ASTROCYSTITES DISTANS SP. NOV., AN EDRIOBLASTOID FROM THE ORDOVICIAN OF EASTERN AUSTRALIA

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ABSTRACT. A new Ordovician edrioblastoid, *Astrocystites distans* sp. nov., and other miscellaneous pelmatozoan plates are described from the lower part of the Cliefden Caves Limestone WNW. of Mandurama, New South Wales. The edrioblastoid is similar to the only other species of *Astrocystites* known, *A. ottawaensis* Whiteaves from the Trenton Limestone of Ottawa, which was hitherto the sole representative of the group. This represents the first record of an edrioblastoid outside North America. Sections of the Australian material have revealed details of internal structures not previously known in the group.

DURING recent geological work in the Lower Palaeozoic successions of the central-west of New South Wales by G. H. Packham and the writer, an abundance of pelmatozoan material was found in a band of fawn-grey thinly bedded limestones. Unfortunately virtually all of it is fragmentary, consisting mainly of stem ossicles, incomplete thecae and disarticulated plates. The thecae and plates form the basis of this paper. The band of limestones also contains polyzoans, brachiopods, corals, gastropods, trilobites, and nautiloids, and lies within the lower thinly bedded part of the Cliefden Caves Limestone. The localities from which the collection was made are situated on the property of Boonderoo, about ¼ mile ESE. of the entrance to Cliefden Caves (Bathurst sheet, 1:250,000; S155–8, Edit. 1–AAS, Series R 502; Grid ref. 186848), and near Little Boonderoo (Grid ref. 186844).

The stratigraphy of the area was described by Stevens (1952), but the faunas have received little attention. Some of the corals in the Cliefden Caves Limestone were described by Hill (1957) and suggest a Trenton age. However, the presence of graptolites, probably of the *Nemagraptus gracilis* zone, in the overlying shales and limestones of the Malongulli Formation (Sherrard 1954) implies an older age. The faunas are being studied by Packham and the writer, and it is hoped to offer a more exhaustive statement on the age and correlation of units in the succession.

SYSTEMATIC DESCRIPTION

The registration numbers of specimens in the University of Sydney, Geology Department, palaeontological collections have the prefix USGD.

Subphylum PELMATOZOA Leuckart 1848
Class EDRIOBLASTOIDEA Fay 1962
Family STEGANOBLASTIDAE Bather 1900
Genus ASTROCYSTITES Whiteaves 1897 (= STEGANOBLASTUS Whiteaves 1898)

Type species. Astrocystites ottawaensis Whiteaves.

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Nomenclature and previous work. Whiteaves (1897) first described *Astrocystites ottawaensis* from the Trenton Limestone of Ottawa. In the same year Bather raised objections to Whiteaves's generic name on the grounds of possible confusion with *Asterocystis* Haeckel, and suggested that Whiteaves substitute the name *Steganoblastus*. The new generic name was introduced by Whiteaves (1898), and the family name Steganoblastidae of the Class Edrioasteroidea added by Bather (1900). Whiteaves's original generic name, *Astrocystites*, was restored by Bassler (1935) on grounds of priority, and he introduced a new family name, Astrocystitidae, to replace Steganoblastidae. However, since Steganoblastidae, which is based on a junior objective synonym, has priority and has been a more widely used name, it would seem desirable that it be retained. This view accords with Art. 40 of the International Code of Zoological Nomenclature.

Astrocystites was interpreted as an edrioasteroid by Bather (1914*b*), and as a blastoid by Hudson (1925). Bassler (1935, 1936) also classified the genus in the Edrioasteroidea, but observed that, since only a few specimens are known and pending further discoveries it might well be assigned to the Protoblastoidea. Fay (1962) contended that it did not belong either to the edrioasteroids or the blastoids, and raised a new class, the Edrioblastoidea, to accommodate it. He noted its resemblances to blastoids in having five petaloid ambulacra with pores between ambulacral plates, five radials, five deltoids, five orals, and a primitive stem, and its differences in exhibiting five basals, numerous infradeltoids, a hydropore, and deep infolds in plates of the theca. His reasons for removing *Astrocystites* from the edrioasteroids are not clearly stated. Judging from Bather's and Fay's descriptions of *A. ottawaensis* it is evident that there are close similarities with edrioasteroids, especially in the nature and arrangement of floor and cover plates, and pores in the ambulacral areas, and in the presence of a cluster of small plates around the anal opening and hydropore. The genus may be distinguished from edrioasteroids by having a pyriform theca, a stem, five basals, five radials, and five deltoids. Regnéll (1966, p. 150) preferred a non-commital term 'third aperture' for the structure usually referred to as the hydropore in edrioasteroids, because it may alternatively be interpreted as a gonopore or a hydrogonopore. In the following account of the new edrioblastoid, the term hydropore has been retained, although it is recognized that the aperture may also have acted as an outlet for sexual products.

The original descriptions of *Astrocystites ottawaensis* by Whiteaves (1897) and Bather (1914*b*) were based on three complete specimens. However, Wilson (1946) and Fay (1962) indicated that only one specimen is now known to exist, the others having been misplaced or lost. Wilson listed the specimen from the Cobourg beds, in Booth Street, Ottawa, the topmost unit of the Ottawa Formation, and of Trenton age. Fay founded the Class Edrioblastoidea on this single remaining specimen. Details of the internal structures remain unknown, yet there seems to be no good reason why this should be so, for Spencer (1938, p. 291) observed that the Trenton rocks of Ottawa contain beds 'composed almost entirely of separate ossicles of species of *Steganoblastus*'; Bassler and Moodey (1943, p. 197) listed *A. ottawaensis* from three different localities and horizons, namely, from the Upper Trenton *Hormotoma trentonensis* beds of Ottawa, from the Hull Limestone of Kirkfield, Ontario, and from the Curdsville Limestone of Mercer County, Kentucky. From these statements, it would, therefore, be surprising if no other material is available either in existing collections or in outcrops. It is to be hoped that further material will be found, and sections cut in order to elucidate the nature of the internal structure of *A. ottawaensis*, enabling closer comparisons to be made with the fragmentary Australian material.

The writer has reservations about the need to separate *Astrocystites* from the Edrioasteroidea and to erect a new class, the Edrioblastoidea (Fay 1962). Even greater doubt is felt about the assignment of edrioasteroids and edrioblastoids to different subphyla (Fell 1965; Fell and Moore 1966). Although Fay's classification has been followed, the obvious morphological similarities of *Edrioaster* and *Astrocystites*, the appearance of *Astrocystites* in the Middle Ordovician during the period of maximum diversification of the edrioasteroids, and the presence of several forms with comparable sac-like form and straight ambulacra (e.g., *Cystaster* and *Cyathocystis*) still regarded as edrioasteroids (Regnéll 1966), support the view that edrioblastoids should be grouped in an order or a suborder of the Class Edrioasteroidea.

Astrocystites distans sp. nov.

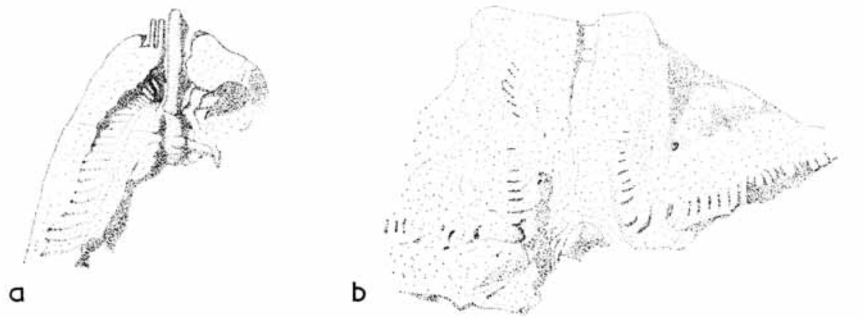
Plate 99, figs. 1–10; Plate 100, figs. 1–8; text-figs. 1–4

Diagnosis. A species of *Astrocystites* with slit-like ambulacral pores, averaging 25–30 per cm., and small, circular hydropore.

Material. Two partially complete specimens (holotype, USGD 2302, and paratype A, USGD 2303), five incomplete specimens showing sections across the theca (paratypes B–D, USGD 2309; other paratypes, 2304–6, 2312, 3303), two serially sectioned specimens (paratypes, USGD 2310–11) and plate fragments (paratypes, USGD 2308, 2313–14). All the type specimens come from the lower part of the Cliefden Caves Limestone ¼ mile ESE. of the entrance to Cliefden Caves, excepting USGD 3303, which is from the same horizon near Little Boonderoo.

Description. Theca medium-sized, incompletely preserved. Holotype (USGD 2302) measures more than 18 mm. in height and 20 mm. in width; paratype A (USGD 2303) is more than 23 mm. high and 25 mm. wide. Base of theca not observed. Basals small, convex plates with strong radial crenulations and small apical openings (probably caused by wear on this more prominent part of the plate); basals 3–6 mm. wide and 2·5–5 mm. in height. Radials large, subpentagonal, estimated to be 8–14 mm. wide and of similar height; lower and lateral parts exhibit gentle to deep crenulations, seemingly at right angles to sutures, and upper medial part of plate underlies distal end of each ambulacrum. Small, tightly fused infradeltoids appear to be represented in posterior interradius around possible anal opening of holotype. These have also been seen in other interradii in cross-section. Deltoids large, subtriangular, thickened plates, approximately 5–8 mm. in both height and width, and with deep to undulating crenulations on external surface. Hydropore circular, 0·5 mm. in diameter, situated near apex of posterior interradius.

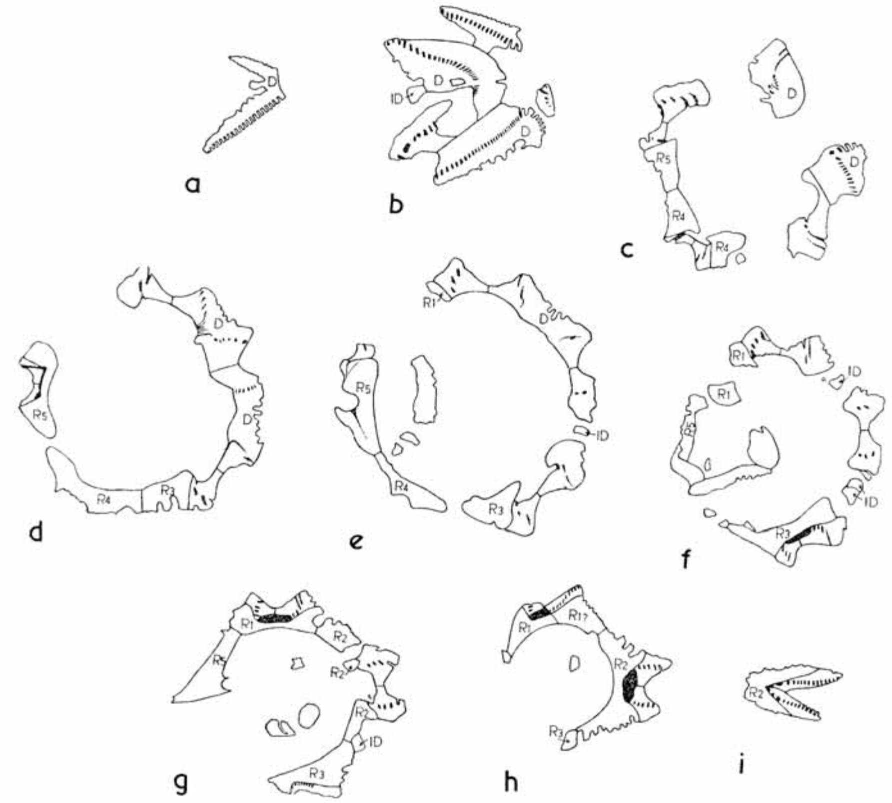
Straight petaloid ambulacra; in holotype ambulacrum 15 mm. long and 6 mm. wide, and in paratype A, more than 22 mm. long and 6·5 mm. wide; ambulacra gently curved around theca in distal and medial regions, but more strongly arched and thickened in proximal region leading to mouth; ambulacral groove bounded by row of floor plates on either side, and united by very close suture; individual floor plates cannot be differentiated, owing to extreme fusion of plates and nature of preservation; regularly spaced, slit-like pores extend along each row of floor plates, about 25–30 per cm., and become smaller and more closely spaced proximally. It is also virtually impossible to recognize junctions between floor plates and deltoids because of the complete fusion and crystallographic continuity of calcite in the plates; they can seldom be distinguished even in thin sections under a polarizing microscope. In the distal part of the ambulacrum pores pass through floor plates into a canal lying between the radial and the floor plates; it presumably opens into the thecal cavity at the top of the radial. Floor plates in proximal part of ambulacrum and margins of deltoids are thickened, producing an inwardly directed flange-like extension through which pores penetrate and communicate with the thecal cavity. Flanges seem to form part of the frame surrounding the peristome.



TEXT-FIG. 1. *Astrocystites distans* sp. nov. *a*, longitudinal section of paratype B, USGD 2309, ×5, showing large, vertical interradial element and the nature of the pores inside the theca. The circum-oral ring of the water vascular system may have crossed the element in the lower part, below the level of adjacent pores. *b*, oral view of holotype, USGD 2302, ×5, showing right postero-lateral ambulacrum and posterior interradius with hydropore. At the top of the ambulacrum there is a plate which may be interpreted as a radial element in the frame, or a foreign plate fragment lying inside the peristome.

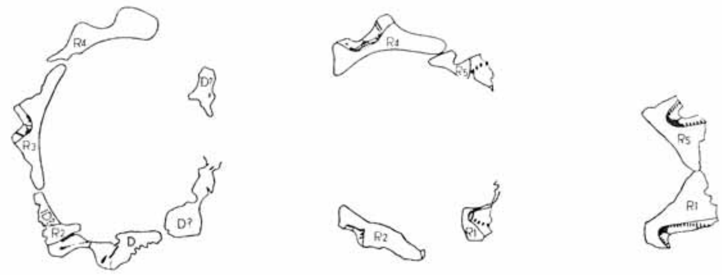
Larger vertical interradial elements are found in the angles between floor plates and adjacent radii, and make up the interradial component of the frame (text-fig. 1*a*); the upper part of the interradial element is smooth and may have been connected in the frame, but the lower part, just below the level of adjacent pores, is irregular, and may have been free. Floor plates on either side of the interradial element are apparently narrower and taper inwards, as associated pores are smaller and slope obliquely in towards larger vertical canals on either side of the interradial element. Structure interpreted as stone canal extends from the interior in an adoral direction between interradial element of the posterior interradius and left posterior ambulacrum. From the interior a narrow canal expands into a double chamber, which is linked by a narrow obliquely inclined canal to a funnel-shaped chamber (Pl. 100, fig. 3). It opens to the exterior by the centrally placed hydropore. A radial element is suggested from the oral region of the holotype (text-fig. 1*b*) but it has not been confirmed in other specimens. Cover plates and oral plates have not been observed. Tiny pits scattered on the external surface of parts of the theca possibly represent attachment points for small spines.

A series of cross-sections, unfortunately slightly oblique, was prepared from paratype USGD 2310; the specimen is fragmentary, lacks basals, and a prominent joint intersects one side of the theca, resulting in recrystallization and disruption of plates. Radials, deltoids, infradeltoids, and floor plates are represented (text-fig. 2). Pores, although mainly cut obliquely, appear to extend through floor plates along the length of the ambulacra, and canals between radials and floor plates are clearly exhibited in the distal parts of ambulacra (text-fig. 2*f*–*h*).



TEXT-FIG. 2. *Astrocystites distans* sp. nov. Slightly oblique cross sections of paratype, USGD 2310, × 2. Camera lucida drawings from cut sections and cellulose peels at intervals of 0·5 (*a*), 2·5 (*b*), 6·0 (*c*), 8·3 (*d*), 9·9 (*e*), 12·2 (*f*), 14·7 (*g*), 17·0 (*h*), and 20·0 mm. (*i*) below the top of the theca. Sections are not oriented according to convention as the position of the anus cannot be determined, but the radials (R) have been numbered clockwise from above. Deltoids (D) and infradeltoids (ID) are also indicated. Floor plates above the radials can be easily differentiated by the suture and the central canal (dark shaded), but in the upper part of the theca, floor plates fuse with deltoids and cannot be separated.

Similar canals are shown in a section of another fragmentary specimen, paratype USGD 2311 (text-fig. 3*c*). However, a somewhat different arrangement of canals can be seen in the other sections of this specimen (text-figs. 3, 4). In one of these, the floor plates resting on radial R3 have two small tear-drop shaped canals instead of a larger central canal (text-figs. 3*a*, 4*a*). Two sutures which extend from the canals to the ambulacral groove seem to parallel cleavages in calcite of the floor plates; they separate the floor plates into inner and outer parts. In the other, the floor plates lying on the radial



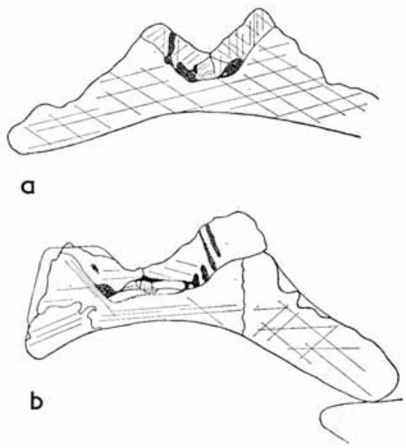
TEXT-FIG. 3. *Astrocystites distans* sp. nov. Slightly oblique cross sections of paratype, USGD 2311, ×2. Camera lucida sketches of thin sections at intervals of 2 (*a*), 7 (*b*), and 12 mm. (*c*) below upper surface of specimen shown in Plate 100, fig. 5. Radials (R) are numbered, and deltoids (D) and infradeltoids (ID) are also indicated.

R4 have three small canals, two lateral and one medial which lies on the line of suture of floor plates just inside the ambulacral groove (text-fig. 3*b*, 4*b*). This medial canal appears to be connected with the laterals by sutures or narrow passages, which thus separate the inner and outer parts of the floor plates, as in the previous example; the inner superficially resembles the lancet plate of blastoids. This is directly underlain by what seems to be another thin plate, but on closer study under polarised light this proves to be a part of R4.

EXPLANATION OF PLATE 99

Figs. 1–10. *Astrocystites distans* sp. nov. 1, 2, Holotype, USGD 2302, ×3, side and oral views showing straight, petaloid right postero-lateral ambulacrum with slit-like pores and ambulacral groove, and posterior interradius with crenulations and hydropore near the apex. 3, Holotype, USGD 2302, ×4, detail of posterior interradius showing gentle to deep crenulations with vague, small tightly fused infradeltoids surrounding the anal opening and a small, circular hydropore near the apex. 4, Paratype A, USGD 2303, ×4, showing straight ambulacrum and radials with gentle crenulations. 5, Paratype A, USGD 2303, ×8, detail of a row of slit-like pores in the medial part of the ambulacrum. 6, Paratypes B–D, USGD 2309, ×3, two longitudinal sections (paratype B, top left; paratype C, centre) and basal plate (paratype D, bottom right); B, section showing large vertical interradial element; C, longitudinal section intersected nearer to the outer margin of the theca than in paratype B, and therefore only exhibiting traces of the interradial element; D, fragmentary basal with small apical opening. 7, Paratype, USGD 2304, ×4, oblique view of a single row of slit-like pores penetrating tightly fused floor plates with pores on either side and interradial element at the apex. 9, Paratype, USGD 2313, ×4, small, convex basal with radial crenulations and small apical opening. 10, Paratype, USGD 2314, ×4, convex basal with strong radial, crenulations and small apical opening. *Photographs by G. Z. Foldvary and B. D. Webby.*

Remarks. Astrocystites ottawaensis may be distinguished from *A. distans* by having pores with a circular cross-section, a wider spacing of pores (15 per cm.), and a slit-like hydropore. Few other features can be compared closely because only three specimens of the more perfectly preserved *A. ottawaensis* have previously been studied and details of internal structures are unknown. There are also differences of interpretation of certain structures which must be clarified before close comparisons can be made. For instance, Bather (1914*b*, pp. 196, 199) stated that the radials slope upwards towards the



TEXT-FIG. 4. Enlarged sections of parts of paratype, USGD 2311, ×7. *a*, radial R3 consists of a large calcite crystal with prominent cleavages. It is overlain by floor plates also exhibiting cleavages. Each floor plate has a tear-drop shaped canal, the left also having a connecting pore. An area of recrystallized calcite (lightly stippled) lies between the canals. In addition to the vertical suture between floor plates, there are inclined sutures extending towards the ambulacral groove which seem to parallel cleavages in the calcite of the floor plates. *b*, radial R4 of text-fig. 3*b* consists of a large plate with two faint sutures (one irregular) of unknown significance, and prominent cleavages. Pores in the overlying floor plates seem to be connected to three small canals, two lateral and one medial. The medial canal lies on the suture between adjacent floor plates just below the ambulacral groove, and seems to be joined by sutures or passages to the lateral canals. They divide the floor plates into inner and outer parts. The lightly stippled area consists of recystallized calcite.

ambulacral grooves from the top of the interradial sutures, and are notched for the excavation of the ambulacral grooves 'so that the pores between the floor-plates pass through into the thecal cavity'. Hudson (1925, 1927) and Fay (1962), on the other hand, considered that the radials slope downwards from the top of the interradial sutures rounding the distal ends of the ambulacral grooves.

Another edrioblastoid has recently been collected from the Trelawney Beds of northern New South Wales, which Philip (1966), on the basis of conodont work, regarded as Upper Caradocian (i.e., Trentonian–Maysvillian of North America). The edrioblastoid specimen (USGD 3304) consists of the upper part of an incomplete theca cut in longitudinal section, 1 cm. wide, and exhibiting fused deltoids and floor plates with slit-like pores. It probably represents a species of *Astrocystites* comparable with *A. distans*, but until more material is found closer comparisons cannot be made.

Discussion of edrioblastoid relationships. Bather (1914*b*, p. 202), while observing the similarities in the nature and arrangement of the floor and cover plates in *Astrocystites* and *Edrioaster*, noted that the ambulacra in *Astrocystites* are not sinuous, the cover plates in the oral region are arranged in a different manner, and the floor plates are more rigidly fused. The interradial element of *E. bigsbyi*, formed by the fusion of four floor plates (Bather 1914*a*, p. 165, text-fig. 3), is very different from that in *A. distans*, which is a large rod-like structure flanked by shorter, thin plates inclining towards the element because of the curvature of the theca. The pores in *Edrioaster* pass directly into the thecal cavity through the entire length of the ambulacra, whereas, at least in *A. distans*, they only pass directly into the thecal cavity in the proximal part of the ambulacra. Distally they lead into a canal which apparently opens into the thecal cavity at the top of the radial.

In *A. distans* the hydropore is centrally situated and near the apex of the posterior interradius. Leading from it the stone canal consists of an outer, centrally placed funnel-shaped chamber linked by a narrow oblique canal to an inner double chamber. This lies between the interradial element of the posterior interradius and the left posterior ambulacrum, and is connected to the interior of the theca by a short, narrow canal (text-fig. 5). This arrangement differs from that described by Kesling and Mintz (1966) in the edrioasteroids *Isorophus cincinnatiensis* (Roemer) and *Carneyella pilea*

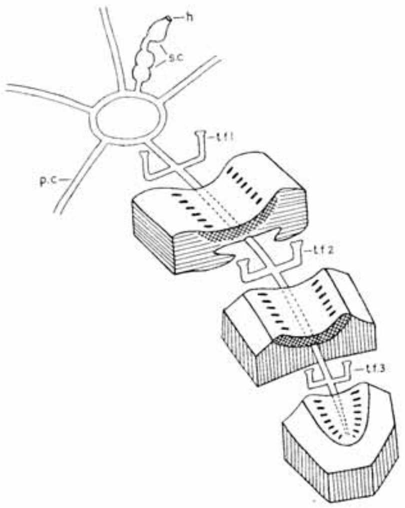
EXPLANATION OF PLATE 100

Figs. 1–8. *Astrocystites distans* sp. nov. 1, 2, Paratype, USGD 2310, ×3, slightly oblique cross-sections at intervals of 2·5 and 17 mm. below the top of the theca; photographed from cellulose peels; 1, Section through two ambulacra showing thickened deltoids and solidly fused floor plates penetrated by pores, which gradually diminish in size proximally (see text-fig. 2*b*). 2, Section showing two ambulacra near their distal ends resting on radials; pores extend through floor plates into a canal overlying the radial; outer surface of radials show strong crenulations and interior surface is smooth (see text-fig. 2*h*). 3, Paratype, USGD 3303, ×3, internal view of adoral part of posterior interradius showing nature of the stone canal and its relationship to the interradial element. 4, Paratype, USGD 2305, ×3, longitudinal section showing thickened deltoids and fused floor plates penetrated by slit-like pores. 5, Paratype, USGD 2311, ×1·5, side view of specimen before sectioning showing two ambulacra separated by an inter-ambulacral area; ambulacra rest on radials R1 and R5 respectively (see text-fig. 3). 6–8, USGD 2311, ×5, thin sections at intervals of 2, 7, and 12 mm. below upper surface shown in fig. 5. 6, slightly oblique section across thecal plates showing surface crenulations and calcite cleavages in the plates; two ambulacra lie on radials R2 and R3 (for interpretations see text-figs. 3*a*, 4*a*). 7, section showing radials, R4 and part of R5, and overlying floor plates (see text-figs. 3*b*, 4*b*). 8, oblique section near distal ends of ambulacra showing them lying in grooves on radials R1 and R5 (see text-fig. 3*c*). Note prominent central canal in each ambulacrum below the floor plates, and well-developed cleavages in calcite of the radial plates.

Figs. 9–16. Miscellaneous pelmatozoan plates. 9, USGD 2307, ×3, large thecal plate. 10, USGD 3300, ×3, circular structure with stellate grooving, and another obliquely cut structure. 11, USGD 2315, ×3, large round columnal with stellate axial canal. 12, USGD 3301, ×3, round columnal with stellate axial canal and crenellae on part of the articulating surface. 13, USGD 3302, ×3, small round columnal with round axial canal. 14, USGD 2307, ×3, round columnal with round axial canal and concentrically grooved articulating surface. 15, USGD 2316, ×3, part of stem showing alternate nodals and internodals. 16, USGD 2315, ×3, small, round articulated columnals. *Photographs by G. Z. Foldvary and B. D. Webby.*

(Hall), where the stone canal extends from the hydropore inwards between the posterior interradius and the right posterior ambulacrum. A similar arrangement is exhibited by *Lepidodiscus fistulosus* (Anderson 1939). On the other hand, Bather (1914*a*, p. 168) observed that in *Edrioaster bigsbyi* the hydropore becomes deeper adorally and in the direction of the left posterior ambulacrum, suggesting a similar pattern to *A. distans*.

Bather (1915, p. 266) concluded that in edrioasteroids (including *Astrocystites*) the ambulacra exhibited an open system (similar to that in asteroids), viz., ampullae in the thecal cavity connected by way of the pores to tube feet and the perradial canal lying in the ambulacral groove. The tube feet were presumed to have acted both in respiration and feeding of the animal. Cover plates were evidently opened when *Edrioaster* was feeding. Anderson (1939, p. 75), in contrast, considered that in *Lepidodiscus fistulosus* and forms described by Bather, including *Astrocystites*, a closed system (as in echinoids) was represented, viz., a perradial canal below the ambulacral groove connected to external tube feet and internal ampullae. The evidence from the study of *A. distans* supports Anderson's suggestion for a closed ambulacral system, but the nature of the closed system differs. Whereas in *L. fistulosus* the theca is flexible and the ampullae and perradial canal lie internal to the skeleton, in *A. distans* the theca is rigidly fused and both ampullae and perradial canal are enclosed between radial and floor plates in the distal parts of the ambulacra, along the lines of the ophiuroid pattern (Nichols 1966, p. 109, fig. 15*e*), and internal to the skeleton in proximal parts of the ambulacra. In a section across the radial and floor plates in the distal part of one ambulacrum (see text-fig. 4*b*), side branches from the medial (perradial) canal lead through the floor plates to pores on the surface. Presumably the side branches contained enclosed ampullae which were surrounded by muscles capable of protraction, and were connected to tube feet occupying the pores.



TEXT-FIG. 5. Schematic perspective diagram of part of one ambulacrum and the inferred water vascular system in *Astrocystites distans*. Deltoids are represented by horizontal lines, the radial by vertical lines and the floor plates by crossed lines. Cover plates are not shown. Hydropore (*h*) and stone canal (s.c.) are situated in the posterior interradius. The stone canal consists of funnel-shaped and double chambers linked by a narrow canal, and connected to a ring canal with a perradial canal (p.c.) leading into each ambulacrum. Three types of tube feet are suggested: long, slender forms (t.f. 1) which penetrate the thickened plates in the proximal region; shorter, thicker forms (t.f. 2) in the medial region; and shorter, thinner forms (t.f. 3) which protude through the rather thin floor plates lying on the radial in the distal region.

In text-fig. 5 the inferred water vascular system in *A. distans* is represented. Judging from the nature of the pores, the tube feet in the proximal part of the ambulacrum were probably thinner and longer (text-fig. 5, t.f. 1) than those situated medially (t.f. 2), and penetrated floor plates and possibly margins of deltoids as well. Distally, the tube feet appear to become thinner and shorter (t.f. 3). From the morphology of the inner, double chamber of the stone canal it may be tentatively suggested that it contained valves which regulated the flow of water through the system.

Specimen B of Bather's description of *A. ottawaensis* exhibited the most complete set of cover plates, the proximal and medial parts being covered but not the distal. Bather (1914*b*, p. 199) added that there was 'no reason to doubt that they were continuous . . . to the extreme end of the floor plates.' It seems probable that the cover plates opened along the margins of each ambulacrum, allowing the tube feet to protrude as in edrioasteroids. The cover plates in the oral region, however, are more irregular in size and shape, with smaller plates intercalated. There are, in addition, triangular oro-tegminal plates lying with their broader ends on interambulacral areas, and narrower ends reaching almost to the oral pole. It may be assumed from this arrangement that the circlet of oro-tegminal and cover plates in the oral region was fixed, and the smaller pores underlying this region, as seen in *A. distans*, contained slender, elongated tube feet. The tube feet of this region may have been mainly sensory and respiratory in function, whereas those in medial and distal parts of the ambulacrum served also in feeding.

Edrioasteroids range from the Lower Cambrian to the Lower Carboniferous, evolving most rapidly in the Ordovician. From the close similarities in plating of the ambulacra and in the nature of the posterior interradius, there seems to be little doubt that during the Middle Ordovician the small, stalked group of edrioblastoids evolved from the basic edrioasteroid stock. Both *Astrocystites* and *Edrioaster* exhibit a hydropore and a cluster of plates around the anus in the posterior interradius. However, *Astrocystites* may be distinguished from *Edrioaster* by the pyriform shape of the theca, the rudimentary stem and, to a certain extent, by the stabilization of the number of thecal plates—five basals, five radials, and five deltoids.

Astrocystites superficially resembles blastoids like *Pentremites* but exhibits fundamental differences. No hydrospires, brachioles or spiracles can be recognized. Even if an internal soft-bodied chamber analogous to a hydrospire existed, it must have been restricted to the region below the proximal part of each ambulacrum, for the pores in the distal part communicate with a medial (perradial) canal lying between the radial and floor plates. If the pores had solely a respiratory function, some type of soft structures, like brachioles attached to floor plates and capable of extension on opening of cover plates, must have been present to catch and direct food particles towards the mouth. However, there is no direct evidence to support any of these speculations, and it must be concluded that edrioblastoids are morphologically distinct from blastoids.

Fay (1962, p. 205; 1967, pp. 242, 286) suggested that some form related to *Astrocystites* could have been ancestral to the blastoids which, according to him, appear in the Middle Silurian and range into the Permian. For an *Astrocystites*-like form to give rise to spiraculate blastoids the following changes would be required: (1) the development of a stem with definite columnals, (2) resorption of two sutures to produce three basals; (3) fusion of the infradeltoids with the deltoids; (4) reduction by fusion in the number of anal plates in the posterior interradius; (5) atrophy of the tube feet and infolding of the deltoids and radials to form the hydrospire; (6) replacement of a single hydropore at the upper extremity of the posterior interradius by a spiracle at the top of each deltoid (some blastoids develop paired spiracles); (7) migration of radial canal inward or outward, and consequent secretion of calcium carbonate to form the lancet plate; and (8) development of brachioles. This, however, would entail more radical changes than by deriving blastoids, in the more generally accepted fashion, from cystoids through the transitional Middle Ordovician form *Blastoidocrinus* (Nichols 1966, pp. 146–8). Moore (1954) suggested derivation from a rhombiferan *Cystoblastus*-like ancestor by shifting of radials downward, laterals upward and partial fusion of basals. Brachioles were already developed, and hydrospires have been shown to be homologous with pore rhombs. However, the derivation of the lancets by modification of the radials seems too conjectural for the ready acceptance of this view.

Miscellaneous pelmatozoan plates. In addition to the thecal plates and fragments which can be positively recognized as parts of *A. distans*, there are numerous stem ossicles and a few plates from the Cliefden Caves locality which cannot be so confidently determined. Two main types of stem columnal can be distinguished; those with a stellate axial canal and those with a circular axial canal. The largest columnal (USGD 2315) is round, 5 mm. in diameter and has a stellate axial canal; part of the articulating surface shows faint crenellae, but it is otherwise smooth (Pl. 100, fig. 11). Another round columnal (USGD 3301), 3·8 mm. in diameter, also shows a stellate axial canal and a patchy development of crenellae on the articulating surface (Pl. 100, fig. 12). The columnal USGD 3302 is 2·0 mm. in diameter, has a small round axial canal and a smooth flat articulating surface (Pl. 100, fig. 13). Another (USGD 2307) is 2·3 mm. in diameter, has a larger round axial canal, and a concentric groove on the articulating surface (Pl. 100, fig. 14). In specimen USGD 2316 a pattern of round alternating nodal and internodal columnals is shown; the nodals have a diameter of 2·5 mm. and the internodals 2·0 mm.; the columnals are spaced about six in 4 mm. (Pl. 100, fig. 15). A thinner articulated specimen (USGD 2315) has round columnals, 1·2 mm. in diameter, and of uniform size, averaging five in 4 mm. (Pl. 100, fig. 16).

It is not possible at the present time to assign any of these columnals to *A. distans*. None of them seem to be comparable with the elements of the stem in *A. ottawaensis*. Bather (1914*b*) described the stem as circular and composed of pentameres, and Fay (1962) similarly observed that it was made up of curved polygonal plates grouped into three columnal rings each with five or more plates. Certainly the variety of stem columnals from the Cliefden Caves locality strongly suggests the presence of at least one other pelmatozoan in the fauna. This is confirmed by two other finds. The first is a large plate (USGD 2307) 14·5 mm. wide and 8 mm. high, with a radiating pattern of fine crenulations, three on the left side, six medial, and three on the right side; it is up to 3 mm. thick on the upper edge (Pl. 100, fig. 9). It resembles a cystoid thecal plate, and it is possible that a pore rhomb has been eroded from the thickened upper edge. Secondly, in USGD 3300, there is a circular structure with five grooves radiating from the centre (Pl. 100, fig. 10). The grooves subdivide away from the centre, and there seems to be a development of partitions across the grooves towards the periphery, forming facets possibly for the attachment of brachioles. To one side of the circular structure there appears to be a less well-defined, obliquely cut structure. The circular structure resembles the oral region of certain rhombiferan cystoids, for example, *Glaphyrocystis* Jaeckel and *Echinoencrinites* Meyer (Hecker 1964, pl. 3, fig. 9*b*; text-fig. 19), or the eocrinoid

Cryptocrinus (Bather 1900, p. 70, text-fig. 37). It is possible that the isolated large plate and the circular structure belong to the same species. The only rhombiferan cystoid previously described from the Ordovician of Australia is *Cheirocrinus merrileesi* Brown 1964, which has very different ornamentation on thecal plates.

Eocrinoids have not yet been reported from Australia.

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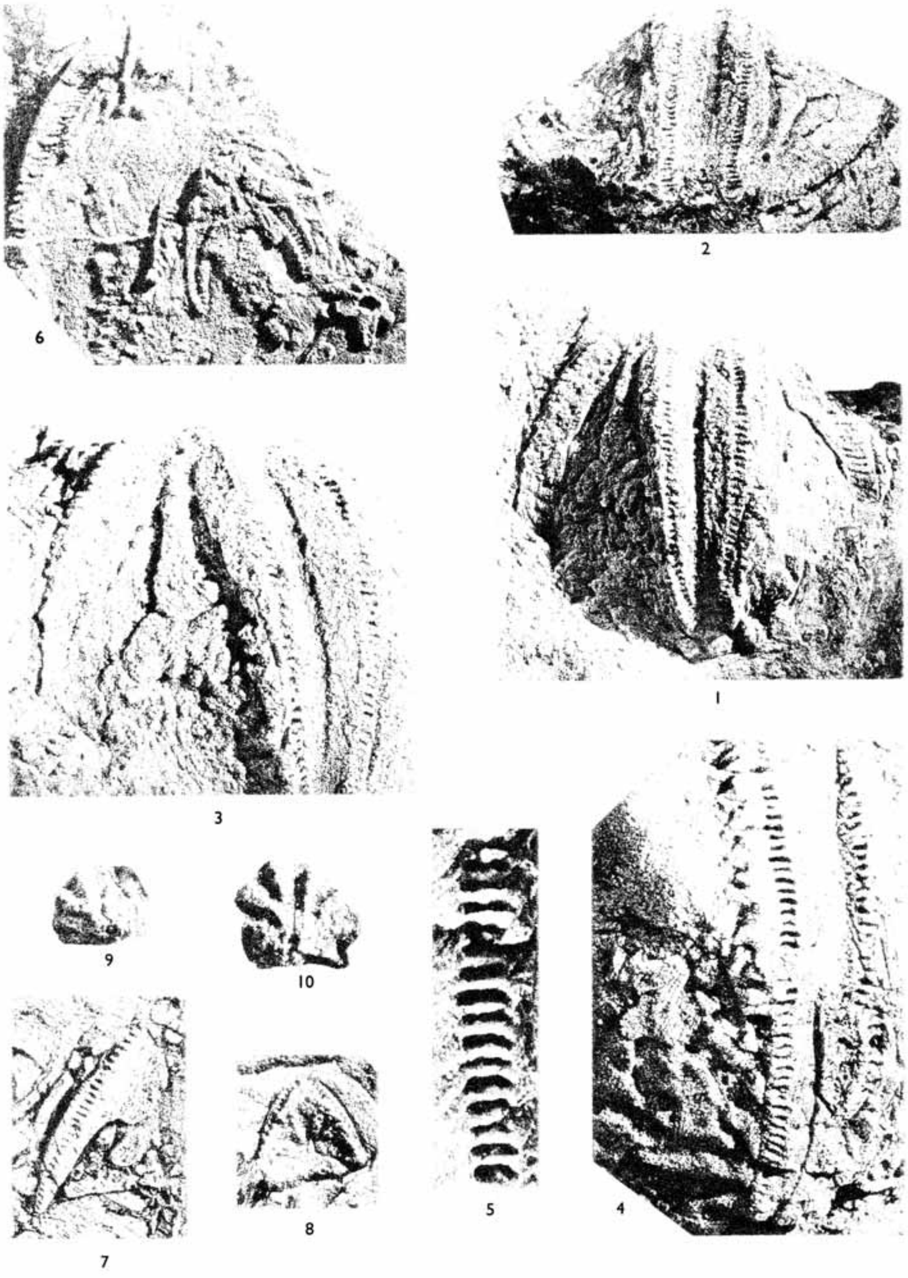
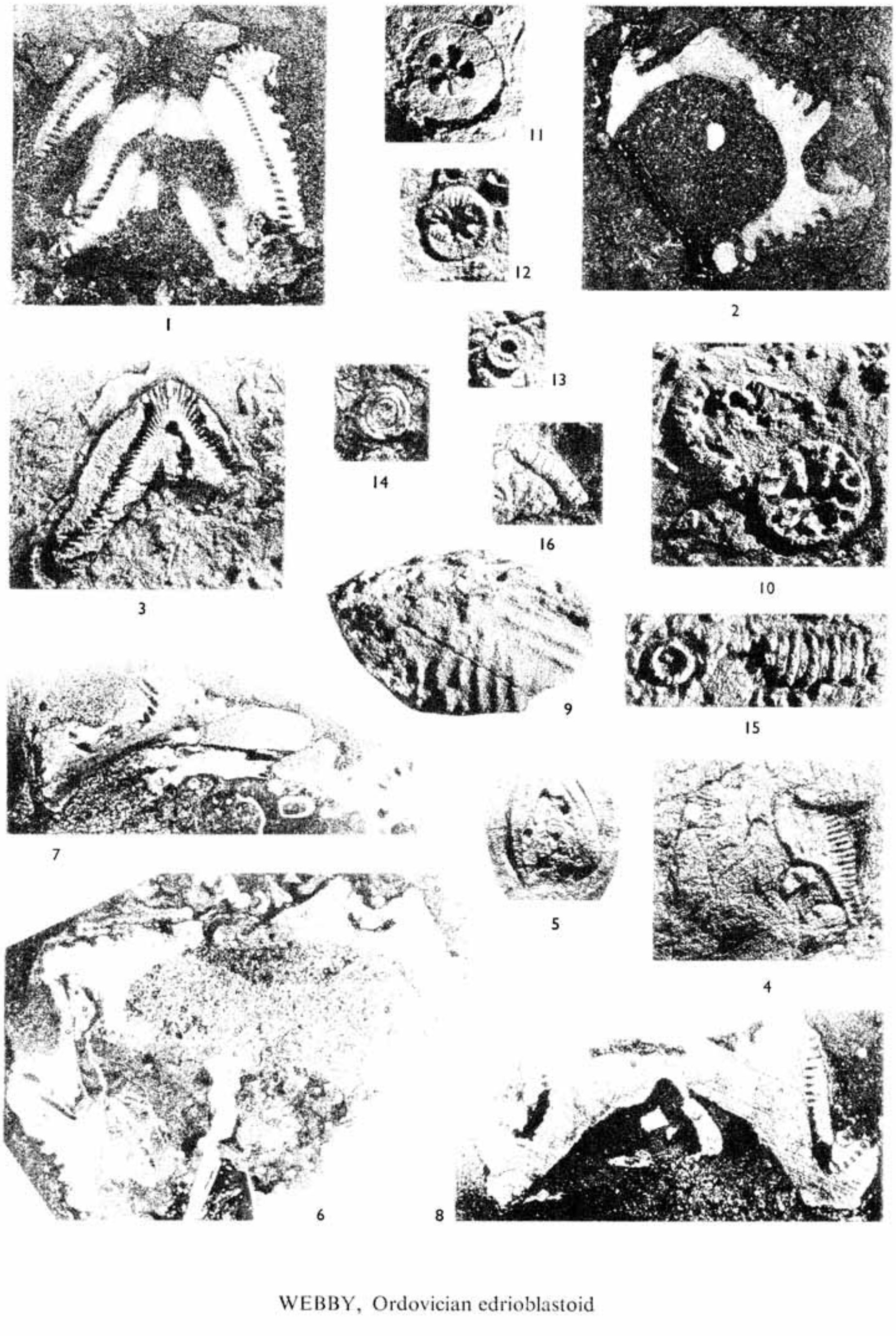


WEBBY, Ordovician edrioblastoid



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