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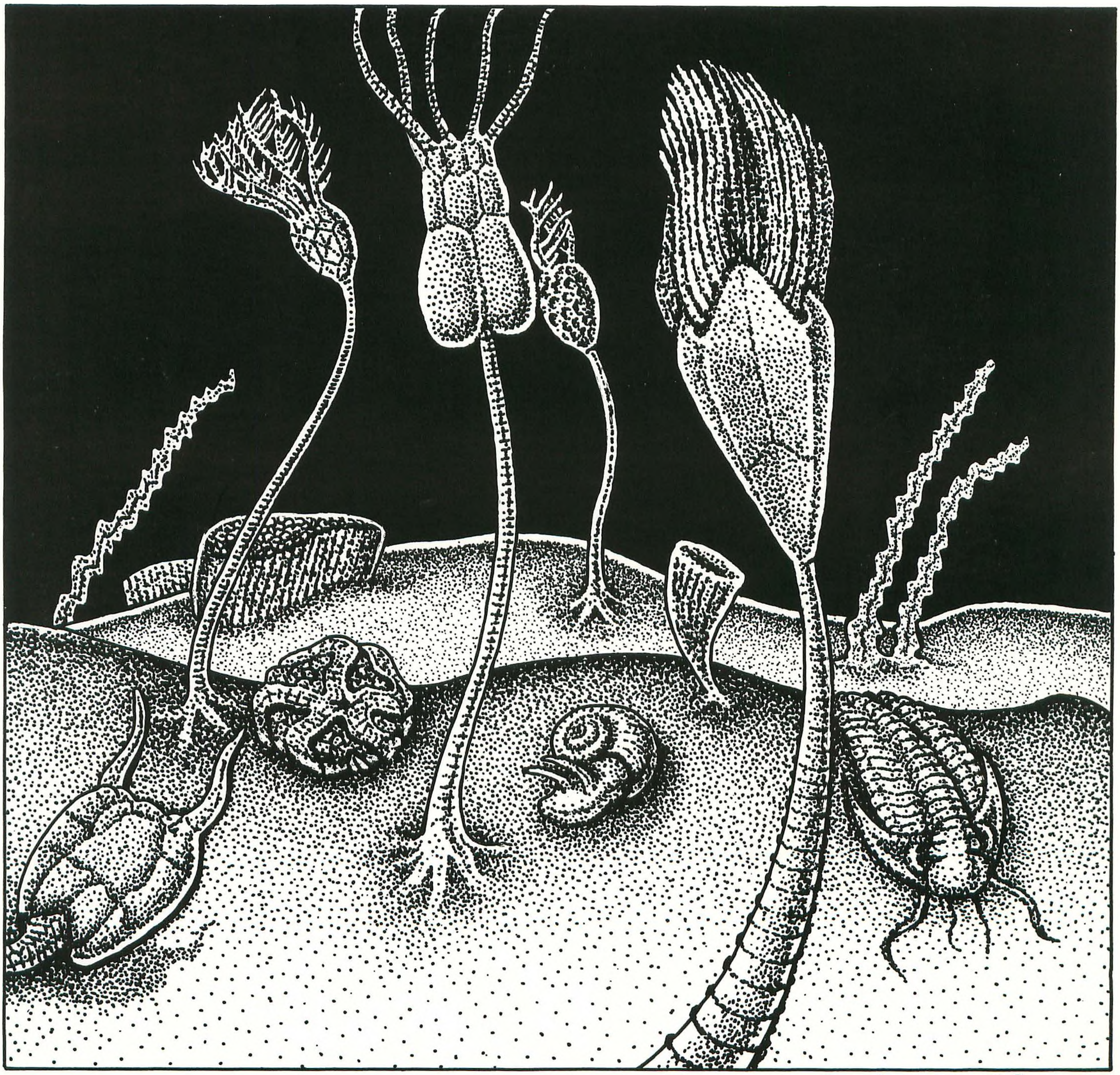

CAN YOU NAME THESE EXTINCT ECHINODERMS?? Answers in Cover Story

R. WHEELER 93

A LOVE OF FOSSILS BRINGS US TOGETHER

ACKNOWLEDGEMENT

The Theme, Titled, EXTINCT ECHINODERMS in its self is an interesting phenomenon, we are in awe at the events which must have happened during the process of extinction of the species we read about and collect. Luckily for us, the "collectors". These species became extinct due to natural environmental evolutionary extinction, and not through man's environmental calamitous behavior.

It never ceases to amaze me how these authors can write such interesting articles on so many different subjects; each of them are comparable to a bank of knowledge, a bank on which we can all draw from and not have to worry about being overdrawn. They are responsible for our interest. If we can absorb all this knowledge it will add to our mental savings account.

I wish to acknowledge these **Authors** and **Artists** for their generousity, for giving of their time and talents to enlighten us on these extinct echinoderms and for sharing their knowledge of fossils with us.

Some of these authors and artists have joined us in preparing the EXPO DIGEST for the first time. I say, "welcome, and we need and want to hear more from you". We all know how much time, travel and expense you put into your hobby, and we know why you do it. Which brings to mind our watch words "A LOVE OF FOSSILS BRINGS US TOGETHER", no matter how far apart we are geographically.

I want to give special recognition to the officers and directors of MAPS; also to the Marvelous speakers we have each year at EXPO. This year "HATS OFF"! to **Dr. Thomas Broadhead.**

TRIBUTE

A special acknowledgement of thanks to Anthony J.(Tony) Verdi, who so unselfishly gives of his time in helping others; had designed and made our EXPO postal cancellation stamp for these six years. And worked tirelessly to get a fossil commemorative stamp. "TONY, THANKS".

The Mid - America Paleontology Society was formed to promote popular interest in the subject of paleontology, to encourage the proper collecting, study, preparation and display of fossil material; and to assist other individuals, groups and institutions interested in the various aspects of paleontology. It is a non-profit society incorporated under the laws of the State of Iowa.

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COVER STORY

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The Extinct Echinoderms on the cover are not of the same period or locality. Starting from left:

CARPOID Placocystites sp.- The range of carpoid is from Mid. Cambrian to L. Devonian, the plates of the theca are imperforate, and except for a stem, which is peculiarly specialzed in the form of a tail-like appendage.

CYSTOID Caryocrinites ornatus - M. Ordovician to M. Silurian, Niagaran, New York, Ind.- Calyx ovid or subglobose, greatest diameter usually below middle summit, slightly convex with arms as much as 50 mm long.

EDRIOASTEROIDS EDRIOASTER sp. - ORD. DEV. MISS. Trenton: Quebec Canada. The ambulacra of this genus reaches the margin of the theca and are very strongly curved.

EOCRINOID Lichenoides sp.- M. Cambrian, Czechoslovakia, an eocrinoid having five well developed unbranched biserial brachioles and large bulbous plates, near the base of the theca.

PARACRINOID Comarocystites sp. - M. Ord. Trenton: Quebec, Canada. This genus has a fairly regular arrangement of plates near the summit of the calyx, but irregular near the stem.

BLASTOID Decaschasma pentalobus - Niagaran: Silurian, Indiana. Calyx long and tapering, smooth devoid of ornatementation, Ambulacra short, pentaloid.

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* Denotes MAPS Member

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BLASTOIDS

Ernest B. Hammons
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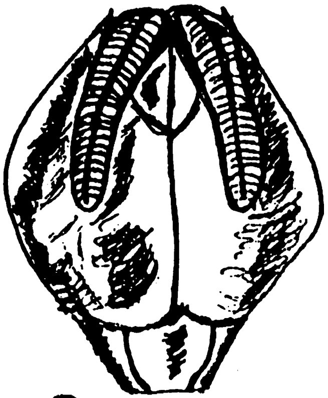
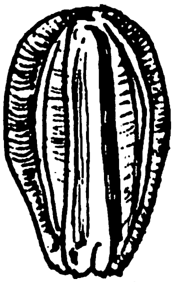
Petersburg, TN 37144


Pentremites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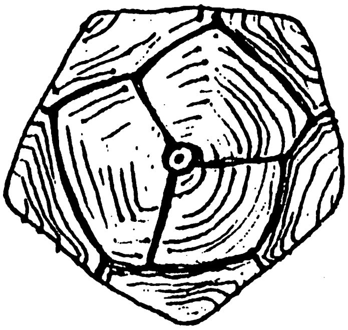
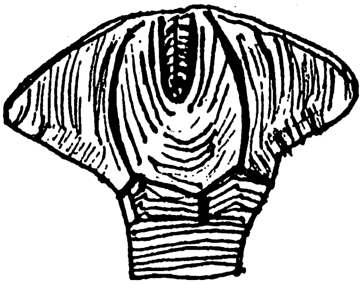
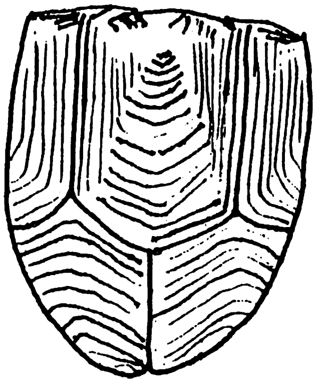



Orophocrinus


Tricoelocrinus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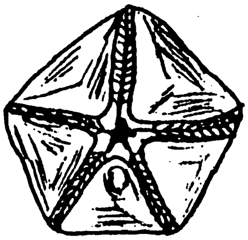
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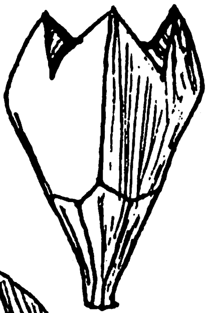
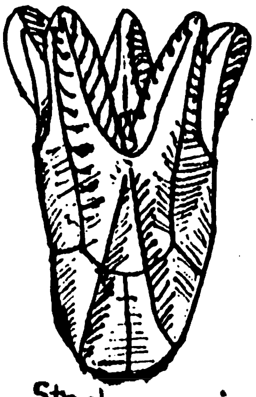
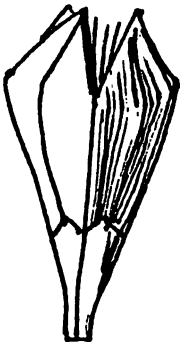



Stephanocrinus


Troostocrinus


Blastoidocrinus

J. Taylor

BLASTOID

This extinct class of echinoderms is limited to the Paleozoic Era, beginning in the Ordovician period, one genus was found in the Chazyan of Canada; Blastoidocrinus billings, this single specimen has many small plates below the large deltiods which bear hydrospire slits. This one Blastoidocrinus was the only one found until Broadhead, in 1980 found an Ordovician specimen in Tennessee. (D. B. Macurda, Jr.)

Blastoids became extinct during the Permian period, or at the end of the Paleozoic era. They reached their peak about the middle of the Mississippian period.

There was much controversy among the early writers, as to a suitable name for this amazing little fossil, (Parkensen, Say, Roemer, Shumard, Lyon, Hambach, Rowley and others all seam to disagree on every aspect of this fossil. These early writer's works are very difficult to find since very few libraries still have these writings available. Even the work of Ulrich (1917) is out of print, so it is necessary to depend greatly upon U.S. Geological Survey Bulletins for informations. However the name "BLASTOID" (THE GREEK WORD BLASTOS) meaning bud or flower bud was finally settled upon. And it was placed in a class distinct from Cystoids and other echinoderms because of (#1) their pronounced symmetry (#2) the uniformity of the arrangement of their 13 to 14 main theca plates; (#3) the development of specialized ambulacral areas which bear many small free brachioles. A distinctive structure of the blastoids, known as the hydrospire hangs into the body cavity beneath the ambulacrum, the detailed nature of the hydrospires, however, and their placement along the ambulacra differ from the organization of any cystoid. Also the blastoid has openings in the plates corresponding to the diplopores.

The Silurian system gives us the STEPHANOCRINUS angulatus by Conrad, found in New York, but are very sparce. The holo type and the para type are now in the U. S. Museum of Natural History. We also find; TROOSTOCRINUS reinwardti, and TROOSTOCRINUS tennesseensis both of which are found in the Brownsport Group of the Silurian of the Western Tennessee River Valley, and are on display at the Department of Geology, Vanderbilt University, Nashville, Tennessee.

The Devonian system yields, NUCLEOCRINUS verneuili (Troost); NUCLEOCRINUS obovatus; NUCLEOCRINUS bondi; NUCLEOCRINUS meloniformis; CODASTER gracilis; CODASTER trilobIastus. The greater part of the Devonian blastoids are found in Iowa and Michigan, however some have been found in Kentucky, New York and Canada.

The Mississippian period yield by far more genera of blastoids than any other period of geological history. I will in no way attempt to name all the genera which have been found in the Mississippian strata, to say nothing of the great number of species named from this period, PLACOBLASTUS sp. from the Chattanooga shale; TRICOELOCRINUS woodmani; ORPHOCRINUS estelliformis; METABLASTUS lineatus; HIPYRAMIDALIS sp.; CRYPTOBLASTUS elongatus; HETROSCHISMA sp. GRANTOCRINUS granulatus (Roemer) Ft. Payne chert Franklin Co. Tennessee, (only 9 specimen have been found).

The Mississippian period also gives us the genus Pentremites with its many species which I will deal with at length later in this article, due to their great abundance and wide spread distribution.

The Pennsylvanian period yields the SHANSIELLA carbonaria from Illinois.

The Permian period gives us the TIMEROBLASTUS from the island of Timor, (East Indies). The discovery of blastoids on the island of Timor, Indonesia in the early 20th century led to a series of publications by Johannes Wanner which greatly expanded our understanding of the morphology and distribution of blastoids, (Treatise on Invertebrate Paleontology) Beaver et al, 1968. In the early 1960's R. O. Fay published many articles on blastoid taxonomy ushering in what James Sprinkle has called "THE GOLDEN AGE OF BLASTOIDS" (D. B. Macurda).

There are approximately 78 presently designated genera and 350 designated species of blastoids grouped in 12 families, 5 of which are in the order Fisiculates and 7 in the order Spiraculata.

Now for a short discussion of the most prominent and widely distributed of all blastoids, Pentremites. The stem, stalk or column as you may prefer to call it, was first described by Say, 1820, and very little has been added to our knowledge of this structure, and very few if any are found attached to the calyx, except a few known as juveniles for the simple reason the stems are cut off by the growth of the basal plates during the gerontic and or the ephebic juvenile stages of growth; so if you should find one with an attached stem, rest assured it is a juvenile. Galloway and Kaska state that the nepionic stage of specimens are seldom found, and the neanic and gerontic stage specimens are rare, but normal ephebic are the most common of ontogenetic stages in collections. The size of the specimen has some bearing on its scientific identity, but care should be taken when considering the ontogentic stage.

It is very difficult if not impossible to make a distinction between the fragments of blastoid, crinoid and cystoid stems. It is so rare to see a blastoid with the stem attached to the calyx, that every picture in every publication is a drawing, the product of someones imagination. However, Etheridge and Carpenter are suppose to have found a specimen in the collection of Wachamuth with a stem 5 inches long, Galloway and Kaska reported seeing one specimen of pentremites with a stem 3 inches long.

Galloway and Kaska have placed all pentremites into 4 groups.

1. Pentremites conoideus group
2. Pentremites godoni group
3. Pentremites pyriformis group
4. Pentremites sulcatus group

They have also given us a key to help us identify each of the four groups, along with each of the species that come under the heading of each group. The most reliable character for identifying the species are; length width ratio; vault pelvis ratio; pelvic angle; concavity or convexity of the ambulacra; and the degree of concavity of the interambulacra, and to these five characters you may add for the sulcatus group, only, the protrusion of the deltoids above the mouth of the spiracles.

Abnormalities: Abnormal elements of blastoids are not uncommon, in the various species of pentremites. I have found 4 specimens with only four ambulacra, and two specimens with six ambulacra, all of which were found in the sulcatus group of the Pennington formation in White County Tennessee, where I have been digging and carrying others to dig for about twenty years. These mutations are in the EON Museum at Petersburg, Tennessee. Defects in blastoids are not listed by Galloway and Kaska in "GENUS PENTREMITES". Defects are not limited to pentremites, Wanner in 1932 distinguished 183 abnormal species of deltablastus from the Permain period of Timor. In a large collection of more than 24000 specimens for a very small ratio. Deformed specimens of numerous other genera have been reported in some writings, but generally the number of abnormalities are very small. The deformities described by Wanner of the deltablastus, globastus and pentremites apparently are genetic defects, whereas some others seem to be damage to thecal elements during life. Etheridge and Carpenter believe that many deformities may be due to inequalites of growth.

Pentremites is the one genus most suitable for study, as a representative of the class, as it is more abundant in described species than any other genus, as well as being more widespread. They are very abundant in the outcrops of the Upper Mississippian rocks of Alabama, Tennessee, Kentucky, Illinois and Indiana, where beautifully perserved specimens may be collected.

The thecal shapes of the blastoids are typically globose or ovoid to pyramidal, but other shapes are not uncommon. At the base of the theca are three outwardly flaring plates, one of which bears the attachment of the stem. One of these basal plates (azygous) is only about one-half the size of the other two basal plates, and invariably this small plate in the anyero-rightinter ray. Next above the basals, are five evenly sized forked plates, called radials.

These are the largest plates in the theca, and are hexagonal in shape, with a distal indentation for the ambulacrum. The deltoid plates form the upper surface of the theca. These plates are quadrangular in shape, and are joined by a pair of radials. At the upper extremity of each deltoid is an opening spiracle which provides an outlet for the water circulatory system. The anal opening is joined with one of the spiracles just above the deltoid. This combined anus and spiracle is readily identifiable because it is the largest opening in any interray.

The five ambulacra are evenly spaced around the mouth, which is centrally located on the summit of the theca. Each ambulacral area is occupied by an elongate single plate, which bears many traverse grooves on its surface. Because of its spear shaped outline it is called the lancet plate. Its middle has a longitudinal groove which leads upward toward the mouth, these grooves formed passageways for the food gathering system. There were many tiny appendages called "brachioles" that rose from the margin of the ambulacra, these were very important in the food gathering process.

Between the base of the brachioles and the outer edge of the ambulacral area are openings which lead to the gill-like structure called hydrospires which are attached to a deltoid and a radial plate, one for each ambulacra, and hang in the central cavity. Through these pores or ducts, sea water can bathe the interior of the hydrospires, and thus aerate the entire body fluids of the blastoid. The water moves through the hyderospires to the spiracle at its upper extremity and escapes.

Despite numerous investigations and publications it is very clear that many problems await us in the study of blastoids. However it is my understanding that currently, Alan Horowitz, Johny Waters and D. B. Macurda are working out the evolutionary history of PENTREMITES.

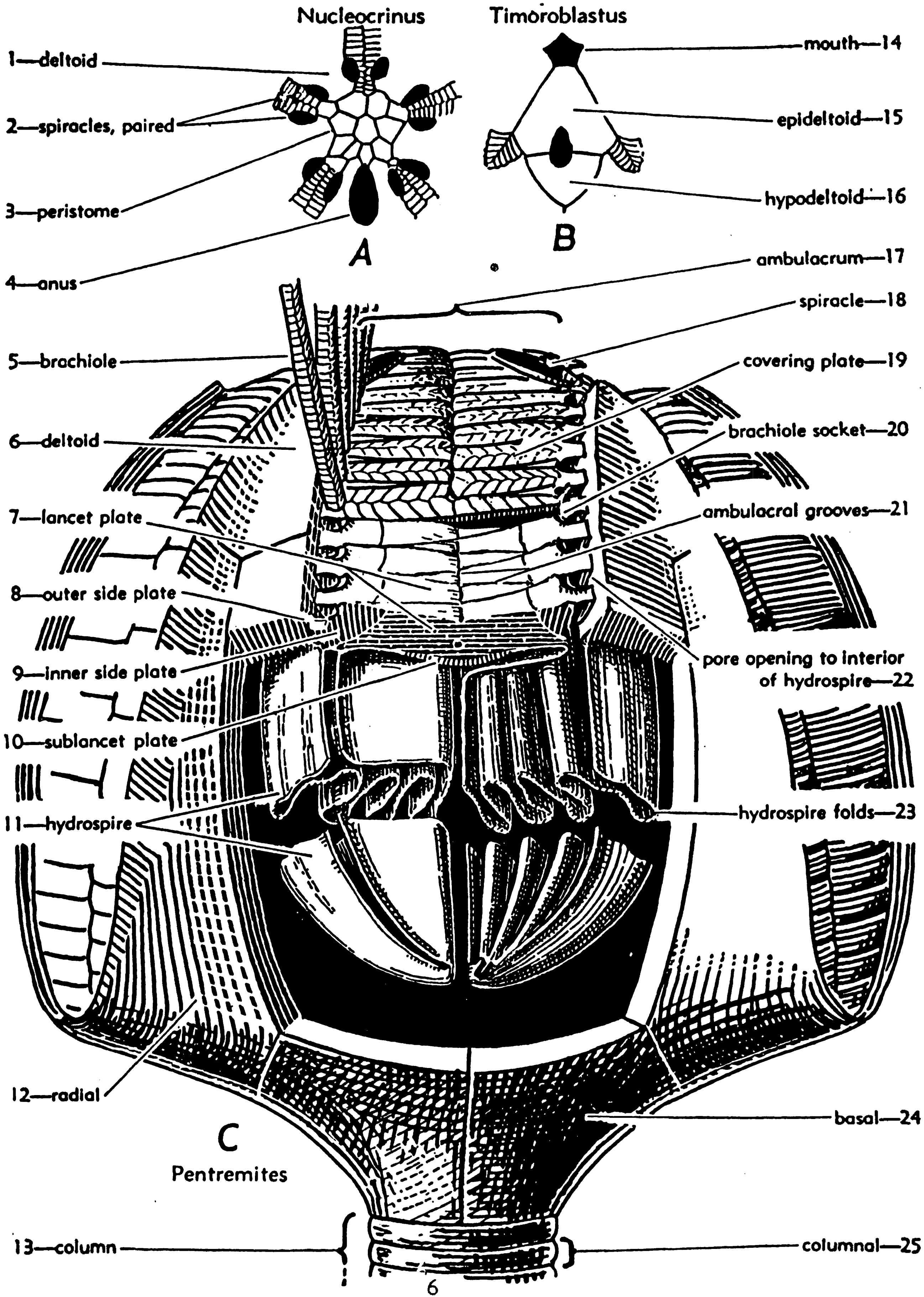


Fig. 17-9. Terminology applied to blastoids. The most commonly used terms employed in the study of blastoids are defined in the alphabetically arranged list which is cross-indexed to the figure by numbers.

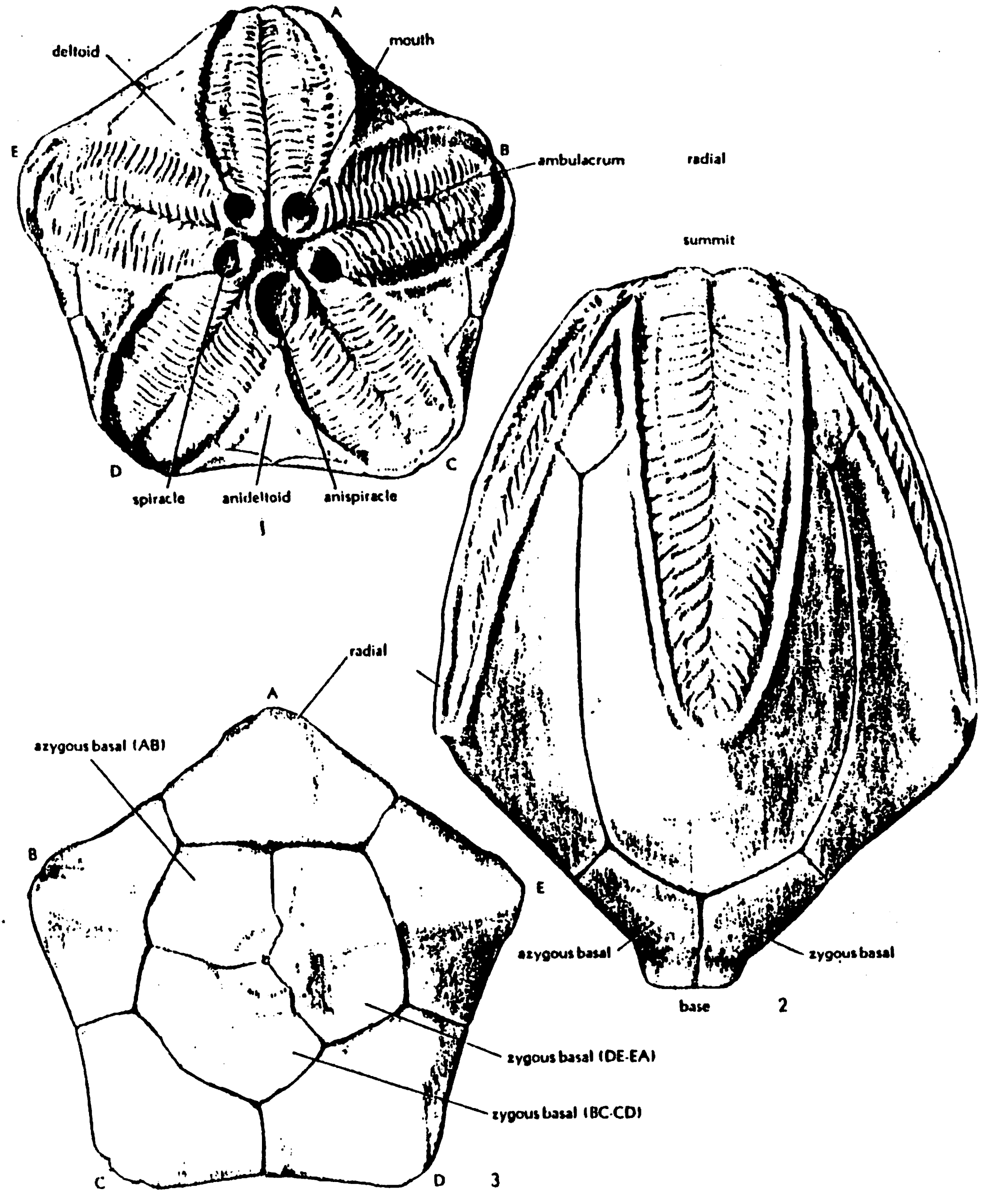
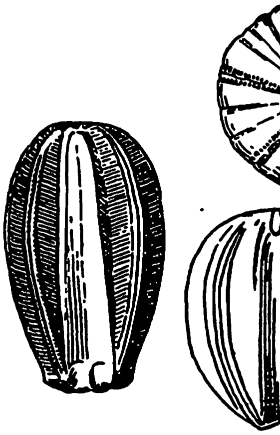
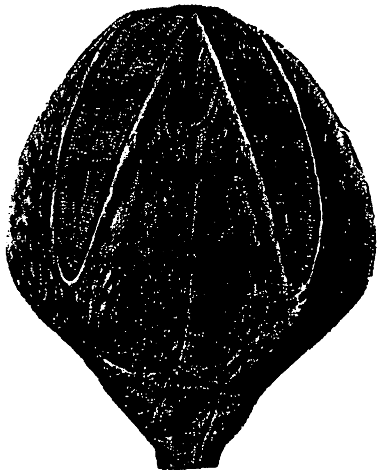


FIG. 178. Calyx of typical blastoid, *Pentremites symmetricus* HALL, U.Miss.(Chesteran), USA(Ill.), showing externally visible parts of theca, X4.5 (drawings by Roger B. Williams; Beaver, n).——*1.* Summit (oral) view, mouth opening at center surrounded by 4 spiracles (relatively small rounded orifices in interambulacral position) and large anispiracle in posterior interambulacrum (below mouth), also showing petaloid ambulacra (*A* at top, followed in clockwise direction by *B*, *C*, *D*, and *E* ambulacra) deltoid plates next to summit between ambulacra.——*2.* Lateral view of calyx from the anterior (*A*-ray) side, especially showing deeply sulcate form of radial plates embracing aboral parts of ambulacra.——*3.* Basal (aboral) view showing the stem impression borne by the basal circlet consisting of 2 large (zygous) plates and 1 small (azygous) plate.

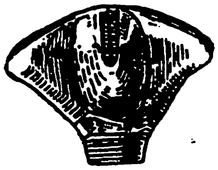


Nucleocrinus

Codaster

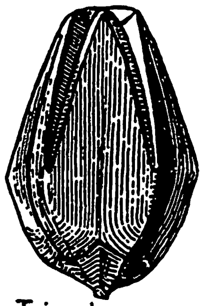


Pentremites 2/3X

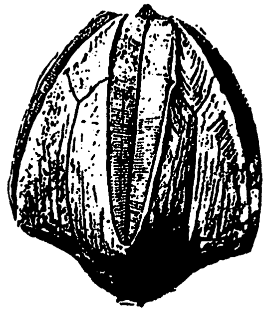


Orophocrinus

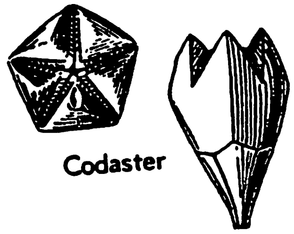
Blastoidocrinus



Tricoelocrinus



Pentremites robustus



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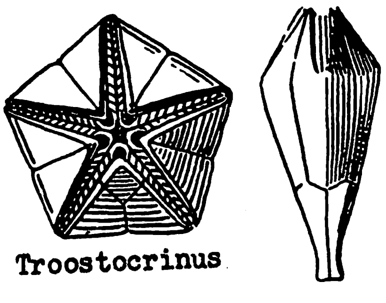
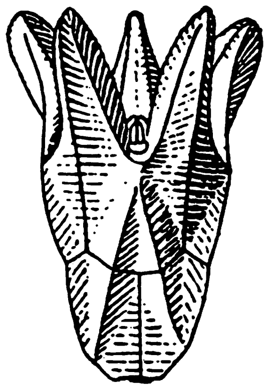
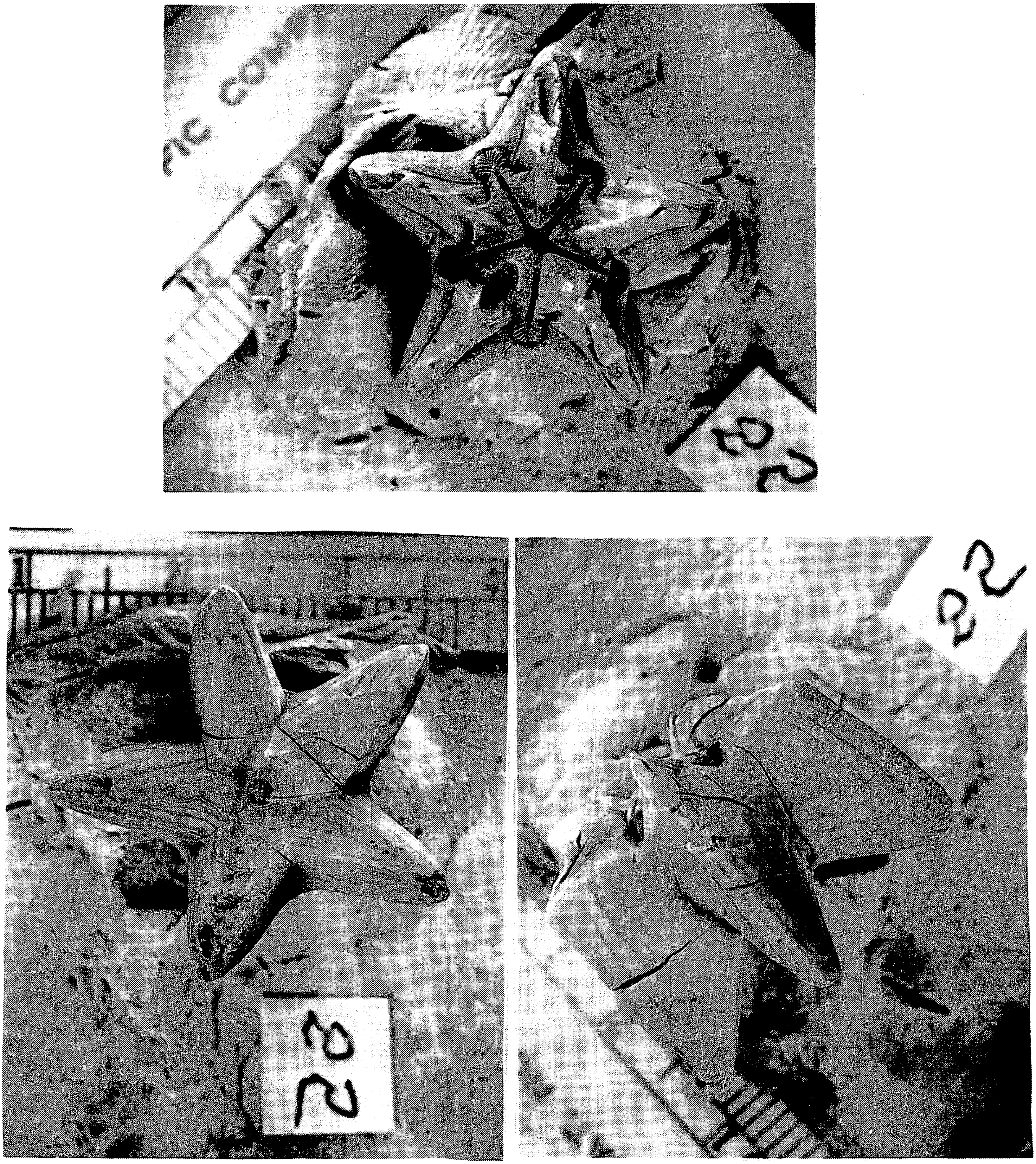


Troostocrinus



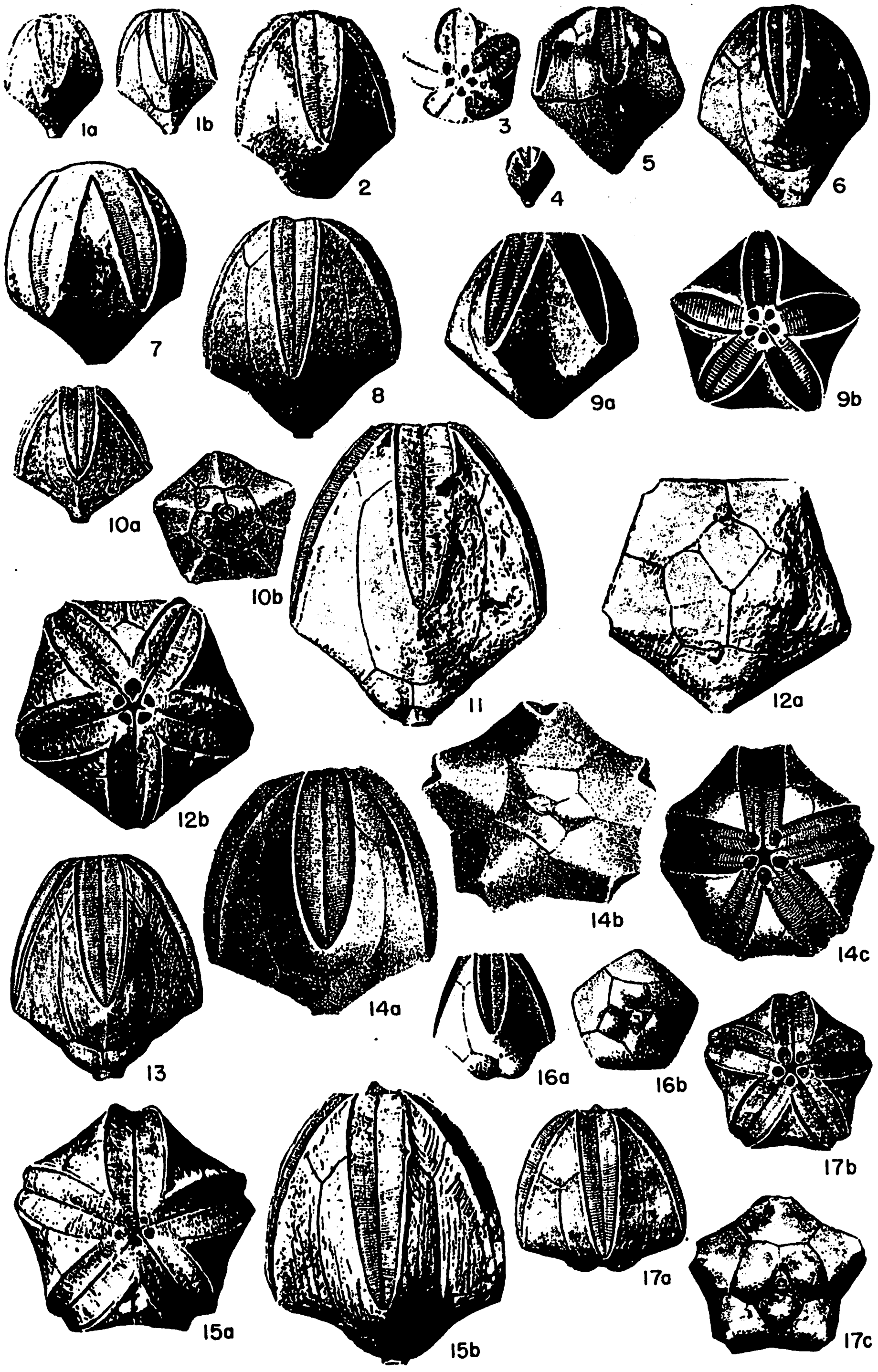
Stephanocrinus



TIMEROBLASTUS

GEOL. SOC. AM., MEMOIR

GALLOWAY and KASKA, PL. 6



PENTREMITES SULCATUS GROUP

S354 *Echinodermata—Crinozoans—Blastoids*

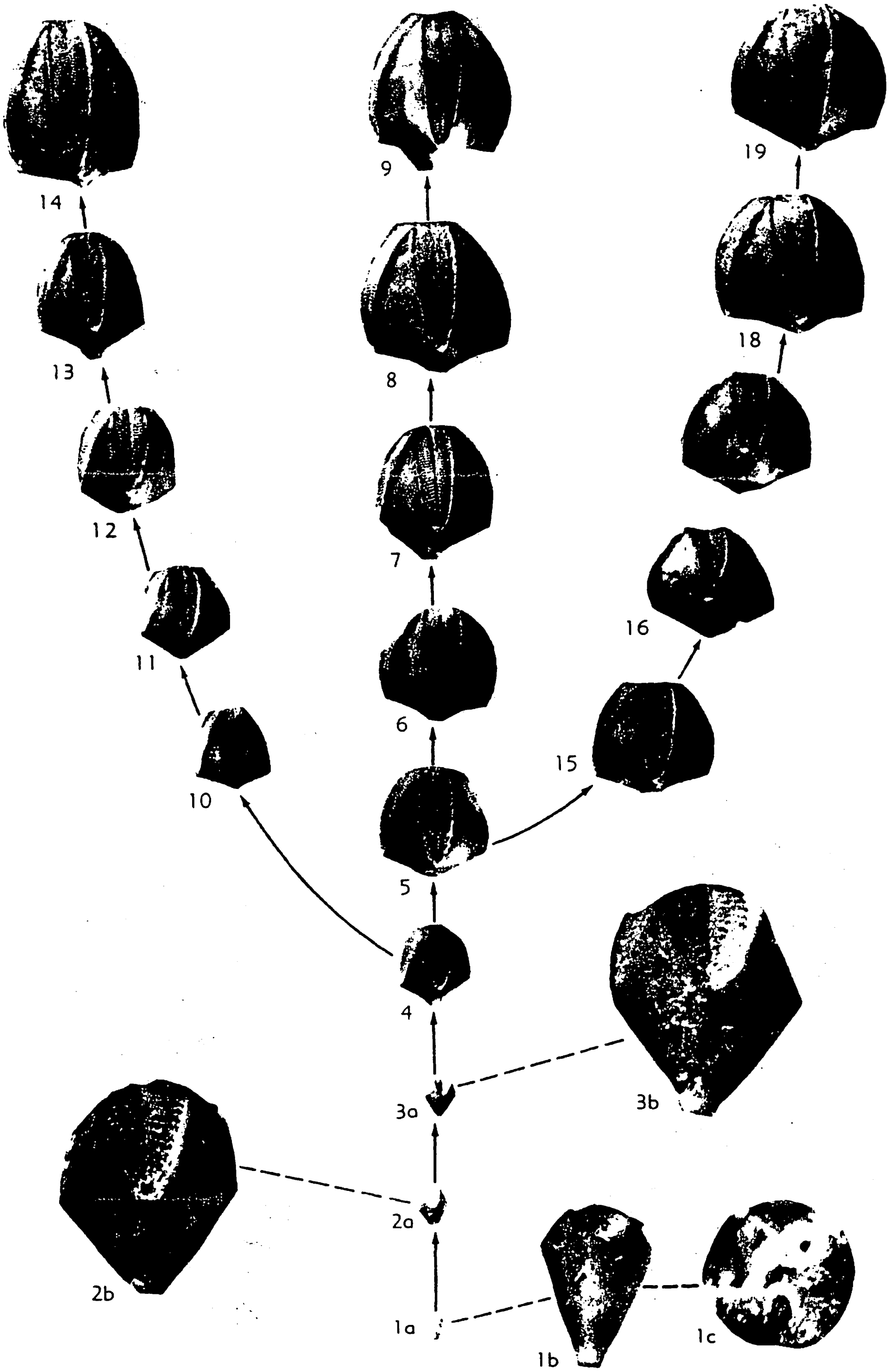


FIG. 208. Growth series of relatively flat-based *Pentremites* calyces (Type 1) represented by *P. godoni* (DEFRANCE), Paint Creek F. (Chester.), near Floraville, Illinois; Subtype 1a, equidimensional, *1-9*; Subtype 1b, slender, *10-14*; Subtype 1c, broad, *15-19*; all figures ×1 except as indicated (Beaver, n).

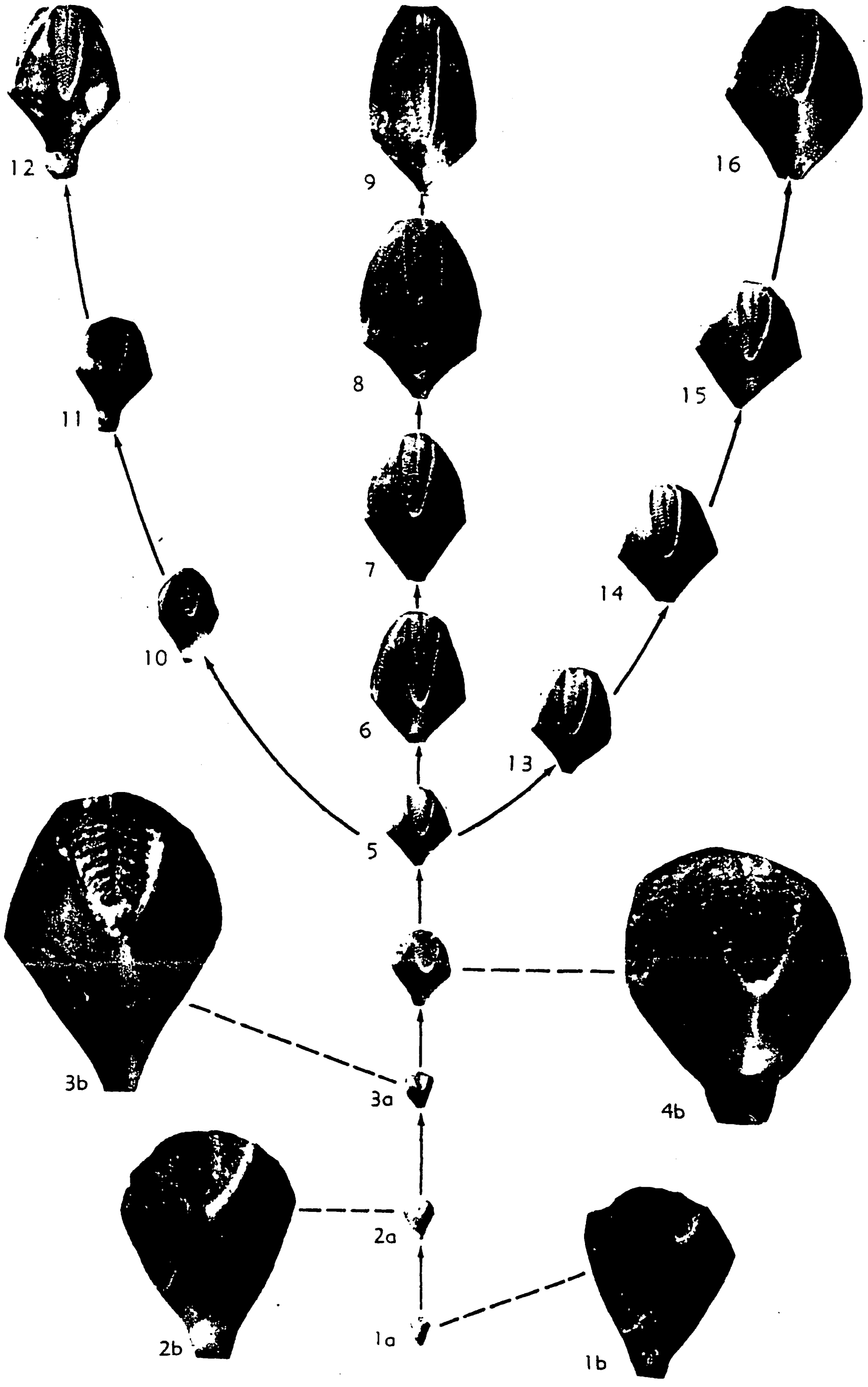


Fig. 209. Growth series of pyriform *Pentremites* calyces (Type 2), all from Paint Creek F. (Chester), near Floraville, Illinois; Subtype 2a, *P. symmetricus* Hall, *6-9*; Subtype 2b, *P. gemmiformis* Hambach, *10-12*; Subtype 2c, *P. pyramidatus* Ulrich, *?13,14-16*; all figures ×1 except as indicated (Beaver, n).

Explanation of plate 6

PENTREMITES, SULCATUS GROUP

1,2,3. PENTREMITES elegans (Lyon) after type figure (Ulrich,1917).

4. PENTREMITES elegans (Lyon), neanic stage.

5. PENTREMITES nodosus (Hambach 1880).

6. PENTREMITES nodosus (Hambach) after (Weller 1920).

7. PENTREMITES hambachi (Butts 1926).

8. PENTREMITES hambachi (Butts).

9. PENTREMITES cerinus (Hall 1858) Chester Limestone Huntsville, Alabama.

10. PENTREMITES cerinus (Hall) Golconda limestone Grantsburg, Indiana.

11,12,13. PENTREMITES fohsi (Ulrich 1905) Princeton, Kentucky.

14,15. PENTREMITES robustus (Lyon 1860) Grayson County Kentucky.

16. PENTREMITES tulipformis (Hambach 1903).

17. PENTREMITES tulipformis (Hambach) Kinkaid Limestone Marion, Kentucky

ACKNOWLEDGEMENTS

I am deeply indebted to a great number of friends who have been of so much help to me via way of encouragement, helping to find written material, that is so hard to find on the subject of blastoids. I am forced to mention Tom, "the old man" Witherspoon, of Dearborn Michigan who has spent many hours, and made many telephone calls to me, and upon my behalf promoting this article. And don't forget "MAGGIE" Kahrs who is a dedicated, untiring worker on behalf of any project sponsored by MAPS.

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DEVONIAN STRATA of ALPENA and PRESQUE ISLE COUNTIES of MICHIGAN, George M. Ehlers and Robert V. Kesling, Museum of Paleontology, University of Michigan.

PART S ECHINODERMATA VOLUME I "BLASTOIDS", Howard H. Beaver, Robert O. Fay, Donald M. Macurda, Jr., Raymond C. Moore and Johannes Wanner.

I must say I have greatly enjoyed the treatise especially the articles by Beaver and Macurda.

Thank you,

Ernest B. Hammons

MAPS DIGEST

Reprinted from: Echinoderms, Notes for a Short Course
University of Tennessee Studies in Geology 3, 1980
(out of print)

Blastozoa

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INTRODUCTION

Blastozoan echinoderms include several classes of stalked echinoderms with a combined stratigraphic range from Lower Cambrian to Upper Permian. Ranges of constituent classes tend to be much shorter, except for the Blastoidea, which are known from the Middle Ordovician (Broadhead, 1980) to the Upper Permian (Breimer & Macurda, 1972).

Subphylum Blastozoa

Class Eocrinoidea (L. Cambrian - M. Silurian)

Class Rhombifera (L. Ordovician (Tremadoc) - U. Devonian)

Class Diploporita (L. Ordovician - L. Devonian)

Class Parablastoidea (L. Ordovician - M. Ordovician)

Class Blastoidea (M. Ordovician - U. Permian)

Class Paracrinoidea (M. Ordovician - L. Silurian)

HISTORY OF CLASSIFICATION

Most classes of the subphylum Blastozoa have been recognized since the early 1900's. Recent changes have included addition of the Paracrinoidea (Regnéll, 1945) and the rejection of "Cystoidea" as a class name for two distinct and divergent groups, the Rhombifera and Diploporita (Paul, 1968b). The subphylum classification of echinoderms has been elaborated only recently from the traditional bipartite classification "Pelmatozoa" and "Eleutherozoa".

Sprinkle (1973a) recognized fundamental differences between several classes of extinct Paleozoic stalked echinoderms and the Crinoidea. These differences, primarily related to feeding structures and calyx growth were used to define a new subphylum, Blastozoa to distinguish the the extinct classes with their unusual morphologies from the subphylum Crinozoa, proposed by Matsumoto (1929) and now containing only the Class Crinoidea.

This classification was criticized by Breimer and Ubaghs (1974) both for its departure from long used taxonomic names such as "Pelmatozoa" and "Cystoidea," and for its division of the stalked echinoderms, which Breimer and Ubaghs considered to be a phyletically unified group. Pelmatozoa was thus regarded as a subphylum containing two superclasses: Cystoidea (= Blastozoa of Sprinkle, 1973a) and Brachiatoidea (containing only the Crinoidea). The Paracrinoidea was unassigned to a subphylum, nor had it been in Sprinkle's classification. Parsley and Mintz (1975) erected a new subphylum Paracrinozoa (parallel to that in Sprinkle's classification, not Breimer's & Ubaghs's) for the Paracrinoidea.

In a later paper, Sprinkle (1976a) refuted the proposals of Breimer and Ubaghs (1974) on the grounds that many of their fundamental unifying characteristics for the Pelmatozoa were due to convergent evolution (stalk) or similar adaptive life styles related to the presence of a stalk-like support. Sprinkle also withheld opinion on the validity of Parsley's and Mintz's proposed Paracrinozoa pending further evaluation. Recent study of an unusual group of Ordovician echinoderms, the family Palaeocystitidae (class uncertain) that are intermediate between the eocrinoids and paracrinoids strongly suggests that the latter also are blastozoans (Broadhead & Breland, 1980 and in preparation).

CHARACTERISTICS OF BLASTOZOANS

Definition: Blastozoans are stalked echinoderms with the viscera enclosed in a multiplated theca containing an oral opening at one end and an anus laterally on the thecal surface. Feeding structures are exothecal and include ambulacra overlying or embayed in the theca supporting brachioles that commonly lack internal canals, and are almost uniformly biserial. Respiration is usually transthecal, and many forms have special modifications of plates that permit gas exchange through thinly calcified areas. Plate growth is almost exclusively holoperipheral, only at sutural margins.

Thecal Form and Symmetry

Most blastozoans exhibit varying degrees of bilateral symmetry characteristic of echinoderms. The symmetry is rarely reflected in thecal plate distribution (as it commonly is in crinoids), but tends to be expressed in ambulacral configurations (such as the common 2-1-2 pseudopentamerous pattern) or in relationships among the principal thecal openings (usually the mouth plus hydropore, gonopore, or anus). The oral - aboral axis of the theca usually extends downward from the mouth on the upper side of the theca to the stalk attachment at the base. The only significant departure from this form occurs in many paracrinoids and related, paracrinoid-like forms. In those groups, ontogenetic enlargement of the anal "side" of the theca produces an adult form that apparently rested upon the sea floor with a trailing nonfunctional adult stalk. Other groups of blastozoans (some blastoids and diploporitans) that have members that completely lack stalks as adults, maintain the usual oral - aboral axis, although body orientation may not have allowed an upward orientation of the oral surface.

Attachment and Support

All blastozoans probably possessed a stalk that supported the theca above the seafloor during at least part of their lives. The distal end of this structure commonly bore a modification for substrate attachment such as a cementation disc or branching root system. Evolution of blastozoan supports (see Sprinkle, 1973a, p. 36-40) exhibits a trend toward condensation from a multiplated holdfast to a column formed of a single series of discoid columnals and apparently is paralleled by later trends in crinoid stalks (Fig. 1). Multiplated holdfasts tend to be poorly demarcated from the overlying calyx and are limited to the Eocrinoidea. Early Cambrian forms have a flexible holdfast of numerous imbricate plates, whereas Middle Cambrian forms (e.g. Gogia) apparently had a flexible, but narrower support with total peripheral articulation of each small ossicle.

Stalks composed of stacked columnals first occur in the late Middle Cambrian eocrinoid Eustypocystis minor (Sprinkle, 1973a) and persisted in all later groups of blastozoans. Many of these stalks and columnals are virtually indistiguishable from comparable structures in crinoids in the absence of articulated thecal plates. However, cirri commonly associated with some crinoids, apparently never developed in any group of blastozoans. Individual columnals are almost always circular in cross section and commonly have a small lumen (contrasting to the large lumen of ancestral holdfast). Articulation between columnals was most commonly either a synostosis (flat surfaces) or symplexy (crenulated interlocking surfaces) held by ligaments. Stalks are formed of either unimorphic, bimorphic (alternating two types), or rarely more complex arrangements of different size columnals. [Note: the terms homeomorphic and heteromorphic used by Moore and Jeffords (1968) are rejected because of other biologic connotations in favor of unimorphic, bimorphic, etc.]

The primary exception to a uniform stalk seen in most blastozoans is the enlargement of the column close to the theca in many rhombiferans of the superfamily Glyptocystitida (Kesling, 1968a), p. S110, fig. 48). The enlarged part of this proxistele commonly is strongly bimorphic, extremely flexible, and has a large lumen. It was probably an adaption to permit correct thecal orientation in the short stalked glyptocystitoids and assisted in the function of the stalk as a locomotory organ in those forms that were apparently free living (Paul, 1967a).

The wide range of stalk forms, functions, and lengths reflects the great variety of postures and feeding capabilities of blastozoans. Sprinkle (1973a) has shown the almost uniformly short nature of eocrinoid holdfasts and columns. Glyptocystitoid rhombiferans commonly had similarly short (3-6 cm.) stalks, but hemicosmitids such as Caryocrinites are known with robust columns longer than 17 cm. (Brett, 1978). Complete stalks are exceedingly rare in blastoids; Strimple (1977) has illustrated a complete Pentremites with a slender column 19.5 cm. long. Paracrinoids commonly sat on the substrate as adults with a short, nonfunctional trailing stem whereas most diploporitans lacked a stem in the adult stage. Complete stalks are unknown in the Parablastoidea.

Feeding structures

The blastozoan mouth is located, most commonly, at the opposite pole of the theca from the stem attachment and was directed generally upward in most instances. This orientation is also observed or inferred in many crinoids and reflects a more or less permanently attached, stalked habit adapted for suspension feeding. The term "filter feeder", although commonly applied to many crinoids with the capability of forming a dense filtration fan of branched pinnulate arms is not so well applied to blastozoans, many of which had comparatively far fewer free feeding appendages.

The basic form of the external elements of the blastozoan feeding system (Figure 2) and their relationships to the theca are one of the primary definitive features of the subphylum. The entire system is exothecal, with all ambulacral grooves converging toward the mouth at the summit rather than entering separately as they do in crinoids. The ambulacra are nearly always biserial, except in forms having undergone secondary reduction (e.g paracrinoids) to a uniserial arrangement. Free moving structures attached alternately along each ambulacrum are the brachioles, which are also most commonly biserial (except in paracrinoids and a few rhipidocystid eocrinoids). The food grooves of the brachioles and ambulacra plus the mouth were most commonly covered by a series of covering plates that are usually a biseries of interfingering cuneiform plates attached alternately on opposite sides of the food groove. Considerable variation does occur in individual brachiolar and coverplate morphology (see Sprinkle,1973a, text-fig. 5).

Four general ambulacral patterns exist among blastozoans and tend to occur vicariously among the different classes (Fig. 3). These are (1) short ambulacra restricted to the thecal summit, (2) long ambulacra recumbent upon the sides of the theca, (3) erect ambulacra, and (4) lanceolate ambulacra that are well delineated and consistently occur in standard positions. There is no definite relationship between these ambulacrum patterns and brachiole number and size although short ambulacrum forms commonly have fewer brachioles than types 2, 3, and 4 and longer brachioles than types 2 and 3.

Ambulacrum restriction to the thecal summit (Figure 3A) characterizes the eocrinoids, most rhombiferans (except some Callocystitidae), diploporitans of the order Sphaeronitida and a few paracrinoids and paracrinoid - like forms (e.g. Columbocystis, Palaeocystites, Schuchertocystis). The number of brachioles in forms with short ambulacra ranges from approximately 50 in some cheirocrinid rhombiferans to 2 in the pleurocystitids and only a single brachiole in the bizarre callocystitid Osculocystis monobrachiolata (Paul, 1967). Brachiole length also appears to have been significantly greater in forms with ambulacra restricted to the summit than in those with recumbent ambulacra (see Koch & Strimple, 1968).

Long ambulacra recumbent or incised upon the theca (Figure 3B) occur in many callocystitid rhombiferans, the diploporitan order Glyptosphaeritida, many paracrinoids, and the paracrinoid-like Ulrichocystis. Brachioles tend to be alternately arranged on either side of ambulacra. Ambulacra of all of these groups, except the diploporitans, are composed of at least a simple biseries of discrete ambulacral plates resting upon flat platforms or shallow incised areas on the principal thecal plates. The ambulacral grooves of the diploporitans, however, are incised into diplopore-bearing thecal plates and are not underlain by specialized ambulacral plates (it is arguable that the groove and brachiole-bearing plates are ambulacral plates incorporated into the theca).

Erect ambulacra (Figure 3C), homeomorphic to the erect arms of crinoids occur in at least one paracrinoid, Comarocystites (Parsley, 1978), a diploporitan, Eumorphocystis, the eocrinoid Trachelocrinus (Sprinkle, 1973a) and may characterize rhombiferans of the order Hemicosmitida. Each of these ambulacra bears brachioles, which are uniserial (as are the ambulacra) in the paracrinoid and biserial in the last three groups. Ambulacral structures otherwise appear to be more complex in erect forms, especially in the hemicosmitids (Sprinkle, 1975; Bockelie, 1979). In Eumorphocystis, short exothecal ambulacral grooves, incised in adoral thecal plates at the summit, bear a small number of brachioles between the mouth and erect ambulacra.

Lanceolate ambulacra (Figure 3D) composed of short, broad ambulacral plates with brachioles attached at their lateral extremities characterize the Blastoidea, Parablastoidea, blastoid homeomorphs of the diploporitan order Asteroblastida, and a few rhombiferans such as Cystoblastus. The biserially arranged ambulacral plates are elaborated upon in blastoids by an additional small plate that assists in support of each brachiole, but parablastoid ambulacra contain no accessory plates. Specifics of ambulacral morphology are unknown in either the Asteroblastida or Cystoblastus.

Respiratory Structures

Blastozoans are especially distinctive in possessing special skeletonized structures across which respiratory gas exchange occurred (Figure 4). Each class further tends to be characterized by a single or at most two or three of these special modifications. Two broad groupings of blastozoan respiratory structures have been described by Paul (1968b, 1972a, 1977b). Exothecal structures are characterized by external respiratory surfaces and occur in some eocrinoids, paracrinoids, and rhombiferans plus all diploporitans. Endothecal structures have an internal site of gas exchange commonly associated with thin inward folds of stereom and occur in blastoids, parablastoids, some rhombiferans, and even a few crinoids, such as Porocrinus (Paul, 1977b, p. 144). Additionally, some eocrinoids (e.g. rhipidocystids) and many paracrinoids lack specialized respiratory structures in thecal plates, and diffusion may have occurred across thin, undifferentiated plate surfaces. This could also be considered to be exothecal respiration. Active respiratory pumping as occurs in holothuroids has been suggested for a number of fossil echinoderms including some rhombiferans (e.g. Amecystis) and eocrinoids (e.g. Lingulocystis) (Broadhead & Strimple, 1975). Multiple functions of endothecal hydrospire folds and excurrent spiracles are evident in some blastoids: respiration, waste elimination through the anal spiracle and broading of eggs in posterior hydrospires (Katz & Sprinkle, 1976).

The presence of tube feet in blastozoans is an unresolved source of debate. Sprinkle (1973a, p. 21-27) suggested that blastozoans probably lacked tube feet in their feeding appendages, although Breimer and Macurda (1972, p. 164-172) successfully argued for such extensions of the watervascular system in blastoids. Other soft, tube foot-like structures may have protruded from diplopores of diploporitans (Paul, 1972) and some epispire pores of eocrinoids (Sprinkle,1973a, p. 28-30).

Whether gases diffused through the stromal tissue permeating porous calcite membranes, across soft podial membranes on the thecal surface or feeding appendages, or internally across a cloacal membrane, an interal coelomic distribution system was necessary. Paul (1977b, p. 142) remarked that many early Paleozoic "primitive" echinoderms "had large thecae and small, inefficient exchange surfaces, while modern crinoids have virtually no theca and all their arms, etc. are thin enough to be oxygenated directly by diffusion from surrounding sea water." An extensive coelom was apparently necessary in the blastozoans to permit circulation of oxygenated fluids within the spacious thecal interior. This has been suggested as a phylogenetically unifying feature closely relating the blastozoans (including paracrinoids) with the homalozoans in a single subphylum (Bell & Haugh, 1979; see also discussion by Haugh and Bell herein).

Thecal Openings

Four principal kinds of thecal openings (Figure 5), excluding those solely related to respiration, commonly occur in blastozoans. Of those the mouth and anus are invariably present; in some classes they are accompanied by a presumed gonopore (genital opening) and a hydropore (probable connection to water vascular system). The mouth is exposed on the summit of the theca at the convergence of ambulacral grooves. Although much of the feeding system (brachioles, ambulacra) probably had movable covering plates over ambulacral grooves, the mouth commonly was protected by covering plates only in rhombiferans, paracrinoids, diploporitans and possibly eocrinoids. Blastoids, however, exhibit a variety of supraoral plates (Beaver, 1968, p. S331) that generally do not resemble simple biserial covering plates. Parablastoids have either five plates or a single large summit plate above the mouth and proximal parts of ambulacra (Sprinkle, 1973a, p. 144).

Comparatively large openings on the sides or near summits of blastozoans thecas are periproct openings and rarely represent the actual size of the anus. Most periprocts, bordered by thecal plates, are covered at least by a pyramid of wedge-shaped plates with the anus at the center. In most cases, this pyramid is surrounded by a least one circlet of plates, but the number of plates may exceed 1000 in the rhombiferan family Pleurocystitidae, many species of which are characterized by a periproct covering nearly the entire ventral surface of the dorso-ventrally flattened sagittate theca. The earliest type of anal structure in Cambrian eocrinoids was typified by a short tube composed of numerous small plates and bearing a terminal anus. The anal tube was located on the oral surface of the theca in imbricate eocrinoids (L. Cambrian) and forms such as Gogia, but in many later blastozoans the periproct occurred considerably lower on the theca and was commonly removed from proximity to any feeding structures. The anus continued to be close to the mouth in successful groups such as the blastoids.

The hydropore and gonopore are not consistently recognizable features in all blastozoan classes. They are poorly known in most eocrinoids; imbricate forms such as Kinzercystis (L. Cambrian) apparently had numerous small plates surrounding each opening. Later blastozoans had a much smaller number of surrounding plates (usually 3 in rhombiferans, rarely more in most diploporitans and paracrinoids). The hydropore and gonopore are unknown in parablastoids. If such structures occur in blastoids, they probably were located within the posterior hydrospires and enlarged anal spiracle. The association of the genital opening and posterior hydrospires is strongly suggested by apparent sexual dimorphism and egg-like bodies described from a specimen of Pentremites rusticus (Katz & Sprinkle, 1976).

ONTOGENY

Blastozoans underwent thecal enlargement by (1) marginal growth of existing thecal plates and (2) addition of new plates by intercalation. Sprinkle (1973a, p. 44) has referred to the first as "holoperipheral growth". It involves a lateral increase at plate margins, but rarely an external deposit of calcite ("overlayering") as is typical of crinoids. Holoperipheral plate growth in blastozoans is partly a consequence of transthecal respiration which largely would be precluded by plate thickening of the overlayering process. Thecal plates bearing respiratory structures must have been restricted to lateral growth and even those eocrinoids and paracrinoids that lack specialized structures tend to have exceedingly thin thecal plates. The presence of growth lines (see Sprinkle, 1973a, p. 47-48) is a consequence of fluctuating environmental conditions not always present in tropical and subtropical environments with which most blastozoans were associated.

Other than increase in stalk, ambulacrum, and brachiole length, not all blastozoans show growth by plate addition. As a general rule, blastozoans with large numbers of thecal plates grow by both plate growth and intercalation (diploporitans, early eocrinoids, caryocystitid rhombiferans, paracrinoids) whereas groups characterized by a small number of plates in standard orientations grow only by holoperipheral plate growth (rhipidocystid and coronate eocrinoids, most rhombiferans, parablastoids, blastoids). Details of plate growth have not been studied in most classes, but Macurda, (e.g. 1966, 1975) has shown the importance of allometry in blastoid ontogeny.

BLASTOZOAN CLASSES

Class Eocrinoidea (L. Cambrian-M. Silurian) - theca of adjacent or imbricate plates with or without transsutural epispires; brachioles arise from oral surface bearing central mouth; theca globular, flattened, or bud-shaped. The eocrinoids are the earliest group of blastozoans and were likely the evolutionary precursors of the later classes. The morphologic diversity in this class has led to the recognition of four orders and three groups of indeterminate order (Sprinkle, 1973a, 1979). The Order Imbricata (L. Cambrian) includes primitive eocrinoids with thecas composed of simple imbricate plates except for the oral surface formed from epispire-bearing adjacent plates. The unusual echinoderm Camptostroma roddyi assigned by Durham (1966) to the Class Camptostromatoidea is probably an imbricate eocrinoid. A second order (Unnamed Order #1 of Sprinkle, 1973a) ranging from the late early Cambrian to the early Ordovician includes forms with large numbers of adjacent, mostly epispire-bearing thecal plates. This group includes the last eocrinoids with multiplate holdfasts and the first with stalks composed of columnals. A third order (Unnamed Order #2 of Sprinkle, 1973a) (M. Cambrian-M. Ordovician) is characterized by mostly stalked forms with globular thecas lacking epispires. The Order Coronata is a peculiar group of blastoid-like echinoderms that have recently been classed as crinoids (Fay, 1978), but which Sprinkle (1979) believes are best assigned to the Eocrinoidea. Additionally, there exist three other groups of eocrinoids, including the distinctive, paddle-shaped rhipidocystids, that are unassigned to order (Sprinkle, 1973a). The eocrinoids remain the most morphologically diverse group of blastozoans, but they lack the unity of other classes.

Class Rhombifera (L. Ordovician-U. Devonian) - thecal respiratory structures are rhomboid sets of exothecal or endothecal folds or canals; theca globular. Paul (1968b, 1972) recognized two orders of rhombiferans: (1) Dichoporita (L. Ordovician-U. Devonian) for forms with endothecal respiratory structures and (2) Fistuliporita (L.-U. Ordovician) for those with exothecal structures. Dichoporite rhombiferans originated from Macrocystella, an earliest Ordovician genus lacking dichopores but possessing thecal plating identical to that of early dichopore-bearing forms such as Cheirocystella and Cheirocystis. The significance of the morphology of Macrocystella had led to its assignment to the Eocrinoidea (Ubaghs, 1968b; Sprinkle, 1973a) and to the Rhombifera (Paul, 1968a; 1972b). The retention of the Fistuliporita in the Rhombifera should be studied carefully. The single superfamily Caryocystitida contains genera that should be reassessed as possible paracrinoids. The caryocystitid genus Ulrichocystis has recently been reexamined (Broadhead & Breland, 1980) and shown to belong in the same family as Palaeocystites and Schuchertocystis; the group shows distinct affinities to the eocrinoids and paracrinoids, but not to the Rhombifera.

Class Diploporita (L. Ordovician-L. Devonian) - thecal respiratory structures are exothecal dipores; theca globular, commonly composed of a large number of dipore-bearing small plates; stalk commonly lacking. Four major groups of diploporitans generally are differentiated on the basis of ambulacral structures. Although they are currently recognized as superfamilies, these groups should be elevated to ordinal status following Paul's (1968b) elevation of the Diploporita from an order to a class. The four orders are Glyptosphaeritida (L. Ordovician-M. Silurian), Sphaeronitida (L. Ordovician-L. Devonian), Aristocystitida (M. Ordovician-M. Silurian), and Asteroblastida (L. Ordovician). Paul (1972a, p. 5-8) recognized two types of dipores: (1) diplopores with a pair of perpendicular canals penetrating the thecal plate united externally by a single more or less calcified tangential canal and (2) humatipores (only the sphaeronitid family Holocystitidae) with multiple tangential canals connecting each pair of perpendicular canals. Active sites of gas exchange were the tangential canals.

Class Parablastoidea (L.-M. Ordovician) - endothecal respiratory folds (cataspires) developed on deltoids; ambulacra lanceolate, composed of one kind of flooring plates; theca bud-shaped. Parablastoids presently are known from seven species assigned to three genera and two families (Sprinkle, 1973a). Although they strongly resemble true blastoids, parablastoids differ by the less complex ambulacral plating, more complex thecal plating, and distinctive summit structures. The internal respiratory folds are attached to both radial and deltoid plates and incurrent pores line the margins of ambulacra, as in blastoids. Numerous excurrent openings, however, perforate the deltoid plates; no structures similar to spiracles exist.

Class Blastoidea (M. Ordovician-U. Permian) - endothecal respiratory folds (hydrospires) developed along ambulacral areas; ambulacra generally lanceolate, composed of more than one kind of flooring plate, underlain by lancet plate; theca bud-shaped, three basal and five radial plates, plus varying number of deltoid plates. Two orders of blastoids have been described (1) Fissiculata with hydrospire openings developed as slits and (2) Spiraculata with hydrospire openings developed as pores and well-defined spiracles. This is the longest ranging, most diverse and abundant blastozoan class and is discussed elsewhere is this volume by D. B. Macurda.

Class Paracrinoidea (M. Ordovician-L. Silurian) - exothecal respiratory structures present in some; feeding appendages mostly uniserial arms (erect or recumbent) and pinnules; globular to lenticular theca with three basal plates, commonly with inflated left side. Although Sprinkle (1973a)regarded the paracrinoids as more closely allied to crinoids than to blastozoans and Parsley and Mintz (1975) erected a separate subphylum (Paracrinozoa) for the class, I am convinced that they are blastozoans. At least some paracrinoids may have evolved from epispire bearing eocrinoids (Broadhead & Breland, 1980). The development of uniserial "arms" and "pinnules" may represent a paedomorphic suppression of biseriality in typically biserial blastozoan ambulacra and brachioles respectively. Characteristics of the class and orders are reviewed by

R. L. Parsley in a later chapter in this volume.

Class uncertain (mostly M. Ordovician). Several Ordovician blastozoan genera have yet to be accepted into any of the existing classes. These include forms lacking respiratory structures, such as *Springerocystis*, *Columbocystis*, and *Foerstecystis* plus some with exothecal respiratory structures including three genera of the Palaeocystitidae: *Palaeocystites*, *Schuchertocystis*, and *Ulrichocystis*. The first group shows numerous similarities to the paracrinoid order Platycystitida, whereas the second show both eocrinoid and comarocystitid paracrinoid characteristics. The reluctance to assign most of these to the paracrinoids has been based on the absence of knowledge of feeding structures.

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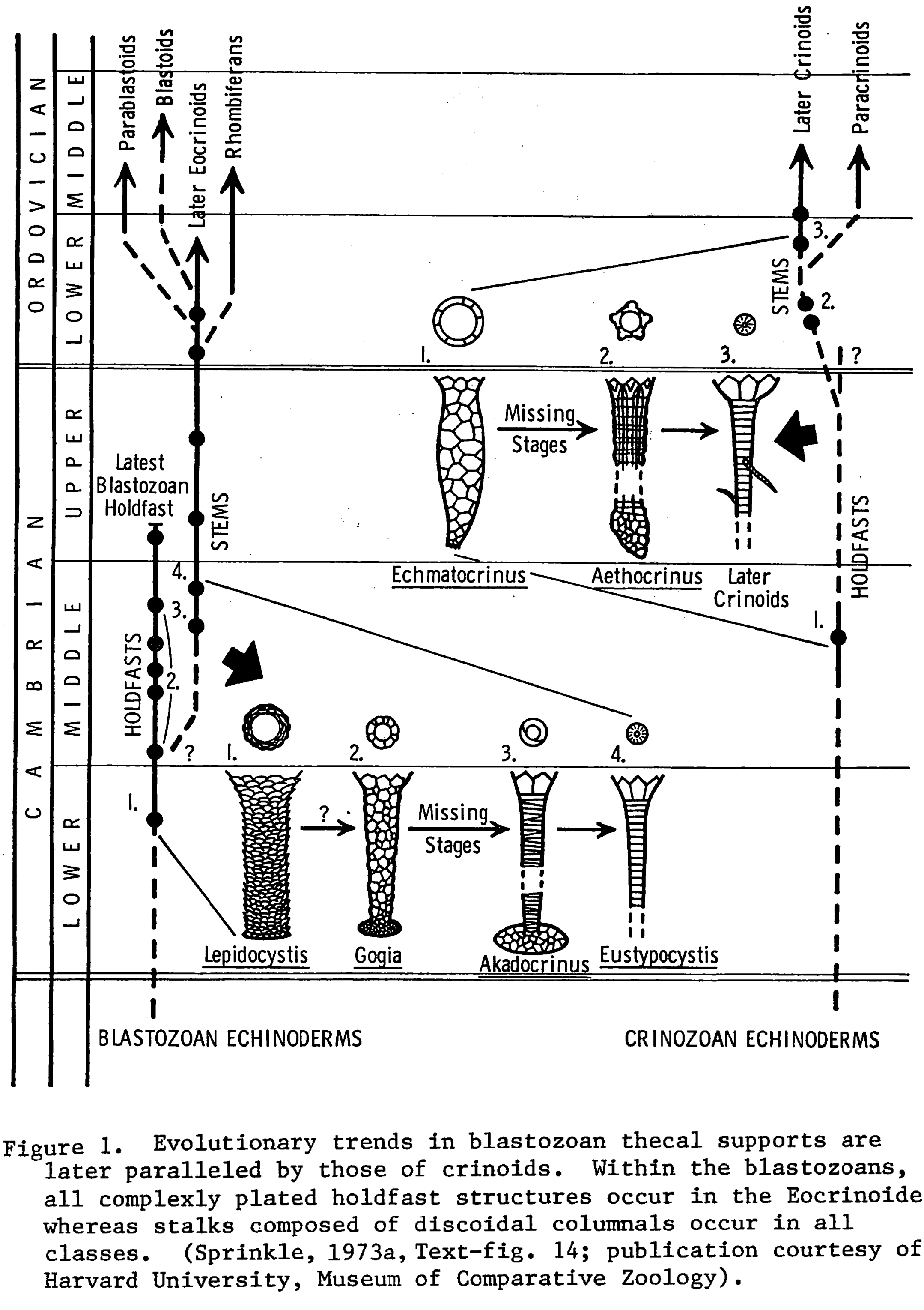

Figure 1. Evolutionary trends in blastozoan thecal supports are later paralleled by those of crinoids. Within the blastozoans, all complexly plated holdfast structures occur in the Eocrinoidea, whereas stalks composed of discoidal columnals occur in all classes. (Sprinkle, 1973a, Text-fig. 14; publication courtesy of Harvard University, Museum of Comparative Zoology).

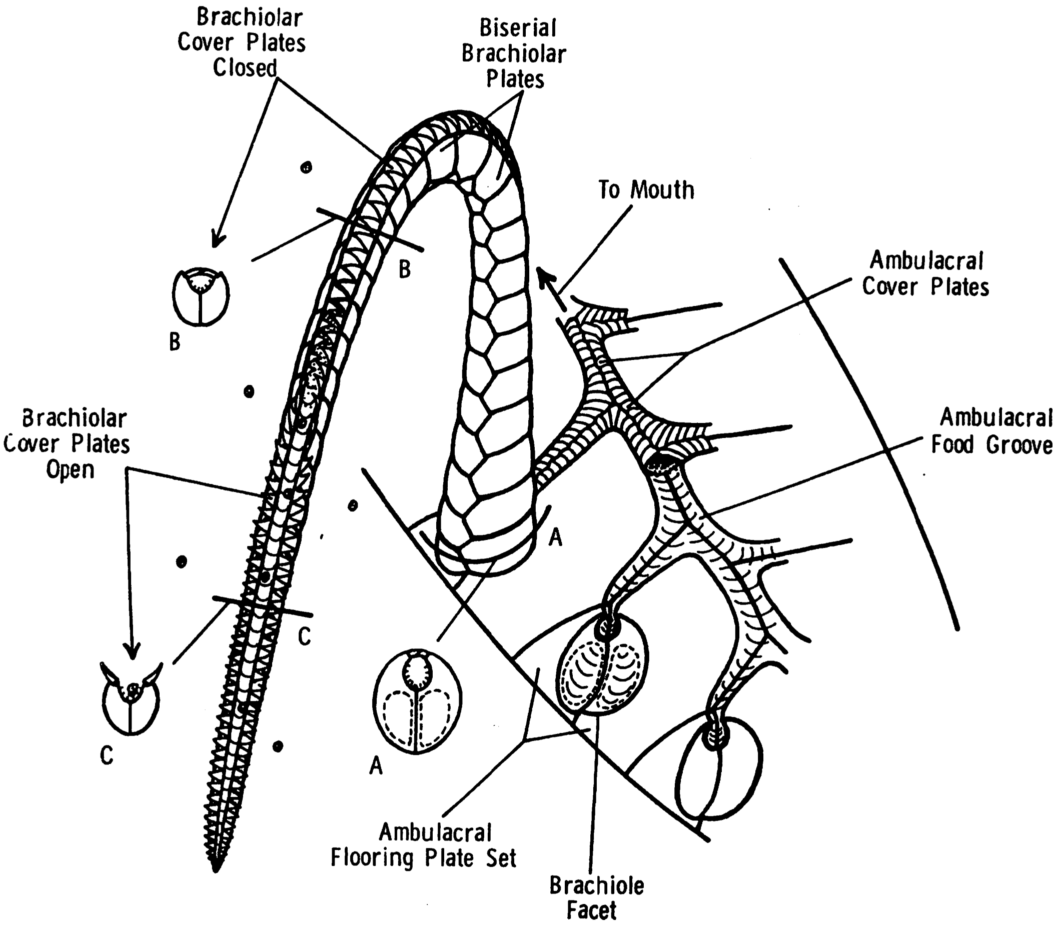

Figure 2. Specialized ambulacral structures and brachioles distinguish blastozoans from crinozoans. The structures shown above are typical of blastoids and rhombiferans with each biserial brachiole supported by a pair of ambulacral plates; no canals penetrate these plates for direct connection of the brachiole to the thecal interior. Food grooves extend upward to the mouth at the thecal summit. (Sprinkle, 1973a, Text-fig. 4; publication courtesy of Harvard University, Museum of Comparative Zoology).

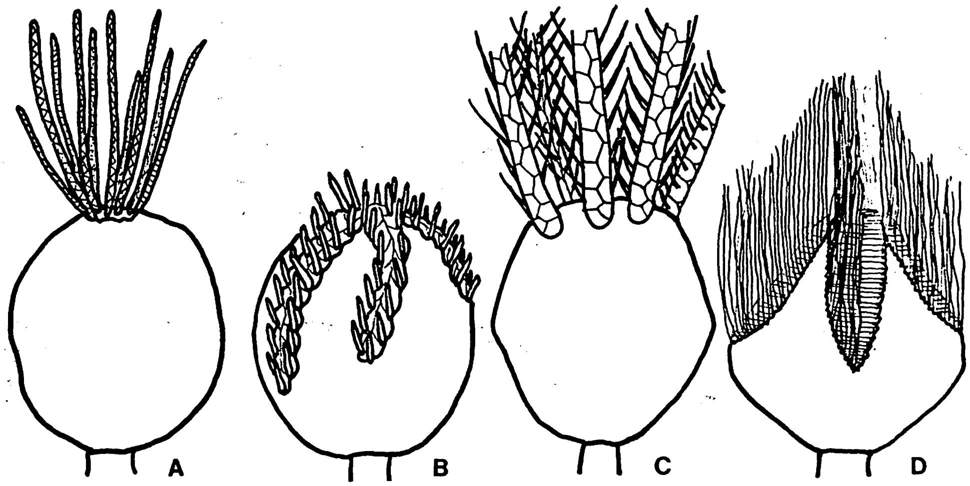

Figure 3. Brachiole and ambulacrum configurations in blastozoans. (Diagrammatic, not to scale.) A. Small number of large brachioles attached to short ambulacra that are restricted to the thecal summit. B. Large number of short brachioles attached to long ambulacra recumbent upon the theca. C. Short brachioles attached to erect ambulacra articulated near the thecal summit. D. Numerous long, slender brachioles attached at lateral extremities of broadly lanceolate ambulacra that commonly are incised into the theca.

Figure 4. Specialized respiratory structures in plates of blastozoans; external surface (upper) and cross-section (lower) views. (Diagrammatic, not to same scale). A-D. Endothecal structures: A. Pectinirhomb of thin folds of stereom in glyptocystitid Rhombifera. B. Cryptorhomb of thin folds with single excurrent pores and clusters of small incurrent pores in hemicosmitid Rhombifera. C. Cataspire of thin folds underlying deltoid plate with incurrent pores at ambulacral margins and excurrent slits through deltoid in Parablastoidea. D. Hydrospires of thin folds of stereom underlying ambulacral areas with incurrent slits (Order Fissiculata) or ambulacral pores (Order Spiraculata) and excurrent spiracle (especially in Spiraculata) at summit in Blastoidea. E-L. Exothecal structures: E. Epispires that were possibly filled with soft tissue, but in some were covered by thin domes of calcite (dashed line) in Eocrinoidea and some problematical forms. F. Tangential and inner oblique canal system of Ulrichocystis (?Paracrinoidea). G. Simple humatirhomb superficially like F, but with perpendicular rather than oblique canals at ends of tangential canals in caryocystitid Rhombifera. H. Complex humatirhomb with each pair of perpendicular canals joined by more than one tangential canal in caryocystitid Rhombifera. I. Internally arched structure with paired reniform foerstepores (notches along sutures are exposed only by erosion) in Comarocystites (comarocystitid Paracrinoidea). J. Arched structure

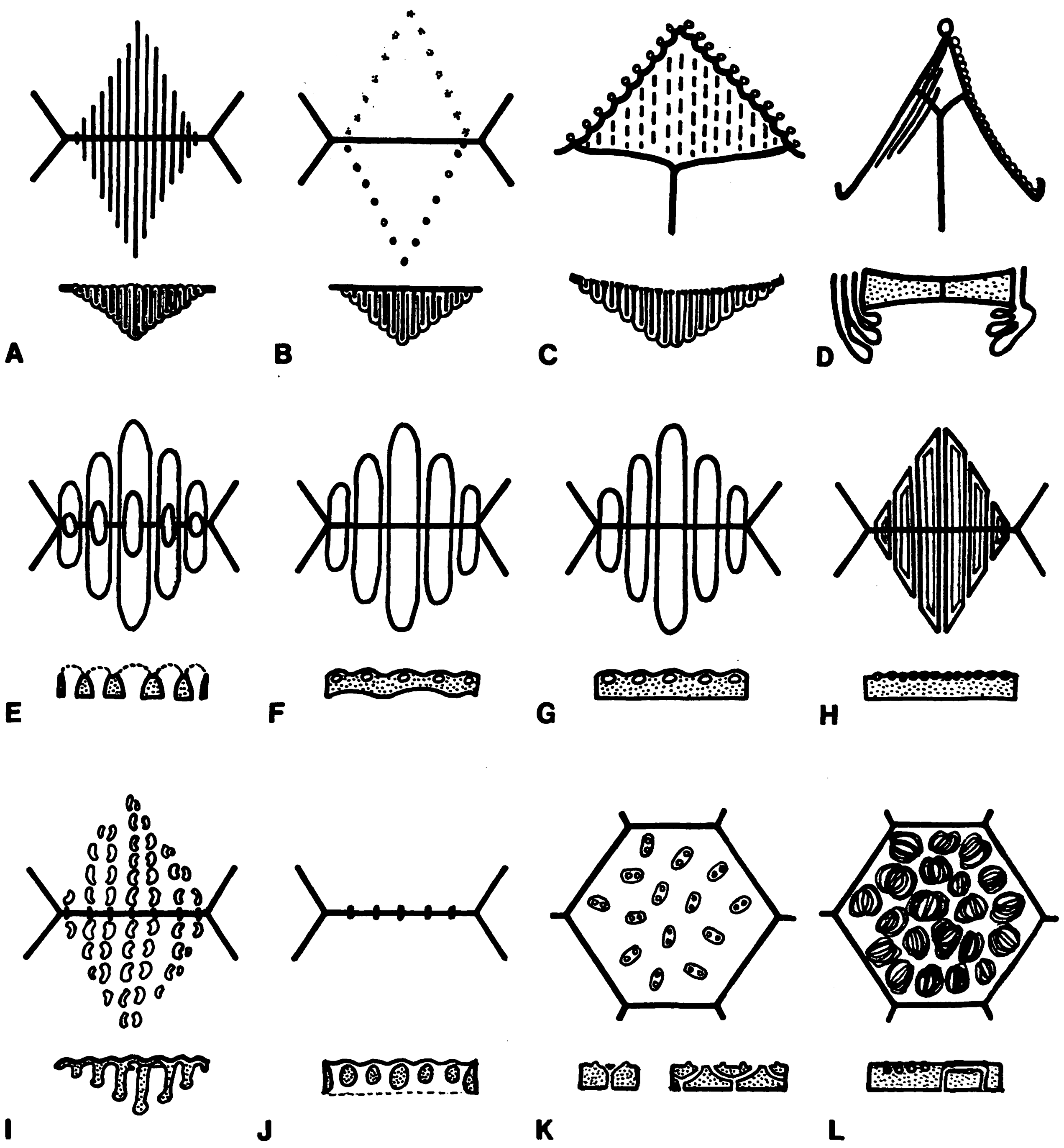

Figure 4 (cont.). modified to series of bars covered at surface only by thin layer of calcite (notches along sutures exposed only by erosion) in *Sinclairocystis* (comarocystitid Paracrinoidea). K. Diplopores surrounded by raised rims (two possible means of connection between pores in a pair or between pores of different pairs) in most Diploporita. L. Humatipores of short curved tangential canals, covered at the surface with perpendicular canals at each end in Holocystitidae (Diploporita).

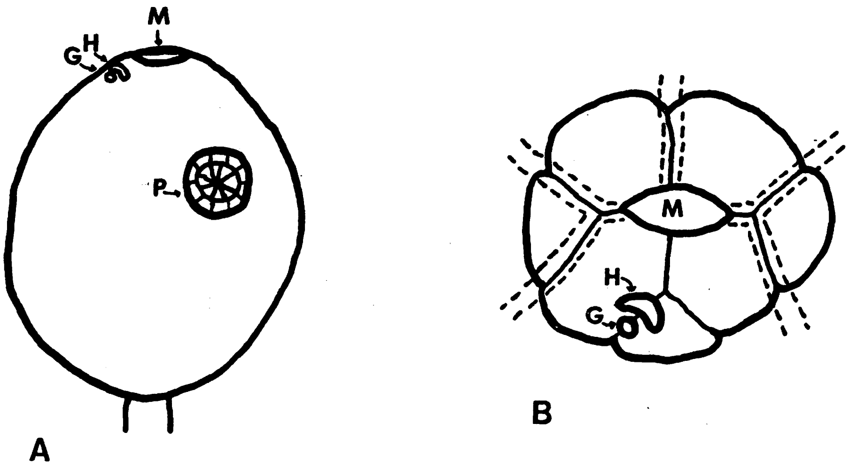

Figure 5. Principal thecal openings in blastozoans. A. Lateral view of theca showing mouth (M) at summit associated with hydropore (H) and gonopore (G). The periproct (P) is shown with a single ring of small periproctal plates surrounding a circlet of wedge-shaped plates with the anus at the center. B. Summit plating and thecal openings common in glyptocystitid rhombiferans. Seven oral plates surround the mouth (M) and the hydropore (H) and gonopore (G) commonly are shared by two orals. Dashed lines represent locations of ambulacral tracts in the 2-1-2 arrangement, but ambulacral development in the blastozoans may be highly variable.

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Postscript to the 1980 Notes on Echinoderms.

Research on fossil echinoderms continues, but not at as brisk a pace, and certainly not for primitive echinoderms. My own research has taken me into the realm of experiments with conodonts as sedimentary particles and studies of the growth forms of middle Paleozoic tabulate corals. I now have only two projects dealing with rhombiferan cystoids. Other work, however, continues from Ronald Parsley on both paracrinoids and "carpoids." James Sprinkle is actively working on some early Ordovician faunas in the western United States that hold promise for insight into the evolutionary origins of many cystoid and eocrinoid groups. Johnny Waters continues his extensive work on Carboniferous blastoids, including new material that he has collected on several trips to Ireland.

Three papers published since the 1980 short course merit particular attention. Work by Christopher R.C. Paul and Andrew Smith (Paul and Smith, 1984; Smith, 1984; Paul, 1988) has brought significant interpretations of the probable relationships among "blastozoan" or "cystoid" groups of primitive echinoderms. The greatest level of uncertainty remains concerning some of the very early forms with imbricated plates and primitive ambulacra (Camptostroma, Kinzercystis). Paul (1988) believes that Gogia is possibly the common ancestor of all later, and more advanced "cystoids" (in which he includes blastoids and paracrinoids). The final word has not yet been written on these topics.

The other major study, now underway, that is worth note is that of James Sprinkle and Thomas Guensburg in the western U.S. Preliminary results (Sprinkle, 1990; Guensburg and Sprinkle, 1992) indicate that many questions of morphological evolution in blastozoan groups may be answered by material from the Lower Ordovician.

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ECHINODERM GROWTH - IMPORTANCE IN EVOLUTION: A CALL TO "ARMS"

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INTRODUCTION

The relationship between growth of an organism and its evolution is one of the most important relationships in the biologic world and is one of the most exciting areas for the study of morphology of fossils. Why do plants and animals look the way they do? What, if anything, does their appearance tell us about their ancestry?

Complex animals and plants undergo numerous, complex changes between the fertilized egg and adulthood. As they grow, cells increase in number by cell division, but if there were not additional changes during growth, we would all be big blobs of identical cells. The process by which cells change to different types that form body layers, tissues, and organs leads to a rapid increase in complexity during early growth stages. Collectively, these changes are called "ontogeny" (from the Greek "ontos" - being + "genus" - birth or origin). Thus, the changes in shape of the skeleton of an animal represent "skeletal ontogeny" - but how does this help us to understand the evolution of the shape of the skeleton?

In the late 1800's, embryology, the study of early ontogeny in animals and plants, showed, for example, that all vertebrate animal embryos were extremely similar in their earliest stages of development. However, as early development proceeds, the embryos of amphibians, reptiles, birds, and mammals become increasingly different from those of fish. At later stages, reptiles, birds, and mammals become increasingly different from amphibians, and so on. In the case of humans, embryos develop to the point where they have a strong resemblance to other mammalian embryos, but much less so to any nonmammallian groups. At birth, humans bear a resemblance only to newborn apes, our closest relatives. The sequence of development, at times resembling early ontogenies of other vertebrate groups, led the German biologist Ernst Haeckel to propose what has come to be known as the "biogenetic law." This is commonly stated as "ontogeny recapitulates phylogeny." Generally speaking, it predicts that at least some aspects of phylogeny (evolutionary history) are represented in early ontogeny. The implications of this relationship between early development and ancestry for fossils was quickly recognized by Alpheus Hyatt, an American worker studying fossil cephalopods. Hyatt recognized that ammonoid septa underwent rapid changes in shape during early ontogeny, producing a preservable record of changes in suture pattern in a single ammonoid shell. In many instances, juvenile suture patterns appear similar to those of adult ancestors. In other cases, adult suture patterns appear similar to those of juvenile ancestors. Here, locked in the record of skeletal ontogeny, were clues to ancestors. As has been emphasized by Broadhead & Waters (1984), the so-called "missing links" or intermediate forms of evolutionary sequences exist in the ontogenies of plants and animals.

Applications of ontogenetic information to interpret evolutionary relationships among extinct organisms were not pursued in earnest from the time of Hyatt until the late 1960's. Major efforts to use ontogeny to interpret evolutionary relationships have blossomed since the publication of Stephen Jay Gould's book, Ontogeny and Phylogeny in 1977. (This book provides an incomparable historical account, plus excellent examples and discussions. I was fortunate that it was published while I was writing my Ph.D. dissertation at the University of Iowa, and it provided me with a new way of looking at my old fossils!)

Echinoderms are a wonderful group of animals to investigate both in terms of ontogeny and phylogeny. I have looked primarily at crinoids in suggesting relationships between growth forms and ancestors. Other echinoderm workers, including Johnny Waters and Brad Macurda (blastoids), James Brower (crinoids), James Sprinkle (blastozoans, edrioasteroids), and Michael McKinney and Kenneth McNamara (echinoids), have provided important insight and documented spectacular examples of growth patterns and their signficance in the evolution of echinoderms.

Echinoderm workers are blessed by dealing with a relatively easily understood group with modest complexity of form, but are cursed by the problems of specimen preservation that often leave them with little more than handsful of disarticulated plates and columnals. To understand the importance of echinoderm growth, we must understand the basic patterns of change in their skeletons.

1. Most echinoderms grow by adding parts to their skeletons (blastoids and some cystoids are important exceptions).
2. Most plates and columnals undergo some growth after they form.

Sprinkle (1973) discussed differences in plate growth between crinoids and blastozoans, emphasizing that many blastozoans increase plate size in such a way that "growth lines" can be seen on the outer surfaces of plates. Numerous papers by Macurda and the monographs by Breimer & Macurda (1972) and by Macurda (1983) show how measurements of these growth lines, even from a single specimen, can document how each plate changes shape during ontogeny and how those result in a change in thecal shape. Waters has shown how the resulting change in thecal shape can be interpreted in an evolutionary sense (Broadhead & Waters, 1984). More recently, I have discussed the importance of growth patterns on evolution in Paleozoic crinoids (Broadhead, 1988).

What does this mean for the future of echinoderm studies? Collectors and students of echinoderms must pay greater attention to the tiny, juvenile specimens that often pass through our collecting screens. "Picking" small echinoderms and even isolated ossicles from shale residues has been done for many years by many, including Gary Lane, George Sevastopulo, Harrell and Christina Strimple, and Jim Sprinkle. More data on growth patterns of many species will be a key to a great future in the interpretation of the evolution of echinoderms.

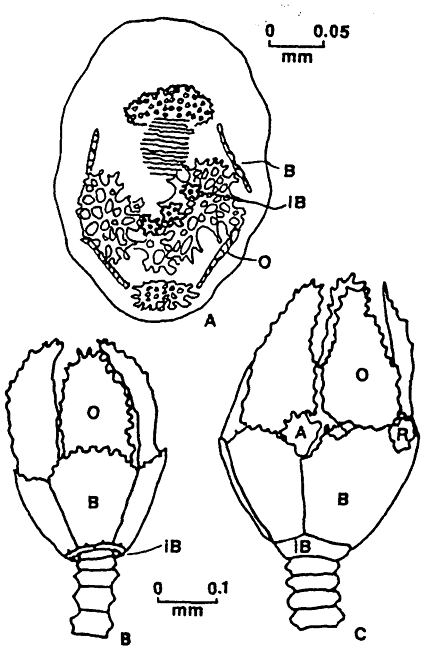

Figure 1. Early developmental stages in the modern comatulid, *Compsometra serrata* (after Mortensen, 1920) typify some of the disparities between adult and juvenile form. A. Calyx and stem ossicles begin to form in the free-swimming larval stage, which inverts upon settlement. B, C. Early and later stalked "pentacrinid" stages show the pattern of development of other calyx plates. It is important to emphasize that the stalk is missing in the free-living adult, and the most prominent cup plates become the radials. Thus, the juvenile form is markedly different from the adult.

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THE EXTINCT ECHINODERMS OF THE ORDOVICIAN AND SILURIAN OF KENTUCKY

BY

CHARLES EDWARD OLDHAM

FOREWORD

For the last twenty years, I have been collecting specimens, manuscripts, published papers, theses, retired geologist's notebooks, etc., on fossil occurrences of Kentucky and surrounding states. The purpose of this endless task is to gather enough information to publish a comprehensive paleontology of the state of Kentucky. The last attempts was made in 1931 by Willard Rouse Jillson.

Very little has been published on the echinoderms of the ordovician and silurian periods of Kentucky. And what is available is scattered in various journals, whose titles generally do not indicate that material from Kentucky is described.

For the last year I have been tracking down rumors, leads and false trails, searching for information on extinct echinoderms of Kentucky. I have always made an attempt to verify the occurrence of fossils as reported. Too many time I have visited reported localities of various fossil assembledges only to find no trace of the fossils described. And then several years later to learn that the described fossils were collected several counties away and the reported locality was a "typical locality" and occasionally not even in the same formation.

ORDOVICIAN ROCKS:

The ordovician rocks outcrop in the north central area of the state, controlled by the Cincinnati Arch. The ordovician rocks were laid down in horizontal layers in a ancient seafloor and as the millenia passed these beds were slowly folded upward to form a structural feature called an arch. The Cincinnati Arch formed a structural high, an area that may have been above sea level at its apex or at least an area that accumulated little sediment. In the present landscape its flanks are deeply eroded, exposing an extensive sequence of the upper ordovician called the Cincinnatian Series. In the area surrounding Lexington, Kentucky ordovician rocks of the Champlainian Series are exposed. These rocks are middle ordivician. In the drainage of the Kentucky River in the area of Frankfort, Kentucky are the oldest exposed rocks in the state. These rocks are of the lower middle ordovician.

ORDOVICIAN ECHINODERMS:

The ordovician rocks of Kentucky contain a rich fauna of echinoderms. The extinct groups are represented by two cystoids, three homalozoans, one paracrinoid, one cyclocystoid and twenty-nine edrioasteroids.

CYSTOIDS

ATELEOCYSTITES balanoides - Meek

Maysville - Corryville

LEPADOCYSTIS moorei - Meek

Richmond - Lower Whitewater
- Elkhorn

HOMALOZOANS:

BELEMNOCYSTITES sp. - Miller and Gurley, 1894

Middle Ordovician

ENOPLOURA popei - Caster

Middle Ordovician

E. cf. punctata - Bassler, 1932

Lexington Limestone - Curdsville

PARACRINOIDS:

AMYGDALOCYSTITES florealis - Billings, 1854

Lexington, Limestone - Curdsville

CYCLOCYSTOIDS:

CYCLOCYSTOIDS cincinnatiensis - Miller and Faber 1892

Lexington Limestone - Curdsville

CYCLOCYSTOIDS CONT...

isolated plates

Lexington Limestone - Perryville

Maysville - Grant Lake Limestone

EDRIOASTEROIDS:

CARNEYELLA faberi - Miller

Richmond - Saluda

C. forrestei - Bassler and Schideler

Richmond - Arnheim - Sunset member
- Oregonia member

C. holbrooki - James

Maysville - Corryville

C. pilea - Hall, 1866

Clays Ferry - Point Plesant Tongue

C. pileus - Hall, 1866

Maysville - Fairmont
- Bellevue
- Corryville

CINCINNATIDSCUS endensis - Bassler, 1936

Eden - McMicken

C. stellatus - Hall

Mayville - Bellevue

C. Turgidus - Bassler

Richmond - Lower Whitewater

CYSTASTER granulatus - Hall

Eden - Fairmount

C. stellatus - Hall, 1866

Clays Ferry - Point Plesant Tongue

EDRIOASTEROIDS CONT...

C. ulrichi - Bassler, 1936

Eden - Economy

EDRIOASTER bigsbyi - Billings, 1857

Lexington Limestone - Curdsville

E. priscus - Miller and Gurley, 1894

Lexington Limestone - Curdsville

HEMICYSTITES rectiradiatus - Shider, 1918

Richmond - Lower Whitewater

H. richmondensis - Bassler

Richmond - Waynesville
- Liberty
- Saluda

HUDSONASTER incomptus - Meek

Richmond - Elkhorn

ISOROPHUS austini - Foerste

Richmond - Elkhorn
Saluda

I. cincinnatiensis - Roemer

Maysville - Corryville
- Bellevue
- Fairmount

Eden - Southgate

Lexington Limestone - Grier

I. germanus

Richmond - Blanchester
- Clarksville
- Ft. Ancient

I. holbrooki - James

Richmond - Oregonia
- Sunset

EDRIOASTEROIDS CONT...

I. schideleri - Bassler

Richmond - Elkhorn

I. warrenesis - James

Richmond - Blanchester
- Clarksville
- Ft. Ancient
- Sunset

Maysville - Fairmount

MESOPALAEASTER wilberanus - Meek and worthen

Richmond - Elkhorn

PROMOPALAESTER granulosus - Hall

Richmond - Elkhorn

P. wykoffi - Meek and Gurley

Richmond - Elkhorn

STREPTASTER reversata - Foerste

Eden - Southgate

S. Septembrachiatus - miller and Dyer

Richmond - Elkhorn
- Liberty
- Blanchester
- Clarksville
- Ft. Ancient

S. vorticellatus - Hall

Richmond - Oregonia
- Sunset

Maysville - Mount auburn
- Corryville
- Bellevue

Eden - Fairmount

Lexington Limestone - Millersburg

EDRIOASTEROIDS CONT...

URASTERELLA grandis - Meek

Richmond - Elkhorn

OBSERVATIONS AND NOTES:

Three of the edrioasteroids, one of the cystoids and all of the homalozoans, paracrinoid and cyclocystoids were described from acid residue samples that were part of a large project conducted by the USGS. During the geological mapping of the state of Kentucky the USGS collected hundreds of pounds of rock from every horizon of rock that was suspected to contain silicified fossils. In spite of the large diversity of echinoderms in the ordovician rocks of Kentucky only eight-four (84) of the one thousand and eight-six (1086) collections made by the USGS contained silicified echinoderm remains.

Currently a graduate student is working on some cystoid and paracrinoids from the Curdsville Member of the Lexington Limestone.

Most of the edrioasteroids that were found in Kentucky were collected from about 1890 to about 1940 and were not usually found in abundance. Only one or two specimens are known to occur in some of geologic horizons.

A large fauna of crinoids and perhaps paracrinoids were found about fifteen years ago from somewhere in south central Kentucky. The reported horizon was the Clays Ferry. I saw the material at the time it was collected and it was so abundant that some of the local schools were using it for lab material. The locality was never revealed and recent inquires were to no avail. In fact no one seems to know what happened to the material or if anyone described the occurrence or is working on the echinoderms.

A large fauna of edrioasteroids was described from the undifferentiated Eden formation from somewhere in Central Kentucky. In the literature, it is referred to as "Stewart's Secret Locality".

Isolate plates of the cystoid GYLPTOCYSTITES fultonensis are reported to be common in the Eden and Maysville of Ohio, however none are described from Kentucky.

SILURIAN ROCKS:

The silurian rock outcrop is wrapped around the ordovician rocks and thus is controlled in part by the Cincinnati Arch. Some of the silurian formations that occur on one side of the Arch do not occur on the other. Generally speaking the stratigraphy of west side Arch during the silurian is similar to the silurian of southern Indiana. The silurian outcrop on the east side of the Arch has some of the characterists of the silurian of southern Ohio. However the silurian of the east side of the Arch in Kentucky has not been studied in much detail. Or, at least not as far as the echinoderms are concerned.

SILURIAN ECHINODERMS:

The silurian rocks of Kentucky contain a rather sparse fauna of echinoderms. The extinct echinoderm groups are represented by eleven (11) ? cystoids and one (1) ? blastoid. There are several reasons for this apparent paucity: (1) Paleoenviromental conditions were not condusive to echinoderms; (2) Poorly exposed sections of outcrop; (3) Heavily dolomitization of silurian carbonates; and (4) Overall thinning of silurian formations to the south.

The Waldron Shale which has a rich echinoderm fauna in Southern Indiana and Central Tennessee is practically devoid of fossils in Kentucky. The Osgood shale and limestones of Southern Indiana which have an rich fauna of cystoids is sparsely fossiliferous in Kentucky. Although a number of cystoids are figured in various works on the silurian of Kentucky, all are from Southern Indiana. Inquiries of various state collections did not turn up any verified finds of echinoderms other than fragmentary remains.

The Brassfield Dolomite occurs on both sides of the Cincinnati Arch. Due to the dense nature of the formation and poor exposures little collecting has been done. The formation is too thin to be of any commercial use and therefore is only exposed in a few naturel exposures and road cuts.

The Louisville Limestone has a rich fauna of corals and brachiopods, however, only one cystoid is described and perhaps a blastoid. The Laurel Limestone is severely dolomitized. Generally the Laurel is sparsely fossiliferous, however, an isolated area in the vicinity of Bardstown, Nelson County, Kentucky has a rich echinoderm faunal content.

CYSTOIDS:

ALLOCYSTITES hammelli - Miller

Osgood formation
Laurel Limestone

CARYOCRINITES indianensis - Miller

Brassfield Dolomite
Osgood formation
Laurel Limestone
Waldron Shale
Louisville Limestone

CYSTOIDS CONT...

HOLOCYSTITES subovatus - Miller

Osgood formation
Laurel Limestone

HOLOCYSTITES parvulus - Miller

Osgood Formation
Laurel Limestone

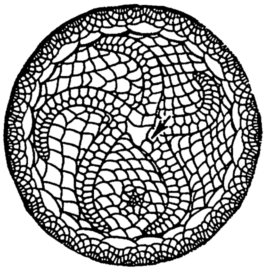
BLASTOIDS:

TROOSTOCRINUS sanctipaulensis

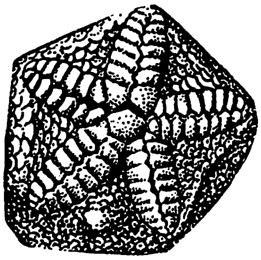
Osgood formation

TROOSTOCRINUS sp.

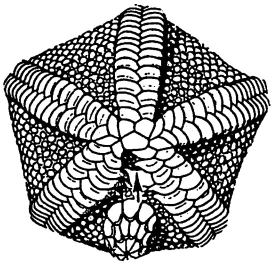
Laurel Limestone
Louisville Limestone



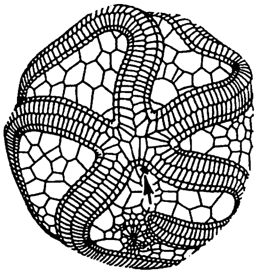
Carneyella (U.Ord.)



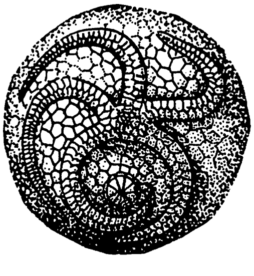
Cincinnatidiscus



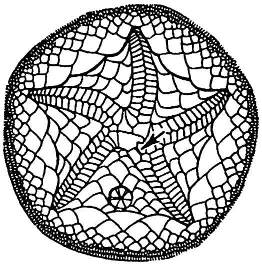
Cystaster (U.Ord.)



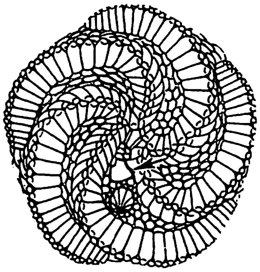
Edrioaster (M.Ord.)



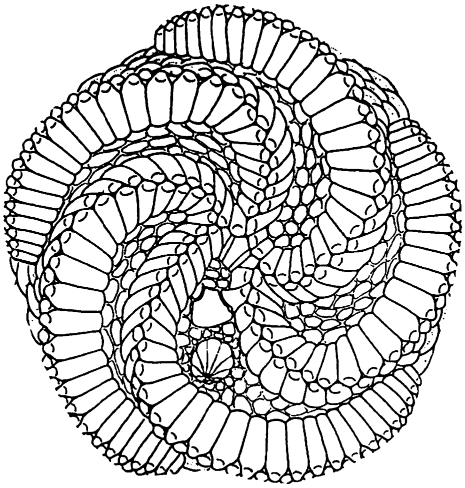
Isorophus



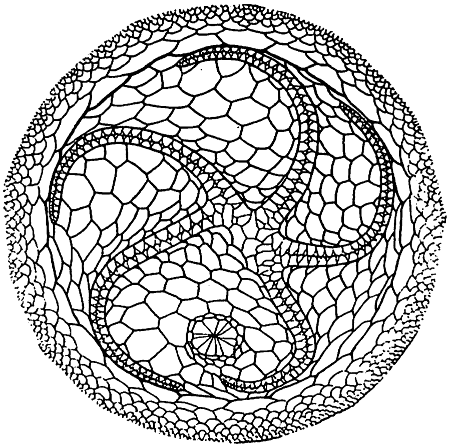
Hemicystites (M.Ord.)



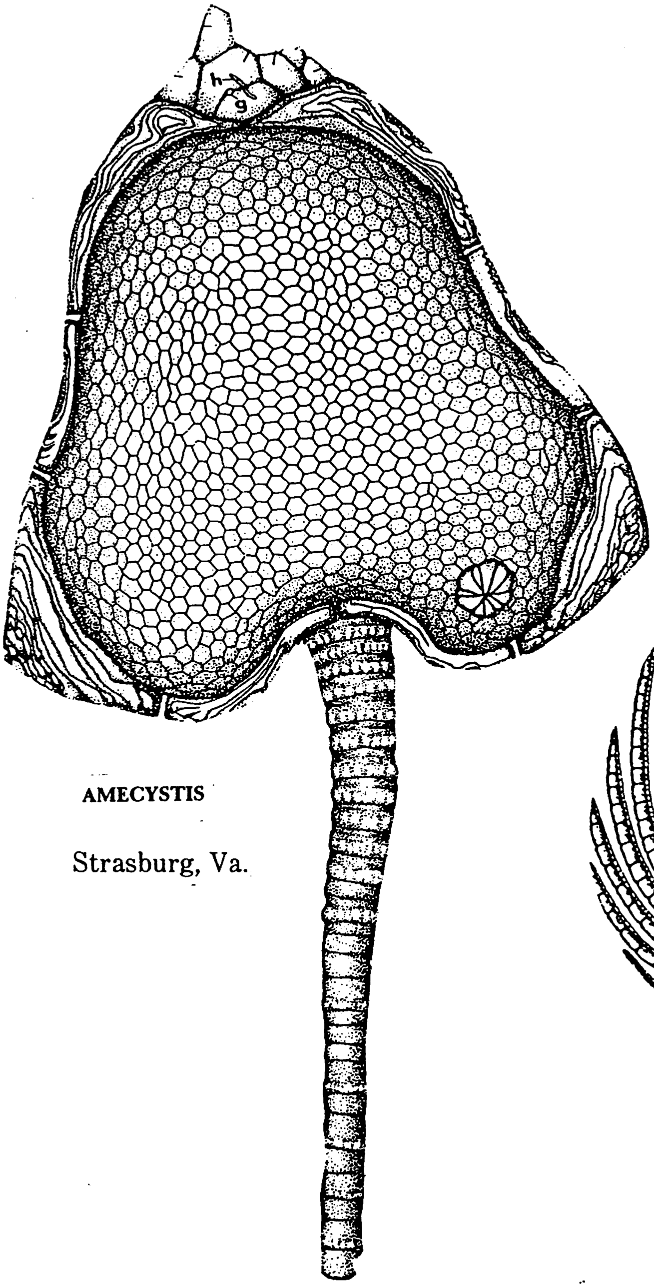
Streptaster (U.Ord.)



Streptaster



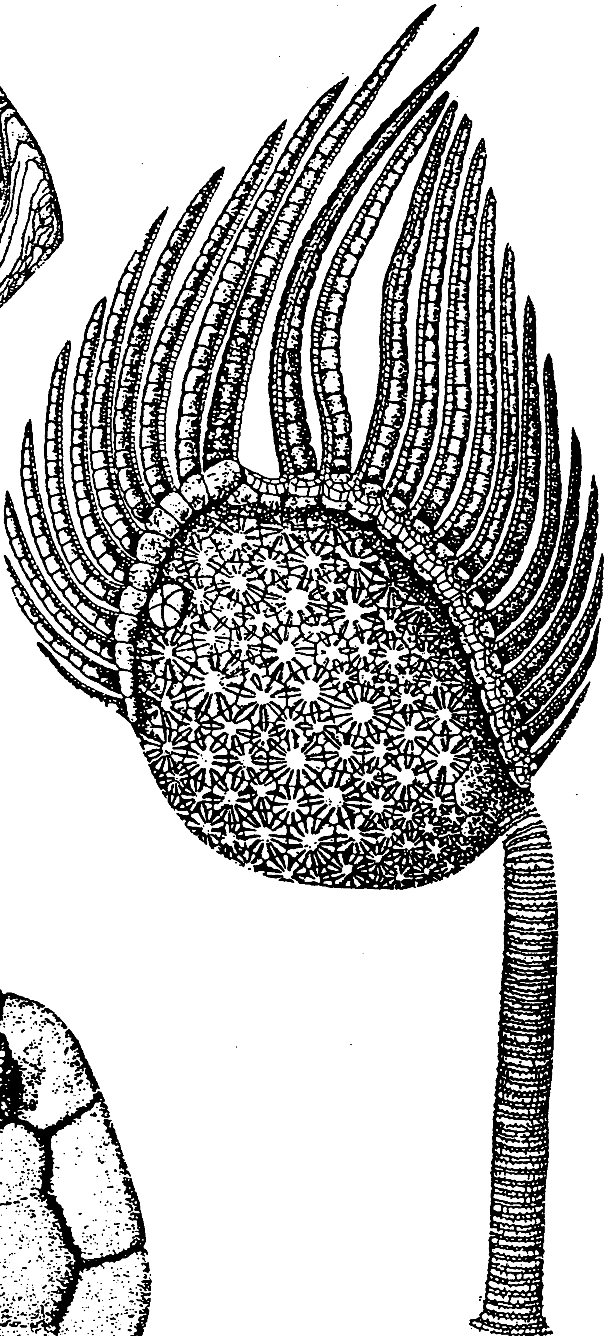
Isorophus

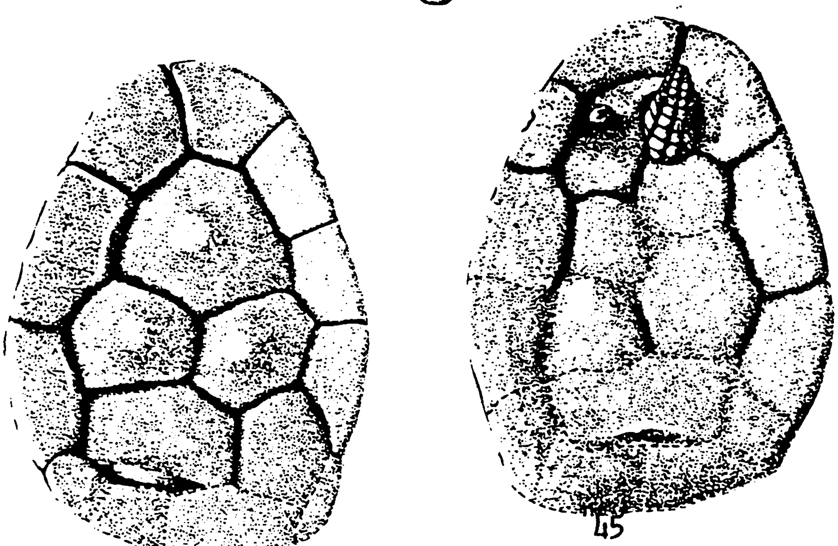


AMECYSTIS

Strasburg, Va.

AMYGDALOCYSTITES





BELEMNOCYSTITES sp.

The Cystoids of the Osgood Shale

by Don Bissett
Hamilton, Ohio

Underlying sections of Ripley, Decatur, Jennings, and Jefferson Counties in southeast Indiana is a deposit called the Osgood Shale. This bed has sporadically produced an abundance of quality invertebrate marine fauna. Of the wide diversity of fossils found, the cystoids appear to have received the most attention by both amateurs and professionals. Cystoids, which usually are not particularly common fossils, have, on occasion, been found in great numbers in the Osgood Shale.

The Osgood Shale

The Osgood Shale is from the Silurian period, approximately 420 million years old. It is named apparently for the small town of Osgood, Ripley County, Indiana. The shale outcrops in a quarry there.

From personal observations of the shale layer in the accessible outcrops, the layer varies in thickness from a few inches to approximately 4 feet, although a published report (1) indicates it can be much thicker at least in one outcrop. The shale is overlain by the Laurel Limestone and sits on top of the Brassfield Limestone, both of which are also from the Silurian. In age, the Osgood Shale is older than the well-known Silurian Waldron Shale which outcrops to the west.

The shale varies in hardness from very soft to extremely hard, containing significant chert, limestone, and pyrite. The fossils in the soft shale are relatively easy to clean with Quaternary O or by air abrasion. The material fround in the harder matrices can be a significant challenge to clean.

The Osgood Cystoids

There is a wide diversity of cystoid genera and species to be found in the Osgood Shale. A recent study, done from specimens Dan Cooper, Bruce Gibson, and I provided to Harrell Strimple and Terry Frest (University of Iowa) approximately 13 years ago, is nearing completion and should be published in early 1994. (Thanks go to Doug DeRosear for originally putting me in contact with Harrell Strimple.) I eagerly await the publications which will describe in detail the genera and species and permit accurate species designations for the material I have collected. I describe here the genera I have collected and can easily distinguish.

Of the hundreds of specimens I have collected or seen from the Osgood, none have brachioles preserved. Otherwise, the cystoids are generally in a fine state of preservation. While the brachioles are not preserved, the brachiole attachments can clearly be seen around the oral opening. Except for a single specimen of one species (a *Caryocrinites ornatus*), I have also not found any stem attached to the base of the cystoids which grew on stems, even though many specimens were collected from their original matrix.

By far the most common cystoid genus in the Osgood Shale is *Holocystites*. A publication by Chris Paul (2) is the best single description of this cystoid genus I have seen. *Holocystites* *scutellatus* (Figure 1) is the most common species found. The theca is oval shaped with a stem-like projection from the base, pustular plates shaped and arranged irregularly, and five brachiole attachements. The theca are generally about 1.5 inches in height. The stem-like projection at the base was for attachment, and the species apparently lived in an upright position.

Interestingly, this species, like the other Osgood *Holocystites* species, often has "bore" holes in the surface of the theca. None of the holes penetrate through the theca, so presumably the cystoid survived the "attack." Some specimens have dozens of such holes in the theca. Paul (2) speculates that the bore holes may be attachment sites for parasites which were fairly specific for species.

All other species of cystoids in the Osgood are rare in comparison to *Holocystites scutellatus*.

There are two *Holocystites* (*Megacystites* in older reports) species which are cylindrical in shape. Both have a short, thin, stem-like process for attachment at the base, have theca which are typically 2.5 inches in length, and have five brachiole attachments. One species (Figure 2) has large hexagonal plates arranged in rows around the theca, while the other species has alternating rows of large hexagonal plates and of small polygonal plates. While they had stem-like processes for attachment, these species appeared to typically lay on their sides since bore holes occur only on one side (presumably the exposed side facing upward), and the oral area is usually at an angle relative to the long axis of the theca, thus permitting the food-gathering brachioles to face upward.

There are several species of *Caryocrinites*, including *C. ornatus* (Figure 3) which occurs in numerous other Silurian formations. The typical specimen has a theca which is less than 1 inch in height, although I found one measuring in at nearly 2 inches and have found fragments of some much larger. The theca has relatively large polygonal plates which, in *C. ornatus*, are highly ornamented with concentric rows of pores. This genus has a relatively flattened top to the theca and grew on a stem.

The largest genus is *Triamara* (Figure 4). The theca is elongate and slightly swollen above the middle. I have one specimen which is almost 4 inches in length, and I have seen fragments of some which were probably much larger. This genus has only three brachiole attachments, and the three ambulacra leading to the oral area cut deep into the top of the theca (Figure 5). *Triamara*, like *Holocystites scutellatus*, had a short stem-like projection at the base for attachment.

My favorite species are from the genera *Trematocystis* and *Paulocystis*. They have four brachiole attachments and four relatively long, elevated ambulacra running to the square oral area. The squat theca are generally less than 1 inch in height. They have attachment bases which in some cases are as large in diameter as the theca. These species probably sat directly on the bottom. Species of the genus *Trematocystis* have few relatively large and indistinct thecal plates. Species of the other genus, a new one (tentatively called *Paulocystis* by Harrell Strimple), have numerous small, irregularly shaped plates which are arranged somewhat in rows around the theca (Figure 6).

As an indicator of the relative abundance of the various cystoid species, the table below lists the approximate number of specimens (this includes complete and incomplete specimens) found per year, based on my 14 years of collecting the Osgood Shale:

Species	Number found per year
Holocystites scutellatus	100
Holocystites sp. (cylindrical species)	6
Caryocrinites	4
Triamara	2
Paulocystis	1
Trematocystis	< 1

I have partials of other even rarer species which do not fall into the groupings listed above. I await the publication of the study by Strimple and Frest to classify these.

Other Osgood Echinoderms

There are several species of crinoids in the Osgood Shale. Like the cystoids, they do not have attached arms or stems, although an abundance of stem sections can be found. *Eucalyptocrinites* and a few other large species (calyxes > 1/2 inch) are less common than many of the cystoid species. They also are not as well preserved as the cystoids. However, there is an abundance of small species (*Pisocrinus* and *Stephanocrinus*), which are typically 1/4-inch tall calyxes. I used to bring home buckets of shale and wash it down to recover about 50 of them from 5 gallons of weathered shale.

One specimen of a blastoid (< 1/4 inch theca) was recovered from washings I sent to Harrell Strimple. To my knowledge, no other specimens have been found. I also have one specimen of a paracrinoid (1.25 inches tall theca).

Other Osgood Invertebrate Fossils

In addition to the wide variety of echinoderms from the Osgood Shale, there are many other invertebrate species found: corals, bryozoa, brachiopods, cephalopods, gastropods, occasional sponges, and a single specimen of a pelecypod (again from the shale washings examined by Harrell Strimple). I sent specimens to several professionals at institutions in the US. Based on their assessments, the specimens belong to known genera, but most have not been studied extensively nor classified as to species. Here is an opportunity for study.

There are at least three genera of trilobites found: *Bumastus, Dalmanites, Spathacalymene*). I have only seen fragments of the former two species, and complete specimens of the latter (the "snout-nosed" trilobite) are rare. I have only one complete specimen and three which are about 90% complete.

Collecting Localities

There are few Osgood Shale localities that are readily accessible, and the occurrence of fossils is not uniform. Even within a locality, the abundance of fossils can vary greatly over even very short distances.

The shale layer apparently acquired its name from the town of Osgood, IN where a quarry permitted collecting until operations ended there many years ago. That quarry is now full of water, the state in which I first observed it over 10 years ago. I did not find any specimens on my visit, but I have seen fine quality cystoid material from there in a small collection in the Geology Department at the University of Cincinnati.

Historically, a very rich locality was the creek bank in what is now Jefferson Proving Grounds, a military weapons testing area. However, permission to collect is difficult to obtain, and collecting is hazardous because of the unexploded shells on the surface. I have not collected this site, but professionals have been permitted to collect material there (2). The site may now or in the future be more accessible since this area will be shut down as a weapons testing facility as part of the military budget cut-back.

The most accessible site is the active quarry in Napoleon, IN. Permission to collect can generally be obtained, although on many occasions permission cannot be obtained when quarrying operations were particularly heavy (especially true in summer). In the quarry, the contact between the lower Silurian and upper Ordovician strata can be seen, and some Ordovician fossils (mostly corals, bryozoa, and brachiopods) can be found on the spoil piles. Approximately fourteen years ago, hundreds of Silurian cystoids were collected when an area of high concentration in the Osgood Shale was exposed. The prolific output of the quarry lasted only 2 years. Extraction of the "good" shale ended when the property line was reached, and the producing spoil piles have long since been buried as quarrying continues. The shale layer in the remaining parts of the quarry is much thinner than that mined previously, and there has not been a significant discovery of cystoids since. I periodically collect the quarry, and occasionally specimens do crop up on the spoil piles, although now most of the shale piles are buried under overburden, primarily top soil.

There are several other active quarries in which the Osgood Member outcrops. New Point Stone in Batesville, IN has a foot thick seam of Osgood Shale. Fossils are few and far between here. St. Paul Quarry in St. Paul, IN is well known for its Waldron Shale material but has also been reported to occasionally produce Osgood fossils from the very base of the wall. I have collected this quarry on many occasions but have not encountered any Osgood material. Other quarries in the area with Osgood Member strata do not permit collectors on the property.

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2. C. R. C. Paul, "Revision of the *Holocystites* Fauna (Diploporita) of North America," Fieldiana Geology, vol. 24, pp. 1-166, September 29, 1971.

Figure 1. *Holocystites scutellatus*, side view.

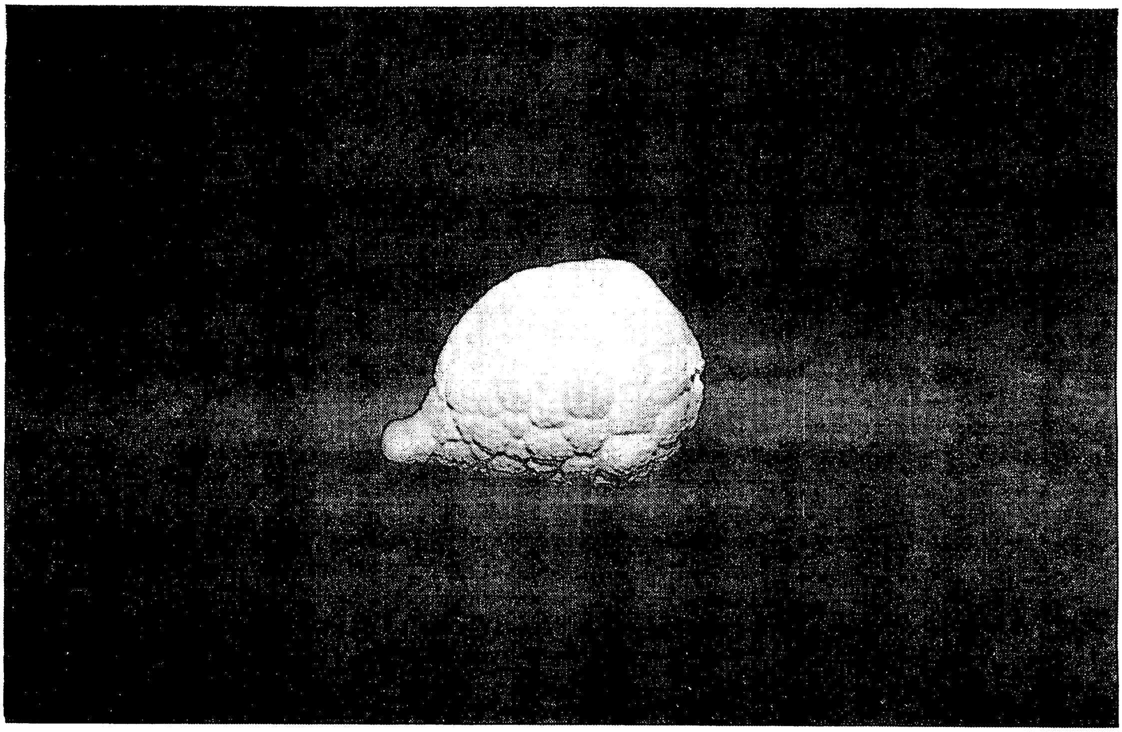


Figure 2. *Holocystites* sp., side view.

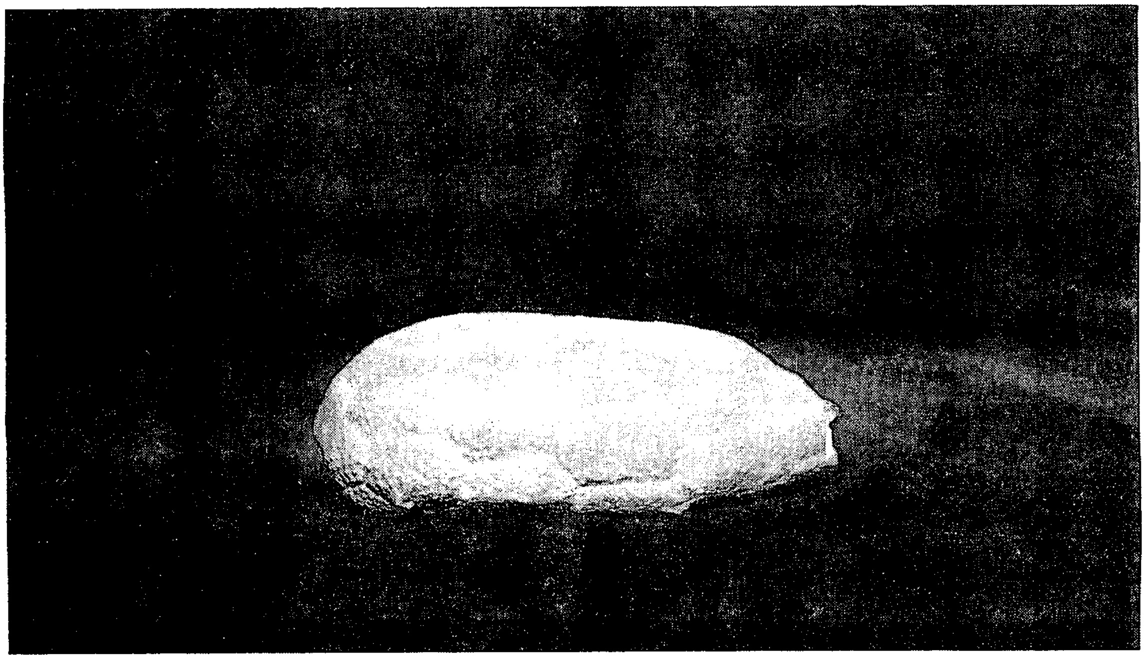


Figure 3. *Caryocrinites ornatus*, side view.

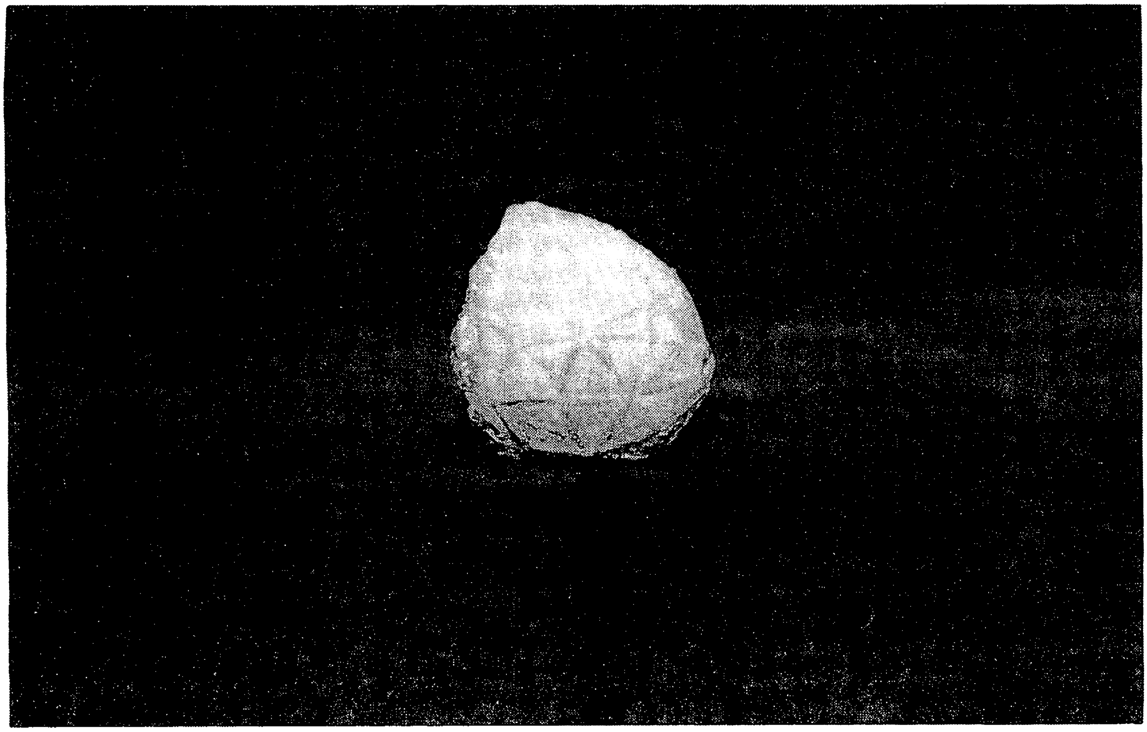


Figure 4. *Triamara* sp., side view.

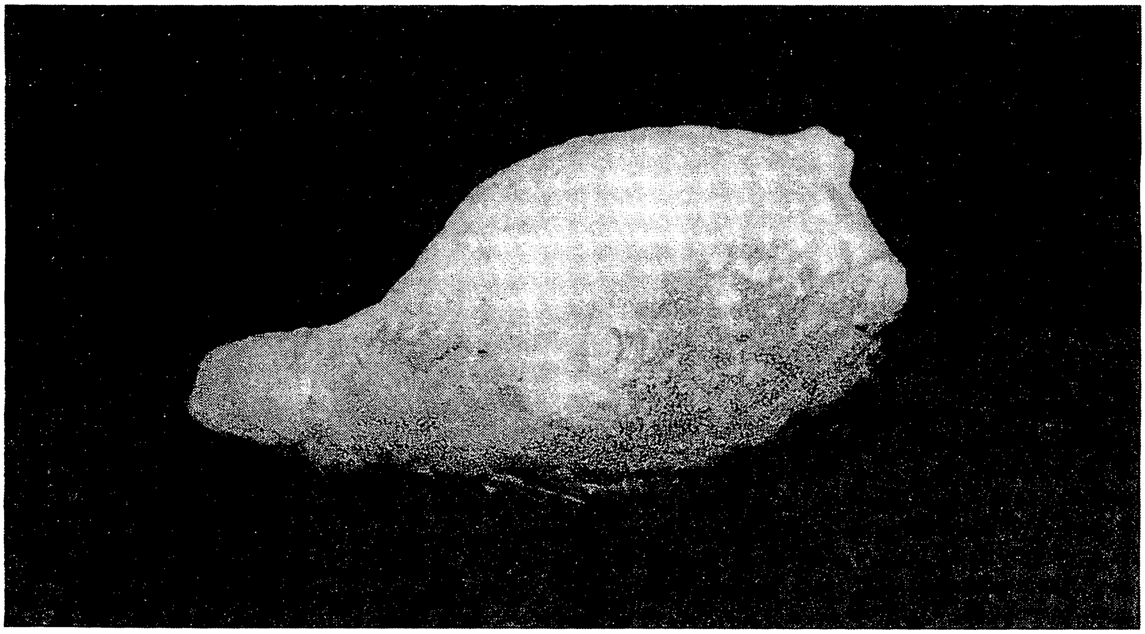


Figure 5. *Triamara* sp., view of oral area.

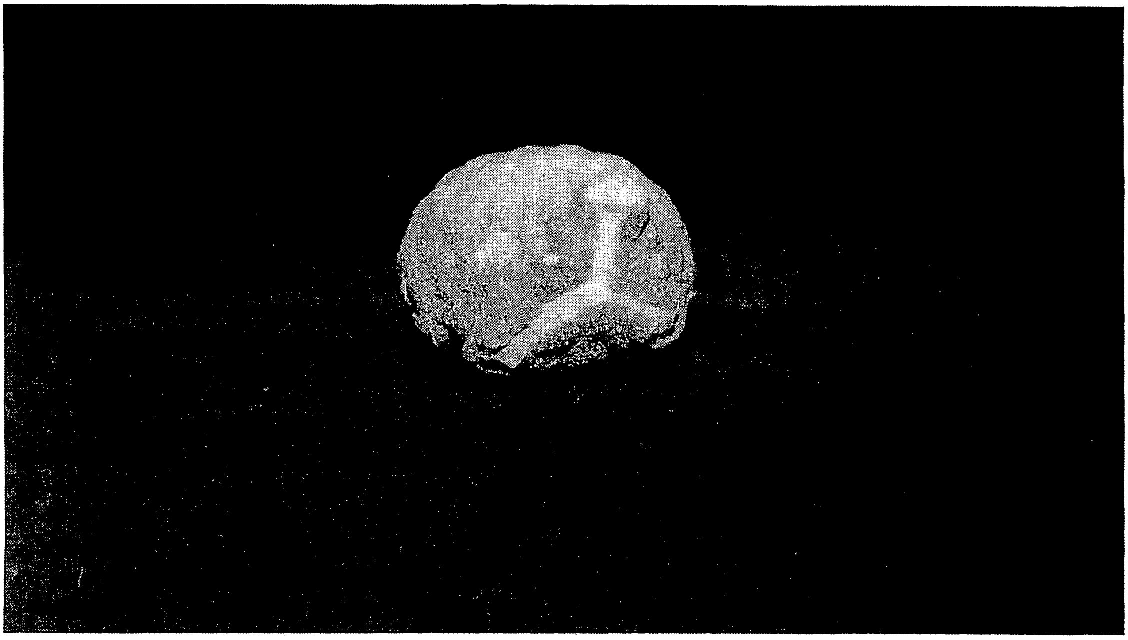
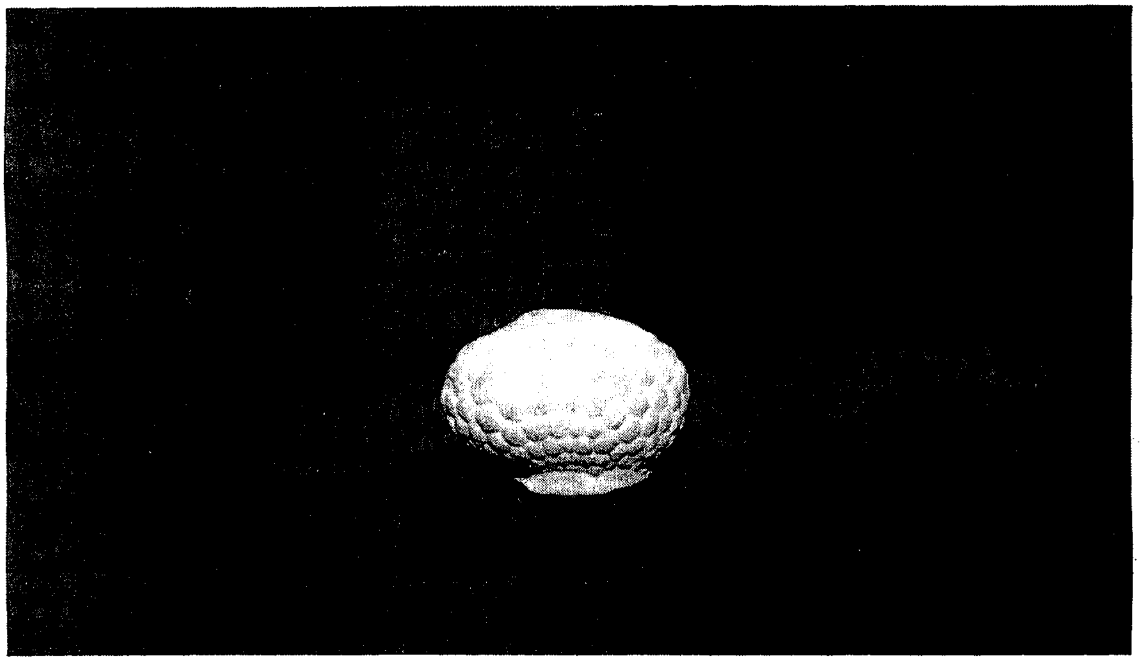


Figure 6. *Paulocystis* sp., side view.



COLOR MARKINGS OF THE CARBONIFEROUS BLASTOID PENTREMITES

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Abstract - Recent collections of the blastoid Pentremites have yielded distinct color markings from two localities. These markings are strikingly similar and suggest a common origin. The purpose of this article is to document and describe these occurrences and to promote further research on the subject.

INTRODUCTION

Blastoids retaining color markings were previously reported (Reimann, 1961) from a single isolated occurrence in the Devonian Widder Formation of Thedford, Ontario. The markings in these Devonian specimens, originally described as Hyperoblastus alveata, have distinct markings that run parallel to the growth lines. The markings in the Pentremites run perpendicular to the growth lines and have been observed in four specimens, from at least two localities. Both of these localities correlate in age and have very similar blastoid faunas. There are other specimens in both the Devonian and Mississippian that retain possible color markings, but lack a number of specimens showing consistent patterns to be considered valid color markings at this time.

Color Markings of Pentremites

Radials: All of the specimens retain markings on the radials that run perpendicular to the growth lines. These markings run the complete length of the plate and appear to be present in all five plates where preservation allows.

Deltoids: Again all of the Pentremites retain markings on the deltoids that run perpendicular to the growths lines in a chevron like pattern. In some of the specimens the pattern of these markings are harder discern.

Basals: Only two of four specimens have markings retained on the basal plates. This difference is probably due to preservation differences. Again the marking run perpendicular to the growth lines in all specimens.

relate to increased success of Pentremites in the Chesterian. These markings could have reduced predation by camouflaging of the most prominent part of the blastoid and allowed Pentremites to reach its larger stature towards the end of the Chesterian.

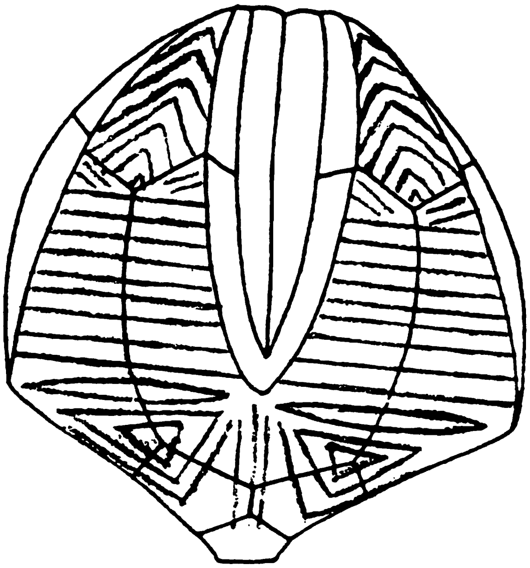

Figure 1 -- Sketch of the color markings on the blastoid Pentremites godoni, from the Elwren Formation, Locality #1, Specimen #1.

Paleontology

Locality 1: This occurrence is from the Elwren Fm. of Kentucky, and two specimens have been collected from here. The blastoids are found in a fine grained shale and both specimens were surface collected. The blastoids here are abundant and are occasionally found with their cover plates still attached. About 1500 specimens of the species Pentremites godoni were examined to produce these two specimens. Specimen #1 is approximately 16mm high and the markings about .5mm thick and about .5mm apart. The markings are retained on all plates of this blastoid. Specimen #2 is approximately 9mm high and the markings are .25mm thick and .5mm apart. The markings are retained on all plates of this blastoid except for a portion of the basals that are missing.

Locality #2: This occurrence is from the Paint Creek Fm., Ridenhower Shale Mbr. at Prarie Du Long Creek, Illinois and two specimens were collected from here. The blastoids were dug from a fine grained shale at the base of this locality. The blastoids here are abundant and some retain the brachioles and stem. About 1000 specimens of the species Pentremites godoni were examined to produce these two specimens. Specimen #1 is approximately 26mm high and the markings are .5mm thick and .25mm apart. The markings are absent from the basals and weathered from one deltoid. Specimen #2 is approximately 20mm high and the markings are .25mm thick and .5mm apart. Unfortunately the specimen is in matrix and only two deltoids and three radials are exposed, but all retain markings.

Comparison

The differences in the color markings from these two localities are slight, but the chief difference is in the preservation. The specimens from localities have markings that are dark bands on the lighter background. In contrast the color markings in Hyperoblastus are light bands on a darker backgroud that run in alternating bands that are parallel to the growth lines. The specimens from locality #2 have slightly thinner markings that in some cases, near the margin of ambulacral rim, intersect each other. Also the markings on the deltoids from locality #2 are harder to discern, possibly due to their size or preservation.

Conclusion

At this point further studies are needed to determine the exact origin of these markings. It is possible the markings are an artifact of some structure or actual color marking on the living blastoid. It is also possible that these markings are by-product of the process of fossilization or weathering, and relate to the calcite crystal replacing the blastoid plate, but this seems less likely due to the uniformity in the markings. If the color markings are remnants of the living blastoid color, this could

Localities

Locality #1: Elwren Formation. Roadcut on east side of State Highway 24, Hardin Springs, Hardin County, Kentucky. Madrid 7.5 minute quadrangle, Carter coordinates C 20-N-39.

Locality #2: Paint Creek Formation, Ridenhower Shale Member. South bank of Prarie du Long Creek, Near Millstadt, St. Clair County, Illinois. Millstadt 7.5 minute quadrangle, SW 1/4, SE 1/4, SW 1/4, Sec. 3, T28, R9W.

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BLASTOIDS OF MICHIGAN

Alex J. Fabian

INTRODUCTION

The blastoids of Michigan all occur in the Middle Devonian, from three different areas of the state. Blastoids have been collected from this state in great number and diversity for over a hundred years. The primary area for blastoids is in Alpena County. What is so unusual about this area is that stratigraphically only New York provides a comparable set of sections that produce blastoids. But in New York these Sections are geographically set apart by some distances. In contrast, Alpena County affords collecting a large section of blastoid producing strata within a ten mile area. The other two blastoid collecting areas are a single Silica Shale locality near Milan and an exposure of Whiskey Creek Formation near Norwood.

Table 1 -- Middle Devonian Sections of Michigan, * denotes occurrence of Blastoids.

Northeast Section	Northwest Section	Southeast Section
Squaw Bay Limestone		
*Thunder Bay Fm.	*Whiskey Creek Fm.	
*Potter Farm Fm.	Petoskey Fm.	
*Norway Point Fm.		
*Four Mile Dam Fm.		
*Dock Street Clay Member Four Mile Dam Fm.	Charlevoix Fm.	Ten Mile Creek Dolomite
*Alpena Limestone	Gravel Point Fm.	
Newton Creek Limestone		
*Genshaw Fm.		
*Ferron Point Fm.		
Rockport Limestone		*Silica Shale Fm.
*Bell Shale Fm.	Bell Shale Fm.	
Rogers City Limestone		

Table 2 -- Occurrence of Blastoids in Michigan.

Abbreviated Formation Names

	SS	BS	FP	GF	AL	DSC	FMD	NP	PF	TB	WC
Eluetherocrinus sp.						*					
Heteroschisma alatum									*		
Heteroschisma canadese						*					
Heteroschisma subtrunctatum										*	*
Heteroschisma sp.		*			*		*				
Hyperoblastus arrecta		*									
Hyperoblastus bassleri										*	*
Hyperoblastus cooperi								*			
Hyperoblastus decipens?						*					
Hyperoblastus reimanni	*										
Hyperoblastus sp.			*	*							
Nulceocrinus meloniformis										*	
Nucleocrinus sp.		*				*			*		
Placoblastus ehlersi						*					
Placoblastus obovatus										*	*
Placoblastus sp.							*				

Paleontology

Silica Shale Formation: Blastoids from this Formation occur from one locality near Milan, Michigan. A single species, Hyperoblastus reimanni, is found here. Several tens of specimens have been collected from the dump piles, many very well preserved.

Bell Shale Formation: Blastoids from this formation occur in several localities in and near Alpena County. Three species of blastoids occur here: Hyperoblastus arrecta, Heteroschisma sp. and Nucleocrinus sp.. Probably several hundred specimens from this locality have been collected over the years. Very rarely Hyperoblastus arrecta from this formation retain some brachioles. Both the Heteroschisma and Nucleocrinus have yet to be described from this formation.

Ferron Point Formation: Blastoids from this formation have been collected from one locality in Alpena County. Only one specimen of an undescribed Hyperoblastus has been found in this formation.

Genshaw formation: Blastoids from this formation occur in several locations in Alpena county. Only three complete specimens and several plates of an undescribed Hyperoblastus are known from this formation.

Alpena Limestone: Blastoids from this formation have been collected from one locality in Alpena County. Only one complete and one partial specimen of an undescribed Heteroschisma are known from this formation.

Dock Street Clay Member of the Four Mile Dam Formation: Blastoids from this formation have been collected from at least four localities in Alpena County. At least five species of blastoids occur here: Eluetherocrinus sp., Heteroschisma canadese, Hyperoblastus decipens?, Nucleocrinus sp. and Placoblastus ehlersi. Several tens of specimens from this formation have been collected and some retain brachioles.

Four Mile Dam Formation (exclusive of Dock Street Clay Member): Blastoids from this formation have been collected from one locality. At least two species of blastoids occur here: Heteroschisma sp. and Placoblastus sp. (plates only). About a dozen specimens of an undescribed Heteroschisma have been collected and one even retains a proximal portion of the stem. The Placoblastus sp. is only represented by a single plate and the generic assignment of this specimen is assumed by its size.

Norway Point Formation: Blastoids from this formation come from a single locality in Alpena County. About hundred specimens of Hyperoblastus cooperi have been collected.

Potter Farm Formation: Blastoids from this formation come from several localities in Alpena County. Only two species of blastoids occur here: Heteroschisma alatum and Nucleocrinus sp.. Several hundred specimens of Heteroschisma alatum and two complete and many plates of an undescribed Nucleocrinus sp..

Thunder Bay Formation: Blastoids from this formation come from one locality in Alpena County. At least four species of blastoid occurs here: Heteroschisma subtrunctatum, Hyperoblastus bassleri, Nucleocrinus meloniformis and Placoblastus obovatus. Several thousand specimens, primarily Heteroschisma subtrunctatum, have probably been collected here.

Whiskey Creek Formation: Blastoids from this formation come from one locality near Norwood. Three species of blastoid occur here: Heteroschisma subtrunctatum, Hyperoblastus bassleri and Placoblastus obovatus. Several hundred specimens, primarily Heteroschisma subtrunctatum, have been collected here. Some of the Hyperoblastus bassleri retain some brachioles and proximal stem segments.

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A CAMBRIAN STALKED ECHINODERM

Pelmatozoans (stalked echinoderms which are attached by a holdfast) such as crinoids and blastoids, were abundant and diverse in shallow, epicontinental sea deposits of Paleozoic age. Except in the Cambrian period, stalked echinoderms are often (as fragments if not as complete specimens) abundant fossils. In the Cambrian eocrinoids can be abundant, but these lack a true stalk or holdfast. Eocrinoids, in their absence of a stem as well as other features, make them quite distinct from crinoids and they consequently are placed in a separate, and extinct, taxonomic class.

In the Upper Cambrian Davis Formation of Missouri, particularly in the "old lead belt area" wart-like holdfasts of a stalked echinoderm are fairly common. These occur on the top of layers of pecular limestone pebble conglomerate beds. These layers of conglomerate must have presented a firm and hard surface upon which the pelmatozoans attached. The illustrated pelmatazoan was found associated with these holdfasts in a roadside excavation. The fossil probably represents that part of the animal which was attached to one of the holdfasts. It's not a crinoid, at least in the normal crinoid make-up of a calyx with arms and pinnules. Its stem however, does look like that of a true crinoid. Is this a crinoid or not? It's questionable and its definitely not an eocrinoid. Only a few Cambrian crinoids have been found, one being from the famous Burgess shale of British Columbia.

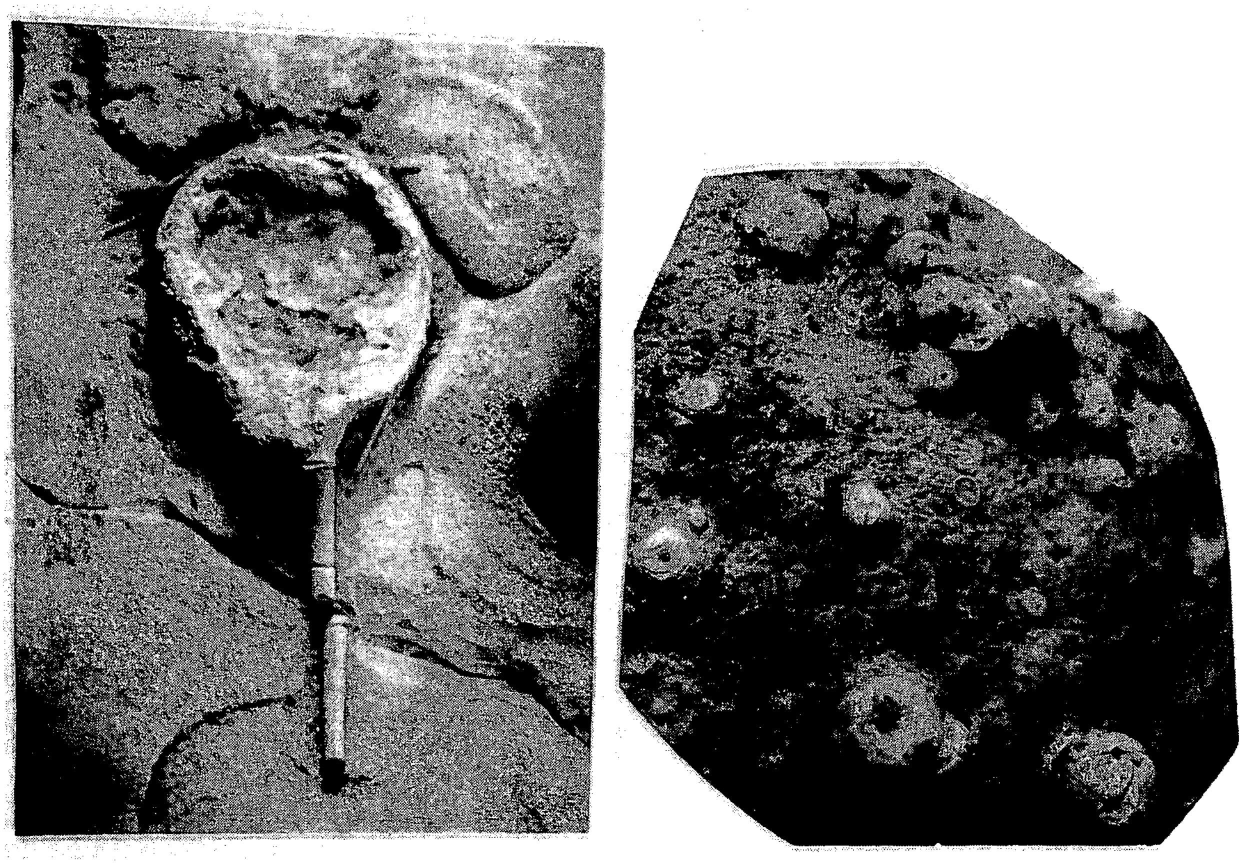
It's an enigma, true to form for a lot of Cambrian fossils. Many Cambrian fossils, once thought to be ancestors of later life forms are turning out instead to be evolutionary dead ends. Evolutionary dead ends which left no descendents either in later geologic time or today.

One wishes that when a fossil like this is found that more than one specimen would turn up. Multiple specimens would give more definite information on the organism that does just a single specimen as was the case with this fossil. Unfortunatly no more were to be found even after considerable searching. Somewhere however, in Cambrian strata lie numerous fossils of these interesting organisms. Fossils which would probably solve the mystery as to what group of echinoderms these pelmatozoans are related to, be they crinoids, eocrinoids or something completely different.

Bruce L. Stinchcomb

Left. Pelmatozoan echinoderm from Upper Cambrian Davis Formation near Bonneterre Missouri. Pebble of conglomerate at 2:00 O'clock from the circular calyx, X 1.0.

Right. Pelmatozoan holdfasts attached to hardground of limestone pebble conglomerate. Upper Cambrian Davis Formation near Bonneterre Missouri, X 2.0



Edrioasteroids

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"Edrioasteroids are not common fossils." These words begin the introduction to Bruce Bell's book, A Study of North American Edrioasteroidea. It's true. Look around at the MAPS Expo - you'll see trilobites from China and Moroccan ammonites, but few "edrios". But they aren't totally uncommon fossils either, because when you find a bed of edrios, you generally find dozens or hundreds of them.

Some of my first "digs" involved looking for edrios in the Cincinnati area about ten years ago. Cincinnati has had a special role in the study of these echinoderms. Specimens uncovered in this area in 1964 prompted Bell to do a major review of the class, since attempts to classify the prolific number of fossils produced inconsistencies. Bell credits an amateur, W. H. White, Jr., in revealing the occurrence of the specimens.

It's easy to see that edrios are echinoderms. Their five-fold symmetry is obvious, as can be seen in Figure 1, which illustrates a specimen from my collection. In fact, their appearance is that of a small starfish perched on a platform. But their mode of living was different than those of other typical echinoderms we think of, such as crinoids and echinoids. The fact that they left no living ancestors for comparative study means that our understanding of them is even more difficult to come by.

I first collected edrios with a co-worker, Don Bissett. We dug slabs of limestone from a bank behind a shopping center in Fairfield, OH. We had to cut down through a large amount of overburden to reach the layer. We examined the limestone for the telltale mounds which denoted an edrio perched on top of a brachiopod. Some we could see, others required weathering (sometimes in a vacant lot near Don's house). We found a few specimens. They aren't spectacular, and they are on thick and unwieldy limestone slabs. But they were some of the first fossils I wrestled from the ground with pick and shovel. Now Don is my neighbor, the vacant lot is no longer vacant, and we've since dug edrios many times.

Just how common, or uncommon, are edrios? They range from the lower Cambrian to the Mississippian, where they disappear from the fossil record. In terms of number of genera, they reached a peak in the middle Ordovician, with a smaller peak in the upper Devonian. The Treatise on Invertebrate Paleontology, Part U, Echinodermata 3 notes that the Edrioasteroidea have not been recorded in abundance outside of North America and Europe. It would appear that they are indeed uncommon fossils. My view of them is clouded by the fact that the Cincinnati Arch has yielded such numbers of specimens.

Descriptive Morphology

The viscera were enclosed in a capsule called the theca. The theca is divided into five ambulacral and five interambulacral areas by the ambulacral grooves. The groove served to move food to the mouth by means of ciliary currents. Many species have curved ambulacra. The curve may be clockwise or counter-clockwise. All may curve in one direction, or they sometimes curve in opposite directions on the same specimen. Distal plates form a peripheral ring around the perimeter of most species. The outer plates of the ring were capable of adjusting their shape to that of the attachment surface. The peripheral ring is often raised above the central portion of the theca, though this is due to the collapse of the central area following decay of the animal.

The adoral surface of the theca is defined as that containing the mouth and anus, and is directed upward. The aboral surface is directed downward. Some species exhibit a series of plates as the aboral surface, but little information is available about the aboral structure of most. In species that were attached to an object by the entire aboral surface, dissection is necessary for examination. When Foereste etched away the clay inside the theca of *Carneyella cincinnatiensis,* he found no aboral plates, even though the underlying *Rafinesquina* shell was preserved. He concluded that in these forms the aboral plates were obsolete, and that a fleshy surface was better for attachment.

The peristome is the area containing the mouth, and is similar in most genera. The mouth chamber is made up of five triangular-shaped plates. Food was passed from the ambulacral grooves to the gullet through this chamber. The periproct, or anal area, is located on the same surface as the peristome. A third aperture may have been used as an intake for water into the vascular system (hydopore), or as an outlet for the genital system (gonopore), or served both functions.

A stem is not found in the edrioasteroids. In some genera, the theca is extended in the vertical direction, as compared with the disclike theca of most specimens, in effect serving as a stem.

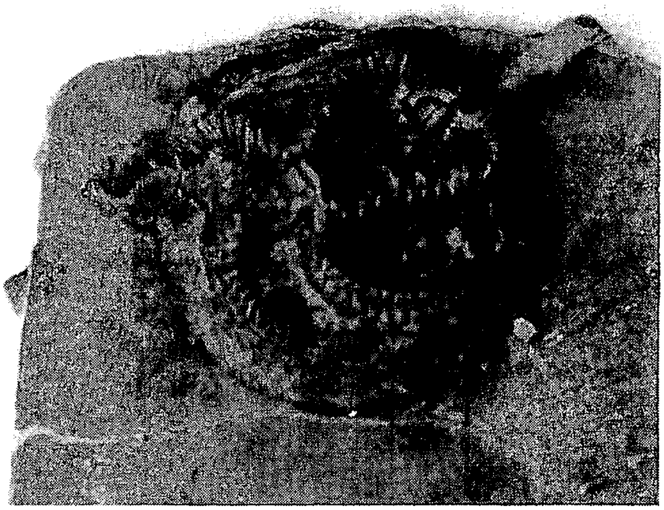


Figure 1

Carneyella

Organ Systems

The organization of the digestive tract may be inferred from comparison to crinoids. Presumably, a ciliated groove extended along each ambulacral trough to conduct food to the central mouth. A looped gut may have coiled around the thecal cavity, as is found in other echinoderms.

The hydrovascular system included the hydropore and associated internal canals. The hydropore lies between the oral and anal areas, as in many other primitive echinoderms such as crinoids and cystoids. Little evidence for the internal structures is found, leaving much open to interpretation. Two different modes of respiration seem to have been employed. The order Edrioasterida and the suborder Lebetodiscina are thought to have respired using external extensions of the hydrovascular system which were directly exposed to the seawater when the ambulacral coverplates were open. Respiration would have occurred by exchange of gases at the surface of the membrane. The suborder Isorophina appear to have performed this function via anal pumping of seawater. Their anal structure is shaped as a valve, with overlapping triangular plates. The flexible theca would allow expansion and contraction, providing intake and exit of water. This valve-like structure contrasts with the loose and irregular circle of anal plates found in the Edrioasterida and Lebetodiscina.

Evolutionary Trends

Edrioasteroids adopted a pelmatozoan way of life, which is characterized by spending their post-larval life attached to a substrate. Figure 2 (from the Treatise) schematically illustrates a possible phylogenetic relationship between the echinozoans. The echinozoans are a subphylum characterized as globoid or cylindrical, and lacking arms or brachioles that occur in most crinozoans, and lacking the outspread rays found in the subphylum asterozoa (starfish, for example). Thus the edrioasteroids are more closely related to echinoids and cyclocystoids than to the more familiar crinoids, blastoids and starfish. The figure also illustrates the disappearance of edrios in the Carboniferous, as well as the lack of knowledge of Precambrian ancestors.

Within the edrioasteroids, a general evolutionary trend toward lengthening the ambulacral grooves is found. This may be due to the fact that these grooves retained the function of collecting food, with obvious advantages to a larger collecting area. A limit to the extension of the ambulacra was set by the peripheral ring, which in many cases was rigid. This led to curvature of the ambulacra, which is more obvious in the geologically younger genera.

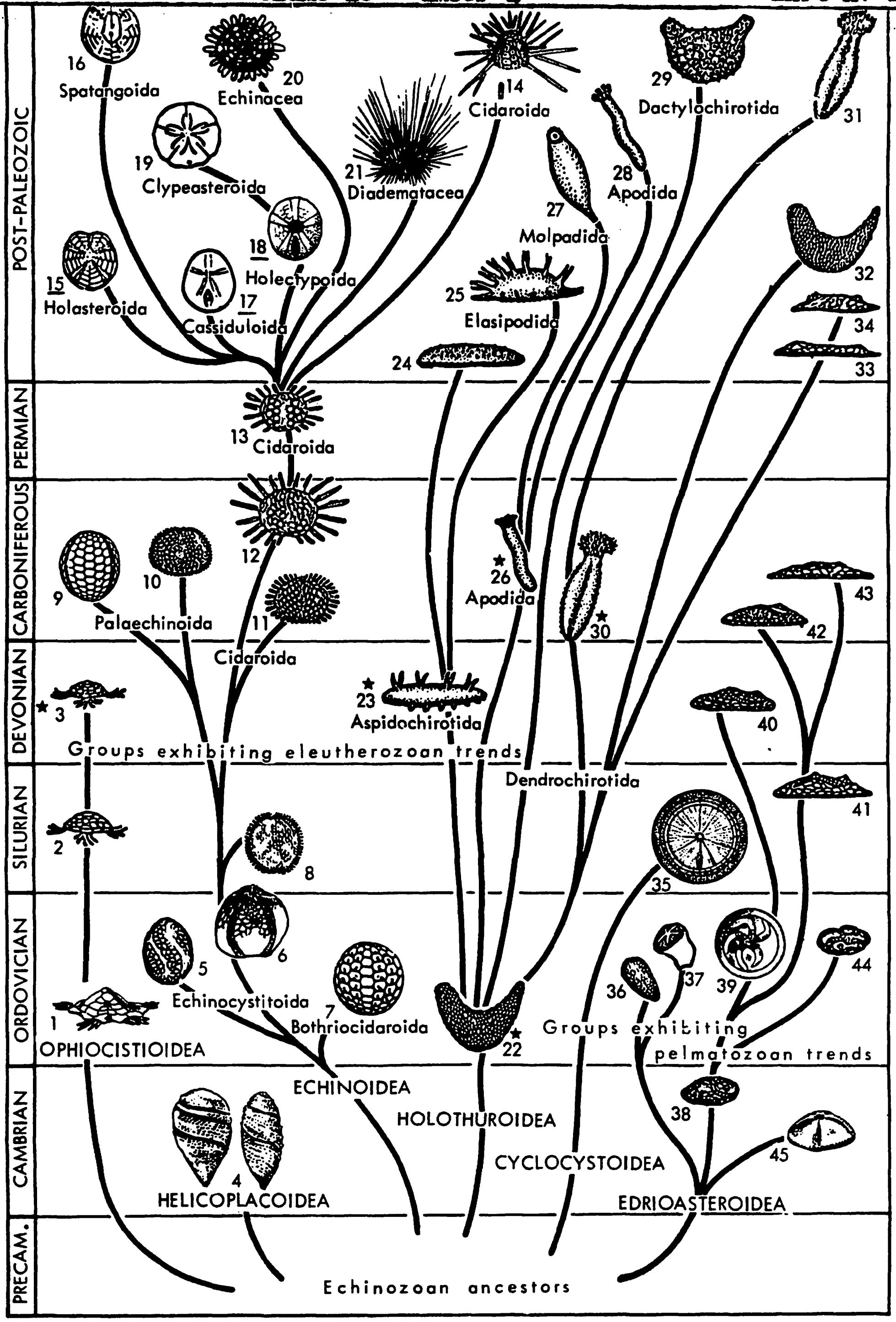


Diagram representing postulated phylogenetic relationships of echinozoan classes and orders (modified from Fell). [Explanation: Highly conjectural reconstructions of some genera indicated by star. Numbers are for identification of genera selected to illustrate class and order groups, forms known only as fossils in post-Paleozoic part of chart marked by underlined numbers. 1, *Volchovia;* 2, *Sollasina;* 3, *Rhenosquama;* 4, *Helicoplacus;* 5, *Eothuria;* 6, *Aulechinus;* 7, *Bothriocidaris;* 8, *Echinocystites;* 9, *Palaechinus;* 10, *Pholidocidaris;* 11, *Lepidocidaris;* 12, *Archaeocidaris;* 13, *Miocidaris;* 14, *Cidaris;* 15, *Holaster;* 16, *Echinocardium;* 17, *Nucleolites;* 18, *Holectypus;* 19, *Arachnoides;* 20, *Colobocentrotus;* 21, *Diadema;* 22, *Thuroholia;* 23, *Protocaudina;* 24, *Stichopus;* 25, *Deima;* 26, *Thallatocanthus;* 27, *Molpadia;* 28, *Chiridota;* 29, *Ypsilothuria;* 30, *Calclamna;* 31, *Cucumaria;* 32, *Placothuria;* 33, *Lepidopsolus;* 34, *Psolus;* 35, *Cyclocystoides;* 36, *Cystaster;* 37, *Cyathocystis;* 38, *Walcottidiscus;* 39, *Isorophus;* 40, *Agelacrinites;* 41, *Hemicystites;* 42, *Lepidodiscus;* 43, *Hemicystites;* 44, *Edrioaster;* 45, *Stromatocystites.*]

Figure 2

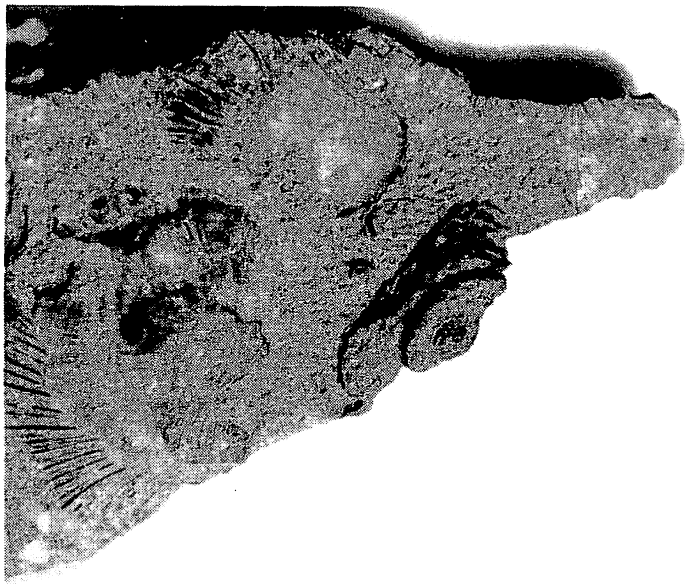
Ontogeny

Ontogeny refers to the development within an organism as it grows from embryo to adult. This type of growth series has been observed in a few edrioasteroid species. The tiniest specimens were about 0.5 mm in diameter, representing adults who grow to 15 to 18 mm in diameter. The dominant feature of the smallest ones is the peripheral rim, which forms two-thirds of the total surface area. The central area is made up of the oral-ambulacral plates. This is in the form of a trilobed structure. As plates are added to the ambulacral region, the peripheral rim adds new circles of plates, enlarging the circumference of the rim. Two of the three ambulacral radii bifurcate to form four lateral ambulacra. As more ambulacral plates are added, the area takes on a five-part shape. This occurs when the theca diameter is about 3 mm. Curvature of the ambulacra begins at a diameter of 4-5 mm, in those species in which curvature occurs. The interambulacral plates increase in number as the ambulacra lengthen. Beyond the 5 mm stage, adult features are more pronounced.

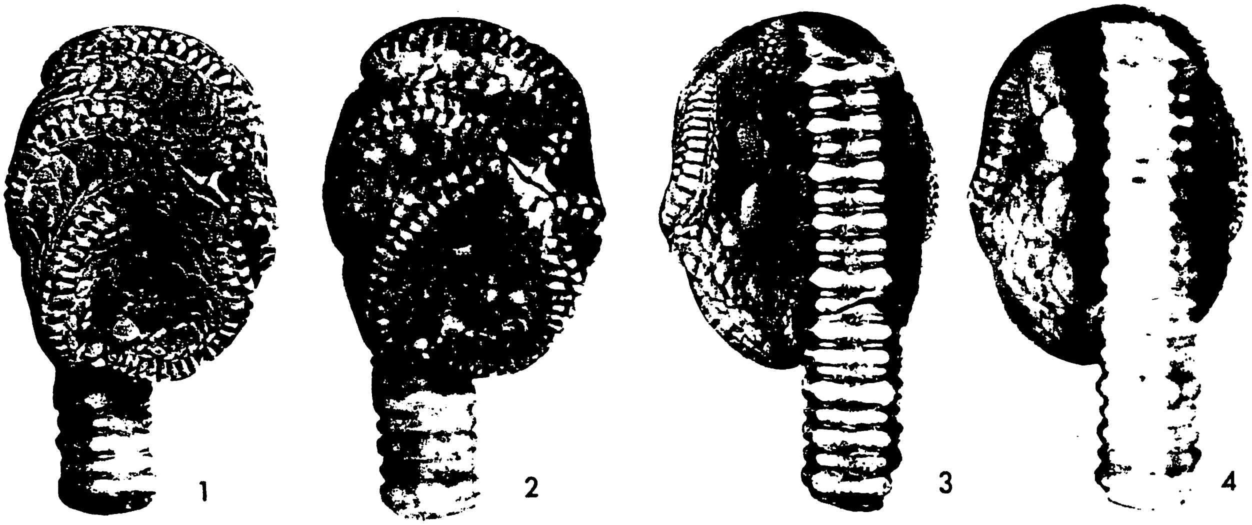
Ecology

Edrioasteroid fossils have been found within sandstones, shales, marls, and limestones. Some may have been attached directly to the firm bottom surface, though most were attached to some hard, external object. Most often this attachment was to the valve of a brachiopod (especially *Rafinesquina*). Other examples include corals, bryozoans, or crinoids. Figure 3 shows a specimen of *Isorophus cincinnatiensis* from my collection which is attached to a section of bryozoan. Figure 4 is taken from Bell's Plate 17, showing *Carneyella pilea* attached to a crinoid stem, in a remarkable show of flexibility. Most species seem to have been selective in their choice of hosts. They don't appear to have been parasitic, nor does it seem that they were attached to dead organisms, since they aren't found on trilobite molts, for example. Most were permanently attached, while others were able to perform some shifts in position. Young specimens of some species are found on the lateral margins of brachiopods, while adults of the same species are centered on the brachiopod, implying migration to the center of the valve. Convincing evidence that some species were immobile is found from fossils showing larger individuals overgrowing portions of smaller individuals. If movement were possible, surely the smaller ones would have moved laterally to avoid overgrowth. The method of adherence is unknown, though it could have been that the basal membrane maintained a constant suction.

Figure 3



Isorophus cincinnatiensis



Carneyella pilea **(Hall), 1866.**

1-4. **UCMP 26324,** specimen resting on a segment of crinoid stem with peripheral rim and distal parts of interambulacra 1-4 and ambulacra II and IV flexed under upper (oral) side of theca.

1. Oral side of theca, × 3, whitened.
2. Oral side of theca, × 3, in xylene.
3. Lower side of theca, × 3, whitened.
4. Lower side of theca, × 3, in xylene.

Figure 4

Preservation

Almost all specimens have undergone collapse of the theca, resulting in the upper oral surface being depressed onto the the underlying surface or lower surface plates. This in turn may cause slippage of the plates, altering the fossil's features. Burrowing animals may also disrupt individuals. Trails have been traced from overlying shales through the specimens. This occurs most often when the overlying mud is thin. A final modification is from etching of the plates due to groundwater moving along the limestone/shale interface, leaving misleading features.

Collecting Edrios

The largest number a specimens in my collection came from a development site in Fairfield, OH. This site is now a parking lot and office buildings, but for several years it offered relatively easy digging for edrios, since overlying matrix had been removed. Digging was performed by raking back clumps of shale to expose a layer of *Rafinesquina*. This could be accomplished with a rock hammer. The brachiopds were searched for edrios. Sometimes we merely swept the dust from the layer to be able to see the *Isorophus cincinnatiensis*. Other times we would use water and a scrub brush to highlight the edrios. Sometimes the whole layer was removed, subjected to scrubbing in a bucket of water, and each brachiopod individually examined (by the truly industrious). This area yielded many specimens, though most were poorly preserved, except for the peripheral ring. This may have been due to thecal collapse and a subsequent jumbling of the plate structure.

By far the most visually striking specimens I've collected came from a hillside in Kentucky (also lost as a site). These include *Cystaster* and *Carneyella* (?) specimens. These required removal of several feet of limestone and shale overburden, but were worth the effort. The same techniques as above were used to visualize the specimens in the field. These edrios are small, but many are very well preserved. Two and sometimes three specimens were found on a single brachiopod. The two species were obviously intermingled in life, as both may be found as a "double" on some brachiopods.

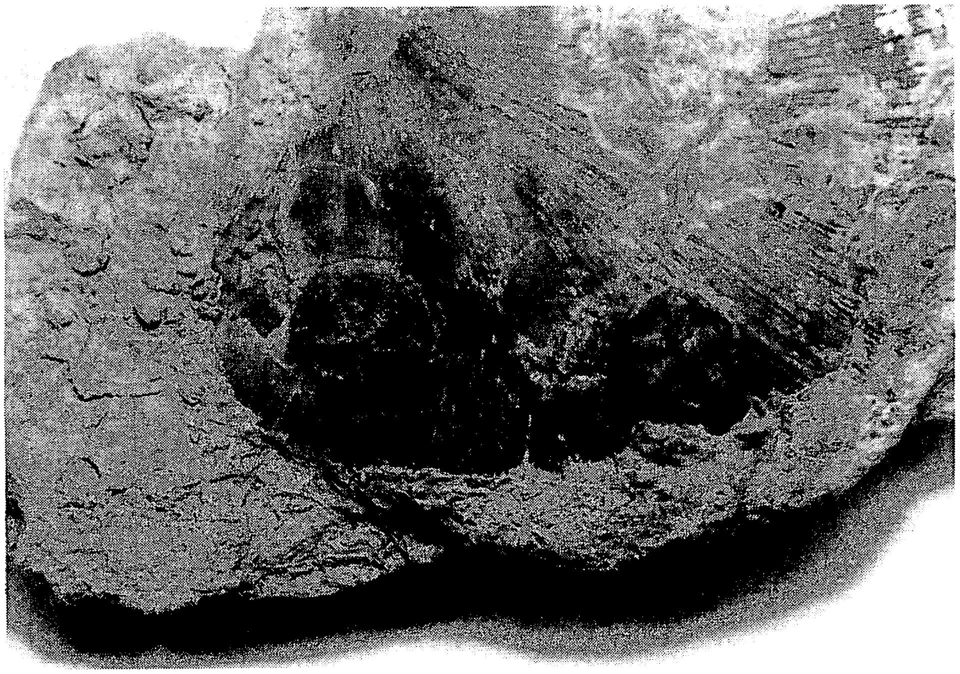
I've only found one edrio in a situation that did not entail a mass burial of many specimens. This one came from a site noted for large *Flexicalymene* trilibites, Monroe, OH. On the spoil pile, I noticed a circular object of rusty color, about the size of a dime. It came loose from the limestone matrix, and I was surprised to see it was an edrio. It wasn't even attached to a brachiopod. It's not an impressive specimen, but its uniqueness makes it special. As far as I know, its the only edrio found in years of digging in that spot. It makes me wonder how it lived such a solitary existence as kind of a castaway, separated at sea from its kin. That kind of wonder, I believe, is why I'm writing this article, and why you are now reading it.

Photography

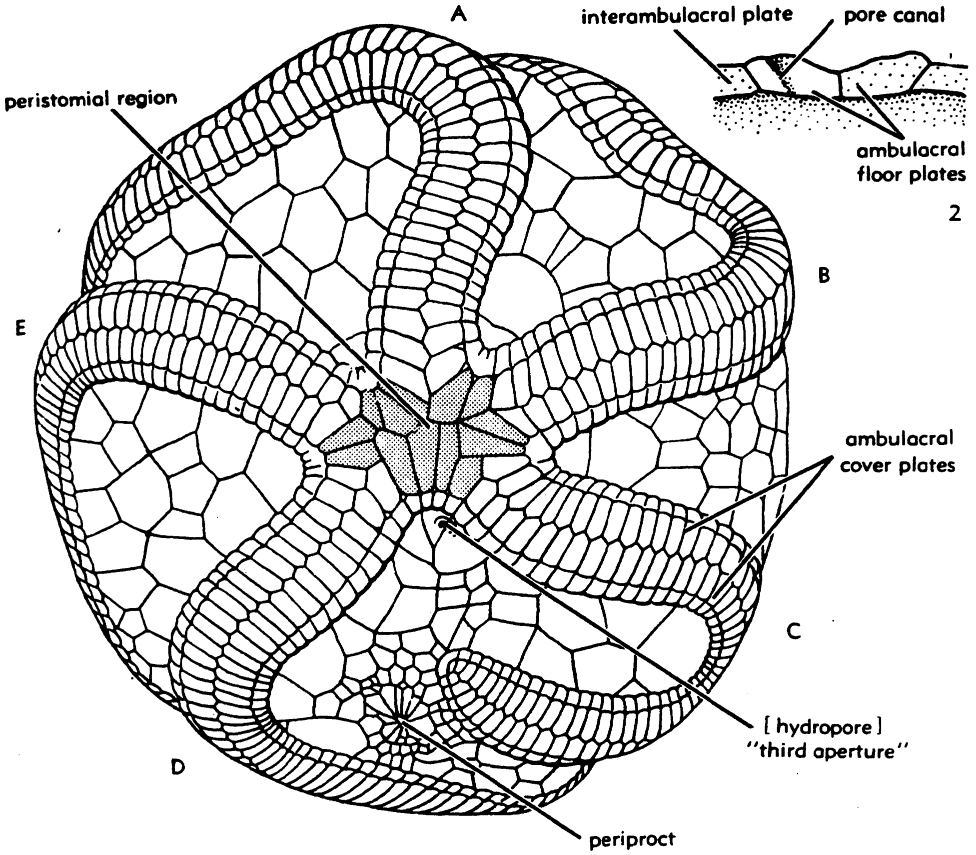
Pictures taken for this article were made using a Canon AE-1 camera and Kodak TMX 135 black-and-while film, ASA 100. Extreme close-ups were made with an 80-200 mm Sigma zoom lens with a macro lens attachment and a 2X teleconverter, providing 8X total magnification. F-stops were varied from F11 to F22, with shutter speeds of 0.5 and 1 second. Three to four table lamps were used for lighting. A tripod and shutter cable were used for stability during the long exposure times. Lesser magnifications were made with a 50 mm lens and a +4 diopter close-up lens, using F4 and F5.6 apertures and 1/60 of a second exposures.

Classification Examples (from Bell)

- Class Edrioasteroidea
  - Order Isorophida
    - Suborder Lebetodiscina
      - Family Lebetodiscidae
        - Genus *Cystaster*
      - Family Carneyellidae
        - Genus *Carneyella*
    - Suborder Isorophina
      - Family Isorophidae
        - Genus *Isorophus*
          - *I. cincinnatiensis*

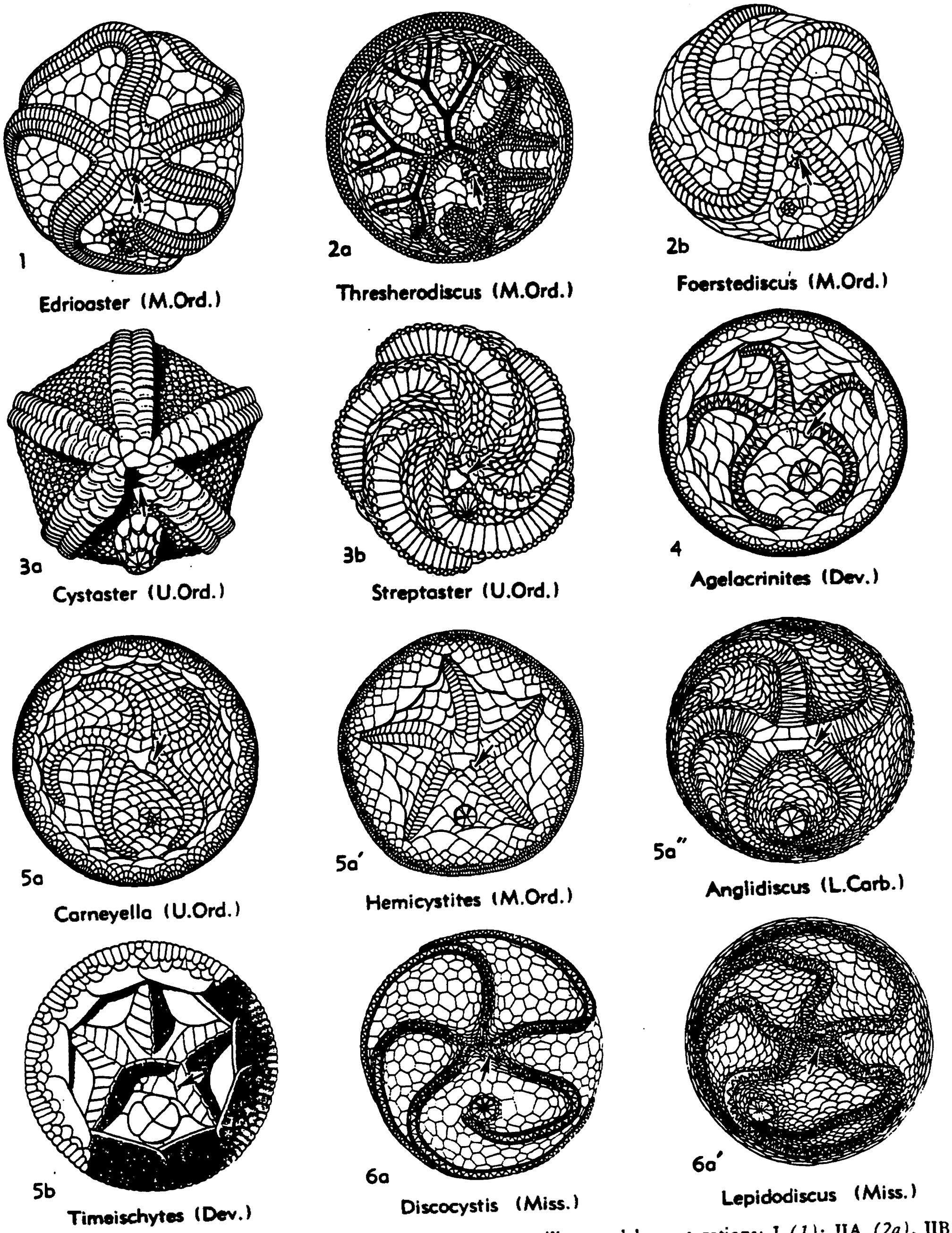


Cystaster



Typical edrioasteroid, *Edrioaster bigsbyi* (Billings), M.Ord., Ontario, illustrating some morphological features.——*1*. Adoral surface showing ambulacra with biserially arranged cover plates adjoined on each side by row of adambulacral plates, interambulacral areas distinguished by relatively large irregularly arranged plates; ambulacra marked by letters of Carpenter system; ill-differentiated plates of peristomial region unshaded; posterior interambulacrum with low anal pyramid (periproct) and near peristome with "third aperture" interpreted as hydropore; ×2.5 (after 24, modified from 7, pt. 4).——*2*. Transverse section of ambulacral floor plates showing their relation to adjoining interambulacrals; floor plate at left viewed on its sutural surface, showing pore canal, floor plate at right viewed on cut surface; ×5 (7, pt. 4).

Carneyella



1 Edrioaster (M.Ord.)

2a Thresherodiscus (M.Ord.)

2b Foerstediscus (M.Ord.)

3a Cystaster (U.Ord.)

3b Streptaster (U.Ord.)

4 Agelacrinites (Dev.)

5a Carneyella (U.Ord.)

5a′ Hemicystites (M.Ord.)

5a″ Anglidiscus (L.Carb.)

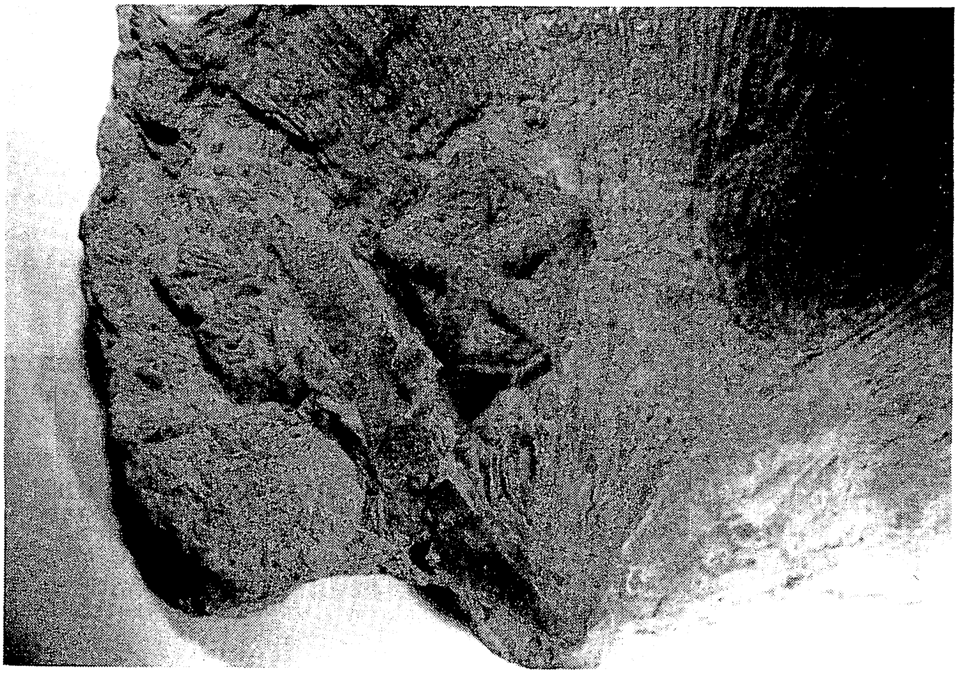
5b Timeischytes (Dev.)

6a Discocystis (Miss.)

6a′ Lepidodiscus (Miss.)

Types of hydropores distinguished by KESLING, illustrated by restorations: I *(1)*; IIA *(2a)*, IIB *(2b)*; IIIA *(3a)*; IIIB *(3b)*; IV *(4)*; VA *(5a,a′,a″)*, VB *(5b)*; VI *(6a,a′)* (24).

Cystaster



OCCURENCES OF EXTINCT ECHINODERM CLASSES IN THE STATE OF OKLAHOMA

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DATE: September 1992

INTRODUCTION

The phylum Echinodermata is well represented in the fossil record of Oklahoma. The Paleozoic section in Oklahoma has yielded the remains of 16 of the 20 recognized classes of echinoderms known today. There have been literally hundreds of echinoderms described from the Ordovician and Pennsylvanian sections, and more will be found as diligent collecting continues.

When Margaret Kahrs asked me to do an article on the extinct echinoderms of Oklahoma, I fully expected to document all published occurences of echinoderms in the state. I soon realized this was too ambitious of a project, and I would quickly get in way over my head. I decided to limit it to the extinct echinoderm classes in the Sooner state. Therefore, this review will not cover the extant classes Crinoidea (sea-lillies), Asteroidea (starfish), Ophiuroidea (brittle-stars), Echinoidea (sea-urchins), or the Holothuroidea (sea-cucumbers).

PHYLOGENY & STRATIGRAPHIC RANGES

This paper will follow the phylogenic hierarchy used by Sprinkle (1980) in which the phylum Echinodermata is broken down into the following 5 subphyla:

CRINOZOA
Crinoids
Paracrinoids

BLASTOZOA
Diploporans
Rhombiferans
Eocrinoids
Blastoids, Parablastoids

ASTEROZOA
Asteroids
Ophiuroids

ECHINOZOA
Echinoids
Holothurians
Edrioasteroids
Ophiocistoids
Cyclocystoids, Helicoplacoids, Edrioblastoids

HOMALAZOA
Ctenocystoids
Stylophorans
Homosteleans
Homiosteleans

There is still not 100% agreement on any phylogenic tree for the echinoderms, and the lines seperating the classes (and hence the subphyla) is blurred sometimes in the fossil record as some of these classes have characteristics of classes in other subphyla. As can be seen, the subphyla Blastozoa and Homalozoa, which includes the cystoids, blastoids, and carpoids, have no living decsendents. Or at least none have been discovered yet. There is always the possibility that one of them has migrated to some undiscovered deep -water habitat.

In Oklahoma, these extinct classes of echinoderms occur in 2 broad outcrop belts. The first is in south-central Oklahoma in the Arbuckle Mountains and Criner Hills area. The sedimentary rocks range from upper Cambrian thru the Permian (see Figure 1). Ages where extinct echinoderm classes occur are symbolized with a black dot on the columnar sections in Figure 1. The other major collecting area is on the southwestern flank of the Ozark Dome where Pre-Cambrian thru Pennsylvanian rocks are exposed in northeastern Oklahoma (see Figure 1).

The echinoderms are undoubtedly one of the oldest multi-celled life forms possessing a calcareous exoskeleton. Their early evolutionary history is hazy due to a scanty fossil record in the early Cambrian. By the end of the middle Ordovician (440 MYA), all 20 echinoderm classes had made an appearence, and 3 of them had already become extinct (the Ctenocystoids, Helioplacoids, and the Homosteleans). We tend to think of the Mississippian as the age of the crinoid (which it was), but the Ordovician was truly the age of the echinoderm.

The trilobites had already reached their zenith in the Cambrian in terms of sheer numbers, and evolutionary expansion. The Ordovician, especially the middle Ordovician, was the heydey of the echinoderms. As a phylum they fully experimented with a variety of body forms, feeding habits, and bottom environments as they explored the ancient seas. Some were low-level, epifaunal suspension feeders (edrioasteroids, cyclocystoids, holothuroids, paracrinoids?). Others were medium to high level suspension feeders (crinoids, blastoids, rhombiferan cystoids, eocrinoids, parablastoids, paracrinoids?). And still others were mobile, epifaunal herbivores (echinoids) while some were mobile, epifaunal detrius feeders (carpoids, pleurocytitids). Towards the top of the food chain, others were mobile, epifaunal carnivores (asteroids, echinoids?). Echinoderms inhabited all types of substrates including quiet lagoons, tidal flats, offshore shoals, inter-reef areas, and muddy shelfs.

In Oklahoma the echinoderms flourished in abundance in the warm shallow seas that dominated the area during most of the Paleozoic. By the middle Ordovician, 16 of the 17 then-living echinoderm classes were present in Oklahoma. The crinoids and paracrinoids in particular seemed to have thrived in the tropical carbonate banks offshore of the continent now called Laurentia. In fact, the paracrinoids were actually out competing the crinoids as the main suspension feeding echinoderm on the sea floor. By the end of Bromide deposition (see Figure 1),the paracrinoids had already ceded their position of dominance to the crinoids, and would quickly disappear from the scene in most parts of the world.

Figure 2 is a composite diagram of representative extinct echinoderms found in the Mountain Lake and Pooleville members of the Bromide formation in southern Oklahoma. They are shown in their inferred living postions in association with some of the other benthic fauna that they shared the sea bottom with. I will descibe in detail each echinoderm present (except for the camerate crinoids) later in the article.

The extinct classes of echinoderms were confined to the Paleozoic as only those classes living today survived the Permian-Triassic extinction event. Past the Ordovician in Oklahoma, blastoids have been reported in the Silurian, unconfirmed cystoids in the Devonian, and blastoids and carpoids in the lower

Pennsylvanian. Only brittle starfish and crinoids (both extant classes) have been reported in the lower Permian of Oklahoma in the extreme northern part of the state bordering Kansas.

PARACRINOIDS

Paracrinoids are by far the most abundant of the extinct echinoderm classes found in Oklahoma. They range from the middle Ordovician of North America (Chazyan to Trentonian), the upper Ordovician of Scotland (Ashgillian) to the lower Devonian Birdsong shale of Tennessee. Paracrinoids are primitive pelmatazoans with elements of crinoids, blastoids, and cystoids in their morphology. However, they cannot be directly linked to any known group of echinoderms and any common ancestor is currently unkown.

Paracrinoids resemble crinoids in their uniserial, pinnuliferous arms which can be free-standing (exothecal) or recumbent (epithecal) along the sides of the theca. They are different from crinoids in that their body covering is arranged in a continuous theca versus a two-part calyx and tegmen. This continuous theca is the same body plan as the cystoids, but the pinnulate arms are quite different from the brachioles of the cystoids. Paracrinoids have the holomerous stem of the blastoids but can be distinquished from them by the arms, thecal plate growth, and arrangement of the pore system.

Respiration and gaseous exchange took place via transverse slits between thecal plates. These were covered by a thin layer of epistereom (essentially skin) in the ORDER Comarocytida. In Oklahomacytis tribrachiatus, featured in Figure 2, the pore slits show up very well in weathered specimens where the outer plate layer between sutures is gone. These slits resemble the pore rhombs (dichopores) of the Rhombiferan cystoids.

The arms number two to four and can be exothecal or epithecal. Epithecal arms have lateral food grooves as in Oklahomacystis. of the 475 Oklahomacytis tribrachiatus I have collected, 2 individuals have split an arm into two so that they have four arms total. There are a number of possibilities for this to have happened. A juvenile could have been injured at an early stage of its ontogenetic development and the arm grew into 2 seperate pieces as it healed. Or it may be a random genetic mutation as it is such a small percentage of the total number of specimens I have collected (.004 %).

Some paracrinoids were were elevated above the sea floor on a short stem, and others were probably recumbent on the sea bottom. In either case they were suspension feeders that required at least a moderate uni-directional current for an adequate food supply.

Some authors (Durham 1975, Strimple 1979) favor a recumbent mode of life for some of the paracrinoids, specifically the ORDER Platycystitidae. The stem was too small to support the weight of the theca and instead served as an anchor in the substrate to hold the theca upright on the sea floor. Of the hundreds of Oklahomacystis and Sinclairocystis I have collected, only a handful have had the stem attached. In all instances, the stem does appear too small of a diameter to support the weight of the theca and arms. However, I do not know how bouyant the theca was and it may

have resembled a balloon bobbing in the currents. I do believe that Platycystites laid erect on the sea floor with its stem imbedded in the sediment. Parsley and Mintz (1975) have a full discussion on the possible feeding modes of paracrinoids.

In Oklahoma, paracrinoids are quite common in the Mountain Lake member of the Bromide formation. Especially in what is referred to as the "upper and lower echinoderm zones" within the Mountain Lake member. As of September 1, 1992, I have collected 475 Oklahomacystis, 82 Sinclairocystis, 17 Platycytites, and 3 Bistomiacystis from these 2 zones at 5 localities.

FORMATION: Mountain Lake member/Bromide fm./Simpson group
AGE: upper middle Ordovician/Blackriverian stage/Champlainian series (lower Caradocian - Europe)
PHYLUM: Echinodermata SUBPHYLUM: Crinozoa CLASS: Paracrinoidea

ORDER: Comarocystitida
FAMILY: Comarocystitidae
GENUS: Sinclairocystis praedicta
FAMILY: Amygdalocystitdae
GENUS: Oklahomacytis triabrachiatus, O. bibrachiatus, O. spissus

ORDER: Platycystitida
FAMILY: Platycystitidae
GENUS: Platycystites levatus, P. cirsatus, Arbuckleacystis pyriformis
FAMILY: Bistomiacystidae
GENUS: Bistomiacystis globosa

EOCRINOIDS

Eocrinoids are the oldest known crinozoans, and are well known to North American collectors from the various species of Gogia found in the lower to middle Cambrian of the western United States. Eocrinoids are likely the stem group from which all other Blastozoan classes arose. Like the paracrinoids, they have characteristics of both crinoids and cystoids. Their thecal form is essentially cystoid-like but their sutural pores function differently than the diplopores or pore rhombs of cytoids. Eocrinoids differ from crinoids in having brachioles instead of arms as the major feeding appendages. Eocrinoids range in age from the lower Cambrian thru the middle Ordovician, and have been recovered in Europe, and North and South America.

In Oklahoma, eocrinoids of the FAMILY Paleocystitidae occur in the middle Ordovician Bromide rocks of Murray, Carter, Johnston, and Pontotoc counties. Paleocystitids are a very rare element of the echinoderm fauna with only a few complete specimens known. However, there is a thin zone in the Mountain Lake member of the Bromide named the Bromidocystis bed because of the thousands of disarticulated plates which have a very distinctive ornamentation.

The theca was apparently very fragile and rapidly disarticulated upon death if conditions were not favorable for preservation. I have collected one nearly complete specimen which I nearly mistook for a club-shaped bryozoan colony as it was completely encrusted by one. Very few other echinoderms occur in the Bromidocystis zone, and it may have been a r-selection oppurtunist. This means it colonized sites first that were marginal environments for other echinoderms. If conditions became more stabilized for a broader range of echinoderms, then the

Paleocystitids were "edged-out" of their niche by more competitive species.

Bromidocystis had a large club-shaped theca as shown in Figure 2. The plates are 4 to 8 sided instead of the normal pentagonal and were highly ornamented. The mouth is central on the summit and is surrounded by 5 short ambulacra. It resembles a blastoid in this respect. A minimum of two brachioles were attached to each ambulacrum and lied recumbent along the sides of the theca pointing downward. It is not known if this was the normal feeding postion.
FORMATION: Mountain Lake & Pooleville members/Bromide fm.
AGE: upper middle Ordovician/Blackriverian stage/Champlainian series (lower Caradocian - Europe)
SUBPHYLUM: Blastozoa
CLASS: Eocrinoidea
FAMILY: Paleocystitidae
GENUS: Bromidocystis bassleri, B. sinclairi

CYSTOIDS

Cystoids are primitive stemmed echinoderms which at one time were considered the ancestral stock from which all other stemmed echinoderms are descended. They share many featues in common with the blastoids. Both possess brachioles in the ambulacra which usually extends a good distance down the sides of the theca. Cystoids range in age from the lower Ordovician thru the upper Devonian but were most abundant in numbers and diversity during the Ordovician.

The two classes of cystoids are defined on the basis of thecal pores. The CLASS Rhombifera have respiratory structures called pore rhombs. Poer rhombs are tubes or grooved passageways between adjacent plates that allowed for gaseous exchange between the body cavity or coelom and the outside sea water. The outline of the pore- bearing area is rhombic-shaped; hence the name pore rhombs. Almost all the middle Ordovician cystoids from the Bromide formation belong to this class.

The rhombiferans are a relatively minor element of the Bromide echinoderm faunas but are the dominant type in some zones such as the "cystoid shale" which is an old field mapping term for the green shales above the basal sandstone unit in the Bromide formation. All the Bromide rhombiferans belong to the SUPERFAMILY Glyptocystitidea, and the FAMILY Glyptocystitidae or the FAMILY Pleurocystitidae. There is a world of difference between these two families as each took a seperate fork down the path of life as far as lifestyles are concerned.

The FAMILY Glyptocystitidae are what I consider your typical rhombiferans. Many members of M.A.P.S. have seen the representative genus of this family, Glyptocystites at the Illinois show sold by Steve Hess from the Trentonian of Ontario, Canada. These beds are slightly younger than the Bromide formation but contain many of the same genera. The following are common to both: crinoids - Abludoglyptocrinus, Archeocrinus, Carabocrinus, Cremacrinus, Hybocrinus, Porocrinus; rhombiferan cystoid - Pluerocystites; edrioasteroid - Edrioaster; edrioblastoid - Astrocystites; and the cyclocystoid Cyclocystoides.

Glyptocytitids have a variable thecal shape that can be cylindrical, ovoid, or pyriform. Ambulacra arise out of the domed summit and can be either confined to the top as in Strabocystis fayi or can extend down the sides of the theca as in Glyptocystella loeblichi. The stem is short to medium in length. I have yet to see a stem that is greater than 2x the length of the theca from a rhombiferan of the Bromide formation. The stem is flexible, well articulated, and tapers rapidly down from its proximal portion to the distal end (see Figures 2 & 3). The stem can be considered a tail in that it was used as a means of propulsion on and above the sea floor.

Rhombiferans such as Glyptocystella lived unattached on the sea bottom. They were highly mobile suspension feeders that fed upon the planktonic-size organic matter that drifted by in the currents. They could use their enlarged proximal stem for short bursts of swimming to escape predators or seek more productive feeding grounds. I envisage them moving about much like the modern day pelecypod Pecten which propels itself by rapidly opening and closing its valves when it senses danger approaching. In Figure 3 I show a possible sequence of locomotion for a rhombiferan. Like many other bottom-dwelling invertebrates, it was not able to escape rapid burial events.

The upper and lower echinoderm zones of the Mountain Lake member represent nutrient-rich, well-oxygenated, shallow-water shelf environments. Salinity and temperatures were normal most of the time. This is where most of the rhombiferans occur. A few of the rarer forms were r-selection oppurtunists that inhabited very shallow -water, nearshore environments that were constantly buffeted by storm waves and even tidal currents.

Members of the FAMILY Pleurocystitidae are the most specialized of all the rhombiferans in terms of adaptation to an alternate lifestyle. Pleurocystitids assumed a bottom-dwelling habit of detrius feeding along the sediment-water interface. Adaptations include the flattening of the theca which involved a change from a pentameral to a dominately biradial symmetry. It also involved a reduction in the number of brachioles from many to two very stout brachioles as can be seen in Figure 4. The brachioles are commonly 1.5 - 2x the length of the theca and were capable of sweeping the sea floor in a 90 degree arc in front of the animal. Detrital organic matter along the bottom was collected in the biserial food grooves of the brachioles and transported down to the mouth.

The flattening of the theca was an evolutionary response to a life of active grazing along the sea floor. The low profile produced less lift when strong bottom currents scoured the sea floor. This in turn decreased the chances of the pleurocystitid flipping over into a vulnerable position. This is the same type of adaptation to body form that the trilobites, sea cucumbers, sea slugs, carpoids, asteroids and others took to a mobile life on the sea floor.

The other main group of cystoids is the CLASS Diploporida in which the respiratory pores extend vertically through the thecal walls in pairs called diplopores. The theca is globular and composed of a large number of diplore-bearing small plates. A stem is commonly lacking and the individual rested on the sea floor with the summit of the theca and the feeding appendages oriented upwards.

The only representative from the CLASS Diploporita is the species Eumorphocystis multiporita. Eumorphocystis is unique among all non-crinoid pelmatazoans in having pinnulated exothecal food appendages that are also triserial versus uniserial or biserial (see Figure 5). The theca is an elongated oval shape composed of 130 to 700 plates. Primary ornamentation of the thecal plates is a series of radiating ridges across plate boundries as shown in Figure 5. The stem is apparently long with the distal portion and the holdfast unkown.

Eumorphocystis was adapted to a medium to high-level suspension feeding habit. It probably competed with rheophylic crinoids such as Archeocrinus and Pararcheocrinus shown in Figure 2. Archeocrinus is shown in the normal feeding position with its arms extended in an umbrella-like fan while Pararcheocrinus is in a defensive or resting position with its arms and pinnules facing down current. With the arms extended like an umbrella they exposed the maximum surface area of their feeding appendages to the current and strained the water for organic matter. It is hard to explain why the tribrachial filtration system of Eumorphocystis was not any less efficient than the filtration fans of the camerate crinoids. So why did Eumorphocystis apppear, flourish, and then disappear so briefly during the middle Ordovician?

FORMATION: Mountain Lake & Pooleville members/Bromide fm/Simpson Gr
AGE: upper middle Ordovician/Blackriverian stage/Champlainian series
SUBPHYLUM: Blastozoa
CLASS: Rhombifera
ORDER: Dichoporita
FAMILY: Glyptocytitidae
GENUS: Glyptocystella loeblichi
Pirocystella strimplei
P. cooki, P. bassleri, P. ornatus, Hesperocystis deckeri, Cheirocystis ardmoreensis
Strabocystis fayi, Tanocystis watkinsi, Quadrocystis graffami
FAMILY: Pleurocystitidae
GENUS: Pleurocystis squasmosus, Praepleurocystis watkinsi

CLASS: Diplopora
ORDER: Diploporita
FAMILY: Eumorphocytitidae
GENUS: Eumorphocystis multiporata

CARPOIDS

Carpoids is a kind of a catch-all junk-basket term to describe four distinct classes of echinoderms of the SUBPHYLUM Homalozoa. They all exploited the same ecological niche on the sea floor. Carpoids were superficially similar to the cystoid pleurocystitids. Both groups lived a mobile, bottom-dwelling life in which they fed on organic detrius that accumulated on the bottom.

Carpoids ranged from the middle Cambrian to the early Pennsylvanian with their greatest diversity in the last half of the Ordovician. The youngest occurence is in the Morrowan age sediments of Oklahoma where thousands of tiny, disarticulated specimens have been found at one locality called Daube Ranch in the

Arbuckle Mountains. Until this discovery, it was thought that the carpoids became extinct in the middle Devonian in the ocean of present-day Bohemia.

All carpoid classes can be recognized by a laterally compressed theca of bilateral to asymmetrical shape. Most Homalozoan tests display thick marginal plates and smaller central ones that are thinner, and were probably more flexible to aid in cloacal pumping of the body cavity. Two of the four known classes occur in Oklahoma; the Homoiostelea and the Stylophora. They closely resemble each other in body shape but are oriented exactly opposite one another as far as locomotion and feeding is concerned.

The GENUS Myeinocystites sp. from the Pooleville is a typical member of the ORDER Soluta of the CLASS Homoiostelea. The theca is flattened, oval in outline, and with ordered and rigid plates much like the stylophoran carpoids of the ORDER Mitrata (see Figure 6). This is no coincidence as they are homeomorphs, and competed for the same food supply in the same food chain during the same geologic timespan. As can be seen in Figure 6, the main elements of this carpoid are the theca, a single biserial arm, and a triparite stele or tail. The biserial arm was quite flexible and scoured the sea bottom in search of organic matter. The three part stele was the primary means of propulsion along the sea floor. It was partitioned into proximal, medial, and distal ends. Figures 6 and 7 are comparisons of a solute and mitrate carpoid in living positions with their arms in a up-current direction.

The mitrate Anatiferocystis papillata in Figure 7 appears much like a solute carpoid except that its body plan is reversed. What looks like the stele is actually the feeding appendage called an aulacophore. The aulacophore is also triparite like the solutan stele. Scientists still debate if the distal end of the aulacophore contains the mouth or an anus/mouth which implies a U-shaped gut. Arguments can be made for both cases but either way the aulacophore was definately the food-gathering extremity of the animal. The Pennsylvanian form Jaeckelocarpus oklahomaensis may have been an infaunal detrius feeder tunneling just under the surface in its quest for substenance. The Ordovician form Anatiferocystis is quite common at some localities in the Criner Hills of southern Oklahoma.

FORMATION: Pooleville member/Bromide fm/Simpson group
AGE: upper middle Ordovician/Blackriverian stage/Champlainian series
SUBPHYLUM: Homalozoa

CLASS: Stylophora	CLASS: Homoiostelea
ORDER: Mitrata	ORDER: Soluta
FAMILY: Kirkocystidae	FAMILY: Belemnocystitdae
GENUS: Anatiferocystis papillata	GENUS: Myeinocystis natus

FORM: Gene Autry Shale member/Golf Course fm/Dornick Hills group
AGE: lower Pennsylvanian/Morrowan series (Bashkirian - Europe)
CLASS: Stylophora ORDER: Mitrata FAMILY: ?
GENUS: Jaeckelocarpus oklahomaensis

BLASTOIDS

Next to the crinoids, blastoids are by far the most common stalked echinoderm fossils in the United States and elsewhere. They are especially common in the Mississippian age rocks of the Mississippi and Ohio River valleys. In Oklahoma, they are conspicuous by their absence in the Mississippian. Blastoids have only been found in the Silurian and lower Pennsylvanian even though there are abundant Mississippian carbonates in the northeastern part of the state. Blastoids range from the middle Ordovician Benbolt formation of Tennessee to the Permian deposits from Australia and the Isle of Timor.

Blastoids are easily recognized by their acorn-like shape and the regular arrangement of their thecal plates. The pentameral symmetry of their tests is obvious to anyone who has picked up a Pentremites. The theca is usually composed of 13 or more plates; 3 basals, 5 radials, 4 regular deltoids, and a variable number in the anal interarea. The ambulacra are found on the radials and are the most complex part of the blastoid. On Pentremites they resemble the petals of a flower. The mouth is found at the summit of the theca.

Each ambulacral area is occupied by an elongate single plate which is marked by regularly spaced travsvers grooves and is called the lancet plate. The grooves are roofed by covering plates wich in life protected soft tissue extending from inside the theca. The feeding appendages are termed brachioles and extend upward from the margins of the ambulacra. Each one was long and slender. Food was captured by the brachioles and transported down the brachioles, along the ambulacral food grooves, and up to the mouth at the center of all the ambulacra. The particles were then ingested in the body cavity's gut.

Running underneath each ambulacral plate is a respiratory structure unique to blastoids called the hydrospire. To quote from Moore, Lalicker, and Fischer (1952) from page 599;"Each hydrospire may be compared to pleated folds of a curtain hanging downward into the body cavity...". The hydrospire was connected by pores or slits to the ambulacral area, and thru it moved the sea water from outside and spent body fluids from inside via gaseous exchange.

The blastoids were a very successful group of echinoderms that seemed to have held there own during the Mississippian against the crinoids. By the beginning of the Pennsylvanian however, they only survived in the United States in Arkansas and Oklahoma in Morrowan age rocks. The shelf they inhabited was along a tectonically active seaway that faced the slowly approaching continent of Gondwana. These two continents would collide by The Permian to form the super continent of Pangea that so much of plate tectonics theory is based on. In the Permian the blastoids reappear in what is now southeast Asia with at least 20 genera and 67 species having been discovered. One of the current mysteries of the fossil record is what happened to the blastoids in North America during the Pennsylvanian to Permian interval.

FORM: Henryhouse formation/Hunton group
AGE: upper Silurian/Lockportian stage/Niagaran series (Ludlovian/Pridolian - Europe)
SUBPHYLUM: Blastozoa CLASS: Blastoidea
GENUS: Polydeltoideus enodatus

FORM: Suasbee & McCully formations/Wapanucka formation

AGE: lower Pennsylvanian/Morrowan series (Bashkirian & lower Muscovian - Europe)
GENUS: Pentremites rusticus

EDRIOBLASTOIDS

Edrioblastoids are echinozoans that superficially resemble blastoids but are actually closer to the edrioasteroids than any other echinoderm class. The theca is bud-shaped with a regular pentameral symmetry. The theca consists of 20 main plates; 5 basals 5 radials, 5 parabolic deltoids, and 5 orals versus the 13 main plates of true blastoids. They were primitive stemmed echinoderms that may have originally been an edrioasteroid that adapted to an attached suspension-feeding way of life from a sessile ancestor in the Cambrian.

Unlike the ambulacra of blastoids, the ambulacral cover plates of edrioblastoids are in offsetting opposing rows that meet in a distinctive zigzag pattern down the center of the ambulacrum (see Figure 2). I have personally collected three ambulacra from different individuals of the GENUS Astrocystites from the Mountain Lake member of the Bromide formation. Instead of brachioles, the pores of the ambulacra were openings for tube feet which extended outward when feeding. This is one reason why the edrioblastoids show closer affinities to the edrioasteroids (tube feet) than the blastoids (brachioles). In figure 2, you can see that the main thecal plates are marked by a distinctive pattern of broad and deep grooves that run across and parallel to adjacent plates.

Edrioblastoids range from the middle to upper Ordovician in North America, Sweden, and Australia. The only complete specimens are the four found from the Coburg limestone (Trentonian) of Ottawa, Ontario in Canada. These are the type species Astrocystites ottawaensis. Their remains are very rare in the Bromide formation of Oklahoma with only individual plates having been discovered to my knowledge.

FORMATION: Mountain Lake member/Bromide formation/Simpson group
AGE: upper middle Ordovician/Blackriverian stage/Champlainian series
SUBPHYLUM: Echinozoa
CLASS: Edrioblastoidea
ORDER: Pentacystida
FAMILY: Steganoblastidae
GENUS: Astrocystites sp.

EDRIOASTEROIDS

As I mentioned in the previous section, the closest relatives to the edrioblastoids were the edrioasteroids. In fact, Astrocystites has many morphological characters in common with the isophorid edrioasteroid Cyathocystis. This genus is also found in the Bromide formation of southern Oklahoma. It may be that these Arbuckle Mountain localities record the early radiation of two closely allied forms just a few million years after the initial divergence of a common ancestor.

Edrioasteroids are sessile benthic echinoderms that were commonly attached to a firm substrate. Usually it was a hardground surface or some skeletal debris. One species, Prygocystis, was adapted to life on a muddy substrate by modifying the normally flat aboral end into a bullet-shaped theca that it buried into the mud. Another species, Hadroclthus, only attached itself to the living theca of the cystoid Adocetocystis. Edrioasteroids ranged from the middle Cambrian to the upper Pennsylvanian with their greatest radiation and speciation occuring during the middle Ordovician.

Most species apparently inhabited the shallow subtidal zones and some lived in the intertidal zone. I can easily envisage a form such as Cyathocytis living a barnacle-like existence attached to rocks along the shoreline of a tidal pool. This would not be an environment conductive to preservation, and may help explain why these fossils are not as common as they should be. Where they are found they are usually found in significant numbers indicating large populations of them at one time or another. Edrioasteroids were passive suspension feeders and relied on the currents to supply them with an adequate food supply. They did not have food gathering appendages such as brachioles but used tube feet or cilia to capture food particles.

The isophorid Cyathocystis americanus is the only common edrioasteroid found in any of the echinoderm zones in the Bromide formation. At one locality known as the Fittstown Quarry section it comprised 59% of all the echinoderms collected there in the study done in 1965-1967 by Graffam, Strimple, Watkins, and others. In all other localities it was a minor constituent of the total echinoderm faunas.

The cyathocystids were specially adapted to life in a shallow-water, moderate to high energy environment. The theca is small, cylindrical and elongate, and the lower part is fused into a massive cup. The oral surface plates are fused into five large triangular plates and an anal vent. Figure 2 shows four individuals attached to a large bryozoan colony. Three of the four have their ambulacral plates open and the tube feet or cilia extended in a feeding posture.

FORMATION: Mountain Lake & Pooleville members/Bromide formation/ Simpson Group
AGE: upper middle Ordovician/Blackriverian stage/Champlainian series
SUBPHYLUM: Echinozoa CLASS: Edrioasteroidea

ORDER: Edrioaterida
FAMILY: Edrioasteroidae
GENUS: Edriophus laevis

ORDER: Isophorida
FAMILY: Lebetodiscidae
GENUS: Foerstediscus spendens

FAMILY: Cyathocystitdae
GENUS: Cyathocystis americanus

CYCLOCYTOIDS

Cyclosystoids are probably the single most enigmatic group of Paleozoic fossils known due to their scant fossil record and the poor preservational quality of the ones that have been found. Only one bonafide genus is accepted by all workers and that is Cyclocystoides. Cyclosystoids range from the middle Ordovician to the middle Devonian. Only a few isolated plates have been collected from the Bromide formation.

Cyclocystoids were small, flattened to domal, disc-shaped echinoderms that lived attached to the sea bottom like a modern-day limpet. They had no column and their feeding appendages (brachioles or tube feet?) had migrated outward to form a circular pattern on the submarginal ring as shown in Figure 2. They were apparently free-living and inhabited a variety of substrates under normal marine conditions.

Cyclocystoids are characterized by a flattened aboral disc that was attached to the sea floor. The disc was composed of weakly calcified plates in a tough leathery tegmen that may have resembled a sea cucmber's. The oral disc faced upward with a mouth located centrally on the summit. Numerous food grooves radiated outwards from the mouth in all directions towards the submarginal ring. The submarginal ring contained the food-gathering appendages on their inner surface. In Figure 2 I show an individual with its tube feet extended and feeding in the current. They closely resemble edrioasteroids in their overall shape but had a greater degree of freedom than their sessile cousins.

It is currently believed that cyclocystoids are derived from a diploporitan cystoid in which the original globular theca became oral-aborally compressed, the ambulacrals fused into the submarginal ring, and the brachioles migrated outward away from the mouth. This adaptive strategy may have happened only a few million to tens of million of years before the deposition of the Bromide layers in the ancient sea that one time covered Oklahoma.

CONCLUSION

Oklahoma has a rich fossil heritage recording the expansion of echinoderm groups into all the possible niches available on the marine shelf during the middle Ordovician. The Bromide formation records the initial radiation of new echinoderm classes from a few more primitive stocks in the lower Ordovician. The middle Ordovician truly was the Age of the Echinoderm as this multiform phylum experimented with all the potential lifestyles available to it in the ancient seas. That is one of the reasons I find it so exciting to collect fossils in the Arbuckle Mountains of southern Oklahoma.

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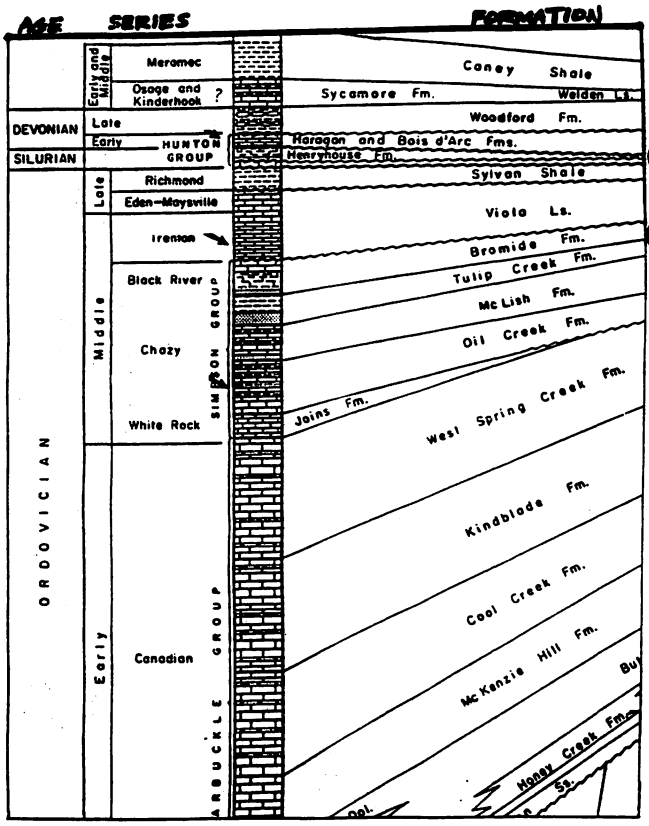
INDEX TO FIGURE 2.

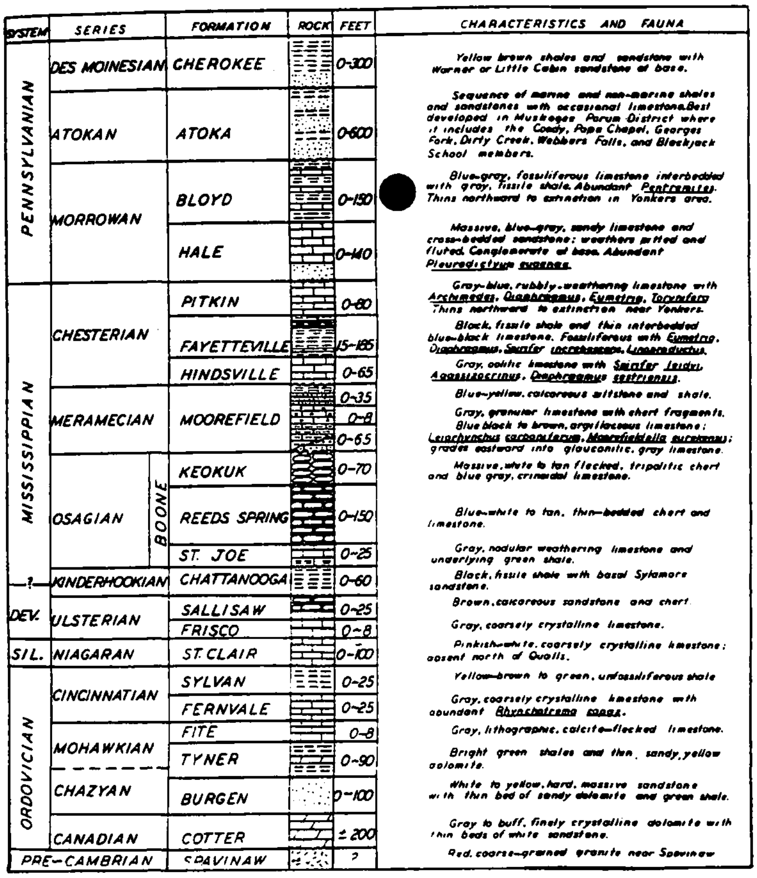
1) CYLINDRICAL BRYOZOAN Hallopora dubia
2) ARCHEOGASTROPOD Cyclonema bilix
3) CAMERATE CRINOID Archeocrinus subovalis
4) PARACRINOID Oklahomacystis tribrachiatus
5) STROPHOMENID BRACHIOPOD Sowerbyella indistincta
6) EDRIOBLASTOID Astrocystites sp.
7) EDRIOASTEROID Cyathocystis americanus
8) CAMERATE CRINOID Pararcheocrinus decoratus
9) STYLOPHORAN CARPOID Anatiferocystis papillata
10) RHOMBIFERAN CYSTOID Glyptocystella loeblichi
11) CYCLOCYSTOID Cyclocystoides sp.
12) EOCRINOID Bromidocystis bassleri

FIGURE 1.

COLUMNAR SECTION FOR THE ARBUCKLE MOUNTAINS REGION, SOUTHERN OKLAHOMA:

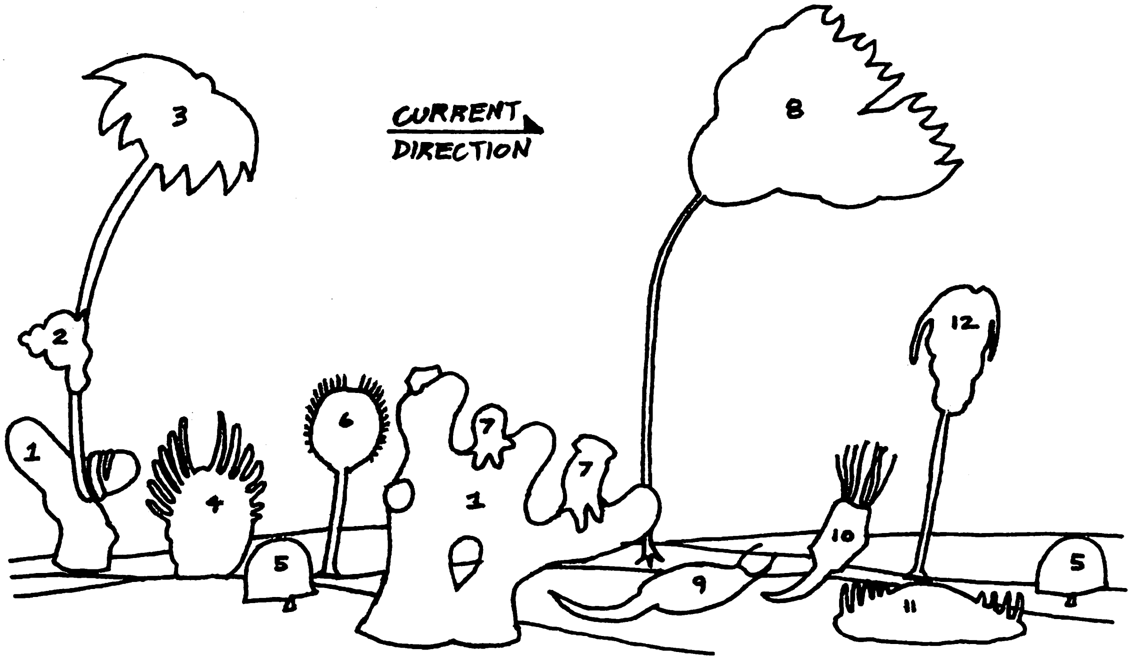


COLUMNAR SECTION FOR THE OZARK UPLIFT REGION, NORTHCENTRAL OKLAHOMA:



SYSTEM	SERIES		FORMATION	FEET	CHARACTERISTICS AND FAUNA
PENNSYLVANIAN	DES MOINESIAN		CHEROKEE	0-300	Yellow brown shales and sandstone with Warner or Little Cabin sandstone at base.
	ATOKAN		ATOKA	0-600	Sequence of marine and non-marine shales and sandstones with occasional limestone. Best developed in Muskogee Porum District where it includes the Coody, Pope Chapel, Georges Fork, Dirty Creek, Webbers Falls, and Blackjack School members.
	MORROWAN		BLOYD	0-150	Blue-gray, fossiliferous limestone interbedded with gray, fissile shale. Abundant Pentremites. Thins northward to extinction in Yonkers area.
			HALE	0-140	Massive, blue-gray, sandy limestone and cross-bedded sandstone; weathers pitted and fluted. Conglomerate at base. Abundant Pleurodictyum eugenae.
MISSISSIPPIAN	CHESTERIAN		PITKIN	0-60	Gray-blue, rubbly-weathering limestone with Archimedes, Diaphragmus, Eumetria, Torynifera. Thins northward to extinction near Yonkers.
			FAYETTEVILLE	15-185	Black, fissile shale and thin interbedded blue-black limestone. Fossiliferous with Eumetria, Diaphragmus, Spirifer increbescens, Linoproductus.
			HINDSVILLE	0-65	Gray, oolitic limestone with Spirifer leidyi, Agassizocrinus, Diaphragmus cestriensis.
	MERAMECIAN		MOOREFIELD	0-35	Blue-yellow, calcareous siltstone and shale.
				0-8	Gray, granular limestone with chert fragments.
				0-65	Blue black to brown, argillaceous limestone; Leiorhynchus carboniferum, Moorefieldella eurekensis; grades eastward into glauconitic, gray limestone.
	OSAGIAN	BOONE	KEOKUK	0-70	Massive, white to tan flecked, tripolitic chert and blue gray, crinoidal limestone.
			REEDS SPRING	0-150	Blue-white to tan, thin-bedded chert and limestone.
			ST. JOE	0-25	Gray, nodular weathering limestone and underlying green shale.
?	KINDERHOOKIAN		CHATTANOOGA	0-60	Black, fissile shale with basal Sylamore sandstone.
DEV.	ULSTERIAN		SALLISAW	0-25	Brown, calcareous sandstone and chert.
			FRISCO	0-8	Gray, coarsely crystalline limestone.
SIL.	NIAGARAN		ST. CLAIR	0-100	Pinkish-white, coarsely crystalline limestone; absent north of Qualls.
ORDOVICIAN	CINCINNATIAN		SYLVAN	0-25	Yellow-brown to green, unfossiliferous shale
			FERNVALE	0-25	Gray, coarsely crystalline limestone with abundant Rhynchotrema capax.
	MOHAWKIAN		FITE	0-8	Gray, lithographic, calcite-flecked limestone.
			TYNER	0-90	Bright green shales and thin, sandy, yellow dolomite.
	CHAZYAN		BURGEN	0-100	White to yellow, hard, massive sandstone with thin bed of sandy dolomite and green shale.
	CANADIAN		COTTER	± 200	Gray to buff, finely crystalline dolomite with thin beds of white sandstone.
PRE-CAMBRIAN			SPAVINAW	?	Red, coarse-grained granite near Spavinaw

INDEX FOR FIGURE 2.



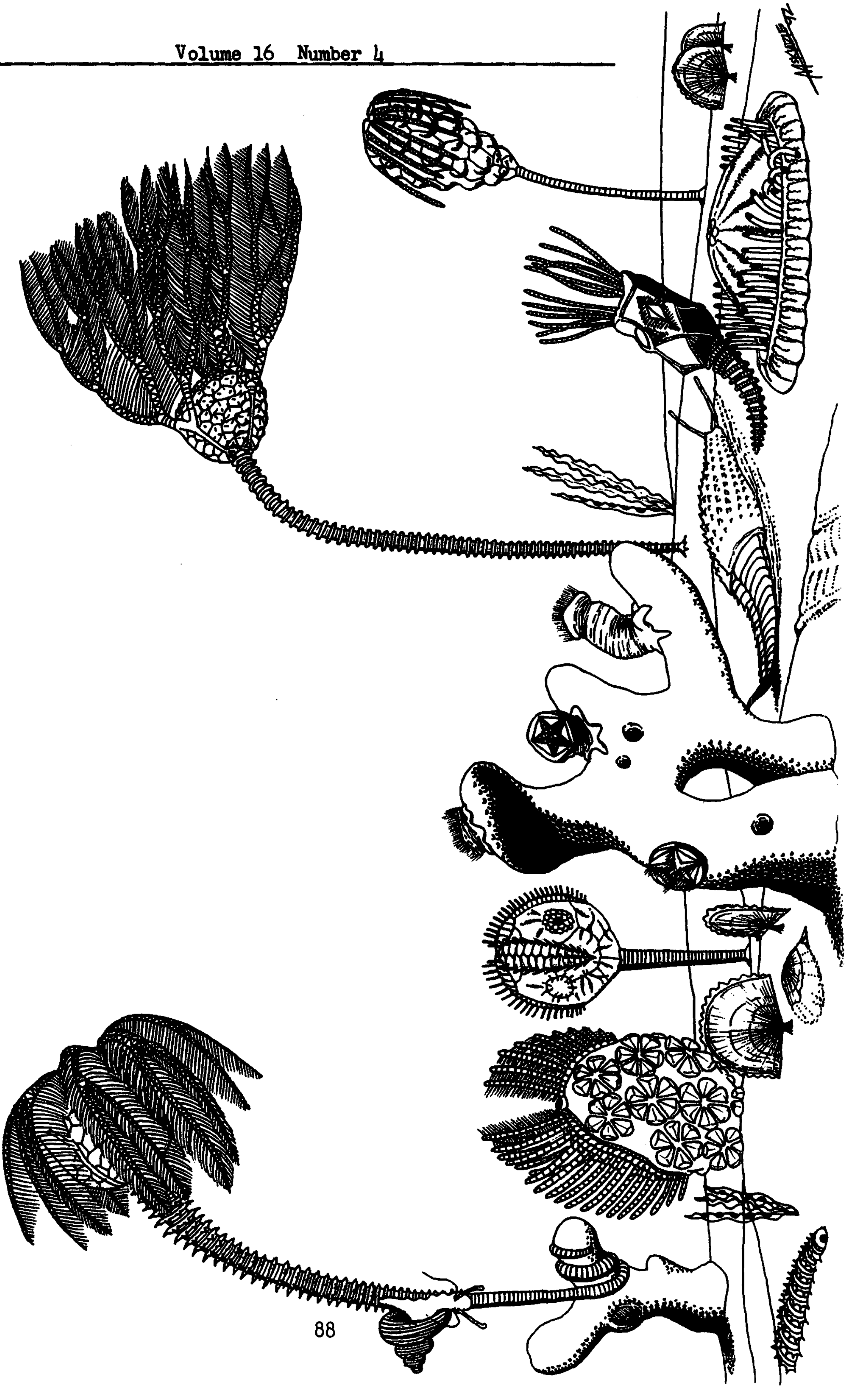
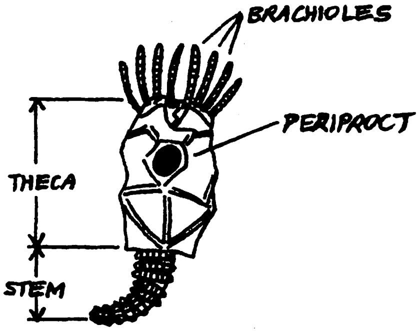


FIGURE 2.

FIGURE 3.



IDEALIZED RHOMBIFERAN CYSTOID

INFERRED MODE OF TRAVEL OF RHOMBIFERAN CYSTOID USING STEM AS MEANS OF PROPULSION:

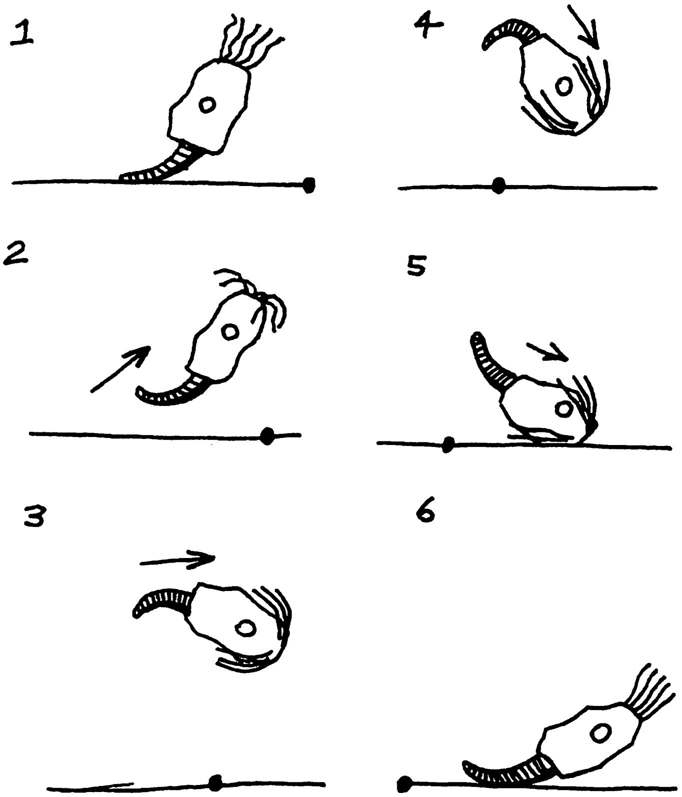


FIGURE 4.

PLEUROCYSTID <u>PRAEPLUEROCYSTIS WATKINSI</u> IN INFERRED LIFE POSITION SWEEPING SEA FLOOR FOR ORGANIC DETRIUS WITH PAIRED BISERIAL BRACHIOLES:

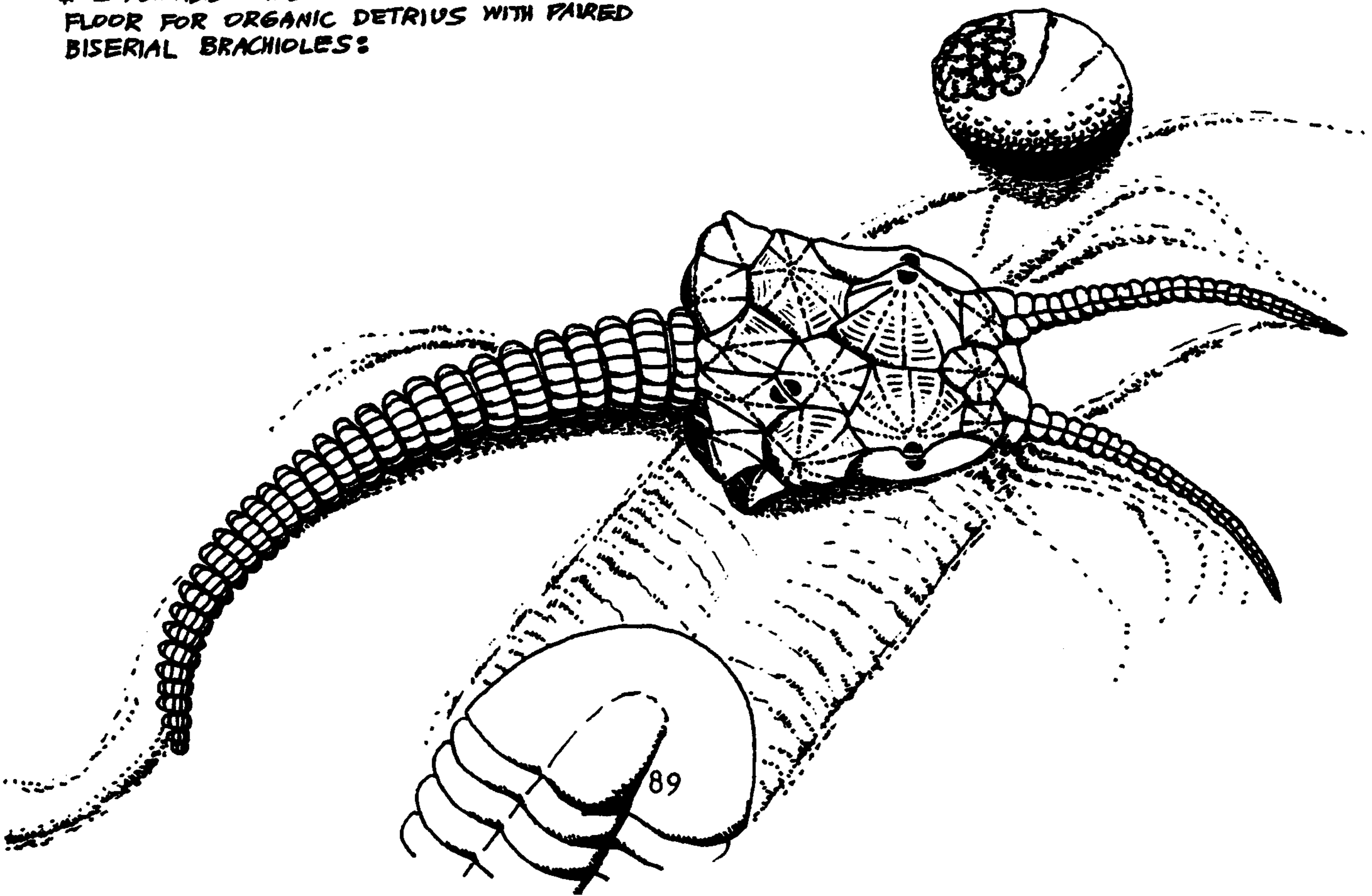


FIGURE 5.

DIPLOPORITE CYSTOID
EUMORPHOCYSTIS MULTIPORATA

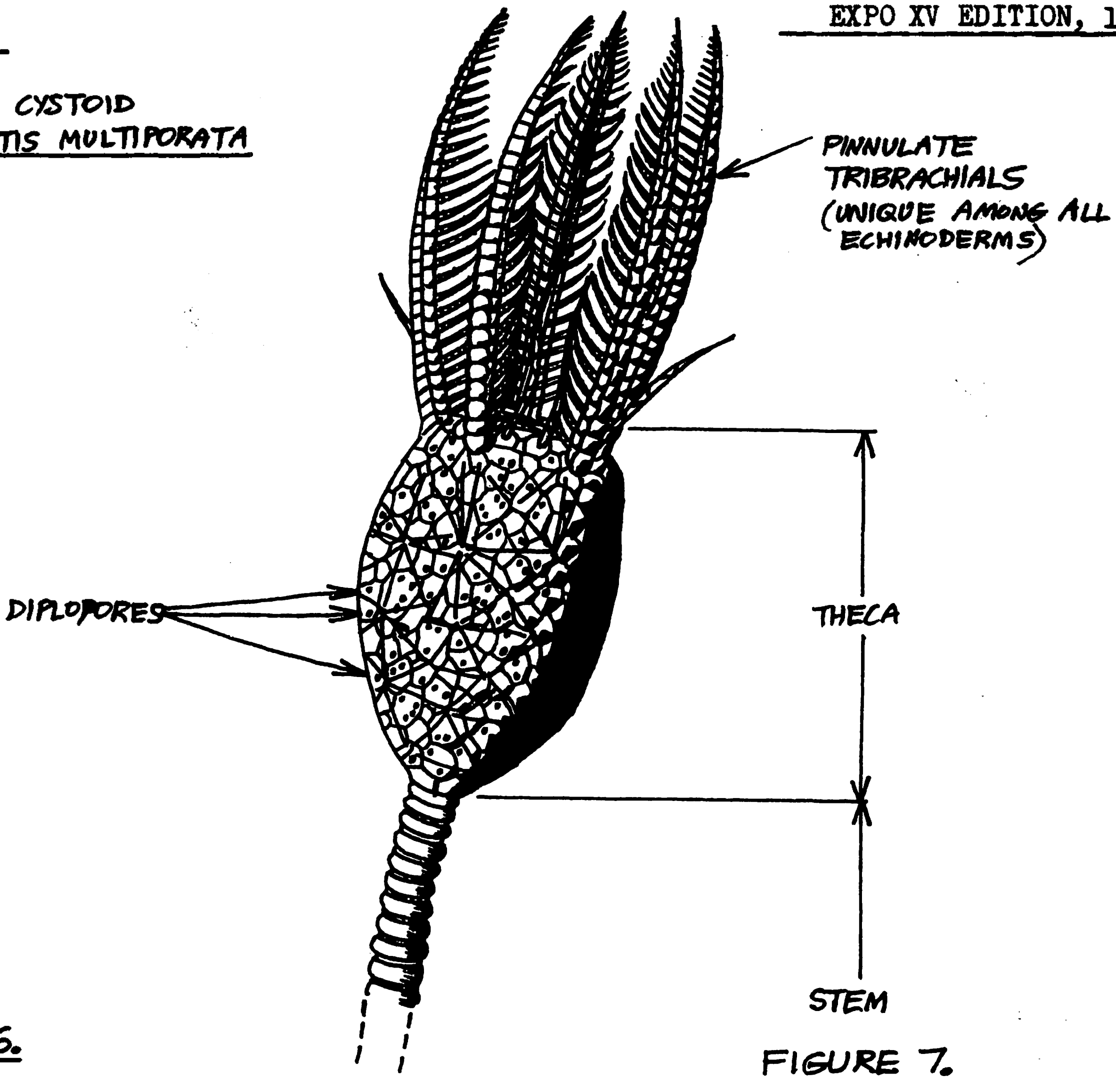
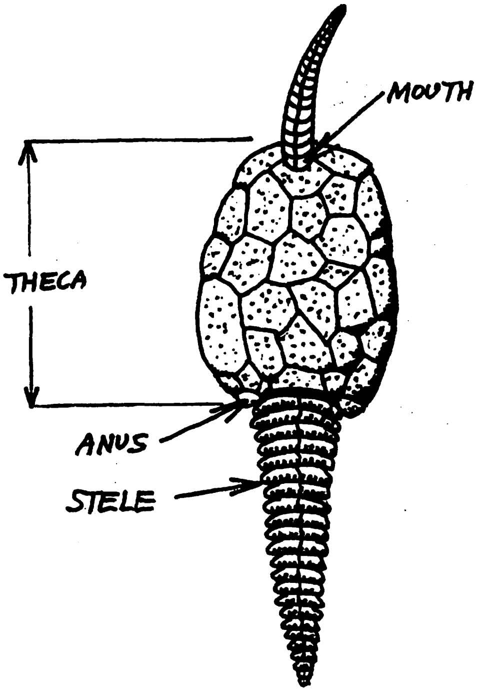


FIGURE 6.

SOLUTE CARPOID
MYEINOCYSTITES NATUS



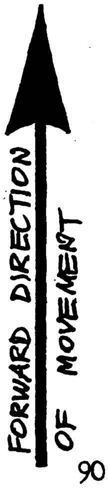
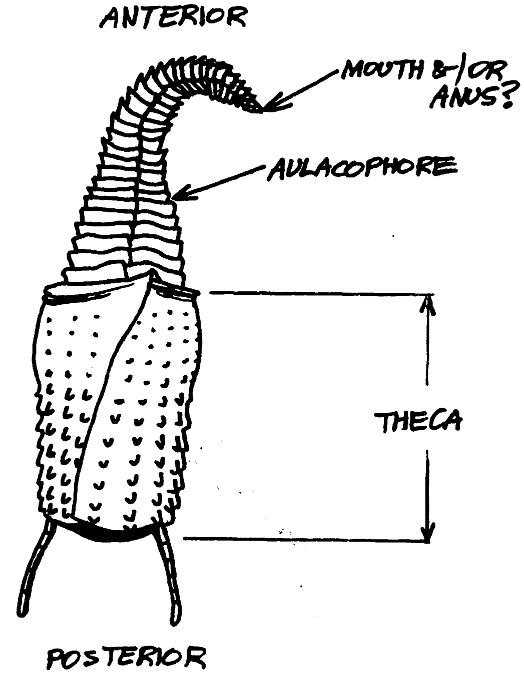


FIGURE 7.

MITRATE STYLOPHORAN
ANATIFEROCYSTIS PAPPILATA



FIRST REPORTED OCCURENCE OF MACROCYSTELLID EOCRNOID FROM THE LOWER ORDOVICIAN OF EL PASO, TEXAS

BY: Mark G. McKinzie
DATE: January 1993

INTRODUCTION

Over the Christmas holiday of 1992 I had the oppurtunity to collect lower Ordovician fossils at El Paso, Texas. The entire lower Ordovician section is magnificently exposed in the Franklin mountains which the town of El Paso lies at the southern foot of. I discovered a single bedding plane containing a variety of nearly complete fossils including a crushed eocrinoid and an enrolled trilobite. The eocrinoid is described and compared to other lower Ordovician echinoderms from the south-central United States.

REGIONAL GEOLOGY

The most complete section of lower Ordovician rocks in the southwest is located at the Franklin mountains of extreme west Texas and south-central New Mexico.The Ordovician section here is divided into the lower El Paso group, and upper Montoya group. The El Paso group is correlatable with the Ellenberger group of central Texas, and the Arbuckle group of Oklahoma.

The El Paso group is divided into the following formations in ascending order from oldest to youngest; Bliss ss.,Sierrite, Cooks, Victorio Hills,Jose,McKelligon Canyon,Scenic Drive, and the Florida Mountains formations. I concentrated my collecting in the Florida Mountains formation as a literature search indicated the presence of abundant "cystoid" plates in it. The formation is uppermost lower Ordovician, Canadian stage (which is now called the Ibexian), and Cassinian substage. It is approximately 483 - 488 million years old in absolute age.

The Florida Mountain formation is approximately 36 feet thick at the southern end of the Franklin mountains along Scenic Drive. It is composed of a series of alternating limestones with thin shale partings, and gets progressively dolomitic towards the top. The limestones are primarily biomicrudites, biomicrites, and micrites that are inequigranular. Numerous bedding surfaces contain abundant fossil debris; usually thumbnail size or smaller, and incomplete fragments. The limestone is mottled dark gray with yellow to buff sandy layers.

I discovered a zone near the base of the formation containing numerous complete fossils; including an enrolled trilobite and a crushed eocrinoid. There was also the usual "fossil hash" of brachiopod valves, trilobite moults, pelmatazoan plates, and an occasional gastropod mold.

At the time of depostion of the upper El Paso group, the ancient sea covered a large expanse of the southern mid-continent (see Figure 1.). The broad, nearly featureless shelf was very shallow for a length of hundreds of miles in a east-west direction. The very gentle slope extending offshore meant that miles of sea bottom extending from the shoreline were influenced by tidal forces and storm agitation.

At that time, our continent was actually south of the equator, and this epieric sea was within the tropical latitudes so that the water was very warm, and conductive to calcium carbonate precipitation. Many low-lying areas along the coastine were occasionally emergent and supplied fine sand and silt for offshore depostion. Even greater areas were tidal flats that were inhospitable to a normal marine fuana. It is believed that for miles offshore from the coastline that the water depth was less than a man's height.

Cloud and Barnes recognized in 1948 that the El Paso/Ellenberger/Arbuckle carbonates are analogous to the Bahama Banks of today in that you have a humid, tropical climate carbonate shelf extending for hundreds of miles. However, the Bahama Banks are dwarfed in comparison with the lower Ordovician carbonate ramp.

GENERAL CHARACTERISTICS OF EOCRINOIDS

Eocrinoids, along with the helicoplacoids and the edrioasteroids, were the oldest and most primitive of the echinoderm classes. In North America they are known from the lower half of the Cambrian in California, and the middle Cambrian Burgess Shale fauna of British Columbia. The eocrinoid skeleton consists of three parts; the stem, the theca, and the brachioles.

The stem was a hollow structure commonly differentiated into proximal and distal parts. The theca, like that of the cystoids, was composed of numerous plates of solid crystalline calcite in a generally pentaradiate symmetry. The brachioles were simple, exothecal, food-gathering appendages attached to the oral summit.

The eocrinoids are definately related to the cystoids as they are currently classified, and share many characters in common. These include a poly-plated theca that totally enclosed the living organism, organization of the ambulacra as in the cystoids, and in possessing brachioles instead of the arms of crinoids.

In fact, the specimen I found, which I tentatively identify as Macrocystella, looks so much like the rhombiferan cystoid Cheirocrinus that I originally mistook it for one. It was not until I examined the nearby stem that I felt comfortable it was an eocrinoid. The only major skeletal difference that seperates the two genera is the presence of pore rhombs in the cystoid, and the lack of them in the eocrinoid. This is obviously an aspect echinoderm classification that needs urgent attention as it is not a satisfactory differentiation of closely-related forms.

EOCRINOID DESCRIPTION

PHYLUM: Echinodermata
SUBPHYLUM: Blastozoa
CLASS: Eocrinoidea
ORDER: Plicata
FAMILY: Macrocystellidae
GENUS: Macrocystella (Mimocystites) ?

The specimen is a nearly complete theca with two sections missing where the thecal plates have weathered away. The stem was found approximately a foot downslope from the theca and may not belong to the same individual. It is slightly shorter than the thecal length which I find unusual for an adult rhombiferan cystoid and presumably a macrocystellid eocrinoid. The theca is 3.5 cm long from the aboral end to the summit, and 2.5 cm at its widest point. The original thecal shape is unknown due to the crushed nature of the specimen (see Figure 2.).

The theca is composed of at least 4 circlets of plates as identified in Figure 2. The exact number of plates per circlet is unkown due to the missing plates. The basal circlet plates appear the same size as the other plates of the theca, and like the others are roughly pentagonal in outline. Each plate is strongly marked by radiating ridges which divides the plates into triangles. Each triangle is ornamented by a series of ridges which intersect ridges of adjacent plates. Superficially the plates resemble those of the eocrinoid Paleocystites.

The oral summit and the brachioles are unkown as they were not preserved. The periproctal area is large and oval-shaped as seen in Figure 2. It occurs between the 2nd and 3rd circlets.

The stem can be subdivided into 2 parts based on the columnals; a narrow, slender distal end, and a rapidly-tapering proximal region composed of heterogeneous columnals that are minutely ribbed. In Figure 2,you can see that the distal region is compsed of long, narrow columnals with a smooth exterior. The preserved length of the columnal is 3 cm. The distal attachment (if any) is unknown.

Macrocystella is synonymous with Mimocystites and can be considered a "form genus". Probable different genera and species have been assigned to it on both sides of the Atlantic. This specimen has a few features unique to it, and is definitely a new species if not a new genera for the FAMILY Macrocystellidae. I even hesitate to call it a eocrinoid with 100% certainty as it so strongly resembles a cheirocrinid cystoid.

OCCURENCE: Near the base of the Florida Mountain formation of the El Paso group in lower Ordovician age rocks. Along a bedding plane at the quarried area across the street from the Sierra Hospital at the base of the Franklin mountains, El Paso, El Paso county, Texas.

ASSOCIATED FAUNA & COMPARISON WITH OTHER OCCURENCES

This eocrinoid was part of a fairly non-diverse benthic assemblage characterized by stalked pelmatazoans, trilobites, orthid brachiopods, gastropds, and blue-green algae(see Table 1.). The fauna is well-known to academia, and the cephalopods (not listed or found at this site) have been used to zone the entire lower Ordovician interval in the Franklin mountains.

The lack of diversity in this fossil community is in part related to preservational bias and in part to the original makeup of the benthos. Though the remains are probably close to their original resting place, the general broken and concentrated nature of the fossils indicates some transportation before burial. However, the occasional complete specimen indicates some of the organisms died very close to where they were found. The exception to this are the molluscs, specifically the gastropods and cephalopods. Their aragonitic shells dissolved before burial in the well-oxygenated waters and appear in lower concentrations than they actually were.

All these fossils represent "normal" marine forms that lived in normal ranges of salinity, temperature, and oxygen levels. The water level was very shallow here, probably not much below low-tide base, and subject to occasional strong currents caused by storms.

In Table 1 I have catalogued the fossils from El Paso and other localities of comparable age in the central United States. Notice the overall similairity of the major fossils groups in each case. Orthid brachiopods, stalked echinoderms, trilobites, and gastropods(?) dominate the shelly faunas at each. Also note the lack of reef-building organisms such as bryozoans or corals.

I also included the slightly younger Oil Creek formation of Oklahoma (10 - 15 million years younger) as it is so similair to the others. The main difference is the introduction of bryozoans to the community, and the establishment of patch "reefs". There is also an increased diversification of stalked echinoderms.The setting was in slightly deeper water offshore than the other examples. The overall similairity is not surprising if you go back to Figure 1 and realize that the broad, level shelf of the lower Ordovician sea offered a stable environment with few impediments to the migration of species along its coastline.

CONCLUSION

To my knowledge, this is the first reported occurence of a nearly complete eocrinoid from the lower Ordovician section at El Paso, Texas. It establishes the eocrinoids here, as at other localities in the south-central United States, as the dominant stalked echinoderm of that time. It was a postion the eocrinoids soon lost to the cystoids, paracrinoids, and especially the crinoids by the end of the middle Ordovician in North America.

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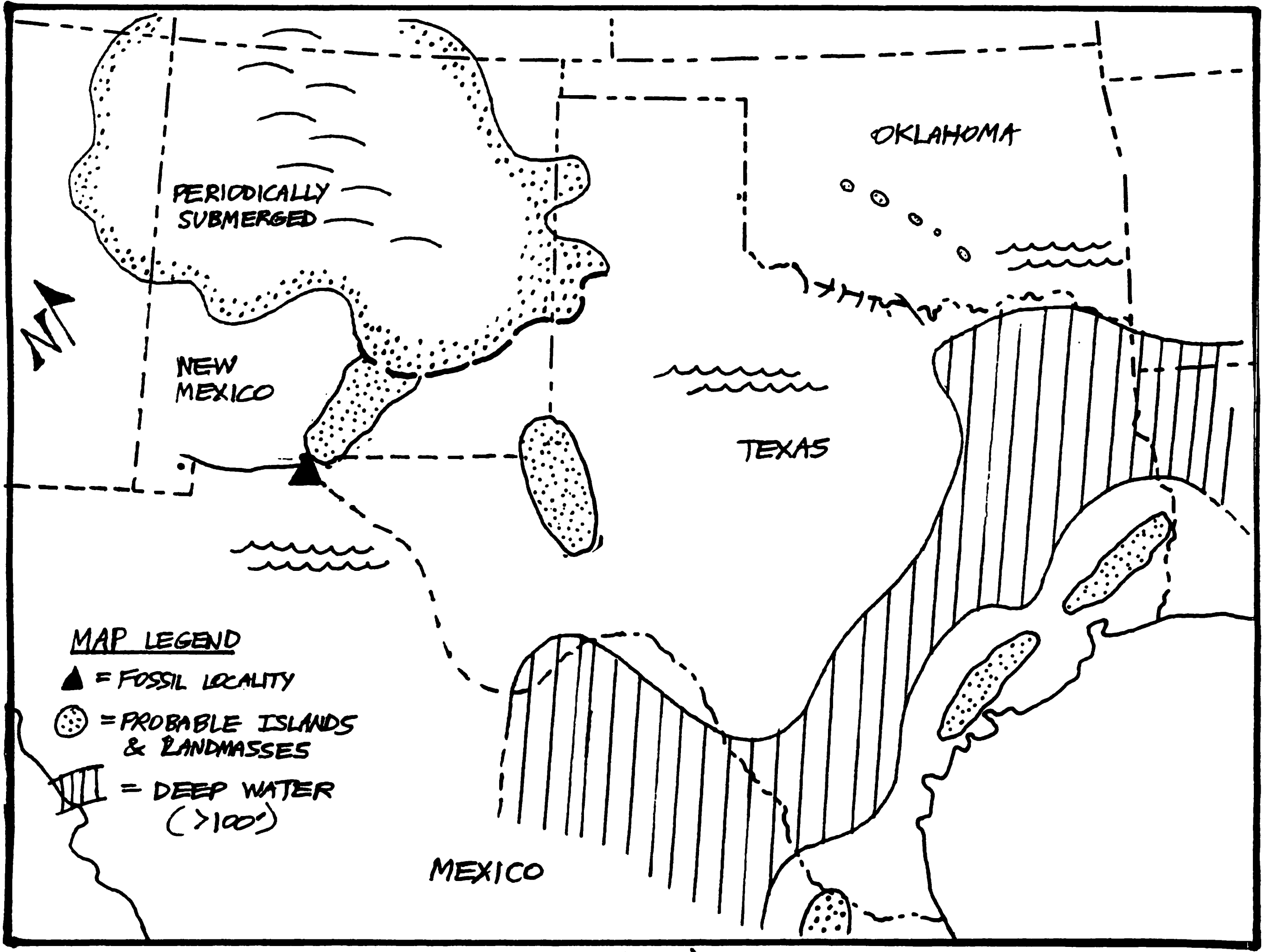
FIGURE 1.

LOWER ORDOVICIAN (IBEXIAN) PALEOGEOGRAPHY SHOWING DISTRIBUTION OF ISLANDS, PENNNSULAS, & DEEP-WATER REGIONS DURING EL PASO DEPOSITION:



* MODIFIED AFTER BARNES ET AL (1959)

FIGURE 2.

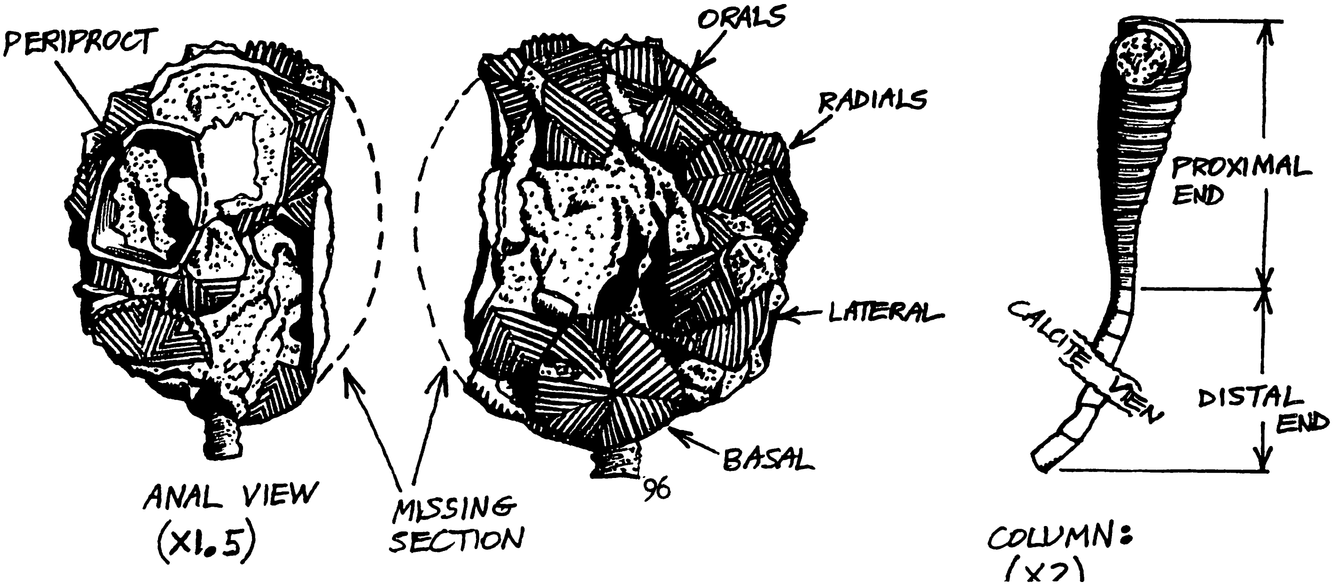


TABLE 1.

AGE: LOWER ORDOVICIAN
STAGE: CANADIAN (IBEXIAN)
SUBSTAGE: CASSINIAN
SEQUENCE: SAUK III

ABSOLUTE AGE: 485-487 MYA

	FLORIDA MTN. FM. EL PASO GROUP FRANKLIN MTNS., TX.	W. SPRING CREEK FM. ARBUCKLE GROUP ARBUCKLE MTNS., OK.	WAH WAH FM. POGONIP GR. IBEX AREA, UT.	OIL CREEK FM. SIMPSON GROUP ARBUCKLE MTN, OK.
TRILOBITES	Isoteloides whitfieldi? Asaphus curiosus Pliomerops nevadensis Cybeloides primus	Isoteloides flexus Isoteloides polaris Aponileus latus Bathyurellus? sp.	Ektenonthus westoni Psuedomera barrendei Pliomerops nevadensis Psuedocybele nasuta	Illaenus arturus Pliomerops nevadensis OIL CREEK IS LWR. MDL. ORD. - WHITEROCKIAN STAGE (475-485 MYA)
GASTROPODS	Liospira sp. unidentified internal molds	Ceratopea buttsi Ceratopea knighti Ceratopea hami Ceratopea unguis Holopea sp. Lophospira sp. Ophileta sp.	?	Liospira progne Lecanospira compacta Malcurites oceanus Palliseria robusta Pluerotomaria obesa Scenella montrealensis
ECHINODERMS	Macrocystellid eocrinoid unidentified echinoderm plates	unidentified pelmatazoan plates & columnals	?	(EOCRINOIDS) Mandalacystis dockeryi Paleocystites tenuiradiatus (CRINOIDS) Hybocrinus sp. Archaetaxocrinus burfordi
ORTHID BRACHIOPODS	Archeorthis sp. Tritoechia typica Hesperonomia (Toffia) Syntrophopsis magma (PENTAMERID)	Anomalorthis? sp. Polytoechia subrotunda Diparelasma typicum Desmorthis nevadensis	Anomalorthis sp. Hespernomiella minor	Anomalorthis oklahomensis Orthis ignicula Orthis acutiplicata Dinorthis pectinella Aitamobonites porrea
BRYOZOANS	NO	NO 97	?	YES

SOME MIDDLE CAMBRIAN ECHINODERMS OF UTAH

by Lloyd and Val Gunther

Ctenocystoids

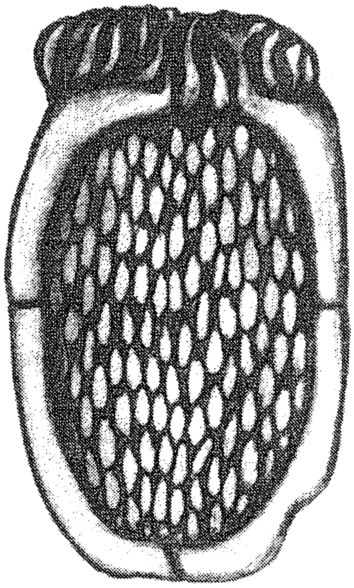
Ctenocystoids belong to the subphylum Homalozoa, Class Ctenocystoidea. Two species, *Ctenocystis utahensis,* and *Ctenocystis colodon,* have been found in the Spence shale of Northern Utah and the Wheeler shale of West Central Utah. The specimens have a flattened, ovoid, flexible theca with doubled-layered marginal frame, near bilateral symmetry, peculiar ctenoid feeding apparatus, and mouth and anus at opposite body poles. Both species have been described by Robison and Sprinkle.

These tiny primitive echinoderms measure from 3 to 9 mm in length and average about 6 mm, width ranges from 2 to 6 mm and average about 4 mm.

Locomotion may have been achieved by periodic rapid expulsion of water from the anal pyramid. Rhythmical expansion and contraction of the flexibly plated superior and inferior body walls, hinged along thin sutures between superior and inferior marginals, would produce a bellow-like pumping action. Three posteriorly directed spines on intermarginal plates in the anal region also would exert a stabilizing influence and impede lateral and posterior motion of the body. The concave inferior body surface may have functioned like an airfoil to enable the animal to glide on a cushion of water just above the sea floor.

The feeding apparatus possessed by ctenocystoids is unique among known echinoderms and probably was used for detritus or filter feeding. It apparently involved a series of 18 movable ctenoid plates, two elongate lateral plates, and at least parts of one superior and four inferior marginal plates. The grill-like array of ctenoid plates most likely was used for digging, sifting, or filtering out small food particles, perhaps aided by mucus secretion or ciliary currents, or both.

These animals may also have been gregarious as we have collected slabs containing numerous (sometimes hundreds) of individuals.



Ctenocystis utahensis
Wellsville Mts.

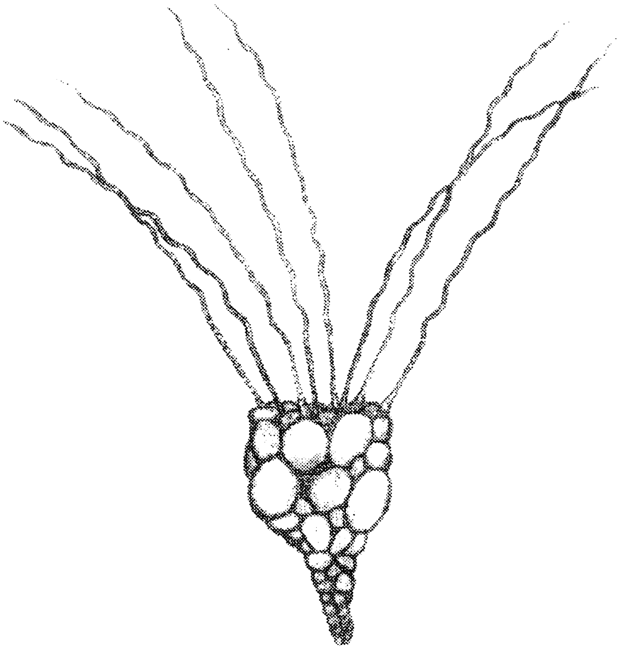
Eocrinoids

Eocrinoids belong to a subphylum Blastozoa, Class Blastoidea, which are a heterogeneous group including several different thecal designs. They are the earliest brachiole-bearing echinoderms and among the first echinoderms to appear in the fossil record. They were apparently the ancestral group for all other blastozoan classes.

They possessed a globular to flattened theca with numerous irregular to regular arranged plates. Their food gathering system composed of long erect brachioles mounted on two to five simple ambulacra. The mouth is usually central on the summit, anus lateral, hydropore and gonopore usually just below the mouth. Sutural pores are present in early forms. Holdfast appendage long to short, most were attached high-level suspension feeders, but a few were unattached or recumbent on the sea floor. Eocrinoids were the first group to develop a true columnal-bearing stem late in the Middle Cambrian, about 30 million years before crinoids made the same transition. Some 30 plus genera are recognized and range from Early Cambrian to Late Silurian.

Of the thousands of articulated eocrinoid specimens collected from Cambrian deposits in North America, probably more than half are from the Spence, Wheeler, and Marjum Lagerstatten of Utah. Most of those we have collected are of the Genus *Gogia* and are often found in "gardens" indicating their gregarious nature. Some slabs we have collected contain more than a hundred individuals, and nearly all oriented in the same direction. *Gogia* occurrences seem to have been produced by catastrophic sediment slumps that killed and buried large colonies of these gregarious animals.

According to Sprinkle, *Gogia* seems to have been one of the most successful eocrinoids that ever lived, and much more still remains to be learned about its taxonomy, distribution, and paleoecology. A number of new species of this genus have recently been found and are under study. It is interesting that no two Gogia species are known to occur together; when two species are found in a single locality, they seem to occur in different stratigraphic intervals.



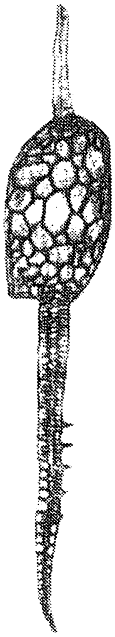
Undescribed Eocrinoid
Gogia n. sp.
Promontory Mts.

Homoiostelean Carpoids

We have collected hundreds of specimens of two species of these primitive echinoderms from the House Range in West Central Utah. These specimens after having been described by Ubaghs, Robison, and Sprinkle have been deposited in the National Museum.

Castericystis vali occurs in both limestone and shale beds of the Middle Cambrian Marjum Formation. In the interbedded limestone, specimens are preserved on silty parting surfaces. The dark-gray or black calcite endoskeleton stands out clearly against the lighter color of the rock. The fragmentary condition of most of these specimens appears to be the result of weathering or partial decomposition before burial, or both. In contrast those found in shale beds are most often complete. Many specimens are large (thecal length up to 28 mm). Juveniles are common, free or attached to an adult. These Homoiosteleans are most abundant in the light-colored shale and may individuals may be found on a single slab, most oriented in a single direction. The regular alignment is indicative of current action at the time of burial and by storm-generated sediment on a gently sloping sea-floor below wave base.

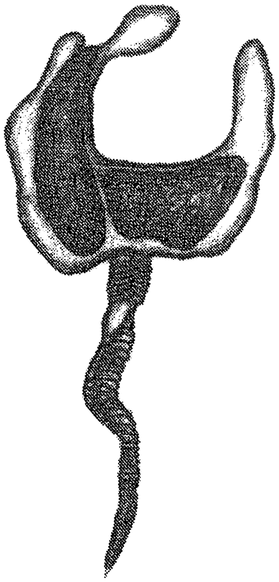
Castericystis sprinklei occurs mostly in light-gray calcareous shale of the Middle Cambrian Wheeler Shale Formation. Most are small calcite-encrusted masses of irregular shape. Some retain the general outline of the body, and some show a few thecal or arm plates. Because of being masked by the calcite coating, none show stele plates. The arm is about as long as the theca and the stele is about twice as long as the theca. In all available specimens, its anatomy has been obliterated by secondary crystallization. The fossiliferous bedding surface is about 10 to 20 meters below the top of the formation and about one half meter below a thin bed that has been mined for abundant specimens of the trilobite *Elrathia kingii* (Meek).



Castericystis vali
House Range

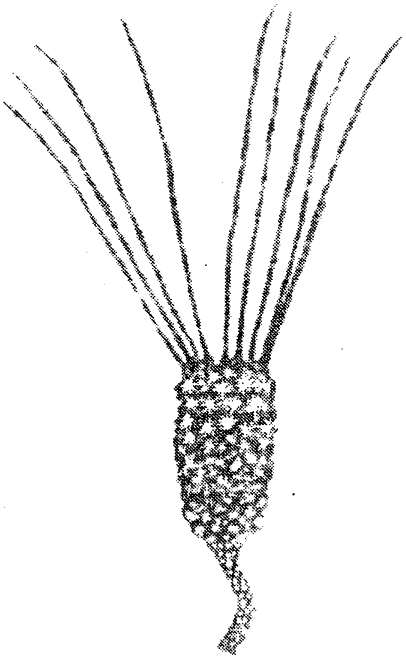
Stylophoran Carpoids

We have collected approximately 100 specimens of a new species *Cothurnocystis bifida* described by George Ubaghs and R.A. Robison from a locality along the southern flank of Antelope Mountain in the Central House Range. All specimens were deposited in the U.S. National Museum. Many specimens are covered with a thick crust of secondary calcite. Rarely, parts of the thecal frame, glossal process, and digital process are exposed. Parts of the inferior face, including the aulacophore, are free of incrustation in a few specimens. Many specimens retain the glossal process and at least part of the aulacophore (including cover plates), which suggests rapid burial at or near the place they lived.

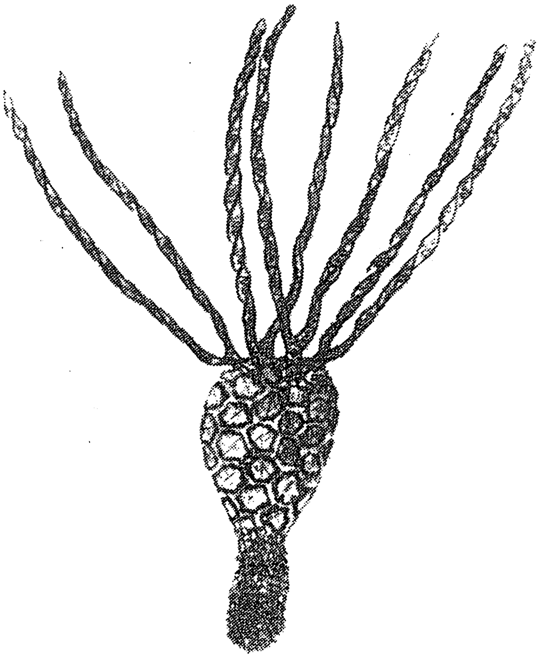


Cothurnocystis (?) bifida
House Range

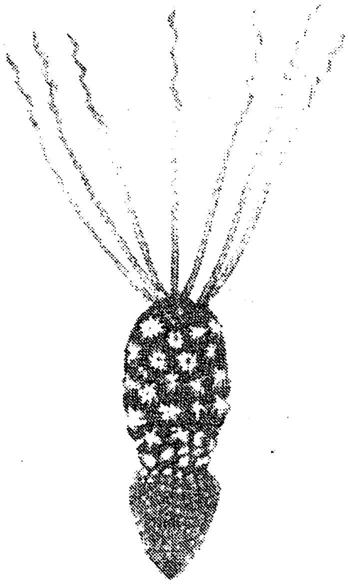
Undescribed Stylophoran
Wellsville Mts.



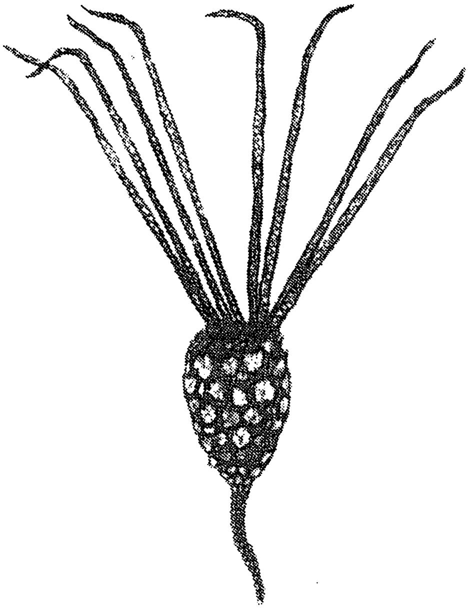
Gogia palmeri
Bear River Range



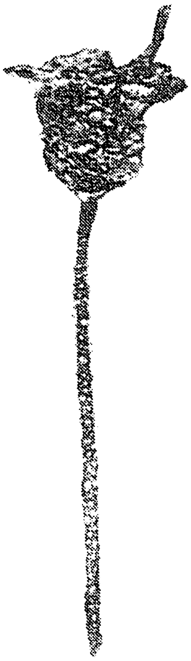
Gogia spiralis
House Range & Drum Mts.



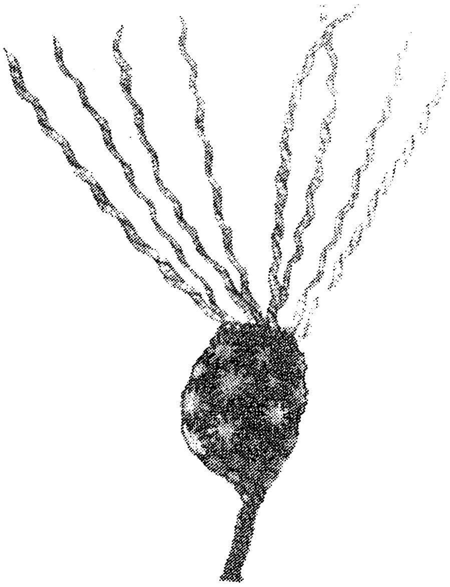
Gogia guntheri
Wellsville Mts.



Gogia n. sp.
Wellsville Mts. &
Bear River Range



Undescribed Eocrinoid
Wellsville Mts.



Gogia granulosa
Wellsville Mts.

LOWER MISSISSIPPIAN BLASTOIDS FROM OHIO

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INTRODUCTION

Three blastoid specimens, perhaps belonging to two new species, have recently been recognized from Lower Mississippian strata of northern Ohio. Although a diverse crinoid fauna has been known from the Lower Mississippian Cuyahoga Formation since the monographic works of James Hall (Hall, 1863; Hall and Whitfield, 1875), blastoids have never been reported from these strata. These blastoids are not only significant because they represent a new occurrence, but this is also a very interesting paleoecological occurrence of blastoids from this age.

The Cuyahoga Formation was deposited contemporaneously with parts of the Burlington Limestone of Missouri, Iowa, and Illinois (middle Osagean). Blastoid abundance and diversity reached its historic high in the Burlington Limestone. Approximately 17 blastoid genera are recognized from the Burlington Limestone, and blastoids are one of the most common fossils in this unit. The Burlington is typical for middle Osagean and older blastoids, because they typically are most common in carbonate environments (Waters, Broadhead, and Horowitz, 1982). The Cuyahoga Formation blastoid occurrence stands in sharp contrast to the Burlington Limestone. Although blastoids are very rare, the Cuyahoga gives us a record of the blastoids that lived in siliciclastic environments during the middle Osagean. This is important, because the environmental preferences of blastoids changed during the late Osagean, where they were known from a wider variety of environments (Ausich, Meyer, and Waters, 1988). Also, by Chesterian times (Late Mississippian) the blastoid *Pentremites* dominated in both carbonate and siliciclastic environments.

Two of these blastoid specimens were collected by R.L. Guenther, and the third was found in the collections of the U.S. National Museum of Natural History by W.I. Ausich. In this report we announce the discovery of this material and offer preliminary descriptions. Formal systematic description of this material must await further study.

STRATIGRAPHY AND LOCALITIES

Specimen A is from an exposure of the Cuyahoga Formation east of Homerville, Ohio where the Black River has cut down through silty limestone and gray shales more than 20 feet. Specimen A was preserved in a siderite concretion, and concretions are scattered throughout the formation at this locality. The blastoid-bearing concretion was collected from the silty limestone layer about two feet above the water level and about 14 feet below the top of the formation.

Specimen B is from the Cuyahoga Formation in the central part of Ashland County, east of Hayesville, Ohio. Siderite concretions are also present in the Cuyahoga at this locality, but this blastoid is from a gray shale layer about 14 feet below the top of exposures at this locality. It was collected about eight inches above water level.

Specimen C was discovered in a drawer at the U.S. National Museum of Natural History. The label accompanying this specimen has the following information "Loose Rx in stream bed Meadville fm. West Branch of Rocky R. at junction of small stream south of Abbyville, Medina Co., Ohio Coll. J.J. Happinger." This was undoubtedly from Cuyahoga Formation strata.

DESCRIPTIONS

Specimen A

Specimen A is still partially buried in matrix are preserved as a cast with an outer coating of siderite. The distal portion of the basals and broken away, but plate surface details are very well preserved and still display fine growth lines. The theca is small (less than 1.0 cm), is probably biconical in shape, has a rounded pentagonal outline in oral view, and has a vault probably subordinate in height to the pelvis (Figure 1a).

This specimen has three high basals with interbasal sutures straight, well preserved fine growth lines, and the stem attachment broken away. Radial plates are high, probably form approximately the upper half of the pelvis and the lower part of the vault, are higher than wide, have the interradial areas slightly depressed, and growth lines preserved proximally. Radial-basal sutures are slightly curved. Ambulacra probably occupy the upper third of the radial plate. Details of the ambulacra, deltoids, summit, hydrospire, column, and brachials not known.

Additional preparation is still required on this specimen in order to reveal the summit area. We suspect that this is a fissiculate blastoid and that it probably belongs to *Hadroblastus*, but this identification needs to be verified.

Specimen B

Specimen B is a very poorly preserved, compressed specimen slightly more than 1.0 cm high. It is a very poor cast in a gray shale. The only evident aspect of this specimen is the presence of long ambulacra, which probably align it with Specimen C.

Specimen C

Specimen C is a nearly complete blastoid with brachials attached (Figure 1b). However, because it is preserved as an external mold of less than half of the specimen, its identity is obscure.

Specimen C has a medium sized, elliptical theca with height greater than width and the widest portion of the theca nearly at the base. The pelvis is broad, and ambulacra nearly reach to the base of the theca. The oral view outline is pentagonal, and prominent vertical growth lines are present along the limbs of the radial plates. Radial plates are higher than wide, the limbs form the major proportion of the theca height, the radial sinus nearly extends to the base of the theca, and each radial limb is approximately as wide as the sinus. Deltoids are small, rhombic, slightly higher than wide. Ambulacra are linear, taper in width gradually, extend nearly to base of theca. Probably spiracles present interradially. Brachials extend at least the equivalent of one thecal height above the theca summit. Details of the basal plates, summit, hydrospires, and stem not known. Preserved theca nearly 1.5 cm high; theca and brachials more than 3.0 cm high.

The morphology of this blastoid, along with the poorly preserved remnants of probable spiracles suggest that specimen C is a spiraculate blastoid. Without detailed knowledge of the summit, more precise systematic assignment cannot be made at this time.

DISCUSSION

Although these blastoids cannot be definitively named at this time, their occurrence in the Cuyahoga Formation of northern Ohio is quite significant. This occurrence demonstrates that probably both fissiculate and spiraculate blastoids were present in shallow water siliciclastic environments during the middle Osagean, even though this was not an optimum habitat. At the close of the middle Osagean, a major extinction event occurred among blastoids (Ausich, Meyer, and Waters, 1988). Immediately following that extinction, blastoids were no longer common and diverse in shallow-water carbonate environments like the Burlington Limestone. Instead, they were better represented in basinal siliciclastic or mixed siliciclastic/carbonate facies such as the New Providence Shale Member of the Borden Formation or the Fort Payne Formation (Ausich, Meyer, and Waters, 1988;

Ausich and Meyer, 1988). Further study of these Lower Mississippian blastoids from Ohio may reveal the ancestral roots of the late Osagean basinal blastoid faunas. Did they evolve from members carbonate environment blastoids such as the Burlington Limestone or from blastoids in siliciclastic environments such as these reported here from the Cuyahoga Formation?

ACKNOWLEDGMENTS

We thank William Hammer, Augustana College, and Jann Thompson, U.S. National Museum of Natural History for allowing us access to two blastoid specimens discussed above.

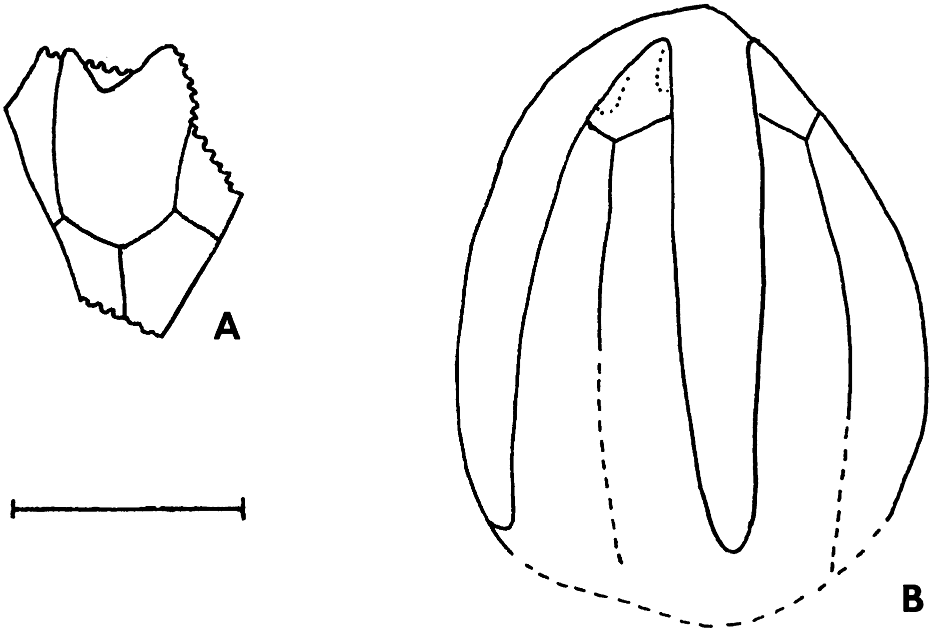

FIGURE 1 -- Camera lucida drawings of Cuyahoga *Formation blastoids.* Dashed lines represent inferred plate boundaries, jagged line is limit of preservation, scale is 5 mm. A, specimen A; B, specimen C, note dotted features near summit, which are thought to be remnants of the spiracles.

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EXTINCT ECHINODERMS OF KENTUCKY

DEVONIAN AND MISSISSIPPIAN

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There are only a handful of extinct echinoderm classes found in the Devonian and Mississippian periods. Most have not been reported from Kentucky. There is one class that has been synonomous with Kentucky paleontology for over a 150 years - the blastoid Pentremites. It was called the "Kentucky Astral Fossil" by David Dale Owen, Kentucky's first State Geologist.

The Devonian is best represented in the state in exposures around Louisville. Good exposures also occur in southern Indiana. Two limestone units (one partially argellaceous) and a thick black shale sequence comprise the Devonian.

The Middle Devonian Jeffersonville Limestone (Emsian/Eifelian) and Sellersburg Group (Givetian) contain five and two blastoid species, respectively (see Table 1). As a comparison, the same formations are represented by 19 and 38 crinoid species, respectively. It is possible that the rarer echinoderms: cyclocystoids, edrioasteroids, ophiocystoids, rhombiferids or stylophorids may be found with diligence and luck. This writer has not encountered any references to local occurences nor found anything conclusive through extensive field work to date.

The Mississippian period contains even less extinct echinoderm classes than the Devonian. Blastoids reached their acme during this time and at least 14 genera have been reported from Kentucky. Table 2 lists extinct echinoderms (blastoids and edrioasteroids). A single microblastoid has been reported by Conkin & Conkin (1971) from the early Mississippian (Kinderhookian) Jacobs Chaple Shale in southern Indiana. It requires 30x or better to be seen well. Blastoids are rare in the lower part of the Osagean (Lower Middle Mississippian). The genus Pentremites becomes common by the beginning of the Meramecean (Upper Middle Mississippian). In the Chester (Upper Mississippian), Pentremites become more diversified into many species. (Most paleontologist consider this genus to be "oversplit".)

The Osagean blastoids are much more ornate than most earlier (and many later) species. Deliablastus, Euryoblastus, Granatocrinus and Xyleleblastus are particularly striking.

Two Chesterian edrioasteroids have been reported from the Glen Dean Formation at Eckerty, Crawford County, Indiana (Larry Osterberger, personal comment.) It is posssible that these occur in adjacent areas in Kentucky.

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Table 1: Devonian Blastoids,

Jeffersonville Limestone

- Eleacrinus greeni (Miller & Gurley)
- E. venustus (Miller & Gurley)
- E. vernueilli (Roemer)
- Eleuthrocrinus cassedayi (Shumard & Yandell)
- Trionoblastus ? americanus (Shumard)
- T. pyramidatus (Shumard)

Beechwood Limestone

- Eleuthrocrinus cassedayi (Shumard & Yandell)
- Placoblastus angularis (Lyon)

Table 2: Mississippian Blastoids & Edrioasteroids

Kinderhookian (Early Mississippian)
Jacobs Chapel Shale
Kallimorphiocrinus sp. (Microblastoid)
Osagean (Borden Group/fort Payne Fm.)

- Deliablastus cumberlandensis (Ausich & Meyer)
- D. tribulosus (Ausich & Meyer)
- Dentablastus macurdai (Ausich & Meyer)
- Euryoblastus veryi (Rowley)
- Euryoblastus n. sp. (collected by writer)
- Granatocrinus granulatus (Roemer)
- G. kentuckyensis (Conkin)
- Hadroblastus briemeri (Ausich & Meyer)
- H. kentuckyensis (Shumard)
- Hadroblastus sp.
- Metablastus sp.
- Perittoblastus liriatus (Ausich & Meyer)
- Schizoblastus sp.
- Xenoblastus decussatus (Shumard)
- Xyleleblastus magnificus (Ausich & Meyer)

Meramecian Blastoids

- Diploblastus sp.
- Metablastus bipyramidatus (Hall)
- M. wachsmuthi (Gurley)
- M. wortheni (Hall)
- Pentremites conoideus & varieties (Hall)
- Tricoelocrinus meekanus (Etheridge & Carpenter)
- T. woodmani (Meek & worthern)

Chesterian Blastoids

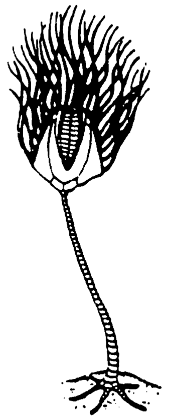
Diploblastus glaber (Meek & worthern)
D. incurvatus (Weller)
Pentremites spp. galore

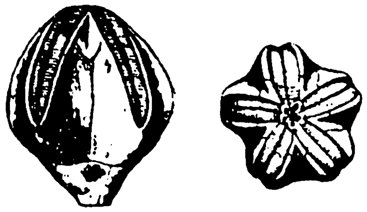
Chesterian Edrioasteroids

Discocystis sp.
Lepidocystis laundeni

MAPS EXPO XV STA.

BLASTOID





FOSSIL

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RECONSTRUCTION

THE YEAR OF EXTINCT ECHINODERMS