INTERNAL STRUCTURES IN TWO EDRIOASTEROID SPECIES, *ISOROPHUS CINCINNATIENSIS* (ROEMER) AND *CARNEYELLA PILEA* (HALL)

BY

ROBERT V. KESLING and LEIGH W. MINTZ

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VOLUME XV

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INTRODUCTION

To learn more about the internal structures in the edrioasteroids *Isorophus* and *Carneyella,* a well-preserved specimen of each of their type species was ground down and studied as a series of polished surfaces. Photographs of these polished surfaces are reproduced in Plates III-IV and VII-VIII. They show the relationships of structures between the oral and aboral surfaces in these edrioasteroids.

Much of our knowledge of internal structures of edrioasteroids has been based on examination of the very few specimens in which the aboral surface is exposed. Previously only one paleontologist attempted grinding down an edrioasteroid to see how aboral and oral features fitted together—Mr. W. K. Spencer, who in 1904 did pioneer work on the morphology of *Carneyella pilea* (Hall).

Although study of internal structures from polished surfaces has been sorely needed, no paleontologist has had well-preserved specimens that he was willing to sacrifice for such a project. Edrioasteroids are rare fossils. Only in 1957, when Mr. William Deak collected several hundred from

strata exposed during construction work on Hamilton Avenue, Cincinnati, Ohio, were specimens of *Isorophus cincinnatiensis* (Roemer) and *Carneyella pilea* (Hall) available in such numbers. Mr. Deak presented his collection to the Museum of the University of Cincinnati. Recently, Dr. Kenneth E. Caster, who has charge of the Museum, consented to our using one specimen of each species for this study. We are sincerely grateful for this opportunity.

Selection of the specimens to be ground down posed a serious consideration. Well-preserved edrioasteroids are very few, but only such specimens can yield reliable information on internal structures. Whereas, to destroy an excellent edrioasteroid is profane to a paleontologist, to acquire data from any other is definitely not sacred to science. In this dilemma we compromised, choosing specimens with good preservation in most of the peristomial region, posterior interambulacrum, and the proximal parts of the ambulacra, but with certain minor defects. We do not believe these defects have influenced the validity of our interpretations.

We wish to express our deep gratitude to the generosity of Dr. Kenneth E. Caster and to the perspicacity of Mr. William Deak, without which this study could not have started. Dr. Caster loaned specimens from the University of Cincinnati Museum, Dr. Matthew H. Nitecki from the Walker Museum of Paleontology at the University of Chicago, and Dr. Donald F. Squires from the American Museum of Natural History. Dr. Chester A. Arnold and Dr. George M. Ehlers critically read the manuscript and offered helpful suggestions. To all who have helped us we are grateful.

Repositories are identified by the following abbreviations preceding the catalogue numbers: UCM, University of Cincinnati Museum; UCWM, University of Chicago, Walker Museum; and AMNH, American Museum of Natural History.

PREVIOUS WORK

In this review and summary of published information on the internal structures of edrioasteroids, we have limited most of our consideration to *Isorophus cincinnatiensis, Carneyella pilea,* and other species of these genera.

In 1873 (pp. 55–56) Meek described the aboral surface of a specimen which he assigned to "*Agelacrinites (Lepidodiscus) Cincinnatiensis* Roemer" but did not illustrate it. His observations on the flooring plates were correct. This description, because of its historical significance, we quote:

I have before me a specimen, a little more than an inch in diameter, apparently of this species, belonging to L. B. Case, Esq., of Richmond, Indiana (found by him at that place), that seems to have grown on one of the valves of an *Ambonychia*. The

shell had separated in such a manner as to take with it the under side of the *Agelacrin-ites,* and leave its upper side in the matrix so situated as to expose its inner surface. The inner side of each arm or ray is here seen to be composed of a single series of quad-rangular pieces that are not imbricating . . .

The whereabouts of this specimen are now unknown.

Miller and Faber in 1892 described the edrioasteroid catalogued as UCWM No. 8825 for the first time. Subsequently, Foerste (1914) rede-scribed and illustrated it, and in this paper we discuss and show it in our Plate V, Figures 1–2. In this specimen of *Carneyella pilea,* Miller and Faber evidently based their observations of ambulacral plates on ambulacra IV and V, which have the flooring plates missing, for they confused the aboral sides of the covering plates with the flooring plates. They stated (1892, p. 85) that "The under side of the rays, as seen from below, consist of a row of plates on each side of the furrow, which interlock at the bottom of the furrow, and are, therefore, without reference to abutting imbricating plates, pentagonal instead of quadrangular, as Meek described them."

Apparently Miller and Faber referred to the outer ends of the covering plates as they continued (p. 85): "They extend beyond the margin of the imbricating plates into the visceral cavity half the depth of the ambulacral furrows, and are separated from each other, in their extensions laterally into the visceral cavity, so as to present a strongly serrated edge, as shown in the illustration (Miller and Faber, Pl. 1, Fig. 10)." They probably spoke of the flooring plates, but said: ". . . the plates are so small and the sutures so indistinct, that they could not be shown, except in a greatly magnified view." From their illustration, we assume Miller and Faber regarded the flooring plates, which they called "the covering," as composed of a mosaic of very small plates, a misinterpretation that we cannot understand, because the sutures are clearly defined (see our Plate V, Fig. 2).

Miller and Faber also (1892, p. 85) presented a curious analysis of the frame around the peristome. They described a subpentagonal rim in the center of the specimen formed by the union of the "coverings of the rays," which they interpreted to be the structure by which the edrioasteroid at-tached itself. They correctly noted, however, that (p. 85), "Within this pentagonal rim there is a pit showing the five subovate mouths of the ambulacral canals . . ."

W. K. Spencer (1904, pp. 39–44, Figs. 8–12) was the first investigator to grind down an edrioasteroid to learn about the internal structures. From photographs of successive polished surfaces of a specimen of *Carneyella pilea,* he prepared wax models of the plates. His work on the aboral parts of the ambulacral covering plates agrees very well with our conclusions. He also correctly demonstrated the nature of the ambulacral flooring plates

and the frame around the peristome. He did not, however, note the hydropore or passageway for the stone canal, structures which are conspicuous in our polished surfaces. Nor did he mention or illustrate the aboral configuration of the peristomial covering plates.

Foerste (1914, pp. 417–18, 427–29, Pl. 1, Fig. 5; Pl. 2, Fig. 4) redescribed and reillustrated the specimen studied by Miller and Faber. He correctly observed the relationships of the ambulacral covering and flooring plates, described the frame around the peristome (which he called the "substomial chamber"), and called attention to the structure that we interpret to be the passageway for the stone canal. Of the last he stated (1914, p. 429): "This leaves to be accounted for a peculiar margined depression along the proximal part of the right hand margin of the right posterior ray (No. 5), as viewed from below. This impression involves the two proximal covering plates on the left side of the right posterior ray, while adjoining the right margin of the large posterior peristomial plate, as seen from above. Possibly a duct passed by this path, but its presence could not be verified with confidence."

Bather (1915*a*, p. 55) accepted Spencer's (1904) interpretation of the flooring and ambulacral plates in *Carneyella pilea*. Later in the same year, he referred to Foerste's (1914) article and repeated many of Dr. Foerste's statements and conclusions. Concerning the "peculiar margined depression" described by Foreste and quoted in the paragraph above, Bather (1915*b,c*, p. 266) said: "If, as Dr. Foerste suggests, 'a duct passed by this path,' then the duct in question would most naturally be the hydropore-canal."

Williams (1918) discussed edrioasteroid morphology based on much new material. Although he had only a fragment of *Carneyella pilea* and no *Isorophus cincinnatiensis* with the aboral side exposed, he had available many specimens of the related *Isorophus austini* (Foerste), which he called (with variations in punctuation and capitalization) "*Agelacrinites austini* var. lawshe," many of them with the aboral surface uppermost. He said (p. 70) that "The aboral view of the large peristomial plate P in the posterior interradial space has been obtained in several specimens [of his *A. austini* var. lawshe]. . . . Foerste's description of it as ridged like the letter W on its surface toward the substomial cavity gives a good idea of that surface." On the following page he stated: "In the best preserved of the Lawshe specimens the substomial chamber is bounded definitely by the five first flooring plates with their projecting lateral processes and the posterior peristomial plate."

Williams described the outer ends of ambulacral covering plates as follows (p. 73):

> The condition of cover plates in Miller and Faber's specimen of *A. pileus* as described by Foerste is not common either for the specimens of *A. pileus* at hand or for

A. austini . . . . In the Lawshe specimens the aboral [outer] end of cover plates is shown in many cases where the floor plate of the ray has slipped. The plate ends rather squarely with two enlargements one the point of articulation with the flooring plate and one more oral in position, which must have been for muscular attachment. It is this enlargment or a point just above it which must be prolonged as the basal extensions of the lateral covering plates in *A pileus* Miller and Faber and in *A. cincinnatiensis* . . . . Might it not be that in aged specimens there was a deposit in the tissues attached to these plates so as to produce these basal extensions?

The last sentence quoted is a strange suggestion. It seems more likely that there are specific differences among the outer processes of *Carneyella pilea, Isorophus cincinnatiensis,* and *I. austini.*

Anderson (1939) described the aboral surfaces of several specimens of *Anglidiscus fistulosus* (Anderson), which he assigned to *Lepidodiscus.* He reported (p. 74) that the suture between flooring plates were pierced by pairs of pores. He thought that the radial canal lay below the flooring plates, with extensions passing upward through the paired pores. He also described the peristome (1939, p. 79) as "bounded by truncated triangular plates, the five modified proximal flooring plates of the ambulacra, with the posterior peristomial plate." He also stated (p. 80) that "Slightly posterior to the lobate impression and close to the origin of V is the impression of a small canal running from the anal interradius towards the mouth, which may represent the stone-canal as it lies in the position postulated for that organ by Bather."

Ehlers and Kesling (1958, pp. 269–70) described a structure that they considered might be a genital pore in the posterior interambulacrum of *Discocystis laudoni* Bassler. In one of the cotypes they found a polygonal depressed area where apparently one or more plates are missing and which contains a narrow, elongate opening bordered by relatively small plates. In the other cotype, this area is overlain by one large polygonal plate. Since they knew of no other edrioasteroid structure save the peristome and ambulacra in which the plates of the oral surface are underlain by additional plates, they suggested the possibility that this structure is a genital pore which (p. 270) "opened below a protective interambulacral plate and connected with some kind of duct leading out between the interambulacral plate and the subthecal plates." They postulated that a groove anterior to the opening may have served as the duct.

Kesling (1960, pp. 158, 166–57) identified the raised structures described by Foerste in *Isorophus cincinnatiensis* and *Carneyella pilea* as hydropores. He also established the location of hydropores in several other edrioasteroids and (pp. 172–76) catalogued hydropores in six groups according to their relative position. Both *Carneyella* and *Isorophus* were classed (p. 173) as having the "hydropore along the juncture between a

short proximal ambulacral plate and the right posterior plate of the peristomial region." The hydropore in *Carneyella pilea,* he reported (p. 167), involves three plates: the proximal covering plate on the left side of ambulacrum V, the posterior peristomial plate, and the unpaired right posterior peristomial plate. The hydropore in *Isorophus cincinnatiensis* was described similarly (pp. 158–59), except that it has an extra peristomial covering plate between the anterior parts of the posterior peristomial plate and the ambulacral covering plate.

<center>*Isorophus cincinnatiensis* (Roemer)</center>

<center>Aboral Surface</center>
<center>(Pl. I)</center>

Insofar as we are aware, the only specimen of this species ever reported in which the aboral surface was exposed is that described by Meek (1873, pp. 55–56), quoted in this paper under "Previous Work." It was part of a private collection, and was not subsequently referred to directly.

Among the specimens in the collection of the Museum of the University of Cincinnati is UCM No. 26536, illustrated in our Plate I. This edrioasteroid lacks the peripheral rim and the distal tips of ambulacra II and III, but otherwise it is remarkably well preserved. In particular, the peristomial region, the proximal parts of all ambulacra, and the posterior interambulacrum are in excellent condition. Our notes on the aboral surface of *Isorophus cincinnatiensis* are based on this specimen.

Frame around peristome.—As seen aborally, this is composed of the proximal parts of the first flooring plates of the ambulacra, disposed in a ring that surrounds the peristome except posteriorly, where there is a gap. The edges of the flooring plates of ambulacra II-IV form a smooth arch, nearly semicircular but with the ends curved outward. The junctions between these three plates are narrow (Pl. I, Fig. 2). In contrast, the junctions of the first flooring plates of ambulacra I and II and of ambulacra IV and V are both wide. Ambulacra I and V are not in contact.

Edges of the flooring plates of ambulacra II-IV are raised (as seen aborally) to form a continuous rim around the anterior border of the peristome. The raised edges of ambulacra I and V are nearly mirror images. The outer part of each is a single ridge, but the inner part bifurcates into narrow proximoanterior and proximoposterior ridges.

Although the peristome is now partly filled with matrix, obscuring the opening of the ambulacra, it appears that the ambulacra proper, the tunnels formed between the flooring and covering plates, led directly from the peristome. We suppose that the gut extended distally through the gap in

the posterior part of the frame. Whether it followed a straight course to the anal pyramid or coiled once around, like that in living sea urchins, is conjectural.

Passageway for stone canal.—As viewed aborally, the edrioasteroid has a subtriangular funnel next to the proximal inner side of ambulacrum V, which is interpreted to be the passageway for the stone canal. The innermost wall of this funnel (Pl. I, Fig. 1) is narrow and steep, projecting posteriorly from the inner end of the proximoposterior ridge of the first flooring plate of ambulacrum V. The posterior wall slopes orally at a much lower angle. The third wall is formed by the inner edges of the first two flooring plates of ambulacrum V. The whole funnel, or passageway, is considered to be part of the peristomial region because (1) it does not include any of the imbricating plates characteristic of the posterior interambulacrum, (2) the plate forming the posterior wall extends orally beyond the level of the posterior interambulacrum, and thus seems clearly to be associated with the other peristomial covering plates, and (3) the innermost wall of the funnel appears to be a crest on the aboral side of one of the large posterior peristomial covering plates.

Radial canal into ambulacrum V.—The proximal part of ambulacrum V has flooring plates arranged differently from those in the distal part. This arrangement is not found in other ambulacra. As viewed aborally, the first two flooring plates lie below the level of the others, and the proximo-median* margin of the third flooring plate appears to bear an opening into the ambulacrum. It is more than coincidence, we believe, that this arrangement occurs in the ambulacrum nearest to the passageway for the stone canal. The water-vascular system of edrioasteroids, we assume, was similar to that of living echinoderms, consisting of a hydropore (or madrepore), stone canal, ring canal, and radial canals into the ambulacra. When one considers that the aboral end of the stone canal was outside the frame around the peristome, the ring canal could hardly have been circular. If it were, it would have to cross under the frame twice, one at ambulacrum V and again at ambulacrum I. Any compression of the flexible theca would pinch the ring canal between the frame and the object to which the edrioasteroid was attached. More likely, the posterior part of the ring canal was compressed so that it passed through the gap in the frame between ambulacra V and 1. Such a circuit, however, would place the radial canal to ambulacrum V far from the stone canal, separated from it by the distance from the passageway to the gap in the frame and thence to the ambulacral opening. It is our

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* In this paper the terms for orienting ambulacral structures are used differently from those for other parts of the edrioasteroid. *Proximal* is along the ambulacrum in the direction leading, albeit circuitously, toward the peristome; *distal* is the opposite of proximal, leading away from the peristome; *median*, toward the midline of the ambulacrum; and *outer*, the opposite of median, away from the midline.

theory that, as the frame, the ambulacra, and the water-vascular system evolved, the radial canal to ambulacrum V came to bypass the first two flooring plates in *Isorophus cincinnatiensis*. The structure of ambulacrum V indicates that the radial canal joined the ring canal very close to the junction of the latter with the stone canal and entered into ambulacrum V through the opening at the proximomedian margin of the third flooring plate. In the other four ambulacra, the radial canals seem to have entered from the peristome.

Outer ends of ambulacral covering plates.—This specimen also shows the tips of the ambulacral covering plates extending beyond the flooring plates (Pl. I, Fig. 1). As Foerste suggested (1914, p. 423) from his study of oral surfaces in which the adjacent interambulacral plates were missing: "Immediately beyond the point where the covering plate passes beneath the adjacent interambulacral plate, the covering plate begins to narrow rapidly, and then the sides become approximately parallel, forming the basal extension, which only slightly exceeds one-fourth the total length of the plate." The outer ends of the covering plates are not nearly as long nor as broad as those in *Carneyella pilea*.

Ambulacral flooring plates.—These plates taper throughout the length of the ambulacra. Except in curved parts of the ambulacra, where they are trapezoidal, all plates except the proximal are subquadrate. The modification of the proximal two flooring plates in abulacrum V has already been mentioned. The plates fit closely together, and no evidence of pores through their junctions could be found.

Interambulacral plates.—These imbricate on the aboral surface in the opposite manner to that on the oral surface, that is, overlapping with their distal edges rather than proximal. Each plate has a faint crest along its distal margin (Pl. I, Fig. 1).

Anal pyramid.—Each plate in the anal pyramid bears an aboral ridge tapering from its outer border to the center of the pyramid. Possibly, these ridges served as places of attachment for closing muscles. Although the plates of the pyramid are clearly differentiated from those of the surrounding posterior interambulacrum, we could not distinguish the way in which the two kind of plates articulated.

Genital duct ?—Near the left anterior margin (as seen aborally) of the anal pyramid, the posterior interambulacrum appears to consist of two layers of plates (Pl. I, Fig. 2). This disposition of plates is very similar to that described in the corresponding area in *Discocystis laudoni* by Ehlers and Kesling (1958, p. 270):

In No. S3886*b* there is a structure in the posterior interambulacrum that has the general form of a pore, and its position suggests that it may have been the genital pore.

This feature lies to the right of the anal pyramid. The posterior interambulacrum has a polygonal depressed area, apparently where one or more large interambulacral plates are missing from the specimen, which contains an elongate, narrow opening bordered by plates. The bordering plates are much smaller than those in the adjacent area. In No. S3886*a*, the corresponding area is covered by one large polygonal plate.

We can discern no opening between the two layers of plates, but if one were present it would probably be filled with matrix and obscured.

Polished Surfaces
(Figs. 1–2; Pls. II–IV)

The specimen selected for polished surfaces, shown before grinding in Plate II, has a few defects in preservation. The right anterior peristomial covering plate was found to be shoved inward and twisted, so that the oral part was out of position (Pl. III, Figs. 2–3) and the aboral termination was no longer properly inserted between the expanded proximal edges of the first flooring plates of ambulacra III and IV (Pl. III, Fig. 7). The proximal part of ambulacrum I had been elevated, so that it was the first part of the specimen to be ground off (Pl. III, Figs. 1–6). Some of the plates in interambulacrum I were tipped up, out of their normal relationship to other plates. Apart from these defects, the specimen had very good preservation in the ambulacra, the peristomial region, the interambulacra, and the peripheral rim. The anal pyramid was complete and undistorted.

An interesting feature of the specimen was a small round hole drilled through the plates, partly in interambulacrum 3 and partly in the left side of ambulacrum IV (Pl. II, Figs. 1–2; Pl. III, Figs. 1–8). We assume that this hole was made by some predator; possibly, much of the edrioasteroid's soft parts were thus eaten, or the physiological damage resulted in death. We point out that the most elevated ambulacrum, as fossilized, is the one diametrically opposite the hole.

Peristomial covering plates.—The left anterior plate, which was preserved in place, has its proximal edges sloping aborally away from the outer surface (Figs. 2*a–b*; Pl. III, Figs. 1–3). A longitudinally narrow but transversely wide aboral extension of this plate is inserted in a notch between the expanded proximal edges of the flooring plates of ambulacra II and III (Figs. 2*c–d*; Pl. III, Fig. 7). The large posterior plate bordering the hydropore has a thin bladelike process on its aboral side, which forms the left side of the passageway for the stone canal (Fig. 2*b*; Pl. III, Figs. 3–5).

Frame around peristome.—As correctly interpreted by Spencer (1904), Foerste (1914), and Williams (1918), the frame around the peristome on

the aboral side in *Carneyella* and *Isorophus* is composed of the expanded proximal edges of the first flooring plates of the ambulacra (Fig. 2e). Just above the aboral surface of the peristome, however, the inserted edges of the anterior peristomial covering plates form integral parts of the frame in
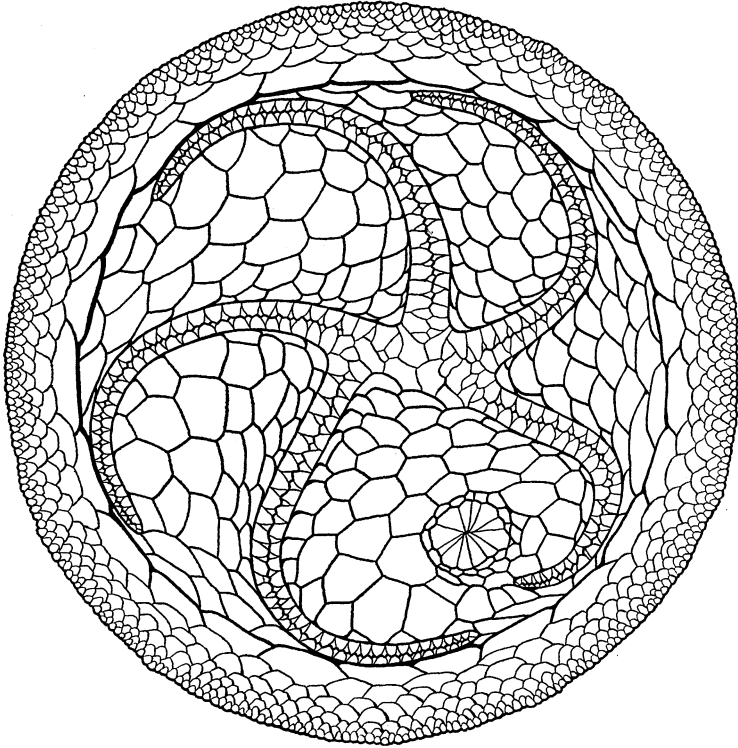

FIG. 1. *Isorophus cincinnatiensis* (Roemer). Restoration of oral view of specimen ground down and studied as a series of polished surfaces. Photographs of this specimen are shown on Plate II.

interambulacral positions, as described in the paragraph above (Figs. 2c–d; Pl. III, Fig. 7).

Passageway for stone canal.—From the hydropore, a short triangular funnel expands aborally (Fig. 2a; Pl. III, Figs. 1–4). Near the hydropore, this opening is bordered only by the same three plates which form the hydropore (Pl. III, Figs. 3–4), but below this it is also bordered by other plates of ambulacrum V (Fig. 2b; Pl. III, Fig. 5). The bladelike process on the large posterior peristomial plate, as noted above, forms the left wall of the passageway.

Radial canal into ambulacrum V.—The third flooring plate of ambulacrum V shows a narrow opening passing through it radially (Fig. 2c; Pl. III, Figs. 8–9). As we analyze the series of polished surfaces, this opening led proximally on a diagonal from the ambulacral groove to the aboral sur-
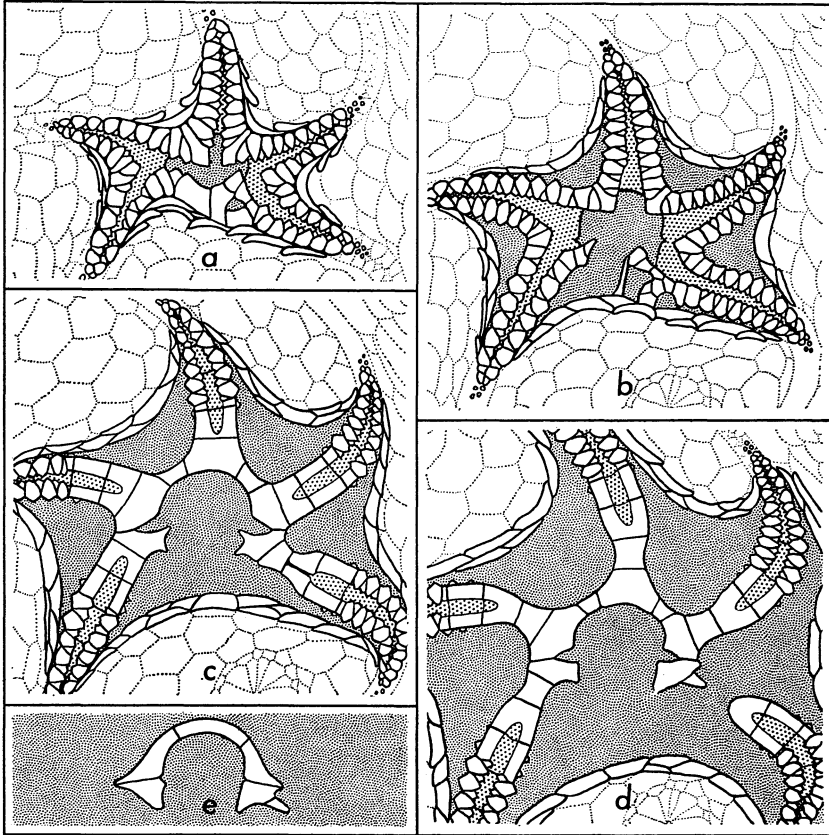
Fig. 2. *Isorophus cincinnatiensis* (Roemer). Restorations of oral views of selected polished surfaces of the specimen shown in Fig. 1 and Pl. II. *a,* based on Pl. III, Figs. 1–3; *b,* based on Pl. III, Fig. 5; *c,* based on Pl. III, Figs. 6–9; *d,* based on Pl. III, Figs. 7–8 and Pl. IV, Fig. 1; and *e,* based on Pl. III, Fig. 8, and Pl. IV, Figs. 1–5.

face of the ambulacrum. Other ambulacra and other plates of ambulacrum V have no such opening. Because the distal end of this tubelike opening lies in the groove of the ambulacrum and the proximal end lies at the location of the opening observed on the aboral side of the ambulacrum in UCM No. 26536 (see Pl. I, Fig. 1–2), we believe this opening accommodated the radial canal into ambulacrum V, bypassing the first two flooring plates.

Ambulacral covering plates.—Aborally the small median covering plates expand so that they are only slightly narrower than the outer covering plates and their ends extend as far as the outer border of the flooring plates (Pl. III, Fig. 9). This agrees generally with the statement by Williams (1918, p. 68) that "the outer covering plates [in *I. cincinnatiensis*] are grooved on their sides and the cylindrical median plate fills the space left by the grooving of two adjacent lateral plates. Its free end only is visible, alternating with the opposite median plate and both entirely covered from the side by the two rows of lateral covering plates." We did not, however, observe any aboral increase in width of the outer covering plates, as would be the case if they were grooved on their sides. Instead, they appear to narrow gradually to their aboral sides. As we interpret the junctions of the two kinds of covering plates, the edges of the larger overlap orally the beveled edges of the intercalated smaller.

Only the larger covering plates have outer processes extending beyond the outer border of the flooring plates, and these are noticeably shorter than those in *Carneyella pilea*. Williams (1918, p. 73) found no outer processes on any covering plates in *Isorophus austini;* hence it is possible that, despite their lack of projections beyond the border of the flooring plates, the median plates in *Isorophus cincinnatiensis* were opened directly by muscles, rather than indirectly by the action of the outer covering plates.

Ambulacral flooring plates.—The flooring plates are seen in oblique section on many polished surfaces (Pl. III, Figs. 6–9; Pl. IV, Figs. 1–6). All suture lines appear as straight lines on the surfaces, indicating that the junctions between flooring plates are essentially vertical planes. Although the junctions are not closely fitted, we have seen no evidence of pores along them. The ambulacra have well-defined median grooves (Figs. 2c–d; Pl. III, Figs. 6–8).

Genital duct ?—As we ground through the region of the anal pyramid, we looked for a double layer of plates, like that observed in UCM No. 26536 in aboral view. Our results were inconclusive. The plates near the right anterior edge of the anal pyramid seem to be thicker than other interambulacral plates (Pl. IV, Figs. 4–5), but it is possible that there were two layers at this place and the junction was passed through in grinding without our being aware of it. Another specimen will have to be sacrificed at some future time to decide whether there is a structure in this region that could qualify as a genital pore.

Other features.—The larger plates in the anal pyramid have beveled edges that fit over the sides of the smaller plates. On the aboral side, the plates are nearly equal in width. This arrangement would permit the plates to remain in contact even when the pyramid was at least partly open.

The sides of the interambulacral plates taper rather abruptly to sharp edges, which fit closely between the similarly tapered edges of the laterally adjacent plates immediately distal and proximal. Such overlapping of the margins would still retain a "shingled" covering of the interambulacra when the theca was considerably inflated.

The large plates in the proximal part of the peripheral ring fit together in the same manner as those of the interambulacra. Because they stand at a rather high angle on the inner margin, each polished surface intersects the peripheral ring through a thickness of about four plates (Pl. IV, Fig. 6).

Carneyella pilea (Hall)

Aboral Surface

(Pls. V, IX)

Our description of the aboral surface in *Caryneyella pilea* is based on two specimens, both of which were studied, described, and figured by Foerste (1914, pp. 427–29, Pl. 1, Fig. 5; Pl. 2, Figs. 3–4), UCWM No. 8825 (here shown in Pl. V) and AMNH No. 13266-1-x (here shown in Pl. IX).

In the first of these specimens (Pl. V, Figs. 1–2), the posterior interambulacrum, including the anal pyramid, is poorly preserved, ambulacra I and II are distorted, the distal end of ambulacrum IV is crushed, all the flooring plates of ambulacra IV and V are missing, and only the proximal flooring plates of ambulacra II and III are present. Despite these deficiencies, this specimen provides valuable information on the frame around the peristome, the passageway for the stone canal, and the relationships of the ambulacral covering and flooring plates.

In the second specimen (Pl. IX, Figs. 1–2), the left posterior region is missing from the middle of the posterior interambulacrum to ambulacrum III. The anal pyramid is present, but not clearly exposed. The frame around the peristome is distorted on the left side of the specimen (the right side as seen aborally) and incomplete posteriorly. In contrast, ambulacra III–V are complete and interambulacra 2–4 are well exposed. The entire aboral surface of the specimen is somewhat weathered.

Frame around peristome.—Although the frame is more nearly complete in AMNH No. 13266-1-x (Pl. IX, Figs. 1–2), it is more distorted than that in UCWM No. 8825 (Pl. V, Figs. 1–2). From a study of both, however, nearly all of the characteristics of the frame can be learned. It is noteworthy that the frame in *Carneyella pilea* is not proportionally much larger than that in *Isorophus cincinnatiensis* (compare Pl. IX, Fig. 1, with Pl. I, Fig. 1), although the peristomial region as seen orally is much larger in *C. pilea* than in *I. cincinnatiensis* (compare Fig. 3 with Fig. 1). One may

conclude that the peristome in *Carneyella* does not expand as much aborally as that in *Isorophus*.

Insofar as we may judge from AMNH No. 13266-1-x, the lateral tips of the frame do not project beyond the junction of ambulacra I and II and ambulacra IV and V, as they do in *Isorophus cincinnatiensis*. The part of the frame formed by the edges of the flooring plates of ambulacra II–IV is semicircular. In AMNH No. 13266-1-x (Pl. IX, Fig. 2) these edges are much narrower than those in UCWM No. 8825 (Pl. V, Fig. 2), leading us to believe that the aboral surface of frame in the latter has been planed off by abrasion. In fact, the configuration of the suture lines between the anterior peristomial covering plates and the preserved parts of the proximal flooring plates in ambulacra II–IV strongly suggest that the aboral surface has been abraded nearly to the level at which the peristomial plates are inserted in the frame (Pl. V, Fig. 2). The radially directed aboral ridges on the anterior peristomial covering plates can be seen in both specimens, but they are especially prominent in UCWM No. 8825.

The aboral surface of the large posterior peristomial covering plate, which lies in the posterior gap in the frame, is better preserved in UCWM No. 8825 (Pl. V, Fig. 2), although we strongly suspect, by comparison with polished surfaces (Pl. VII, Figs. 9–10; Pl. VIII, Figs. 1–9), that the median aboral ridge in this specimen has had its distal part broken off.

Passageway for stone canal.—The aboral opening of the passageway is clearly visible in both specimens, along the right side (as viewed aborally) of ambulacrum V, between the flooring plates of the ambulacrum and the large posterior peristomial covering plate. AMNH No. 13266-1-x, in which the flooring plates of ambulacrum V are preserved, does not show clearly the deep indentation shared by the first two flooring plates as seen on polished surfaces (Pl. VIII, Figs. 5–10). We assume that this is partly filled with matrix.

Ambulacral covering plates.—As pointed out by Foerste (1914, p. 422), in UCWM No. 8825, "the basal extensions are wider on the convex side of the rays and narrower on the concave side, where there is less room." Foerste also described in this specimen (p. 422): "Along that part of the base of each covering plate which serves as its fulcrum, there are two striations, which extend in a direction parallel with the ray, and a moderate distance apart. These striations seem to fit against the inner margin of the narrow lateral groove which is seen on the upper side of the flooring plates in certain species." In our opinion, the "striations" are simply the two borders of a low ridge, which crosses the aboral "base" of each covering plate in a proximo-distal direction (Pl. V, Fig. 1). Without a coating of sublimated ammonium chloride (as in Pl. V, Fig. 2) these ridges are scarcely

discernible; for this reason, they may have been overlooked by Foerste. These ridges, as Foerste suggested, probably served as fulcra for the plates, fitting into grooves on the oral margins of the flooring plates.

Aborally, each covering plate is seen to have a median ridge projecting from the proximomedian side of its base (Pl. V, Fig. 2). These structures are not clearly indicated on any of the polished surfaces, possibly because they are very thin. Considered in conjunction with the "braided" pattern of projections on the aboral sides of the covering plates (Pl. VII, Figs. 4–10), however, they indicate that the covering plates of one side fit with those of the opposite side much in the manner of the teeth in a zipper, so that Foerste's suggestion (1914, p. 412) that each tooth "interlocks with the opposing" may be correct. This arrangement is further discussed below under "Polished Surfaces."

Flooring plates.—Adjacent flooring plates have rather close-fitting junctions. We can find no evidence of any pores between plates. The first two flooring plates of ambulacrum V (Pl. IX, Fig. 2) have an indentation between their right parts (as viewed aborally), but they are not depressed below the level of the other flooring plates of the ambulacrum as are the corresponding plates in *Isorophus cincinnatiensis* (Pl. I, Fig. 2).

Interambulacral plates.—These plates differ in appearance in UCWM No. 8825 (Pl. V, Fig. 1) and AMNH No. 13266-1-x (Pl. IX, Fig. 1). In the former the surfaces appear to overlap successively outward, whereas in the latter they appear to overlap successively inward. In other words, the direction of imbrication of plates in one seems to be opposite to that in the other. The plates in the American Museum specimen (Pl. IX, Fig. 1) seem to retain ornamentation on their aboral surfaces and are much thicker than those in the Walker Museum specimen (Pl. V, Fig. 1), which are now quite thin, possibly the result of corrosion. The difference leads us to believe that the American Museum specimen retains interambulacral plates more nearly in their original form. If this is true, then each ambulacral plate must taper to a thin edge distally, fitting into a groove on the proximal edge of the distally adjacent plate. Thus, the plates on both oral and aboral sides would appear to imbricate or overlap in the same manner. With such an arrangement the theca of the edrioasteroid would have an aboral limit to which it could be compressed without distortion or disruption of the plates.

Other features.—The anal pyramid is crushed in the Walker Museum specimen (Pl. V, Fig. 2) and partly filled with matrix in the American Museum specimen (Pl. IX, Fig. 2). We can learn very little about the anal pyramid and the surrounding plates. There is no apparent double layer of plates near the pyramid, as was found in the specimen of *Isorophus cincinnatiensis.*

KESLING AND MINTZ

Polished Surfaces

(Figs. 3–4; Pls. VI–VIII)

The specimen ground down is shown in its entirety in Plate VI. It is far from perfect. The left posterior part of the peripheral ring, the outer halves of interambulacra 1 and 3, the middle one-third of ambulacrum II,
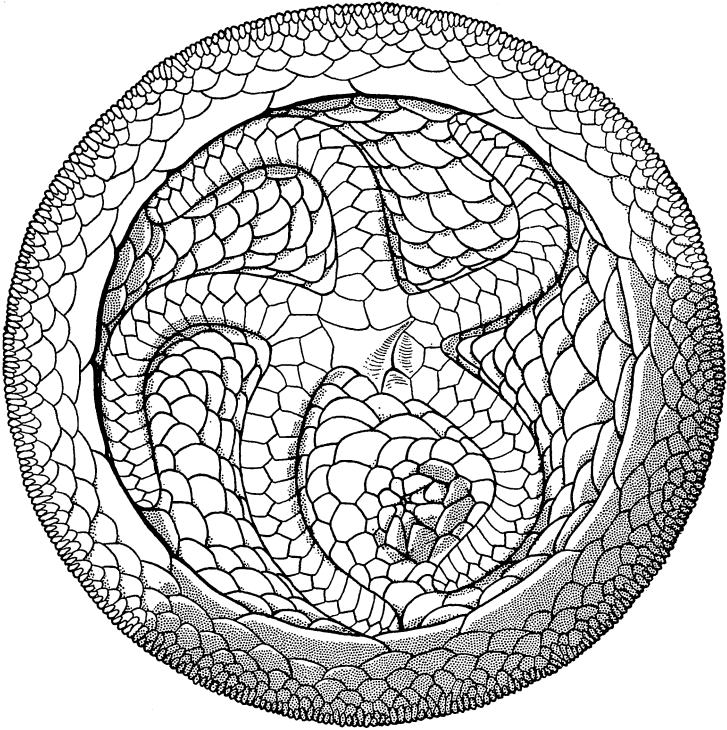

FIG. 3. *Carneyella pilea* (Hall). Restoration of oral view of specimen ground down and studied as a series of polished surfaces. Photographs of this specimen are shown on Plate VI.

and the distal two-thirds of ambulacrum IV are missing. In addition, the middle of ambulacrum III is bent and broken and plates are missing in interambulacrum 4. The specimen is adequate for our study, however, because the central part, posterior interambulacrum, and ambulacra I and V are complete and well preserved. Internally, we found, the aboral side of the frame around the peristome is cracked and slightly distorted and the flooring plates of ambulacrum IV are somewhat askew. Inasmuch as the corresponding structures are in good condition in other parts of the edrio-

asteroid, we do not consider these defects as serious obstacles in our investigation.

Peristomial covering plates.—These plates can readily be followed
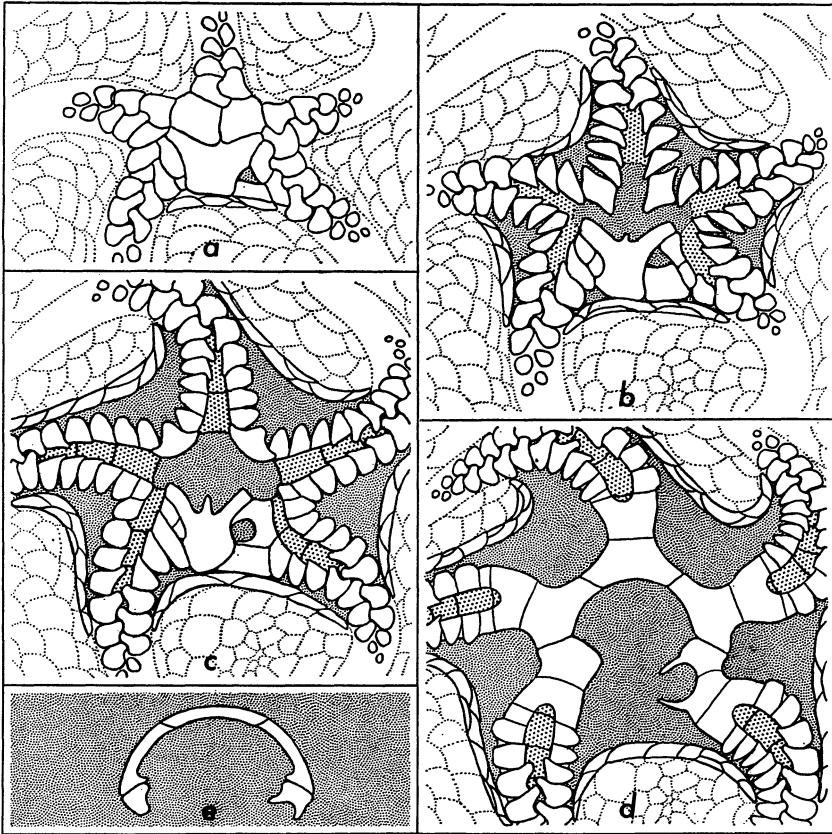
FIG. 4. *Carneyella pilea* (Roemer). Restorations of oral views of selected polished surfaces of the specimen shown in Fig. 3 and Pl. VI. *a,* based on Pl. VII, Fig. 3; *b,* based on Pl. VII, Fig. 6; *c,* based on Pl. VII, Fig. 10, and Pl. VIII, Figs. 1–2; *d,* based on Pl. VIII, Figs. 6–9; and *e,* based on Pl. VIII, Figs. 11–14.

through the sequence of polished surfaces, since there are only four and each is large and distinctive.

The two anterior peristomial covering plates are nearly mirror images and lie in interambulacral positions (Fig. 4*a*; Pl. VI, Figs. 1–2; Pl. VII, Figs. 1–3). Near the oral surface, the arrangement is like that described and illustrated by Spencer (1904, p. 40, Fig. 9). Proximally, each plate has thin edges and a thick central part. A short distance below the surface, how-

ever, when the thin edges have been ground away, only the thick central part projects toward the center of the peristome (Fig. 4b; Pl. VII, Figs. 5–6). The thick central parts of these two plates are the two radially disposed ridges which are so prominently displayed on the aboral surface of UCWM No. 8825 (Pl. V, Fig. 2). Still deeper, the proximal tips of these ridges are ground off, and each plate becomes subrhomboidal (Pl. VII, Figs. 7–8). The distal parts of the two anterior peristomial covering plates are much thicker. In its aboral part, each of the plates has a cross section in the shape of the head of a battle-ax (Fig. 4c; Pl. VIII, Fig. 1–4). The aboral terminations of the plates are wedge-shaped, inserted in notches between the expanded proximal edges of the flooring plates as units in the frame around the peristome (Pl. VIII, Figs. 3–4).

The large posterior peristomial covering plate is complex. Its anterior edge (at the junction with the two anterior covering plates just described) is nearly a straight line on the oral surface (Pl. VI, Fig. 1), but a short distance below this surface it becomes a broad V (Pl. VII, Figs. 2–3). At the oral surface this plate is bounded on the left by one covering plate of ambulacrum I (Pl. VII, Figs. 1–2), but below it is bounded by two of these covering plates (Fig. 4b–c; Pl. VII, Figs. 5–7). At the oral surface the anterior margin of the plate is nearly straight (Pl. VI, Fig. 2); deeper, it is V-shaped (Pl. VII, Figs. 3–4); still deeper, it has a central anterior projection (Fig. 4b; Pl. VII, Figs. 6–7); and, aborally, it is W-shaped (Fig. 4c; Pl. VII, Figs. 8–10). The central anterior projection is long and deep (Pl. VIII, Figs. 1–9). We suspect that part of it is broken off in UCWM No. 8825 (Pl. V, Fig. 2). Aborally, the proximal tips of the plate are notched (Pl. VII, Figs. 7–10), just as in UCWM No. 8825 (Pl. V, Fig. 2). This plate forms the left wall of the passageway for the stone canal, but does not extend nearly to the aboral end of the passageway (Pl. VII, Figs. 3–10).

The small posterior peristomial covering plate forms the rear boundary of the hydropore (Pl. VII, Fig. 1) and the rear wall of the passageway for the stone canal (Pl. VII, Figs. 3–10). It is a triangular plate that slopes down posteriorly. Proximally, it is nearly flat (Pl. VII, Figs. 3–5), but distally it is slightly arched, so that it is crescentic in cross section (Pl. VII, Figs. 9–10; Pl. VIII, Fig. 1). The distal end of this plate appears to be underlain directly by a lateral projection from the second flooring plate of ambulacrum V (Pl. VIII, Figs. 4–5); however, the exact limits of the plate could not be determined.

Frame around peristome.—The frame is composed of the expanded proximal edges of the first flooring plates of the ambulacra and the distal parts of the two anterior peristomial covering plates. The former are the

only plates in the aboral part of the frame (Pl. V, Fig. 2), and the latter are inserted like tenons a little higher in the theca.

Near the aboral limit of the peristome, the polished surfaces intersect only the liplike edges of the flooring plates (Fig. 4*e–f*; Pl. VIII, Figs. 11–14). Slightly higher, they intersect the expanded proximal margins of the flooring plates Fig. 4*d*; Pl. VIII, Figs. 7–9), and, still higher, they also cut through the peristomial covering plates (Pl. VIII, Figs. 3–4). The covering plates, as pointed out above, have thick distal parts which are wedge-shaped aborally. The left anterior covering plate is inserted between the flooring plates of ambulacra II and III, whereas the right anterior covering plate is inserted between ambulacra III and IV.

Passageway for stone canal.—The passageway for the stone canal is much longer in *Carneyella pilea* than in *Isorophus cincinnatiensis*. It extends from the hydropore (Pl. VII, Figs. 1–2) to the aboral surface of the first flooring plate of ambulacrum V, involving different plates in the oral and aboral parts.

The oral part is a subtriangular funnel expanding downward, formed of the same three plates that bound the hydropore: the two posterior peristomial covering plates and the first covering plate of ambulacrum V (Figs. 4*a–b*; Pl. VII, Figs. 3–6). A little deeper, it is bounded on the right by the first two covering plates of ambulacrum V (Pl. VII, Figs. 7–9).

The aboral part is a deep troughlike indentation in the first two flooring plates of ambulacrum V (Fig. 4*d*; Pl. VIII, Figs. 4–9). Each of the first two flooring plates has a long, thin lip projecting toward the left, curved around the sides of the subcircular indentation like the horns of a crescent (Pl. VIII, Figs. 4–8). The aboral end of the passageway seems to be an indentation in only the first flooring plate (Fig. 4*e*; Pl. VIII, Figs. 11–13).

The stone canal, if it extended along the full length of this passageway, projected aborally beyond the adit of the ambulacrum.

Radial canal into ambulacrum V.—There is no conclusive evidence on the exact course of the radial canal leading to ambulacrum V. The radial canal evidently entered the ambulacrum where the passageway for the stone canal is confluent with the ambulacrum (Pl. VIII, Fig. 3). Possibly, if the radial canal branched from the ring canal below the peristome, it shared the lower part of the passageway with the stone canal. It is conceivable, however, that the radial canal branched directly from the stone canal rather than from the ring canal and entered ambulacrum V at the same level (Pl. VII, Fig. 3). Such a circuit is unknown in living echinoderms, but in edrioasteroids the water-vascular system was strongly affected by the frame around the peristome and the oral location of the hydropore.

Ambulacra.—Ambulacra I and II are confluent at the left side of the peristome, and ambulacra IV and V at the right side (Figs. 4*b–c*; Pl. VII, Figs. 6–10). Ambulacrum III joins the peristome directly. Within the peristome, therefore, the passages are broadly trimerous.

Ambulacral covering plates.—The shape of the ambulacral covering plates in Carneyella pilea is far more complex than has been described.

Spencer (1904, pp. 39–40) stated: "Viewed externally the ambulacra of *Lepidodiscus pileus* are seen to be roofed over by an alternating series of plates which are shaped like a bent finger, fig. 9. These do not completely enclose the groove. There is no trace of any separate side plates. We may therefore call this upper series of plates 'side-covering plates.'" His Fig. 8, a diagram of a cross section of an ambulacrum, shows the oral side of the flooring plate to be a flat surface. This is not so. As shown in our Pl. VIII, Figs. 7–10, the flooring plates are definitely channeled, forming the lower half of the ambulacral cavity. Furthermore, Spencer's conclusion that the covering plates do not completely enclose the groove is in error, apparently based on the polished surface shown in his Fig. 9, which lies at some distance below the oral sides of the plates. If the covering plates of his specimen were shaped like a "bent finger" when "viewed externally," we can only conclude that the distal part had been eroded away before he started grinding on it; in well-preserved edrioasteroids, as in the one we ground, the oral aspect of the covering plates is not at all like a "bent finger" (see Pl. VI, Fig. 1) and the plates fit closely together.

From his observation of isolated plates, Foerste (1914, p. 412) described their median parts as follows:

> In by far the greater number of specimens the proximal side of each cover plate is elongated into an acute spinous tooth which projects across the median line of the ray and interlocks with the opposing cover plate. The latter also has a spinous prolongation on the proximal side, and both cover plates are curved concavely on the distal side of this spine, along the median line of the ray, so as to admit the interlocking.

As shown in a complete specimen (Pl. VI, Fig. 1) these descriptions apply to the aboral parts of the plates but not to the oral surfaces.

Bather (1915*a*, p. 55), accepting the interpretation of Spencer, said that the cover plates of *Agelacrinus* (in which he included *Carneyella pilea*), *Hemicystis* (error for *Hemicystites*), *Cystaster*, and *Streptaster* were "boot-shaped, with the sole of the boot adoral (= proximal) and the toe of the boot admedian, and in consequence of this shape they cannot close in the groove so completely as do the symmetrical cover-plates of the Edrioasteridae." This is an endorsement of error.

Successive polished surfaces show that the previous descriptions failed to relate the oral and aboral parts of the covering plates, which form very

different patterns by their junctions. For two examples, compare the oral and aboral parts of these plates in the distal part of ambulacrum III (Pl. VI, Fig. 1, and Pl. VII, Fig. 9) and in the distal part of ambulacrum I (Pl. VI, Fig. 1, and Pl. VIII, Fig. 13). On the oral surface, each covering plate has parallel sides and a pointed median end that fits tightly between the ends of the two opposite covering plates. Below this surface, however, each plate has a proximomedian extension that lies between similar extensions of the two opposite plates (Spencer's "bent finger," Foerste's "spinous tooth," and Bather's "toe of the boot"). Here, the extensions appear to be "braided" but this is an illusion, since they terminate flush and are not intertwined. Although the junctions between plates on one side and those on the other form a serrate line on both the oral and aboral surfaces, the serrations on the aboral surface are offset proximally from those on the oral surface. At and near the oral surface, the median end of each plate is bluntly acuminate (Fig. 3; Pl. VII, Fig. 1); slightly below, it is indented in the middle (Fig. 4a; Pl. VII, Figs. 2–3); and farther below, it projects proximally and is truncated by the extension of plate opposite and proximal to it (Fig. 4b; Pl. VII, Fig. 4).

From these relationships we can reconstruct the shape of each plate and explain how it fits against the others. Each plate has a proximomedian extension from the aboral half of its proximal edge. As pointed out correctly by Foerste (1914, p. 412), these extensions project under and beyond the oral position of the median line of the ambulacrum. Each extension fits into a rabbet or recess in the aboral half of the distomedian part of the covering plate lying opposite and proximal to it. Furthermore, it is prevented from moving outward by a small distomedian tip on the aboral half of the opposite and proximal plate. In similar fashion, the plate itself is rabbeted under its distomedian part for reception of the proximomedian extension from the covering plate opposite and distal.

As pointed out above in the discussion of the "Aboral Surface," there are median ridges projecting from the proximomedian sides of the bases of the covering plates (Pl. V, Fig. 2), which do not show up clearly on the polished surfaces and which we presume were very thin.

In this unusually complicated arrangement, the covering plates seem to have interlocked much like the teeth in a zipper. A plate could move from the closed position only if the plates on the opposite side of the ambulacrum also moved, inasmuch as its extension was overlain by a thin oral shelf of the opposing plate and underlain by the thin median end of the ridge from the proximomedian side of the base of the opposing plate. Thus, covering plates on both sides of the ambulacrum had to swing open simultaneously. We think that the median ends of the covering plates were mor-

tised, rather than dovetailed, so that our comparison with a zipper may tend to overemphasize the permanence of their junction in the closed position. It is particularly appropriate, however, as regards the form and relationships of the plates.

The significance and use of this complex closure is unknown. It gave great rigidity and strength to the ambulacral cover, particularly in the closed position. It would also have increased the filtering action of the plates in the open position.

The outer processes of the covering plates project beyond the flooring plates, as also observed in the aboral view of UCWM No. 8825 (Pl. V, Fig. 2). As in the latter specimen, also, the processes on the convex side of the ambulacrum are much broader than those on the concave side (Pl. VIII, Figs. 7–10, 13).

The covering plates are more numerous than the flooring plates, but do not appear to have been spaced on them in any particular arrangement.

Ambulacral flooring plates.—Except for the first flooring plates of the ambulacra, which form part of the frame around the peristome, the plates taper rather evenly toward the distal end of the ambulacrum. Suture lines between flooring plates are nearly straight on polished surfaces, so that there do not seem to be any configurations on the contact surfaces (Pl. VIII, fig. 13).

Other features.—The interambulacral plates, like those in *Isorophus cincinnatiensis,* fit closely together, with the tapered edges of one plate inserted between similar edges of the bordering plates.

No evidence on the nature of the genital duct was found in this specimen.

<div align="center">CONCLUSIONS</div>

From our observations of oral, aboral, and polished surfaces, we conclude that *Isorophus cincinnatiensis* and *Carneyella pilea* both have: (1) three plates, two in the right posterior part of the peristomial region and one in the adjacent left side of ambulacrum V, which form a low pyramid and which are underlain directly by a passageway to the interior of the edrioasteroid. We believe that the three plates formed the hydropore and the passageway below accommodated the stone canal; (2) the aboral part of the frame around the peristome composed of the expanded proximal parts of the first flooring plates of the ambulacra, as previously reported in literature; (3) the aboral ends of the anterior peristomial plates inserted wedge-like between the first flooring plates of the three anterior ambulacra, forming an integral part of the frame around the peristome; (4) a gap in the posterior part of the frame around the peristome, which is overlain by the

covering plates of the posterior part of the peristome; (5) ambulacral covering plates with basal extensions, which presumably were for attachment of muscles; (6) flooring plates of the ambulacra which fitted closely together and had no pores along their junctions; and (7) interambulacral plates beveled at their lateral edges to fit between similarly beveled plates lying immediately proximal and distal at the sides.

We note as differences between the two species that: (1) the arrangement of ambulacral covering plates is much more complicated in *Caryneyella pilea,* although it lacks the median series of plates which is found in *Isorophus cincinnatiensis*; (2) although the peristomial covering plates in *Isorophus cincinnatiensis* covers a smaller area than that in *Carneyella pilea,* its peristome expands aborally so that the frame around the peristome is proportionally about the same size in both species; (3) the flooring plates in the proximal part of ambulacrum V have different configurations in the two species; and (4) the basal extensions on the ambulacral covering plates are longer in *Carneyella pilea* than in *Isorophus cincinnatiensis*.

In *Carneyella pilea* we found that the bases of the ambulacral covering plates have ridges on their aboral surfaces, presumably for articulation with grooves in the oral sides of the flooring plates, and that the covering plates of one side of an ambulacrum fit with those on the other side much like the teeth of a zipper, preventing the plates of one side from opening or closing independently of those opposite.

In *Isorophus cincinnatiensis* the small ambulacral covering plates increase aborally, so that on the aboral side they are nearly the same size as the larger plates. In like manner, the smaller plates of the anal pyramid also expand aborally. Each plate of the anal pyramid has an aboral radial ridge, thought to be for attachment of muscles.

The following four of our interpretations need additional confirmation:

1. In *I. cincinnatiensis,* the aboral view shows a double layer of plates adjacent to the anal pyramid, comparable in position to the structure in *Discocystis laudoni* described by Ehlers and Kesling (1958) and suggested to be a genital pore. We observed no pore leading between the two layers of plates.

2. In *I. cincinnatiensis,* the first two flooring plates in ambulacrum V do not extend aborally as far as the others, and the third flooring plate has a tube leading into the ambulacrum. Whether this tube served as the passageway for the radial canal, bypassing the first two flooring plates, as we suggested, is speculative.

3. In *C. pilea,* there is a deep notch between the first and second flooring plates, on the left side of ambulacrum V. We do not know whether this served as the adit for the radial canal or had some other function.

4. In *C. pilea,* comparison of oral and aboral surfaces leads us to believe that each interambulacral plate is distally beveled to fit into a groove of the plate beyond it. This could not be confirmed in polished surfaces.

All in all, their type species are constructed so similarly that we seriously question that *Isorophus* and *Carneyella* belong to different families of edrioasteroids.

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PLATES

EXPLANATION OF PLATE I

Figs. 1–2. Aboral views of UCM No. 26536; from the Upper Ordovician Maysville group, McMillan formation, Corryville member; Stonelick Creek, 100 yards below bridge, 1 mile west of Newtonville, Ohio; collected by John K. Pope in 1953. Figure 1 is a stereogram of the specimen lightly coated with sublimated ammonium chloride ($\times$ 4). Figur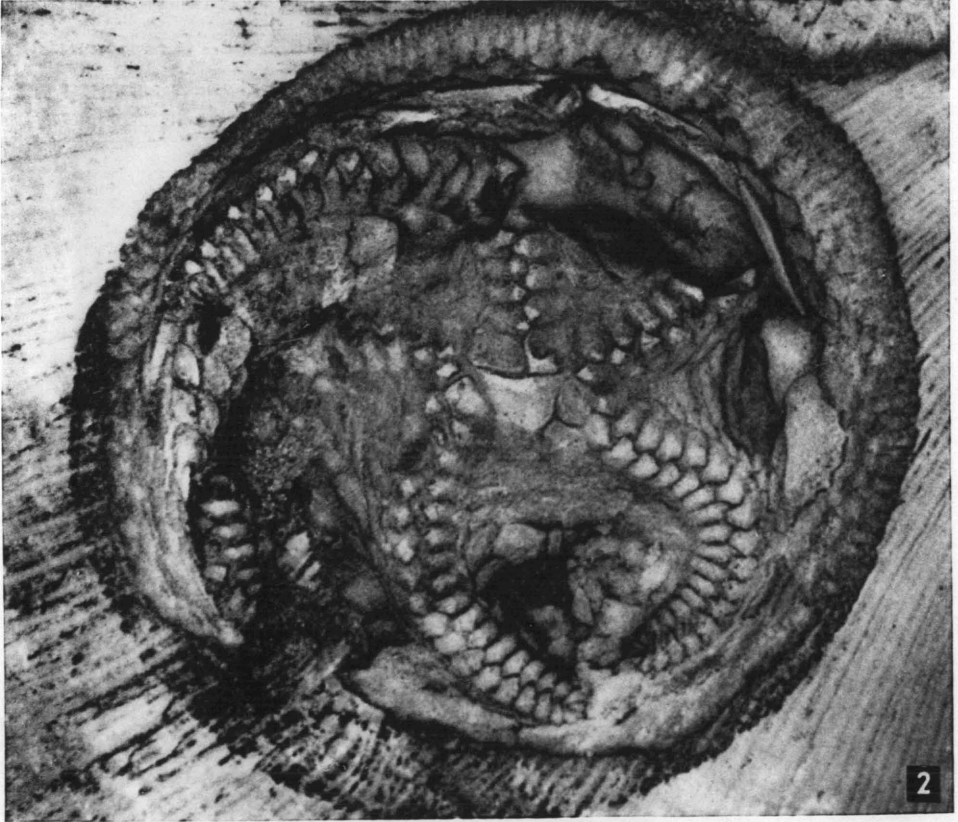e 2 is a view of specimen submersed in xylol $\times$ 7½). Ambulacrum V, at the lower left in each figure, shows the offset of the proximal two flooring plates and what is interpreted as an opening at their distal edge. Near the left anterior margin (as seen aborally) of the anal pyramid, the posterior interambulacrum appears to consist of two layers of plates; possibly, the genital duct passed between them.

PLATE I
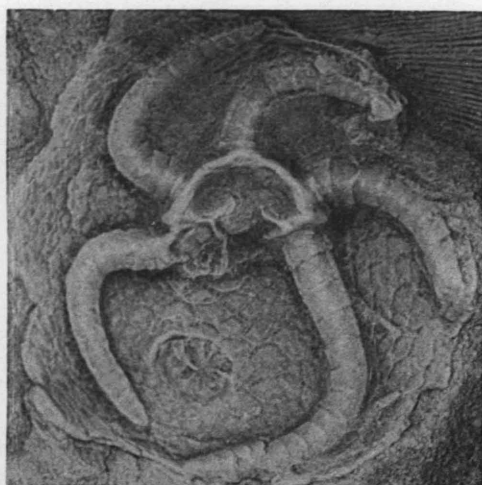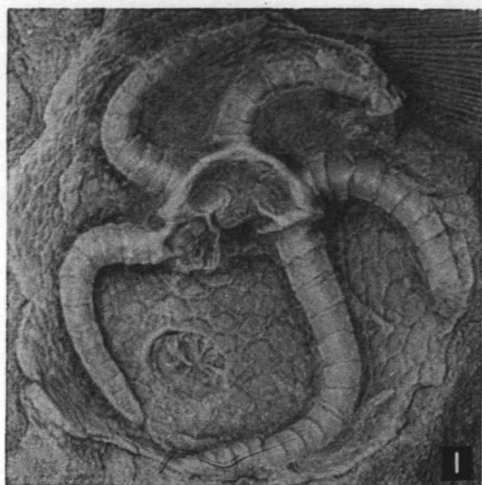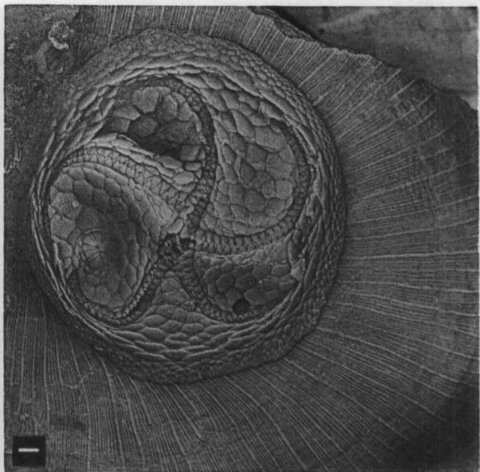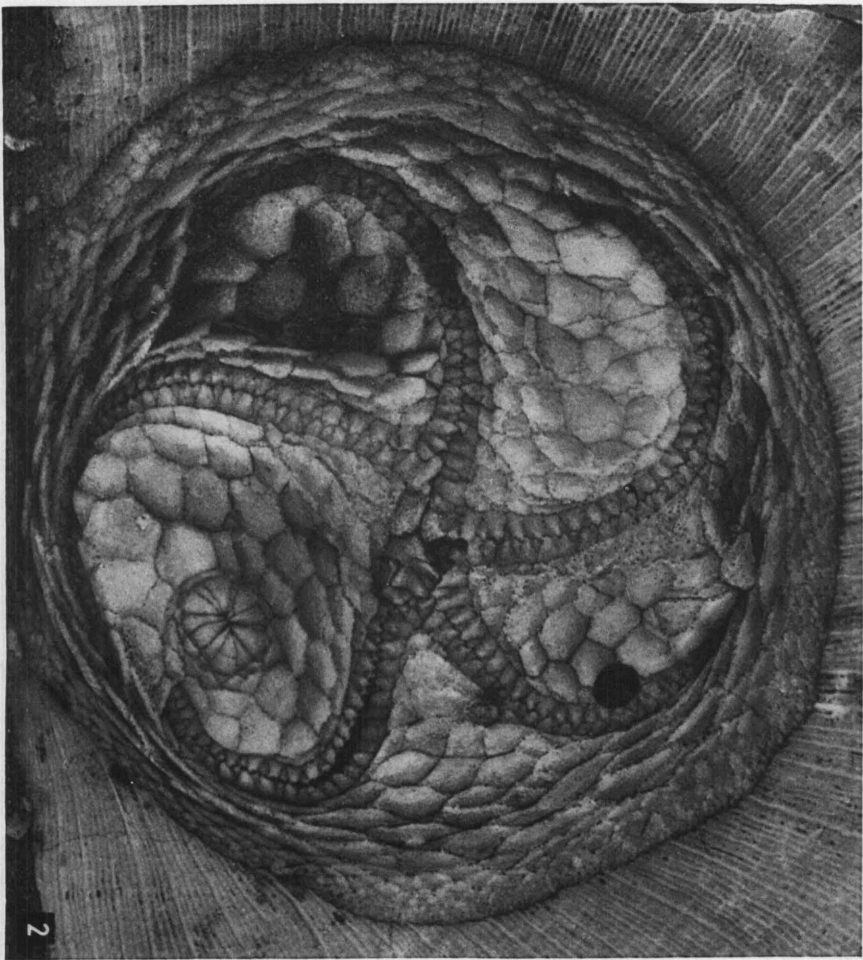
PLATE II

EXPLANATION OF PLATE II

FIGS. 1–2. Oral views of specimen which was subsequently ground down in the study of its internal structures; from the Upper Ordovician Maysville group, McMillan formation, Bellevue member; Hamilton Avenue, opposite Frisch's Big Boy Restaurant, Cincinnati, Ohio; collected by Mr. William Deak in 1957. Figure 1 is a stereogram of specimen lightly coated with sublimated ammonium chloride ($\times$ 2). Figure 2 is a view of specimen submersed in xylol ($\times$ 5). Polished surfaces of this specimen are shown in Plates III and IV.

EXPLANATION OF PLATE III

FIGS. 1–3. 5–8. Oral views of successive polished surfaces of specimen shown in Plate II, each submersed in xylol ($\times$ 2½). This series shows the passageway for the stone canal, the relationships of some of the ambulacral covering plates to the underlying flooring plates, the frame around the peristome (formed by the proximal flooring plates of the ambulacra), and what seems to be a duct through the third flooring plate of ambulacrum V. Additional polished surfaces of this specimen are shown in Plate IV.

FIGS. 4, 9. Enlargements of parts of Figures 3 and 8 ($\times$ 7½). Figure 4 shows the passageway for the stone canal immediately below the hydropore. Figure 9 shows part of the frame around the peristome, the proximal flooring plates of ambulacrum IV, and what seems to be a duct through the third flooring plate of ambulacrum V.

PLATE III
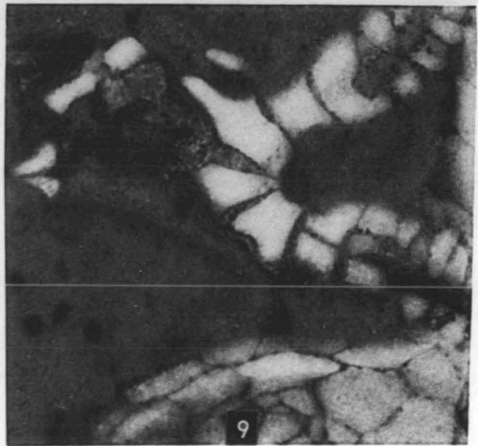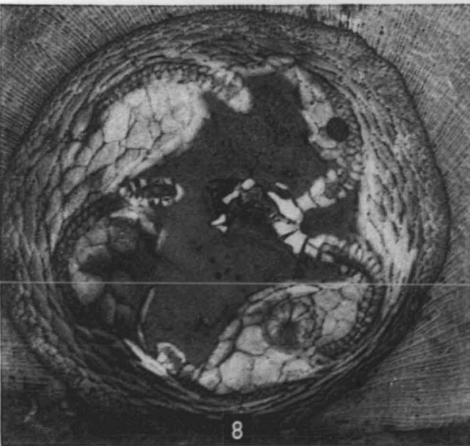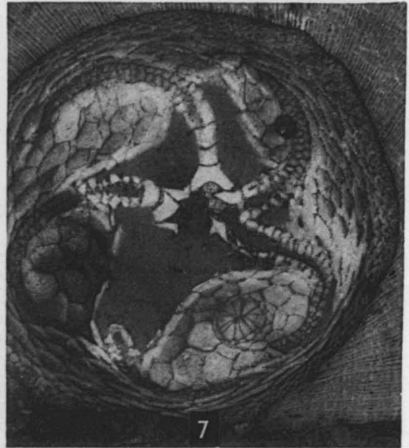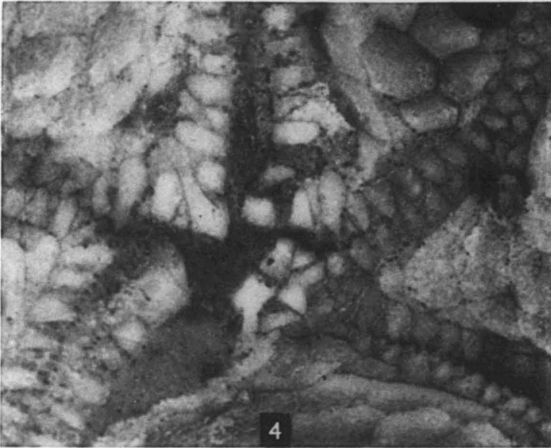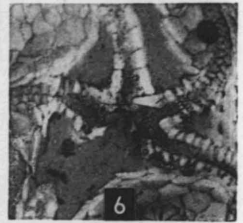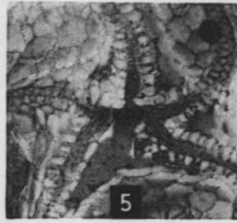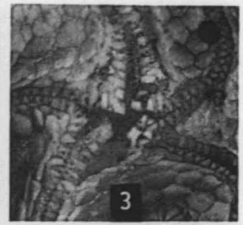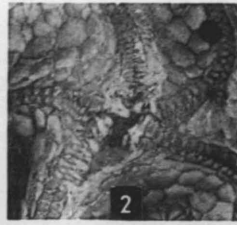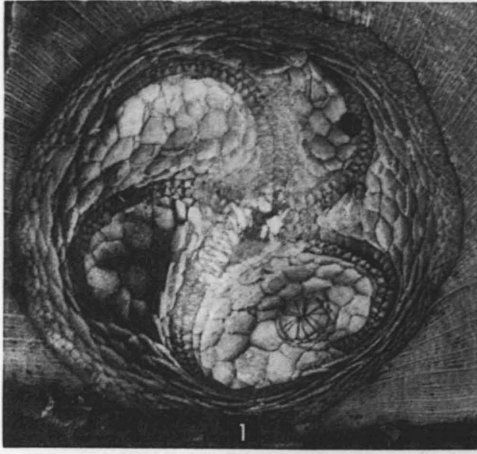
PLATE IV
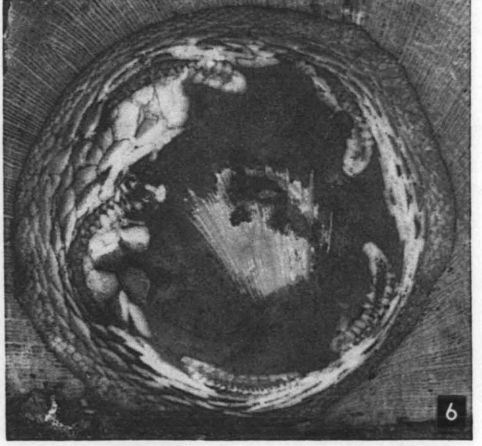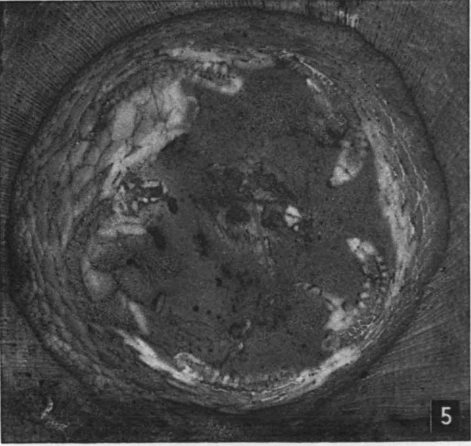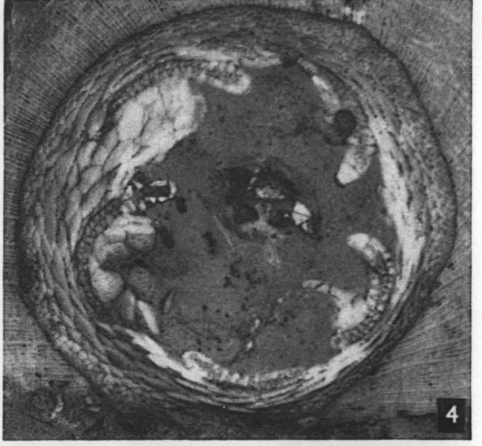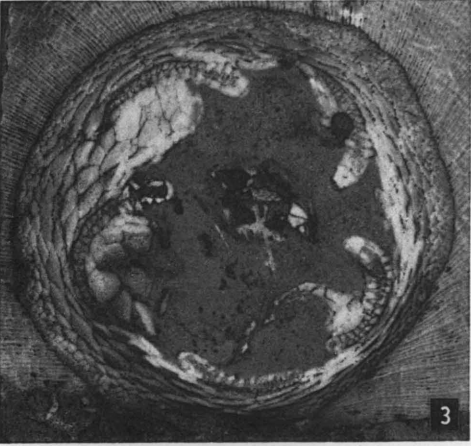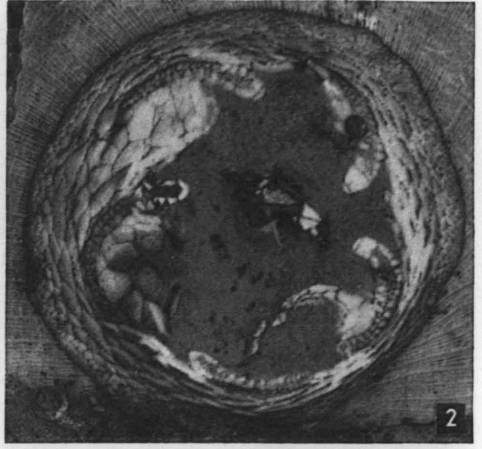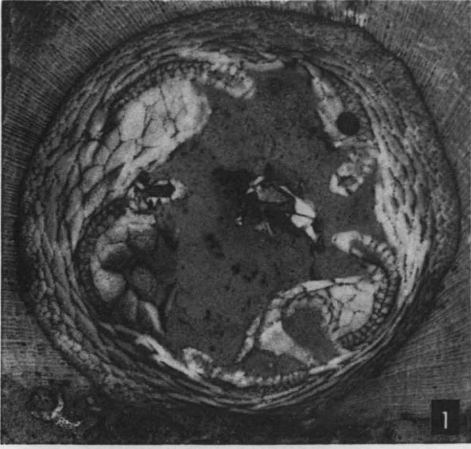
EXPLANATION OF PLATE IV

(All figures × 2½)

FIGS. 1–6. Oral views of successive polished surfaces of specimen shown in Plate II, each submersed in xylol. These surfaces follow those shown in Plate III. This series shows the aboral part of the posterior interambulacrum around the anal pyramid and oblique surfaces through the ambulacra.

EXPLANATION OF PLATE V

FIGS. 1–2. Aboral views of UCWM No. 8825; from the Upper Ordovician Maysville group, McMillan formation, Corryville shale member; Cincinnati, Ohio. This specimen was figured by Miller and Faber (1892, Pl. I, Fig. 10) and later by Foerste (1914, Pl. II, Fig. 4). It shows the lateral extensions of the ambulacral covering plates particularly well. Figure 1 is a stereogram of the specimen lightly coated with sublimated ammonium chloride ($\times$ 3½). Figure 2 is a view of specimen submersed in xylol ($\times$ 7).

PLATE V
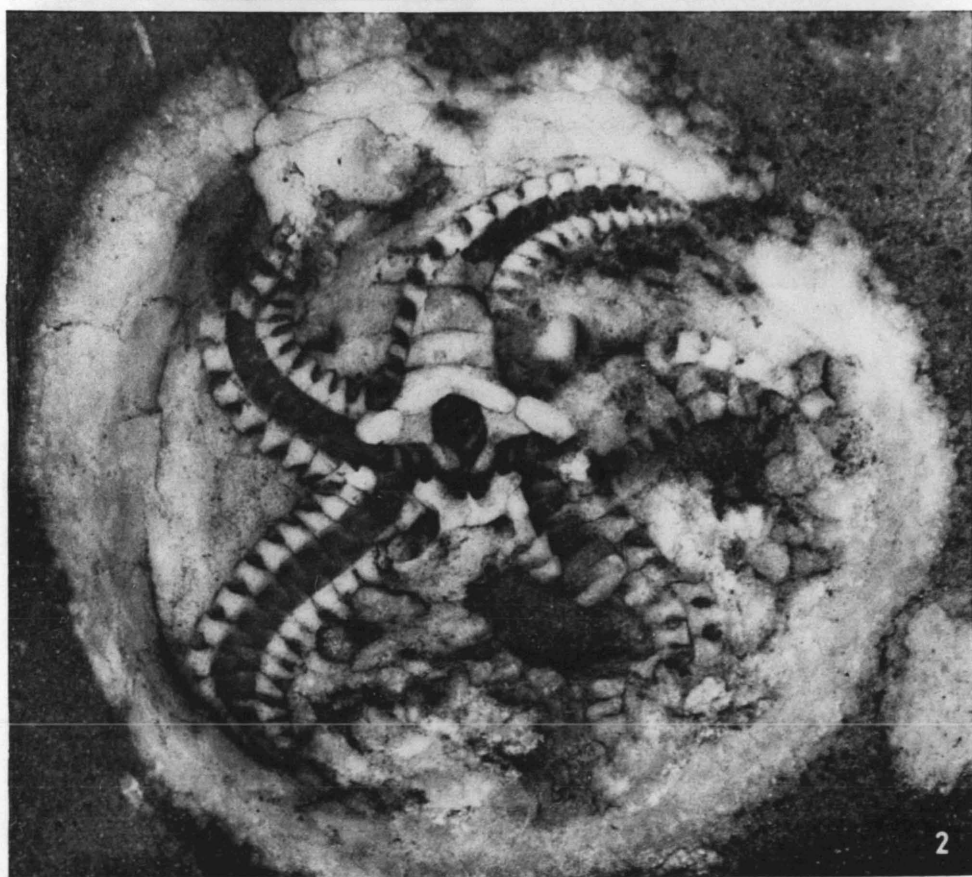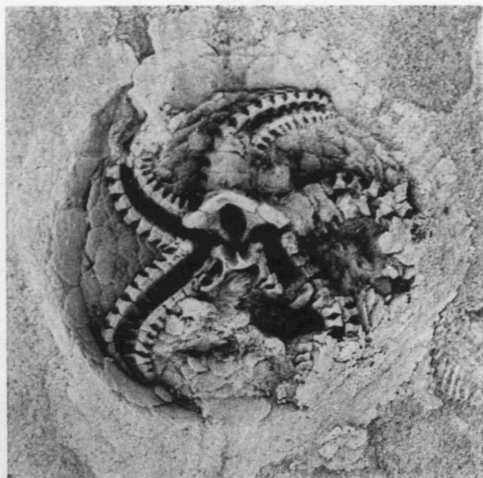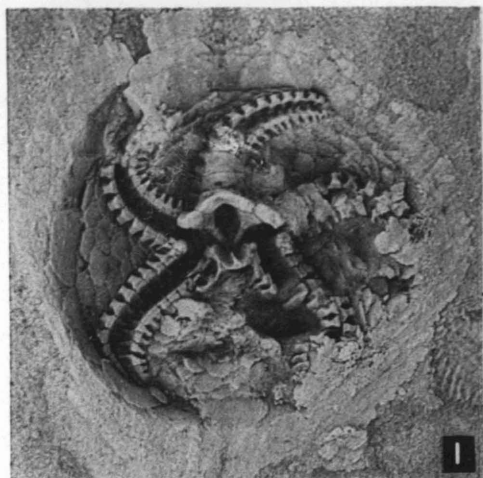
PLATE VI

EXPLANATION OF PLATE VI

Figs. 1–2. Oral views of specimen which was subsequently ground down in the study of its internal structures; from the Upper Ordovician Maysville group, McMillan formation, Bellevue member; Hamilton Avenue, opposite Frisch's Big Boy Restaurant, Cincinnati, Ohio; collected by Mr. William Deak in 1957. Figure 1 is a stereogram of specimen lightly coated with sublimated ammonium chloride ($\times$ 4). Figure 2 is a view of specimen submersed in xylol ($\times$ 7½). Polished surfaces of this specimen are shown in Plates VII and VIII.

EXPLANATION OF PLATE VII

(All figures × 7½)

FIGS. 1–10. Oral views of successive polished surfaces of specimen shown in Plate VI, each submersed in xylol. This series shows the passageway for the stone canal leading down from the hydropore, the peristomial covering plates (particularly the W-shaped anterior part of the large posterior plate), and the junctions and lateral extensions of the ambulacral covering plates. Additional polished surfaces of this specimen are shown in Plate VIII.

PLATE VII
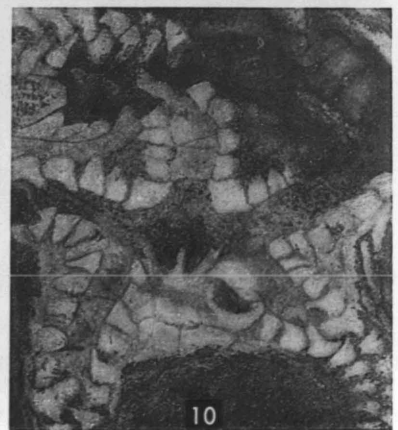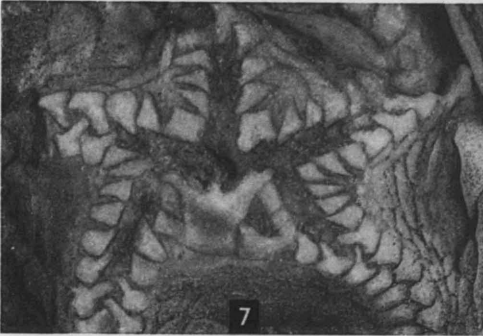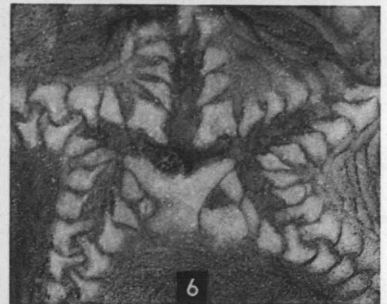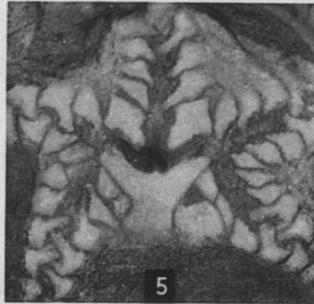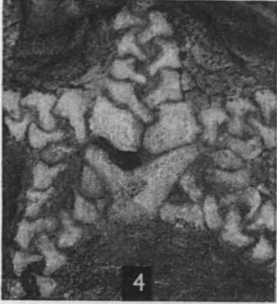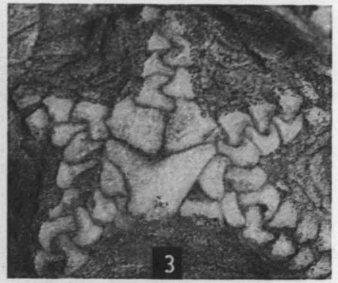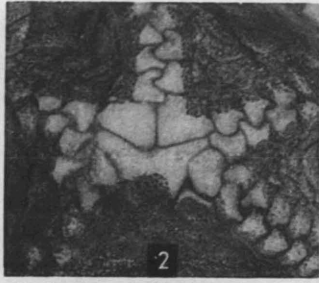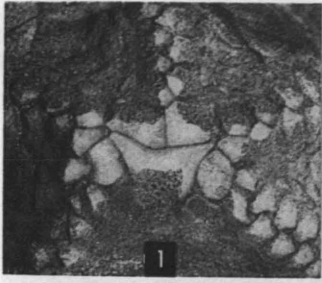
PLATE VIII
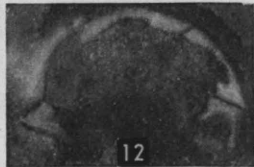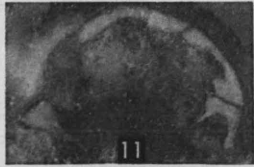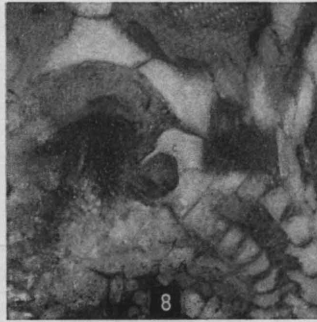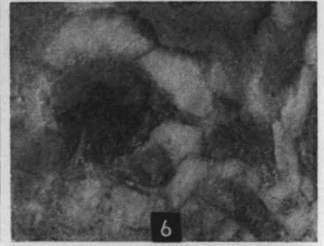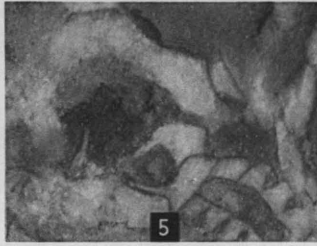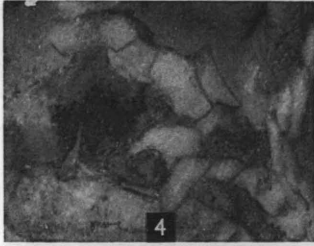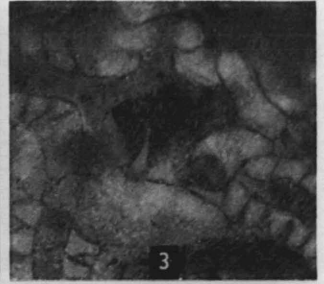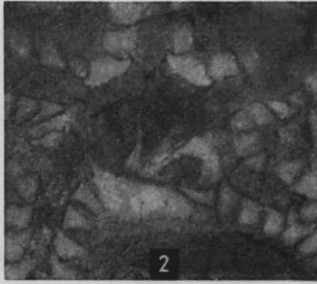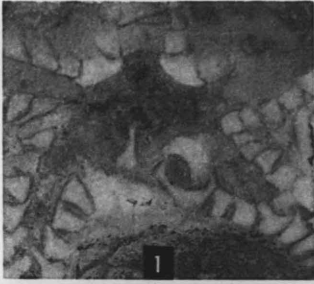
EXPLANATION OF PLATE VIII

(All figures × 7½)

FIGS. 1–14. Oral views of successive polished surfaces of specimen shown in Plate VI, each submersed in xylol. These surfaces follow those shown in Plate VII. This series shows the aboral extension of the passageway for the stone canal, the frame around the peristome (formed by the proximal flooring plates of the ambulacra), and the relationships of some of the ambulacral covering plates to the underlying flooring plates.

EXPLANATION OF PLATE IX

FIGS. 1–2. Aboral views of AMNH No. 13266-1-x; from the Upper Ordovician Maysville group, McMillan formation, Corryville shale member; Cincinnati, Ohio. This specimen was described and figured by Foerste (1914, pp. 418, 428, Pl. II, Fig. 3). Figure 1 is a stereogram of the specimen rather heavily coated with sublimated ammonium chloride ($\times$ 5). Figure 2 is a view of specimen very lightly coated with sublimated ammonium chloride (approximately $\times$ 8).

PLATE IX