30 (B).

CUÉNOT (1887) reported in *Asterina gibbosa* that the organ is situated singly, not paired, in the madreporic interradius, but the writer unexceptionally observed paired Tiedemann's bodies in this interradius of *A. batheri.* The madreporite is placed nearer the centre than the margin of disc, the external surface being convex and circular. There is no spine on the external surface. The madreporite of *Patiria pectinifera* is traversed by numerous grooves which are mostly continuous from the centre to the margin. *Asterina batheri* has on the madreporic surface a large number of grooves which are not continuous from the centre to the margin, but are uniformly scattered (Fig. 2A). When the madreporite is sectioned horizontally, numerous minute pores are recognized at the bottom of the grooves. In *Patiria pectinifera* the external openings of the pore canals are regularly arranged in the madreporite from the centre to the margin

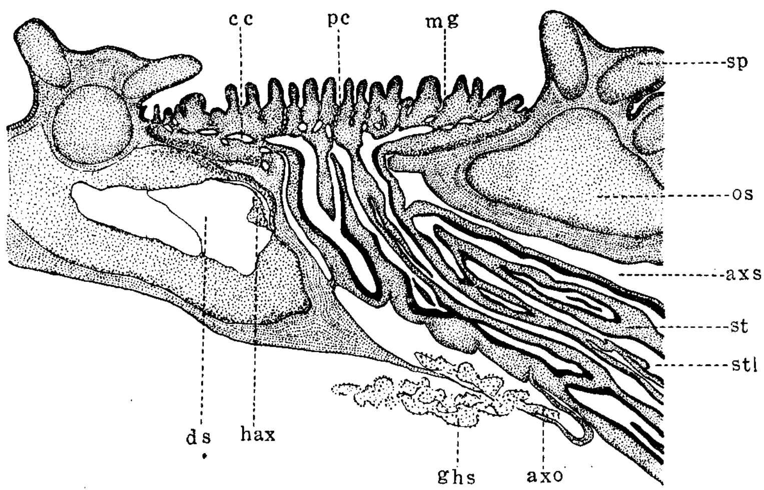

Fig. 3. *Patiria pectinifera*; vertical section of madreporite and stone canal. ×20; axo axial organ, axs axial sinus, cc collecting canal, ds dorsal sac, ghs gastric haemal strand, hax head process of axial organ, mg madreporic groove, os ossicle, pc pore canal, sp spine, st stone canal, stl lumen of stone canal.

along the bottom of the grooves (Fig. 6C), while in *Asterina batheri* the pore canals open to the bottoms of the corresponding grooves, one pore for each groove (Fig. 2B). In both the species the pore canals open into the collecting canals, which communicate with the stone canal. Some of them, placed near the margin, are in direct communication with the axial sinus. The madreporite encloses the dorsal sac, within which the head process of the axial organ is situated (Figs. 3, 4, 5A, C). The stone canal of *Henricia sanguinolenta* var. *ohshimai* is attached to one of the free ends of the axial

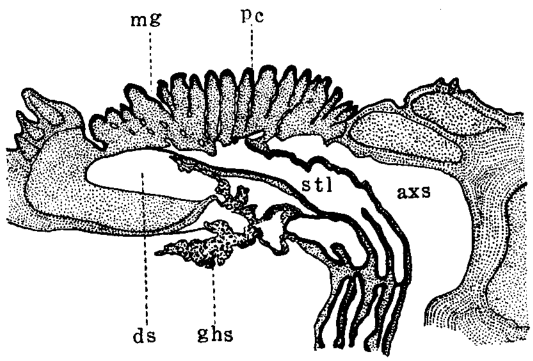

Fig. 4. *Asterina batheri*; vertical section of madreporite and stone canal. ×25; axs axial sinus, ds dorsal sac, ghs gastric haemal strand, mg madreporic groove, pc pore canal, stl lumen of stone canal.

organ, while the canals of these two sea-stars are lodged in the axial sinus and are directly supported by the wall of the axial sinus. It is also connected with the axial organ directly or indirectly. The stone canal is separated into several lumina by longitudinal septa, of which the number increases by double numbers from the oral portion of the stone canal to the aboral portion, therefore, the structure of the stone canal is most complex near its aboral end (Figs. 3, 4, 5, 7, 8). The structure of the stone canal recorded in *Asterina gibbosa* is rather similar to that of *Henricia sanguinolenta,* but in *A. batheri* it is exceedingly complex as is shown in Figure 5. It is more complex than that of *Patiria pectinifera* (Fig. 5). At its oral end the stone canal communicates with the ring canal in the madreporic interradius (Figs. 8, 9). The external surface of the madreporic grooves is covered with columnar, strongly ciliated cells. Their

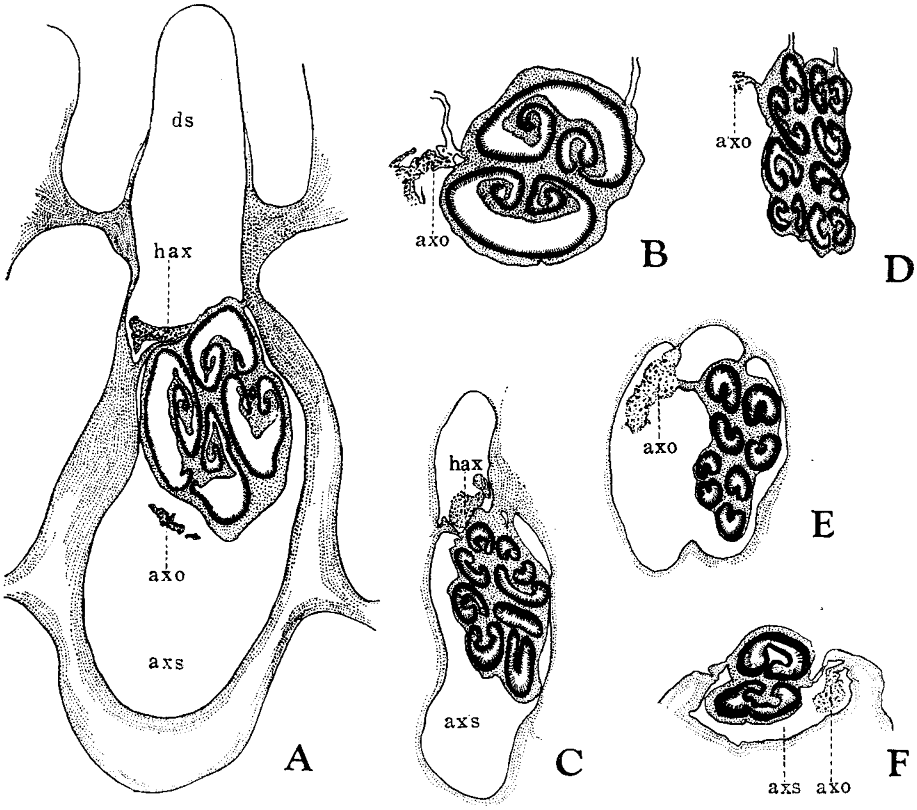

Fig. 5. Horizontal section of stone canal of *Patiria pectinifera* (A, B) and *Asterina batheri* (C, D, E, F). A. aboral portion. ×20. B. middle portion. ×50. C, D. aboral portion. ×25. E. middle portion. ×25. F. oral portion. ×40; axo axial organ, axs axial sinus, ds dorsal sac, hax head process of axial organ.

nuclei are placed near the basal end and stained sharply with haematoxylin. There are found a number of mucous cells at the tips of the groove ridges of the two species as is recorded in *Asterias rubens* by CHADWICK (1923) (Fig. 6E). Towards the pore canals the cells with round nuclei become cubical (Fig. 6A, B). In the collecting canal the cells are cubical and then become flat. In the stone canal the cells again become suddenly columnar, and their nuclei are elongated (Fig. 6D). These cells appear in the epithelium covering the madreporic grooves. The structures of the Tiedemann's bodies

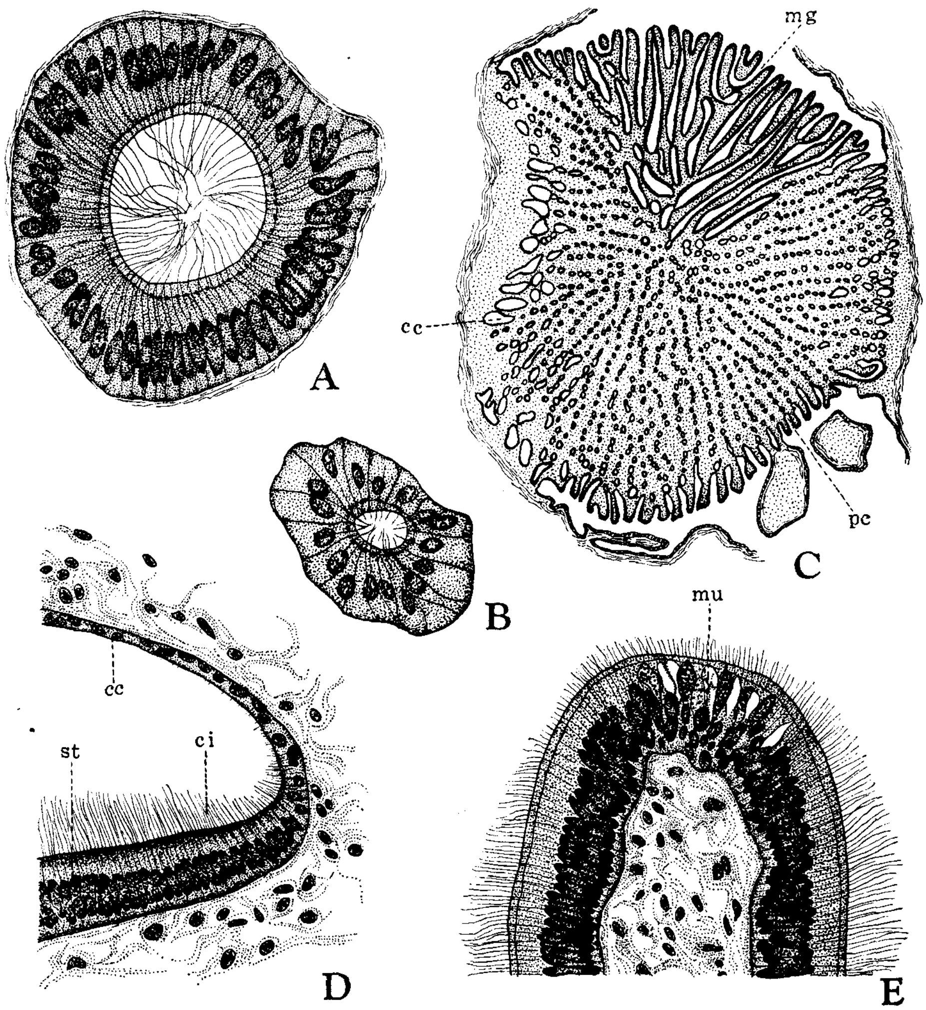

Fig. 6. A. *Patiria pectinifera*; horizontal section of pore canal. ×1300. B. *Asterina batheri*; horizontal section of pore canal. ×1000. C. *Patiria pectinifera*; horizontal section of madreporite. ×20. D. *Patiria pectinifera*; vertical section of aboral end of stone canal. ×600. E. *Patiria pectinifera*; vertical section of madreporic ridge. ×600; cc collecting canal, ci cilia, mg madreporic groove, mu mucous cell, pc pore canal, st stone canal.

and tube-feet are quite similar to those of *Henricia sanguinolenta* var. *ohshimai*. The Polian vesicle is composed of a very thin inner, and an outer epidermis, with two thin muscular layers between them; the outer layer seems to be longitudinal and the inner circular.

Haemal system. The haemal tissue is enclosed in the perihaemal spaces. The arrangement of this system resembles in general that of *Henricia sanguinolenta* var. *ohshimai*. The axial organ, attached to the wall of the axial sinus by means of mesenteric folds, is of remarkable gland-like structure. The aboral end of the axial organ is placed in the dorsal sac (Figs. 3, 4, 5A, C). Near the aboral end the organ is continuous with the subpentagonal aboral

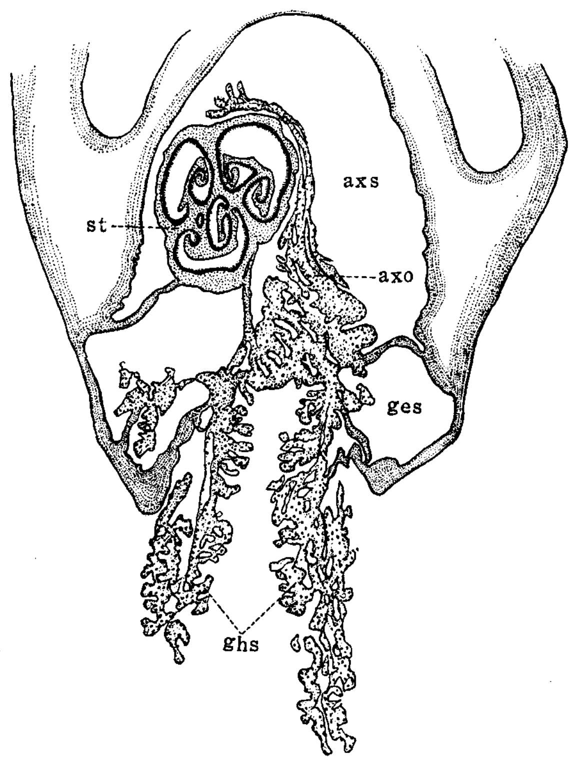

Fig. 7. *Patiria pectinifera*; horizontal section of madreporic interradius, near its aboral end. ×20: axo axial organ, axs axial sinus, ges genital perihaemal sinus, ghs gastric haemal strand, st stone canal.

haemal ring. From each corner of the ring are given off paired strands to adjacent rays, with their extremities merged into the gonads (Fig. 11). Very close to the junction of the aboral haemal ring with the axial organ paired strands are given off into the perivisceral cavity, penetrating the wall of the axial sinus. They are conspicuously tuft-like (Figs. 3, 4, 7). While it has often been recorded that the gastric haemal tufts are connected with the wall of the cardiac portion of the stomach, the writer reported in *Henricia sanguinolenta* var. *ohshimai* that the strands seem not to be connected with the wall of the cardiac stomach. In the two species here described the writer confirmed that the strands are distinctly

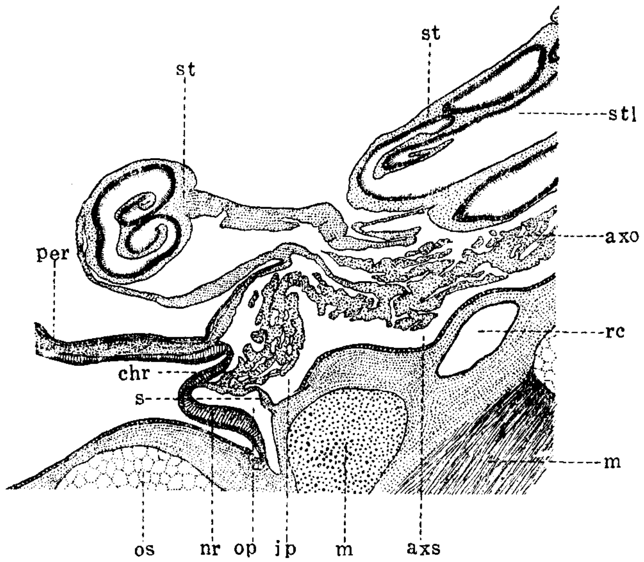

Fig. 8. *Patiria pectinifera*; vertical section of mouth part. ×20; axo axial organ, axs axial sinus, chr circumoral haemal ring, ip inner perihaemal canal, m muscle, nr nerve ring, op outer perihaemal canal, os ossicle, per peristome, rc ring canal of watervascular system, s oblique septum, st stone canal, stl lumen of stone canal.

connected with the aboral wall of the pyloric stomach, penetrating the wall of the axial sinus. The same fact is also observed by him in other species belonging to the genera, *Asterias amurensis* and *Leptasterias* sp. There is no strand which is set off from the one corner of the aboral haemal ring to the side opposite to the genital strands as is found in *Henricia sanguinolenta* var. *ohshimai*. The axial organ becomes gradually narrow towards its oral end. It is continuous with the circumoral haemal tissue which rests upon the oblique septum separating the outer circumoral perihaemal canal from the inner one (Fig. 8). From the oblique septum is given off a vertical septum into each radial perihaemal canal. The radial haemal tissue rests upon the vertical septum. The axial organ and its extensions are composed of tubular anastomosing strands crowded with wandering cells.

Nervous system. The nerve ring of the ambulacral system is situated in the circumference of the peristome, forming a pentagonal thickened ridge (Figs. 8, 9). From the nerve ring radiate the radial nerve cords, one for each ray, along the roof of the ambulacral furrow. Each radial nerve cord terminates in an eye-spot situated just below the azygous tentacle. From the radial nerve cord issue nerve layers into the ectoderm of the general actinal wall and of the tube-feet, in which a well-marked nerve ring is formed near the terminal sucker. Running along the peristome the circumoral nerve ring is continuous with the nerve layers of the digestive system. The nerve layer of the rectum is connected with that of the general abactinal ectoderm running along the anus. On the nerve ring the ectoderm cells are exceedingly columnar, covered with a thin cuticular layer, and having their nuclei situated near the external

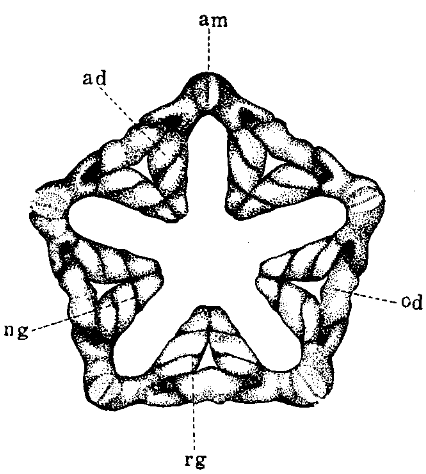

Fig. 9. *Patiria pectinifera*; buccal skeleton. ×3; ad adambulacral ossicle, am ambulacral ossicle, ng groove of nerve ring on adambulacral ossicle, od odontophore, rg groove of ring canal of watervascular system on adambulacral ossicle.

surface. In *Patiria pectinifera* a number of eosinophilic cells are scattered near the peristome. The radial nerve cord is represented by a triangular thickening of the ectoderm, covered with a cuticular layer. The nuclei of the cells lie near the external surface. Among them numerous mucous cells are scattered. In the sagittal section of the eye-spot the ectoderm layer corresponding to the foldings

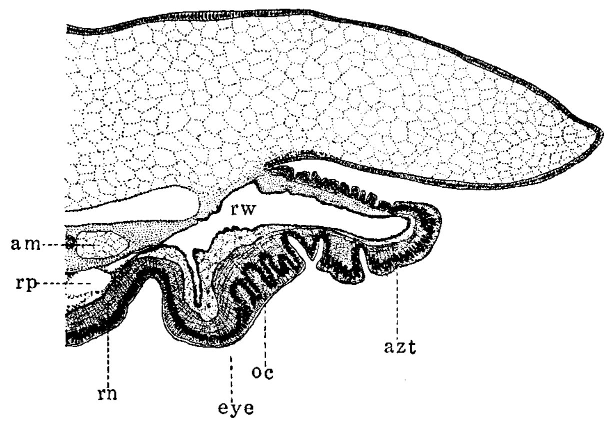

Fig. 10. *Asterina batheri*; longitudinal section of tip of ray. ×80; am ambulacral ossicle, azt azygous tentacle, eye eye-spot, oc optic cup, rn radial nerve cord, rp radial perihaemal canal, rw radial canal of watervascular system.

forms optic cups. In both the species here considered the optic cups are found in the half dimension of the eye-spot near the azygous tentacle (Fig. 10). So far as the writer's observation goes, the lens-like structure could not be observed above the optic cups. The deep-oral system, Lange's nerve, is observable separated from the ambulacral nerve cord by a thin layer resembling connective tissue. The apical nerve cord seems not to be present in the two species.

Reproductive system. The sexes cannot be distinguished externally. A pair of gonads are present in each interradius. The gonads of both the species are in lobular clusters, ovaries being yellowish orange and testes less coloured. In the breeding season the gonads become exceedingly enlarged and occupy almost all the space of the body cavity. The sex-ratio of 131 specimens of *Patiria pectinifera* collected in August at Amakusa, was 62 (♀):69 (♂). Regarding the structure of gonads and hermaphroditic tendencies found in *A. batheri*, OHSHIMA (1925 & 1929) recorded his interesting observations. In this species the wall of the ovary is divided into two layers. The outer layer is composed of the epithelium of the perivisceral cavity, underlying outer connective tissue and outer muscular layer. The inner layer is composed of the inner muscular layer, inner connective tissue and the epithelium lining the lumen of ovary. The testis of the species lacks the outer and inner muscular layers. The thickness of the outer and inner layers is variable in individuals. Between the outer and inner layers are situated the genital sini, which contain the haemal tissue and are given off in a pair at the angled corners of the aboral perihaemal ring to the corresponding gonads. The connective tissue and muscular layer of *Patiria pectinifera* are more weakly developed than those of *Asterina batheri*. The testis of the former has weakly developed muscular layers. In both the species each lumen of lobular gonads opens into a strongly ciliated common duct which opens outside through the genital pore on the abactinal side. According to the writer's observation, *A. batheri* has pelagic larval stages in the process of development in August at Amakusa. This fact seems to favour the opinion of MORTENSEN (1921) concerning the relation between the situation of the genital

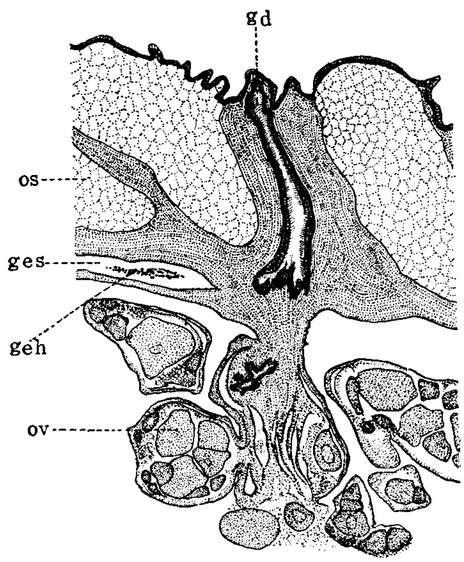

Fig. 11. *Asterina batheri*; vertical section of ovary. ×40; gd genital duct, geh genital haemal strand, ges genital perihaemal sinus, os ossicle, ov ovum.

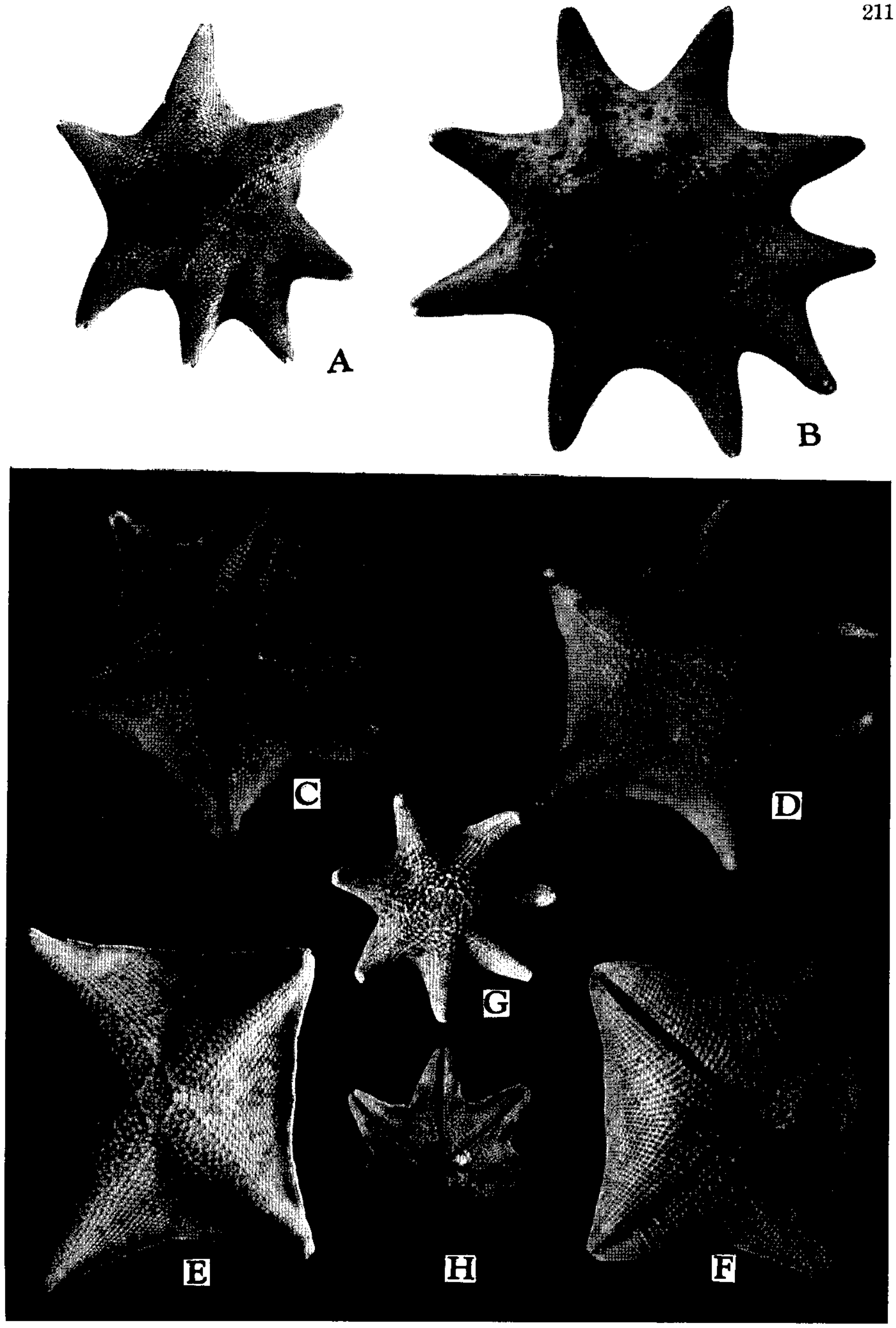

Fig. 12. *Patiria pectinifera*; abnormally rayed specimens. A. 7-rayed specimen (R 48 mm), viewed from abactinal side (K. BABA photo.). B. 9-rayed specimen (R 40mm), viewed from abactinal side (K. BABA photo). C, D. 6-rayed specimen (R 51 mm), viewed from abactinal and actinal sides. E, F. 4-rayed specimen (R 50 mm), viewed from abactinal and actinal sides (R. OHNO photo.). G, H. 7-rayed specimen (R 28 mm), viewed from abactinal and actinal sides (R. OHNO photo.). Specimens of A and B from Amakusa, and specimens of C, E and G from Oshoro.

pore and the production of the pelagic or the sedentary larvae in sea-stars belonging to the *Asterina*-group.

Abnormally rayed specimens. In *Patiria pectinifera,* though generally five-rayed, six-rayed specimens are not uncommon. Four-, seven- or nine-rayed specimens are rarely found (Fig. 12). The writer after dissecting a number of six-rayed specimens of the species observed that digestive organs in these specimens are provided with five paired hepatic caeca, five paired caeca and one unpaired, or six paired caeca. The rectal sac of these specimens seems to have five caeca, and the cardiac portion of the stomach is not always distinctly divided into six cardiac pouches. In *Asterina batheri* four-rayed or six-rayed specimens are rare.

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Plate IX

Explanation of Plate IX

1) Dissection of *Patiria pectinifera* showing watervascular system. × 1.5.

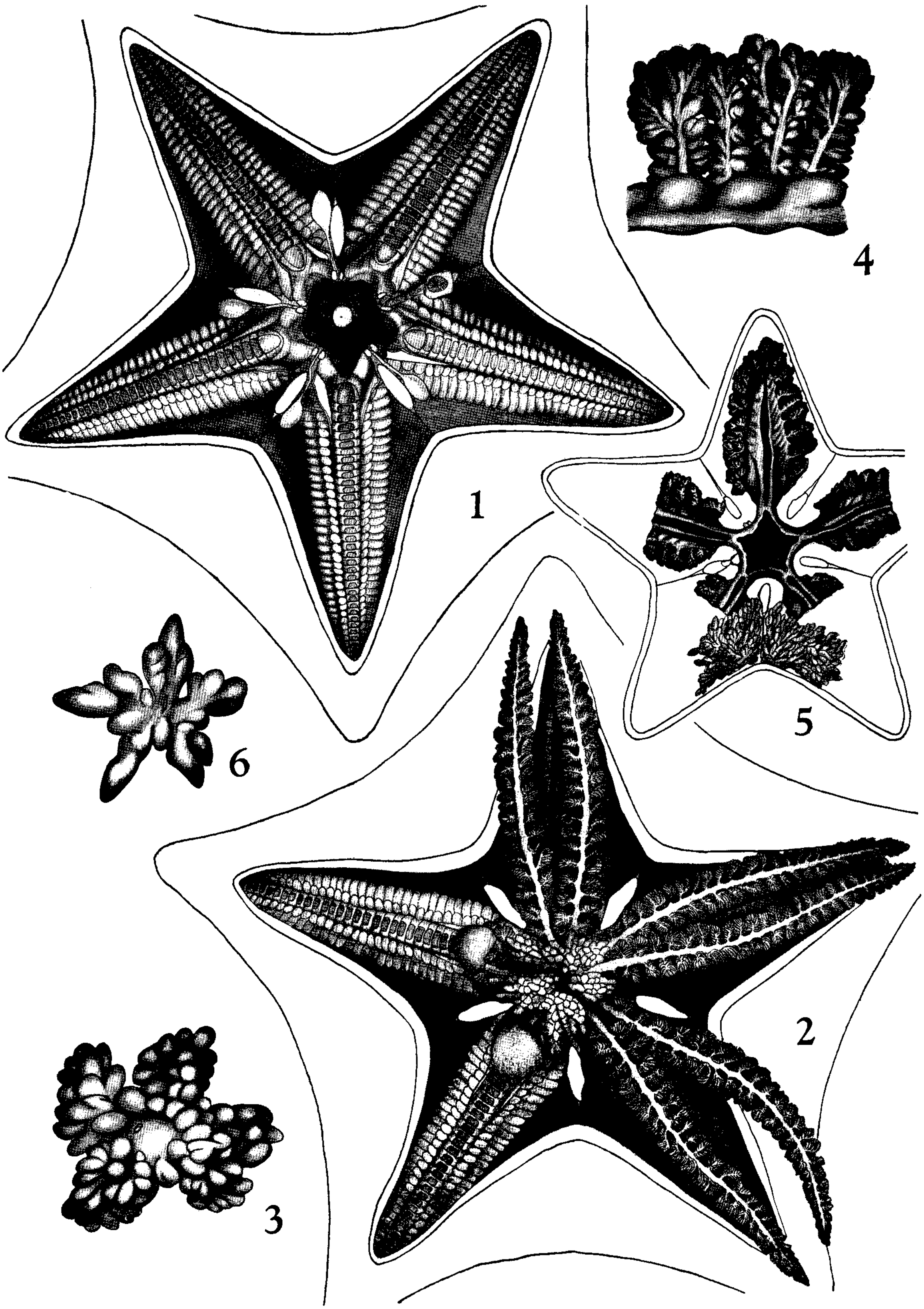
2) Dissection of *Patiria pectinifera* showing digestive system. × 1.5.

3) Rectal sac of *Patiria pectinifera*. × 3.

4) A part of hepatic caecum of *Patiria pectinifera* viewed from lateral side. × 7.

5) Dissection of *Asterina batheri* showing digestive system viewed from oral side, with gonads (♂) in an interradus, cardiac portion of stomach being removed. × 3.

6) Rectal sac of *Asterina batheri*. × 7.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