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HYDROPORES IN EDRIOASTEROIDS

BY

ROBERT V. KESLING

MUSEUM OF PALEONTOLOGY
THE UNIVERSITY OF MICHIGAN
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CONTENTS

INTRODUCTION

CERTAIN STRUCTURES in edrioasteroids of the families Agelacrinitidae and Hemicystitidae appear to be hydropores. Previously, hydropores have been known only in one family, the Edrioasteridae, although their presence has been suggested in a few species in others. All structures that I interpret as hydropores are located in the right posterior part of the peristomial region or in the nearby part of the posterior interambulacrum. Because this report is merely intended as an introduction to the subject, only representative species from selected genera are included. Later, it is hoped to continue the investigation and to substantiate the structure of the supposed hydropores of these and other species by study of polished serial surfaces through well-preserved specimens.

Since the structure here called hydropore has been known by other terms, it is desirable to define it here to avoid misunderstanding. The hydropore is an opening on the oral side in the right posterior quadrant of the edrioasteroid, presumably functioning as the only adit and exit to the water-vascular system. As in the cystoids, it lies between the anal pyramid and the oral region, but may be offset toward the right.

From the nature of their fossilized remains it is evident that edrioasteroids combined, in a unique way, features of several otherwise unlike echinoderms. In them, the mouth, hydropore, and anus were on the same side of the body, as in a cystoid. The body was elastic with plated armor, like that of a carpoid. The ambulacra radiated out from the mouth, like those of a starfish, but were fixed on the theca, like those of a blastoid. Their food-gathering system in part resembled that of a starfish and in part that of a crinoid. While the ambulacral grooves were roofed over by plates resembling the adambulacrals of a starfish, the mouth, quite unlike that of the starfish, was covered by plates and resembled the subtegminal mouth of a crinoid. Some edrioasteroids were attached, like pelmatozoans, whereas others were free, like eleutherozoans.

Very early in the course of study of these forms, edrioasteroids were compared to members of the class Stelleroidea of the subphylum Eleutherozoa. In the same article in which he established the class name Edrioasteroidea, Billings (1858, p. 85) wrote, "I have placed *E. Bigsbyi* in the order Asteriadae, because its structure appears to me to be more like that of the Star-fishes than that of the Cystideae." Over fifty years later Bather (1915*b*, pp. 393–403) made an elaborate comparison of edrioasteroids and asteroids. At the present time, edrioasteroids are assigned to the Pelmatozoa, because they are thought to have been essentially sedentary, in spite of the fact that their long, curved, covered ambulacra and spherical, discoidal, or stumplike flexible thecae are recognized as unique in that subphylum.

For several reasons edrioasteroids are still poorly understood, both anatomically and taxonomically, for they are not only specialized but extinct, rare, and small. Furthermore, since many specimens are poorly preserved, they are often unassignable. Specialization in edrioasteroids presumably resulted from their adaptation to a stationary way of life. Even those found unattached may have been fastened to some object during most of their lives. Apparently, edrioasteroids at best had very little locomotion and, with fixation, the food-gathering system became highly developed. Just opening and closing the ambulacral covering plates called for complicated mechanisms. Although no animal is simple, one which lives sessile, carrying on growth, digestion, respiration, and reproduction at one site, must be regarded as very specialized. In consequence, the morphology of these complex, extinct animals, without clearly defined zoological affinities, is difficult to decipher from their fossil remains.

Insofar as known, edrioasteroids died out in the Pennsylvanian period without leaving any descendants. Because they are extinct and have no living close relatives, edrioasteroids are more difficult to study than fossil echinoderms which have them. One can only infer how the animal lived from the hard parts that are preserved. Any paleontologist working with extinct organisms is often tempted, with little or no justification, to homologize their structures with those in living organisms. He faces this dilemma: a structure preserved in a fossil is meaningful only as it is interpreted to be a functional part of an animal, but for extinct animals such an interpretation is fallible. However, although the nature of an edrioasteroid can only be inferred, certain lines of evidence are very convincing. For instance, Bather's detailed work (1900*b*) on *Edrioaster buchianus* Forbes leaves scarcely any room for doubt that the species had a water-vascular system that opened through a hydropore.

Edrioasteroids are relatively rare. Although the Upper Ordovician rocks in Cincinnati, Ohio, have yielded hundreds of specimens, this collecting ground is exceptional and, hence, world famous. In other places and from strata of other ages, these echinoderms are not nearly so well known. The paleontologist, therefore, finds it extremely difficult to make a comprehensive study, even at the generic level. Several genera are represented by a single species, and that one known only from the type specimen. In spite of long, painstaking searches at type localities and elsewhere, no additional specimens have ever been found for many species. It is particularly unfortunate that some forms are based only on very poorly preserved and incomplete holotypes.

A morphological survey of hydropores is even more difficult than a study of the whole animal, because many edrioasteroids are so very small. Only a few, such as *Edrioaster bigsbyi* (Billings), *E. buchianus* Forbes, and *Lepidodiscus squamosus* (Meek and Worthen), attain a diameter greater than 40 millimeters. Most of them are much smaller and some are only a few millimeters in diameter. Because the entire fossil is not large, it is hard to discern such a relatively much smaller structure as the hydropore.

Still another source of difficulty is the mode of their preservation. Very few specimens are found with all plates in nearly their original positions. The living edrioasteroid was composed of a blister-like sac containing the soft parts, which was shingled or tiled over with protective calcareous plates. Except for the flooring plates under the ambulacra, there were no hard parts within the "blister" to strengthen it and, moreover, not all edrioasteroids had a base of hard parts on the underside. As soon as the animal died, therefore, decomposition soon ruptured the sac, which collapsed like a punctured balloon. If the edrioasteroid was attached to an inclined surface, as many were, the plates on the lower side were crowded together or disrupted by the sag of the body. In some specimens, only a few plates have been retained on the body itself, the others are scattered at random. In the species with a rigid peripheral ring of plates, the interambulacra show the greatest distortion due to collapse of the sac. All in all, the general body plan of the edrioasteroid is not conducive to good preservation. Excellent specimens are very rare.

This study was made possible by the co-operation of many workers, to each of whom I am greatly indebted. Dr. Remington Kellogg, Dr. Porter M. Kier, and Dr. G. Arthur Cooper, all of the U. S. National Museum, loaned specimens from that institution. Dr. Hans Frebold arranged for loans from the Department of Mines and Technical Surveys of the Geological Survey of Canada. Dr. Kenneth E. Caster and Mr. John Pope made available hundreds of exceptionally well-preserved edrioasteroids from the collections in the University of Cincinnati Museum. The manuscript of this paper was reviewed by Dr. G. M. Ehlers, Dr. L. B. Kellum, and Dr. C. A. Arnold; their helpful comments and criticism are appreciated. Mr. Herbert W. Wienert was the photographer.

Specimens are identified by catalogue numbers preceded by the abbreviation of the depository as follows: UCM, University of Cincinnati Museum; USNM, U. S. National Museum; CGS, Canadian Geological Survey; and UMMP, University of Michigan Museum of Paleontology.

PREVIOUS WORK

The first report of a hydropore in an edrioasteroid that I have located is that by Bather (1900*a*). Bather wrote the chapter on Edrioasteroidea in Lankester's *A Treatise on Zoology, Part III, The Echinoderma,* and in this account furnished an illustration of *Edrioaster bigsbyi* (Billings) (Fig. VI-1), in which a structure was labeled "M" and identified in the explanation as a "madreporite." Since, under his description of the class Edrioasteroidea, he stated (p. 205), "Hydropore (usually, if not always, present) between mouth and anus," later writers assumed that a hydropore was known in all or nearly all edrioasteroids at that time. This is not so. Only in *Edrioaster bigsbyi* was a hydropore identified in 1900, and the first mention of it is in the legend to Bather's figure on page 209.

It is true that in this treatise Bather also illustrated *"Agelacrinus" hamiltonensis* (1900*a*, Fig. III, p. 207) with a structure labeled "M" which he referred to in the explanation as "supposed madreporite." But his figure of this species was copied from Hall (1872, Pl. 6, Fig. 14) and Bather apparently mistook the representation of sculpturing on one of the posterior interambulacral plates for a hydropore. When Clarke (1901, Pl. 10, Fig. 6) reillustrated *Agelacrinites hamiltonensis* as a drawing based on a cast of the type specimen, there was no sign of an opening to be observed at the place where Bather had indicated the "supposed madreporite."

In 1900 Bather also published the second of his important *Studies in Edrioasteroidea* in the *Geological Magazine*. In this article he described details of *Edrioaster buchianus* Forbes and stated (1900*b*, p. 198): "The proximal or adoral pores were connected with one another above this stereom ring, but below the outer theca, so as to form a closed ring-canal (hydrocircus) around the mouth. In the posterior interradius was a madreporite or hydropore-plate, the inner surface of which formed a semi-circular projection for the attachment of the upper end of the stone-canal." In this instance, Bather's conclusions were based on a specimen preserved as a steinkern; it is illustrated in his Plate 10, Figure 2.

In Bather's fourth study in the *Geological Magazine* (1914, p. 118), he said of *Edrioaster bigsbyi,* "In the posterior interradius, two large interradials, adjoining the peristome, are traversed by an elongate hydropore." On the same page (in Fig. 1) Bather published a drawing of *E. bigsbyi* in which the hydropore was identified as a "water-pore." This drawing has been copied in many texts and articles; a modification of it is presented here as Figure 1. Bather also illustrated the hydropore of this species in his Plate 10, Fig. 1, and Plate 11, Figs. 1–2. He said (1914, pp. 167–68) that "The Hydropore, or at least the thecal opening which I thus identify, lies at the adoral end of the posterior interradius close to the margin of the right posterior groove . . . The hydropore was not mentioned by E. Billings at any time, but his restored figure (1854, Fig. 10) shows that he observed something in the region where we now know it to occur." In his diagnosis of the family Edrioasteridae, Bather (1914, p. 170) included the statement that "a hydropore (probably always) pierces an adoral interradial of the posterior interradius."

Up to the present a distinct hydropore has not been detected in edrioasteroids of the family Hemicystitidae, but the presence of some such structure in *Carneyella pilea* (Hall) was observed by Foerste in 1914. Foerste studied specimens of *C. pilea* in which the aboral side of the peristomial cavity was exposed, and he recorded and figured (1914, p. 429, Pl. 1, Fig. 5*a*; Pl. 2, Figs. 3–4) "a peculiar marginal depression along the proximal part of the right hand margin of the right posterior ray (No. 5), as viewed from below." Of it he said, "This impression involves the two proximal covering plates on the left side of the right posterior ray, where 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." In his comment on Foerste's account Bather (1915*a*, p. 266) stated that if a duct were present "then the duct in question would most naturally be the hydropore-canal."

Foerste indicated that the hydropore in *Carneyella pilea* might be an elongate slit between plates in the right posterior part of the peristomial region. From the form and position of the plates in this region he concluded (1914, p. 415): "This suggests the possibility of exit of some duct at the angle between these three plates, the posterior peristomial plate (P), the plate immediately adjacent on the right (X), and the first covering plate of ambulacrum V (5). No aperture actually penetrating a plate has been noted." As may be seen in Foerste's figure (1914, Pl. 1, Fig 5*a*), his plate "X" appears to be part of the peristomial region, rather than of the posterior interambulacrum as he considered it.

The structure of the peristomial plates in *Carneyella pilea* was also noted and figured by Williams (1918, p. 77; Pl. I, Fig. 2). He wrote: "There are two plates . . . in the posterior inter-radial space by the proximal end of arm 5 which appear as [though] a duct had passed between them." He commented (p. 77) as well on a specimen having "a plate in this same region which has a distinct pit or pore in it" and on another in which "there is a notch on the edge of the plate next the inter-radial space." Both comments refer to structures that are probably the result of imperfect preservation. But Williams concluded (1918, p. 80) that there "is a hydropore in the posterior inter radius near the posterior peristomial plate and near arm 5."

The morphology of edrioasteroids was reviewed by Bather in his seventh study (1915*a*). He again stated the evidence for a water-vascular system in *Edrioaster,* and added (p. 226), "In the Agelacrinidae . . . an external hydropore has not as yet been detected, but it is conceivable that the hydrocircus opened into the oral vestibule, and that it may have been connected with some canal passing up in the posterior interradius."

Of the aboral side of *Anglidiscus fistulosus,* which Anderson had the opportunity to study, he wrote (1939, pp. 79–80), "In one specimen of *L.* [*epidodiscus*] *fistulosus,* the posterior peristomal plate has been displaced to the left. Slightly to the right of the centre is the impression of a lobate organ with a canal leading to the right posterior. This probably indicates the position of the stomach and intestine. 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." These features are illustrated in his Figure 10.

That some sort of hydropore exists in members of the family Agelacrinitidae was suggested by Hecker (1940, p. 99; 1941, p. 321), who had observed the asymmetrical structure of the peristomial region in *"Agelacrinites" ephraemovianus* (Bogolubov). Regnéll, who transferred this species to *Lepidodiscus,* referred to the structure (1950, p. 5) as "a bulging into the anal interambulacrum of the oral field suggesting the presence of some wider opening, according to the interpretation of Hecker." A similar asymmetrical structure has been observed in *Lepidodiscus squamosus* (Meek and Worthen) by Kesling and Ehlers. They stated (1958, p. 931), ". . . additional plates in the right posterior part make the peristomial region asymmetrical. The crushing in of the plates in this part strongly suggests that this unpaired structure was underlain by a hollow duct. No opening that could be termed a distinct hydropore was observed, although the plates are caved in and distorted so that even a large hydropore might not have been preserved."

Ehlers and Kesling (1958*b*, p. 268) described the peristomial region of *Discocystis laudoni* in detail and called attention to an unpaired structure in the right posterior region. They said, "The arcuate shape of the slit in *D. laudoni* suggests that it was an opening into the peristome, and its position strongly indicates that it is the hydropore."

SYSTEMATIC DESCRIPTIONS

Family Edrioasteridae
Genus *Edrioaster* Billings, 1858
Edrioaster bigsbyi (Billings)

(Figure 1; Pl. I, Figs. 1–2)

Cyclaster Bigsbyi Billings, 1857, pp. 293–94.
Edrioaster Bigsbyi Billings, 1858, pp. 82–83, Pl. 8, Figs. 1, 1*a,* 2, 2*a.*

Hydropore.—The hydropore was adequately described by Bather (1914, p. 118) as follows: "In the posterior interradius, two large interradials, adjoining the peristome, are traversed by an elongate hydropore." In a specimen, UMMP No. 5731, in the University of Michigan collections, however, one plate adjoins the peristomial region and the other adjoins the

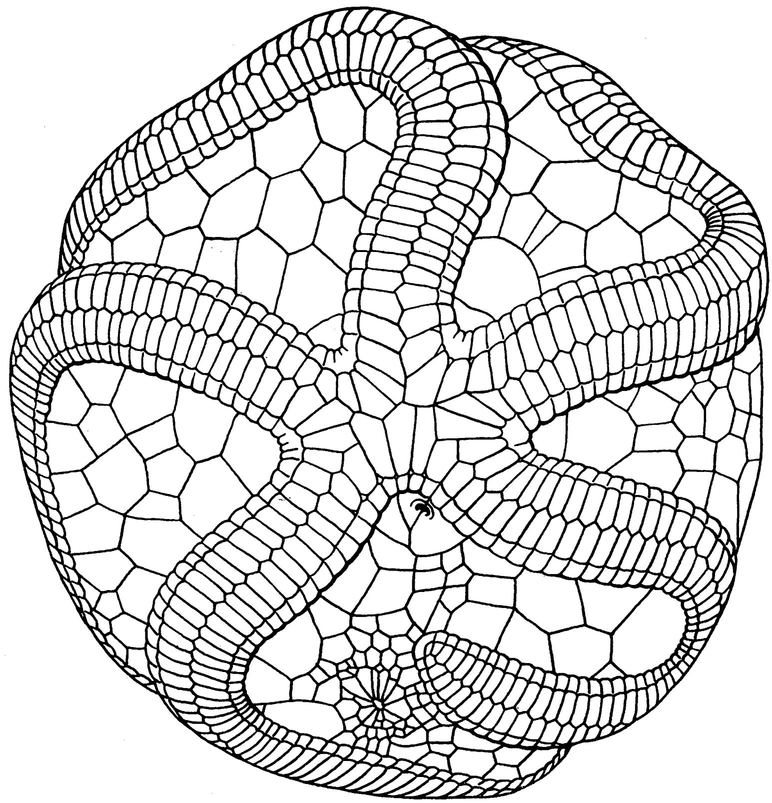

FIG. 1. *Edrioaster bigsbyi* (Billings). Restoration modified from Bather (1900*a*, Fig. VI-1; 1914, Fig. 1; Pl. X, Figs. 1–11; Pl. XI, Figs. 1–2; 1915*b*, Fig. 3). Compare with Plate I, Figures 1–2.

left side of ambulacrum V. This seems to be a normal arrangement. Probably, Bather regarded the proximal parts of the ambulacra as the outer margin of the peristomial region, as indicated, indirectly, in his Figure 1 (here modified as Fig. 1), which seems to have about the same distribution of plates as that in the University of Michigan specimen (Pl. I, Figs. 1–2).

Remarks.—*Edrioaster bigsbyi* is the edrioasteroid most familiar to paleontologists, because Bather's drawing of it (1900*a*, Fig. VI–1; 1914, Fig. 1; 1915*b*, Fig. 3) has been reproduced so many times. Moreover, numerous well-preserved specimens have been found, and the species is so large that the hydropore can be easily located.

Illustrated specimen.—UMMP No. 5731. Middle Ordovician Trenton group, Kirkfield, Ontario. The specimen, obtained from the Springer Collection by exchange, is worn and does not show the ornamentation typical of the species.

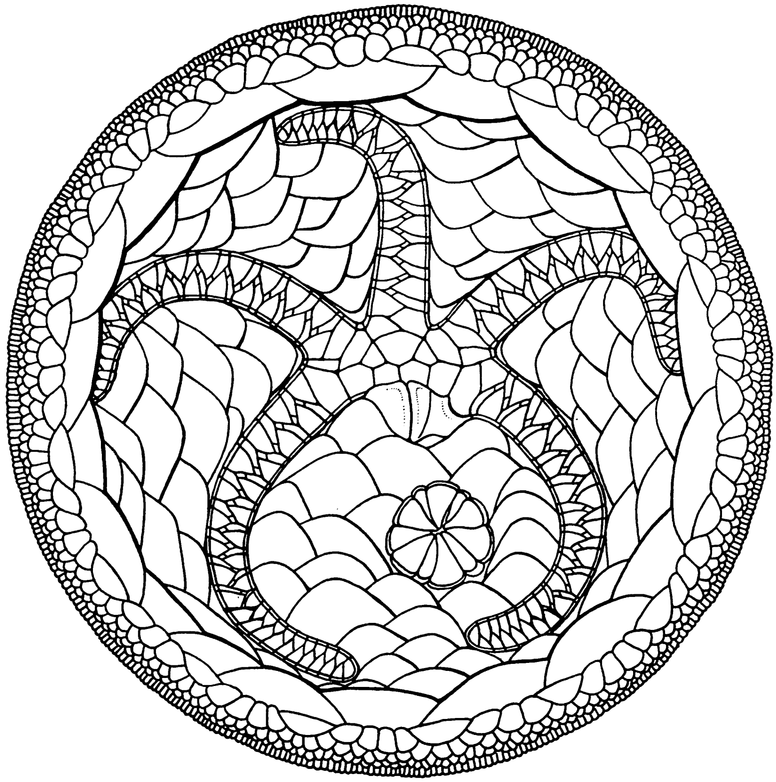

FIG. 2. *Agelacrinites* sp. B. Restoration based on specimens UMMP Nos. 4796 and 21203, illustrated in Plate V, Figures 1–2.

Edrioaster levis Bather

(Pl. I, Figs. 3–4)

Edrioaster levis Bather, 1914, pp. 117, 119, 121–22, 163, 166–68, 171, Pl. 12, Figs. 1–2; Fig. 2.

Hydropore.—The hydropore, like that of *Edrioaster bigsbyi,* is an opening shared by two plates (Pl. I, Fig. 4). It is large, conspicuous, and surrounded by a raised rim. In UMMP No. 26428 it tapers towards the right posterior end and has a slight constriction.

I regard the plates containing the hydropore as part of the posterior interambulacrum, although they are closely associated with the peristomial region. Because the elongate covering plates are considered to be the distal limits of the ambulacra, the hydropore-bearing plates are part of the posterior interambulacrum. In such an analysis, the large plate is bordered by one ambulacral covering plate of ambulacrum I, three plates of the peristomial region, and one plate of ambulacrum V, in addition to the those of the posterior interambulacrum and the companion plate containing the other half of the hydropore. The plates adjacent to the ambulacra and peristomial region, however, have a regular border with the other interambulacral plates, more or less parallel to the edges of the ambulacra. If they are regarded as part of the ambulacra and peristomial region, then the hydropore is located within a posterior expansion of the peristomial region.

Illustrated specimen.—UMMP No. 26428. Middle Ordovician Trenton group; Kirkfield formation, Kirkfield, Ontario. Collected by Dr. G. Winston Sinclair.

Family Agelacrinitidae

Genus *Agelacrinites* Vanuxem, 1842

Agelacrinites sp. A

(Pl. IV, Figs. 1–5)

Hydropore.—In the largest specimen, UMMP No. 35387, assumed to be an adult, the most noticeable feature in the posterior part of the peristomial region is a vaulted structure formed by two large plates, one left and one right, which are strongly elevated at their juncture (Pl. IV, Figs. 1–2). Such a structure has not been reported previously in edrioasteroids. The two plates have a long, nearly straight suture line between them, with the edge of the right plate slightly concave. The left plate, the smaller of the two, is subtrapezoidal, tapering toward the left. The right plate has a deep longitudinal groove through its middle; it has the general shape of a lopsided saddle. Its anterior edge fits against the first plate on the left side of ambulacrum V and its concave right edge borders the distally expanded second plate. It is this juncture, between the largest plate in the posterior part of the peristomial region and the second plate on the left side of ambulacrum V, that appears to be the hydropore.

On the right posterior side of the large plate described above, and extending to the right of it, is a conspicuous subquadrate plate which borders the third and fourth plates on the left side of ambulacrum V. In this ambulacrum the first three plates on the left side are considerably longer than the others, and the second is distally convex and expanded, so that it is subpalmate.

In the adult specimen it is difficult to determine the border between the peristomial region and the posterior interambulacrum, but the two large plates forming the vaulted structure join distinctly and evenly with the imbricating plates of the interambulacrum and are included, therefore, in the peristomial region. Tentatively, the subquadrate plate at the right is also assigned to the posterior interambulacrum.

One of the young specimens, UMMP No. 35379, as well, shows a vaulted structure formed of two large plates, which are proportionally larger than those in the adult (Pl. IV, Fig. 4). The ambulacral plate that fitted against the right side of the larger plate is now somewhat askew in this individual, but it seems to be the first plate on the left side of ambulacrum V. Another immature specimen, UMMP No. 35377, intermediate in size between the two preceding, has the two large plates in the posterior part of the peristomial region well preserved (Pl. IV, Fig. 3). The right side of the larger plate fits against the first ambulacral plate and part of the second on the left side of ambulacrum V. In a very small specimen, UMMP 35389, less than 3 mm. in diameter, the two large plates likewise form a vaulted structure (Pl. IV, Fig. 5), but details of the hydropore are not clear.

Admittedly, this is an incomplete ontogenetic series, but in very young edrioasteroids the right side of the larger of the two plates appears to have bordered the first ambulacral plate; in the older but still immature, the first and second ambulacral plates; and, finally, in the adult, the second plate only. Presumably, the conspicuous vaulted structure may have operated like a hinge, with the larger plate lifting to admit water through the hydropore along its right edge.

Remarks.—*Agelacrinites* sp. A has much narrower ambulacra and more numerous interambulacral plates than *A. southworthi* Bassler. In addition, the largest specimen so far found, UMMP No. 35387, is smaller than the holotype of *A. southworthi,* USNM No. S3478. It is considered to be an adult, even though the ambulacra do not extend to the peripheral ring, as they do in adults of other species of *Agelacrinites.* In having narrow ambulacra and numerous interambulacral plates, it resembles *A. legrandensis* Miller and Gurley, from the Lower Mississippian Legrand formation, but it differs in having little or no taper in each of the ambulacra.

Illustrated specimens.—UMMP Nos. 35377, 35379, 35387, and 35389. Middle Devonian Traverse group, Ferron Point formation. Abandoned shale pit of Alpena Portland Cement Company, about 8 miles northeast of Alpena, Alpena County, Michigan, SE ¼ sec. 18, T. 32 N, R. 9 E. Collected by Mr. I. G. Reimann.

Agelacrinites sp. B

(Figure 2; Pl. V, Figs. 1–2)

Hydropore.—In each of two specimens, UMMP Nos. 4796 and 21203, some of the plates in the posterior part of the peristomial region are displaced or missing. The bigger of the two, No. 4796, has the first plate on the left side of ambulacrum V slightly larger than the adjacent ambulacral plates, and the plate which evidently fitted against it thrust under its distal end (Pl. V, Fig. 1). Two other plates are displaced toward the left; and the configuration of the interambulacral plates adjacent to them suggests that they were the posterior plates of the peristomial region. The arrangement of plates in the peristomial region seems to be intermediate between that of *Agelacrinites* sp. A and that of *A. southworthi* Bassler, but, unfortunately, specimens with this region better preserved have not yet been found; hence, my restoration (Fig. 2) is tentative.

The smaller of the two specimens, UMMP No. 21203, has a peristomial plate missing next to the first ambulacral plate on the left side of ambulacrum V. In its place, there is what I interpret to be the beginning of a duct leading downward from the hydropore.

The peristomial plates in *Agelacrinites* sp. B apparently correlate with those in *Agelacrinites* sp. A (described above.) In the posterior region of sp. B, the left plate seems to correspond to the left plate in sp. A, and the other two plates, together, to correspond to the right plate in sp. A. It is possible, however, that what I have called two plates on the right are, in reality, not two separate plates of the peristome but only the broken parts of a single plate. If this latter interpretation were correct, then the similarity between the peristomial region in sp. B and that in sp. A would be even more striking.

Remarks.—*Agelacrinites* sp. B, which came from the Middle Devonian Ferron Point formation of Michigan, differs from *Agelacrinites* sp. A, in the same strata, in having much broader ambulacra and larger interambulacral plates. Indeed, it is more closely related to *A. southworthi* Bassler, from the Arkona shale (from beds which may be the same age as the Ferron Point formation), but differs from it in having proportionally wider ambulacra and distinct, narrow bordering plates along them. Both *Agelacrinites* sp. B and *A. southworthi* are remarkably similar in the form of the peripheral ring and the interambulacral plates; they can be distinguished only by their ambulacra.

Illustrated specimens.—UMMP Nos. 4796 and 21203. Middle Devonian Traverse group, Ferron Point formation. Abandoned shale pit of Alpena Portland Cement Company, about 8 miles northeast of Alpena, Alpena County, Michigan SE 1/4 sec. 18, T. 32 N., R. 9 E. No. 4796 collected by G. M. Ehlers and No. 21203 by I. G. Reimann.

Agelacrinites southworthi Bassler

(Pl. V, Figs. 3–4)

Agelacrinites southworthi Bassler, 1936, p. 16, Pl. 4, Fig. 12.

Hydropore.—In the holotype, USNM No. S3478, the posterior part of the peristome is overlaid by three large, conspicuous plates. The left one is subtrapezoidal, slightly convex posteriorly, and adjoins the middle plate with a prominent, straight suture. The middle plate is subtriangular, with one apex directed posteriorly; it is elevated along the juncture with the first plate, in more or less the same way that the two plates in *Agelacrinites* sp. A together form a vaulted structure. The right plate, subtriangular and transversely elongate, has its right anterior border indented parallel to the convex end of the adjacent ambulacral plate. The hydropore seems to be between the indentation in the right posterior peristomial plate and the adjacent part of ambulacrum V.

A very young specimen, USNM No. 94643 (Pl. V, Fig. 4), also shows a distinct feature here interpreted as a hydropore. Like specimens of *Agelacrinites* sp. A, it has a vaulted structure of two plates in the rear part of the peristomial region, although it is low, practically a slight convexity with a longitudinal ridge along the juncture of the plates. The right plate is the homologue of the middle and right plates (combined) in the corresponding region in the adult. Its orientation differs, however. In the adult, USNM No. S3478, the plates are elongate to the right and posterior, so that the supposed hydropore lies slightly behind the vaulted structure; but in the very young individual, the right plate is elongate to the right and anterior, so that the supposed hydropore lies slightly ahead of the vaulted structure. In the adult, moreover, the hydropore appears to border the second large plate on the left side of ambulacrum V, whereas in the young it lies along the first ambulacral plate. The ontogenetic development of the plates in *Agelacrinites southworthi,* therefore, parallels that observed in *Agelacrinites* sp. A, in that the hydropore migrates distally along the left edge of ambulacrum V.

Remarks.—If an ontogenetic series of well-preserved specimens is ever found, some should be sectioned to determine the relationship of the supposed hydropore to the underlying structures.

Illustrated specimens.—Holotype, USNM No. S3478; Middle Devonian Hamilton group, Arkona shale, 20 to 30 feet below the Encrinal limestone (Hungry Hollow formation) Marsh's Mills, Arkona, Ontario. USNM No. 94643; the label with the specimen gives the stratigraphic occurrence as "Widder" at Thedford, Ontario. Dr. G. A. Cooper is uncertain about the history of this edrioasteroid, but states that the matrix resembles the Arkona shale instead of the younger Middle Devonian Widder formation.

Genus *Thresherodiscus* Foerste, 1914

Thresherodiscus ramosus Foerste

(Figure 3; Pl. XIII, Figs. 1–2)

Thresherodiscus ramosa Foerste, 1914, pp. 432–39, Fig. 1; Pl. I, Fig. 8; Pl. 3, Fig. 3.
T. ramosus Bassler, 1936, p. 15, Pl. 2, Fig. 8.

Hydropore.—The feature thought to be the hydropore is near the left side of ambulacrum V. Although the plates bordering it are distinct, the

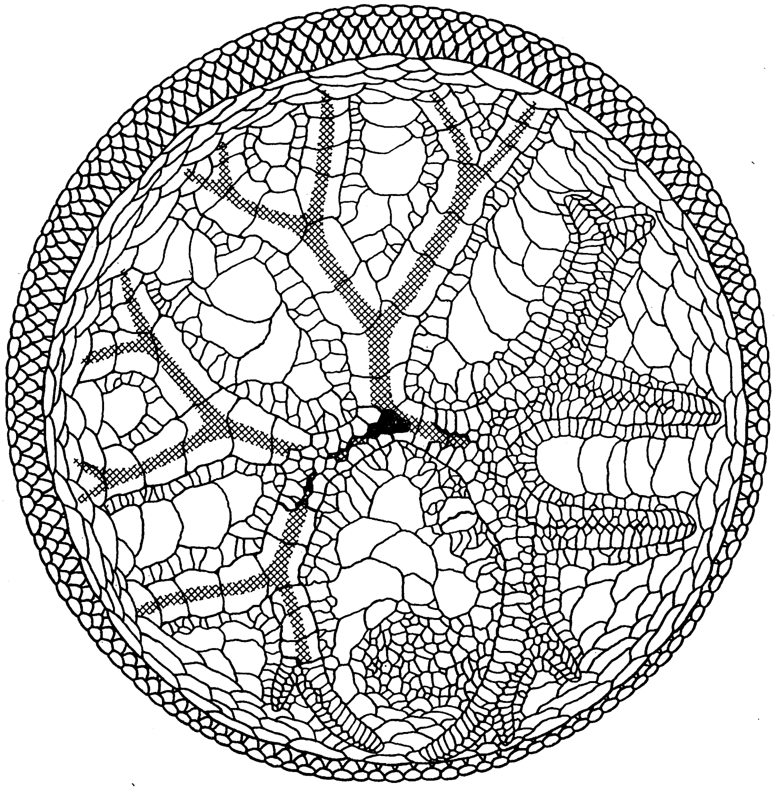

FIG. 3. *Thresherodiscus ramosus* Foerste. Restoration based on the holotype and only known specimen, CGS No. 8446, illustrated in Plate XIII, Figures 1–2. Cross-hatched areas are ambulacral grooves, seen where covering plates are missing.

interpretation as a hydropore is subject to question, particularly since only the holotype is known for this unusual species and genus.

The posterior interambulacrum is covered by plates of two distinct types, in addition to the small plates composing the anal pyramid. The central part of the region contains a few large, subpolygonal, slightly imbricating plates, the margins next to the ambulacra and peristomial region smaller plates, which Foerste (1914, p. 437) referred to as "bordering plates." Most of these bordering plates are of two kinds, although there are many irregular ones that do not fit into either of the following categories. Those next to the large interambulacral plates are long and narrow with their longer axes more or less perpendicular to the edges of the interambulacrum, whereas those along the border of the ambulacra and peristomial region are more irregular, commonly triangular and interfingering with the long, narrow plates.

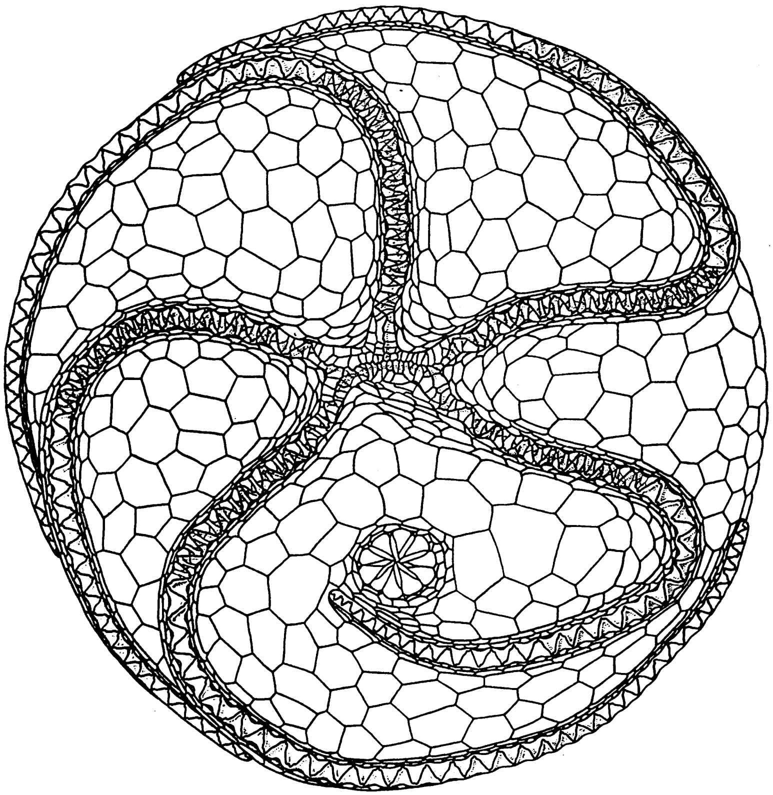

FIG. 4. *Discocystis laudoni* Bassler. Restoration based on cotypes USNM Nos. S3886*a* and S3886*b*, the latter illustrated in Plate III, Figures 1–3.

In the right anterior part of the posterior interambulacrum there is an outstanding anomaly in the general pattern of bordering plates. At the left side of ambulacrum V, about midway between its bifurcation and its junction with ambulacrum IV, there are two plates larger than the other bordering plates; together they form an oval with the long axis roughly perpendicular to the ambulacrum (Pl. XIII, Fig. 1). The two semioval plates are nearly equal, but their line of contact is crooked; the proximal part of the anterior plate projects into a notch in the posterior.

When the holotype is submersed in xylol (Pl. XIII, Fig. 2), the area around the junction of the two anomalous bordering plates appears dark. Apparently this indicates that the plates are thin at this place, because other thin parts of the oral side also appear dark in xylol. For example, the deeper parts of the flooring plates of the ambulacra (the ambulacral grooves), which are exposed where the covering plates are missing, are seen as dark bars across the plates. Since in other edrioasteroids that have been sectioned the flooring plates are thinnest at the ambulacral grooves, it seems logical to assume that the dark color in xylol is due to thinness of the plates. Anomalous posterior interambulacral plates that exhibited dark areas when submersed in xylol are also noted in *Foerstediscus splendens* Bassler (which see), and are interpreted in that species as the hydropore.

One cannot be certain that the two semioval plates covered the entrance to the stone canal and that the junction between them was the hydropore, but they are in about the same position as the hydropore in *Foerstediscus splendens* Bassler. They do not, however, have raised margins along the edge of the supposed hydropore, such as have been noted on the plates adjacent to the hydropore in other edrioasteroids. Nevertheless, I am inclined to regard them as those bordering the hydropore, inasmuch as the hydropore is bounded by anomalous plates in this part of the posterior interambulacrum in several other edrioasteroids.

Remarks.—Unfortunately, this unusual genus is known only from the type species, and the type species only from the holotype. One can merely trust that the characters seen in this specimen faithfully represent those of the genus and species.

Although Foerste (1914, pp. 432–39) gave a detailed account of *Thresherodiscus ramosus,* which for most features is extremely accurate and lucid, one part of his description needs clarification. He stated (p. 437), "If the anus was protected by a pyramid of small plates, this pyramid is concealed at present at the base of the anal depression." Preceding his systematic description of the species, however, he wrote (p. 425), "In *Thresherodiscus* it has been impossible to determine whether the anus is located in the bottom of the depression on the right side of the posterior interambulacral area, or at the top of the immediately adjacent part of the elevation which is present on the distal side of this depression." I believe the anal opening to be at or near the summit of the pyramid, although the irregularity of the small plates precludes an accurate location. As one can see in the stereogram of the holotype (Pl. XIII, Fig. 1), only a few plates of the anal pyramid seem to be crushed inward at what Foerste termed the "anal depression." Most of the plates form a distinct elevation; they are small and irregular and are not arranged in a rosette as are those in *Discocystis laudoni* Bassler (Pl. III, Figs. 1, 3), *Lepidodiscus squamosus* (Meek and Worthen) (Pl. II, Fig. 2), *Agelacrinites* sp. B (Pl. V, Fig. 1), *Isorophus cincinnatiensis* (Roemer) (Pl. XII, Figs. 1, 3, 5), and many other species.

It might also be pointed out that in *Thresherodiscus ramosus* each of the two main branches of ambulacrum II appears to have bifurcated, as evidenced by shallow extensions of the ambulacral groove, and similarly, the left of the four distal branches of ambulacrum III (Pl. XIII, Fig. 1).

Illustrated specimen.—Holotype, CGS No. 8446. Middle Ordovician Trenton group. Goat Island, northeast of Little Current, Manitoulin Island, Ontario, where the railroad from LaCloche Island strikes the northeastern edge of Goat Island, from strata 18 feet stratigraphically above the lowest strata exposed at the edge of the lake. Collected by Dr. A. F. Foerste in 1912.

Genus *Discocystis* Gregory, 1897
Discocystis laudoni Bassler
(Figure 4; Pl. III, Figs. 1–3)

Discocystis laudoni Bassler, 1936, p. 21, Pl. 3, Figs. 7–8.

Hydropore.—The hydropore is a transversely elongate, curved slit lying wholly within the posterior part of the peristomial region and only partly in contact with ambulacrum V. Regarding it, Ehlers and Kesling (1958*b*, p. 268) stated:

The peristomial region . . . like that in *L[epidodiscus] squamosus* . . . is strongly asymmetrical with the left half much narrower than the right. The covering plates in the right posterior region form a conspicuous arcuate slit, the left half of which is roughly parallel to the transverse serrate line across the middle of the peristome; the right half is parallel to the proximal part of ambulacrum V. This slit in *D. laudoni* corresponds to a line in the right posterior part of the peristome in the holotype of *Lepidodiscus squamosus* along which the plates are caved in. The arcuate shape of the slit in *D. laudoni* suggests that it was an opening into the peristome, and its position strongly indicates that it is the hydropore. The plates between the slit and the transverse line form a shallow trough. Posteriorly, the slit is bounded by large, broad covering plates.

Remarks.—This unusual species, from the Lower Mississippian Gilmore City formation in Iowa, is known only from the cotypes. One, USNM No. S3886*b*, shows the hydropore and is illustrated in Plate III.

Illustrated specimen.—Cotype, USNM No. S3886*b*. Lower Mississippian Kinderhookian series, Gilmore City limestone, Gilmore City, Iowa. Collected by Dr. L. R. Laudon of Tulsa University.

Genus *Lepidodiscus* Meek and Worthen, 1868
Lepidodiscus squamosus (Meek and Worthen)
(Figure 5; Pl. II, Figs. 1–2)

Agelacrinites (Lepidodiscus) squamosus Meek and Worthen, 1868, pp. 357–58.

Hydropore.—Kesling and Ehlers (1958, p. 930) called attention to the doubly lobate bulge in the right posterior part of the peristomial region and to crushing in of plates along a line in the holotype, the only known specimen. Because the plates are crushed in, they cannot be photographed to show their relationship. Figure 5 was reconstructed from a number of

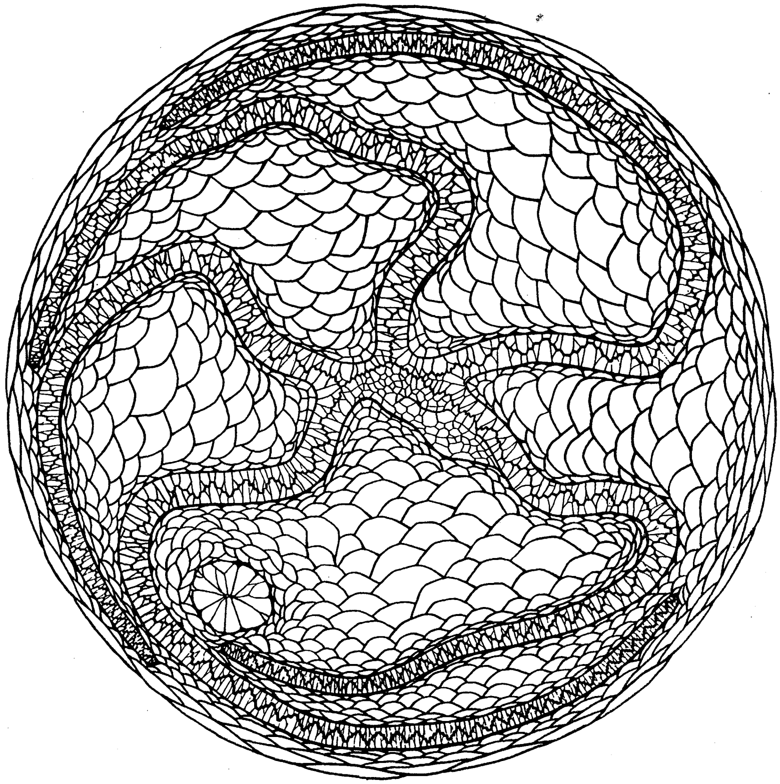

FIG. 5. *Lepidodiscus squamosus* (Meek and Worthen). Restoration based on the holotype, UMMP No. 5420, illustrated in Plate II, Figures 1–2.

camera lucida drawings that were made from various angles while the specimen was submersed in xylol. The reconstruction reveals that the plates in this region formed a curved slit, which agrees in character with that described in *Discocystis laudoni* in the following particulars: (1) the slit lies within the posterior part of the peristomial region, (2) part of it follows along the proximal side of ambulacrum V and the rest is roughly parallel to the center line of the peristomial region, and (3) the plates posterior to the slit are larger than those anterior to it. In *Lepidodiscus squamosus* the slit seems to have been convex posteriorly, whereas in *D. laudoni* it is distinctly convex anteriorly. I believe this slit was the hydropore and that the plates bounding it caved in because it was underlain by a hollow duct, the stone canal.

Remarks.—This species, from the Lower Mississippian Edwardsville formation in Indiana, was restudied by Kesling and Ehlers (1958), and their investigation has added many details to the original description.

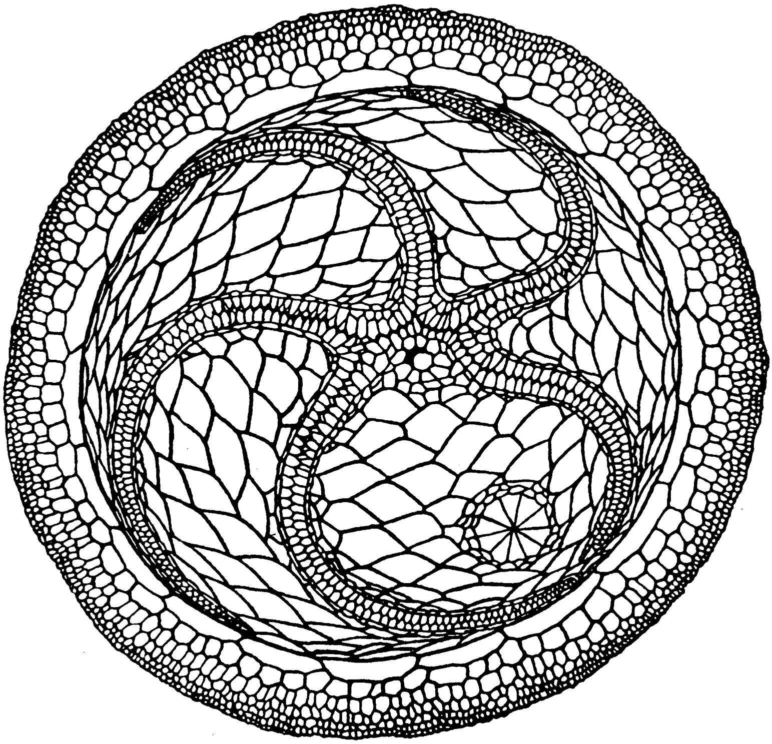

FIG. 6. *Lepidodiscus ephraemovianus* (Bogolubov). Restoration copied from Regnéll (1950, Fig. 1).

Illustrated specimen.—Holotype, UMMP No. 5420. For the history of this specimen, see Kesling and Ehlers (1958).

Lepidodiscus ephraemovianus (Bogolubov)
(Figure 6)

Agelacrinus ephraemovianus Bogolubov, 1926, pp. 33–38.
Lepidodiscus ephraemovianus Regnéll, 1950, p. 5, Fig. 1.

Hydropore.—I have not seen specimens of this species, but from the description by Hecker (1940, p. 99; 1941, p. 321) I strongly suspect that the bulging structure in the posterior part of the peristomial region was associated with a hydropore. The bulge reported by Hecker (p. 99) may correspond to the doubly lobate bulge in the right posterior part of the peristomial region in *Lepidodiscus squamosus,* the type species. Insofar as one may judge from Hecker's figure, however, the slit (if indeed one exists) does not extend to the proximal side of ambulacrum V. Hecker's figure, as copied by Regnéll (1950, Fig. 1), is here reproduced as my Figure 6.

Remarks.—Ehlers and Kesling (1958b, p. 270) raised the question whether many of the species now assigned to *Lepidodiscus,* including *L. ephraemovianus,* are correctly classified, in view of their having ambulacral covering plates in a pattern distinctly different from that in the type species, *L. squamosus.* Certainly, the edrioasteroids now placed in this genus need serious study and, most probably, systematic revision.

Genus *Isorophus* Foerste, 1916
Isorophus cincinnatiensis (Roemer)

(Pl. X, Figs. 1–4; Pl. XI, Figs. 1–2; Pl. XII, Figs. 1–6)

Agelacrinus cincinnatiensis Roemer, 1851, p. 372, Pl. 5, Fig. 3.
Agelacrinus (Lepidodiscus) cincinnatiensis Hall, 1872 [1866], p. 214, Pl. 6, Fig. 7.
Isorophus cincinnatiensis Foerste, 1916, pp. 340–41.

Hydropore.—For an edrioasteroid not even assigned to the same family, *Isorophus cincinnatiensis* is strongly reminiscent of *Carneyella pilea* (Hall), particularly in the form of the hydropore. The right half of the peristomial region is much broader than the left, and contains the hydropore. In the right posterior part of the region, three of the plates have raised margins along the junctures leading to the point at which they meet. These plates are (1) a large posterocentral plate of the peristomial region, (2) the right posterior plate of the peristomial region, and (3) the proximal covering plate on the left side of ambulacrum V. They correspond to the three plates bounding the hydropore in *Carneyella pilea.* But *Isorophus cincinnatiensis* differs from *C. pilea,* insofar as the area around the hydropore is concerned, in having an extra peristomial covering plate inserted between the anterior parts of the posterocentral and the ambulacral covering plate.

The large posterocentral plate is always longitudinally elongate, medially constricted, and anteriorly bluntly acuminate. In other respects, it shows considerable individual variation. For example, in some specimens the posterior end is acuminate (Pl. X, Figs. 1–4; Pl. XI, Figs. 1–2), but in others it slopes evenly, coming to a posterior point on the left (Pl. XII, Figs. 3–4) or the right (Pl. XII, Figs. 1–2). The right border has (1) an anterior notch, which fits around the end of a sloping spatulate plate of the peristominal region; (2) a central projection, which extends to the junction with the proximal covering plate of ambulacrum V; and (3) a posterior extension adjoining the right posterior plate of the peristomial region (Pl. XII, Fig. 4).

The right posterior peristomial plate is variable both in size and shape and, in some specimens (Pl. XII, Figs. 3–4), it is very large.

The proximal covering plate of ambulacrum V adjacent to the hydropore slants posteriorly and toward the left, with the two sides of its acuminate distal end fitting against the posterocentral and right posterior peristomial plates. Apparently, the shape of the right half of this plate changes during ontogeny. In specimens smaller than 25 mm. in diameter, the plate has nearly parallel sides, and is bordered on the left anterior by the sloping spatulate plate mentioned above (Pl. XI, Fig. 2); in larger specimens, however, the plate has an anterior indentation to accommodate a small wedgelike plate that develops between it and the spatulate plate (Pl. XII, Fig. 4). To be consistent in terminology, one must regard the one which extends to the junction of ambulacra IV and V as the first plate on the left side of ambulacrum V. Whereas, with this definition, the ambulacral covering plate bordering the hydropore is the first plate in young specimens (Pl. X, Fig. 2), because of the development of the wedgelike plate on its proximal border, it becomes the second plate in older specimens (Pl. X, Fig. 4).

The University of Cincinnati Museum has over 200 uncatalogued specimens of this species, many of them well preserved. Several of them have the three plates slightly agape, rather than in contact. It seems reasonable to assume that one or more of the plates was movable, perhaps in the same manner as the ambulacral covering plates.

Illustrated specimens—USNM No. 40746; Upper Ordovician Maysville group; Cincinnati, Ohio. UCM No. 34542; Upper Ordovician Maysville group, McMillan formation, Bellevue member; Hamilton Avenue, opposite Frisch's Big Boy Restaurant, Cincinnati, Ohio; collected by Mr. John Pojeta. UCM Nos. 34538-34541; same member and locality as UMC No. 34542; collected by Mr. William Deak in 1957.

Family Hemicystitidae

Genus *Hemicystites* Hall, 1852

Hemicystites devonicus Bassler

(Pl. X, Figs. 5–7)

Hemicystites devonicus Bassler, 1936, p. 14, Pl. 7, Fig. 1.

Hydropore.—The hydropore and the associated plates are like those in *Timeischytes megapinacotus*. In the right posterior part of the peristomial region, which is much larger than the left, there is a large unpaired plate inserted between the large posterior plate of the peristomial region and the proximal three or four plates on the left side of ambulacrum V. This unpaired plate is subquadrate, with more or less straight left and posterior edges and slightly concave right anterior and right edges. Its slightly concave edges fit against ambulacrum V.

The hydropore appears to be restricted to the long slit between the right anterior edge of the unpaired plate and ambulacrum, although the junction between the right edge of the plate and the ambulacrum may also be part of it. If the junction is included, the hydropore slit extends about

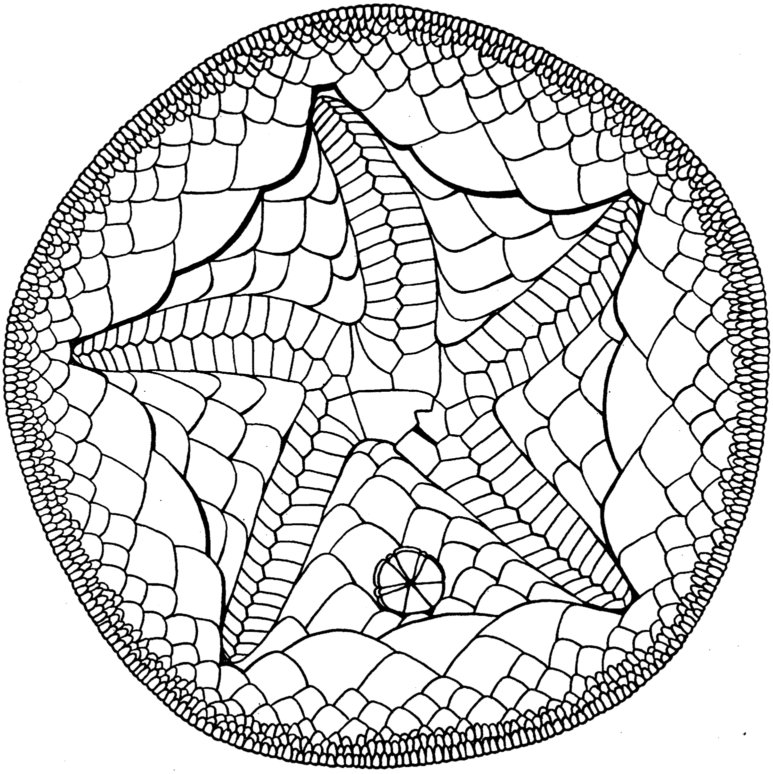

FIG. 7. *Hemicystites chapmani* (Raymond). Restoration based on figure by Bassler (1936, Pl. 3, Fig. 9).

half the length of ambulacrum V, much as it does in *Timeischytes megapinacotus* Ehlers and Kesling.

Remarks.—In the original illustration (Bassler, 1936, Pl. 7, Fig. 1), the holotype is turned counterclockwise nearly 90 degrees. The peristomial plates in the holotype are somewhat disarranged, but in a smaller but much better preserved topotype (Pl. X, Fig. 6) the plates in the posterior half of the peristomial region can be seen to have nearly the same arrangement as those in *Timeischytes megapinacotus*. Even a very small specimen (Pl. X, Fig. 7) has the unpaired plate and hydropore slit.

Illustrated specimens.—Holotype, UMMP No. 17295, and topotypes, UMMP Nos. 21123 and 35390. Middle Devonian Traverse group, Ferron Point formation. Abandoned shale pit of Alpena Portland Cement Company, about 8 miles northeast of Alpena, Alpena County, Michigan, SE 1/4 sec. 18, T. 32 N., R. 9 E. Collected by Mr. I. G. Reimann.

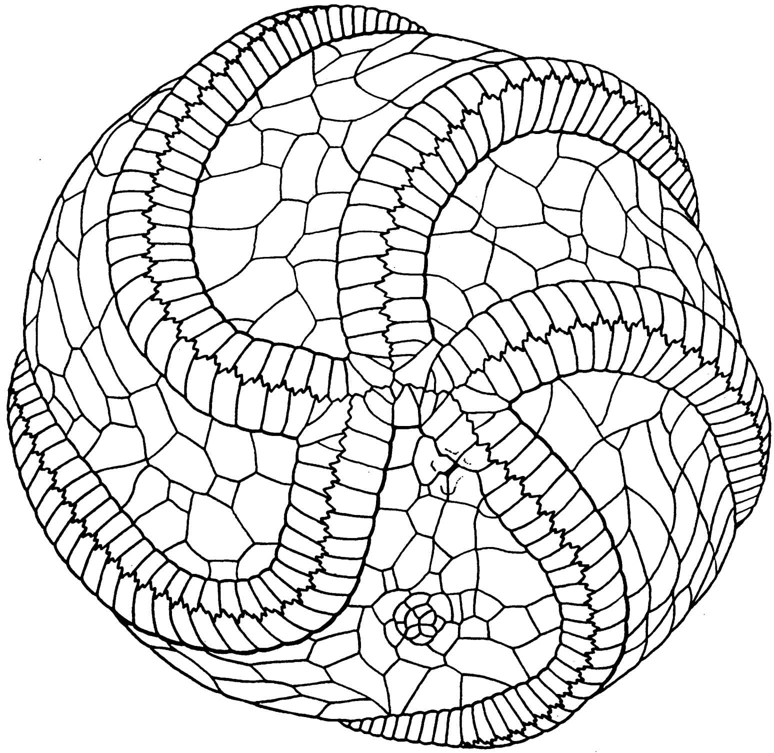

FIG. 8. *Foerstediscus splendens* Bassler. Restoration based on the holotype and only known specimen, USNM No. S4079, illustrated in Plate VII, Figures 1–2.

Hemicystites chapmani (Raymond)

(Figure 7)

Lebetodiscus chapmani Raymond, 1915, p. 58, Pl. 1, Fig. 3.
Carneyella chapmani Foerste, 1916, p. 341.
Hemicystites chapmani Bassler, 1936, pp. 11–12, Pl. 3, Fig. 9.

Hydropore.—Essentially, the hydropore is like that in *Hemicystites devonicus* Bassler, but the plates involved are proportionally smaller. In the right posterior part of the peristomial region, the unpaired plate is much smaller than the other three peristomial covering plates; it is scarcely larger than one of the proximal ambulacral covering plates. As in *Carneyella pilea* and *Isorophus cincinnatiensis,* the proximal plates on the left side of ambulacrum V are shorter than the rest, forming a recess to accommodate the unpaired plate of the peristomial region, so that the left posterior edge of the unpaired plate and the distal plates of the adjacent ambulacrum form a continuous line. The unpaired plate lies next to the proximal three plates on the left side of ambulacrum V.

The hydropore seems to be limited to the slit between the unpaired plate and the first covering plate on the left side of ambulacrum V, but the juncture between the unpaired plate and the posterior plate of the peristomial region may also be part of it.

Genus *Foerstediscus* Bassler, 1935
Foerstediscus splendens Bassler
(Figure 8; Pl. VII, Figs. 1–2)

Foerstediscus splendens Bassler, 1936, p. 10, Pl. 7, Fig. 13.

Hydropore.—The holotype, USNM No. S4079, and only known specimen has a peculiar arrangement of plates in the posterior interambulacrum next to ambulacrum V (Pl. VII, Fig. 1). Together with two ambulacral covering plates, the interambulacral plates near the peristomial region form a structure that is conspicuous because the edges of the plates bordering it are turned upward around a slotlike gape—the presumed hydropore.

Two of the interambulacral plates involved are fused, together having the general shape of a buckle (Fig. 8). The smaller is subhexagonal, transversely elongate; its left half fits into a notch in the larger plate, and its right half, which projects, is bounded by four plates. These are the second and third covering plates on the left side of ambulacrum V and two interambulacrals, one large and nearly square next to the third covering plate and the other small and subquadrate, situated at the rear. The projecting half of the smaller fused plate, and the proximal margins of the four plates around it, are flared upward in the form of a large pustule, in the center of which is a slotlike opening lying between the fused plate and the nearly square interambulacral.

The larger of the fused plates is elongate in an anterior-posterior direction, and is subrhombic except for the notch which accommodates the left half of the smaller plate. Its left border is slightly convex to bluntly acuminate, abutting against two large interambulacrals.

When submersed in xylol, the smaller of the two fused plates is dark (Pl. VII, Fig. 2), apparently indicating that it is very thin, but many parts of the specimen are pyritized, so that one cannot be certain whether this dark color is due to the thinness of the plate or to the partial, selective replacement by pyrite. A dark area around the presumed hydropore in *Thresherodiscus ramosus* Foerste has already been noted (above). If the smaller plate is thin, it is conceivable that it served as a lid over the stone canal and that the larger plate was movable, pivoted at its ends, and functioning as a hinge. A more conservative theory is that the slot described above is the hydropore and that the plates around it were embedded as firmly as others in the posterior interambulacrum.

Illustrated specimen.—Holotype, USNM No. S4079. Middle Ordovician Trenton group (near base), Decorah shale, at top of the *Rhinidictya* bed. Near the Ford plant, St. Paul, Minnesota. Collected by I. G. Reimann.

Genus *Streptaster* Hall, 1872 [1866]

Streptaster sp. cf. *S. vorticellatus* (Hall)

(Figure 9; Pl. VI, Figs. 1–2)

Hydropore.—The hydropore seems to be an opening between a very large plate of the posterior interambulacrum and the second covering plate of the left side of ambulacrum V (Fig. 9). One well-preserved specimen (Pl. VI, Fig. 1) shows what I interpret as an aperture formed by an expansion of part of the juncture between these two plates. The second covering plate of ambulacrum V is distally extended beyond the rest of the left border of the ambulacrum; its anterior edge projects farther than its posterior. Most of the plates in the posterior interambulacrum, except those of the high conical anal pyramid, are small and subpolygonal, apparently not fitting closely together. About midway between the anal pyramid and the peristomial region, however, is a very large plate, which forms the left boundary of the aperture. This plate is roughly subtrapezoidal with a broad concave indentation in the left anterior corner and a smaller notch bounding the aperture.

Remarks.—The presence of an unusual plate in the posterior interambulacrum next to the left border of ambulacrum V has also been noted in *Foerstediscus splendens* Bassler, *Cincinnatidiscus carnensis* (Foerste), and *Cystaster granulatus* (Hall). In each of these species, the hydropore is believed to lie between the unusual plate and a covering plate of ambulacrum V.

In *Streptaster reversata* Foerste, Foerste (1914, p. 453) noted, "A single large prominent plate extends from the proximal end of the right posterior ray toward the anal pyramid. The homology of this plate is unknown." Foerste (1914, pp. 429–31, Pl. 4, Fig. 2) also described and illustrated a specimen of *Streptaster septembrachiatus* Miller and Dyer, in which only the aboral surface was exposed, and gave many details of the peristome, which he termed the "Central or substomial cavity." He wrote (pp. 430–31):

> Immediately in front of the median part of the posterior part of the rim there is a vertical cavity, less than a millimeter in diameter, apparently leading to the oral surface of the theca. This aperture, as seen from below, is bounded on the left by a quadrangular plate filling in most of the lower left hand quarter of the substomial chamber. On the left side of this quadrangular plate, near the junction between the lateral margins of the proximal floor plates belonging to the right and right posterior rays (Nos. 4 and 5), there is a broad inclined groove.

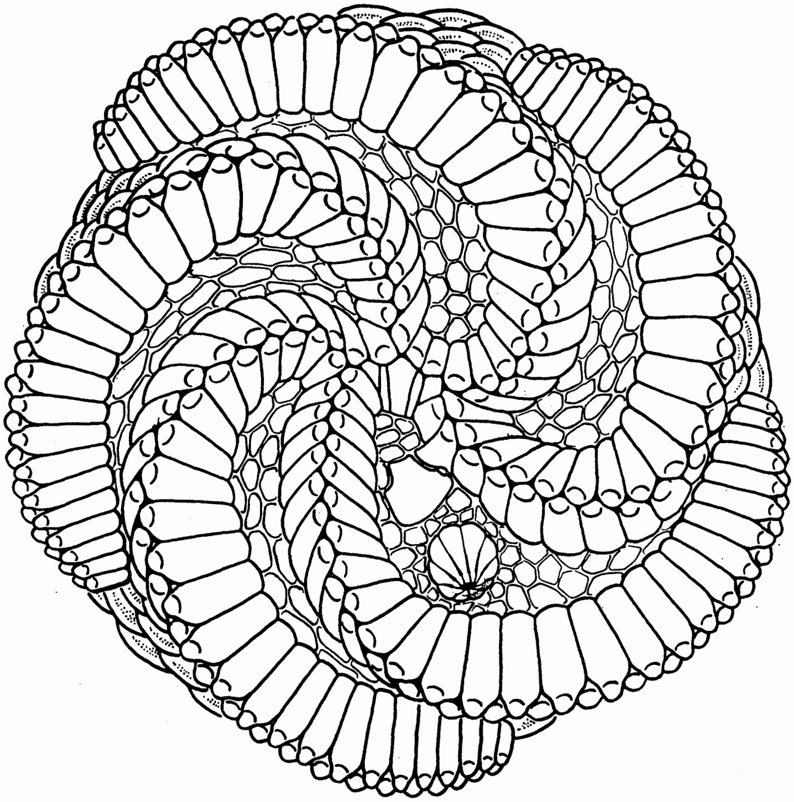

FIG. 9. *Streptaster* sp. cf. *S. vorticellatus* (Hall). Restoration based on specimen UCM No. 34533, illustrated in Plate VI, Figures 1–2.

But he (p. 431) declined "to speculate regarding the use of the deep depression or aperture at the posterior margin of the substomial chamber, or the purpose of the inclined surface or broad groove . . ."

The aperture Foerste described in *Streptaster septembrachiatus* is almost directly below the position of the supposed hydropore in *Streptaster* sp. cf. *S. vorticellatus*. It is highly probable that the opening he observed was the lower end of the tube through which the stone canal passed from the hydropore above, and that the groove near the proximal ends of the flooring plates of ambulacra IV and V accommodated a part of the ring canal, which extended around the border of the peristome.

Illustrated specimen.—UCM No. 34533. Upper Ordovician Maysville group, McMillan formation, Corryville shale member. West Cincinnati Quadrangle, north of Carthage, Galbraith Road. Collected in 1942 by Dry Dredgers, a local collecting club in Cincinnati, Ohio.

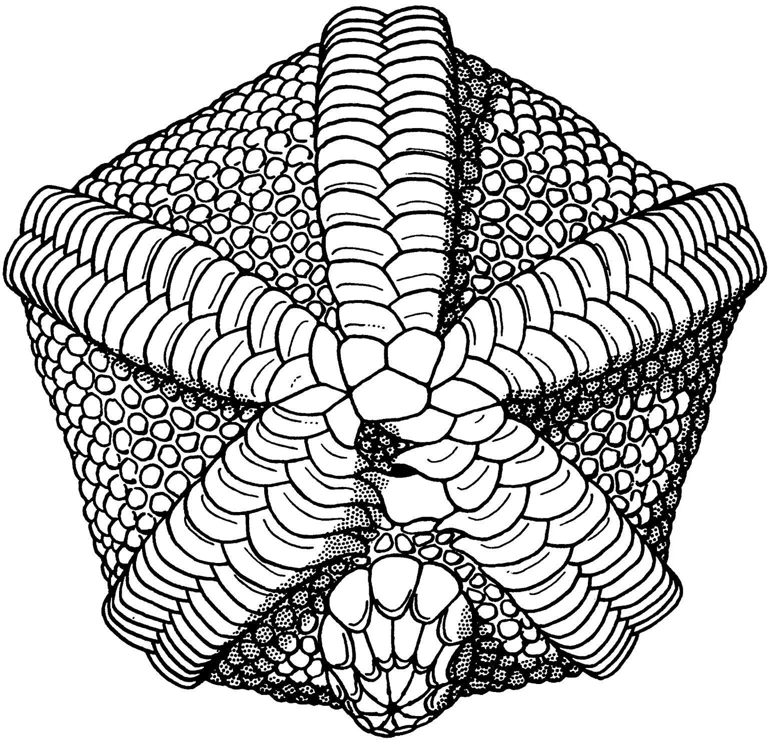

FIG. 10. *Cystaster granulatus* (Hall). Restoration by Mr. Erle G. Kauffman, based on specimens USNM Nos. S3188*a* and S3188*b* and UMMP No. 5412, illustrated in Plate IX, Figures 1-6.

Genus *Cystaster* Hall, 1871
Cystaster granulatus (Hall)
(Figure 10; Pl. IX, Figs. 1-6)

Hemicystites (Cystaster) granulatus Hall, 1872 [1871], explanation of Plate 6 and Pl. 6, Figs. 1-4.
Cystaster granulatus Foerste, 1914, Pl. 6, Fig. 5.

Hydropore.—One specimen, UMMP No. 5412, although worn, shows what appears to be an elliptical opening in the proximal part of the posterior interambulacrum (Pl. IX, Figs. 5-6). Two others, both included under USNM No. S3188, are much better preserved but do not reveal it as conspicuously (Pl. IX, Figs. 1-4). This opening is interpreted to be the hydropore. It is bounded in part by an extension of the second covering plate on the left side of ambulacrum V and by an unusually large plate of the posterior interambulacrum. This large plate lies about midway between the prominent anal pyramid, which is composed of numerous small plates imbricating like the petals in the flower head of an artichoke, and the small peristomial region. It is transversely elongate, with the longest side anterior, and bears a shallow notch that forms the posterior boundary of the hydropore.

The second plate on the left side of ambulacrum V is distally attenuated, but the extended part does not completely enclose the anterior side of the hydropore. The third plate on the left side is shorter than the other ambulacral plates, and fits against the right side of the unusually large interambulacral plate. The fourth plate is slightly longer than the other ambulacral covering plates. The second to fifth plates on the right side of ambulacrum I are longer than the others, but none of them reach as far as the hydropore.

The two best-preserved specimens (Pl. IX, Figs. 1–3) have the plates in their peristomial regions pulled apart. If these and adjacent plates of ambulacra I and V and the posterior interambulacrum are adjusted so that the peristome has no gape, the left tip of the large peristomial plate will fit between the second and third plates on the right side of ambulacrum I (Fig. 10).

Remarks.—The occurrence of a hydropore between an unusual interambulacral plate and a covering plate of ambulacrum V is also inferred in *Cincinnatidiscus carnensis* (Foerste) and *Streptaster* sp. cf. *S. vorticellatus* (Hall). It seems to be rather constant in this group of hemicystitid edrioasteroids.

Illustrated specimens.—UMMP No. 5412; Upper Ordovician Cincinnatian series; Cincinnati, Ohio; collected by Dr. Carl Ludwig Rominger. Two specimens included under USNM No. S3188; Upper Ordovician Maysville group, Fairmont formation; Cincinnati, Ohio.

Genus *Carneyella* Foerste, 1916

Carneyella pilea (Hall)

(Figure 11; Pl. XI, Figs. 3–8)

Agelacrinus pileus Hall, 1872 [1866], pp. 214–15, Pl. 6, Figs. 8–10. Foerste, 1914, pp. 427–29, Pl. 1, Figs. 5A–D; Pl. 2, Figs. 1–4; 1916, pp. 340–41.
Carneyella pileus Bassler, 1936, pp. 6–7.

Hydropore.—The plates associated with the hydropore have been fully described by Foerste (1914, pp. 414–15, 427–29) from both oral and aboral sides. Although he did not specify that the structure was a hydropore, when he wrote (p. 415) concerning the oral view, he said, "This suggests the possibility of the exit of some duct at the angle between these three plates," and (p. 429), with regard to the aboral view, that "Possibly a duct passed by this path . . ." There can be little doubt that the structure seen in oral view was the hydropore and the "duct" enclosed the stone canal. The comments by Bather on these statements (1915*a,* p. 266) and the observations of Williams (1918, pp. 77, 80) have already been discussed under Previous Work.

In this species, three plates are concerned with the hydropore: (1) the proximal covering plate on the left side of ambulacrum V, (2) the posterior plate of the peristomial region, and (3) the unpaired right posterior plate of the peristomial region. The edges of all three are raised along their junctions (Pl. XI, Figs. 4, 6, 8) and, as illustrated by Foerste (1914, Pl. 1, Fig. 5A; Pl. 2, Fig. 4), the junctures are underlain by a depression in the aboral side of the theca, which lies along the proximal part of the row of flooring plates in ambulacrum V. Possibly, the unpaired plate of the peristomial region was movable, allowing water to enter the stone canal only when it was lifted. In most specimens the slit between the unpaired plate and the ambulacrum is larger than those between the other two junctions and it almost directly overlies the aboral depression.

Illustrated specimens.—UCM Nos. 34535–34537. 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.

Genus *Cincinnatidiscus* Bassler, 1935
Cincinnatidiscus stellatus (Hall)

(Pl. VIII, Fig. 1)

Agelacrinus (Hemicystites) stellatus Hall, 1872 [1866], p. 215–16, Pl. 6, Figs. 5–6.
Hemicystites stellatus Foerste, 1914, p. 454, Pl. 6, Figs. 6A-B.
Cincinnatidiscus stellatus Bassler, 1935, p. 4, Fig. 6; 1936, p. 5, Pl. 2, Figs. 11–12.

Hydropore.—In the proximal part of the posterior interambulacrum, one plate is larger than the others and, between it and a covering plate on the left side of ambulacrum V, there seems to be an opening, which is assumed to be the hydropore. Unlike *Cystaster granulatus,* in which an ambulacral covering plate is attenuated along the anterior side of the transverse hydropore, this species has an ambulacral plate about as long as those adjacent to it and its hydropore is a slit along the edge of ambulacrum V.

Illustrated specimen.—UCM No. 34534. Upper Ordovician Maysville group, probably McMillan formation and Bellevue member. On talus below Bellevue escarpment, Bald Knob, southwest of intersection of Beekman Street and Queen City Avenue, Cincinnati, Ohio. Collected by John K. Pope and Adolf Seilacker.

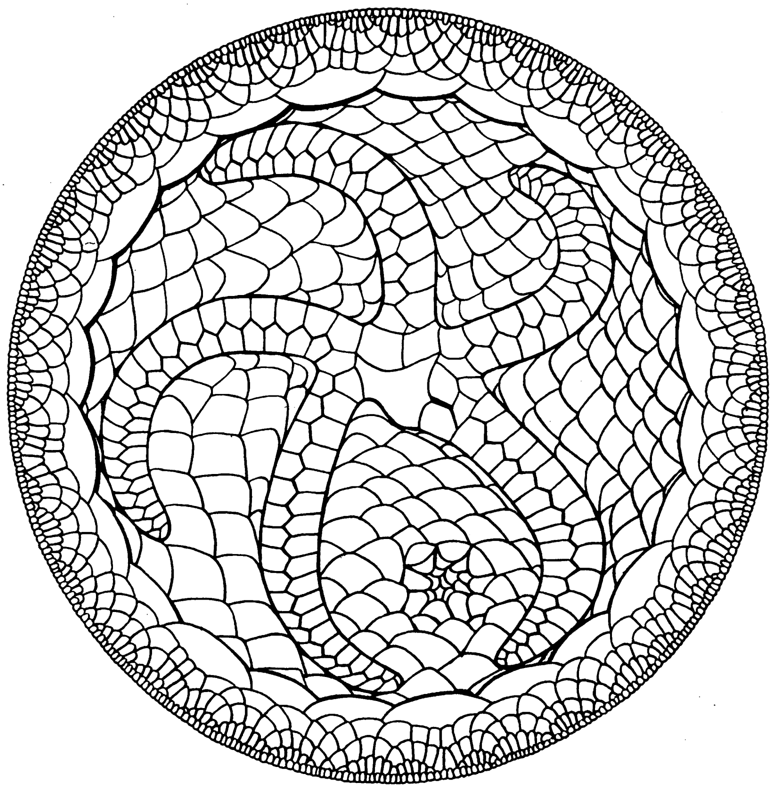

FIG. 11. *Carneyella pilea* (Hall). Restoration based on figures by Foerste (1914, Pl. II, Figs. 1–2). Compare with Plate XI, Figures 3–8.

Cincinnatidiscus carnensis (Foerste)
(Pl. VIII, Figs. 3–4)

Hemicystites carnensis Foerste, 1914, pp. 455–56, Pl. 3, Figs. 2A-B.
Cincinnatidiscus carnensis Bassler, 1935, p. 4; 1936, pp. 5–6, Pl. 5, Fig. 4.

Hydropore.—Good specimens of this species are rare. Both cotypes have a plate in the right anterior part of the posterior interambulacrum that is larger than the others. No details of its junction with the covering plates of ambulacrum V can be established because of the poor preservation, but the large interambulacral plate is believed to be homologous to that in *Cincinnatidiscus stellatus.*

Illustrated specimens.—Cotypes, USNM No. 87163 (two specimens on one slab of rock). Middle Ordovician Trenton group, described by Foerste (1914, p. 480) as: "At the *Strophomena vicina* horizon, correlated with strata immediately below the Brannon siliceous limestone." Several

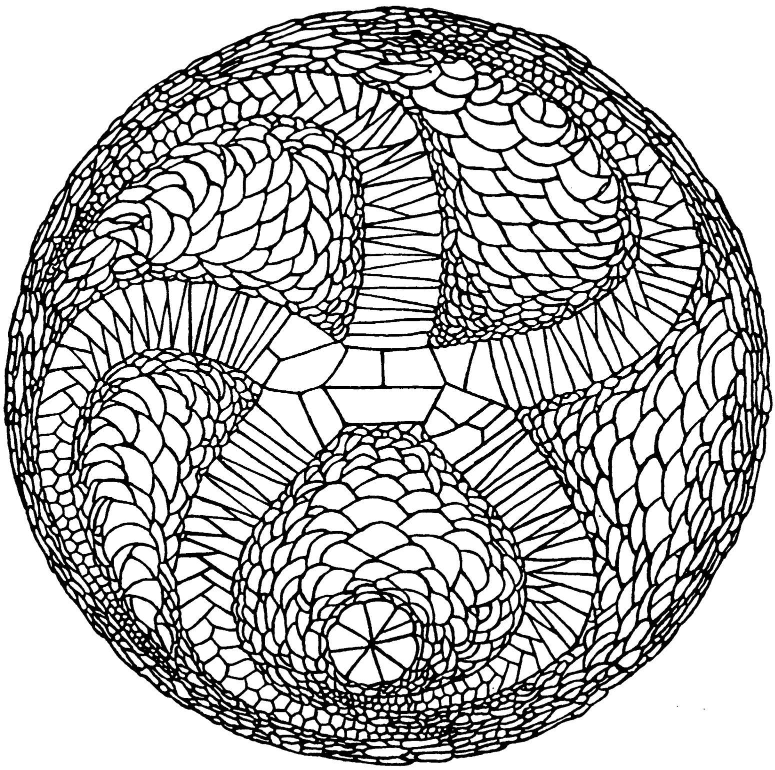

FIG. 12. *Anglidiscus fistulosus* (Anderson). Restoration by Mr. Erle G. Kauffman, modified from Regnéll (1950, Fig. 2).

hundred yards up the creek from the railroad at Carntown, in the north-edge of Pendleton County, Kentucky, about 20 feet above the level of the Ohio River. Collected by Dr. A. F. Foerste.

Genus *Anglidiscus* Regnéll, 1950
Anglidiscus fistulosus (Anderson)
(Figure 12)

Lepidodiscus fistulosus Anderson, 1939, pp. 68–81, Fig. 1, Pl. 5, Figs. 1–10.
Anglidiscus fistulosus Regnéll, 1950, pp. 6–10, Fig. 2.

Hydropore.—This species is the only known representative of the genus. It is unusual in that it is the only edrioasteroid in which the proximal covering plates of the ambulacra are uniserial instead of biserial. The posterior part of the peristomial region contains one very large trapezoidal plate, and, by analogy with *Carneyella pilea* and *Hemicystites chapmani,* I include also in this part of the peristomial region the small subtrapezoidal plate and, with some question, the slightly larger subpentagonal plate situated at the right posterior (Fig. 12). The edges of these two plates form a continuous line with the left side of the ambulacrum. On the opposite side of the posterior interambulacrum, the proximal plates of ambulacrum I are uniserial and, if the two unpaired plates are assigned to the peristomial region, then all proximal plates of ambulacrum V are likewise uniserial.

No details of a possible opening associated with the plates mentioned has been described, but their arrangement closely resembles that in *Carneyella pilea*. Therefore, I believe the hydropore was a slit between the small subtrapezoidal plate and the proximal plate of ambulacrum V.

Anderson (1939, pp. 79–80), observing the aboral surface of the peristomial region, interpreted the impression of a small canal ("close to the origin of V . . . running from the anal interradius towards the mouth") as probably the stone canal. There is no reason to doubt that (1) the "impression," which he showed in his Figure 10 and labeled "stone canal?," was the aboral end of the tube around the stone canal and (2) that the oral end terminated at the place which I regard as the hydropore.

Genus *Timeischytes* Ehlers and Kesling, 1958

Timeischytes megapinacotus Ehlers and Kesling

(Figure 13; Pl. VIII, Fig. 2)

Timeischytes megapinacotus Ehlers and Kesling, 1958*a*, pp. 934–36, Pl. 121, Figs. 1–6; Text-fig. 1.

Hydropore.—The original authors (1958*a*, p. 936) described an "unpaired right posterior covering plate very large, subtrapezoidal" in the peristomial region. This plate (Pl. VIII, Fig. 2) is remarkably similar to the unpaired one in the corresponding position in species of *Hemicystites* and *Carneyella*. It is separated from the two adjacent plates of ambulacrum V by narrow slits, which are interpreted as parts of an elongate hydropore.

Remarks.—Unfortunately, the species is known only from the two type specimens, UMMP Nos. 35392 and 35428. Because it seems highly unlikely that any more will be found, it is not permissible to grind down a specimen to determine whether the region next to the proximal part of the left side of ambulacrum V is underlain by a duct, such as that described in *Carneyella pilea* (Hall) by Foerste (1914, pp. 427–29), or not.

Illustrated specimen.—Paratype, UMMP No. 35428. Middle Devonian, Traverse group, Four Mile Dam limestone, Dock Street clay member. Abandoned quarry of the Thunder Bay Quarries Company, now owned by the Huron Portland Cement Company of Alpena, on the eastern side of Alpena, Michigan, SE ¼ sec. 14, T. 31 N., R. 8 E.

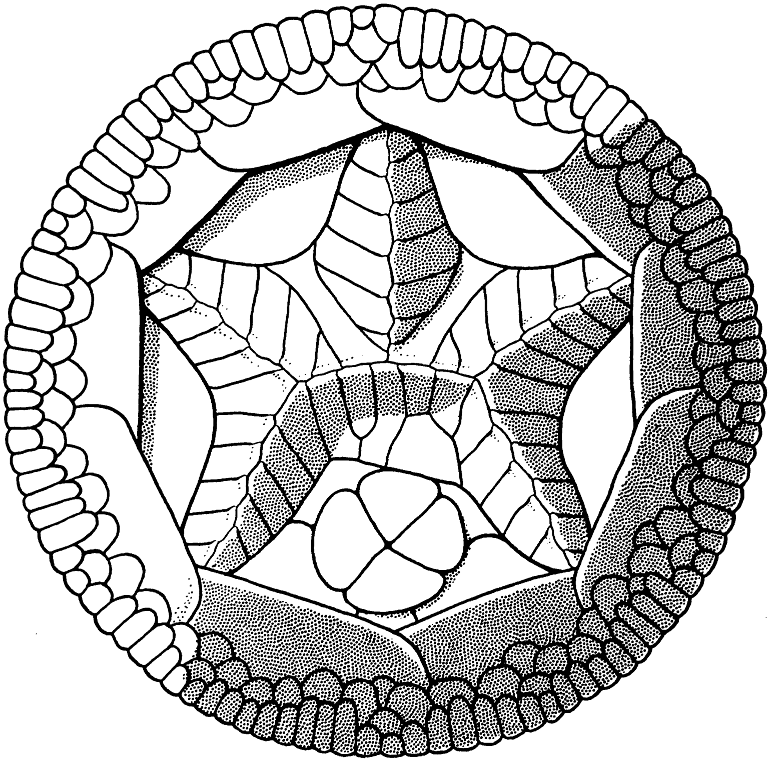

FIG. 13. *Timeischytes megapinacotus* Ehlers and Kesling. Restoration copied from Ehlers and Kesling (1958*a*, Text–fig. 1). Compare with Plate VIII, Figure 2.

CONCLUSIONS

The structures which are here interpreted as hydropores have the following characteristics: (1) each is located in the right half of the edrioasteroid, (2) each is within or adjacent to the proximal part of the posterior interambulacrum or the posterior part of the peristomial region, (3) each is bordered by plates which are not paired in the opposite half of the specimen, and (4) most are bordered by plates with raised margins or edges. In other features, however, they vary greatly.

In *Edrioaster, Carneyella,* and *Streptaster,* excellent specimens with the aboral side exposed have been found, which clearly show a depression, pit, or passageway leading to the structure on the oral side designated as the hydropore. In these three genera, the presence and location of the hydropore are regarded as established with certainty. Since the aboral side of other edrioasteroids is either incompletely known or is unknown, the nature of the hydropore must be inferred from comparison of the plate structures in these with those in the three genera mentioned above.

Only in *Edrioaster* is the hydropore a large, permanent, subcircular opening. For *Streptaster* and *Carneyella* there is some question about the exact nature of the hydropore. In these two and in the other genera, the hydropore was either (1) a slit or small opening between fixed plates, which acted like a strainer, or (2) a larger opening below the plates, one or more of which were hinged and could be lifted up to admit water. Although the plates are in the "closed position" in all known specimens, the second interpretation is possible, for movable plates were developed over the ambulacra and the anal opening and there is no reason to doubt that they might occur in other parts of the edrioasteroid.

The hydropore in *Streptaster,* located between a posterior interambulacral plate and a covering plate of ambulacrum V, strongly resembles the structure observed in *Cincinnatidiscus* and *Cystaster*. The supposed hydropores in *Thresherodiscus* and *Foerstediscus,* lying near ambulacrum V but within the boundary of the posterior interambulacrum, appear to be intermediate between those in *Edrioaster* and *Streptaster*.

In still other edrioasteroids the hydropore lies wholly within the peristomial region. The hydropore in *Carneyella,* situated between a right posterior peristomial plate and a short proximal plate of ambulacrum V, is practically duplicated in *Hemicystites, Timeischytes, Isorophus,* and *Anglidiscus*. *Agelacrinites* has a structure, assumed to be the hydropore, that is nearly intermediate between those of *Streptaster* and *Carneyella*. Although I consider the large plate bordering the structure in *Agelacrinites* to be part of the peristomial region, it is not clearly associated with either the peristomial region or the posterior interambulacrum. The supposed hydropores in *Discocystis laudoni* and *Lepidodiscus squamosus,* wholly within the peristomial region, may have evolved from the type found in *Carneyella*.

The structures that I interpret as hydropores may be divided into six basic types (see Table I and Fig. 14):

Type I.—Hydropore within the posterior interambulacrum, in the right proximal region, consisting of a large permanent opening shared by two plates. *Edrioaster* the only known genus having this type.

Type II.—Hydropore within the posterior interambulacrum near ambulacrum V, not a large opening. Subtype A, exemplified by *Thresherodiscus,* consists of two large "bordering plates," each semioval, with a long juncture between them. When submersed in xylol, the holotype of *T. ramosus* shows a dark area along the juncture, suggesting that a larger opening underlies the thin margins of these plates. Subtype B, exemplified by *Foerstediscus splendens,* apparently involves three plates in the posterior interambulacrum around a short slot set perpendicular to the edge of ambulacrum V. The anterior of these plates is fused to another interambulacral plate and, judging from the appearance in xylol, is very thin. The arrangement is such that the larger of the two fused plates may have acted like a hinge.

Type III.—Hydropore a small opening along the boundary between the posterior interambulacrum and the edge of ambulacrum V. In subtype A, found in *Cystaster granulatus,* it is bounded posteriorly by a very large interambulacral plate and anteriorly by a long lateral extension of an ambulacral plate. In subtype B, noted in *Streptaster,* the opening is much smaller and extends along the edge of ambulacrum V to the right of an unusually large interambulacral plate.

Type IV.—Hydropore along the juncture between an expanded proximal ambulacral plate and a large plate of the peristomial region. The posterior part of the peristomial region projects into the posterior interambulacrum, but is not distinctly set off from it, and includes two plates with raised edges that form a vaulted structure where they join. Possibly, one of these plates hinged on the other to expose more of the hydropore. *Agelacrinites* is the only genus in which this type occurs.

Type V.—Hydropore along the juncture between a short proximal ambulacral plate and the right posterior plate of the peristomial region. In subtype A, exemplified by *Carneyella pilea, Hemicystites chapmani, Isorophus cincinnatiensis,* and *Anglidiscus fistulosus,* the peristomial plate is aligned with the left series of covering plates of ambulacrum V, so that it appears to be the proximal left plate of the ambulacrum. However, if the plate arrangement is more carefully analysed, it will be seen that the ambulacrum is sharply indented to accommodate this plate, and the plate must then be regarded as the right posterior extension of the peristomial region. In subtype B, represented by *Timeischytes megapinacotus* and *Hemicystites devonicus,* the right posterior plate is larger and more clearly associated with the peristomial region. Although the proximal plates on the left side of ambulacrum V are shorter than those on the right side of ambulacrum I, directly opposite, they do not completely accommodate the anomalous unpaired plate, which does not appear to be a continuation of the ambulacrum.

Type VI.—Hydropore within the right posterior part of the peristomial region. Although this transverse structure is in part bordered by the covering plates of ambulacrum V, it is not closely related to the ambulacrum. *Discocystis laudoni* and *Lepidodiscus squamosus* furnish good examples, and *L. ephraemovianus* also seems to belong to this type.

From a study of the edrioasteroids described in this paper, I postulate

TABLE I

CORRELATION OF GEOLOGICAL AGE OF EDRIOASTEROIDS WITH TYPE OF HYDROPORE

Edrioasteroid	Geological Age					Type (or Subtype) of Hydropore								
	M.Ord.	U.Ord.	Sil.	Dev.	Miss.	I	IIA	IIB	IIIA	IIIB	IV	VA	VB	VI
Edrioasteridae														
Edrioaster bigsbyi	x	..	..	..	..	x	..	..	..	..	..	..	..	..
E. levis	x	..	..	..	..	x	..	..	..	..	..	..	..	..
Agelacrinitidae														
Thresherodiscus ramosus	x	..	..	..	..	..	x	..	..	..	..	..	..	..
Isorophus cincinnatiensis	..	x	..	..	..	..	..	..	..	..	..	x	..	..
Agelacrinites spp.	..	..	..	x	..	..	..	..	..	..	x	..	..	..
Lepidodiscus ephraemovianus	..	..	..	x	..	..	..	..	..	..	..	..	..	x
L. squamosus	..	..	..	..	x	..	..	..	..	..	..	..	..	x
Discocystis laudoni	..	..	..	..	x	..	..	..	..	..	..	..	..	x
Hemicystitidae														
Foerstediscus splendens	x	..	..	..	..	..	..	x	..	..	..	..	..	..
Cystaster granulatus	..	x	..	..	..	..	..	..	x	..	..	..	..	..
Streptaster sp.	..	x	..	..	..	..	..	..	..	x	..	..	..	..
Cincinnatidiscus stellatus	..	x	..	..	..	..	..	..	..	x	..	..	..	..
Carneyella pilea	..	x	..	..	..	..	..	..	..	..	..	x	..	..
Hemicystites devonicus	..	..	..	x	..	..	..	..	..	..	..	..	x	..
H. chapmani	x	..	..	..	..	..	..	..	..	..	..	x	..	..
Timeischytes megapinacotus	..	..	..	x	..	..	..	..	..	..	..	..	x	..
Anglidiscus fistulosus	..	..	..	..	x	..	..	..	..	..	..	x	..	..

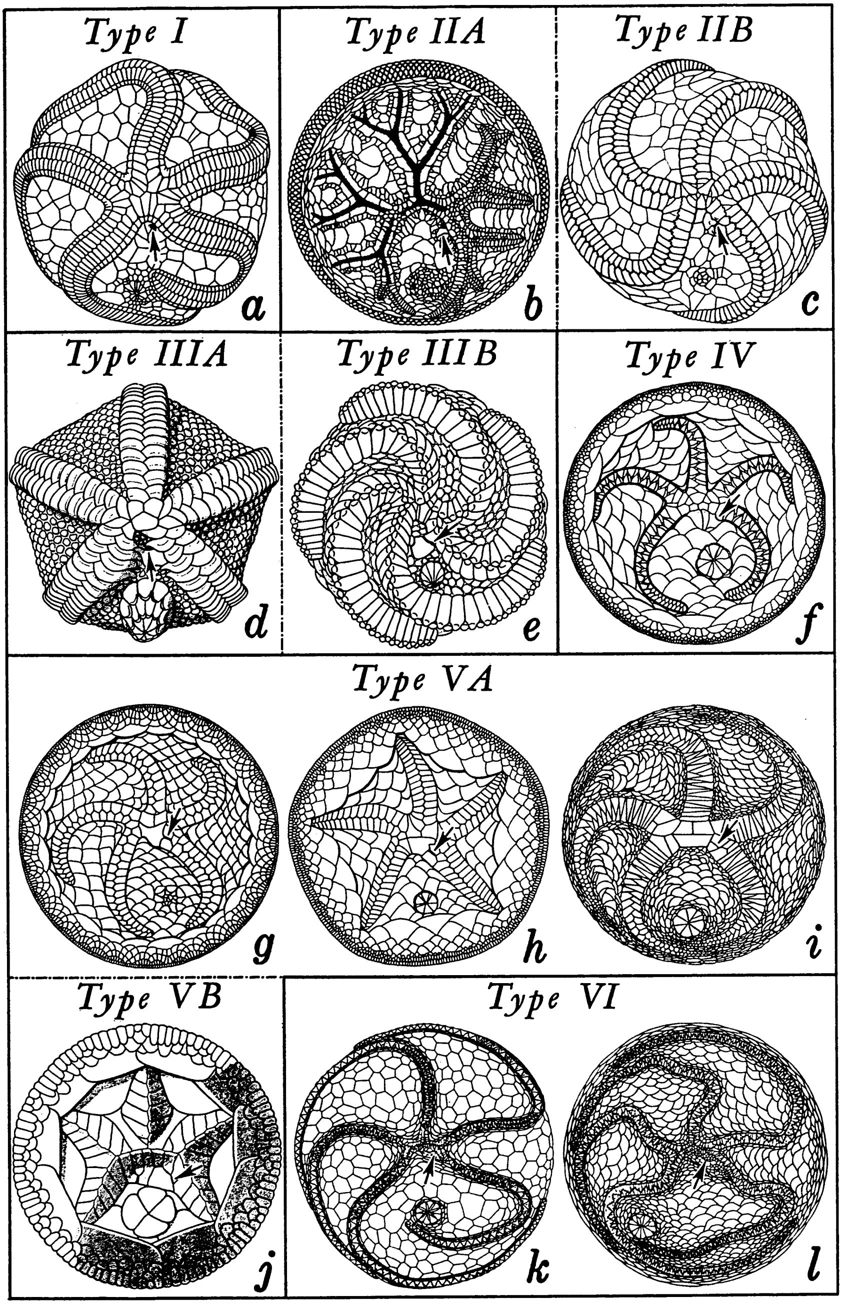

FIG. 14. Types of hydropores observed in this study, illustrated by restorations. *a. Edrioaster bigsbyi* (Billings). *b. Thresherodiscus ramosus* Foerste. *c. Foerstediscus splendens* Bassler. *d. Cystaster granulatus* (Hall). *e. Streptaster* sp. cf. *S. vorticellatus* (Hall). *f. Agelacrinites* sp. B. *g. Carneyella pilea* (Hall). *h. Hemicystites chapmani* (Raymond) *i. Anglidiscus fistulosus* (Anderson). *j. Timeischytes megapinacotus* Ehlers and Kesling. *k. Discocystis laudoni* Bassler. *l. Lepidodiscus squamosus* (Meek and Worthen).

that the hydropore followed an evolutionary sequence, in which it originated in the posterior interambulacrum, migrated toward the left side of ambulacrum V, thence proximally along the edge of the ambulacrum, and finally came to lie almost wholly within the peristomial region. The trend may be demonstrated briefly by the following series: *Edrioaster bigsbyi* (M. Ord., Trenton; Type I), *Thresherodiscus ramosus* (M. Ord., Trenton; Type II), *Hemicystites chapmani* (M. Ord., Trenton; Type V), and *Discocystis laudoni* (L. Miss., Kinderhook; Type VI). Hydropores of Types I and II are known only from Middle Ordovician edrioasteroids. During Middle Ordovician, those of subtype VA evolved. This common type continued at least into Mississippian, at which time it was represented by *Anglidiscus fistulosus*. In Middle Devonian, subtype VB stemmed from it. Hydropores of Type VI are known only in edrioasteroids of Devonian and Mississippian age.

As outlined above, most of the evolution of the hydropore took place during Middle Ordovician time, although no examples of Types III and IV have yet been discovered in edrioasteroids of that age. Hydropores of Type III are known at present only from Upper Ordovician hemicystitids; the genera in which this type occurs include the unusual mushroom-shaped *Cystaster* and related button-shaped *Cincinnatidiscus*. The Middle Devonian *Agelacrinites,* with a Type IV hydropore, is apparently more closely related to edrioasteroids having hydropores of subtype VA than to those with Type III. Possibly, this genus was derived from the Upper Ordovician *Isorophus*. Very few Silurian edrioasteroids are known, so that the geologic record is far from complete.

It must be emphasized that the foregoing remarks are based only on the edrioasteroids included in this study. Because hydropores are not mentioned in most descriptions, details of their structure can be learned only from direct examination of well-preserved specimens. I have not yet worked with the Cambrian stromatocystitids, *Walcottidiscus* and *Stromatocystites,* nor the Lower Ordovician hemicystitid, *Hemicystites boehmi* (Thoral). Further investigations of hydropores may modify the postulated evolutionary sequence, and may also lead to the discovery of new types.

At this time, several important questions concerning hydropores remain unanswered:

1. What kinds of hydropores, if any, existed in the earliest known edrioasteroids, those from Lower Cambrian strata?

2. Does the nature of the hydropore have taxonomic significance? For example, is the occurrence of the same type of hydropore in *Carneyella* and *Isorophus* (1) an example of convergent evolution or (2) an indication of relationship?

3. Are the plates around the hydropores in various genera homologous? If so, by what criteria can plates of the posterior interambulacrum be differentiated from those of the peristomial region?

4. Were the hydropores in some edrioasteroids reduced to mere slits between fixed plates, functioning as a strainer to keep foreign objects from the water-vascular system? Or, were there movable hinged plates, which were lifted to admit water?

5. What was the function of the water-vascular system? Did it require intake of great quantities of water? Was the hydropore used continuously, frequently, or seldom?

6. Did the hydropore change appreciably during ontogeny? If so how?

To obtain answers to these questions, it will be necessary to locate well-preserved edrioasteroids and study the internal structure of the hydropore in selected specimens by means of polished surfaces. In particular, ontogenetic series are desired. The pressing need, therefore, is more and more diligent collecting.

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PLATES

EXPLANATION OF PLATE I

FIGS. 1–2. Oral view of entire specimen (× 1) and of peristomial and adjacent regions (× 5). UMMP No. 5731. Specimen is worn and does not show the characteristic ornamentation of the species nor the lip around the right anterior side of the hydropore. Compare with Figure 1 in text. Middle Ordovician Trenton group; Kirkfield, Ontario. Hydropore: Type I.

FIGS. 3–4. Oral view of entire specimen (× 1) and of peristomial and adjacent regions (× 5). UMMP No. 26428. Part of the posterior interambulacrum is missing, but the hydropore is well preserved. Middle Ordovician Trenton group, Kirkfield formation; Kirkfield, Ontario. Hydropore: Type I.

PLATE I

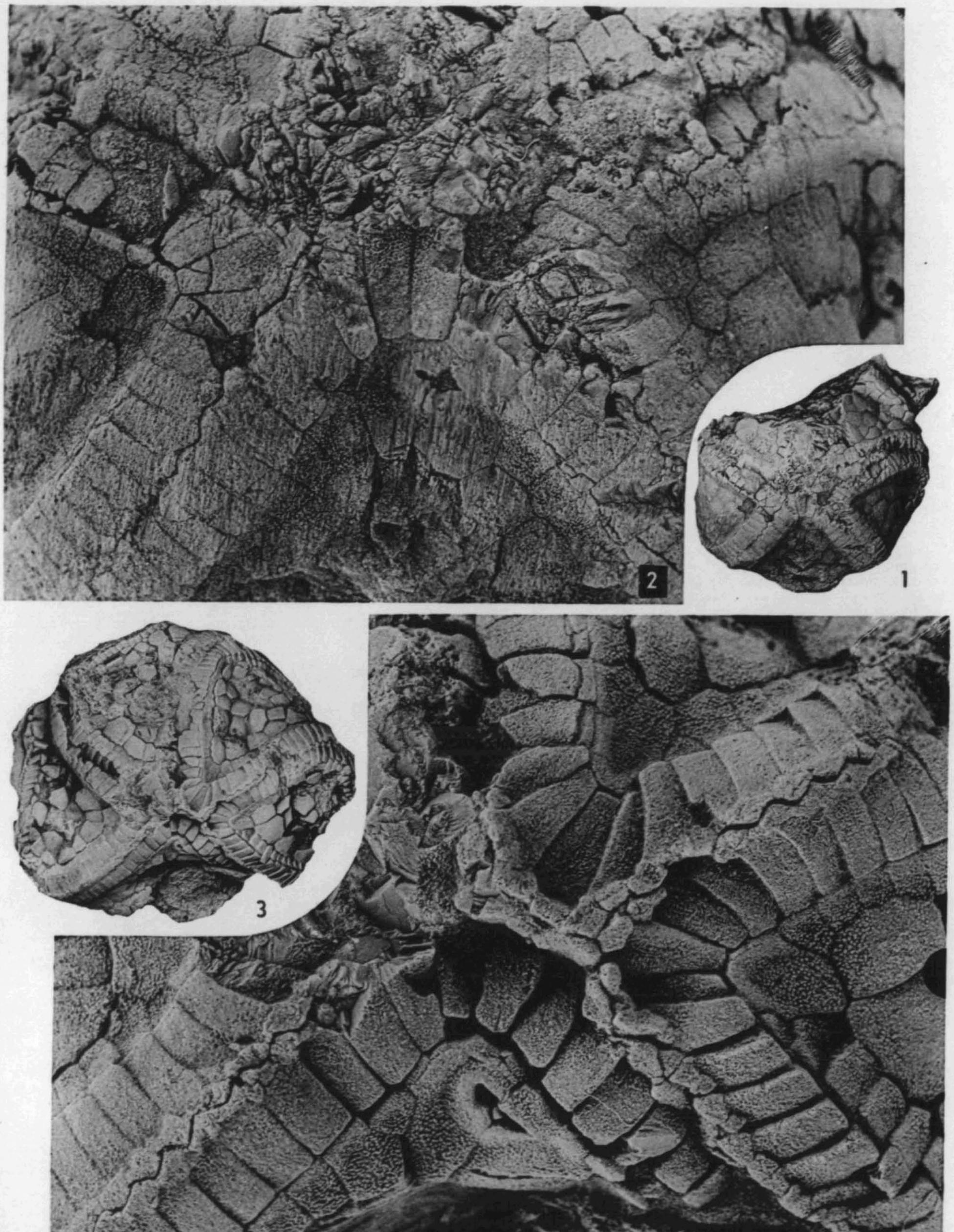


PLATE II

1

2

EXPLANATION OF PLATE II

PAGE

Lepidodiscus squamosus (Meek and Worthen) ....,...................... 155

FIGS. 1–2. Oral view of specimen coated with a sublimate of ammonium chloride (× 1) and submersed in xylol (× 4). UMMP No. 5420. Plates along the supposed hydropore are crushed in. Compare views with restoration in Figure 5 in text. Lower Mississippian Osagean series, Borden group, Edwardsville formation; Crawfordsville, Indiana. Hydropore: Type VI.

EXPLANATION OF PLATE III

FIGS. 1–3. Three oral views of USNM No. S3886*b*. Figure 1. Entire specimen coated with sublimate of ammonium chloride (× 2). Figures 2–3. Peristomial and adjacent regions (× 10). In Figure 2 coated with sublimate of ammonium chloride, and in Figure 3 submersed in xylol. Compare these views with restoration in Figure 4 in text. Lower Mississippian Kinderkookian series, Gilmore City limestone; Gilmore City, Iowa. Hydropore: Type VI.

PLATE III

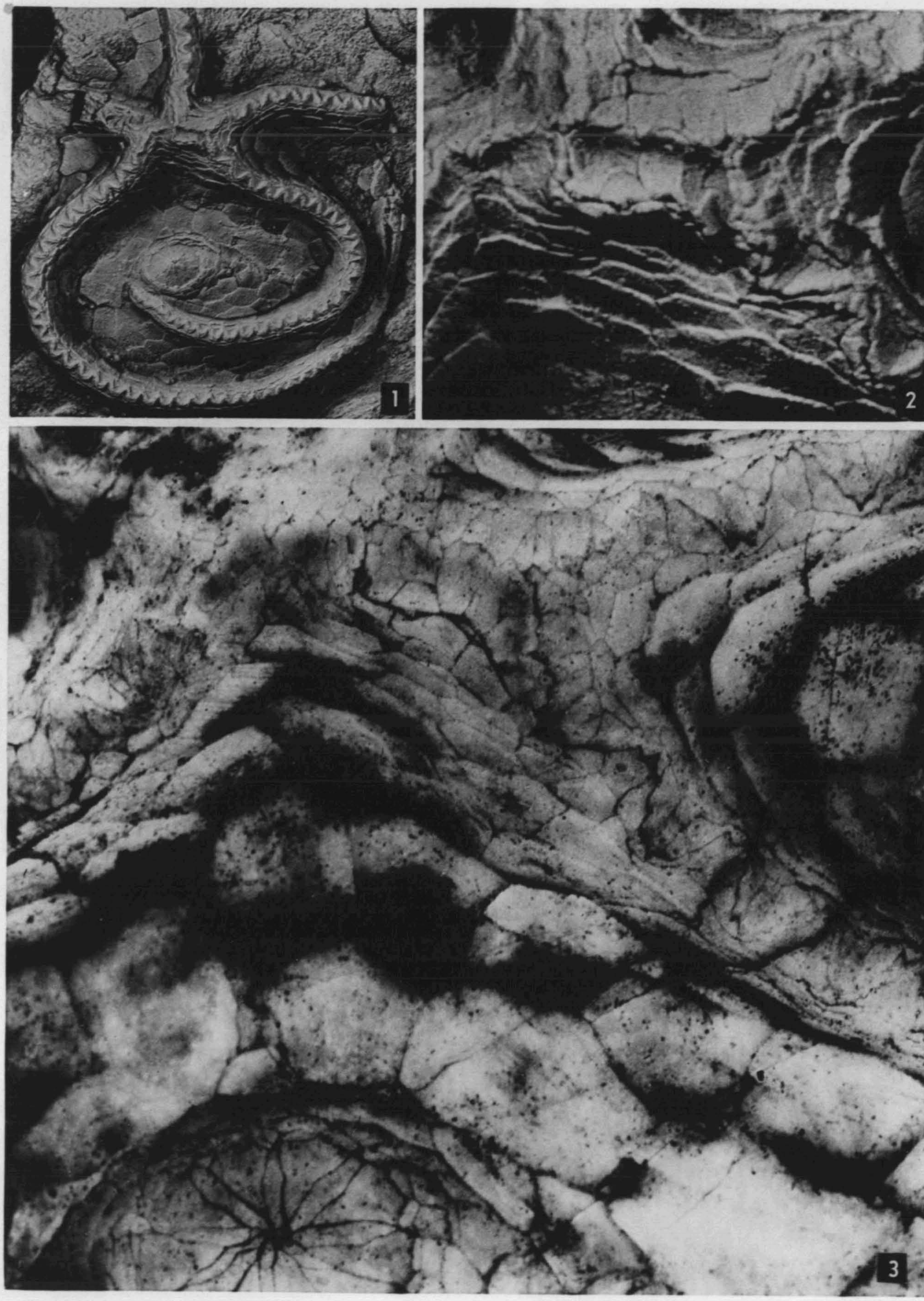
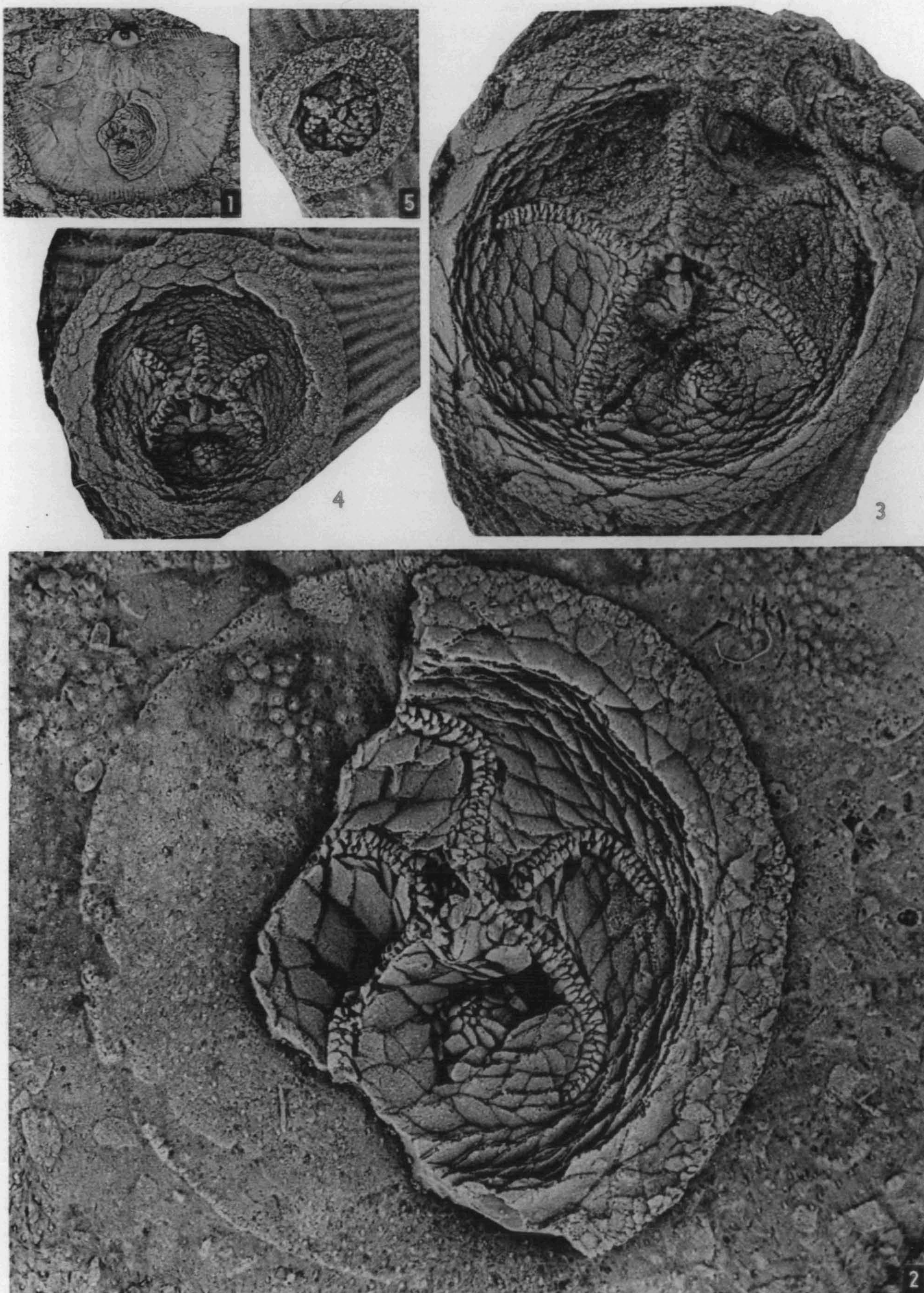


PLATE IV



EXPLANATION OF PLATE IV

(Figures $\times 8$ except as noted)

PAGE

Agelacrinites sp. A 148

All specimens from Middle Devonian Traverse group, Ferron Point formation; Alpena County, Michigan. Hydropores: Type IV.

FIGS. 1–2. Two oral views of UMMP No. 35387. (Figure 1 is natural size.) Specimen is attached on the inner surface of a pedicle valve of *Strophomena*. Where part of the edrioasteroid was broken off, it left a scar on the brachiopod valve.

FIG. 3. Oral view of UMMP No. 35377.

FIG. 4. Oral view of UMMP No. 35379.

FIG. 5. Oral view of a very young specimen, UMMP 35389.

EXPLANATION OF PLATE V

(All figures $\times 5$)

PAGE

Agelacrinites sp. B 149

Both specimens from Middle Devonian Traverse group, Ferron Point formation; Alpena County, Michigan. Hydropores: Type IV.

FIG. 1. Oral view of UMMP No. 4796. Compare view with restoration in Figure 2 in text.

FIG. 2. Oral view of UMMP No. 21203.

Agelacrinites southworthi Bassler 150

Hydropores: Type IV.

FIG. 3. Oral view of holotype, USNM No. S3478. Middle Devonian Hamilton group, Arkona shale; Arkona, Ontario.

FIG. 4. Oral view of very young specimen, USNM No. 94643. The hydropore is distinct, although the specimen is only 5 mm. in diameter. Probably from same formation and locality as holotype.

PLATE V

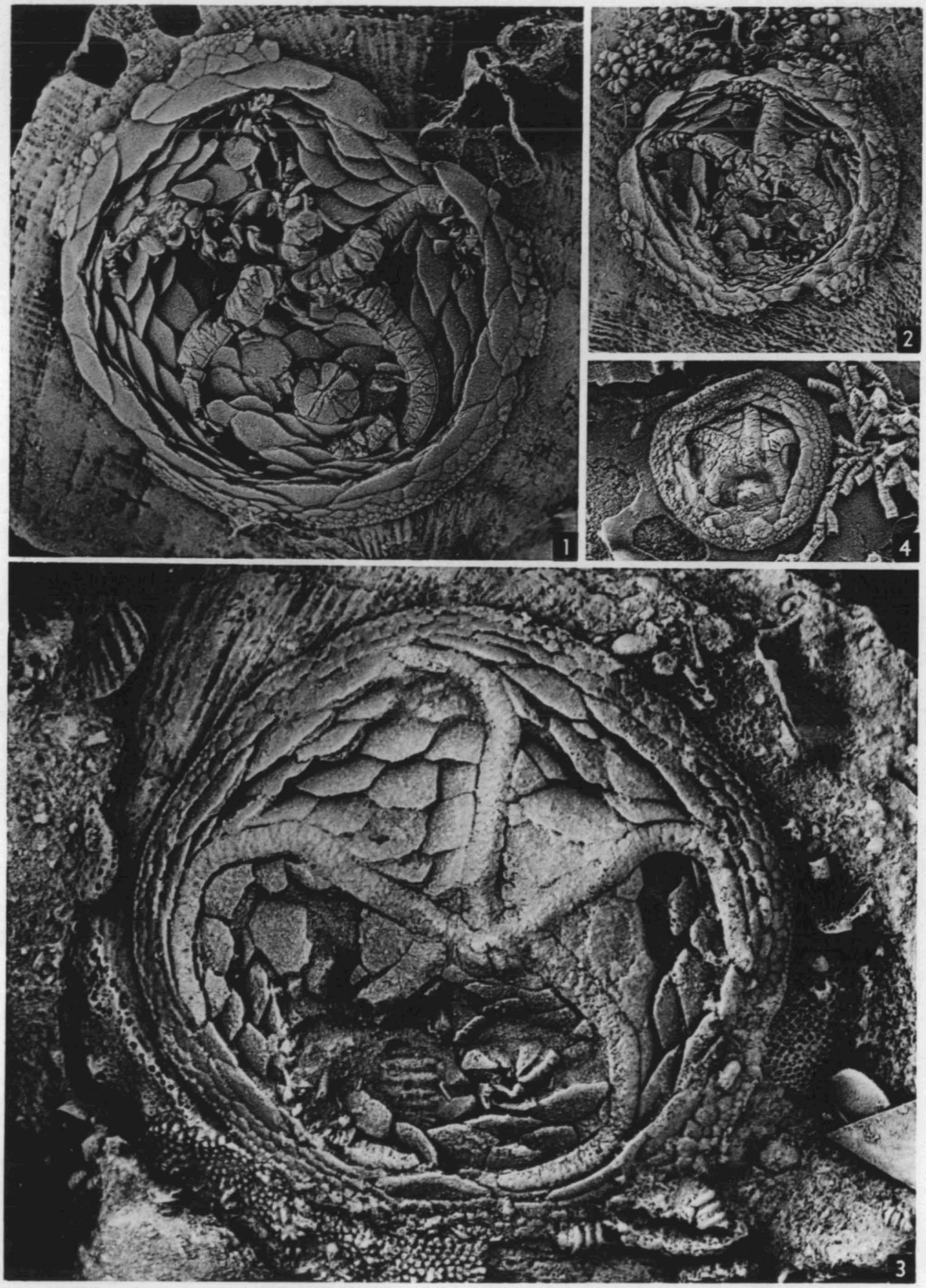
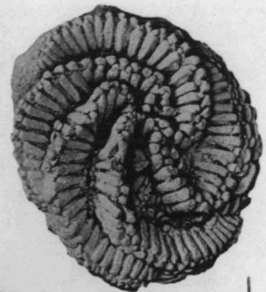


PLATE VI



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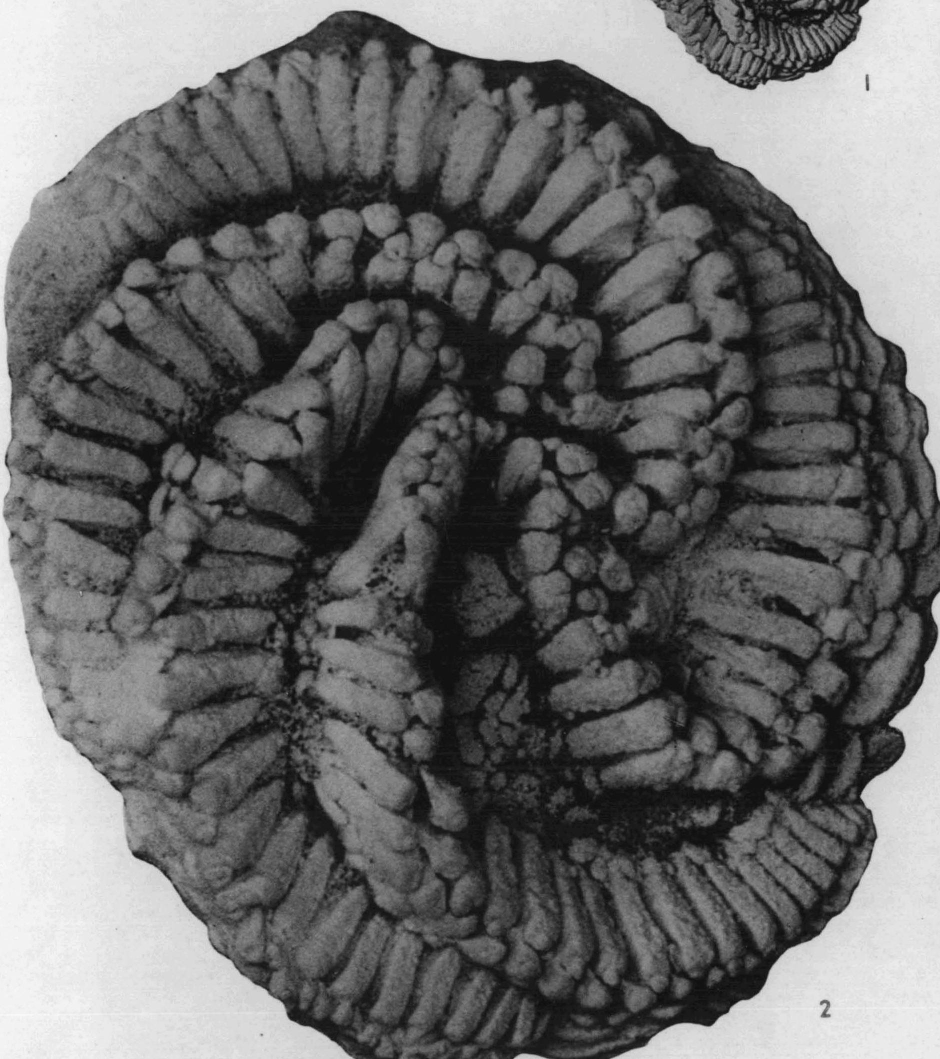

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EXPLANATION OF PLATE VI

PAGE

Streptaster sp. cf. *S. vorticellatus* (Hall) 163

FIGS. 1–2. Two oral views of UCM No. 34533. (× 2 2/3 and × 10). Compare views with restoration in Figure 9 in text. Upper Ordovician Maysville group, McMillan formation, Corryville shale member; Cincinnati, Ohio. Hydropore: Type IIIB.

EXPLANATION OF PLATE VII

FIGS. 1–2. Oral view of complete specimen coated with sublimate of ammonium chloride (× 4) and of peristomial and adjacent regions submersed in xylol (× 10). Holotype, USNM No. S4079. Compare views with restoration in Figure 8 in text. Middle Ordovician Trenton group (near base), Decorah shale *(Rhinidictya* bed); St. Paul, Minnesota. Hydropore: Type IIB.

PLATE VII

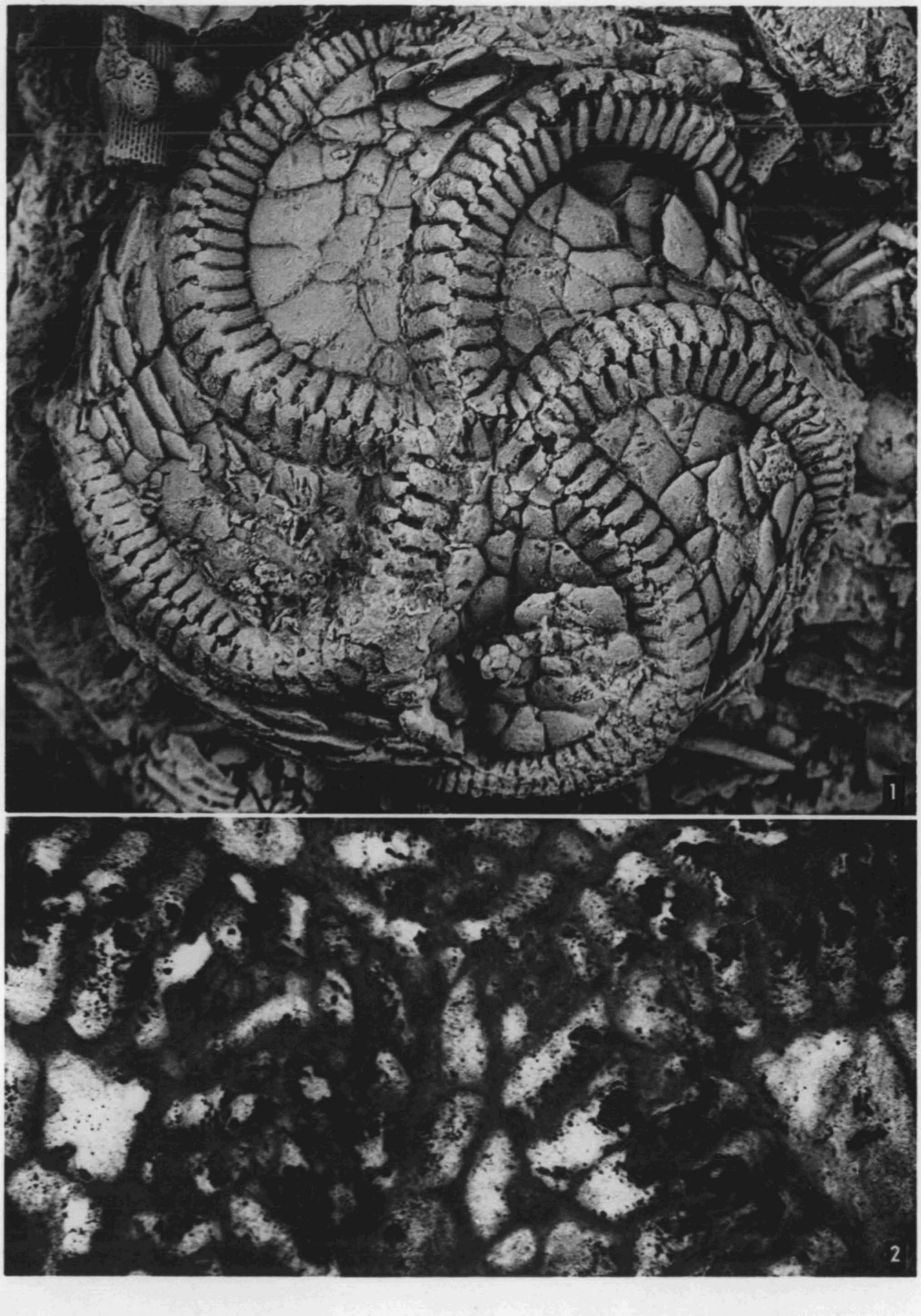
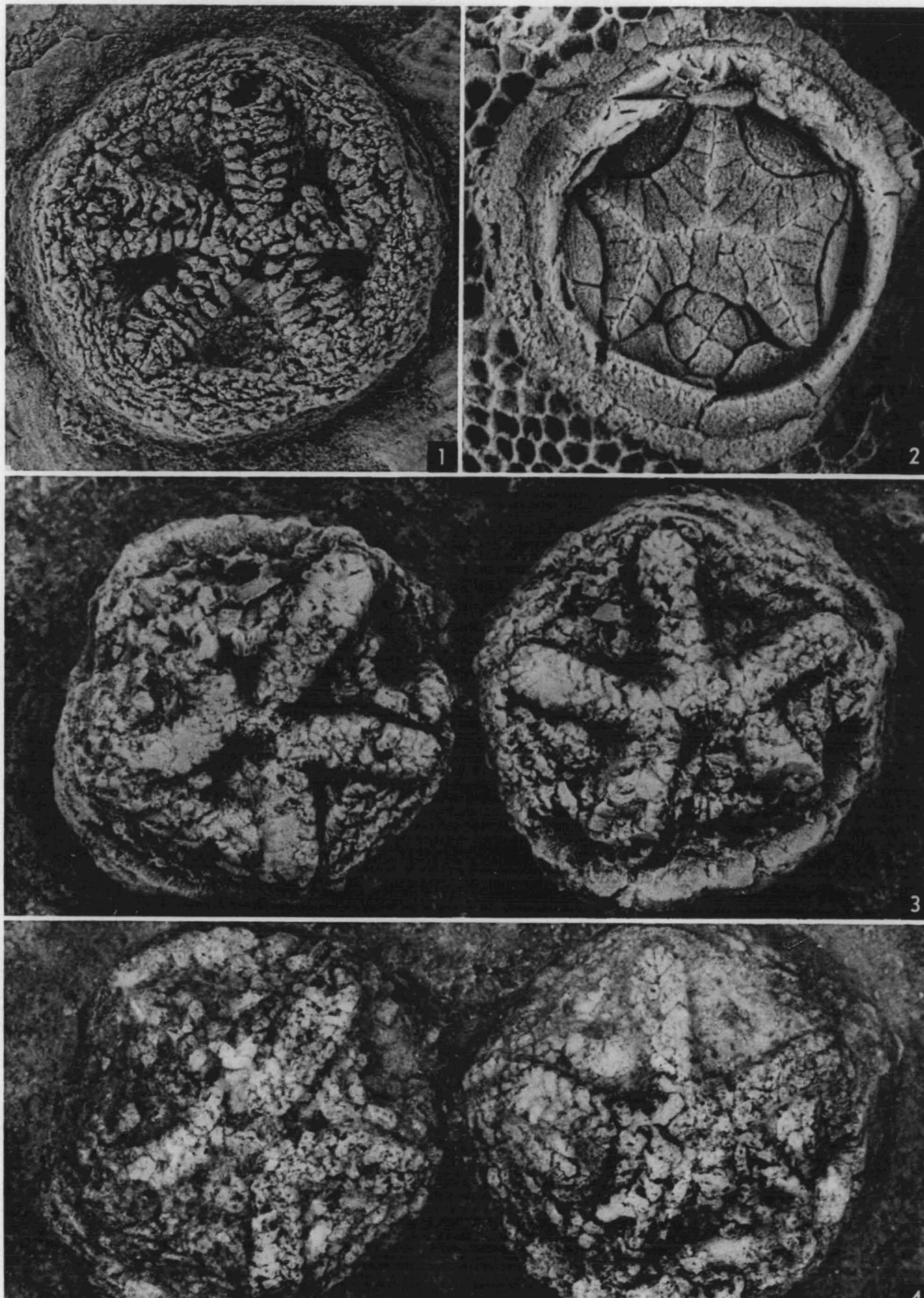


PLATE VIII



EXPLANATION OF PLATE VIII

PAGE

Cincinnatidiscus stellatus (Hall) 167

FIG. 1. Oral view of UCM No. 34534. (× 8). Upper Ordovician Maysville group, McMillan formation, Bellevue member; Cincinnati, Ohio. Hydropore: Type IIIB.

Timeischytes megapinacotus Ehlers and Kesling 170

FIG. 2. Oral view of paratype, UMMP No. 35428 (× 15). Compare view with restoration in Figure 13 in text. Middle Devonian Traverse group, Four Mile Dam limestone, Dock Street clay member; Alpena, Michigan. Hydropore: Type VB.

Cincinnatidiscus carnensis (Foerste) 168

FIGS. 3–4. Oral views of Cotypes, USNM No. 87163 (× 8). In Figure 3 coated with sublimate of ammonium chloride; in Figure 4 submersed in xylol. Middle Ordovician Trenton group; Carntown, Kentucky. Hydropore: Type IIIB.

EXPLANATION OF PLATE IX

PAGE

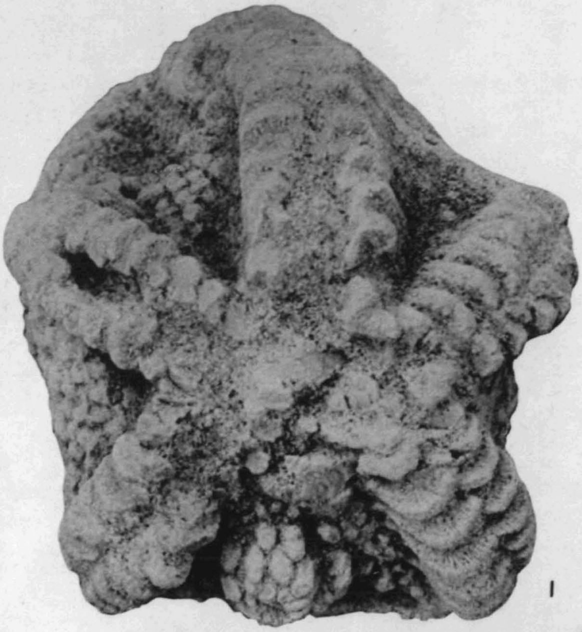
Cystaster granulatus (Hall) 165

Hydropores: Type IIIA. Compare these views with Figure 10 in text.

FIGS. 1–4. Oral views of two specimens coated with sublimate of ammonium chloride (× 10) and submersed in xylol (× 4½). USNM Nos. S3188*b* and S3188*a*. Upper Ordovician Maysville group, Fairmount formation; Cincinnati, Ohio.

FIGS. 5–6. Oral view of specimen coated with sublimate of ammonium chloride and submersed in xylol (both × 5). UMMP No. 5412. Upper Ordovician; Cincinnati, Ohio.

PLATE IX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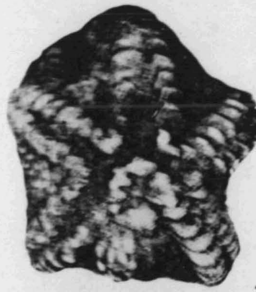
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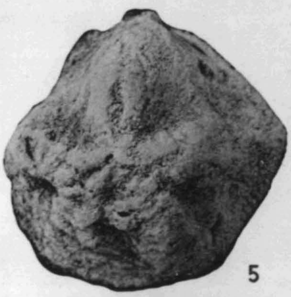
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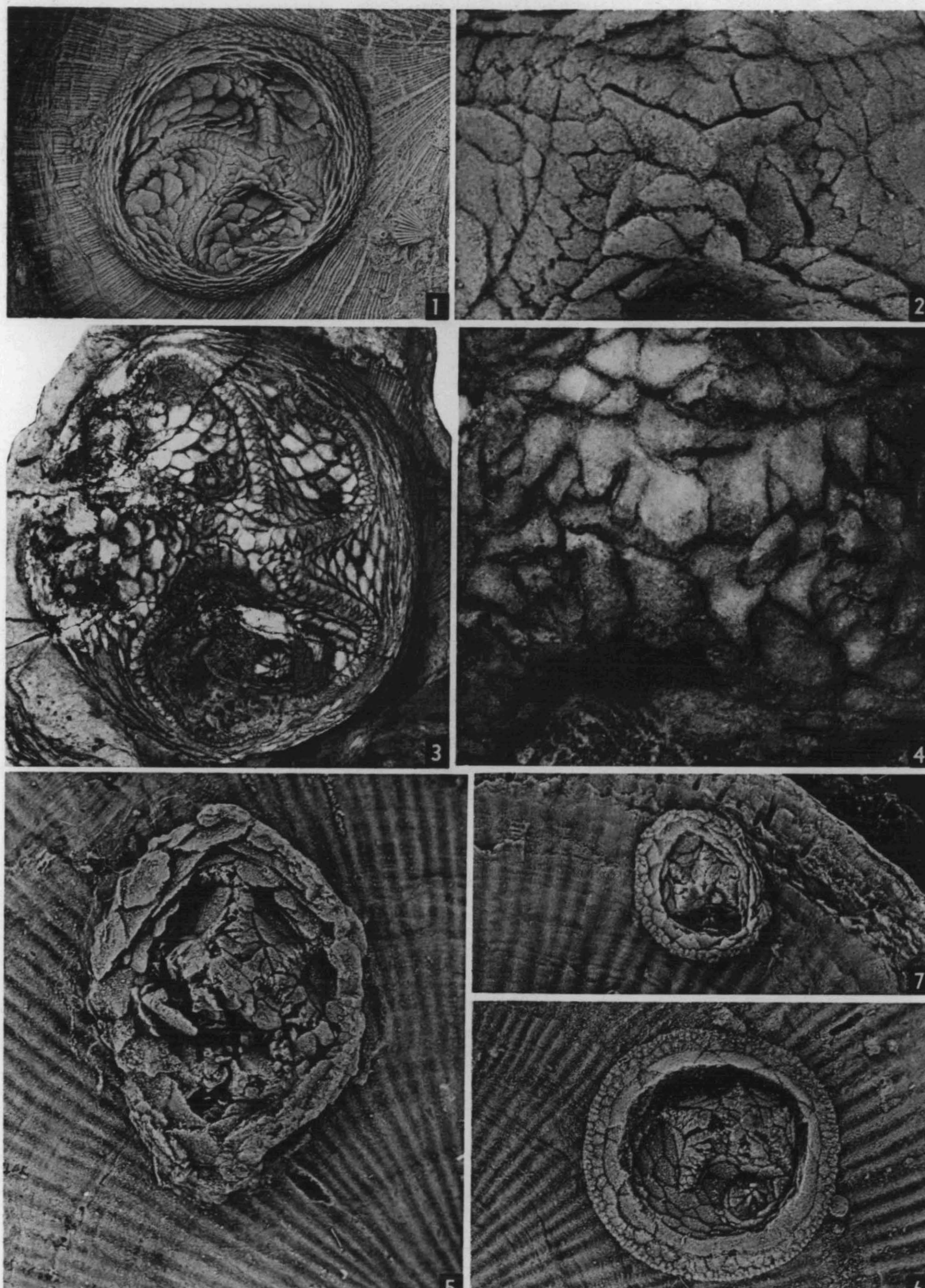
PLATE X



EXPLANATION OF PLATE X

PAGE

Isorophus cincinnatiensis (Roemer) 158

Hydropores: Type VA.

FIGS. 1–2. Oral view of complete specimen (× 2) and of peristomial and adjacent regions (× 8). UCM No. 34541. Upper Ordovician Maysville group, McMillan formation, Bellevue member; Cincinnati, Ohio.

FIGS. 3–4. Oral view of complete specimen (× 2) and of peristomial and adjacent regions (× 8). Specimen submersed in xylol. USNM No. 40746. Upper Ordovician Maysville group; Cincinnati, Ohio.

Hemicystites devonicus Bassler 159

All specimens from Middle Devonian Traverse group, Ferron Point formation; Alpena County, Michigan. Hydropores: Type VB.

FIG. 5. Oral view of holotype, UMMP No. 17295 (× 8). Specimen oriented differently than in original figure (Bassler, 1936, Pl. 7, Fig. 1).

FIGS. 6–7. Oral views of two immature specimens, UMMP Nos. 21123 and 35390 (× 8).

EXPLANATION OF PLATE XI

All specimens on this plate from Upper Ordovician Maysville group, McMillan formation, Bellevue member; Cincinnati, Ohio. Hydropores: Type VA.

PAGE

Isorophus cincinnatiensis (Roemer) 158

FIGS. 1–2. Oral view of complete specimen (× 2) and of peristomial and adjacent regions (× 8). UCM No. 34538.

Carneyella pilea (Hall) 166

FIGS. 3–8. Oral views of three specimens (× 2) and of their peristomial and adjacent regions (× 8). UCM Nos. 34535–34537.

PLATE XI

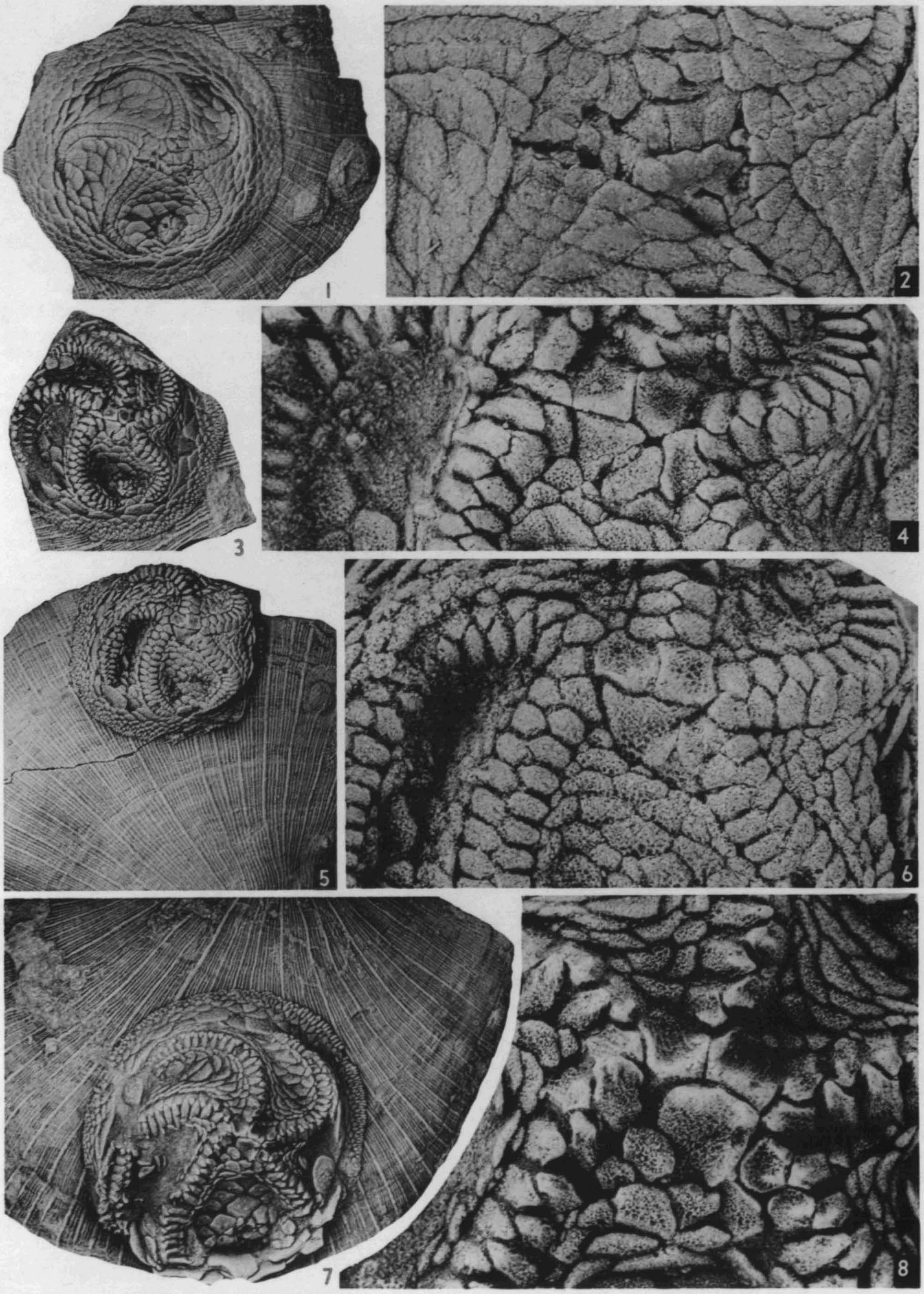
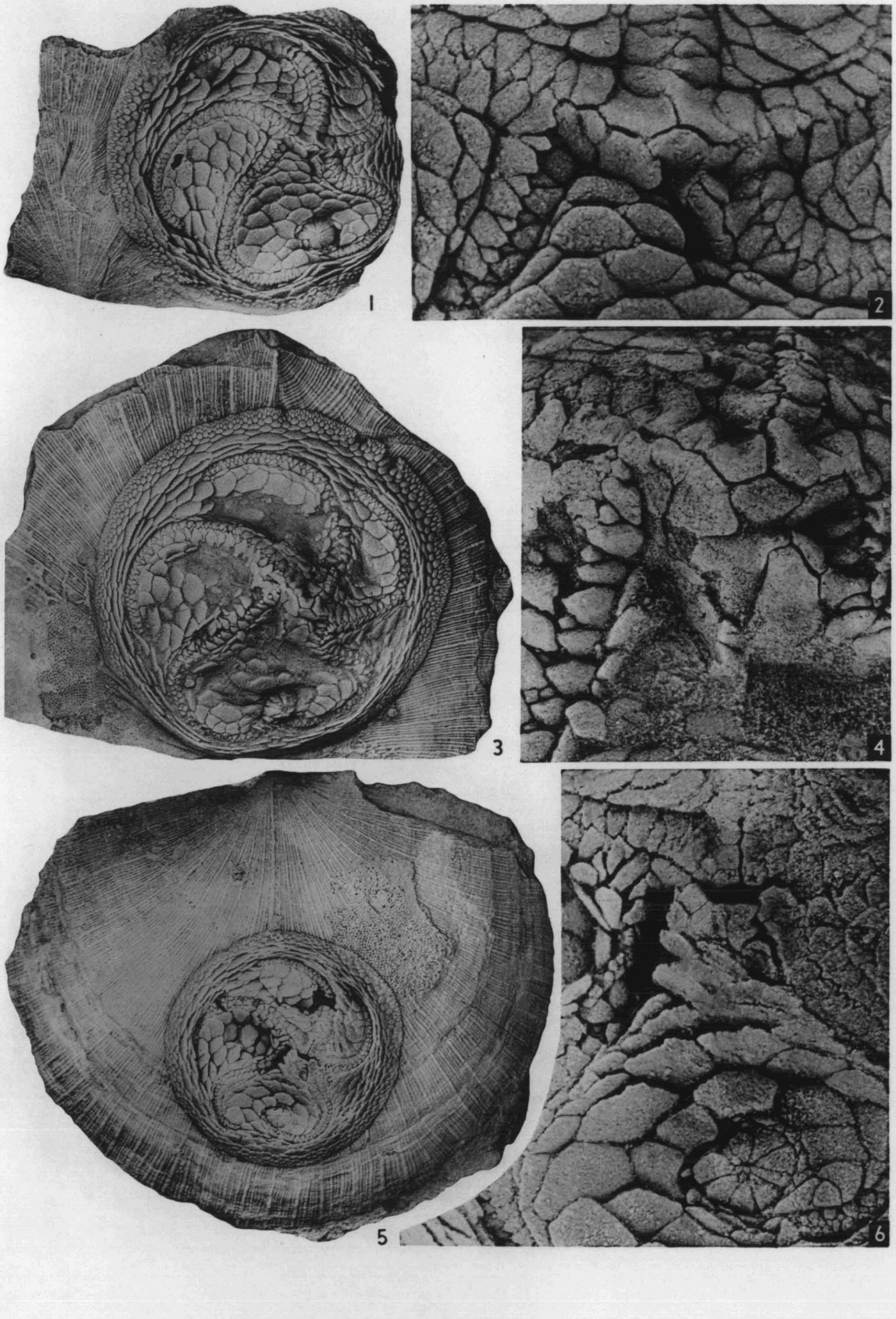


PLATE XII



EXPLANATION OF PLATE XII

FIGS. 1–6. Oral views of three specimens (× 2) and of their peristomial and adjacent regions (× 8). UCM Nos. 34539, 34542, and 34540. All specimens from Upper Ordovician Maysville group, McMillan formation, Bellevue member; Cincinnati, Ohio. Hydropores: Type VA.

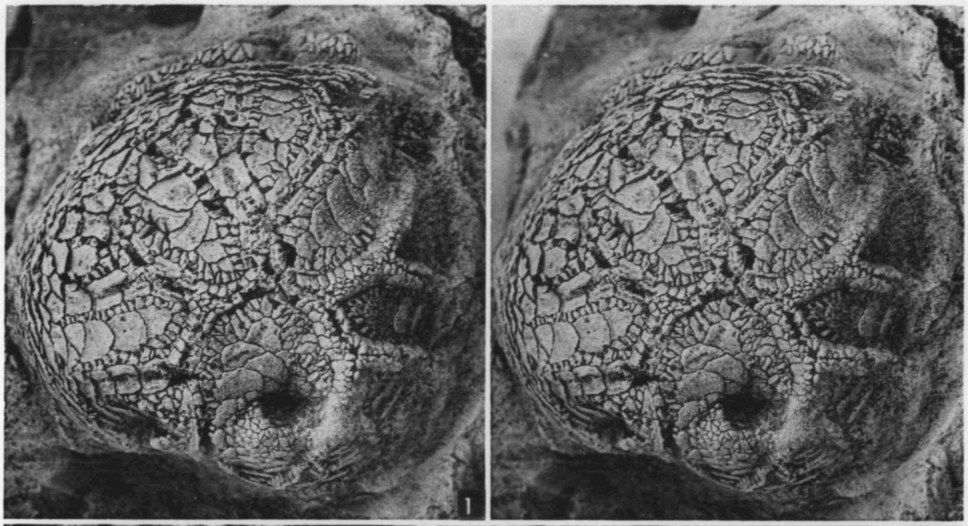
EXPLANATION OF PLATE XIII

PAGE

Thresherodiscus ramosus Foerste 151

FIGS. 1–2. Oral views of holotype and only known specimen, CGS No. 8446. Figure 1 is a stereogram of specimen that has been coated with sublimate of ammonium chloride (× 4). Figure 2 is a view of the specimen submersed in xylol (× 15); the supposed hydropore is near the lower right corner, adjacent to ambulacrum V. Compare views with restoration in Figure 3 in text. Middle Ordovician Trenton group; Goat Island, Lake Huron, Ontario. Hydropore: Type IIA.

PLATE XIII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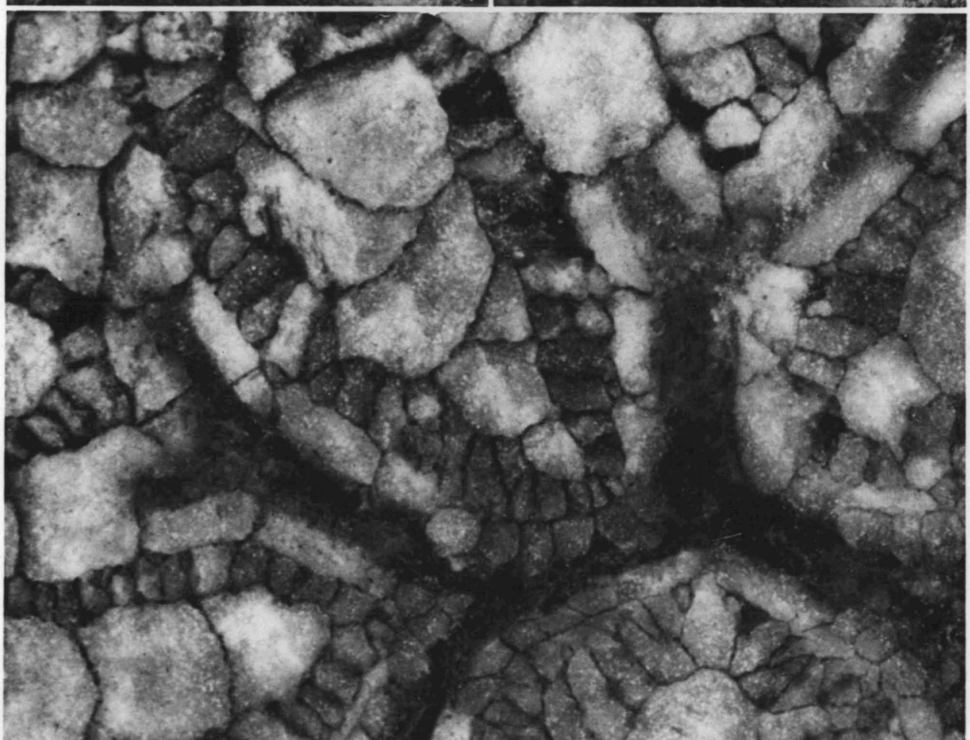
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