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# Bulletins of American Paleontology

VOLUME 95, NUMBER 330

JUNE 8, 1988

Hombergian (Chesterian) Echinoderm Paleontology and  
Paleoecology, south-central Kentucky

by

Donald R. Chesnut, Jr.

and

Frank R. Etnensohn

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# HOMBERGIAN (CHESTERIAN) ECHINODERM PALEONTOLOGY AND PALEOECOLOGY, SOUTH-CENTRAL KENTUCKY

By

DONALD R. CHESNUT, JR.<sup>1</sup>, and FRANK R. ETTENSOHN<sup>2</sup>

## ABSTRACT

A highly fossiliferous unit in the lower part of the Pennington Formation (Chesterian), herein called the Sloans Valley member, was one of the most important Carboniferous fossil beds in the United States during the nineteenth century. The Sloans Valley member was deposited in a protected, shallow-water, marine environment shoreward of a carbonate-shoal complex, which is represented by the Glen Dean Limestone. Oxygenated waters from the seaward direction and land-derived nutrients promoted a prolific echinoderm fauna in this wave-protected environment.

Forty-five species of echinoderms belonging to 38 genera were found in the Sloans Valley and Glen Dean and are described in this study. The classes Crinoidea, Blastoidea, Edrioasteroidea, Echinoidea, Asteroidea, and Ophiuroidea are represented. Four new species, *Linocrinus laurelensis*, *Palaechinus jacksoni*, *Archaeocidaris hemispinifera*, and *Calyptactis spenceri*, and two new genera, *Wetherbyocrinus* and *Pulaskicrinus*, are described and illustrated. In addition, numerous new combinations and taxonomic revisions are suggested. Finally, the concepts of various species within the genera *Zeacrinites*, *Dasciocrinus*, *Cymbiocrinus*, *Aphelecrinus*, *Ampelocrinus*, *Phanocrinus*, *Eupachycrinus*, and *Pterotocrinus* also are revised.

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We also wish to thank the staff of the Field Museum, Chicago, IL; Lois Campbell, Geology Dept., University of Kentucky, Lexington, KY; Alan Horowitz, Geology Dept., Indiana University, Bloomington, IN; and Daniel Blake, Geology Dept., University of Illinois at Champaign-Urbana, Urbana, IL; for lending us specimens. We would like to thank Frederick Collier, Jann Thompson, and Mary Lawson of the U. S. National Museum for allowing us access to the Springer Collection and for the use of their photographic equipment.

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We would also like to thank Professor Z. L. Lipchinsky of Berea College, who showed to us the Morrill locality and donated a fine specimen of *Lepidodiscus laudoni* (Bassler, 1936) to the collection at the University of Kentucky.

We wish to warmly thank Dr. and Mrs. John Trodahl of Alexandria, Virginia, who invited us, almost total strangers, to stay with them while we visited the National Museum, and who treated us with great hospitality and enthusiastic support.

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We wish to thank our wives and families for their understanding of the long hours we spent working on the manuscript.

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## INTRODUCTION

Well-preserved, diverse fossil echinoderms have been found in the Middle Chesterian (late Viséan; Hombergian) rocks of south-central Kentucky (Text-fig. 1) since the late 1800's. The echinoderm fossils from this



area were known throughout the paleontological world during the late 1800's and early 1900's, and many of these specimens now reside in museums in the United States and Europe. Perhaps the most famous locality in this area is Sloans Valley in Pulaski County (Text-fig. 1). Specimens from this locality were collected or described by many prominent American paleontologists including Wetherby (1879a, 1879b, 1881), Miller (1879), Miller and Gurley (1895, 1896), Wachsmuth and Springer (1880), Ulrich (1905, 1918), Wood (1909), Butts (1918, 1922), Springer (1920, 1926), Weller (1920), Sutton (1934), Kirk (1937, 1940a, 1942a, 1942b, 1944b), Sutton and Winkler (1940), and Moore and Laudon (1943, 1944). Lists of echinoderms from Sloans Valley were compiled by Bassler and Moodey (1943). More recently, Horowitz (1965) and Strimple and Horowitz (1975) described fossils from the same area.

Locality descriptions in the above studies suggest that many of the primary types of "Glen Dean" fossils or those labelled "Pulaski County, Kentucky" were collected from this site. Most of these fossils were collected from spoil piles of shale and limestone that were removed to make the Sloans Valley railroad tunnel, part of the old Cincinnati, New Orleans, and Texas Pacific Railroad (Macfarlane, 1890), later known as the Cincinnati-Southern Railroad System (Butts, 1922). Thus, the locality was accessible by train, which was boarded in Cincinnati and stopped near the collecting locality at the Sloans Valley station (Macfarlane, 1890). According to Springer (1920), the Sloans Valley locality was initially discovered by Wetherby and later rediscovered by Wachsmuth.

Our field work revealed six additional localities (Text-fig. 1) that yielded prolific echinoderm faunas. Positions of the collecting localities and descriptions of the sections at each are given in Appendix 2. Together, these localities have yielded more than 700 well-preserved specimens representing approximately 50 different species from six echinoderm classes. Perhaps an equal number of older specimens reside in museums. Crinoids, blastoids, echinoids, edrioasteroids, ophiuroids, and asteroids are represented. The diverse fauna also includes brachiopods, bryozoans, pelecypods, gastropods, rugose corals, conularids, ostracods, foraminifers, fish remains, and trace fossils. The excellent exposures, prolific faunas, and extraordinary preservation provide an unparalleled opportunity to study in greater detail the so-called Sloans Valley echinoderm fauna, its stratigraphic occurrence, and its paleoecologic and paleoenvironmental framework. Hence, it is the purpose of this study to describe the systematic paleontology of the echinoderm fauna, including both new and old forms, as well as its stratigraphic occurrence and probable paleoecology.

#### ABBREVIATIONS OF REPOSITORIES

Repositories that supplied specimens examined in this study are represented in the text by the following abbreviations:

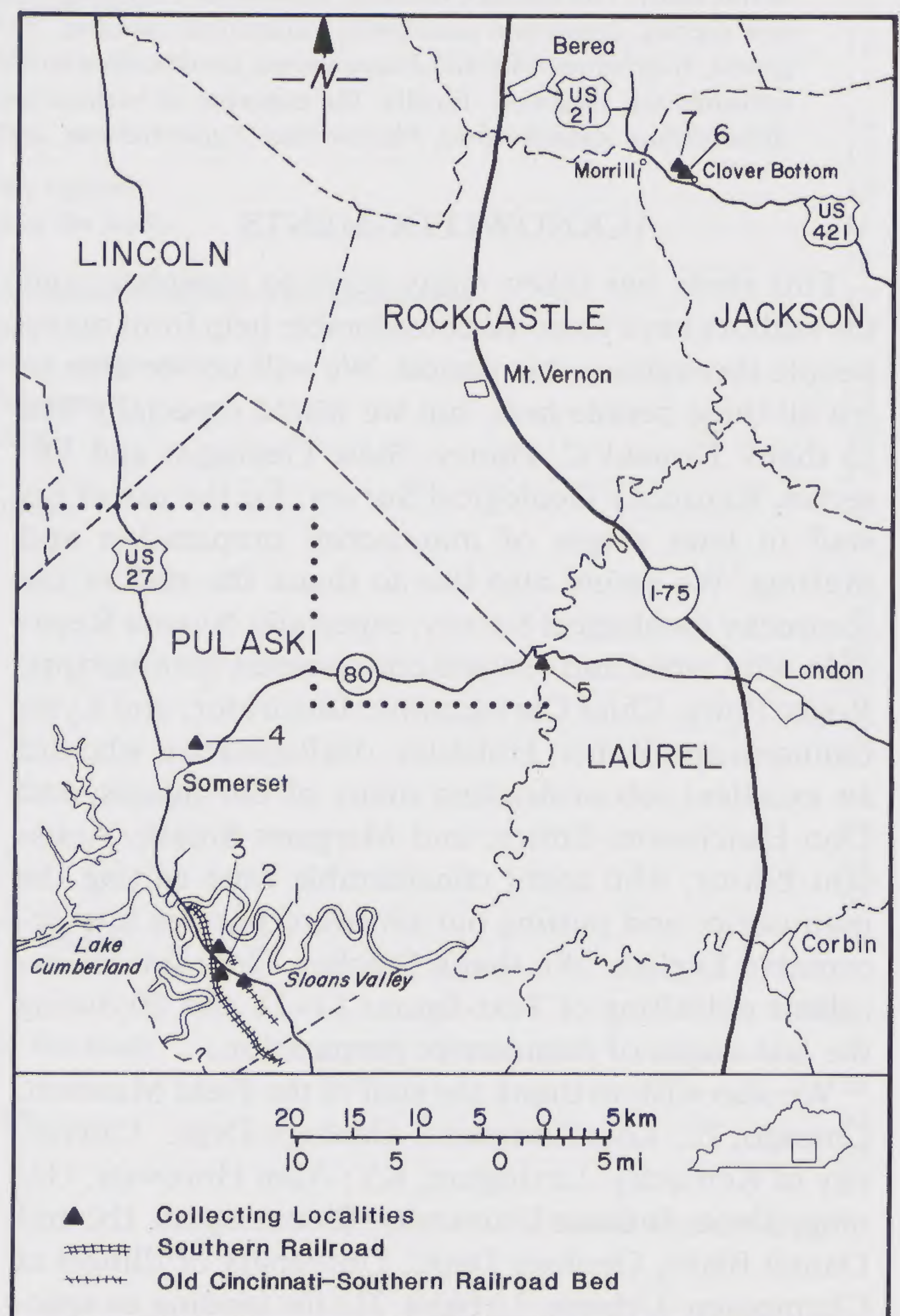
IU: Geology Department, Indiana University, Bloomington, IN, U.S.A.

UC: Field Museum, Chicago, IL, U.S.A.

UK: Geology Department, University of Kentucky, Lexington, KY, U.S.A.

USNM: Springer Collection, United States National Museum of Natural History, Smithsonian Institution, Washington, DC, U.S.A.

UI-X: Geology Department, University of Illinois at Champaign-Urbana, Urbana, IL, U.S.A.



Text-figure 1.—Map showing the location of the seven echinoderm-collection sites in the lower part of the Pennington Formation of south-central Kentucky. North of the heavy dotted line carbonates immediately below the Pennington are included in the Glen Dean Member of the Newman Limestone; south of the line, stratigraphically-equivalent carbonates are included in the Bangor Limestone. See Appendices 1 and 2 for descriptions of collecting localities. (1) Cincinnati-Southern Railroad cut (old bed); (2) Southern Railroad cut (new bed); (3) Strunk Quarry; (4) Somerset Stone Company Quarry; (5) Laurel County Quarry; (6) Clover Bottom; (7) Morrill.



## STRATIGRAPHY

In the early literature, the rocks from which the Sloans Valley echinoderms come were classified as part of the Kaskaskia Group. Ulrich (1905), however, placed them in the lower part of the Birdsville Formation. After the Chesterian rocks in the Illinois Basin were described, the nomenclature from that area was introduced into central and eastern Kentucky, where rocks at the horizon of the Sloans Valley member were included within the Glen Dean Limestone of the upper Middle Chesterian Series (Hombergian) (Text-fig. 2).

The stratigraphic units discussed in this paper are the Hardinsburg Member (Hartselle Shale), Glen Dean Member (Bangor Limestone), and the two lowermost informally-named members of the Pennington Formation (Text-fig. 2). During the U. S. Geological Survey-Kentucky Geological Survey joint geologic mapping program, the Illinois Basin nomenclature [Hardinsburg and Glen Dean members] was replaced in south-central Kentucky as far north as Pulaski County (Text-fig. 1) by terms carried northward from Tennessee [Hartselle Shale and Bangor Limestone] (Lewis and Thaden, 1965). The Hardinsburg Shale Member of the Newman Limestone south of Pulaski County became the Hartselle Shale or Sandstone whereas the Glen Dean Member of the Newman Limestone became the Bangor Limestone to the south (Text-

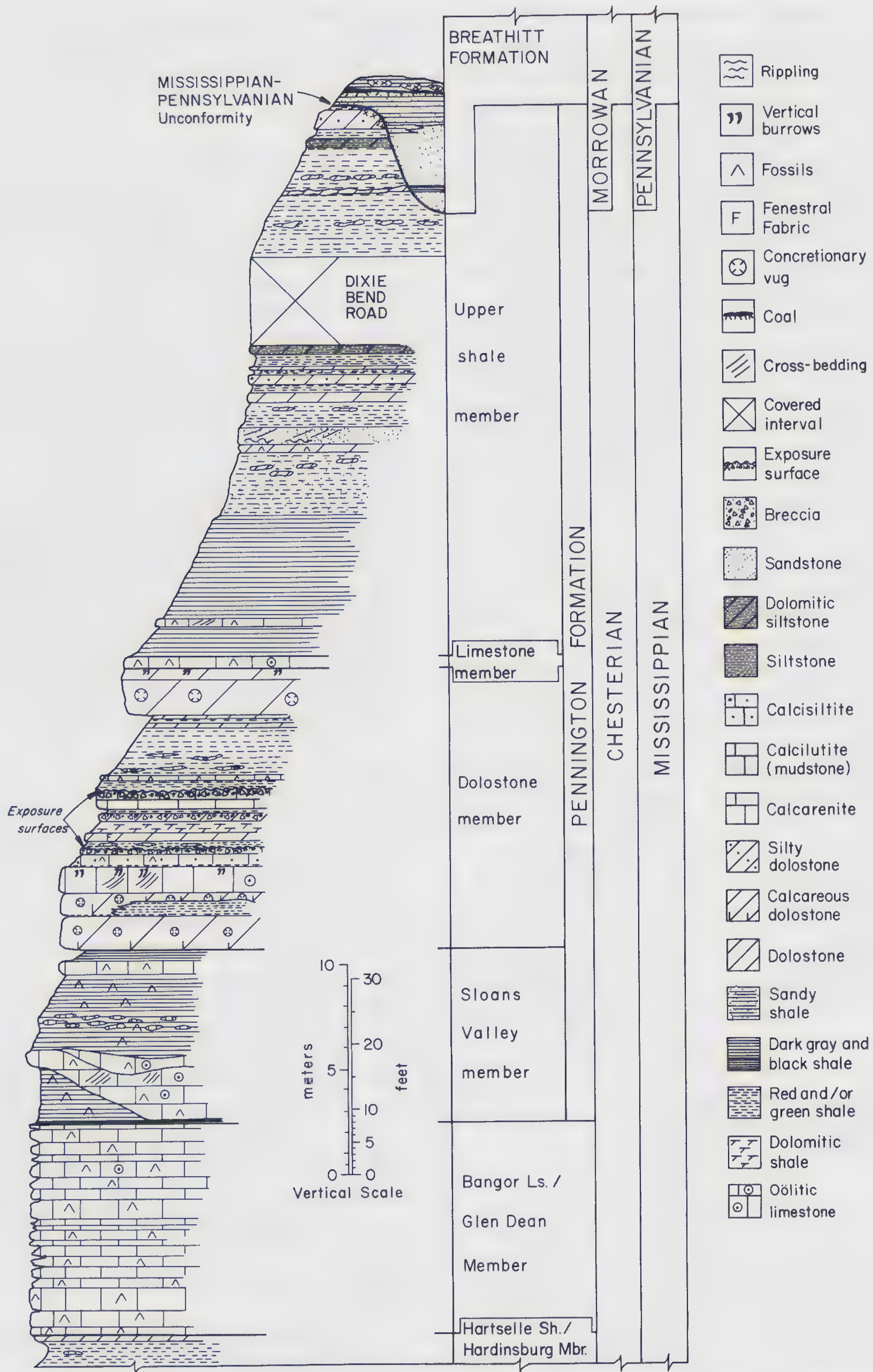
fig. 2). Both nomenclatures are used in the study area, but in the interest of simplicity, and because most workers are more likely to be familiar with the older Illinois Basin terminology, we have chosen to use it in this study.

The term "Pennington", however, is still used for the mixed carbonate-clastic sequence that overlies the Glen Dean. The nature of the boundary between the Glen Dean and the Pennington has been unclear for some time. In the older literature (*e. g.*, Butts, 1922), the Glen Dean Limestone was divided into a lower massive limestone unit and an upper unit of interbedded limestone and shale called the "upper Glen Dean" (Text-fig. 2). Most of the echinoderms ascribed to the Glen Dean in the earlier literature were actually collected from the "upper Glen Dean". In parts of northeastern Kentucky, this interbedded unit also has been mapped as part of the shale member (Englund and Windolph, 1975) or as the upper member of the Newman Limestone (Englund, 1976), in an attempt to correlate these units with similar lithologies in the Newman Limestone outcrop belt on Pine Mountain in eastern Kentucky (see Englund, Roen, and DeLaney, 1964). On most of the U. S. Geological Survey geologic quadrangle maps in east- and south-central Kentucky, however, the interbedded shales and carbonates of the "upper Glen Dean" were mapped as the basal part of

TYPE SECTION	BUTTS, 1922	CURRENT USAGE	
<i>Mississippi River Valley</i>	<i>Eastern Kentucky</i>	<i>Northeastern and East-Central Kentucky</i>	<i>South-Central Kentucky</i>
Tar Springs Sandstone	Pennington Formation	Pennington Formation	Pennington Formation
Glen Dean Formation	Glen Dean Limestone	Clastic member	Dolostone member
		Carter Caves Ss. / Lower dark shale mbr.	Sloans Valley member
Hardinsburg Formation	Golconda Shale	Newman Limestone	
		Glen Dean Member	Bangor Limestone
		Hardinsburg Member	Hartselle Shale

Text-figure 2.—Approximate chronostratigraphic correlation of Middle Chesterian rocks in the study area and adjoining regions with rocks in the Chesterian type section from the Mississippi River Valley.





Text-figure 3.—Reference section for the Sloans Valley member, Pulaski County, Kentucky. See Text-figure 1 and Appendices 1 and 2 for location and detailed descriptions.



the Pennington Formation, a practice that we continue here. Most of the Pennington Formation is composed of sparsely fossiliferous, variegated brown, green, and maroon shales, interbedded with lenses of sandstone and siltstone in the upper part and with layers of dolostone and limestone in the lower part. In contrast, the "upper Glen Dean", or lowermost part of the Pennington Formation in the study area, consists of highly fossiliferous, interbedded shales and limestones. Because of difficulties in correlating the Newman, Pennington, and Glen Dean with their namesakes in their type areas, these names recently have been revised to Slade Formation, Paragon Formation, and Poppin Rock Member, respectively, in northeastern and east-central Kentucky (Ettensohn *et al.*, 1984).

This study deals with echinoderms from the "upper Glen Dean" or lowermost part of the Pennington Formation. The use of either of these stratigraphic terms in south-central Kentucky is awkward and outdated. Therefore, we informally designate the fossiliferous interbedded shales and limestones of the lower Pennington Formation as the "Sloans Valley member of the Pennington Formation" (Text-fig. 2). A reference section for the Sloans Valley member and adjacent units is provided in Text-figure 3 and is described in detail in Appendix 1. This is a composite section based on roadcuts on U. S. Highway 27 between Sloans Valley and Dixie Bend Road, near the famous Sloans Valley collecting locality in the Burnside Quadrangle, Pulaski County, Kentucky (Carter-coordinate location 800 ft. FEL  $\times$  1800 ft. FSL, 18-F-60).<sup>3</sup>

Strimple and Horowitz (1975) suggested that the crinoid-bearing rocks in what we have defined as the Sloans Valley member are equivalent to rocks mapped with the Tar Springs Formation in Indiana. This is not meant to imply any biostratigraphic correlation with the type Tar Springs, but merely reflects Indiana Geological Survey rock-stratigraphic terminology. The Sloans Valley member and similar rocks in Indiana yielded fossils described as "Glen Dean" in age by Perry and Horowitz (1963) and subsequently cited in Horowitz and Strimple (1974). Moreover, palynological and conodont work by Ettensohn and Peppers (1979) and Ettensohn and Bliefnick (1982) indicates that lateral equivalents of the Sloans Valley member and lower dolostone member of the Pennington Formation in northeastern Kentucky (Text-fig. 2) are Middle Chesterian, Glen Dean time-equivalents. Hence, the massive limestones of the Glen Dean Member in the study area (the Bangor Limestone of east- and south-central Kentucky) are probably correlative only with lower parts of the type Glen Dean; whereas the Sloans

Valley member and lower parts of the dolostone member are apparently correlative with upper parts of the type Glen Dean (Text-fig. 2). However, not even the massive limestones of the Glen Dean appear to be wholly correlative along the outcrop belt, for these limestones thicken southward at the expense of the Pennington, suggesting that the top of the Glen Dean (Bangor) becomes younger southward along the outcrop belt (Text-fig. 2). Limited biostratigraphic evidence from a core just south of the Kentucky-Tennessee boundary along strike with the outcrop belt supports this interpretation (Horowitz *et al.*, 1979, pp. 212, 215, and 217).

#### DEPOSITIONAL ENVIRONMENTS

The Glen Dean Member of the Newman Limestone and the Sloans Valley member of the Pennington Formation are interpreted to be parts of a westwardly prograding tidal coastline (Ettensohn and Chesnut, 1979; Text-fig. 4). The progradational sequence includes the upper parts of the Hardinsburg Member of the Newman Limestone and the dolostone member of the Pennington Formation (Text-figs. 4-6). Depositional environments were inferred from the use of thin-section petrography, sedimentary structures, stratigraphic position, and paleontology.

The predominance of fine-grained sediments (shale, calcilutite) in the Hardinsburg Member throughout the study area suggests open-marine deposition in quiet conditions well below wave base (Ettensohn, 1977, 1980; Ettensohn and Chesnut, 1979).

The overlying Glen Dean Member is a massive, cross-bedded, skeletal calcarenite that is locally oolitic. The unit is typically a crinoidal calcirudite or calcarenite, but occasionally is made up of calcisiltite and fossiliferous calcilutite. Many beds are dolomitic. Chert nodules and bands, as well as vugs of dolomite and calcite, also occur. Individual beds contain a sparse, thick-shelled fauna, reflecting high-energy conditions. Bedding planes and thin, overlying shale partings, however, may exhibit a more abundant and diverse fauna, commonly including *Archimedes* spp. and productids. Except for *Agassizocrinus* Owen and Shumard, 1852a, a stemless crinoid adapted to high-energy conditions (Ettensohn, 1975b), crinoids are rarely found in the massive Glen Dean Member. The Glen Dean Member is interpreted to represent deposition on a shallow, high-energy carbonate sand belt of migrating shoals at or near wave base (Ettensohn, 1977; Ettensohn and Chesnut, 1979; Text-figs. 4-6). Conditions on the sand belt were probably too agitated to support a diverse, prolific fauna except during relatively quiet periods and in quiet, deeper depressions on the sand belt. The best evidence for the periodic presence of quiet areas on the sand belt is the shale breaks that occur locally

<sup>3</sup> the Carter-coordinate system is an alpha-numeric grid used for location within Kentucky, similar to the township and range system used elsewhere.



throughout the Glen Dean Member. Fossils on bedding plane surfaces below these shales apparently reflect near-life assemblages of sessile filter feeders that were suddenly buried by clay and silt.

The uppermost parts of the Glen Dean Member become more thinly bedded and contain more argillaceous carbonates and shale interbeds. Locally, this part of the Glen Dean Member intertongues with the Sloans Valley member. Whole fossils become more numerous on the upper surfaces of these thinner beds and in the intervening shales. These beds yielded the most fossils at the Laurel County locality (Text-fig. 1, loc. 5), where numerous specimens of *Archimedes* Owen, 1838, fenestellids, partial and complete crinoid crowns, echinoids, edrioasteroids, and delicate ramose bryozoans were found. The uppermost beds are dolomitic mudstones and contained many specimens of *Archimedes*, fenestellids, crinoid stems and plates, brachiopods, and delicate ramose bryozoans. The general fining-upward

nature of the Glen Dean Member and the upward increase in diversity reflect deposition in somewhat deeper, protected, back-sand belt environments transitional between the Glen Dean sand belt and a deeper, shoreward Pennington lagoon (Text-figs. 4, 6).

The Sloans Valley member of the Pennington, which overlies and intertongues with the Glen Dean Member, consists largely of dark-gray, organic-rich shale with interbedded lenses and shoal-like bodies of calcarenite. The calcarenite bodies may be dolomitic, fossiliferous, or arenaceous. The arenaceous beds are most common at the Laurel County Quarry locality (Text-fig. 1, loc. 5). Lenses of calcirudite composed of intraclasts, phosphatic pebbles, or fragmented fossils occur locally. Some of these lenses and bodies are cross-bedded.

Shale in the Sloans Valley member is generally one of three types. A dark-gray, organic-rich, clayey shale is the most abundant. Although this shale is not always fossiliferous, fossils that do occur are most commonly



Text-figure 4.—Reconstruction of Late Chesterian depositional environments in the study area. Interpretive diagram of major depositional environments along a late Middle to early Late Chesterian prograding tidal shoreline in central Kentucky shows the location of the study area (from Ettensohn and Chesnut, 1979).

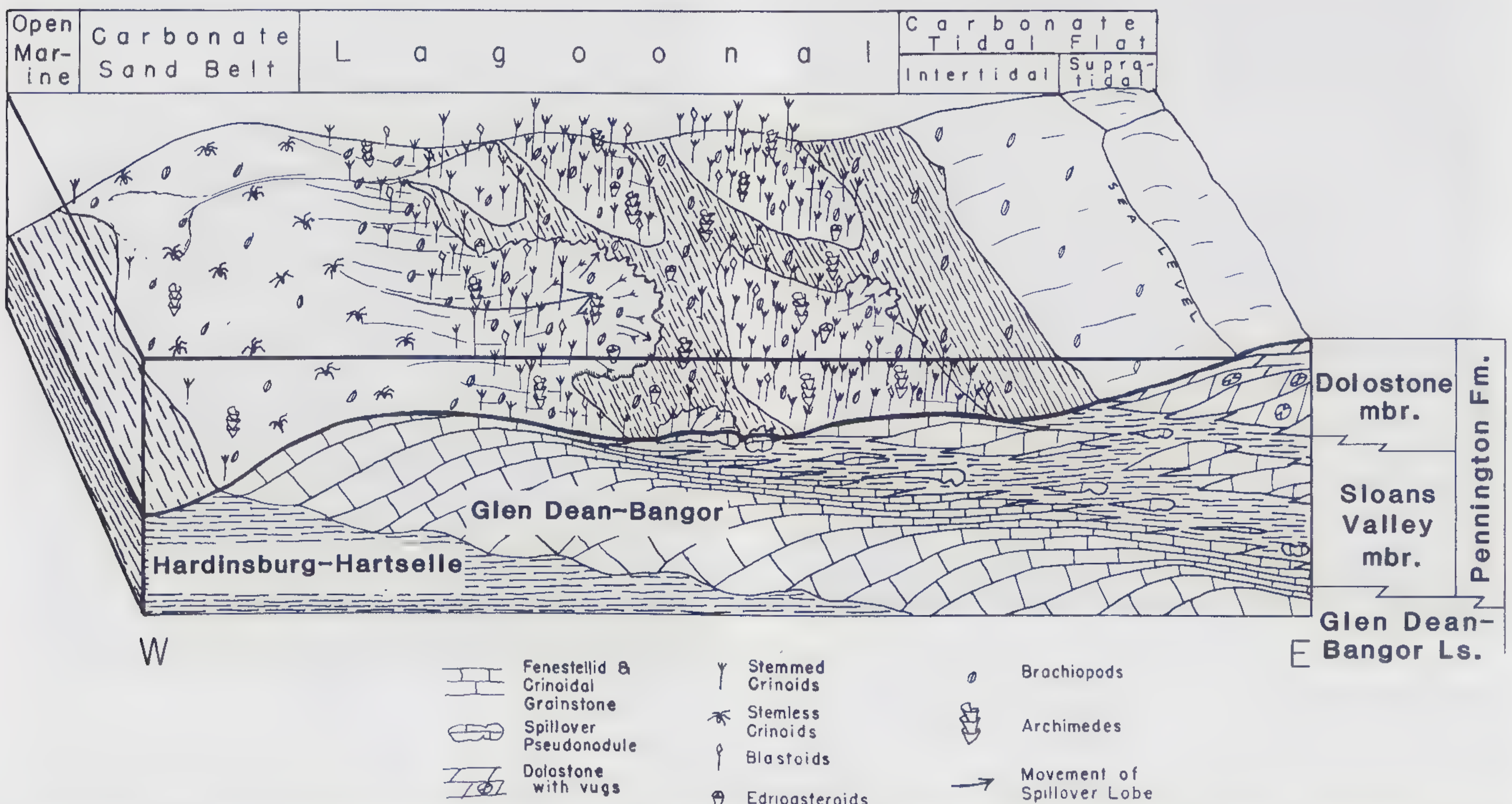


System	Formation and Member	Lithology	Depositional Environment	Regional Event
PENNSYLVANIAN	Lee and Breathitt Formations		Shoal-Water Deltaic	Westerly Deltaic Progradation
			Clastic Tidal Flat and Lagoonal	
MISSISSIPPIAN	Pennington Formation		Upper shale member	Easterly Transgression
			Limestone mbr.	
			Dolostone member	
	Newman Limestone		Sloans Valley member	Westerly Progradation of Irwin-Shaw Sequence
			Glen Dean (Bangor Limestone)	
		Hardinsburg Member (Hartselle Sandstone)	Open Marine	

delicate fenestellid bryozoans, productid brachiopods, and pectinid pelecypods. The second most abundant shale type is blue-gray, calcareous, and fossiliferous. Most of the echinoderm fossils studied herein were collected from these calcareous shales or interbedded calcarenite lenses. The third type, a sandy to silty shale containing lenses or flaser beds of calcareous sandstone, is the least common; it is known only from the Laurel County Quarry locality (Text-fig. 1, loc. 5). The Laurel County Quarry also yielded an unusual bed composed of arenaceous calcirudite with rip-up clasts (up to 10 cm in diameter) of micritic limestone containing phosphate nodules, as well as phosphatized gastropods, cephalopods, and bryozoan fragments. This bed apparently represents a high-energy (storm?) event followed by a period of slow sedimentation.

The Sloans Valley member at all localities contains evidence of periodic agitation and currents. Evidence includes large transported lithoclasts, major cross-bedding in some limestone and sandstone beds, flaser bedding, interference ripples, and beds consisting almost entirely of worn and abraded fossil and phosphate-nodule debris. Some irregular masses (pseudonodules) of contorted biocalcarenite (15-30 cm thick) within the shales (Text-fig. 7), contain whole crinoids in an irregularly-swirled pattern throughout the nodular mass. They probably represent storm-transported

Text-figure 5.—Lithologic column for the studied sequence showing unit names and inferred depositional environments. The Sloans Valley and Glen Dean members, which contain the studied echinoderms, are part of a westwardly-prograding nearshore environmental continuum shown schematically in Text-figure 6.



Text-figure 6.—Environmental reconstruction of the late Middle and early Late Chesterian progradational continuum represented by the sequence of units from the Hartselle-Hardinsburg through the dolostone member of the Pennington Formation in south-central Kentucky.



masses of semi-lithified sediment dumped with their epifauna into adjacent quiet basins (Ettensohn and Chesnut, 1985a). The localized layers containing phosphate nodules may also indicate the periodic incursion of upwelling currents into shallow Sloans Valley environments from deeper seaward environments during periods of little sedimentation.

The Sloans Valley member generally represents deposition in intermittently quiet, shallow, protected lagoonal waters behind a higher energy sand-belt or shoal environment; the sand belt or shoal is represented by the underlying Glen Dean Member (Ettensohn, 1977, 1980; Ettensohn and Chesnut, 1979; Text-figs. 4–6). Deposition of argillaceous and calcareous muds apparently dominated in this quiet-water environment, but storms, waves, and high tides also seem to have influenced it. These agents apparently transported coarser, bioclastic debris from the adjacent sand belt into the lagoonal environment in the form of migrating dunes, shoals, spillover lobes, and ripped-up chunks of semi-lithified sediment. Some of these bodies of bioclastic debris can actually be traced back into the Glen Dean from which they originated as spillover lobes (Ettensohn and Chesnut, 1985a). The lobes and dunes formed small shoals in the lagoon, which were colonized by the echinoderms [principally crinoids and blastoids] (Text-fig. 8). The shoals of bioclastic debris



Text-figure 7.—Irregularly shaped, echinoderm-bearing pseudonodule of skeletal sand within dark basinal shales of the Sloans Valley member at locality 2 (see Text-fig. 1). Contorted bedding and fossils within the nodules and irregularly truncated and deformed shale beds below suggest that semi-lithified parts of shoals and their epifauna were ripped up and dumped onto basinal muds during storms. The pseudonodules are restricted to specific horizons within the Sloans Valley member.

not only provided the firm substrates needed by stemmed echinoderms, but also provided elevation into or near a zone of dominantly horizontal water movement, needed by most suspension-feeding echinoderms (Text-fig. 9). Colonization by the stemmed echinoderms further enhanced the buildup of the shoal through baffling and the addition of ossicles, and created many new niches for other echinoderms and invertebrates. Other fauna such as fenestellid and ramose bryozoans, brachiopods, corals, gastropods, and pelecypods lived on or within the muds of the quiet, deeper intervening basinal areas.

The overlying dolostone member of the Pennington is composed largely of dolomitic mudstones interbedded with shales, as well as minor oolitic and bioclastic calcarenites and pelletal mudstones. This member exhibits abundant laminae; subaerial exposure features; horizontal and vertical burrows; nodules containing calcite, dolomite, celestite, and strontianite; and a very sparse fauna. It is interpreted to represent deposition in an intertidal to supratidal environment very near the shore (Ettensohn and Chesnut, 1979; Text-figs. 4, 6).

The above units represent parts of an extensive tidal shoreline that seems to have dominated eastern Kentucky (Text-fig. 4) during the late Middle and early Late Chesterian. Tidal-flat environments apparently prograded westwardly and reflect the beginning of ma-



Text-figure 8.—Ten-meter segment of a calcarenitic shoal body pinching out southeasterly into dark basinal shales of the Sloans Valley member at locality 2 (see Text-fig. 1). Note cross-bedding dipping southeasterly above senior author's head. Most echinoderms from the Sloans Valley member are found on top of or closely associated with shoal-bodies such as this.



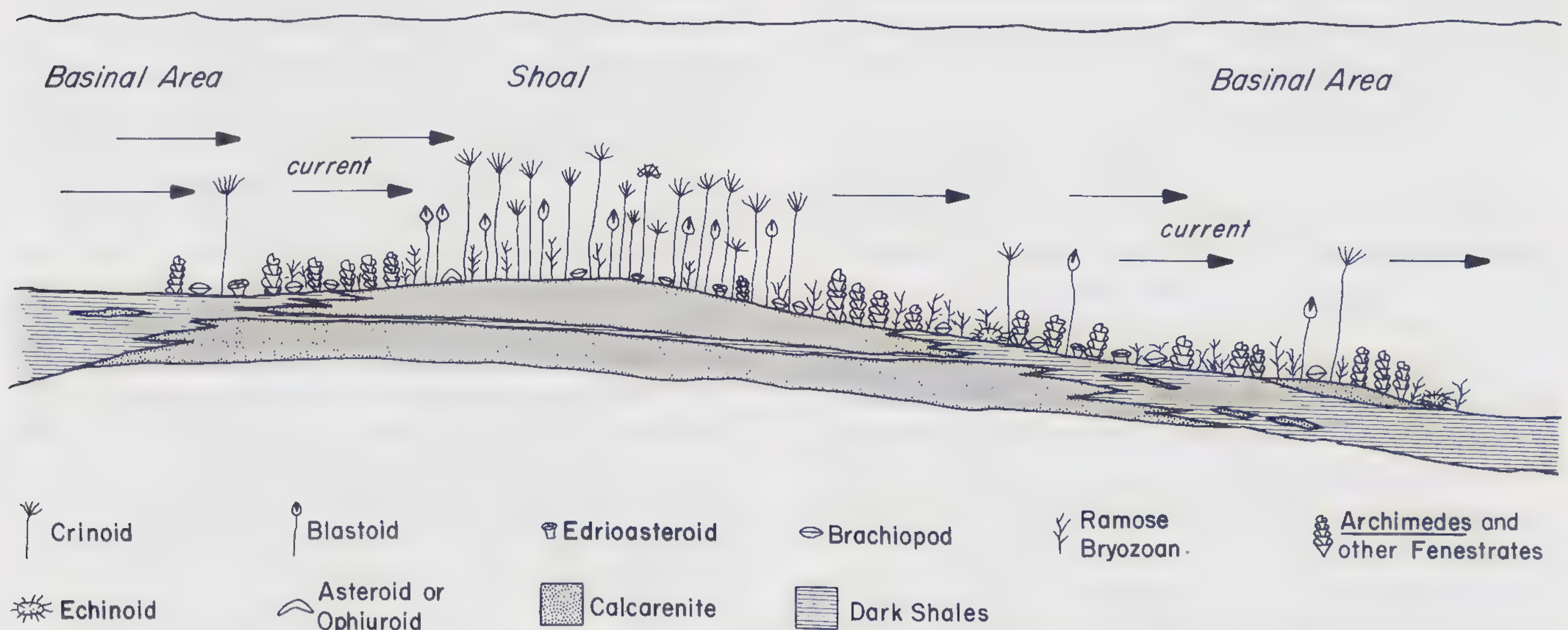
major regional regression, which continued throughout the remainder of the Paleozoic. Paleocurrent studies in rocks regarded by the authors to be Pennington (Ferm *et al.*, 1971; Ettensohn, 1975a, Short, 1978) suggest a northern source for clastics in the lower Pennington Formation. The Carter Caves Sandstone (Text-fig. 4), partially equivalent to the lower dark shale and clastic members of the Pennington Formation to the north (Text-fig. 2), may represent such a source. This linear, channel sandstone has been variously interpreted to be a tidal delta (Englund and Windolph, 1971), a tidal channel (Ettensohn, 1975a, 1980), and a distributary channel (Short, 1978). Any clastic sediments derived from this channel would have been transported farther south and reworked onto the clastic tidal flats (Text-fig. 4), represented by the clastic member of the Pennington Formation to the north (Text-fig. 2). Coastal areas near the Waverly Arch apical island and basement fault zone (see Ettensohn, 1980, 1981) were apparently slightly higher than other parts of the tidal coastline and supported local paralic marshes, represented by thin coals in the Pennington Formation. Pennington coals in east-central Kentucky are restricted to the clastic member and occur only on and near structural features (Ettensohn and Peppers, 1979; Text-fig. 4).

The clastic member of the Pennington Formation (Text-fig. 2) is characterized by a fining-upward clastic sequence with numerous tidal features (Ettensohn, 1975a, 1977, 1980) as far south as Rockcastle County, Kentucky (Text-fig. 1). This apparently was as far south as the coarser clastics were transported. South of this point, carbonate muds, silts, and sands replaced clastic sediments on the tidal flats (Text-fig. 4). Locally, evap-

orites may have been deposited (Frazier, 1975). Carbonate sedimentation in this area apparently outstripped any clastic influx into the area. The dominance of carbonate sedimentation is also reflected in the greater abundance of carbonates and skeleton-producing organisms found in the Sloans Valley member, compared with its northern equivalent, the lower dark shale member (Text-fig. 2). Echinoderms, for example, are generally rare in the lower dark shale member.

Chesterian tidal-flat deposition in eastern Kentucky was abruptly ended by renewed transgression, represented by the limestone member of the Pennington Formation (Text-fig. 5). The limestone member is a thin but persistent, argillaceous, oolitic to bioclastic calcarenite. The limestone is highly fossiliferous and represents a shallow open-marine to shoaling environment.

The overlying upper shale member (Text-fig. 5) consists predominantly of maroon and green silty shales with interbedded sandstones, siltstones, and thin, brecciated dolostones. Mudcracks occur in some of the dolostones, whereas ripple marks and flaser beds are common in the siltstones. The shales contain abundant macerated plant debris and evidence of bioturbation, but invertebrate fossils are rare. The member is interpreted to represent the return of extensive tidal mud flats and shallow coastal lagoons, but this time the tidal flats were dominated by clastic muds, and there was only local accumulation of carbonate mud. Brecciation in these carbonates apparently represents subaerial exposure and vadose diagenesis (Fisher, 1981). Additional information on the stratigraphy and depositional environments of the Pennington Formation can be found in Ettensohn and Chesnut (1985b).



Text-figure 9.—Schematic reconstruction of carbonate shoals and nearby muddy basinal areas in the Sloans Valley lagoon showing inferred stratification of suspension feeders and relative positions of common organisms on and near shoals.



## PALEOECOLOGY

### INTRODUCTION

Most of the echinoderms and associated fauna from the Glen Dean and the lower Pennington Formation do not represent new discoveries. They are abundant and widespread in Chesterian rocks throughout the east-central United States. Most of the work to date has dealt with their systematics, and few ecologic interpretations have been made. This is largely the result of poor preservation, poor outcrop conditions, bad luck (few areas with such large colonies have been found), and the fact that modern concepts of echinoderm ecology had not yet been elucidated. In the Sloans Valley area, the abundance of specimens, excellent preservation, and a number of fresh exposures in quarries, roadcuts, and railroad cuts (Text-fig. 1) make such a comprehensive paleoecological analysis possible. Although many of the details are still not known, the excellent preservation of specimens, their relationship to each other, and the unusual morphological features of many species provide clues to their paleoecologic relationships.

### PHYSICAL ENVIRONMENT

The Sloans Valley lagoon contained many slightly elevated shoals on which skeletal sands were deposited, and intervening basinal areas in which carbonate and argillaceous muds predominated (Text-fig. 9). Although the shoals were higher than the basinal areas, a mud matrix observed in thin-sections of most shoal calcarenites indicates the ineffectiveness of winnowing and suggests that the shoals were generally below normal wave base, but not necessarily below tidal range and storm-wave base.

The Sloans Valley shoal calcarenites are composed primarily of pelmatozoan sands. Many of the shoals probably originated as spillover lobes from the seaward Glen Dean sand belt or from local shoals (Text-fig. 6). During storms and high tides, lobes of skeletal sand were transported shoreward from the sand belt, and existing shoal sands were transported onto lagoonal muds. Some of the larger shoal bodies (Text-fig. 8) appear to represent numerous accretionary events or abandoned tidal deltas; smaller limestone lenses with only a single layer of skeletal debris represent a single episode of sand transportation. The shoal bodies range in length from approximately 3 m to at least 160 m and exhibit thicknesses up to 4 m. Some of the smaller calcarenite lenses are only a few meters long and a few centimeters thick (Ettensohn and Chesnut, 1985a, fig. 8). Once agitation decreased to the point that the transported sands became stable, these sands formed a firm substrate that was easily colonized and stabilized by sessile benthos. Addition of skeletal parts from dead

organisms contributed to the upward growth of each shoal.

The communities on the shoals were dominated by stemmed crinoids and blastoids, probably because the shoals provided firm substrates for attachment and elevated positions that provided the crinoids access to feeding currents higher in the water column (Text-fig. 9). Most modern crinoids live in areas of dominantly horizontal water movement, and feed with their arms arrayed into filtration fans oriented perpendicular to water movement (Macurda and Meyer, 1974). The abundance of crinoids on the Sloans Valley shoals, as well as evidence of horizontal water movement already discussed, suggest that these crinoids lived on shoals where water movement similarly facilitated food capture.

The intervening basinal areas were characterized by lower energy and supported a fauna that lived closer to the substrate. Most of the fauna found in the shales are usually associated with thin lenses of skeletal debris that apparently provided relatively firm substrates. Tracks and trails are everywhere common in the Sloans Valley member, and bioturbation is present in many of the limestones. Bioturbation also may have formed some of the marls found in the basinal facies, although storm mixing cannot be overlooked; the marls consist of echinoderm ossicles in a dark muddy matrix. Traces of bioturbation are generally absent in the dark shales, as is most evidence of infauna. This indicates that conditions below the surface were too reducing to support much infauna, although bottom circulation and oxygenation were sufficient to support a diverse and abundant epifauna on or above the sediment-water interface.

Both shoal and basinal lithologies exhibit an increased faunal diversity and abundance in the Sloans Valley member compared with the underlying Glen Dean Member and the overlying dolostone member. We believe that this discrepancy can be best explained in terms of the following environmental parameters:

1. The Sloans Valley member represents a protected open-lagoonal environment shoreward of the Glen Dean sand belt (Text-figs. 4, 5). The deeper, protected waters behind the sand belt created more stable environments, which would have promoted greater populations and diversity (Heckel, 1972);
2. More species were capable of living in the Sloans Valley environment because a greater variety of niches were available. The shoals and intervening basinal areas in the lagoon not only offered a number of substrate types, but also access to various energy levels. Most of the pelmatozoans seem to have colonized the shoals because of their firm substrates and access to currents; and



3. The lagoonal environments were ideally situated to receive nutrients from both seaward and landward sources (Text-figs. 4, 5). Wave- and tide-generated currents could have carried open-marine plankton or dissolved nutrients across the sand belt or through tidal channels into the lagoon. Localized phosphate accumulations suggest at least periodic incursions of upwelling currents carrying phosphate and other dissolved nutrients from deeper, seaward waters. Land-derived nutrients, on the other hand, could have debouched directly into the lagoon. Finely macerated plant debris, abundant palynomorphs, and fresh-water algae (*Botryococcus* Kützing, 1849, and charophytes) (Ettensohn, 1975a; Ettensohn and Peppers, 1979) strongly indicate a landward source. The presence of organic debris in these lagoonal environments is indicated by the dark, organic-rich nature of the shales in the Sloans Valley member.

#### TAPHONOMY

Excellent preservation of fauna is present in the dark, organic-rich shales deposited in the basinal areas. These fissile, dark shales commonly contain a remarkably-preserved fauna of fenestrate bryozoans, pectenids, brachiopods, and other invertebrates. The fissile nature of the shale, the organic content, and the lack of bioturbation suggest that preservation is probably due to anoxic conditions just below the sediment-water interface. The preserved assemblages probably approximate the benthic make-up of the original basinal communities, because major transportation was not likely in this quiet-water environment.

Although some complete crinoid calyxes and edrioasteroids have been found in shales adjacent to the calcarenite bodies, most of the echinoderms, particularly crinoids, occur on the upper surfaces of calcarenite bodies and lenses and exhibit detailed preservation; these surfaces are always overlain by shale. Because echinoderms are easily disarticulated after death, the well-preserved assemblages in the Sloans Valley were not transported far and almost certainly lived on the shoals. Hence, the preserved assemblages are thought to reflect closely the nature of the benthic populations in the original shoal communities.

Long stem segments with attached calyxes and thecae are commonly preserved in the Sloans Valley member, as are the arms, pinnules, and wing plates of various crinoids and the brachioles and summit plates of blastoids. Brachiopod and pelecypod valves are articulated and usually crushed, both of which suggest rapid burial, and continuous growth series are present for many taxa.

Detailed preservation of this quality requires rapid burial following minimal post-mortem transportation.

The bedding planes on which these well-preserved echinoderms occur are invariably overlain by shale. Some of the shoal sequences are composed almost wholly of calcarenite layers alternating with thin shales, and the communities that developed on the calcarenite surfaces were repeatedly buried by sudden influxes of argillaceous sediment.

The crinoids and blastoids in these communities are all preserved without holdfasts. Crinoid and blastoid stems apparently were broken suddenly, moved a short distance, and buried in mud. We suggest that this occurred during storms that churned the bottom of the lagoon, placing great amounts of mud into suspension. During this turbulence, the crinoids and blastoids were probably flung about violently until their stems broke; then calyxes with attached stems were moved a short distance and dropped on the bottom. As the storms subsided, suspended muds slowly settled and buried the devastated communities. Not only did the storms churn up muds from the lagoon itself, but they may have greatly increased sediment influx into the lagoon from nearby terrestrial sources.

Although the storms may have ripped up stems and transported faunal elements for short distances, these events, no matter how damaging they might have been, were probably not the final cause of death. More likely, death resulted from the clogging of respiratory and food-gathering apparatus by the great fallout of suspended mud and silt that eventually buried the communities. The currents that had helped clean and provide oxygen and nutrients to the pelmatozoans higher in the water column were not available on the bottom. Moreover, because the lagoonal environments were relatively close to terrestrial influence, sudden fresh-water influxes accompanying storms may have altered salinity long enough to cause death to the stenohaline echinoderms. Terrestrial plant fragments and palynomorphs, brackish-water algae, and fresh-water algae previously noted indicate that fresh water periodically entered the system.

The storm hypothesis is also suggested by a unique preservational mode encountered in the Sloans Valley member. In a few horizons, large numbers of well-preserved echinoderms are found in muddy calcarenite pseudonodules present within the darker basinal shales (Text-fig. 7). These pseudonodules are composed of poorly-sorted calcarenites with contorted bedding and abundant shale intraclasts. Echinoderms occur randomly in these pseudonodules, and many crinoids and blastoids in the pseudonodules occur with stems and exhibit the same excellent preservation of delicate parts found elsewhere in the Sloans Valley member. The stems and crowns may be partially wrapped around these pseudonodules, and many appear to have been rolled when examined in cross-section. We suggest that



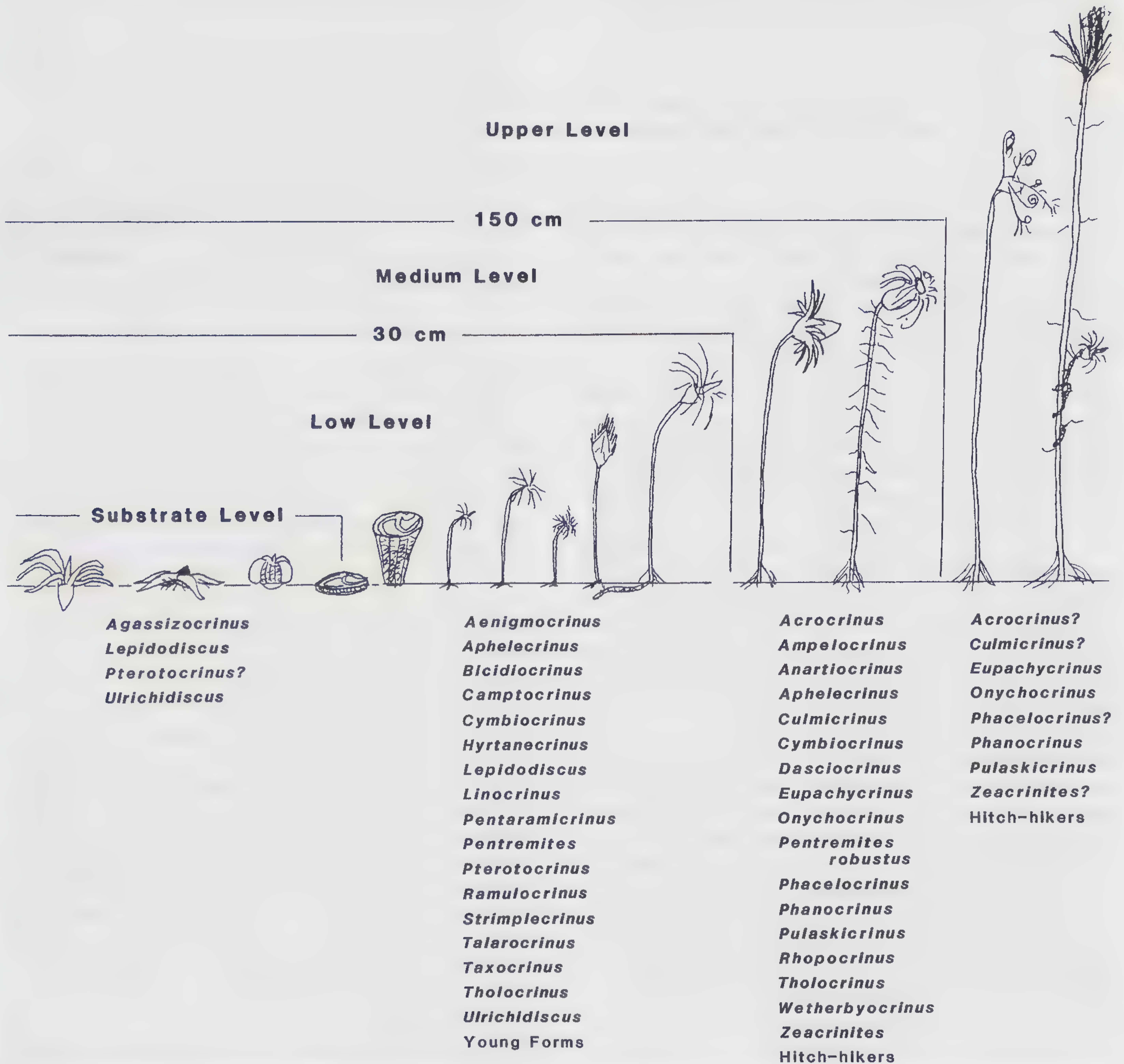
these pseudonodules represent small, semi-lithified portions of shoals that were scoured out during storms, transported a short distance with their echinoderm communities nearly intact, and then dumped or rolled into the soft muds of adjacent basinal areas (Text-fig. 6) (Ettensohn and Chesnut, 1985a).

SYNECOLOGY

Communities

*Firm-Bottom Community.*—Firm-bottom communities are recognized on all the calcarenitic shoals (Text-

fig. 9). These communities were dominated by stemmed crinoids and blastoids. *Tholocrinus spinosus* (Wood, 1909), *Pterotocrinus acutus* Wetherby, 1879a, and one of the species of *Pentremites* Say, 1820, seem to occur on nearly every shoal, but they cannot be said to dominate the shoals. Some shoals, however, apparently were dominated by only one or two species, because shoals exhibiting only blastoid thecae, or calyxes of *Onychocrinus pulaskiensis* Miller and Gurley, 1895, and *Pulaskicrinus campanulus* (Horowitz, 1965) have been found. Why these shoals were dominated by one or two species to the exclusion of all other echinoderms



Text-figure 10.—Interpretation of feeding levels or tiers for major echinoderm genera in the study, based on the preserved lengths of stems or shape and orientation of thecae or calyxes.



is uncertain. However, the shoals appear to be small, and these species may have arrived first and come to dominate the shoals before others arrived. The colonization of shoals may have been relatively random, depending largely on the availability of attachment sites.

Most of the fauna on the shoals were suspension feeders, and it is likely that a vertical stratification or tiering (Ausich and Bottjer, 1982) of these feeders existed (Text-fig. 10). Crinoids apparently had representatives filling every tier, from semi-infaunal bottom-dwelling forms like *Agassizocrinus* Owen and Shumard, 1852a, and possibly *Pterotocrinus* Lyon and Casseday, 1859, to forms like *Onychocrinus pulaskiensis* that lived in the uppermost tiers (Text-Fig. 10).

The highest, central parts of each shoal appear to have been inhabited largely by crinoids and blastoids, although fenestrate and ramose bryozoans seemed to have occupied much of the understory. The thinning margins of the shoals were inhabited by a fringing thicket of largely fenestrate bryozoans (Text-fig. 9), including *Fenestella* Lonsdale, 1839, *Archimedes* Owen, 1838, *Polypora* M'Coy, 1844b, *Septopora* Prout, 1860, and *Lyroporella* Simpson, 1895. Brachiopods, such as *Composita subquadrata* (Hall, 1858), *Cleiothyridina sublamellosa* (Hall, 1858), and *Anthracospirifer* cf. *A. leidy* (Norwood and Pratten, 1855) were present locally. Rare colonies of low (cap-shaped) and thickly-branched trepostome bryozoans also were noted on the calcarenite shoals, but probably occupied more open positions. The slightly deeper, less agitated shoal margins provided firm substrates for attachment and some protection from turbulence; at the same time they provided access to lower energy nutrient-bearing currents. Similar habitats have been suggested by McKinney (1978, 1979) and McKinney and Gault (1980) for Glen Dean and Pennington fenestrates. When turbulence reached the bryozoan fringe, the resulting fragmentation apparently was important as a form of asexual colony proliferation for some fenestrates (McKinney, 1979, 1983).

*Soft-Bottom Community.*—In many parts of the Sloans Valley member, shoal calcarenites grade laterally into lagoonal and basinal shales, calcisiltites, and marls. Most of the basinal lithologies are dark, suggesting the presence of abundant organic matter. Some of the basinal shales are essentially barren, and when fossils do occur, they are broad, flat brachiopods like *Orthotetes kaskaskiensis* (McChesney, 1860) or spinose productids like *Diaphragmus cestriensis* (Worthen, 1860), whose morphological adaptations enabled them to live on soft substrates. Shell fragments that washed into the muds provided local islands of firm substrate that were quickly colonized by bryozoans or small encrusters like the worm *Spirorbis* Daudin, 1800,

and the inarticulate brachiopod *Crania* Retzius, 1781. At locality 6, specimens of *Lepidodiscus laudoni* (Basler, 1936), an edrioasteroid (Pl. 10, figs. 1–9), were found attached to bryozoan fronds and to a brachiopod in a thick shale sequence. At other localities, a thin layer of crinoid debris and brachiopod valves deposited on basinal muds was sufficient to provide a substrate for colonization by rhabdomesoid and fenestrate bryozoans. Substrate conditions appear to have largely controlled the development of lagoonal and basinal soft-bottom communities.

Some of the lagoonal and basinal shales exhibit dense accumulations of almost-perfectly preserved rhabdomesoid and fenestrate bryozoans with interspersed brachiopods and pectenid pelecypods. Some of these shales are little more than laminae of compacted bryozoans. The nearly perfect preservation suggests that these bryozoans experienced little, if any, post-mortem transportation; most were apparently buried in living position. We suggest that these communities were dominated by dense thickets of rhabdomesoid and fenestrate bryozoans. The bryozoans appear to have been so densely packed that they may have originally supported each other in a dense and delicately interwoven framework (Text-fig. 9). Brachiopods, including *Composita subquadrata* (Hall, 1858), *Cleiothyridina sublamellosa* (Hall, 1858), *Anthracospirifer* cf. *A. leidy* (Norwood and Pratten, 1855), and *Diaphragmus cestriensis* (Worthen, 1860), apparently occupied small pockets in this lacework, living either on mats of dead bryozoan fronds or within the framework itself. The pectenid pelecypod *Aviculopecten* M'Coy, 1851, probably was attached byssally to the bryozoan framework.

The most common echinoderm in the lagoonal basin setting was *Pterotocrinus depressus* Lyon and Casseday, 1860. *Pterotocrinus depressus* is interpreted to have possessed morphological adaptations that enabled it to live on soft substrates (Chesnut and Etensohn, 1984). It is most common in silty calcareous muds and marls and is not present in the dense bryozoan accumulations. *P. depressus* apparently preferred slightly firmer, more open, basinal environments.

At the classic Sloans Valley locality, many well-preserved specimens of three cirri-bearing species, *Ampelecocrinus kaskaskiensis* (Worthen, 1882) (Pl. 4, fig. 2; Pl. 12, fig. 8), *Rhopocrinus spinosus* Kirk, 1942a (Pl. 3, fig. 11), and *Camptocrinus cirrifer* (Wachsmuth and Springer, 1897) (Pl. 8, figs. 16, 18) were found in dark, calcareous mudstones. We suggest that these crinoids may have used their lower cirri as holdfasts or supports on the muddy substrates (Text-fig. 11) as do some modern stemmed crinoids (Macurda and Meyer, 1974).

Other echinoderms found on former soft bottoms include *Lepidesthes formosa* Miller, 1879 (Pl. 11, figs. 1–3), and an unidentifiable ophiuroid (Pl. 12, fig. 3).



*Lepidesthes formosa*, however, was probably a deposit feeder (Text-fig. 12) and is found on firmer substrates as well. The ophiuroid was probably a scavenger and may have frequented all types of substrates.

*Nektic-Planktic Community*.—Little is known about the nektic-planktic community, and in many cases we must infer which forms were present. Nonetheless, based on fossil teeth, spines, and dermal plates from the Glen Dean and Sloans Valley members, chondrichthyan fish were very common elements of the nektic fauna and included *Agassizodus* St. John and Worthen, 1875, *Acondylacanthus* St. John and Worthen, 1875, *Chomatodus* Agassiz, 1843, "*Cladodus*", *Cochliodus* Agassiz, 1843, *Copodus* St. John and Worthen, 1883, *Ctenacanthus* Agassiz, 1843, *Deltodus* Newberry and Worthen, 1870, *Petalodus* Owen, 1840, *Poecilodus* Agassiz, 1843, *Polyrhizodus* M'Coy, 1848, *Psammodus* Agassiz, 1843, *Psephodus* Morris and Roberts, 1862, and *Sandalodus* Newberry and Worthen, 1866 (Chesnut, in preparation). Except for "*Cladodus*", a form genus with cusped teeth representing several genera, most of the fish had pavement-like teeth and probably were durophagous, feeding on shelled invertebrates. Echinoderms, especially stalked crinoids, were no doubt among their prey. Signor and Brett (1983, 1984) have suggested that increased spinosity, thecal plate thickness, and thecal rigidity in mid-Paleozoic

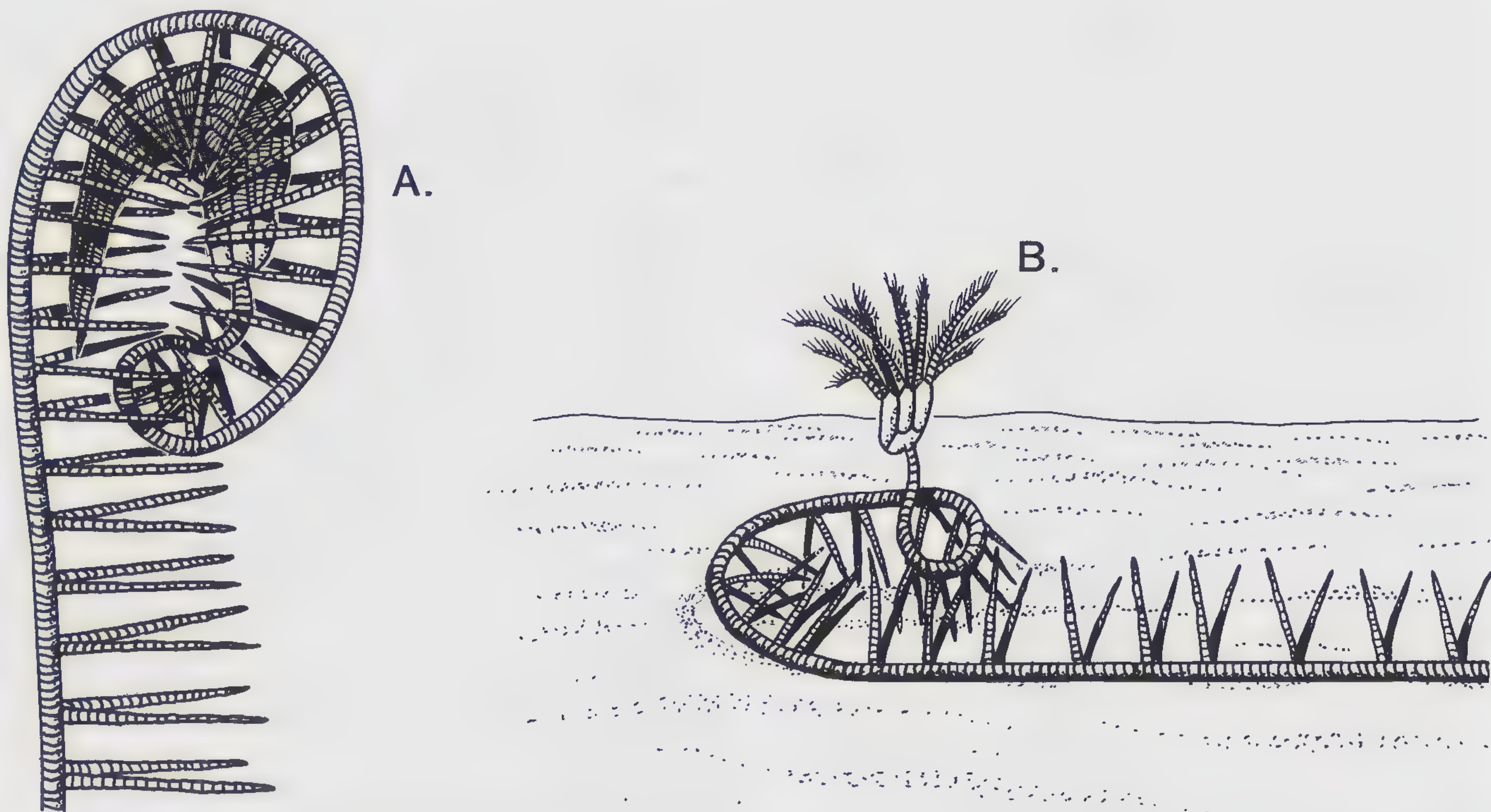
crinoids was the result of a rapid radiation of durophagous feeders, and Meyer (1983) has demonstrated that some modern fish prey on crinoids.

Other nektic animals occurred here as well. Several different conodont animals probably existed in these waters, for abundant conodont faunas have been reported from the Glen Dean Limestone and lower Pennington Formation by Rexroad and Clarke (1960) and Ettensohn and Bliefnick (1982). The conodont animals were probably nektic or nekto-benthic predators feeding on small organisms in the water column.

Even less evidence is available for the planktic community. The only definite planktic form found was *Conularia* Sowerby, 1821, a possible scyphozoan, and as an adult, inferred to have been planktic. However, the presence of such an abundant and diverse suspension-feeding fauna must indicate that microplankton was an abundant and fairly constant source of food. Because the Sloans Valley lagoon was apparently supplied with both terrestrial and marine nutrients, it was ideal for proliferation of microplankton.

#### Species Richness and Equitability

No attempt has been made to quantify community composition, because the specimens were collected over a 15-year period, and few data on sampling within a given collecting locality were obtained. Moreover, some



Text-figure 11.—Two interpretations of cirri function in *Camptocrinus*. A. Upright position, with cirri illustrating possible protective and feeding functions. B. Horizontal position, with cirri used for anchorage, stabilization, and feeding.



of the taxa are known only from museum collections. We did, however, note the sample size of our own collections, and this information is shown in Table 1.

If the relative species richness of each echinoderm class in our collections (Table 1) can be assumed to approximate true diversity and abundance during life, then crinoids were the most abundant echinoderms in the Sloans Valley environments. Crinoids comprise approximately 55 percent of our collections; 24 genera and 38 species are represented. This abundance and diversity may reflect the relative availability of the high suspension-feeding niche on the shoals and the importance of crinoids in creating suitable habitats for lower-level suspension feeders.

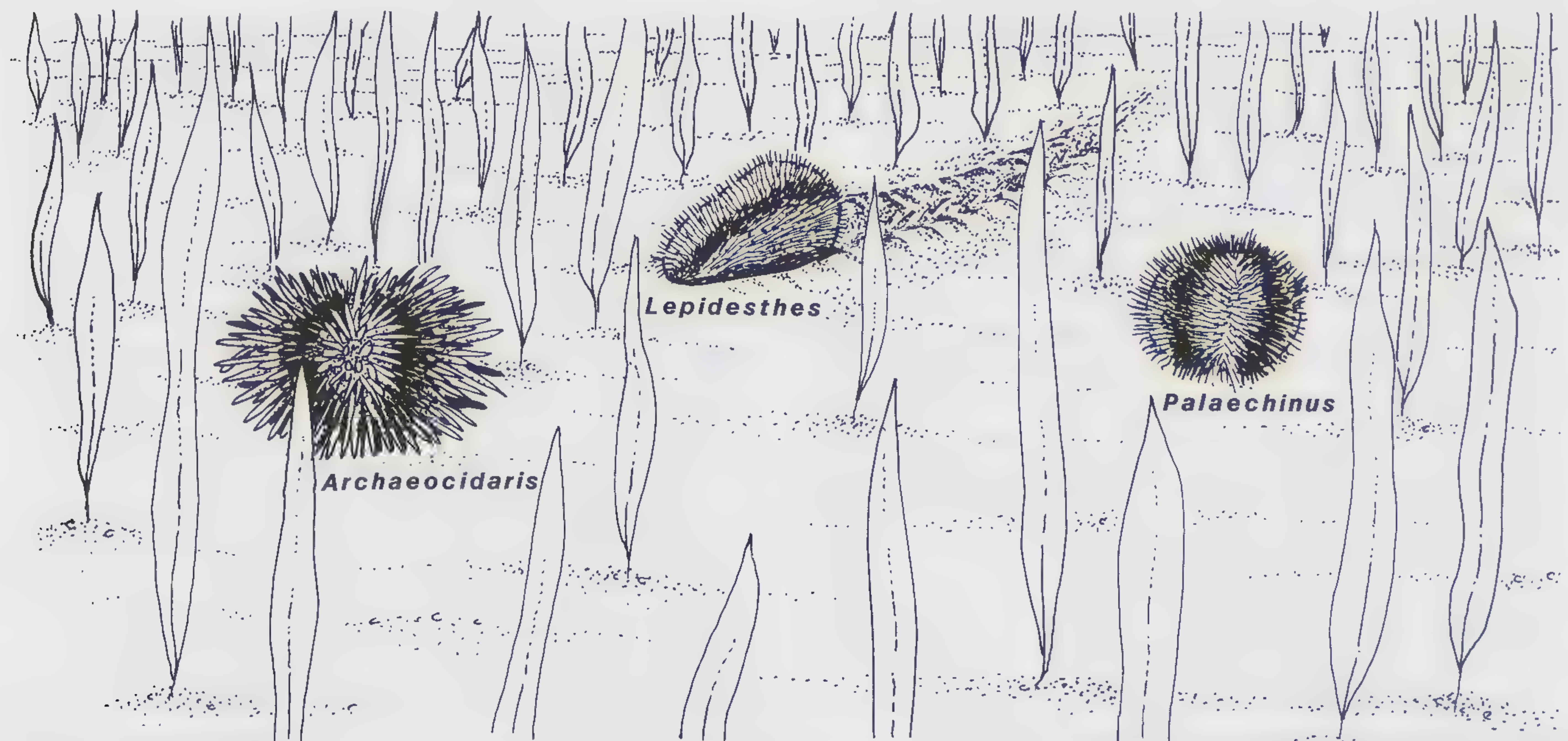
Blastoids comprise 39 percent of our collections; four species of the genus *Pentremites* Say, 1820 (Pl. 9, figs. 8–17), are represented (Table 1). Species of *Pentremites* are found both in shales and on calcarenite lenses, but they are unlikely to have been common on the muds for lack of a firm substrate. Species of *Pentremites* commonly occur with crinoids, and locally may be the dominant echinoderms. A few of the shoal calcarenites are composed largely of blastoid thecae and skeletal parts, reflecting the probable dominance of blastoids on these shoals.

The edrioasteroid *Lepidodiscus laudoni* (Bassler, 1936) (Pl. 10, figs. 1–9), comprises about 4 percent of our collections. Based on its occurrence in our localities, it apparently lived in a variety of environments. It has been found on calcarenite lenses, in shales, and in calcareous sandstones, where most other echinoderms and fossils are lacking.

Three echinoids, *Lepidesthes formosa* Miller, 1879 (Pl. 11, figs. 1–3), *Archaeocidaris hemispinifera*, n. sp. (Pl. 11, figs. 5–9), and *Palaechinus jacksoni*, n. sp. (Pl. 11, fig. 4), comprise about 2 percent of our collections. They are commonly found on thin argillaceous wackestones and packstones along with many delicate fenestellid and rhabdomesoid bryozoans.

The asteroid *Calyptactis* Spencer, 1930 (Pl. 12, figs. 4–7), an unidentifiable asterozoan (Pl. 12, figs. 8, 9), the ophiuroid *Onychaster strimplei* Bjork, Goldberg, and Kesling, 1968a (Pl. 12, figs. 1, 2), and an unidentifiable ophiuroid (Pl. 12, fig. 3) comprise less than 0.5 percent of our collections.

The shales and limestones of the Sloans Valley member also exhibit a rich assemblage of other invertebrates. Most commonly found are brachiopods assignable to the genera *Cleiothyridina* Buckman, 1906, *Composita* Brown, 1849, *Anthracospirifer* Lane, 1963, *Dielasma* King, 1859, *Eumetria* Hall, 1864, *Diaphragmus* Girty, 1910, *Punctospirifer* North, 1920, and *Crania* Retzius, 1781; to the bryozoan genera *Fenestella* Lonsdale, 1839, *Archimedes* Owen, 1838, *Polypora* M'Coy, 1844b, *Lyroporella* Simpson, 1895, *Sep-topora* Prout, 1860, *Fistulipora* M'Coy, 1849b, *Eridopora* Ulrich, 1882, *Meekopora* Ulrich, 1890, *Prismopora* Hall, 1883, *Anisotrypa* Ulrich, 1883, *Tabulipora* Young, 1883, and unidentified rhabdomesoids; to the gastropod genera *Platyceras* Conrad, 1840, *Bellerophon* Montfort, 1808, and *Straparollus* Montfort, 1810; to the pelecypod genera *Aviculopecten* M'Coy, 1851, and *Wilkingia* Wilson, 1959; and to the rugosan coral genus *Zaphrentoides* Stuckenberg, 1895.



Text-figure 12.—Reconstruction of probable epifaunal (*Archaeocidaris* and *Palaechinus*) and semi-infaunal (*Lepidesthes*) browsing life modes for Sloans Valley echinoids.



Table 1.—Number of specimens found at collecting localities in this study. Isolated crinoid plates identifiable to the genera *Agassizocrinus*, *Bicidiocrinus*, *Pterotocrinus*, and *Tholocrinus*, although abundant at several localities, are not included.

	Locality						
	1	2	3	4	5	6	7
<b>Crinoidea</b>							
<i>Acrocrinus shumardi</i> Yandell, 1855	1	—	18	—	8	1	—
<i>Aenigmocrinus anomalos</i> (Wetherby, 1880)	—	—	4	—	—	—	—
<i>Agassizocrinus conicus</i> Owen and Shumard, 1852a	—	—	5	—	—	—	—
<i>Agassizocrinus</i> cf. <i>A. dactyliformis</i> Shumard, 1853	—	—	4	—	—	—	—
<i>Ampelocrinus kaskaskiensis</i> (Worthen, 1882)	—	—	1	—	1	—	—
<i>Anartioocrinus lyoni</i> Kirk, 1940a	—	—	—	1	1	—	—
<i>Aphelecrinus randolphensis</i> (Worthen, 1873)	—	—	12	—	10	—	—
<i>Bicidiocrinus wetherbyi</i> (Wachsmuth and Springer, 1886)	—	—	6	—	12	—	—
<i>Camptocrinus cirrifer</i> (Wachsmuth and Springer, 1897)	—	—	—	—	1	—	—
<i>Culmicrinus vagulus</i> (Miller and Gurley, 1895)	—	—	—	—	—	—	—
<i>Cymbiocrinus grandis</i> Kirk, 1944b	—	—	9	—	7	—	—
<i>Dasciocrinus floralis</i> (Yandell and Shumard, 1847)	—	—	8	—	4	—	—
<i>Eupachyrcrinus boydii</i> Meek and Worthen, 1870	1	—	1	—	1	—	—
<i>Hyratanocrinus pentalobus</i> (Casseday and Lyon, 1862)	—	—	2	—	1	—	1
<i>Linocrinus laurelensis</i> , n. sp.	—	—	1	—	5	—	—
<i>Onychocrinus pulaskiensis</i> Miller and Gurley, 1895	—	—	9	—	—	—	—
<i>Pentaramicrinus gracilis</i> (Wetherby, 1880)	2	—	—	—	—	—	—
<i>Phacelocrinus bisselli</i> (Worthen, 1873)	—	—	—	—	—	—	—
<i>Phacelocrinus longidactylus</i> (McChesney, 1860)	—	—	7	—	4	3	—
<i>Phanocrinus manifformis</i> (Yandell and Shumard, 1847)	4	—	71	—	25	—	—
<i>Phanocrinus parvaramus</i> Sutton and Winkler, 1940	—	2	4	—	1	—	—
<i>Pterotocrinus acutus</i> Wetherby, 1879a	3	1	8	—	5	—	1
<i>Pterotocrinus depressus</i> Lyon and Casseday, 1860	1	—	2	—	6	—	1
<i>Pulaskicrinus campanulus</i> (Horowitz, 1965)	—	—	13	—	—	—	—
<i>Ramulocrinus milleri</i> (Wetherby, 1881)	—	—	14	—	1	—	—
<i>Rhopocrinus spinosus</i> Kirk, 1942a	—	—	—	—	—	—	—
<i>Strimplecrinus superstes</i> (Wachsmuth and Springer, 1897)	—	—	—	—	—	—	—
<i>Talarocrinus decornis</i> Wachsmuth and Springer, 1897	—	—	—	—	—	—	—
<i>Taxocrinus whitfieldi</i> (Hall, 1858)	—	—	10	—	22	1	—
<i>Tholocrinus spinosus</i> (Wood, 1909)	1	—	4	—	16	—	—
<i>Wetherbyocrinus pulaskiensis</i> (Miller and Gurley, 1896)	—	—	—	—	—	—	—
<i>Zeacrinites wortheni</i> (Hall, 1858)	1	1	9	—	8	1	—
<b>Blastoidea</b>							
<i>Pentremites elegans</i> Lyon, 1860	—	2	22	—	2	8	33
<i>Pentremites pyriformis</i> Say, 1825	1	—	14	—	—	1	1
<i>Pentremites robustus</i> Lyon, 1860	—	1	9	—	3	3	6
<i>Pentremites tulipaeformis</i> Hambach, 1903	1	1	133	—	19	13	—
<b>Edrioasteroidea</b>							
<i>Lepidodiscus laudoni</i> (Bassler, 1936)	—	—	2	—	9	19?	1
<i>Ulrichidiscus pulaskiensis</i> (Miller and Gurley, 1894)	—	—	—	—	—	—	—
<b>Echinoidea</b>							
<i>Archaeocidaris hemispinifera</i> , n. sp.	—	—	3	—	8	—	—
<i>Lepidesthes formosa</i> Miller, 1879	—	—	2	—	—	—	—
<i>Palaechinus jacksoni</i> , n. sp.	1	—	—	—	—	—	—
<b>Stelleroidea</b>							
<i>Onychaster strimplei</i> Bjork, Goldberg, and Kesling, 1968a	—	—	2	—	—	—	—
unidentifiable ophiuroid genus and species	—	—	1	—	—	—	—
<b>Asteroidea</b>							
<i>Calyptactis spenceri</i> , n. sp.	—	—	1	—	—	—	—
unidentifiable asterozoan genus and species	—	—	—	—	—	—	—

More detailed faunal lists are provided by Ulrich (1905), Butts (1922), and Bassler and Moodey (1943).

In most of the large crinoid assemblages we collected, the species appeared to be uniformly distributed.

However, on some of the calcarenite shoals at a given locality, and in one instance, throughout the entire locality (loc. 5), one or two species dominated. At locality 5, of 50 crinoids found on a single bedding sur-



face, two-thirds belonged to the species *Bicidiocrinus wetherbyi* Wachsmuth and Springer, 1886. At locality 3, *Phanocrinus maniformis* (Yandell and Shumard, 1847) appeared to be dominant, and at another locality in Wayne County outside of the study area, *Onychocrinus pulaskiensis* Miller and Gurley, 1895 and *Pulaskicrinus campanulus* (Horowitz, 1965) were the only crinoids present on a calcarenite shoal body. We have noted other shoals composed largely of the plates of *Pterotocrinus* Lyon and Casseday, 1859 and of blastoid thecae. We have also noted one large group of 11 edrioasteroids [*Lepidodiscus laudoni* (Bassler, 1936)] on a single slab, suggesting that they also were gregarious. The echinoid *Archaeocidaris hemispinifera*, n. sp., commonly is found in groups of two or more, suggesting that they grazed in groups, as some modern echinoids do.

The apparent increase in species richness and in numbers of individuals at localities 3 and 5 (Table 1) is the result of a collecting bias. Localities 3 and 5 were active quarries, and new material was constantly being exposed. The other localities are man-made cuts, or abandoned quarries, which do not provide a constant supply of new material.

Crinoid communities similar in age and occurrence to those examined in this study are known from the Bangor Limestone of Alabama (Burdick and Strimple, 1982). The communities in the Bangor generally have a crinoid diversity greater than or equal to ours. Other non-crinoid echinoderms are present in the Bangor (Horowitz, written commun., 1985), but their abundance and diversity are unknown.

#### Relationships Between Species

Ager (1963) suggested that two basic types of relationships exist between species: *antagonism*, in which one species suffers because of the actions of another; and *symbiosis*, in which each species benefits without harming the other. Each of these relationships can be further subdivided into more specific interactions. Evidence for three of these interactions, two antagonistic and one symbiotic, is preserved in the Sloans Valley fauna.

#### *Antagonism*

*Exploitation.*—In exploitation, one species benefits at the expense of another. Two forms of exploitation, predation and parasitism, are found in the Glen Dean crinoid gardens. Predation on Recent crinoids by bony fishes has been reported by Meyer and Macurda (1977), Meyer and Ausich (1983), and Meyer (1983). However, we see no direct evidence of predation by the durophagous chondrichthyan fishes that were present. Although some anomalous plates inserted into some

of the calyxes could be construed to be healed wounds, genetic aberrations are an equally-likely explanation. The increased incidence of long spines and the thickening of plates (Text-fig. 13) in our crinoids, however, may be a response to the radiation of durophagous predators (Signor and Brett, 1983, 1984).

Predation by echinoderms is well known, particularly in the asterozoans. Most of the Sloans Valley echinoderms were suspension feeders, although the echinoids and ophiuroids were probably herbivores, detritus feeders, and scavengers. The asteroid *Calyp-tactis* Spencer, 1930, however, was most likely an active predator on bryozoans.

Parasitism is common in nearly all modern echinoderms (Hyman, 1955) and was probably just as common in many of the fossil forms. However, only one possible example has been found in the Sloans Valley echinoderms: a funnel of *Phosphannulus* Müller, Nogami, and Lenz, 1974, on a swollen crinoid stem. According to Welch (1976), some species of *Phosphannulus* were probably ectoparasites on crinoids. Many infrabasal cones of *Agassizocrinus* Owen and Shumard, 1852a, and many crinoid stems show acrothoracic barnacle borings, but the barnacles were not parasitic and apparently made their borings after the crinoids died (Ettensohn, 1978).

*Competition.*—Competition is a significant natural factor in nearly all communities and it can be detrimental to all the individuals involved. The abundance and diversity of suspension feeders in the Sloans Valley echinoderm faunas suggests that competition for suspended nutrients probably was significant. Much of this competition apparently was reduced by niche partitioning through tiering (Ausich, 1980).

#### *Symbiosis*

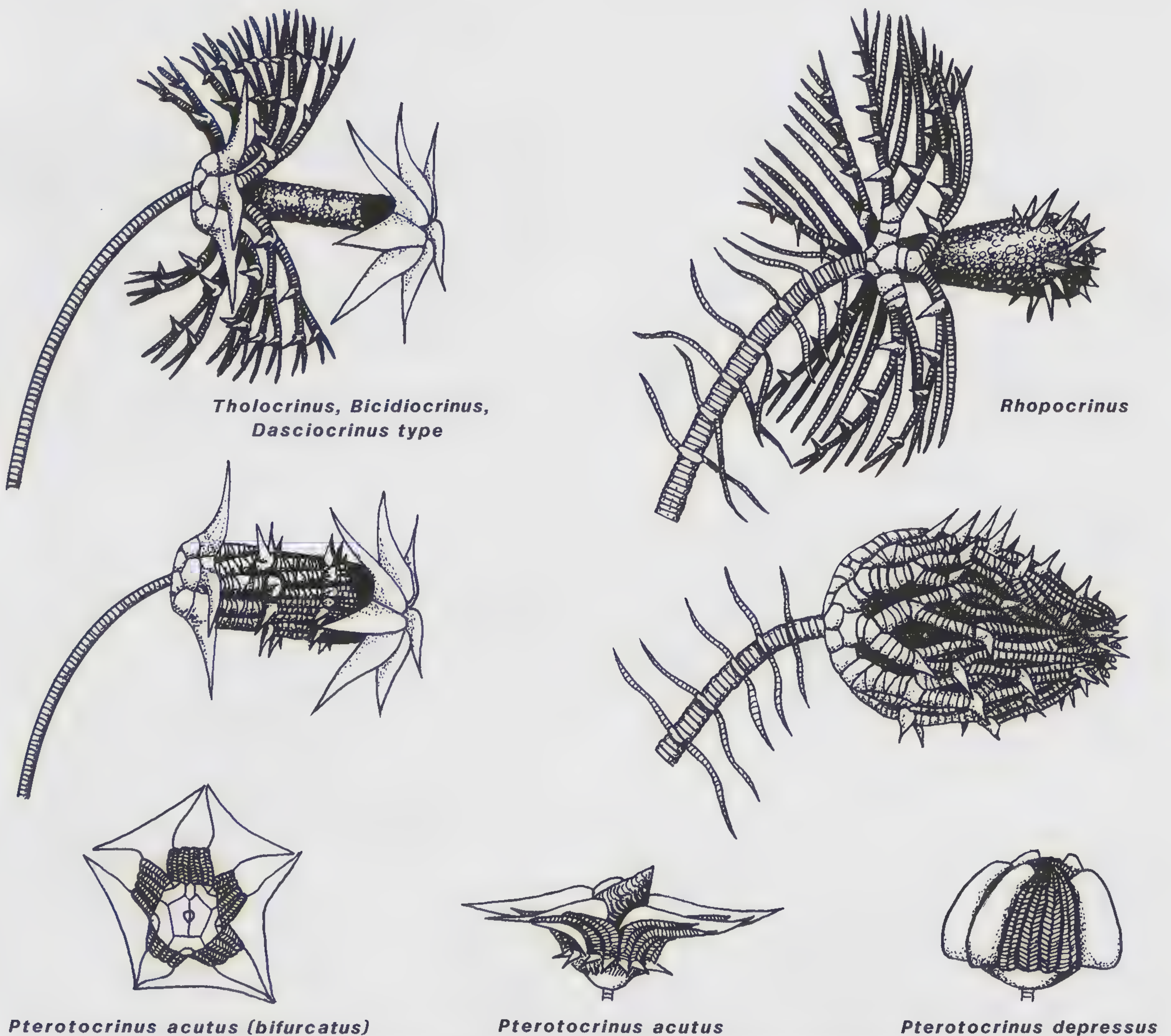
*Commensalism.*—In commensalism, one species benefits while the other is unaffected. A number of commensal relationships are preserved in the Sloans Valley fauna, and others are suggested. The most impressive example in our collections is that involving the ophiuroid *Onychaster strimplei* Bjork, Goldberg, and Kesling, 1968a, which lived within the arms of *Pulaskicrinus campanulus* (Horowitz, 1965) (Pl. 12, figs. 1, 2; Text-fig. 14). Bjork, Goldberg, and Kesling (1968b) suggested that the ophiuroid lived in this manner for protection and utilized the elevation that the crinoids provided to obtain suspended food higher in the water column. If this was the case, then the food particles used by the ophiuroid were probably of a different size than those used by the crinoid. It is also possible, moreover, that the ophiuroid fed on crinoid excrement. This commensal relationship is discussed in greater detail in the remarks for *Onychaster* Meek and Worthen, 1868.



The gastropod *Platyceras* sp. was commonly found on the tegmens of the camerate crinoids *Pterotocrinus* Lyon and Casseday, 1859 (Pl. 7, fig. 12) and *Acrocrinus* Yandell, 1855. The platycerids apparently were attached to the crinoid fairly early in life, because their shells grew to conform to the outline of the tegmen. Evidence from growth lines on the gastropods furthermore suggests that they were attached for much or perhaps all the life of the crinoid (Horowitz, written commun., 1985). These platycerids probably were coprophagous and did not harm the crinoids, which apparently lived for many years with the gastropods attached.

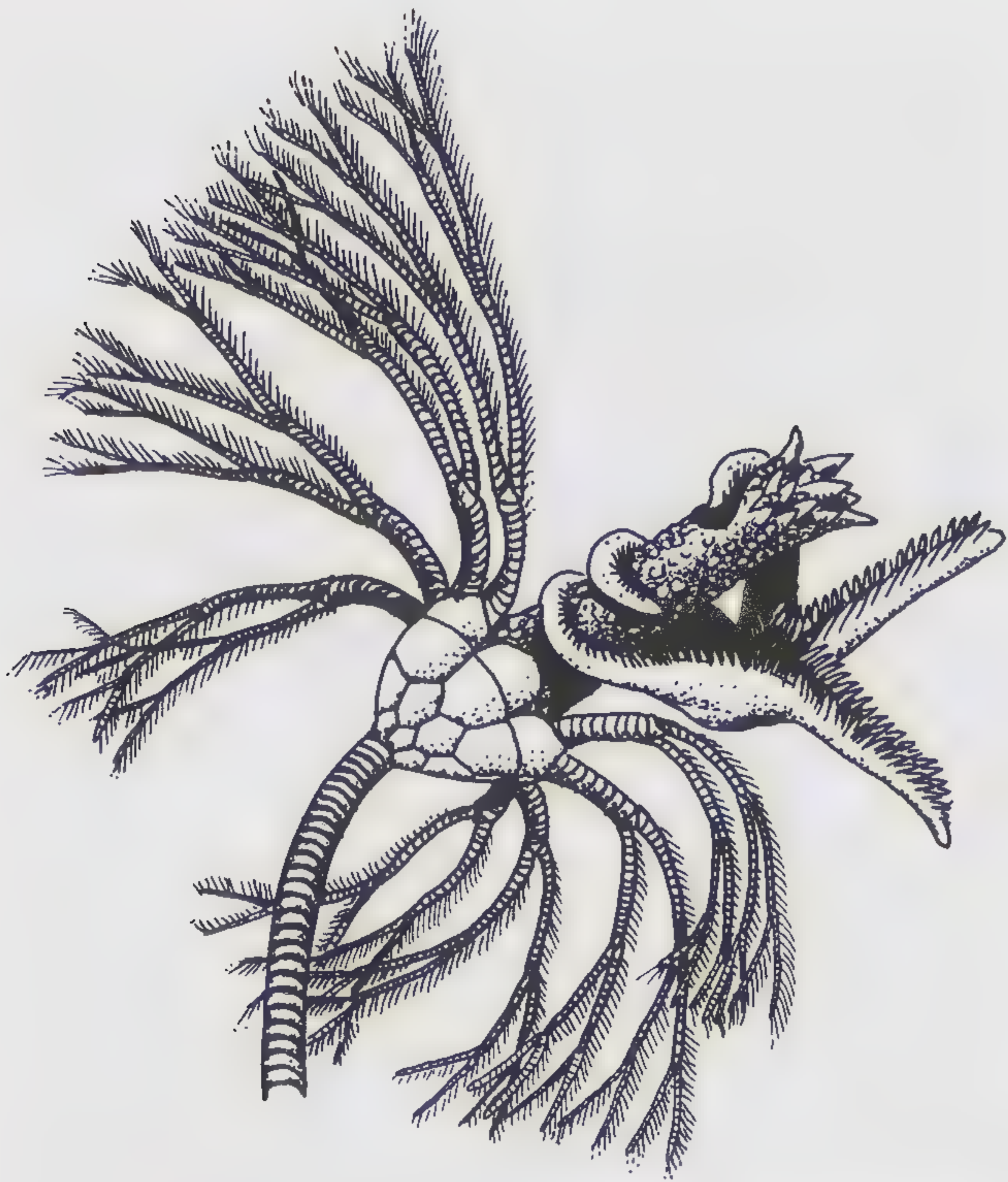
The smaller crinoids such as *Cymbiocrinus* Kirk, 1944b, *Linocrinus* Kirk, 1938, and *Ramulocrinus* Lau-

don, Parks, and Spreng, 1952, may have been epizoans (Meyer and Ausich, 1983), using their cirri and arms to climb onto other organisms, such as bryozoans, and other crinoids, for elevation into the water column (Text-fig. 15). Our best evidence for this idea, though equivocal, is the stem of one specimen of *Cymbiocrinus* that was found loosely wrapped around a frond-bearing column of *Archimedes* Owen, 1838 (Pl. 2, fig. 8). The cirri on the stem may have been used to climb onto and grasp the bryozoan. Cirri in modern crinoids are similarly used for clinging and holding in place (Macurda and Meyer, 1974; Meyer and Macurda, 1980). The unusual zig-zag arms of the very small crinoids *Ramulocrinus* (Pl. 4, figs. 22, 23) and *Linocrinus laurelensis*, n. sp. (Pl. 1, figs. 10-15) appear to have been



Text-figure 13.—Examples of Sloans Valley crinoids bearing spines and spinelike plates.





Text-figure 14.—Possible commensalism between *Onychaster strimplei* and *Pulaskicrinus campanulus*, n. comb.

very flexible, perhaps more than was necessary for forming a filtration fan. We suggest that these crinoids may have used their arms, and perhaps their cirri (specimens have not been found preserved with stems), to climb onto higher structures (Text-fig. 15), to reach more desirable currents higher in the water column, much as some modern crinoids do (Macurda and Meyer, 1974). Whether this was accomplished with or without use of the stem is not known, but all specimens have well-developed stem scars.

Some of the echinoderms, particularly the crinoids, provided firm substrates for a number of epizoans both in life and death. Bryozoans, inarticulate brachiopods, and probable annelids have been found attached to crinoid stems. Encrusting bryozoans have been found completely encircling crinoid stems. Some exhibit ramose branches projecting in all directions normal to the crinoid stem, which seems to preclude their lying on the substrate. *Crania chesterensis* Miller and Gurlley, 1897, *Spirorbis* sp., and *Cornulites*-like worm tubes have also been found attached to and completely encircling crinoid stems. It is most likely that these forms lived on upright crinoid stems, because they probably would not have survived on stems rolling over a muddy substrate. The same forms, however, have also been



Text-figure 15.—Possible commensalism between small "hitchhiking" crinoids and bryozoans.



found attached to the flat portions of the wing plates of *Pterotocrinus* (Pl. 7, fig. 15) and to the flat internal surfaces of the infrabasal cones of *Agassizocrinus* Owen and Shumard, 1852a, as have acrothoracic barnacle borings (Pl. 7, figs. 10, 11, 17, 19, 21–23; Pl. 8, figs. 8, 11, 12). The plates on which these encrusters and borings are found commonly are abraded and oriented by currents, suggesting that they were isolated plates when bored and encrusted. In other instances, the encrusters and borings occur on surfaces (e.g., the internal facets of *Agassizocrinus* infrabasal cones) that were never exposed in life.

#### AUTECOLOGY

##### Feeding Mechanisms

Major feeding mechanisms among the Sloans Valley echinoderm fauna can be divided into five categories: suspension feeding, browsing, scavenging, active predation, and deposit feeding. Suspension feeders composed approximately 84 percent of the echinoderm fauna; scavengers and browsers, approximately 5 percent each; predators, approximately 4 percent; and deposit feeders, approximately 2 percent. As is commonly the case on coarser, less stable sediments (Speden, 1966), suspension feeders dominated. However, contrary to the interpretations of Walker (1972), each of the several dominant species in the communities did not belong to a different feeding (trophic) category, and one species did not dominate each feeding group. Each of the several dominant species were suspension-feeding crinoids, and the dominant crinoid species varied from locality to locality and from garden to garden. Moreover, echinoderms in the other feeding categories were rare. More definite patterns might emerge if other invertebrates like the ubiquitous bryozoans were considered, but most of these invertebrates

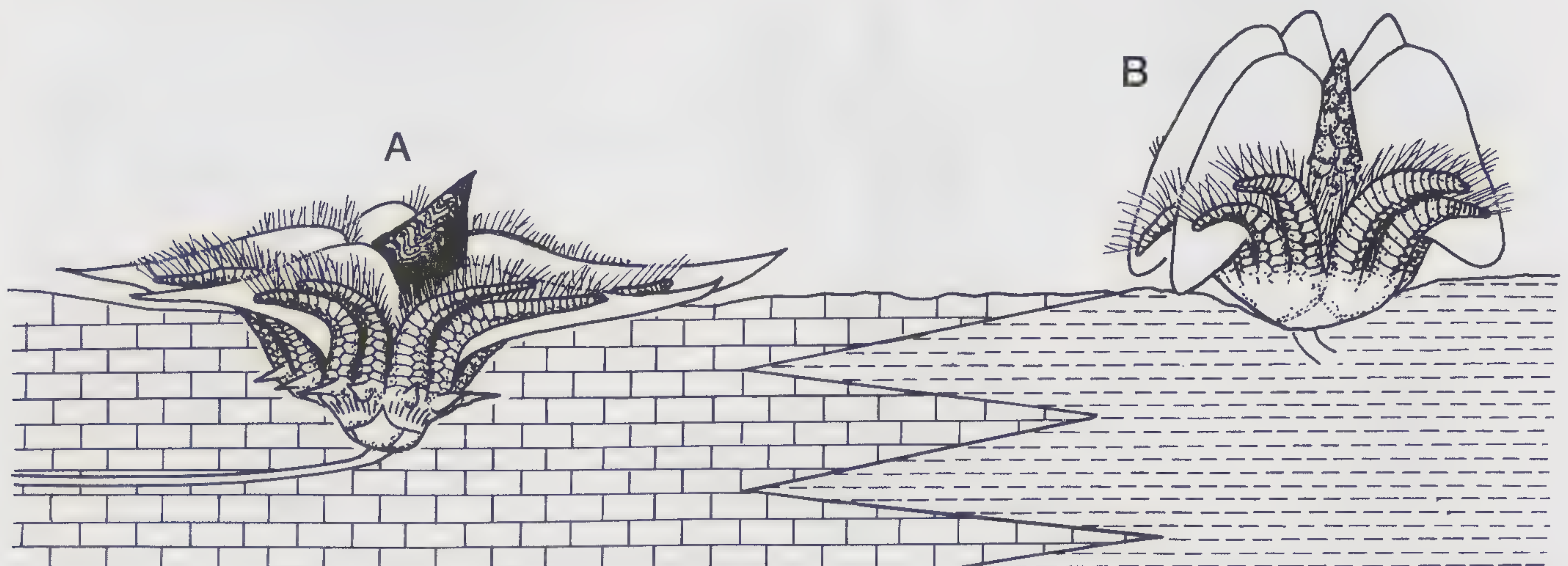
also were suspension feeders. The fact that the echinoderms apparently do not exhibit dominance schemes relative to feeding mechanisms (Walker, 1972) suggests three possibilities:

1. food was so abundant that no partitioning of resources was necessary;
2. some other type of partitioning mechanism was used; or
3. environmental factors like substrate, shoal size, current direction, or other factors such as colonization order were more important in determining the numbers and types of echinoderms than feeding mechanisms.

We believe that all three factors were probably important to varying degrees.

*Suspension Feeders.*—We believe many of the suspension-feeding echinoderms fed at different levels or tiers (Text-fig. 10), and hence tiering (Ausich, 1980; Ausich and Bottjer, 1982) may have been an alternative to the dominance partitioning of Walker (1972). We have assigned suspension-feeding echinoderms to one of four arbitrary levels or tiers based upon the presence or absence of a stem during life, the length and width of preserved stems, the size and robustness of crowns, and the preservation of other features that reflect relative level in the water column (Text-fig. 10). Our definitions of all but the substrate level are arbitrary, with only very general numerical limits; the levels serve only to group the echinoderms in a general way.

Suspension feeders operating at the substrate level included the crinoids *Agassizocrinus* Owen and Shumard, 1852a, and possibly *Pterotocrinus* Lyon and Caseday, 1859, as well as the edrioasteroids *Ulrichidiscus* Bassler, 1935, and *Lepidodiscus* Meek and Worthen, 1868. Adult forms of *Agassizocrinus lobatus*



Text-figure 16.—Possible life position of *Pterotocrinus acutus* and *Pterotocrinus depressus*. A. *Pterotocrinus acutus* on a grainstone substrate. B. *Pterotocrinus depressus* on a muddy substrate.

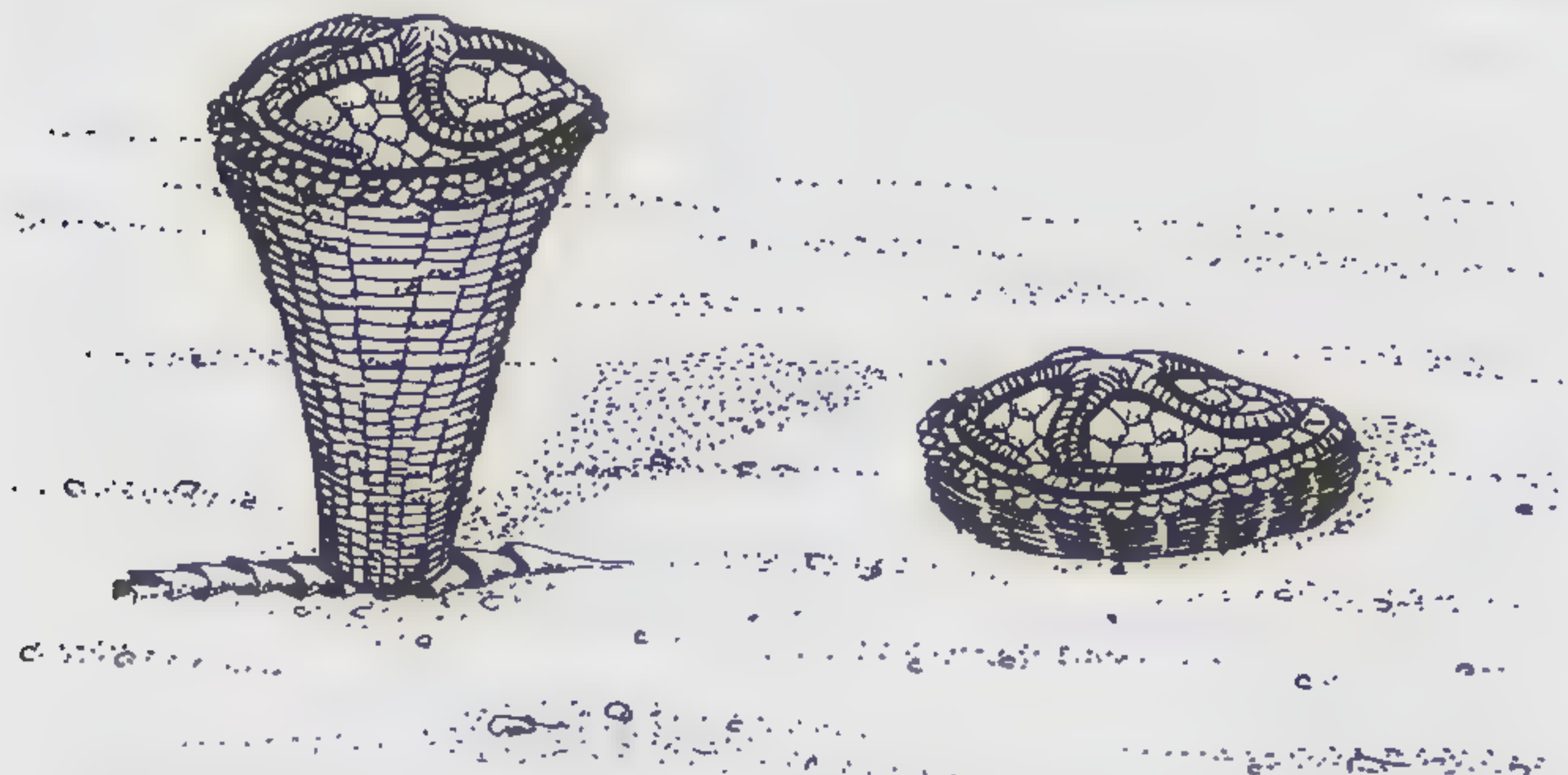


Springer, 1926 from the Haney Member of the Newman Limestone were stemless and lived with their dorsal cups buried in the substrate (Ettensohn, 1975b). We suggest that the Sloans Valley species *Agassizocrinus conicus* Owen and Shumard, 1852a, and *A. cf. A. dactyliformis* Shumard, 1953, lived similarly. *Pterotocrinus acutus* Wetherby, 1879a, and *P. depressus* Lyon and Casseday, 1860, apparently possessed stems throughout their lives but may have lived on the substrate with the stem wholly or partially buried (Text-fig. 16). One specimen of *P. acutus* (UK 115907) was found apparently preserved in place in a grainstone in such a manner. Arms of many specimens were flexed outward onto the substrate as reported for the arms of *Agassizocrinus lobatus* by Ettensohn (1975b). This probable life mode is discussed in greater detail on pp. 46, and 55. *Pterotocrinus acutus*, found frequently in grainstones and packstones, probably lived on higher energy shoals; *Pterotocrinus depressus*, which is commonly found in calcareous shales and marls, as well as some wackestones and packstones, probably lived in quieter basinal areas.

The edriasteroids operated not only at the substrate level, but also in the lower levels of the water column several cm above the substrate (Text-fig. 10). These edriasteroids had peduncles that could expand or contract (Text-fig. 17), within a limited range (probably up to 6 or 7 cm), allowing them to attain different levels.

The low-level suspension-feeding tier (Text-fig. 10) extended from about 2 to 30 cm above the bottom and included all the blastoids (*Pentremites* spp.), the extended edriasteroids, the small or delicately-constructed adult crinoids, and juvenile forms of higher crinoids. We suggest that the genera listed in the low-level column of Text-figure 10 lived within this level.

The medium-level tier (from 30 cm to 80 cm) included the moderate-sized adult crinoids listed in Text-figure 10, juvenile forms of crinoids whose crowns extended even higher, and probably a group we call "hitchhikers". The "hitchhikers" are small echinoderms that climbed onto higher-tier crinoids or other



Text-figure 17.—*Lepidodiscus* in extended and contracted positions.

invertebrates for protection or to gain access to currents higher in the water column. These include some small, normally low, agile crinoids such as *Cymbiocrinus* Kirk, 1944b (Text-fig. 15) and at least one ophiuroid genus, *Onychaster* Meek and Worthen, 1868 (Text-fig. 14).

The upper-level tier included high, robust, adult crinoids probably living at heights of 80 cm or more above the substrate: they are listed in Text-figure 10. This level also probably included several "hitchhikers". Based on preserved stem length and robustness of the crown, the flexible crinoid *Onychocrinus* Lyon and Casseday, 1860, probably was elevated higher above the bottom than any of the other Sloans Valley echinoderms (perhaps reaching levels greater than 1.5 m).

The most abundant and diverse suspension-feeding faunal elements apparently lived within the low- and medium-level tiers.

*Browsers.*—We have categorized the echinoids *Archaeocidaris* M'Coy, 1844a, and *Palaechinus* M'Coy, 1844a, as browsers (Text-fig. 12), not so much for what they ate, but because of the way in which they ate it. Most echinoids will eat nearly everything, but some tend to be dominantly carnivores, herbivores, or general scavengers (Hyman, 1955). We cannot be certain about what the Sloans Valley species of *Archaeocidaris* and *Palaechinus* were eating, but we suspect that algae comprised much of their diet if they were similar to many Recent regular echinoids.

*Deposit Feeders.*—The echinoid *Lepidesthes* Meek and Worthen, 1868, was apparently very flexible, with an elongate shape and small spines (Pl. 11, fig. 1). We suggest that it was probably an epifaunal deposit feeder occupying a niche similar to that of some recent holothurians and irregular echinoids (Text-fig. 12). It was most commonly recovered from marly, argillaceous limestones and apparently fed on softer substrates in deeper, basinal areas.

*Scavengers.*—Recent ophiuroids are dominantly scavengers, although many supplement scavenging with carnivorous feeding and suspension feeding (Hyman, 1955). For this reason, the two Sloans Valley ophiuroids are classified as scavengers, although questions have already been raised about the feeding mechanisms of *Onychaster strimplei* Bjork, Goldberg, and Kesling, 1968a. *Onychaster* Meek and Worthen, 1868, may have been coprophagous on the crinoid *Pulaskicrinus*, n. gen., may have used the crinoid as an elevated perch for suspension feeding, or may have exploited some combination of both strategies (Text-fig. 14). Commensal relationships between modern crinoids and ophiuroids are not uncommon (Hyman, 1955).

*Active Predators.*—Because most asteroids are car-



nivorous and active predators, we suggest that *Calyp-tactis* Spencer, 1930, and an unidentifiable asterozoan species (Pl. 12, figs. 8, 9) in the Sloans Valley fauna fed similarly. Moreover, both of our specimens of *Ca-lyptactis* are closely associated with fenestrate bryo-zoans (Pl. 12, figs. 4, 6, 7). Although the association may be accidental, it is also possible that *Calyp-tactis* lived and fed upon fenestrate bryozoans (Text-fig. 18). Many modern asteroids feed on bryozoans (Day and Osman, 1981; Jangoux, 1982), so the prey is not un-usual. Some of the disruption of delicate fenestrate bryozoan thickets commonly attributed to storms and burial may be related to *Calyp-tactis*. Is it possible that *Calyp-tactis* occupied the same feeding niche relative to Carboniferous bryozoans (Text-fig. 18) that *Acan-thaster* Gervais, 1841, ("Crown of Thorns") occupies today relative to modern reef corals?

#### Functional Morphology

Some of the crinoid genera possessed peculiar or recurring morphological traits that require explana-tion. Because some of these morphologies are present in a number of genera, they may reflect synchronous convergent evolution. The morphologies are discussed below.

*Spines.*—Six of the 28 crinoid genera present possess abundant or well-developed spines. Other crinoids may possess one to a few spines, but are not considered to be exceptionally spinose. Of the six genera, five [*Das-ciocrinus* Kirk, 1939; *Rhopocrinus* Kirk, 1942a; *Thol-ocrinus* Kirk, 1939; *Pterotocrinus* Lyon and Casseday,

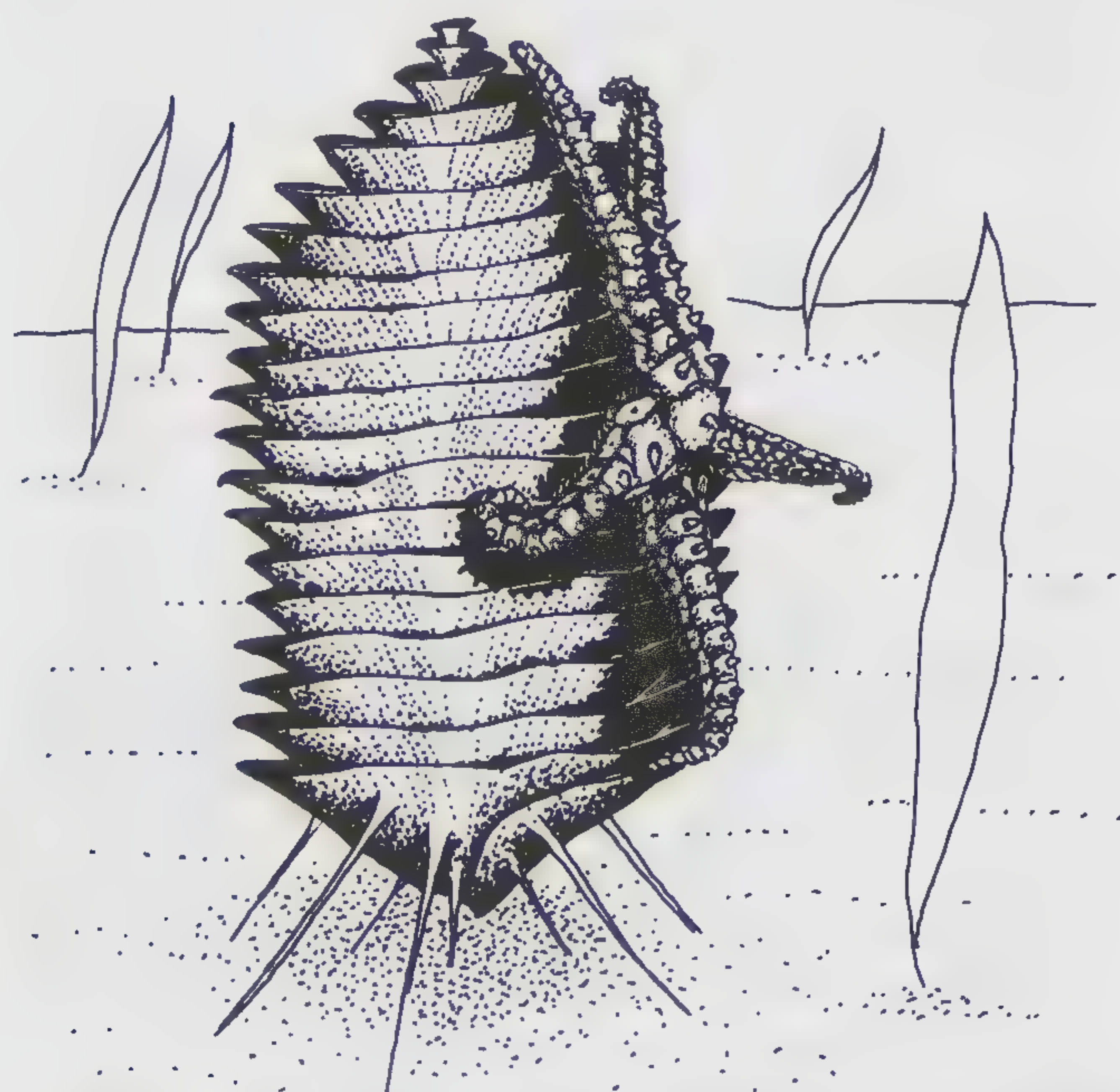
1859; and *Bicidiocrinus* Strimple, 1975b] (Text-fig. 13) are highly spinose, with spines that are large relative to the crown. The sixth genus, *Onychocrinus* Lyon and Casseday, 1860, is moderately spinose, with smaller spines. The spines generally occur in three positions on these crinoids: on the arms, on the anal tube, and, in *Pterotocrinus*, on highly modified tegminal plates (Text-fig. 13).

In the four inadunate genera above, all spines are concentrated on the arms and on the anal tube. Spines on the anal tube no doubt served a protective function at all times, but especially when the arms were ex-tended in their feeding array and the anal tube was fully exposed (Text-fig. 13). Spines on the arms would have been most effective when the arms contracted and assumed a protective stance. In this stance, the arms apparently nestled tightly around the anal tube and just below the terminal spines on the anal tube (Text-fig. 13). The result was a rigid cylinder with cycles of outwardly-projecting spines (Text-fig. 13). The larg-est spines commonly are on the primibrachials at the proximal ends of the arms and on the anal sac at the distal ends of the arms, thus protecting the calyx from both ends. Although the spines may have had second-ary functions such as forming small eddy currents to aid in feeding, their most important function appar-ently was protection. Most of the protection was di-rected toward the anal sac.

The small spines and moderately spinose nature of *Onychocrinus pulaskiensis* Miller and Gurley, 1895, probably reflect different protective needs and strate-gies. *O. pulaskiensis* has only a small anal tube, and the open, expanded nature of the calyx would have precluded the "armored cylinder" strategy of the pre-viously-discussed inadunates. The principal defensive strategy of *O. pulaskiensis* seems to have been inward rolling of the arms and thickened calyx plates (Pl. 6, figs. 1-4).

Many protective strategies exhibited by these cri-noids were probably responses to the abundance of durophagous predators. According to Signor and Brett (1983, 1984), a number of invertebrate groups devel-oped various protective strategies like spines in re-sponse to a mid-Paleozoic radiation of durophagous predators. Among these predators were chondrichthy-an fishes, which were very abundant in environments represented by the Glen Dean Member and lower part of the Pennington Formation (Chesnut, in prepara-tion). Similarly, Meyer (1983) has reported crinoid pre-dation by modern fishes, suggesting that predation may have been an important selective factor in crinoid pa-leobiology.

Species of the camerate *Pterotocrinus* possess "spines" that are completely different in morphology and origin from those of most other crinoids (Pl. 6,



Text-figure 18.—Possible predation by *Calyp-tactis spenceri*, n. sp. on fenestrate bryozoans.



figs. 9–14; Pl. 7; Pl. 8, figs. 1–12; Text-fig. 13). On most crinoids, spines are merely localized extensions of brachial, primibrachial, and anal-tube plates. In *Pterotocrinus*, similar spinose projections are present on some of the free brachials, but the largest spines or “wing plates” are themselves individual (slightly articulated?) tegmental plates. Each of these plates is proximally thickened near its point of attachment, and undergoes distal thinning until the very end, where, in some cases, it bifurcates or produces secondary spinose projections.

Apparently in-place *Pterotocrinus* specimens (described in a following section) indicate that the genus probably lived partially buried in the substrate. About half of the free arms were flexed outward above the level of the wing plates, which appear to have been located at or slightly below the sediment–water interface. Most of the cup was probably embedded in the substrate, and all of the stem was buried below, but parallel to, the substrate surface (Text-fig. 16). We suggest that the wing plates may have acted to support and stabilize the calyx on the substrate in much the same way that outriggers are used to stabilize large sea-going canoes. The lateral expansion and bifurcations that are common at the ends of the plates would have increased the surface area of the plates and further enhanced support on the substrate. Not only would the spines have affected the vertical stability of the crinoid in the substrate, but they would have assured some degree of lateral stability in currents. Plates slightly embedded in or sitting on the substrate may have offered considerable resistance to any type of lateral or rotational movement on the substrate, and the enlarged spines may have helped to retard any destabilizing sediment scour around the crinoid in much the same way as do spines on brachiopods (Alexander, 1984). Some of the various spine morphologies, moreover, may have been ecophenotypic variations in response to varying substrates or current conditions.

Some evidence suggests different substrate preferences for the two Pennington Formation species described herein. *P. acutus* Wetherby, 1879a, is found more commonly on calcarenite substrates and exhibits a more conical cup. *P. depressus* Lyon and Casseday, 1860, however, is found more commonly on muddy calcarenite or shale substrates and has a dish-shaped cup with a flatter bottom. The flatter bottom may have offered more support in muddy substrates.

*Anal Sacs.*—Over half of the crinoid genera described in this study have well-developed anal sacs (Pls. 1–3; Text-fig. 13). The purpose of this sac is unknown, but Lane (1975) suggested that the long anal sac in the Pennsylvanian genus *Aesiocrinus* Miller and Gurley, 1890a, either housed an extended hindgut or a hypertrophied ring-canal system. He postulated that an ex-

tended hindgut may have been needed to absorb organic nutrients greatly diluted by clastics in a turbid environment, and that the pores or tubes associated with the anal sac of *Aesiocrinus* may have supplied extra oxygen to the hindgut. Conversely, the anal sac may have housed a highly-ramified water vascular system (Lane, 1975), the purpose of which is unknown. A large amount of argillaceous material is found in the limestones of the Sloans Valley member, and shale is a major lithology, so terrigenous clastics were abundant in the environment. More recently, Lane (1984) suggested that the anal sac housed gonads and that any excision of the sac by predators would have been less traumatic than attack on the cup itself; the anal sac also would have been more readily regenerated.

Regardless of function, the anal sac apparently contained much soft tissue. The protruding mass of tissues, even though plated, no doubt required special protection in the form of spinose arms and various spinose projections. About half the known anal sacs of Sloans Valley crinoid species bear spines or spiny knobs (see the discussion on spines); the rest are only incompletely known. In *Eupachyrcrinus* Meek and Worthen, 1865, *Phanocrinus* Kirk, 1937, and *Zeacrinites* Troost, 1858, the anal sacs apparently were protected by stout, heavily plated arms. Moreover, in forms like *Zeacrinites*, the tegmen is pyramidal and the calyx exhibits a robust, box-like construction (Pl. 1, figs. 1–4) similar to that of many Lower and Middle Mississippian camerate crinoids. This box-like construction may have provided further protection for the housed tissues.

*Zig-Zag Arms.*—The arms of most Sloans Valley crinoids are typical of Carboniferous crinoids in general. They are uniserial or biserial and composed of cuneate or rectangular brachials. The zig-zag arms of *Linocrinus laurelensis*, n. sp. (Text-fig. 19; Pl. 1, figs. 10–15) and *Ramulocrinus milleri* (Wetherby, 1881) (Pl. 4, figs. 20–23) are quite unusual in comparison. Both of these crinoids are very small, and the central axes of successive brachials lie at a large angle to each other, giving the arms a zig-zag appearance. In *L. laurelensis* the brachials are short, but in *R. milleri* the brachials are very long and bear stout pinnules. Moreover, the pinnules in *R. milleri* are much longer on distal than on proximal parts of the arms. Pinnules are oriented at nearly right angles to the originating brachial, but are roughly parallel to the following brachial and perpendicular to adjacent pinnules on the next arm. The configuration of the arms would have produced a filtration fan with a rectilinear, grid-like appearance. The rectilinear mesh of brachials, pinnules, and tube feet would seem to have been an effective design (Text-fig. 15).

These arms also seem to have been extremely flexible and perhaps capable of some type of manipulative ac-



tivity. The many angles at which pinnules and brachials were oriented on each arm may have facilitated grabbing and clinging onto other crinoids or bryozoans (Text-fig. 15). Hence, the possible agility of the arms or stems may have allowed these small, lightweight crinoids some degree of vertical mobility.

The development of zig-zag arms was not new with the Sloans Valley crinoids. This adaptation has been long-lasting and repetitive, for it is present in crinoids from the Devonian (Schmidt, 1934, 1942) and Pennsylvanian (Strimple and Moore, 1971; Strimple, 1975a, pp. 17, 18). Other small crinoids like *Cymbiocrinus* Kirk, 1944b, apparently relied partly on cirriferous stems for any climbing or clinging ability. One specimen (Pl. 2, fig. 8) was found with its cirriferous stem wrapped around the zoarium of a specimen of *Archimedes* Owen, 1838. Bryozoans and other crinoids apparently not only provided anchorage for these smaller crinoids, but also a means of elevating themselves higher in the water column.

Perhaps the most important implication of highly flexible arms is that not all crinoids were permanently attached to the substrate by their stems. Some, like *Agassizocrinus* Owen and Shumard, 1852a, and possibly *Pterotocrinus* Lyon and Casseday, 1859, lost or ceased using their stems for attachment and developed a semi-infaunal life mode. Others retained their stems but used them along with their arms for temporary anchorage and mobility.

*Coiled Stems.*—The small camerate crinoid *Campocrinus* Wachsmuth and Springer, 1897, possessed an unusual bilaterally symmetrical stem (Pl. 8, fig. 17) that is commonly coiled (Pl. 8, fig. 16) and bears abundant long cirri on the inner side. The cirri are arranged in two rows (Pl. 8, figs. 16, 18), forming what appears to be a V-shaped curtain in which the crown is frequently found (Text-fig. 11). The columnals have fulcral ridges and ligament pits that allowed the stem to partially coil and uncoil (Ubaghs, 1978). The cirri and stem, moreover, are commonly larger and more robust than the crown (Pl. 8, figs. 16–19). The stem–crown relationship is uncertain, but the stem most likely protected the crown (Springer, 1926). Breimer and Lane (1978, p. 340) and Broadhead (1981, p. 146) suggested that the stem lay on the substrate and that the crown and delicate proximal stem uncoiled laterally when feeding (Text-fig. 11). Breimer and Lane (1978, p. 340) even suggested that these crinoids could swim short distances, using their cirri as oars. We believe that the curtain of cirri is much lower on the stem than would have been necessary for protection of the crown alone. Some, and at times, all, of the cirri may have been used for anchorage, but the formation of a V-shaped curtain seems to have been the major function of the cirri. The curtain would have formed no matter wheth-

er the stem was in an upright or horizontal position. We suggest that this curtain may have functioned in one of two ways:

1. if the stem were upright and oriented back side into the current, or horizontal and oriented across the current, eddies would have carried food particles into lower velocity regions within the V-shaped curtain of cirri, where they would become trapped; or
2. if a horizontal or upright stem were oriented into the current, the V-shaped curtain may have funneled food-bearing currents toward the crown.

We favor the first possibility because it is closer to the manner in which modern crinoids feed. In either possibility, the very flexible nature of the proximal stem (Pl. 8, figs. 16, 18, 19) would have enabled the small crown to sweep up and down the length of the stem for particles trapped within the curtain. Only in times of danger would the stem and cirri have curled around the crown to protect it (Pl. 8, fig. 16).

*Recumbent Arms.*—The camerate crinoid *Hyrtanecrinus* Broadhead and Strimple, 1980, (Pl. 8, figs. 13, 14) is the only Sloans Valley crinoid with recumbent arms. Because the arms of *Hyrtanecrinus* are also biserial, they were not very flexible, and it is likely that their recumbent position was permanent. The recumbent arms completely surrounded the calyx, and Broadhead (1981) suggested this position was important in protecting the small, delicate calyx. We suggest, however, that this position was probably more instrumental in feeding. The recumbent position exposes the arms and pinnules over most of the calyx on a nearly spherical surface, an arrangement that allows the crinoid to feed from any direction with minimal or no arm reorientation. This arrangement probably became especially useful in environments with changing currents. The underlying calyx, moreover, provided a rigid support for the arms that could prevent their displacement and deformation in all but the strongest currents. Even in environments with no currents, the arms still were well situated to collect the rain of suspended particles from above, especially if they could be flexed outward to some degree.

In addition, *Hyrtanecrinus* had blade-like pinnules that may have articulated like Venetian blinds. This articulation could have enabled pinnules to reorient rapidly in response to changing currents without reorienting the arms.

We view all the above mechanisms as adaptations to maximize the feeding capabilities of small, low-level crinoids.

*Hypertrophied Arms.*—Two of our species, *Agassizocrinus conicus* Owen and Shumard, 1852a, and *Anartiocrinus lyoni* Kirk, 1940a, exhibit hypertrophied arms. In *A. conicus*, one arm in each ray is hypertro-



phied. Ettensohn (1975b) suggested that the shorter arms in this form were probably used as supportive struts to stabilize this stemless crinoid on the substrate, noting that Clark (1921, p. 604) had observed a similar behavior in some stemless comatulids. However, a stabilizing function cannot be assumed for the two hypertrophied arms of *A. lyoni*, for the genus was stemmed (Pl. 4, fig. 10; Text-fig. 20). In *A. lyoni* only the posterior arms of the B and E rays are hypertrophied, and these two arms are not only slightly longer than the others but are at least twice the width as well (Pl. 4, figs. 7-9). The hypertrophied arms are flexed slightly outward at their midpoints and slightly inward above their midpoints, and are twisted posteriorly on the primibrachials, so that they are always outside of the smaller arms and have a lyre-like appearance (Pl. 4, fig. 10). The apparent flexure of the hypertrophied arms is caused by the increased width of brachials at about the midpoint of the arms; from this point, brachials decrease in width both proximally and distally.

Strimple, Frest, and Miller (1977) suggested that the hypertrophied arms had a protective function, and there can be little doubt that this is true. Commonly, the smaller arms are found tightly enclosed within the two larger arms in an apparent protective stance (Pl. 4, fig. 10). We believe, however, that the hypertrophied arms had other, perhaps more important, functions also; these functions were most likely related to feeding. Hyman (1955, p. 42) indicated that certain comatulids develop hypertrophied arms in response to the exocyclic placement of the mouth on the tegmen. In the calceocrinids, hypertrophy of certain arms along with other unusual adaptations, enabled directed feeding in currents, as well as a protective stance when the calyx was recumbent (Brower, 1966).

The common twisting of the two hypertrophied arms in *A. lyoni* to form a planar lyre-like array with the smaller arms suggests that these two arms were flexible. Moreover, we suspect that the lyre-like array (filtration fan) was the normal feeding posture. We suggest that slight movements of the hypertrophied arms may have reoriented the smaller arms into different lyre-like arrays in response to changing current directions. No doubt in a tidally-dominated area, as the sedimentary structures and stratigraphic sequence indicate this area was, current changes were frequent. In these circumstances, the hypertrophied arms could have easily moved to reorient the feeding array or to assume a protective stance.

## SYSTEMATIC PALEONTOLOGY

### INTRODUCTION

Species from six different echinoderm classes are described in the following section. Because most of the

taxa are not new, they are summarized in brief diagnoses. Complete descriptions are provided for all new genera and species. Abbreviations of terms used in this study are listed in Table 6.

In many of the initial studies of this fauna during the late nineteenth and early twentieth centuries, species differentiation was based solely on morphological traits in individual specimens. Hence, each variation commonly was the basis of a new species. We tried to identify the many species of earlier workers, but soon realized that many of these workers lacked the assemblages to which we had access, knew little or nothing of population studies, and did not realize the extent of intraspecific variation. Most of our assemblages exhibited intraspecific variations, some much more so than others. Our concept of a species is based on assemblages of individuals where they were available. As a result, many older morphospecies have been placed in synonymy. In cases where only a few specimens were available, we were forced to rely wholly on the morphological traits of these few specimens and the work of others.

Our synonymies are of the "equivalence" type, but in instances involving citations from authors whom we deem significant to Chesterian echinoderm research, the synonymies may additionally assume a "menu" format.

The quantification of assemblages and variability in our echinoderm taxa has proven to be problematic. We frequently refer to "assemblages" of individual species, but the term is used in a most general way and may refer to a number of specimens ranging from a half dozen to a few hundred. It is impossible to statistically quantify these "assemblages" because of the varied sampling and collecting techniques we have used. Many of our "assemblages" were collected by the authors from spoil piles, the contents of which could only be approximately related to specific stratigraphic horizons, and we are aware of the vagaries in the numbers and types of fossils one can find, depending upon the techniques used and the purposes for which one is collecting. Our only attempt at any type of quantification is the listing of the numbers of specimens of each species from each locality from our collections in Table 1. The catalogue numbers of specimens are presented in the *Materials* section at the end of each species description. Additional uncatalogued materials collected since the inception of this manuscript are not included. Other "assemblages" from some of our localities were examined at the U. S. National Museum, but they are generally old and poorly-labeled collections, obviously subject to some of the same vagaries we experienced. Our use of these collections is noted in the *Remarks* and *Materials* sections of appropriate species descriptions.



Specimen measurements are provided only where we believe that they are truly taxonomically significant. Where not significant, we describe calyx and crown size in comparative terms. The terms "small" or "small-sized" are generally used to describe crowns less than 2.5 cm in height; the term "medium-sized" is used for crowns ranging in height from 2.5 to 5.0 cm; and crowns greater than 5.0 cm in height are generally called "large". Inasmuch as we believe that many of the slight variations in size and shape of plates, parts of organisms, and organisms, that have served as the basis for many older Chesterian echinoderm species are products of ontogenetic or other intraspecific variation, we do not attach much significance to such measurements. Because of these and other justifications cited in the various *Remarks* sections, some of our synonymies may seem unusually long. There is also the considerable problem of quantifying crushed and otherwise variably-preserved specimens. Additional detail on the size, shape, and conditions of specimens and their parts is presented in Chesnut (1980).

#### DESCRIPTIONS

Class **CRINOIDEA** Miller, 1821

Subclass **INADUNATA**

Wachsmuth and Springer, 1885

Order **CLADIDA** Moore and Laudon, 1943

Suborder **POTERIOCRINITINA**

Jaekel, 1918

Superfamily **ZEACRINITACEA**

Bassler and Moodey, 1943

Family **ZEACRINITIDAE**

Moore and Laudon, 1943

Genus **ZEACRINITES** Troost, 1858

*Type species.*—*Z. magnoliaeformis* Troost, 1858.

*Diagnosis.*—Zeacrinid with subcylindrical crown; saucer-shaped cup with wide basal concavity; infra-basals small, largely hidden by stem; narrow uniserial arms, branching endotomously; short pyramidal anal sac; brachials with two pinnules, one on either side.

*Remarks.*—Specimens of *Zeacrinites* examined by us reflect the division of European and American genera (*Parazeacrinites* Burdick and Strimple, 1971, in Europe and *Zeacrinites* in North America) based on pinnulation (Burdick and Strimple, 1971). Although our specimens show a great deal of variability in many other characteristics, pinnulation of the arms appears to be invariable.

No satisfactory criteria have been established for differentiating species within the genus *Zeacrinites*. Sutton and Hagan (1939) thought that the relationship among anal-area plates and the number of primibra-

chials in the A ray (Table 2) were stable features within any species, and were, therefore, suitable for species recognition, but Springer (1926), Wright (1926, 1952), and Horowitz (1965) found considerable variation in these plate groups. Horowitz (1965) counted the number of secundibrachials to see if they showed less variation, but found consistency in only one species, *Z. doverensis* (Miller and Gurley, 1896), in which only one specimen was compared with the type. Therefore, he concluded that this measurement (Table 3) also was of limited value. He assigned some of his specimens to established species, first on the arrangement of anal-area plates, and second on the number of primibrachials in the anterior ray (Table 2). He also recognized five additional species, but did not name them, because definitive characteristics for species of *Zeacrinites* needed study based on larger collections.

Our studies of *Zeacrinites* assemblages from the lower Pennington Formation indicate a highly variable species. Like Burdick and Strimple (1971), we found criteria such as anal-plate arrangement and number of primibrachials to be highly variable traits in any one assemblage. The only definitive trait in our assemblages and in forms that proved to be different species was the size and shape of the basals; this is the characteristic we use to differentiate the species of *Zeacrinites*. This method has resulted in placing many previously-described species in synonymy with the two species discussed below.

#### *Zeacrinites wortheni* (Hall, 1858)

Plate 1, figures 1–4; Tables 2, 3

1858. *Zeacrinus wortheni* Hall, p. 683, text-fig. 111.

1860. *Zeacrinus bifurcatus* McChesney, p. 9.

1860. *Zeacrinus ovalis* Lyon and Casseday, p. 71.

1865. *Zeacrinus bifurcatus* McChesney. McChesney, pl. 5, fig. 3.

1867. *Zeacrinus bifurcatus* McChesney. McChesney, p. 6, pl. 5, fig. 5.

1894. *Zeacrinus grandiculus* Miller and Gurley, p. 32, pl. 2, figs. 31, 32.

1894. *Zeacrinus obesus* Miller and Gurley, p. 35, pl. 4, figs. 6–8.

1896. *Zeacrinus peculiaris* Miller and Gurley, p. 34, pl. 2, figs. 17–19.

1896. *Zeacrinus doverensis* Miller and Gurley, p. 35, p. 2, figs. 20–22.

1896. *Zeacrinus kentuckiensis* Miller and Gurley, p. 37, pl. 2, figs. 23, 24.

1926. *Zeacrinus wortheni* Hall. Springer, pp. 65, 81, 83; pl. 22, fig. 12; pl. 23, figs. 1–8; text-figs. 6–9.

1931. *Zeacrinus chesterensis* Sutton and Wagner, p. 31, pl. 5, figs. 12–14, text-fig. 1.

1939. *Zeacrinus lanceolatus* Sutton and Hagan, p. 87, pl. 15, figs. 11–13, text-fig. 2.

1939. *Zeacrinus trapeziatus* Sutton and Hagan, p. 88, pl. 15, figs. 15–17, text-fig. 3.

1939. *Zeacrinus lineatus* Sutton and Hagan, p. 89, pl. 15, figs. 7, 8, text-fig. 4.

1939. *Zeacrinus acuminatus* Sutton and Hagan, p. 90, pl. 1, figs. 4–6, text-fig. 3.



Table 2.—Anal areas in holotypes of species of *Zeacrinites*.

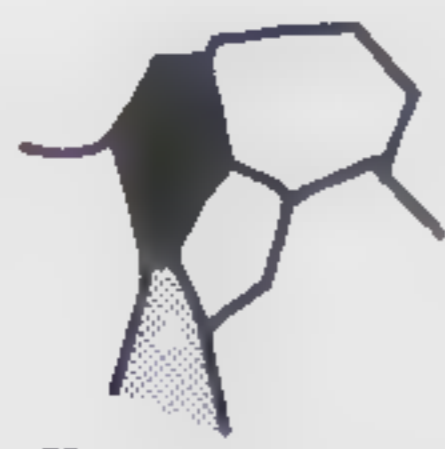


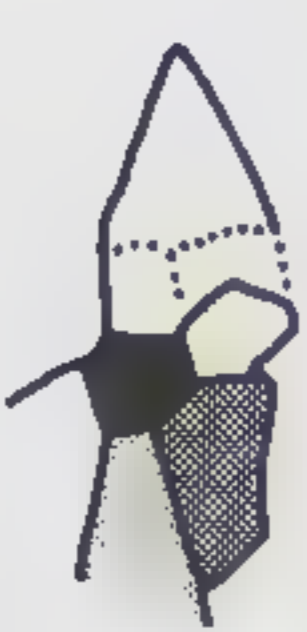















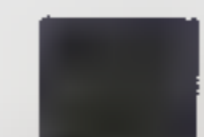
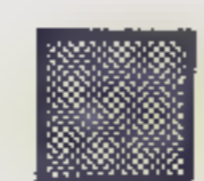



	CD BASAL TOUCHING ANAL X	CD BASAL NOT TOUCHING ANAL X		
TWO ANTERIOR PRIMIBRACHIALS	 <i>Z. sp. C</i> Horowitz	 <i>Z. sp. D</i> Horowitz	 <i>Z. sp. E</i> Horowitz	
	 <i>Z. kentuckiensis</i> (Miller & Gurley)	 <i>Z. grandiculus</i> (Miller & Gurley)	 <i>Z. trapeziatus</i> (Sutton & Hagan)	
	 <i>Z. acuminatus</i> (Sutton & Hagan)	 <i>Z. ovalis</i> (Lyon & Casseday)	 <i>Z. lanceolatus</i> (Sutton & Hagan)	
			 <i>Z. lineatus</i> (Sutton & Hagan)	
			 <i>Z. sp. B</i> Horowitz	
			 <i>Z. peculiaris</i> (Miller & Gurley)	
			 (variable) <i>Z. magnoliaeformis</i> Troost	
	THREE ANTERIOR PRIMIBRACHIALS	 <i>Z. brevilatus</i> (Sutton & Hagan)	 <i>Z. chesterensis</i> (Sutton & Hagan)	 <i>Z. sp. A</i> Horowitz
		 <i>Z. doverensis</i> (Miller & Gurley)	 <i>Z. fusiformis</i> (Sutton & Hagan)	 <i>Z. obesus</i> (Miller & Gurley)
			 ANAL X	
			 RADIANAL	
			 POSTERIOR BASAL	
			 <i>Z. bifurcatus</i> (McChesney)	
		 <i>Z. wortheni</i> (Hall)		



Table 3.—Numbers of secundibrachials in the holotypes of species of *Zeacrinites*. A-E = rays; R. = right; L. = left; Ant. = anterior; Post. = posterior.

	C		B		A		E		D	
	Post.	Ant.	Post.	Ant.	R.	L.	Ant.	Post.	Ant.	Post.
<i>Z. acuminatus</i>	6?	3-4?	3?	4	?	4	4	?	-	-
<i>Z. brevilatus</i>	4	4	4	4	6	6	4	4?	4	4
<i>Z. bifurcatus</i>	?	?	4	5	5	5	?	?	4	?
<i>Z. chesterensis</i>	4	3	5	4	4?	4?	4	4	6	4
<i>Z. doverensis</i>	4	4	4	4	4	4	4	3	4	3
<i>Z. fusiformis</i>	4	?	?	?	7	6	3	5?	?	5
<i>Z. grandiculus</i>	4	4?	4?	5?	6	6	4	3	4	4
<i>Z. kentuckiensis</i>	3	3?	3	4	3	3	3	3	4?	3?
<i>Z. lanceolatus</i>	4	4	3	4	4	4	4	4	4	4
<i>Z. lineatus</i>	4	4	4	4	4	4	4?	3?	4	4
<i>Z. magnoliaeformis</i>	4	4	3	4	4	4	4	-	-	-
<i>Z. obesus</i>	4	4	5	4	4-5?	4-5?	4?	4?	4	4
<i>Z. ovalis</i>	4	4	4	4	3	3	4	4	4	4
<i>Z. peculiaris</i>	3	4	3	4	4	4	4	3	5	3
<i>Z. trapeziatus</i>	6?	-	3?	4	7	6?	5?	-	-	-
<i>Z. wortheni</i>	-	3+	4	4	4	3	4	4	4	3
<i>Z. sp.A</i> Horowitz	4	4	3	5	5	4	2	4	3?	3
<i>Z. sp.B</i> Horowitz	4	3	3	4	4	5	4	3	4	3
<i>Z. sp.C</i> Horowitz	-	-	4	3	4	4	4	4	4	3
<i>Z. sp.D</i> Horowitz	1+	1+	3	1+	4	3	3	2	3	3
<i>Z. sp.E</i> Horowitz	-	-	-	-	3	3	4	4	4	3

1939. *Zeacrinus fusiformis* Sutton and Hagan, p. 91, pl. 15, figs. 9, 10, text-fig. 7.

1939. *Zeacrinus brevilatus* Sutton and Hagan, p. 92, pl. 15, figs. 1-3, text-fig. 8.

1944. *Zeacrinites wortheni* (Hall). Moore and Laudon, in Shimer and Shrock, p. 163, pl. 61, figs. 2a, b.

1965. *Zeacrinites wortheni* (Hall). Horowitz, pp. 17-19, pl. 1, figs. 6-8, 15, 19, text-figs. 2B, C.

1965. *Zeacrinites trapeziatus* (Sutton and Hagan). Horowitz, pp. 16, 17, pl. 1, figs. 3-5, text-fig. 2D.

1965. *Zeacrinites doverensis* (Miller and Gurley). Horowitz, p. 19, pl. 1, figs. 16-18, text-fig. 2A.

1965. *Zeacrinites* sp. A. Horowitz, pp. 19, 20, pl. 1, figs. 1, 2, text-fig. 2F.

1965. *Zeacrinites* sp. B. Horowitz, p. 20, pl. 1, figs. 9-11, text-fig. 2E.

1965. *Zeacrinites* sp. C. Horowitz, pp. 20, 21, pl. 1, figs. 12, 13, text-fig. 2G.

1965. *Zeacrinites* sp. D. Horowitz, p. 21, pl. 1, fig. 14, text-fig. 2H.

1965. *Zeacrinites* sp. E. Horowitz, pp. 21, 22, pl. 2, figs. 1, 2.

*Diagnosis.*—*Zeacrinites* with relatively short **BB**, moderately narrow anal area, and medium-size crown.

*Remarks.*—Upon comparison of our collection with



that at the U. S. National Museum, we observed great variation within assemblages from the same locality. The number of anterior primibrachials vary from one to three. Anal areas show extreme variability; some anal plates make contact with the posterior basal, whereas others do not, and many different arrangements of the anal plates can be observed. Most basals are short enough that they do not extend beyond the basal concavity, and hence, are not visible in lateral views of the cup. In some individuals, however, one or more of the basals are large enough that they extend beyond the basal concavity and may be slightly visible in lateral view. Moreover, some very unusual variations in the size, number, and arrangement of the above plates also occur. For example, we observed one specimen (USNM S-2690) with three anterior primibrachials (the axillary being narrower than the rest, thus allowing the bottom secundibrachials to touch the second primibrachial); the left anterior (E) ray contained two primibrachials (the C, B, and D rays contained one each as usual); and tegminal plates were exposed in life between the E and D ray and between the E and B ray.

We believe that these types of variations are intraspecific, and that all the specimens from this unit represent one species. Examination of our collection, specimens from the U. S. National Museum, and descriptions and illustrations in the literature indicates that most species of *Zeacrinites* differ from each other only in these variable features and are not otherwise different.

For example, variations in anal-plate arrangement and in the number of primibrachials on specimens in our collections would necessitate at least four different species, *Z. acuminatus* (Sutton and Hagan, 1939), *Z. lanceolatus* (Sutton and Hagan, 1939), *Z. peculiaris* (Miller and Gurley, 1896), *Z. trapeziatus* (Sutton and Hagan, 1939), and three other variants not assignable to any existing species (Chesnut, 1980). Moreover, other workers have reported additional species variants, *Z. brevilatus* (Sutton and Hagan, 1939), *Z. kentuckiensis* (Miller and Gurley, 1896), *Z. lineatus* (Sutton and Hagan, 1939), and *Z. wortheni* (Hall, 1858) from locality 1 (Bassler and Moodey, 1943). Based on these variable characteristics, we therefore place in synonymy with *Z. wortheni* these and other similar late Chesterian species: *Z. acuminatus* (Sutton and Hagan, 1939), *Z. bifurcatus* (McChesney, 1860), *Z. brevilatus* (Sutton and Hagan, 1939), *Z. chesterensis* (Sutton and Wagner, 1931), *Z. doverensis* (Miller and Gurley, 1896), *Z. fusiformis* (Sutton and Hagan, 1939), *Z. grandiculus* (Miller and Gurley, 1894), *Z. kentuckiensis* (Miller and Gurley, 1896), *Z. lanceolatus* (Sutton and Hagan, 1939), *Z. lineatus* (Sutton and Hagan, 1939), *Z. obesus* (Miller and Gurley, 1894), *Z. ovalis* (Lyon and Casseday, 1860),

*Z. peculiaris* (Miller and Gurley, 1896), *Z. trapeziatus* (Sutton and Hagan, 1939), and Horowitz's (1965) five informal species.

Only one other Chesterian species, *Z. magnoliaeformis* Troost (*in* Hall, 1858), remains. The differences we find between *Z. magnoliaeformis* and *Z. wortheni* are essentially the same as those noted by Springer (1926). *Z. magnoliaeformis* is generally a larger form with a wider anal area and larger basals. The basals are perhaps the most diagnostic character. All basals are generally large enough to be seen in side view, and the larger C-D basal is typically lanceolate to rectangular. In contrast, *Z. wortheni* is commonly smaller, has a narrower anal area, and has smaller basals that usually cannot be seen in side view (Pl. 1, figs. 1, 2, 4). The larger C-D basal, however, is relatively shorter and has a squat, angular form compared to the same plate in *Z. magnoliaeformis*. *Z. magnoliaeformis* may have some biostratigraphic value, because it appears to be restricted to the Gasperian, whereas *Z. wortheni* apparently occurs throughout the entire Chesterian. Burdick and Strimple (1971, p. 22) reported forms characteristic of *Z. magnoliaeformis* from the Gasperian, transitional forms in the lower Hombergian (Golconda), and forms characteristic of *Z. wortheni* from the upper Hombergian (Glen Dean). However, forms characteristic of *Z. wortheni* by our definition have also been reported from the Gasperian (Sutton and Hagan, 1939). It is difficult to determine which of the species was the evolutionary precursor of the other, but the presence of transitional forms suggests a close relationship.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 1-3, 5, 6.

*Material.*—UK 2901, 115591-115622, 116069, and many specimens under one number (USNM S-2690) in the Springer Collection, U. S. National Museum. UK 115612, 115603, 115614, and one specimen from USNM S-2690 are hypotypes in this paper.

#### Genus **BICIDIOCRINUS** Strimple, 1975b

*Type species.*—*Hydreionocrinus wetherbyi* Wachsmuth and Springer, 1886.

*Diagnosis.*—Zeacrinid with narrow basal invagination; **Brr** usually biserial, branching endotomously; terminal anal disc of six to seven, subhorizontal, spinose plates joined at their bases.

*Remarks.*—*Bicidiocrinus*, compared to *Tholocrinus* Kirk, 1939, has a rounder, more compact cup (Pl. 1, figs. 5, 6), and a narrower basal invagination. *Bicidiocrinus* contains only spine-bearing plates in the terminal anal disc, has only one primibrachial in the anterior ray, and has a round stem with nodes and internodes. *Tholocrinus* has a cup that is somewhat saucer-shaped (Pl. 1, figs. 7, 8) with a broad basal in-



vagination; the arms bifurcate more frequently, and there are several primibrachials in the anterior ray. *Tholocrinus* has a terminal anal disc composed of small plates surrounded by spines (Pl. 1, fig. 9), and has a pentagonal stem. *Dasciocrinus* Kirk, 1939 has a longer crown, uniserial arms, and fewer spines on the terminal anal disc (Pl. 2, figs. 1-4).

**Bicidiocrinus wetherbyi**  
(Wachsmuth and Springer, 1886)  
Plate 1, figures 5, 6

1881. *Hydreionocrinus depressus* Wetherby, pp. 325-328(partim), pl. 9, fig. 4, non pl. 9, figs. 1-3, 6.  
1881. *Hydreionocrinus armiger* (Meek and Worthen). Wetherby, p. 328, pl. 9, figs. 5, 7-11.  
1886. *Hydreionocrinus wetherbyi* Wachsmuth and Springer, p. 245.  
1926. *Hydreionocrinus wetherbyi* Wachsmuth and Springer. Springer, p. 89, pl. 25, figs. 4-12.  
1939. *Tholocrinus wetherbyi* (Wachsmuth and Springer). Kirk, p. 471.  
1975b. *Bicidiocrinus wetherbyi* (Wachsmuth and Springer). Strimple, pl. 1, figs. 7, 11.

*Diagnosis.*—One **IBr** per ray.

*Remarks.*—The holotype is from the "Glen Dean" (almost certainly the Sloans Valley member of the Pennington Formation) at Sloans Valley, Pulaski County, Kentucky. Many of our specimens exhibit six to 10 secundibrachials (Pl. 1, figs. 5, 6). The lowermost secundibrachials are uniserial, but the rest are biserial. Some specimens exhibit spiny axillaries at all levels, whereas others exhibit only spiny primibrachials. Six to eight spines commonly occur on the terminal anal disc; other disc plates are absent.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 3, 5.

*Material.*—UK 115623-115635, 116068, 116074, and specimens in the Springer Collection, U. S. National Museum. UK 115625 is a hypotype in this paper, whereas UK 115623-115626 and 115630-115632 are topotypes.

Genus **THOLOCRINUS** Kirk, 1939

*Type Species.*—*Hydreionocrinus spinosus* Wood, 1909.

*Diagnosis.*—Zecrinitid with deep, broad basal invagination; one **IBr** in all rays except the anterior which has several; **Brr** biserial; arms branch endotomously; terminal anal disc composed of polygonal plates surrounded by horizontally-projecting spines (Pl. 1, fig. 9).

*Remarks.*—For comparisons with other genera, see *Remarks* under *Bicidiocrinus*.

**Tholocrinus spinosus** (Wood, 1909)  
Plate 1, figures 7-9

1881. *Hydreionocrinus depressus* Wetherby, pp. 325-328(partim), pl. 9, figs. 1-3, 6.  
1909. *Hydreionocrinus spinosus* Wood, p. 93.  
1926. *Hydreionocrinus depressus* Wetherby. Springer, 1926, pp. 89, 90, pl. 26, figs. 1-12.  
1938. *Xystocrinus depressus* Moore and Plummer, p. 269(partim), fig. 21.  
1939. *Tholocrinus spinosus* (Wood). Kirk, p. 471.  
1965. *Tholocrinus spinosus* (Wood). Horowitz, p. 2, pl. 2, figs. 5-10.  
1975b. *Tholocrinus spinosus* (Wood). Strimple, pl. 1, figs. 8, 10, 12-14.

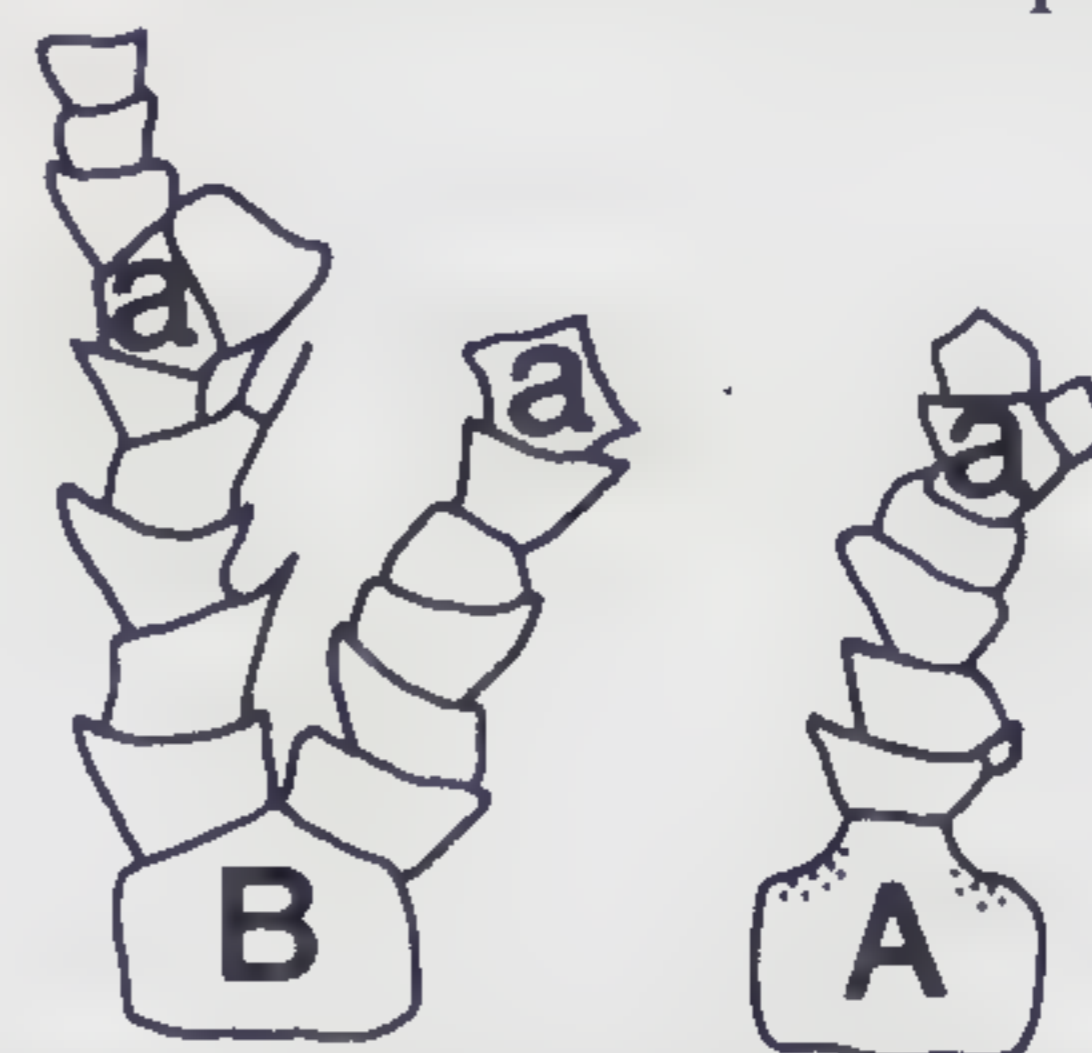
*Diagnosis.*—Lacks pits at apices of **BB** and **RR**; no respiratory slits are present in anal disc; most spine plates in terminal anal disc are in contact.

*Remarks.*—*Tholocrinus unionensis* Strimple, 1975b, has a shallower dorsal cup and more tumid plates with impressed sutures. Respiratory slits are absent in the anal disc of *T. spinosus* (Wood, 1909), and most of the spines are in contact, whereas *T. unionensis* has respiratory slits and an anal disc in which many of the spine plates are not in contact with each other. *T. foveatus* Strimple, 1951b, has small pits at the apices of the basals and radials, and has a broad, flat base. According to Strimple (1975b), *T. armiger* (Meek and Worthen, 1870) probably is conspecific with *Bicidiocrinus wetherbyi*. *T. discus* Strimple, 1975b, has a taller crown and a much smaller terminal anal disc with fewer spines than does *T. spinosus*. In contrast to *T. spinosus*, which has wholly biserial arms, some segments in the arms of *T. discus* are uniserial.

The holotype of *Tholocrinus spinosus* is from the "Glen Dean" at Sloans Valley, Pulaski County, Kentucky (almost certainly the Sloans Valley member of the Pennington Formation). Four to six anterior primibrachials were observed in our specimens, indicating some variability in this character. The only specimen with a completely preserved anal disc (UK 115641) exhibits seven spines and 14 enclosed plates in the terminal anal disc.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 1, 3, 5.

*Material.*—UK 115638-115644, 115646-115654, USNM 401444. UK 115641 and USNM 401444 are hypotypes in this paper, and UK 115637, 115642-115654, and USNM 401444 are topotypes.



Text-figure 19.—"Zig-zag" arms in *Linocrinus laurelensis*, n. sp. A = Anterior ray; B = right anterior ray; a = axillary brachial.



Genus **LINOCRINUS** Kirk, 1938

*Type species.*—*Linocrinus wachsmuthi* Kirk, 1938.

*Diagnosis.*—Subcylindrical crown; saucer-shaped cup with wide basal invagination; three anal plates in cup; anal sac coiled; cup plates usually rugose; one **IBr** in all rays except the anterior, which has three to six; **IBrr** keeled vertically; uniserial arms, in most species tending to branch endotomously, except anterior ray, which branches isotomously.

**Linocrinus laurelensis**, new species

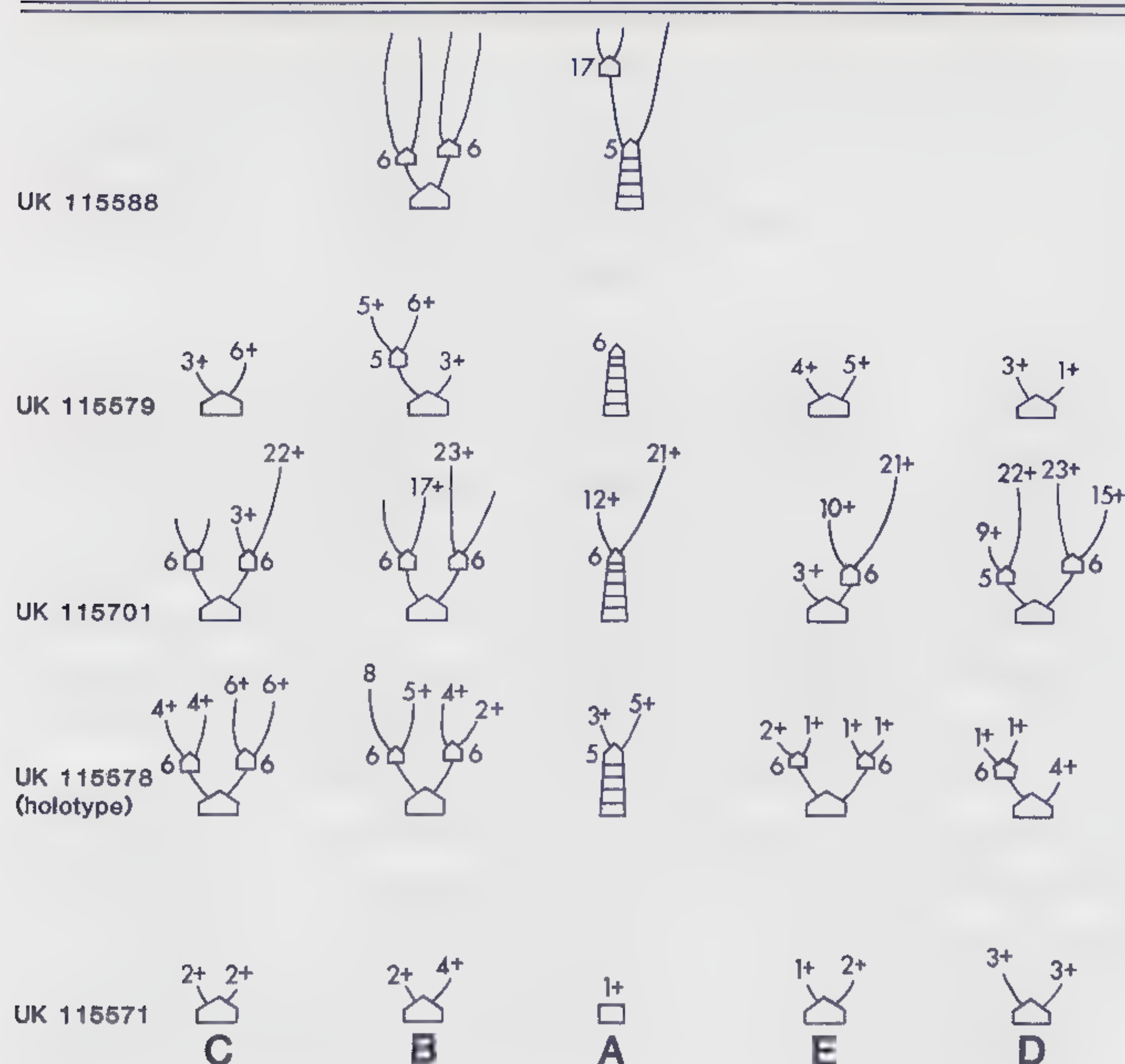
Plate 1, figures 10–15; Table 4; Text-figure 19

*Etymology of Name.*—The species name is derived from the county in which most of the specimens were found.

*Diagnosis.*—Cup ornamented by converging ridges; anterior ray has five to six **IBrr**; peculiar, conical **Brr** (Text-fig. 9) alternately skewed to left, then right; arms branch isotomously.

*Description.*—The crown is small (23 mm in height in the two complete crowns), with a basin-shaped dorsal cup ranging from 5 to 6.5 mm in diameter; plates in cup ornamented by converging ridges that run from plate to plate; depressions are present at triple-plate junctions. Stem is round and columnals have cuneate edges; nodes and internodes are not apparent; column does not fill the basal invagination. **RR** are low and wide, and ornamented like the rest of cup; superior facets occupy full width of **R** and exhibit gaping contact with the **IBrr**. One **IBr** per ray except in anterior ray, which has five to six; axillary **IBrr** are wider than they are high and are ornamented by three converging ridges;

Table 4.—Arm structure of *Linocrinus laurelensis*, n. sp. Numbers of brachials in each branch are indicated. The A ray is anterior.



two lesser ridges from plate corners meet a stronger vertical ridge at plate center; the stronger vertical ridges give a keeled appearance to **IBrr**. In anterior ray, only **IBr1** has the keeled ornamentation; this **IBr** is subequal in size to the other **IBrr**, but is slightly higher; the superior facet forms the narrowest part of the **IBr1**. Remaining anterior **IBrr** (**IBr2–IBr6**) and the **IIBrr** of the other rays are very peculiarly shaped (Text-fig. 19); these brachials have the appearance of inverted, truncated cones with concave superior surfaces in which the succeeding cones lie (the narrow part of the brachial being proximal); in addition, cones are alternately skewed to the left and right to provide more than enough room for the alternating pinnules. Pinnules are composed of stout, cylindrical ossicles with heights approximately equal to heights of the **Brr**; pinnules, 5 to 8 mm in length, are fairly long relative to the overall size of the small crinoid crown. Most rays, except the anterior ray, divide on the sixth **IIBr**; some divide on the fifth **IIBr**; anterior ray may or may not divide again in the **IIBrr** (Table 4). In one specimen (UK 115588, Table 4), the seventeenth or eighteenth anterior **IIBr** is axillary, whereas the other arm is undivided. **IIIBrr** in all rays are cuneate and do not display the cone structure as much as the **IBrr** and the **IIBrr**. Approximately 18 to 20 arms occur in each crown. Arrangement of anal plates is typical of other species of *Linocrinus*; anal plates slightly rugose with depressions at triple-plate junctions. One specimen (UK 115571) exhibits an anal sac that is probably recurved toward the posterior; distal surface of sac is 8 mm above top of **RR** and just above the axillary anterior **IBr**; anal sac is composed of small, pustulose, hexagonal plates arranged in irregular linear rows; pores may be present midway along double-plate boundaries.

*Remarks.*—No other species of *Linocrinus* has the peculiarly-shaped brachials of this species. Other species with keeled primibrachials include: *L. scobina* (Meek and Worthen, 1869), *L. praemorus* (Miller and Gurley, 1890b), *L. wachsmuthi* Kirk, 1938, *L. arboreus* (Worthen, 1873), *L. cariniferous* (Worthen, 1873), *L. faculensis* (Laudon, Parks, and Spreng, 1952), and *L. lautus* (Miller and Gurley, 1896). Of these, *L. scobina* has 11 anterior primibrachials; *L. cariniferous* has nine; *L. praemorus*, *L. wachsmuthi*, *L. arboreus*, and *L. lautus* have five each; and *L. faculensis* has four primibrachials in the anterior ray. *L. laurelensis*, n. sp. has five to six anterior primibrachials (the holotype has five). The arms of *L. laurelensis* branch isotomously; the arms of other species tend to branch endotomously. Although *L. laurelensis* is distinctly different, we believe that many of the above species of *Linocrinus* are conspecific. The number of A-ray primibrachials is probably a highly variable character in any one species



(Table 4). However, because none of the other species occur in the studied unit, revision of these species was beyond the scope of this study.

*Occurrence.*—Upper Mississippian (Middle Chesterian). Localities 3, 5.

*Material.*—UK 115571–115572, 115578–115579, 115588, 115701, and 115578 (holotype). UK 11571, 115572, 115578, 115579, and 115588 are topotypes, and UK 115571, 115588, and 115701 are hypotypes in this paper.

### Superfamily PIRASOCRINACEA

Moore and Laudon, 1943

### Family PIRASOCRINIDAE

Moore and Laudon, 1943

### Genus DASCIOCRINUS Kirk, 1939

*Type species.*—*Cyathocrinus floralis* Yandell and Shumard, 1847.

*Diagnosis.*—Round stem with nodes and internodes; elongate, subcylindrical crown; low, saucer- to bowl-shaped dorsal cup with small basal invagination; **IBB** small, included in basal invagination; triple-plate junctions of **BB** and **RR** may be strongly impressed; anal sac extends to tip of arms or beyond arms and is terminated by a disc of subhorizontal to upward-projecting spines, united at their bases; arms uniserial, branching isotomously about three times.

#### *Dasciocrinus floralis*

(Yandell and Shumard, 1847)

Plate 2, figures 1–4

1847. *Cyathocrinus floralis* Yandell and Shumard, p. 24, 1 pl., fig. 1.  
 1852a. *Poteriocrinus spinosus* Owen and Shumard, p. 91, pl. 11, fig. 4.  
 1852b. *Poteriocrinus spinosus* Owen and Shumard. Owen and Shumard, p. 596, pl. 56, fig. 4.  
 1855. *Poteriocrinus florealis* Shumard, p. 217.  
 1880. *Scaphiocrinus spinifer* Wetherby, p. 157 (14), pl. 5, fig. 5.  
 1920. *Pachylocrinus cachensis* Weller, p. 343, pl. 8, fig. 35.  
 1939. *Dasciocrinus floralis* (Yandell and Shumard). Kirk, p. 472.  
 1939. *Dasciocrinus spinosus* (Owen and Shumard). Kirk, p. 472.  
 1939. *Dasciocrinus spinifer* (Wetherby). Kirk, p. 472.  
 1943. *Pachylocrinus cachensis* Weller. Bassler and Moodey, p. 404.  
 1963. *Dasciocrinus aulicus* Strimple, pp. 101–106, text-figs. 1–4, pl. 1, figs. 8, 9.  
 1975b. *Dasciocrinus spinifer* (Wetherby). Strimple, pp. 6, 7, pl. 2, figs. 1, 2.

*Diagnosis.*—One **IBr** per ray; axillaries spinose.

*Remarks.*—According to Strimple (1975b), the differentiation of species in *Dasciocrinus* largely has been based on the number of secundibrachials, although other characters like relative crown–spine length, smoothness of calyx plates, and the shape of brachials (Weller, 1920; Strimple, 1963) have also been used. We believe that these characters do not make useful

taxobases and that the small variations in these characteristics, on which the five current species are based, are intraspecific in nature. In fact, two of the species, *D. floralis* (Yandell and Shumard, 1847) and *D. spinosus* (Owen and Shumard, 1852a), come from the same locality and may represent different names for the same specimen (Strimple, 1975b). A third species, *D. spinifer* (Wetherby, 1880), comes from the same stratigraphic horizon (Glen Dean equivalent) as the previous two. Regarding the other two species, *D. cachensis* (Weller, 1920) and *D. aulicus* Strimple, 1963 (older and younger, respectively, than the previous three species), Strimple (1963) stated:

Stratigraphically, *D. aulicus* is the youngest known species of the genus and there does not appear to be any significant advancement in characters as compared with those of the oldest known species, *D. cachensis*, from the Paint Creek Formation of Illinois.

His statement summarizes our observations. We deem the slight differences in spine length, number of secundibrachials, and smoothness of cup to be insignificant in terms of species discrimination. For these reasons we have placed the four subsequently-described species in synonymy with *D. floralis*.

In our small collection of 11 specimens, the number of secundibrachials ranges from six to nine, and our specimens are generally shorter than those previously assigned to *D. floralis*. Apparently, the number of secundibrachials and crown height were highly variable characters in this species, although in any one population, these characters may have been more or less stable. Except for these variable traits, our specimens are nearly identical to *D. floralis* and the four other previously-described species.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 3, 5.

*Material.*—UK 115655–115664, 115932. UK 115657 and 115663 are hypotypes in this paper.

### Superfamily TEXACRINACEA

Strimple, 1961

### Family CYMBOCRINIDAE

Strimple and Watkins, 1969

### Genus CYMBOCRINUS Kirk, 1944b

*Type species.*—*Cymbiocrinus grandis* Kirk, 1944b.

*Diagnosis.*—Cymbiocrinid with shallow, saucer-shaped cup; large **RA** in posterior position with two tube plates above; two **IBrr** per ray, constricted laterally at junction; arms short, uniserial.

*Remarks.*—*Cymbiocrinus* is similar to *Ampelocrinus* Kirk, 1942b except that *Ampelocrinus* has laterally visible infrabasals and long arms. *Cymbiocrinus* has a dorsal cup with an invaginated base in which the infrabasals are not visible from the side; the arms are also shorter and stouter.



**Cymbiocrinus grandis** Kirk, 1944

Plate 2, figures 5–8

- 1944b. *Cymbiocrinus grandis* Kirk, p. 238, pl. 1, figs. 6, 7, 10.  
 1944b. *Cymbiocrinus lyoni* Kirk, p. 240, pl. 1, figs. 11, 12.  
 1944b. *Cymbiocrinus romingeri* Kirk, p. 241, pl. 1, figs. 1–4, 8, 9.  
 1944b. *Cymbiocrinus tumidus* Kirk, p. 243, pl. 1, figs. 13, 14.

*Diagnosis.*—Small to medium-sized species; round stem; **Brr** cuneate; first **IIBr** does not make contact along the entire lateral edge of the first **IBr**.

*Remarks.*—The type specimens of *C. grandis* Kirk, 1944b, and *C. tumidus* Kirk, 1944b, both of which are from Sloans Valley, appear to represent the same species. Kirk (1944b) differentiated *C. grandis* from *C. tumidus* by the less tumid nature of its plates, its cuneiform brachials, and its larger, stouter appearance. Examination of the type material revealed that the basal plates of *C. grandis* were so severely eroded during preparation that any tumidity could not be ascertained. The larger size and stout appearance may simply be related to maturity. The type specimen of *C. tumidus* has slightly cuneiform brachials, whereas the brachials of *C. grandis* are very cuneiform throughout. In contrast, our specimens exhibit the smaller size and tumid basals of *C. tumidus*, but also have the very cuneiform brachials of *C. grandis*. Based on these specimens, we suggest that forms with the characters of *C. tumidus* may represent juveniles, whereas those with the characters of *C. grandis* represent adults; the brachials apparently become more cuneiform with age.

The holotype of *C. lyoni* Kirk, 1944b (USNM S-4430), differs from our specimens only in the smaller, less conspicuous basals. We believe that this species and its holotype merely reflect intraspecific variation within *C. grandis*. Kirk's (1944b) paratype for *C. lyoni* (USNM S-4430a), however, is from the Glen Dean Limestone of Grayson Springs, Kentucky, and belongs to the genus *Aenigmocrinus* Strimple, 1973b.

Kirk's (1944b) diagnostic characters for *C. romingeri* Kirk, 1944b, are well within the limits of variation for his other described species. Even though *C. romingeri* probably occurs in rocks (Ste. Genevieve Fm.?) older than those in which the Chesterian species described above was found, the form is indistinguishable from them except for its generally smaller size. However, even some of our specimens have a comparable size. Only *C. dactylus* (Hall, 1860), an older species from the St. Louis Fm., is smaller; but *C. dactylus* is more delicately constructed and consistently has relatively higher primibrachials. We therefore place *C. grandis*, *C. tumidus*, *C. lyoni*, and *C. romingeri* in synonymy with *C. grandis* Kirk, which has page priority, and suggest that *C. dactylus* may be ancestral to this and other species of *Cymbiocrinus*.

The two remaining species of the genus, *C. gravis*

Strimple, 1951b, and *C. pitkini* Strimple, 1955, are distinctly different. *C. pitkini* has only rectangular brachials, and in *C. gravis* the first secundibrachial is in contact with the complete lateral edge of the first and second primibrachials; both characters are unknown in *C. grandis*.

Some of our specimens show well-preserved or unusual characters not previously noted in *Cymbiocrinus*. One specimen (UK 115671), for example, shows that the stem was considerably smaller than the basal invagination and had cirri (Pl. 2, fig. 8). Other specimens (e.g., UK 115670; Pl. 2, figs. 5, 6) exhibit distinct invaginations at triple-plate junctions, and one aberrant specimen (UK 115675) exhibits only four basals and four arm-bearing radials.

The stem is very slender compared to the size of the dorsal cup, filling only a small portion of the basal invagination (Pl. 2, figs. 6–8), and not obscuring the infrabasals. The arms of these specimens converge just above the dorsal cup so that at mid-crown the diameter of the crown may only be two-thirds of the cup diameter.

*Occurrence.*—Upper Mississippian (Meramecian?, Chesterian). Localities 3, 5.

*Material.*—UK 115665–115677, 115933; UK 115666, 115667, 115669, and 115672–115677 are topotypes. USNM S-4433 (holotype of *C. grandis*), USNM S-4430 (holotype of *C. lyoni*), USNM 110708 (holotype of *C. romingeri*), and USNM S-4431 (holotype of *C. tumidus*), as well as UK 115670 and 115671 are hypotypes in this paper.

**Genus AENIGMOCRINUS** Strimple, 1973b

*Type species.*—*Poteriocrinus anomalos* Wetherby, 1880.

*Diagnosis.*—Small, compact crown; stem round with minor nodes and internodes; shallow, saucer-shaped cup with invagination in a broad base; CD basal large, almost reaching top of dorsal cup and supporting two equidimensional anal plates; **RR** are only cup plates visible from side, except for CD basal; anal sac recurved with large flattened spines at summit; nine to 10 arms converge distally through a short distance, two per ray except anterior, which may have one or two; second **IBr** is axillary in all rays except anterior, which may branch on the sixth or seventh **IBr** if it branches at all.

**Aenigmocrinus anomalos** (Wetherby, 1880)

Plate 2, figures 9, 10; Text-figure 20

1880. *Poteriocrinus anomalos* Wetherby, p. 158, pl. 5, figs. 6, 6a, 6b.  
 1886. *Poteriocrinus anomalos* Wetherby. Wachsmuth and Springer, p. 234.  
 1944b. *Cymbiocrinus anomalos* (Wetherby). Kirk, p. 236, pl. 1, fig. 5.



1944b. *Cymbiocrinus lyoni* Kirk, pp. 240–241 (*partim*), pl. 1, fig. 12, *non* pl. 1, fig. 11.

1973b. *Aenigmocrinus anomalos* (Wetherby). Strimple, fig. 10 (1–7).

**Diagnosis.**—First **IBr** is anvil- or ingot-shaped; many lower **Brr** are medially constricted, cuneate.

**Remarks.**—The holotype, two other specimens from Wetherby's collection, and two from the Springer collection came from the "Glen Dean" Formation at Sloans Valley, Pulaski County, Kentucky (almost certainly from the Sloans Valley member). Strimple (1973b) listed four specimens from the Fraileys or Haney Formation in Union County, Illinois. Three of these had unbranched anterior rays; one branched on the sixth primibrachial.

The number of primibrachials in the anterior ray is apparently a highly variable trait, and our specimens also show this kind of variation. One of our specimens (UK 115680) also demonstrates the nature of the stem, which is round (1 mm in diameter) and composed of small nodals and internodals.

**Occurrence.**—Upper Mississippian (Chesterian). Locality 3.

**Material.**—UK 115678–115681, all topotypes. UK 115681 is a hypotype in this paper.

#### Superfamily SCYTALOCRINACEA

Moore and Laudon, 1943

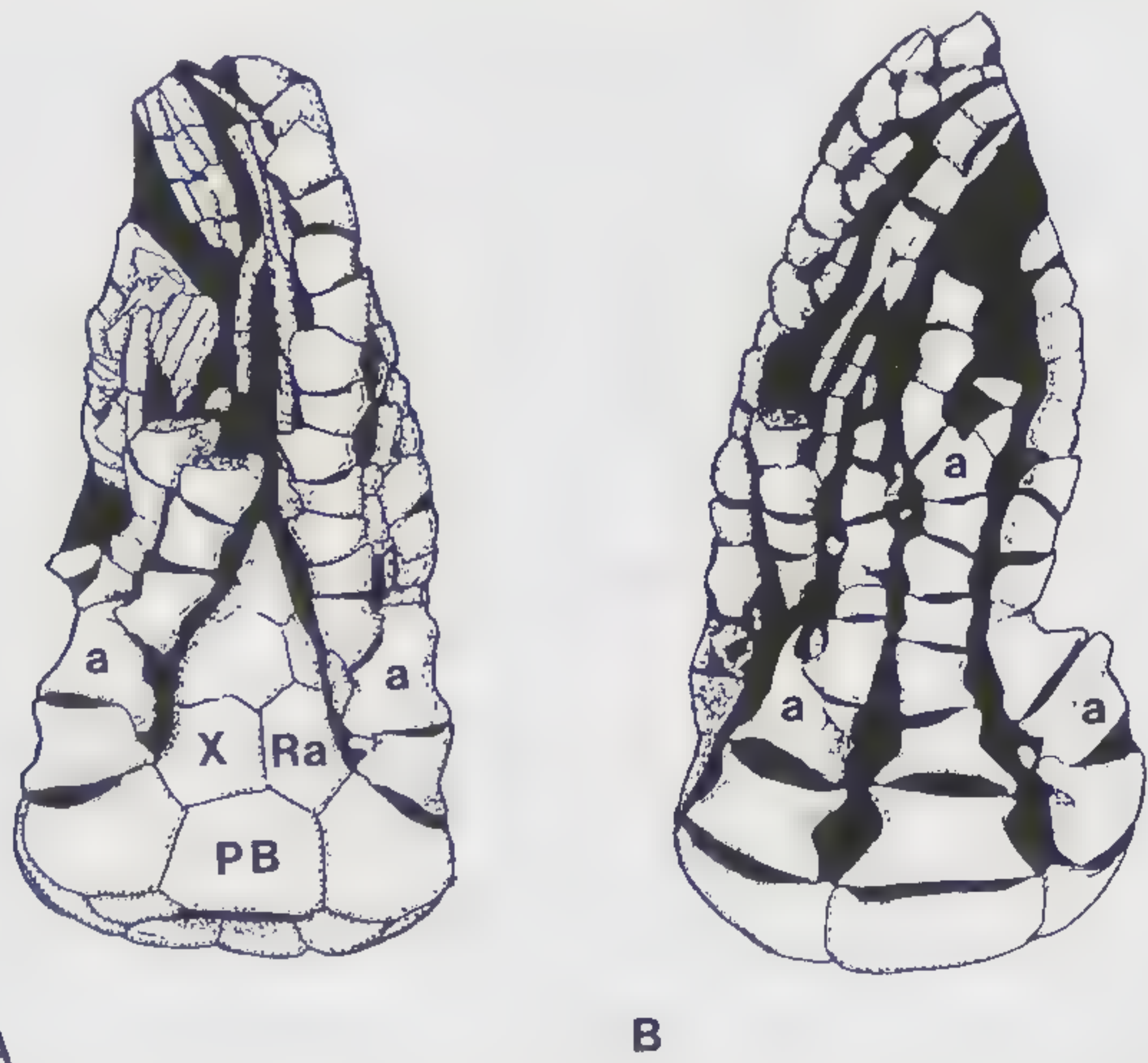
#### Family SCYTALOCRINIDAE

Moore and Laudon, 1943

#### Genus PHACELOCRINUS Kirk, 1940b

**Type species.**—*Poteriocrinus wetherbyi* Miller, 1879.

**Diagnosis.**—Scytalocrinid with pentagonal stem; high subcylindrical or spreading crown; dorsal cup sub-turbinate to campanulate or conical; anal plates typical of family; ventral sac cylindrical, composed of vertical series of equidimensional hexagonal plates; typically



Text-figure 20.—Plate arrangement in *Aenigmocrinus anomalos*. A. Posterior view. B. Anterior view. PB = enlarged posterior (CD) basal; a = axillary brachial; X = anal-X; Ra = radianal.

two undivided arms per ray; two **IBrr** per ray, which may fuse to form one plate that is deeply-constricted medially; **Brr** cuneate with long, slender pinnules.

#### Phacelocrinus longidactylus

(McChesney, 1860)

Plate 2, figures 11–15; Text-figure 21

1849. *Agassizocrinites gracilis* Troost, p. 420 [*nomen nudum*].

1850. *Agassizocrinites gracilis* Troost, p. 62 [*nomen nudum*].

1860. *Scaphiocrinus longidactylus* McChesney, p. 7.

1865. *Scaphiocrinus longidactylus* McChesney. McChesney, pl. 4, fig. 4.

1867. *Scaphiocrinus longidactylus* McChesney. McChesney, p. 4, pl. 4, figs. 4, 5.

1879. *Poteriocrinus wetherbyi* Miller, p. 36, pl. 8, figs. 1, 1a, 1b.

1880. *Poteriocrinus (Scytalocrinus) wetherbyi* (Miller). Wachsmuth and Springer, p. 118 (343).

1880. *Poteriocrinus (Scytalocrinus) longidactylus* (McChesney). Wachsmuth and Springer, p. 117 (340).

1909. *Scytalocrinus? gracilis* (Troost). Wood, p. 88, p. 11, fig. 9.

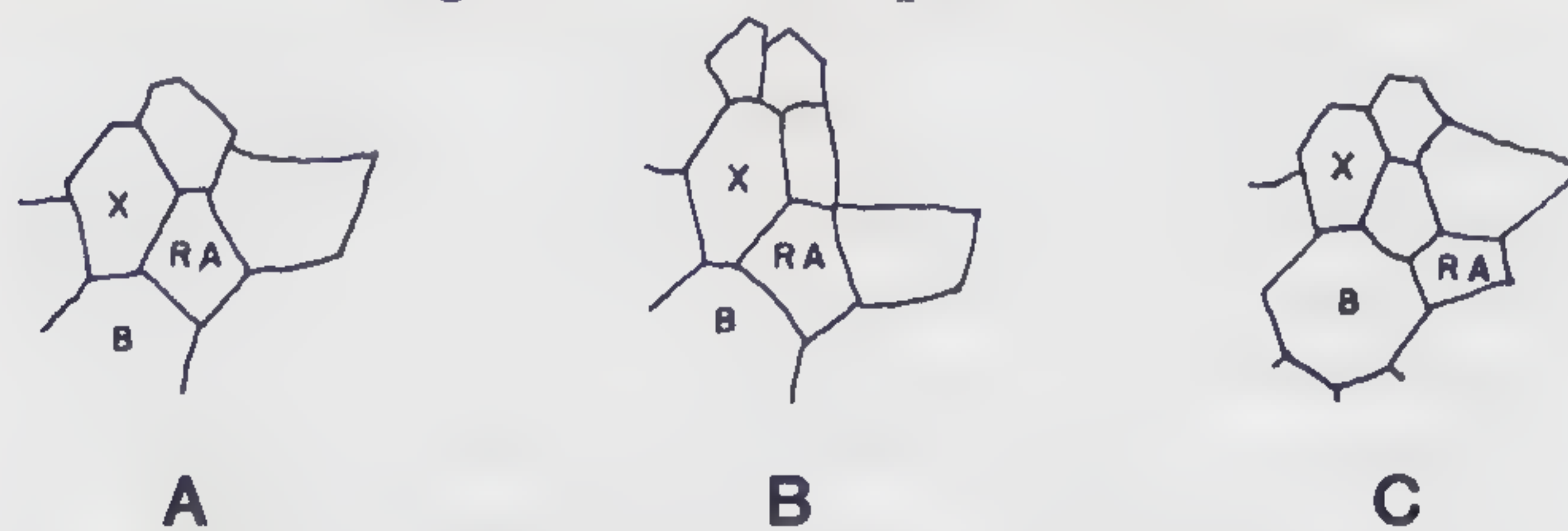
1940b. *Phacelocrinus gracilis* (Troost). Kirk, p. 330.

1940b. *Phacelocrinus longidactylus* (McChesney). Kirk, p. 330.

1965. *Phacelocrinus longidactylus* (McChesney). Horowitz, pp. 28, 29, pl. 2, figs. 19–21.

**Diagnosis.**—Turbinate cup; anal plates variable (Text-fig. 21); two **IBrr** per ray are generally fused (rarely, a ray will exhibit unfused **IBrr**), constricted medially, longer than **RR**; **Brr** cuneate throughout and slightly offset, giving arms a slightly zig-zag appearance (Pl. 2, fig. 14).

**Remarks.**—Species placed in synonymy above were all originally differentiated based on minor variations in the shape of the cup and plates. Because specimens from our assemblages show the same variations, we consider these variations to be intraspecific. Horowitz (1965) recognized the similarities between *P. longidactylus* and *P. wetherbyi* and placed the two in synonymy; we agree that these forms represent the same species. *P. gracilis* has slightly lower infrabasals than *P. longidactylus*, but we consider this type of variation insignificant. *Agassizocrinites gracilis* was listed but not described by Troost (1849, 1850) and is, therefore, a *nomen nudum*. Miller's type (1879) came from Pulaski County, Kentucky (almost certainly from the Sloans Valley member). Troost's (1849) type appears to be from the Ste. Genevieve Formation at Huntsville, Alabama. *P. bisselli* (Worthen, 1873) appears similar but differs in its higher conical cup and in brachials that



Text-figure 21.—Anal areas of *Phacelocrinus longidactylus*. A. Typical anal area. B. Top of RA even with top of radial. C. Four anal plates in anal area (UK 115808). B = basal; RA = radianal; X = anal-X.



change from cuneate in the lower arms to quadrangular in the upper arms. In *P. longidactylus* the brachials are cuneate throughout.

Variability in plate arrangement and number was observed in many of our specimens. For example, various anal-plate arrangements are shown in Text-figure 21. In specimen UK 115809, only two anal plates are present in the dorsal cup, and the primibrachials are smaller than in other specimens (The typical primibrachial is longer than the radials and is constricted medially.). The radianal in this specimen is enlarged and excludes the right tube plate from the cup. Specimen UK 115808 has four anal plates in the dorsal cup in a very unusual arrangement (Text-fig. 21); it appears as if two radianal plates are present. In specimen UK 115807, two primibrachials are present in the right posterior (C) ray, but they are much narrower than the other primibrachials. The first right secundibrachial of the left posterior (D) ray is quite large and almost as tall as its primibrachial. Another specimen, UK 115814, has two (or possibly three) primibrachials in the right anterior (B) ray, which are much narrower than the others. These unusually narrow primibrachials could represent intraspecific variations, regeneration of lost arms, or held-over primitive characteristics. The proximal parts of all stems are pentagonal.

*Occurrence.*—Upper Mississippian (Meramecian–Chesterian). Localities 3, 5, 6.

*Material.*—UK 115586, 115589, 115803–115817, and USNM S-2770. UK 115803, 115808, 115811, and 115815, and USNM S-2770 are hypotypes in this paper.

**Phacelocrinus bisselli** (Worthen, 1873)  
(not figured)

1873. *Poteriocrinites bisselli* Worthen (*in* Meek and Worthen), pp. 546–574, pl. 21, fig. 4.

1880. *Scytalocrinus wachsmuthi* Wetherby, p. 155, pl. 5, fig. 4.

1880. *Poteriocrinus (Scytalocrinus) bisselli* (Worthen). Wachsmuth and Springer, p. 117 (340).

1886. *Scytalocrinus wachsmuthi* Wetherby. Wachsmuth and Springer, p. 238 (162).

1940b. *Phacelocrinus bisselli* (Worthen). Kirk, p. 329.

1940b. *Phacelocrinus wachsmuthi* (Wetherby). Kirk, p. 330.

*Diagnosis.*—Cup more conical in adult forms. **Brr** thicker and cuneate in lower arms, becoming thinner and quadrangular in upper arms; **Brr** slightly thicker in medial parts of arms. Columnar facet with slight marginal rim.

*Remarks.*—Though this species was not found during our study, Wetherby (1880) reported that the type of *P. wachsmuthi* (Wetherby, 1880) was found in the Kaskaskia Group of Pulaski County, Kentucky. This specimen was almost certainly from the Sloans Valley member at Sloans Valley, Kentucky, but could not be located for study.

Comparison of *P. wachsmuthi* with *P. bisselli* (Worthen, 1873) revealed that the arrangement of cuneate and quadrangular brachials in the arms of each species was similar. The change from proximal cuneate brachials to quadrangular brachials distally is distinctive for *P. bisselli*. Hence, it is likely that *P. bisselli* and *P. wachsmuthi* are synonymous; *P. bisselli*, however, has priority. The two species are also similar in the medial thickening of the arms and in the presence of a slight marginal rim at the columnar facet.

One of Worthen's two illustrated specimens (pl. 21, fig. 4a) is larger and exhibits a more conical cup than the other. The smaller, broader specimen compares very favorably with Wetherby's (1880) specimen. We suggest that the smaller specimens with broader cups are juveniles.

*Occurrence.*—Upper Mississippian (Middle Chesterian).

Genus **PULASKICRINUS**, new genus

*Etymology of name.*—The name is taken from Pulaski County, Kentucky, where all the specimens in this study were found.

*Type species.*—*Pulaskicrinus campanulus* (Horowitz, 1965), new combination.

*Diagnosis.*—Scytalocrinid with campanulate to broadly turbinate dorsal cup; **IBB**, **BB**, **RR** large and visible from side view; one **IBr** per ray; space between adjacent **IBrr** filled with tiny tegminal plates attached to sides of **IBrr** and to the upper corners of the radials; rays branch isotomously two or three times above main dichotomy, with tendency toward endotomous division (Table 5); anal area typical of scytalocrinids, wide; ventral sac cylindrical, with distal spines.

*Remarks.*—One species is currently included in the genus, the result of a new combination. *P. campanulus* (Horowitz, 1965) was formerly included in the genus *Hypselocrinus* Kirk, 1940b. The type of *P. campanulus* (IU 5936) was collected from the Glen Dean Formation at Cloverport, Breckinridge County, Kentucky. The new specimens were collected from the Sloans Valley member of the Pennington Formation at locality 3, Strunk Quarry, Pulaski County, Kentucky.

*Pulaskicrinus* is probably most closely related to *Haeretocrinus* Moore and Plummer, 1940 from the Pennsylvanian (Desmoinesian–Virgilian) (Strimple and Moore, 1971). *Haeretocrinus*, however, appears to branch exotomously above the first dichotomy. *Haeretocrinus* has a recurved anal sac, a round stem and appears to lack the small, exposed tegminal plates between the primibrachials.

*Hypselocrinus* typically has nine arms, which branch isotomously. It has a conical cup and a circular stem. Horowitz's type retained no arms, apparently leading to misidentification as *Hypselocrinus*.



**Pulaskicrinus campanulus** (Horowitz, 1965),  
new combination

Plate 3, figures 1–5; Plate 12, figures 1, 2,  
Table 5; Text-figure 22

1965. *Hypselocrinus campanulus* Horowitz, pp. 27, 28, pl. 2, fig. 11–14, text-fig. 3.

*Diagnosis.*—Dorsal cup broadly turbinate to campanulate. Most **IBrr** with straight sides (not constricted).

*Description.*—Column round with nodals and internodals. Scytalocrinid with campanulate to broadly turbinate dorsal cup (Pl. 3, figs. 1–5); **IBB** medium-sized, visible from side, and occupy one-fourth of dorsal cup; **BB** large, hexagonal except CD basal and BC basal, which are heptagonal; **RR** wider than high (slightly less than 2:1 ratio); width of radial articulating facet slightly less than width of radial; small projections on both sides of the facets project upward and inward around the facet and make contact with small tegminal plates between arms (Pl. 3, fig. 2; Text-fig. 22); suture slightly gaping. First **IBr** axillary in all rays, wider than high, short, narrower than **RR** such that a gap exists between adjacent **IBrr**; **IBrr** generally straight-sided, but rarely constricted; smooth tegminal platelets fill gap between **IBrr** and ascend steeply toward the ventral sac (Text-fig. 22); first **IIBr** in each ray is larger than others; above main dichotomy, rays branch two or three times (Table 5); tendency toward endotomous division within arms above the first isotomous branching; proximal **Brr** slightly sloping and quadrangular, becoming more cuneate distally; each **Brr** supports one long, slender pinule. Four to 14 **IIBrr** present in each arm; seven to 10 typical. Axillary **Brr** may be slightly tumid, giving arms a knotty appearance. Anal area is typical of scytalocrinids, but broad (Pl. 3, fig. 3); **RA**, anal **X**, and **RX** plates occur within cup; **RA** pentagonal; anal **X** is large, heptagonal, and is only partially contained in cup; **RX** plate is same size as **RA** and is only partially contained in cup; anal **X** and **RX** plate support three plates on their upper surfaces. Ventral sac is cylindrical and about two-thirds length of arms; plates of ventral sac are small and spinose proximally, increasing in size and spininess near the distal end of the sac. Ambulacra descend from the arms onto the tegmen and exhibit two uniserial rows of small cover plates.

*Remarks.*—*Hypselocrinus campanulus* was originally described by Horowitz (1965) from a single dorsal cup with a few brachials; the arms were unknown. Many of our specimens, however, have the complete arms. *P. campanulus* also displays many small tegminal plates between the primibrachials (see Horowitz, 1965, pl. 2, figs. 12, 13).

A remarkable thing about this crinoid, however, is the presence of the ophiuroid *Onychaster strimplei*

Bjork, Goldberg, and Kesling, 1968a, wrapped around the ventral sacs of at least two specimens (UK 115998, UK 115997; Pl. 12, figs. 1, 2). Other specimens also show evidence of this commensalism. One ophiuroid is situated with its oral disc about halfway up the ventral sac of the crinoid. If the ophiuroid was coprophagous, then its position might indicate the position of the anal opening (the oral disc is on the left anterior side of the crinoid). However, Bjork, Goldberg, and Kesling (1968b) suggested that *Onychaster* Meek and Worthen, 1868, was not coprophagous due to well-developed masticatory apparatus and restricted oral intake. They suspected that the ophiuroid and the crinoid utilized food particles of different sizes and that the specimen of *Onychaster* resided on the crinoid calyx for protection and gathered food particles too large for the crinoid. The crinoids may have also provided elevation into the water column (see p. 65 and Text-fig. 14).

*Occurrence.*—Upper Mississippian (Middle Chesterian). Locality 3.

*Material.*—UK 115832–115842, 115997, and 115998, and IU 5936, the holotype. UK 115834, 115835, and 115837 are hypotypes in this paper.

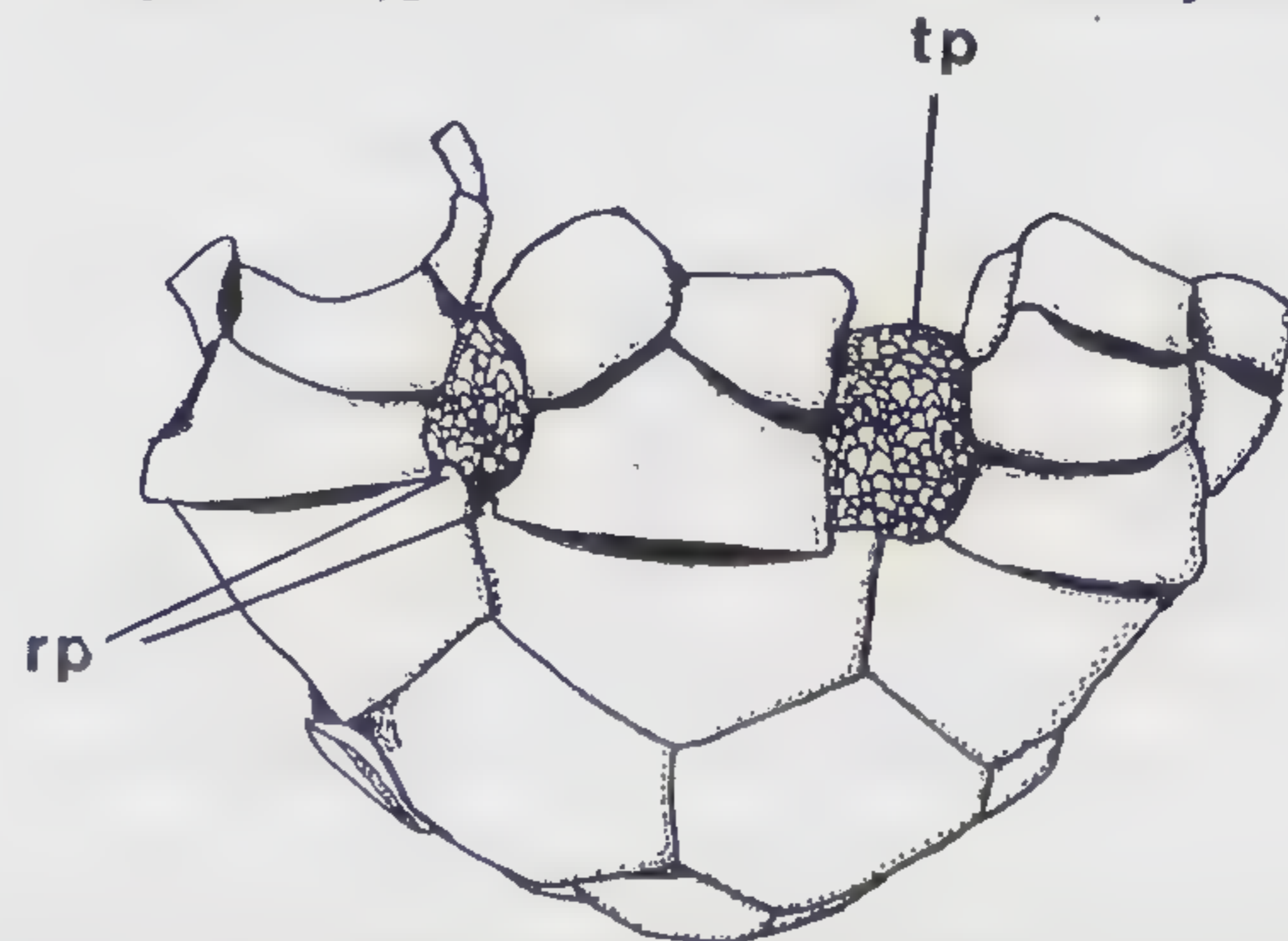
Genus **WETHERBYOCRINUS**, new genus

*Etymology of Name.*—The genus is named after A. G. Wetherby, who found the holotype of the type species and also discovered the classic Sloans Valley collecting locality.

*Type species.*—*Poteriocrinus pulaskiensis* Miller and Gurley, 1896.

*Diagnosis.*—Medium-size scytalocrinid with turbinate dorsal cup; sutures between plates in cup are strongly impressed at triple-plate boundaries (Pl. 3, figs. 6, 7); **IBB** small, visible from side, truncated at base, forming a platform; three anal plates in cup (Pl. 3, figs. 6, 7); one **IBr** per ray.

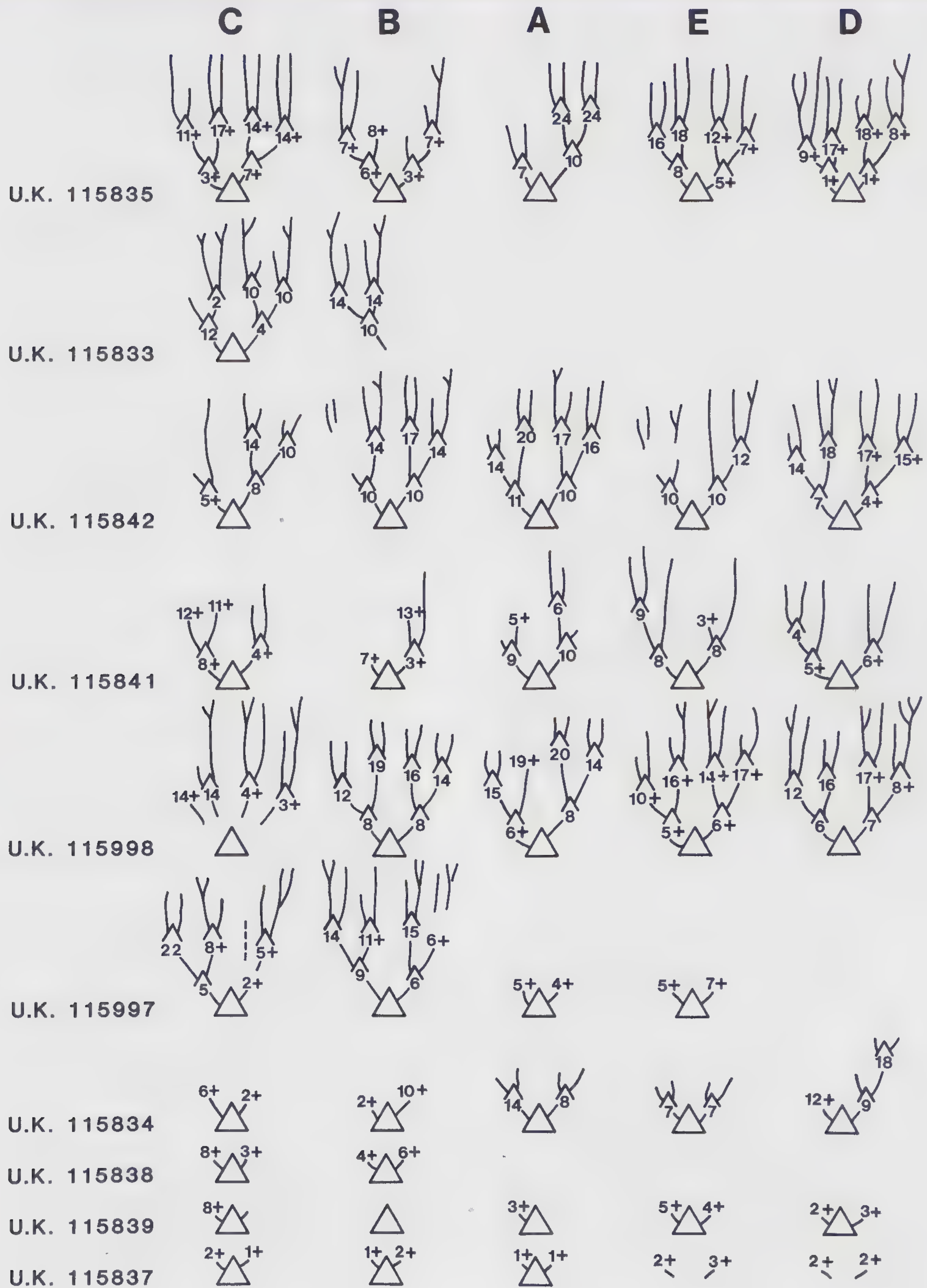
*Remarks.*—Of all the genera and species previously described from the Sloans Valley area, this is one of two species [the other is *Culmicrinus vagulus* (Miller and Gurley, 1895)] that have been virtually forgotten



Text-figure 22.—Interbrachial platelets of *Pulaskicrinus campanulus*, n. comb. **tp** = interbrachial platelets; **rp** = radial process.



Table 5.—Arm structure of *Pulaskicrinus campanulus* (Horowitz), n. comb. Numbers of brachials in each branch are indicated. The A ray is anterior. Triangles represent primibrachials.





since the work of Bassler and Moodey (1943). Bassler and Moodey reassigned the species to *Poteriocrinites* Miller, 1821; however, *Poteriocrinites* subsequently has been split into many genera, and this species no longer fits the modern definition of *Poteriocrinites*. The species was never reassigned to another genus.

The characters of the new genus are similar to those of the families Scytalocrinidae and Aphelecrinidae. However, these characters are more similar to those of the Scytalocrinidae because of the visibility of infrabasals from the side, the truncate base, nature of the preserved arms, and its resemblance to the scytalocrinid *Sostronocrinus* Strimple and McGinnis, 1969.

*Sostronocrinus* has the same general cup shape with a truncate base, and it has strongly-impressed sutures at triple-plate junctures as does *Wetherbyocrinus*. The major difference, however, is that *Sostronocrinus* has two to three primibrachials per ray in contrast to the one primibrachial per ray in *Wetherbyocrinus*. *Sostronocrinus* is an earlier (Kinderhookian) scytalocrinid, and such early forms generally are characterized by a greater number of primibrachials; in later forms, this number is usually reduced to one. We suggest that *Wetherbyocrinus* possibly evolved from a form like *Sostronocrinus* through a loss of primibrachials.

**Wetherbyocrinus pulaskiensis**

(Miller and Gurley, 1896), new combination

Plate 3, figures 6, 7

1896. *Poteriocrinus pulaskiensis* Miller and Gurley, p. 39, pl. 3, figs. 26, 27.  
 1943. *Poteriocrinites pulaskiensis* (Miller and Gurley). Bassler and Moodey, p. 644.

*Diagnosis.*—**IBr** medially constricted.

*Description.*—Dorsal cup 0.8 cm high, 1.2 cm wide, turbinate, plates smooth, slightly tumid; sutures impressed at triple-plate junctions (Pl. 3, figs. 6, 7); maximum diameter at level of **RR** and along a line passing through E ray and B-C interray. No stem present in type specimen, but stem was probably present, because a very small lumen occurs between **IBB**, and the **IBB** form a very truncate platform probably to receive stem. **IBB** quadrangular (diamond-shaped) with proximal facets longer than distal, wider than high, only distal-most portion visible from side view; proximal parts of plates are inturned to form platform for probable stem. Posterior **BB** are wider than high, C-D basal is hexagonal, B-C basal is seven-sided; anterior **BB** are higher than wide, hexagonal. **RR** pentagonal, wider than high, greatest width at top of cup; **R** articular facets wide, each with ligament pits and a transverse ridge that runs length of plate. Three anal plates typical of Scytalocrinidae; upper two plates only partially in cup (Pl. 3, fig. 6). Only E and A ray **IBrr** are preserved; one **IBr** per ray, wider than high with greatest width at level of

**RR**; **IBrr** medially constricted and flaring outward distally (Pl. 3, fig. 7). Arms not preserved, but probably two arms per ray; probably uniserial.

*Remarks.*—In Miller and Gurley's (1896) original description and figures, they indicated two **IBrr** per ray. Our examination of the type specimen, however, indicates only one per ray.

*Occurrence.*—Upper Mississippian (Middle Chesterian).

*Material.*—UC 6488 (holotype).

Family **BLOTHROCRINIDAE**

Moore and Laudon, 1943

Genus **CULMICRINUS** Jaekel, 1918

*Type species.*—*Poteriocrinus regularis* Meyer, 1858.

*Diagnosis.*—Medium to large blothocrinid; stem typically round, cone-shaped cup (Pl. 3, fig. 8); five upflared **IBB** visible from side; three anal plates in primitive arrangement (Pl. 3, fig. 8); long anal sac with anal opening low and on anterior side, numerous small anal-sac plates in vertical series (Pl. 3, figs. 8, 10); arms uniserial, two or more **IBrr** per ray (Pl. 3, figs. 8–10), anterior ray branching much higher if at all, second branching at about mid-crown height; **Brr** cuneate.

**Culmicrinus vagulus**

(Miller and Gurley, 1895)

Plate 3, figures 8–10

1895. *Poteriocrinus vagulus* Miller and Gurley, p. 46, pl. 4, figs. 10, 11.  
 1897. *Scaphiocrinus elegans* Wachsmuth and Springer, pl. 7, figs. 1a, b.  
 1926. *Culmicrinus elegans* (Wachsmuth and Springer). Springer, p. 74, pl. 18, figs. 1, 1a.  
 1943. *Poteriocrinites vagulus* (Miller and Gurley). Bassler and Moodey, p. 645.  
 1943. *Culmicrinus elegans* (Wachsmuth and Springer). Bassler and Moodey, p. 383.

*Diagnosis.*—Moderately conical dorsal cup; **BB** moderately wide; less than 10 **IBrr** per ray except for anterior ray, which may be unbranched.

*Remarks.*—Springer (1926) removed this species from the genus *Scaphiocrinus* Hall, 1858 and placed it in the genus *Culmicrinus*. However, Springer apparently was unaware of earlier work by Miller and Gurley (1895) in which a nearly identical specimen from the same locality as *Scaphiocrinus elegans* Wachsmuth and Springer, 1897, was described as *Poteriocrinus vagulus* Miller and Gurley, 1895. This species has been all but forgotten, except in the work of Bassler and Moodey (1943), where it was included in a synonymy for *Poteriocrinites*. Our examination of the type of *Poteriocrinites vagulus* (Miller and Gurley, 1895) indicates that it is the same species that Springer called *Culmicrinus elegans* (Wachsmuth and Springer, 1897). Moreover, *P. vagulus* and *C. elegans* were col-



lected from the same locality. Because *P. vagulus* has priority, the correct designation for this species is *Culmicrinus vagulus* (Miller and Gurley, 1895). The holotype then becomes that of *Poteriocrinus vagulus*, and the specimens described by Wachsmuth and Springer (1897), and later placed in synonymy by Springer (1926), become topotypes.

The most similar species is *C. missouriensis* (Shumard, 1857), which is from the St. Louis Formation of Missouri. *C. missouriensis* is characterized by a steeply conical cup, smaller plates in the cup, and more than 10 primibrachials per ray; in contrast, *C. vagulus* is characterized by a broader, moderately conical cup, larger plates, and fewer than ten primibrachials per ray. Similar differences in other species have been attributed to intraspecific variation, and these two species are so similar overall that the possibility that they are the same species also must be considered. Nonetheless, the substantial difference in the age of the two species, the fact that similar changes in the shape of the cup and the number of primibrachials have been observed in the phylogeny of other Chesterian crinoids leads us to conclude that *C. missouriensis* is a more primitive form that gave rise to the more advanced *C. vagulus* in the Chesterian.

*Occurrence.*—Upper Mississippian (Chesterian).

*Material.*—UC 6418 (holotype), USNM S-2638 (two specimens, topotypes).

#### Family APHELECRINIDAE Strimple, 1967

##### Genus APHELECRINUS Kirk, 1944a

*Type species.*—*Aphelecrinus elegans* Kirk, 1944a.

*Diagnosis.*—Crown upflared; dorsal cup cone-shaped to campanulate; three anal plates in normal (primitive) arrangement (Moore and Laudon, 1943); anal sac one-half to two-thirds height of arms, may be reflexed, composed of vertical rows of small, polygonal plates; one **IBr** per ray, slightly to very constricted medially; arms moderately long and moderately stout; arms usually divide only once above the **IBrr**; **Brr** sloping, quadrangular to cuneate.

##### *Aphelecrinus randolphensis* (Worthen, 1873)

Plate 4, figures 5, 6, 12, 13

1873. *Poteriocrinus* (*Scaphiocrinus*) *randolphensis* Worthen, p. 551, pl. 21, fig. 14.  
 1880. *Poteriocrinus* (*Scaphiocrinus*) *randolphensis* Worthen. Wachsmuth and Springer, p. 113.  
 1944a. *Aphelecrinus limatus* Kirk, pp. 196, 197, pl. 1, fig. 10.  
 1944a. *Aphelecrinus randolphensis* (Worthen). Kirk, p. 200.  
 1944a. *Aphelecrinus mundus* Kirk, pp. 197, 198, pl. 1, fig. 9.  
 1944a. *Aphelecrinus oweni* Kirk, pp. 198–200, pl. 1, figs. 1–3.  
 1965. *Aphelecrinus randolphensis* (Worthen). Horowitz, pp. 26, 27, pl. 2, fig. 18.  
 1965. *Aphelecrinus oweni* Kirk. Horowitz, pp. 25, 26, pl. 2, figs. 15–17.

1965. ?*Aphelecrinus bayensis* (Meek and Worthen). Horowitz, pp. 24, 25, pl. 2, figs. 3, 4.

*Diagnosis.*—Proximal column, circular to subpentagonal, with nodals and internodals; dorsal cup campanulate; sides of cup diverge moderately to level of **RR**, which then diverge even more abruptly (Pl. 4, figs. 6, 12); ventral sac extends one-half to two-thirds height of arms, recurved, composed of carinate tube plates; distal plates may be subspinose; **IBrr** variable in height and amount of medial constriction (Pl. 4, figs. 5, 12, 13); second branching of arms occurs at varying heights, but usually in the lower half of the arms (Pl. 4, fig. 6); third branching uncommon but may occur independently; long, stout pinnules borne alternately on **Brr** (Pl. 4, fig. 6).

*Remarks.*—*A. randolphensis* (Worthen, 1873), *A. limatus* Kirk, 1944a, *A. mundus* Kirk, 1944a, and *A. oweni* Kirk, 1944a, were differentiated on the basis of characters that we deem to be intraspecific and minor in nature, such as the angle at which the cup diverges, the nature of the stem, and the nature of the constriction on the primibrachials. All specimens have basically the same campanulate cup; greater or lesser degrees of cup divergence are apparently related to mode of preservation. The stems on all three forms appear to be round, although the internodals may have a slight pentagonal outline. All variations in the degree of constriction on the primibrachials occur in our specimens, and in some instances, within a single specimen. The variations in the above characters are great enough in our assemblage that all three of Kirk's species could be identified. Moreover, Kirk's three species probably were collected from the same locality. The above considerations lead us to conclude that the genus has been oversplit in the Glen Dean Limestone, and that Kirk's three Glen Dean Limestone species should be placed in synonymy with *A. randolphensis*. The holotype of *A. randolphensis*, though smaller than most of our specimens, is identical in every other way, and probably was collected from the Glen Dean Limestone at Chester, Illinois.

Examination of the holotype of *A. bayensis* (Meek and Worthen, 1865) also revealed characteristics similar to *A. randolphensis*, except for the probable absence of branching above the primibrachial. The presence of 10 unbranched arms is the most diagnostic character of *A. bayensis*. We believe that this character of the arms also may be an intraspecific variation. However, because we lack specimens from our assemblages showing the character and because the character is so distinctive, we suggest that *A. bayensis* be maintained for the present. Although we have not examined Horowitz's (1965) hypotype of *A. bayensis*, in all other ways it is similar to *A. randolphensis*. Hence, even



though the arms are not preserved high enough above the primibrachial to discern the possibility, we questionably place it in synonymy with *A. randolphensis*.

Over 21 species are currently recognized in this genus, making it one of the largest genera in terms of species in the Late Mississippian. We believe, however, that this genus has been oversplit and is in need of major revision. Although we have examined only species from the Glen Dean Limestone, future study may indicate the need to place even more species in synonymy with *A. randolphensis*.

*Occurrence*.—Upper Mississippian (Chesterian). Localities 3, 5.

*Material*.—UK 115818–115831, 115841, and 116071, USNM S-2618 (holotype of *A. limatus*), USNM S-4437 (holotype of *A. mundus*), and UI X-276 (holotype of *A. randolphensis*). UK 115581, 115826–115827 are hypotypes in this study.

Superfamily LOPHOCRINACEA  
Bather, 1899

Family STELLAROCRINIDAE  
Strimple, 1961

Genus RHOPOCRINUS Kirk, 1942a

*Type species*.—*Rhopocrinus spinosus* Kirk, 1942a.

*Diagnosis*.—Crown of medium height; cup broadly turbinate; **IBB** small, barely visible in lateral view; groove-like depression between distal portions of adjacent **RR** (Pl. 3, fig. 13); articulating facet does not extend full width of **RR**; two **IBrr** per ray; arms stout proximally, becoming slender distally (Pl. 3, fig. 11); strong tendency toward endotomous branching, uniserial except for distal portions, which approach a biserial condition; **Brr** cuneate; axillaries may bear spines; anal sac composed of small nodose plates and may extend three-fourths or more the height of the arms; distal portion bears outwardly projecting spines.

*Remarks*.—Kirk (1942a) placed three species in this genus; however, our examination of these species suggests that *R. municipalis* (Wood, 1909) and *R. proboscidualis* (Worthen, 1875) may not belong to this genus. Some characteristics of this genus reflect affinities to the Aphelecrinidae.

*Rhopocrinus spinosus* Kirk, 1942  
Plate 3, figures 11–13

1942a. *Rhopocrinus spinosus* Kirk, pp. 153, 154, pl. 16.

*Diagnosis*.—*Rhopocrinus* with broadly turbinate cup, some axillaries spinose (Pl. 3, figs. 11–13); **IBrr** and proximal arms are much wider than distal parts of arms.

*Remarks*.—No specimens were found in our study, but Kirk's (1942a) specimens were examined at the U. S. National Museum.

*Occurrence*.—Upper Mississippian (Chesterian).

*Material*.—USNM S-4409a (holotype), and USNM S-4409b–c (two paratypes).

Superfamily AGASSIZOCRINACEA Miller, 1889

Family AMPELOCRINIDAE Kirk, 1942b

Genus AMPELOCRINUS Kirk, 1942b

*Type species*.—*Ampelocrinus kaskaskiensis* (Worthen, 1882).

*Diagnosis*.—Column round to subpentagonal with pentagonal lumen; nodals, internodals, and cirri present; crown high, distally spread or cylindrical; dorsal cup small and cyathiform; CD basal supporting cup's single anal plate; single anal plate supports two other anal-tube plates; anal sac is short, stout, recurved; arms long, isotomous, or occasionally endotomous; two to three **IBrr** per ray, each united by very close suture with narrowing at suture or middle **IBr** (if present) to give appearance of one larger, medially-constricted **IBr** (Pl. 4, figs. 1, 3); one division above primaxil typical; **Brr** predominantly cuneate; syzygial pairs may be present; long slender pinnules borne alternately on **Brr**.

*Remarks*.—*Armenocrinus* Strimple and Horowitz, 1971 differs from *Ampelocrinus* in having a taller, more conical cup with infrabasals clearly visible from the side, and in having more primibrachials. *Cymbiocrinus* Kirk, 1944b, which may occur with *Ampelocrinus* also resembles this genus, but has shorter arms, and its infrabasals are not visible from the side.

*Ampelocrinus kaskaskiensis*  
(Worthen, 1882)

Plate 4, figures 1–4; Plate 12, figure 8

1882. *Poteriocrinus kaskaskiensis* Worthen, p. 27.

1883. *Poteriocrinus kaskaskiensis* Worthen. Worthen, p. 300, pl. 29, fig. 15.

1942b. *Ampelocrinus kaskaskiensis* (Worthen). Kirk, p. 24.

1942b. *Ampelocrinus bernhardinae* Kirk, pp. 25, 26, pl. 1, figs. 1, 2.

1942b. *Ampelocrinus fimbriatus* Kirk, pp. 26, 27, pl. 2, figs. 5, 6.

1973a. *Ampelocrinus kaskaskiensis* (Worthen). Strimple, p. 23, fig. 14.

*Diagnosis*.—Column round with nodals, internodals, and whorls of long, slender cirri (Pl. 4, figs. 1–4); ratio of crown height to cup height is high (20:1) (Pl. 4, fig. 2); dorsal cup cyathiform; arms long and slender, typically branching twice; two to three **IBrr** per ray, united by very close sutures with narrowing at suture or middle **IBr** (if present) to give appearance of one larger, medially-constricted **IBr** (Pl. 4, figs. 1, 3, 4); **Brr** cuneate (Pl. 4, figs. 1, 3), some syzygial pairs; long, slender pinnules.

*Remarks*.—Our examination of the types of *A. bern-*



*hardinae* Kirk, 1942b, and *A. fimbriatus* Kirk, 1942b, indicates that they represent the same species. Kirk (1942b) differentiated the two species based on the shape of the dorsal cup, the nature of the arms, and the number of bifurcations in the arms. The dorsal cups of both forms appear to be cyathiform; any differences are related to the degree of compaction. The arms do not appear to differ in any way, and both type specimens were collected from the same horizon and locality in our study area. Moreover, comparison of *A. bernhardinae* and *A. fimbriatus* with *A. kaskaskiensis* (Worthen, 1882) indicates that they are conspecific, as suggested by Strimple (1973a). Hence, we place *A. bernhardinae* and *A. fimbriatus* in synonymy with *A. kaskaskiensis*, which has priority.

*A. mundus* Kirk, 1942b, appears to be a distinctly different species. *A. mundus* is a smaller form with a higher turbinate cup and high primibrachials, compared to the cyathiform cup and low primibrachials of *A. kaskaskiensis*. The arms are stouter and composed largely of long rectangular brachials compared to the more delicate arms and uniformly cuneate brachials of *A. kaskaskiensis*.

*A. spinosus* Strimple, 1973a, differs from *A. kaskaskiensis* principally in having high primibrachials. We have noted spinose secundibrachials, from which the species derives its name, in the types of *A. kaskaskiensis* and in our specimens. The high primibrachials are the primary distinguishing characteristics, and we wonder whether the extreme height may not be a juvenile characteristic because the specimens are very small; in other aspects they are similar to *A. kaskaskiensis*. We suggest that *A. spinosus* is either an earlier species closely related to *A. kaskaskiensis*, or possibly a juvenile form of *A. kaskaskiensis*; additional specimens and study, however, will be necessary to make this determination.

One of our specimens (UK 115699) exhibits three primibrachials in each of its anterior rays. Although undescribed, this same feature was noted by us in one of Kirk's paratypes for *A. fimbriatus* (USNM S-4403B). This similarity suggests to us that the larger, lower primibrachial in *A. kaskaskiensis*, and perhaps in other species of *Ampelocrinus*, was derived from the fusion of at least two primibrachials. *Ampelocrinus* may have been derived from an earlier ampelocrinid like *Armenocrinus*, which may have two to four primibrachials, by the fusion of primibrachials.

**Occurrence.**—Mississippian (Chesterian). Localities 3, 5.

**Material.**—UK 115697–115699, USNM S-4402A (holotype of *A. bernhardinae*), USNM S-4403A (holotype of *A. fimbriatus*), USNM 37634 (holotype of *A. mundus*), and USNM S-4404A–C (paratypes of *A. mundus*). UK 115699 is a hypotype in this study.

#### Family AGASSIZOCRINIDAE Miller, 1889

#### Genus ANARTIOCRINUS Kirk, 1940a

**Type species.**—*Anartiocrinus lyoni* Kirk, 1940a.

**Diagnosis.**—Column round, small; crown moderately tall; turbinate dorsal cup; five unfused **IBB**; three anal plates in cup (Pl. 4, fig. 11); anal sac obscured, probably small; one **IBr** per ray, which may or may not be medially constricted; all arms uniserial, short, and slender except for posterior arms of B and E rays, which are hypertrophied in length and diameter (Pl. 4, figs. 7–9); **Brr** quadrangular to sloping quadrangular with well-rounded exteriors.

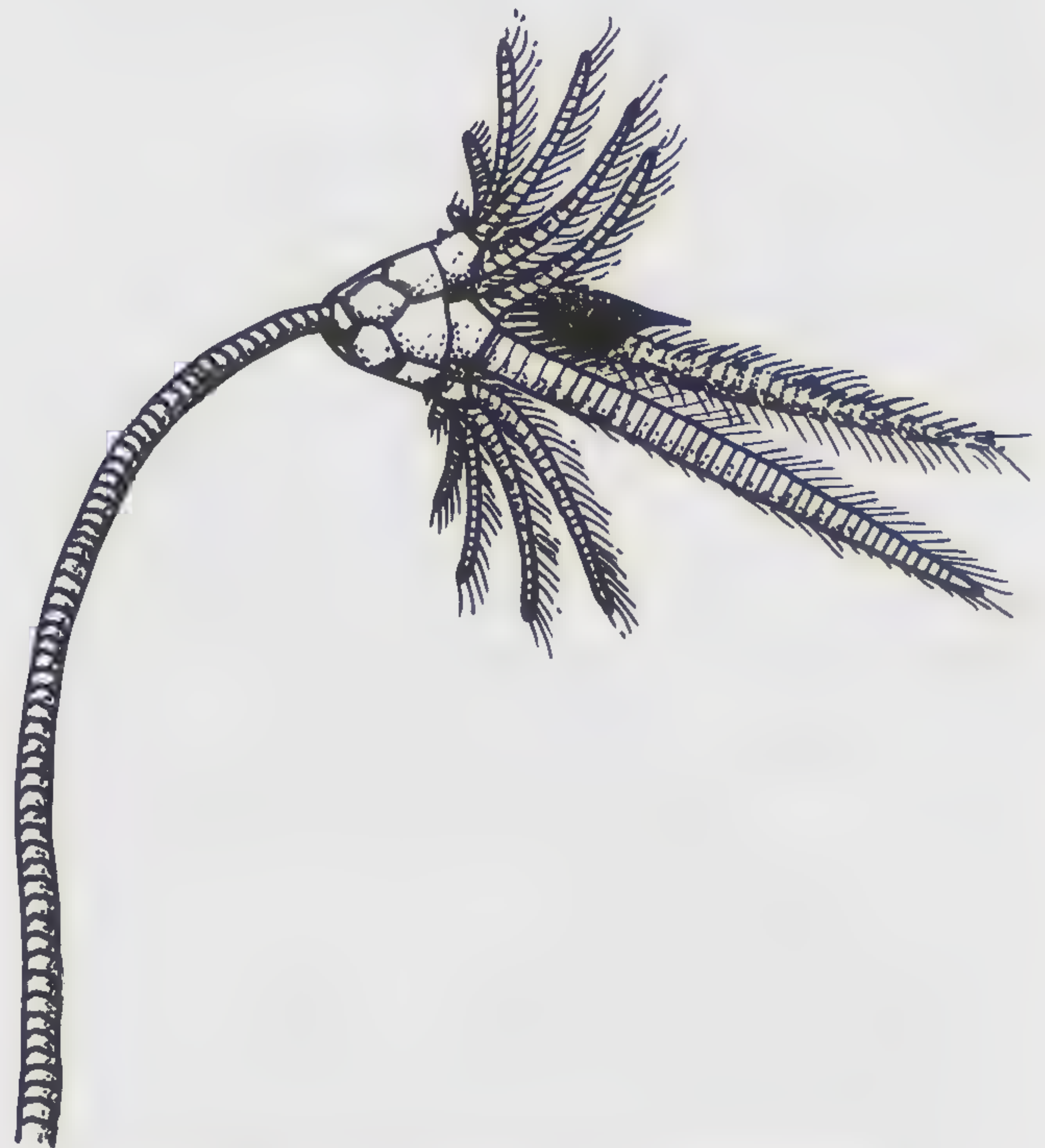
**Remarks.**—No other similar-appearing crinoid has two greatly enlarged arms (Text-fig. 23) with eight other normal, short and slender arms.

#### *Anartiocrinus lyoni* Kirk, 1940

Plate 4, figure 7–9, 11

1940a. *Anartiocrinus lyoni* Kirk, pp. 47–49, pl. 1, figs. 1–5, 9.

**Diagnosis.**—Column unknown; sub-turbinate dorsal cup; C and D **RR** narrower and shorter than other **RR**; three anal plates in cup, **RX** plate only partially in cup (Pl. 4, fig. 11); **IBrr** wider than high, straight sides, disproportionate in size (Pl. 4, fig. 8); B and E **IBrr** are largest; smaller arms less than two-thirds length of large arms (Pl. 4, figs. 7, 8); small arms composed of stout **Brr**, quadrangular to sloping quadrangular, maximum width 2.5 mm; two hypertrophied arms having quadrangular **Brr** (Pl. 4, figs. 7–9), with a maximum width of 5.6 mm.



Text-figure 23.—Hypertrophied arms in *Anartiocrinus*.



*Remarks.*—The only other described species of the genus is *A. maxvillensis* (Whitfield, 1891) from the Maxville Limestone of Newton Township, Muskingum County, Ohio. *A. lyoni* Kirk, 1940a, is larger than *A. maxvillensis*, and the cup is more elongate, especially in the basal portion. The right tube plate lies, in part, below the upper surface of the right posterior (C) radial, whereas in *A. maxvillensis*, it lies above this surface. Furthermore, the primibrachials of *A. lyoni* are higher and more straight-sided than those of *A. maxvillensis*, which are medially constricted.

The cup of *A. lyoni* is also turbinate compared to the more campanulate cup of *A. maxvillensis*, and the crown of *A. maxvillensis* is almost always constricted at the level of the primibrachials.

The overall aspect of these species, however, is such that we are tempted to place them in synonymy, especially in light of specimens from a slightly older unit in which some of these characters vary. Nonetheless, specimens with dominantly “*maxvillensis*” characteristics (Pl. 4, fig. 10) seem to be restricted to the Golconda Limestone and equivalent horizons, whereas specimens with dominantly “*lyoni*” characteristics seem to be restricted to the Glen Dean Limestone and equivalent horizons; however, few specimens are available for study. It may be that more specimens will reveal the two species to be mere intraspecific variations.

*Occurrence.*—Upper Mississippian (Middle Chesterian). Localities 4, 5.

*Material.*—UK 115843 and 115844, hypotypes, USNM S-2788 (holotype), USNM S-2786 (paratype), USNM S-2787 (paratype), and USNM S-5837 (paratype).

#### Genus AGASSIZOCRINUS Owen and Shumard, 1852a

*Type species.*—*Agassizocrinus conicus* Owen and Shumard, 1852a.

*Diagnosis.*—Column always absent in adult stage; five **IBB** fused into a solidly calcified **IB** cone, visible from side (Pl. 4, fig. 16); three to four anal plates in cup (Pl. 4, fig. 17); ventral sac unknown; 10 uniserial arms branch only once on first **IBr**; **Brr** mostly quadrangular; small pinnules, closely packed.

#### *Agassizocrinus conicus* Owen and Shumard, 1852 Plate 4, figures 16–19

- 1852a. *Agassizocrinus conicus* Owen and Shumard, p. 93, pl. 2, fig. 6.  
1926. *Agassizocrinus conicus* Owen and Shumard. Springer, pp. 53, 59, 63, pl. 15, figs. 1–4.  
1965. *Agassizocrinus* cf. *A. conicus* Owen and Shumard. Horowitz, p. 38, pl. 4, figs. 1, 2.

*Diagnosis.*—All trace of column absent; dorsal cup

strictly conical and typically very elongate (Pl. 4, figs. 16, 18); ratio of **IB**-cone height to height of dorsal cup is greater than 0.5; distal surface of **IB** cone relatively flat, central interior invagination round (Pl. 4, figs. 18, 19).

*Remarks.*—According to Ettensohn (1975b), the infrabasal cone of *A. conicus* Owen and Shumard, 1852a, is more conical and its distal surface is flatter (Pl. 4, figs. 18, 19) than other species (e.g., *A. cf. A. dactyliformis* Shumard, 1853; Pl. 4, figs. 14, 15). The central cavity is round (Pl. 4, fig. 19), compared to the cavities of other species which are star-shaped (Pl. 4, figs. 15). It is therefore possible to identify *A. conicus* by its infrabasal cone alone.

There are several beds within the Sloans Valley member that could be considered *Agassizocrinus*- and *Pterotocrinus*-plate biorudites; bedding surfaces are composed almost entirely of *Agassizocrinus* infrabasal cones and the tegminal spines of *Pterotocrinus* Lyon and Casseday, 1859. In these beds, all plates are dissociated and concentrated, suggesting a high-energy environment. In some other beds, four cups in various states of preservation were found.

*Occurrence.*—Upper Mississippian (Middle and Upper Chesterian). Locality 3 (infrabasal cones found at most localities).

*Material.*—UK 115847–115853, 115935. UK 115847, 115850, and 115853 are hypotypes in this study.

#### *Agassizocrinus* cf. *A. dactyliformis* Shumard, 1853 Plate 4, figures 14, 15

1850. *Agassizocrinites dactyliformis* Troost, p. 420 [*nomen nudum*].  
1853, 1854. *Agassizocrinus dactyliformis* Shumard, p. 173, pl. 1, fig. 7.  
1855. *Astylocrinus laevis* Roemer, p. 229, pl. 4, figs. 13a–d.  
1965. *Agassizocrinus dactyliformis* Shumard. Horowitz, p. 38, pl. 4, figs. 3, 4.

*Diagnosis.*—No column present; dorsal cup broadly rounded, ovoid; **IBB** completely fused into a solid cone, occupying one-third or more of dorsal cup; strongly outward-sloping upper distal surface (Pl. 4, fig. 14) on **IB** cone, with a star-shaped interior central invagination (Pl. 4, fig. 15).

*Remarks.*—According to Ettensohn (1975b), the individual cones of *A. dactyliformis* Shumard, 1853 [= *A. laevis* (Roemer, 1855)], cannot be differentiated from some of the individual cones of *A. lobatus* Springer, 1926; complete cups are necessary for certain identification. Nonetheless, lobate cones that characterize at least some forms of *A. lobatus* have not been found in our sections, and field experience leads us to believe that *A. lobatus* occurs no higher than the Golconda Limestone and its equivalents. For these reasons, we



suggest that our specimens probably are *A. dactyliformis*; the infrabasal cones certainly compare favorably.

The infrabasal cones of *A. dactyliformis* are more broadly conical (such as in *A. cf. A. dactyliformis*; Pl. 4, fig. 14) than the steeply conical cones (Pl. 4, figs. 16, 18) of *A. conicus* Owen and Shumard, 1852a. The distal surface of *A. dactyliformis* cones slopes more abruptly outward and the interbasal ridges are high and well defined (as in *A. cf. A. dactyliformis*; Pl. 4, fig. 14). This contrasts markedly with the relatively flat distal surface and subtle interbasal ridges (Pl. 4, fig. 18) of *A. conicus*. The cones of *A. dactyliformis* also have a star-shaped central invagination (as in *A. cf. A. dactyliformis*; Pl. 4, fig. 15) compared to a round central invagination (Pl. 4, fig. 19) in *A. conicus*.

*Occurrence.*—Upper Mississippian (Lower and Middle Chesterian). Locality 3.

*Material.*—UK 115554 and 115568, the latter a hypotype in this paper.

#### Superfamily DECAOCRINACEA

Bather, 1890

#### Family DECAOCRINIDAE Bather, 1890

#### Genus RAMULOCRINUS

Laudon, Parks and Spreng, 1952

*Type species.*—*Ramulocrinus nigelensis* Laudon, Parks, and Spreng, 1952.

*Diagnosis.*—Cup widely flaring (Pl. 4, figs. 21–23); **IBB** may or may not be visible from side; three anal plates in cup (Pl. 4, fig. 21); arms do not divide above the first **IBr**; the A ray may or may not be divided; arms uniserial with zig-zag appearance; pinnules large.

*Remarks.*—*Ramulocrinus* differs from *Decadocrinus* Wachsmuth and Springer, 1880, in number of primibrachials; *Ramulocrinus* has one per ray (Pl. 4, figs. 22, 23), whereas *Decadocrinus* has two.

#### *Ramulocrinus milleri* (Wetherby, 1881)

Plate 4, figures 20–23

1881. *Poteriocrinus milleri* Wetherby, p. 330, pl. 9, figs. 12, 13.

1886. *Decadocrinus milleri* (Wetherby). Wachsmuth and Springer, p. 239.

*Diagnosis.*—Column round, does not fill basal invagination; crown small and cylindrical; **IBB** small and nearly concealed by column; all plates of dorsal cup, including anal plates, exhibit tubercular ornamentation (Pl. 4, fig. 20); anal sac cylindrical(?), two-thirds height of crown, small vertical spine on top; 10 arms, two per ray; one **IBr** per ray, higher than wide, constricted medially (Pl. 4, figs. 21–23); **Brr** higher than wide, zig-zag appearance (Pl. 4, figs. 22, 23), and in some specimens, may be spiny; stout pinnules borne on alternate sides of succeeding **Brr**.

*Remarks.*—*Ramulocrinus* differs from *Decadocrinus*

by having one primibrachial per ray instead of two. Because this species has only one primibrachial per ray, we place it in *Ramulocrinus*. *Ramulocrinus* was likely derived from *Decadocrinus* through fusion of the primibrachials. This derivation is suggested by one of our specimens (UK 115690) that has relict sutures in the medial constriction on two primibrachials (Pl. 4, fig. 23). Laudon, Parks, and Spreng (1952), who erected the genus *Ramulocrinus*, failed to include this species therein.

*Occurrence.*—Upper Mississippian (Middle Chesterian). Localities 3, 5.

*Material.*—UK 115682–115694 and 115696, topotypes, and UK 115695. UK 115685, 115687, and 115690 also are hypotypes.

#### Superfamily CROMYOCRINACEA

Bather, 1890

#### Family PHANOCRINIDAE Knapp, 1969

#### Genus PHANOCRINUS Kirk, 1937

*Type species.*—*Zeacrinus formosus* Worthen, 1873.

*Diagnosis.*—Low, bowl-shaped dorsal cup (Pl. 5, figs. 1–6, 8); basal invagination involving **IBB** and portions of **BB** (Pl. 5, fig. 7); cup may or may not be constricted at top; **RR** generally touching basal plane and curving upward from it; two to three anal plates in cup; anal sac (Pl. 5, fig. 8) terminated with single, elongate spine; nine to ten arms; first **IBr** axillary in all rays, except the anterior ray in nine-armed forms.

*Remarks.*—We do not agree with the division of *Phanocrinus* into two separate genera by Burdick and Strimple (1969) and Moore, Lane, and Strimple (1978). They have retained the name *Phanocrinus* for those forms with radials that curve inward at the superior end; those forms with vertical radials are called *Pentaramicrinus* Sutton and Winkler, 1940. Previously, *Pentaramicrinus* included forms with only five arms. Burdick and Strimple (1969) believed that the curvature of the radials was more significant than the number of arms. They included seven species previously included in *Phanocrinus* (all with more than five arms) within the genus *Pentaramicrinus* because of their vertical radials. According to them, this division leaves *Phanocrinus* with only those species containing 10 arms. However, Burdick and Strimple (1969) also included *P. manifoldis* (Yandell and Shumard, 1847) and *P. bellulus* (Miller and Gurley, 1894) in *Phanocrinus*. These species very possibly have only nine arms. The original description of *P. manifoldis* indicated nine arms; however, the holotype is missing. In *P. bellulus*, the lower portion of the anterior ray is not visible, but there appear to be nine arms distally. We believe that all nine- and 10-armed forms should be included in the genus *Phanocrinus*.



**Phanocrinus manifoldis**  
(Yandell and Shumard, 1847)  
Plate 5, figures 1-8

1847. *Cyathocrinus manifoldis* Yandell and Shumard, p. 25, fig. 2.  
 1855. *Poteriocrinus manifoldis* (Yandell and Shumard). Shumard, p. 217.  
 1858. *Zeacrinus manifoldis* (Yandell and Shumard). Hall, p. 682, pl. 25, fig. 8.  
 1873. *Zeacrinus formosus* Worthen, p. 549, pl. 21, fig. 2.  
 1879. *Scytalocrinus manifoldis* (Yandell and Shumard). Wachsmuth and Springer, p. 340.  
 1886. *Eupachycrinus manifoldis* (Yandell and Shumard). Wachsmuth and Springer, p. 173.  
 1894. *Zeacrinus bellulus* Miller and Gurley, p. 34, pl. 3, fig. 8.  
 1894. *Zeacrinus cylindricus* Miller and Gurley, p. 38, pl. 3, figs. 19-21.  
 1937. *Phanocrinus formosus* (Worthen). Kirk, p. 603, pl. 84, figs. 1, 2.  
 1939. *Phanocrinus cylindricus* (Miller and Gurley). Sutton and Hagan, p. 83.  
 1939. *Scytalocrinus? bellulus* (Miller and Gurley). Sutton and Hagan, p. 83.  
 1940. *Phanocrinus formosus* (Worthen). Sutton and Winkler, p. 553, pl. 68, figs. 17-19.  
 1940. *Phanocrinus cylindricus* (Miller and Gurley). Sutton and Winkler, pp. 553, 554, pl. 66, figs. 11, 12.  
 1940. *Phanocrinus manifoldis* (Yandell and Shumard). Sutton and Winkler, p. 554, pl. 67, figs. 3, 4.  
 1940. *Phanocrinus bellulus* (Miller and Gurley). Sutton and Winkler, pp. 554, 555, pl. 66, figs. 6, 7.  
 1940. *Phanocrinus compactus* Sutton and Winkler, p. 555, pl. 67, figs. 7, 8.  
 1940. *Phanocrinus inflatoramus* Sutton and Winkler, p. 555, 556, pl. 67, figs. 14, 15.  
 1951a. *Phanocrinus cylindricus* (Miller and Gurley). Strimple, pp. 291, fig. 11.  
 1965. *Phanocrinus compactus* Sutton and Winkler. Horowitz, p. 32, pl. 3, figs. 7-9.  
 1965. *Phanocrinus* cf. *P. formosus* (Worthen). Horowitz, pp. 32, 33, pl. 3, figs. 13-15.  
 1969. *Phanocrinus bellulus* (Miller and Gurley). Burdick and Strimple, pp. 4, 9.  
 1969. *Pentaramicrinus compactus* (Sutton and Winkler). Burdick and Strimple, pp. 4, 9.  
 1969. *Phanocrinus cylindricus* (Miller and Gurley). Burdick and Strimple, pp. 4, 9.  
 1969. *Phanocrinus formosus* (Worthen). Burdick and Strimple, pp. 4, 9.  
 1969. *Pentaramicrinus inflatoramus* (Sutton and Winkler). Burdick and Strimple, pp. 4, 9.  
 1969. *Phanocrinus manifoldis* (Yandell and Shumard). Burdick and Strimple, pp. 4, 9.  
 1973b. *Phanocrinus bellulus* (Miller and Gurley). Strimple and Moore, p. 5, figs. 2(1-3), 3(4).  
 1973b. *Phanocrinus* sp. cf. *P. formosus* (Worthen). Strimple and Moore, p. 5, fig. 4.  
 1973b. *Phanocrinus* sp. cf. *P. cylindricus* (Miller and Gurley). Strimple and Moore, p. 5, fig. 3(1-3).  
 1973b. *Phanocrinus planus* Strimple and Moore, p. 6, fig. 6 (1-6).

**Diagnosis.**—Column round (Pl. 5, fig. 1); dorsal cup moderately low, basin-shaped (Pl. 5, figs. 1-6, 8); **IBB** small but not hidden by column (Pl. 5, fig. 7); **BB**

visible from side (Pl. 5, figs. 1, 2, 5); nine to 10 arms, long, uniserial, about eight times longer than height of dorsal cup; **IBrr** one per ray (except in anterior ray in nine-armed forms); **Brr** short, quadrangular, and bear short, stout pinnules.

**Remarks.**—Having examined the many species of *Phanocrinus* described from the eastern Midcontinent, we are convinced that many of the species are conspecific. Examination of these species leads us to place six of the species in synonymy with *P. manifoldis* (Yandell and Shumard, 1847). Even though *P. manifoldis* was poorly described and illustrated, there can be little doubt that the type is the same as the more commonly cited *P. cylindricus* (Miller and Gurley, 1894). The cup is low and basin-shaped with distal parts of the basals visible in side view. The arms have the same sub-fusiform shape and are composed of uniserially arranged, quadrangular brachials. The two species are certainly synonymous, but *P. manifoldis* has priority.

*Phanocrinus bellulus* (Miller and Gurley, 1894) and *P. inflatoramus* Sutton and Winkler, 1940, are two species that differ so slightly from the concept of *P. manifoldis* (or *P. cylindricus*) that the differences are not really significant, in our view. In *P. inflatoramus*, the primibrachials are extremely wide compared to their height, and the arms are unusually inflated. We believe that these variations are intraspecific, and although not common in our assemblage, some of our specimens exhibit these traits. *P. bellulus*, on the other hand, is characterized by high primibrachials and a deep basal concavity; again, these characters, which we deem to be intraspecific, occur in some of the specimens from our assemblage.

*Phanocrinus formosus* (Worthen, 1873) is another commonly cited species, but it is based only on a dorsal cup. According to Sutton and Winkler (1940), *P. formosus* is differentiated from *P. manifoldis* (or *P. cylindricus*) on the basis of granulated plates and basals that are not depressed as they join the infrabasals. The presence of granules on the plates is a product of preservation; some of our specimens from the same horizon exhibit them, whereas others do not. The depressed nature of the basals is another trait that we deem to be intraspecific. Again, some of our specimens from the same horizon and locality exhibit variations on this trait.

*Phanocrinus compactus* Sutton and Winkler, 1940, on the other hand, was characterized as a small species with closely-knit sutures and an unusually large anal X plate. The anal interray is highly variable in this species; hence, the unusually large anal X plate does not seem significant. The small size, compact nature, and well-closed sutures are characteristics that we have



commonly observed in our smaller specimens, and for this reason we suggest that *P. compactus* is merely a juvenile form of *P. maniformis*.

Although we have not examined the types, *P. planus* Strimple and Moore, 1973b, is almost certainly conspecific with *P. maniformis*. The distinguishing planate base is no more planate than the bases of many other variants included in *P. maniformis*.

*Phanocrinus maniformis* and all its variants, however, differ markedly from four other common Chesterian species. *P. fragosus* Sutton and Winkler, 1940, is one of the earliest species (from the Early Chesterian Renault Fm.) and is characterized by small size and delicate construction; one or two primibrachials may occur. We have noticed that an increased number of primibrachials and a small, delicate construction characterize the early species of this and some other common Chesterian genera. *P. nitidus* (Miller and Gurley, 1894) has an unusually constricted calyx at the level of the primibrachials and has short, stout arms composed of irregularly-rectangular to cuneate brachials. *P. parvaramus* Sutton and Winkler, 1940, is characterized by an extremely low, broad, saucer-shaped dorsal cup, relatively short arms, and tumid plates. *P. cooksoni* Laudon, 1941, has more rounded petaliform basals compared to the angular basals of *P. maniformis*. The arms are also stouter and taper more rapidly.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 1, 3, 5.

*Material.*—UK 115585, 115702–115788, 116070; UK 115741, 115749, 115750, 115753, and 115786 are hypotypes.

***Phanocrinus parvaramus***  
Sutton and Winkler, 1940  
Plate 5, figures 9–11

1940. *Phanocrinus parvaramus* Sutton and Winkler, p. 556, pl. 67, figs. 9, 10.  
1940. *Agenaracrinus parvabasalus* Sutton and Winkler, p. 565, pl. 68, figs. 3, 4.  
1948. *Phanocrinus alexanderi* Strimple, pp. 490–493, pl. 77, figs. 1–6.  
1965. *Phanocrinus parvaramus* Sutton and Winkler. Horowitz, pp. 30, 31, pl. 3, figs. 1–3.  
1969. *Phanocrinus parvaramus* Sutton and Winkler. Burdick and Strimple, pp. 3, 4.  
1973b. *Phanocrinus parviramus* [sic] Sutton and Winkler. Strimple and Moore, p. 2, fig. 1, nos. 1, 2.

*Diagnosis.*—Low, saucer-shaped dorsal cup (Pl. 5, fig. 10); smooth, slightly tumid plates (Pl. 5, figs. 10, 11); **IBB** largely hidden by column (Pl. 5, figs. 9, 11); **BB** slightly tumid, distalmost quarter visible from side; **RR** much more tumid than **BB**, three-fourths as high as wide, occupy almost entire height of cup. Anal area variable, one to three plates in cup; **RA** large, fairly

tumid; anal **X** may or may not touch **CD** basal; 10 short uniserial arms, constricted at **IBrr** (Pl. 5, fig. 10); **Brr** rounded, quadrangular to slightly cuneate.

*Remarks.*—*P. parvaramus* Sutton and Winkler, 1940, is an easily-recognized species whose type was collected from the Sloans Valley locality. The plates are much more tumid than most species of *Phanocrinus*, and the dorsal cup is low, broad, and saucer-shaped (Pl. 5, fig. 10) compared to the higher, bowl-shaped cups of other species. The basals are barely visible because of the large size of the radials (Pl. 5, fig. 10). The arms are relatively small and may exhibit a peculiar mid-length constriction (Pl. 5, fig. 10), although this constriction is not universal among specimens. The anal interray is highly variable in this species, and one to three anal plates may occur in the cup.

We have placed *P. alexanderi* Strimple, 1948, in synonymy with *P. parvaramus*, because in nearly every aspect Strimple's species is identical to *P. parvaramus*. Strimple (1948) cited as differences the presence of slightly cuneate brachials and the height (distalmost) at which the arms begin to taper. Our specimens and the holotype exhibit both traits.

Although Burdick and Strimple (1969) suggested that *P. parvaramus* and *P. cylindricus* (*P. maniformis*) may be synonymous, our examination of the material does not support this contention.

*Occurrence.*—Upper Mississippian (Middle and Upper Chesterian). Localities 2, 3, 5.

*Material.*—UK 115789–115796. UK 115789, 115790, and 115792–115796 are topotypes, whereas UK 115796 and UK 115794 also are hypotypes.

**Genus PENTARAMICRINUS**  
Sutton and Winkler, 1940

*Type species.*—*Cromyocrinus gracilis* Wetherby, 1880.

*Diagnosis.*—Tall, cylindrical crown (Pl. 5, figs. 12, 13); bowl-shaped dorsal cup, not constricted at summit (Pl. 5, figs. 12, 13); anal plates variable; anal sac tubular, composed of small polygonal plates, two rows of spines at top; five uniserial arms.

*Remarks.*—*Pentaramicrinus* previously included only five-armed forms (Sutton and Winkler, 1940), but Burdick and Strimple (1969) revised the genus to include all species of *Phanocrinus* Kirk, 1937 that have vertical radials. The number of arms was not considered to be significant by them; hence, the genus *Pentaramicrinus* contained nine- and 10-armed forms as well as five-armed forms. We believe that in this case, the number of arms is far more significant than the orientation of the radials. Therefore, we use *Pentaramicrinus* in the sense that Sutton and Winkler intended, for five-armed phanocrinids.



**Pentaramicrinus gracilis**

(Wetherby, 1880)

Plate 5, figures 12, 13, Text-figure 24

1880. *Cromyocrinus gracilis* Wetherby, p. 248, pl. 16, figs. 2a-e.  
 1886. *Eupachyrcrinus gracilis* (Wetherby). Wachsmuth and Springer, p. 249.  
 1895. *Zeacrinus pulaskiensis* Miller and Gurley, p. 47, pl. 4, figs. 12, 13.  
 1937. *Phanocrinus gracilis* (Wetherby). Kirk, p. 606, pl. 84, fig. 13.  
 1940. *Pentaramicrinus gracilis* (Wetherby). Sutton and Winkler, pp. 558, 559, pl. 66, figs. 14, 15.  
 1940. *Pentaramicrinus magniradianalis* Sutton and Winkler, p. 559, pl. 68, figs. 24, 25.  
 1940. *Pentaramicrinus pulaskiensis* (Miller and Gurley). Sutton and Winkler, p. 559, pl. 66, figs. 1, 2.  
 1969. *Pentaramicrinus gracilis* (Wetherby). Burdick and Strimple, p. 3.

**Diagnosis.**—**IBB** hidden by column; variable anal-plate arrangement; five long, stout arms, which are 10 times higher than the height of the dorsal cup (Pl. 5, figs. 12, 13); **Brr** quadrangular, alternately bearing stout pinnules (Pl. 5, fig. 13).

**Remarks.**—This specimen is one of three *Pentaramicrinus* species originally described from Pulaski County, Kentucky. Burdick and Strimple (1969) considered all three to be synonymous with *P. gracilis*; they differed only in anal-plate arrangement (Text-fig. 24), which in many phanocrinid species is known to vary. We agree that all three species are probably conspecific.

**Occurrence.**—Upper Mississippian (Middle and Upper Chesterian). Locality 1.

**Material.**—UK 115797 and 115798 (topotypes).

Family **EUPACHYCRINIDAE** Miller, 1889Genus **EUPACHYCRINUS**

Meek and Worthen, 1865

1865. *Eupachyrcrinus* Meek and Worthen, p. 159.  
 1940. *Intermediacrinus* Sutton and Winkler, pp. 559–561.  
 1943. *Eupachyrcrinus* Meek and Worthen. Moore and Laudon, p. 62.  
 1943. *Eupachyrcrinus* Meek and Worthen. Bassler and Moodey, p. 470.  
 1969. *Eupachyrcrinus* Meek and Worthen. Burdick and Strimple, p. 6.  
 1969. *Intermediacrinus* Sutton and Winkler. Burdick and Strimple, pp. 7, 8.  
 1978. *Eupachyrcrinus* Meek and Worthen. Moore, Lane, and Strimple, p. T690.  
 1978. *Intermediacrinus* Sutton and Winkler. Moore, Lane, and Strimple, p. T690.

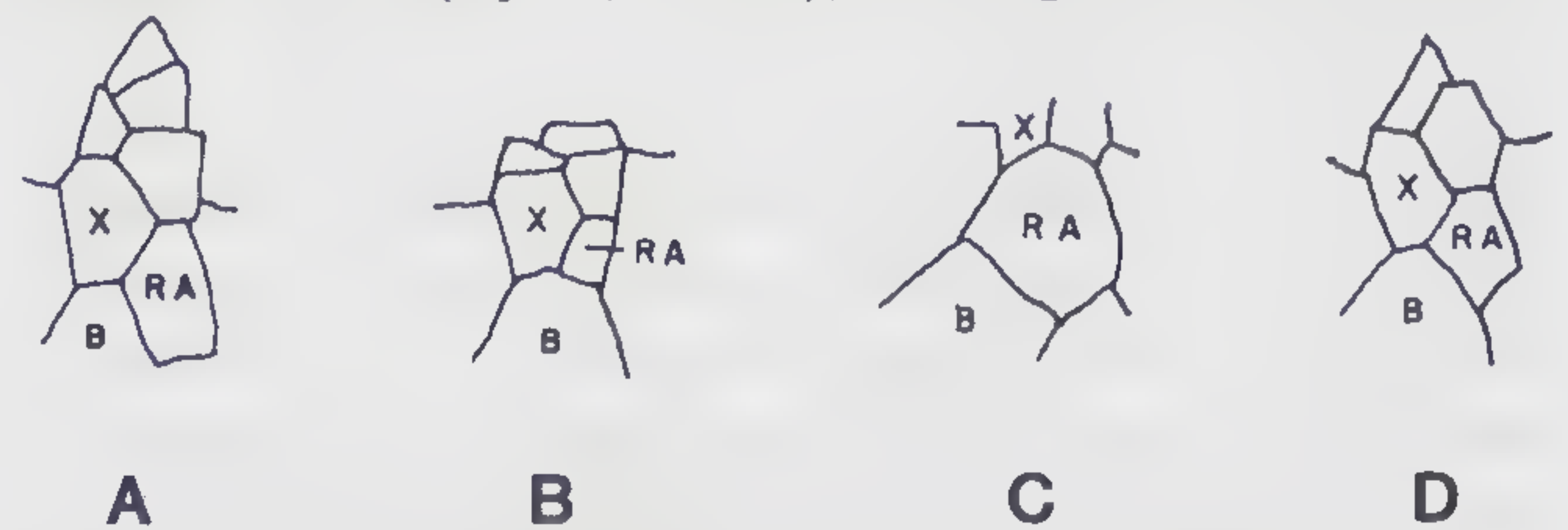
**Type species.**—*Graphiocrinus quatuordecembrachialis* Lyon, 1857.

**Diagnosis.**—Column round with nodals and internodals; crown generally elongate, tapering distally (Pl. 5, figs. 14, 15); cup low, bowl-shaped (Pl. 5, figs. 14, 15) with deep basal invagination (Pl. 5, fig. 17); two

to three anal plates in cup; elongate anal sac terminated with single, elongate spine; 13 to 15 arms, biserial (Pl. 5, figs. 14–16); first **IBr** axillary in all rays (Pl. 5, figs. 14–16); first **IIBr** axillary on anterior side of B, C, D, and E rays (Pl. 5, fig. 15); second **IIBr** may or may not be axillary on posterior side of C ray; two arms in A ray, three arms in B, D, and E rays, and three or four arms in C ray.

**Remarks.**—The nature and histories of the genera *Eupachyrcrinus* and *Intermediacrinus* have been inextricably interwoven since the genus *Intermediacrinus* was defined from *E. asperatus* Worthen, 1882, by Sutton and Winkler (1940). We suggest that the two genera be placed in synonymy. *Intermediacrinus* was originally defined from *E. asperatus* based on differences in the number of anal plates. However, recognition of much variation in this character prompted Moore and Laudon (1943) and Bassler and Moodey (1943) to place the two genera in synonymy. Strimple (1961), however, accepted *Intermediacrinus* as a valid genus because the arm structure in the type species, *I. asperatus*, differed from arm structure typical of *Eupachyrcrinus*. Specifically, *Intermediacrinus* was purported to exhibit four arms in the right posterior ray, whereas *Eupachyrcrinus* typically exhibits three arms in this ray. No major differences occur in the anal interray of the two forms. Furthermore, Burdick and Strimple (1969) indicated that *Intermediacrinus* was found only in Lower Chesterian horizons. In our study area, however, we have a single specimen that contradicts this. In our Middle Chesterian horizon, a single 15-armed specimen (four arms in right posterior ray) was found (Pl. 5, fig. 15); it is identical in every other way with three other 14-armed forms (Pl. 5, fig. 14) referred to *Eupachyrcrinus*. Although our assemblage (four specimens) is small, the similarity of our specimens, except for the number of arms in the 15-armed form, and the fact that they occur in the same horizon, leads us to conclude that the number of arms also is probably a variable trait. For this reason, we choose to place *Eupachyrcrinus* and *Intermediacrinus* in synonymy.

In our examination of various species of *Eupachyrcrinus*, we have noted two major groups that within themselves appear to be synonymous. *E. quatuordecembrachialis* (Lyon, 1857), *E. asperatus* Worthen,



Text-figure 24.—Anal-plate arrangements in *Pentaramicrinus*. A. *P. gracilis*; B. *P. pulaskiensis*, n. comb.; C. *P. magniradianalis*; D. specimen of *P. gracilis* found in this study. B = basal; RA = radial; X = anal-X.



1882, and possibly *E. davidsoni* Burdick and Strimple, 1969, appear to represent a single species characterized by a crown with its greatest width at the level of the primibrachials. *E. boydii* Meek and Worthen, 1870, *E. spartarius* Miller, 1879, *E. germanus* Miller, 1879, *E. durabilis* (Miller and Gurley, 1895), *E. irregularis* Sutton and Winkler, 1940, and *E. variabilis* (Sutton and Winkler, 1940) appear to represent another species characterized by a crown with its greatest width at the level of the radials. This species will be described in the following section.

**Eupachyrcrinus boydii**

Meek and Worthen, 1870

Plate 5, figures 14–17

1870. *Eupachyrcrinus boydii* Meek and Worthen, p. 30.  
 1873. *Eupachyrcrinus boydii* Meek and Worthen. Meek and Worthen, p. 554, pl. 21, fig. 6.  
 1879. *Eupachyrcrinus spartarius* Miller, p. 38, pl. 8, fig. 2.  
 1879. *Eupachyrcrinus germanus* Miller, p. 40, pl. 8, fig. 3.  
 1895. *Zeacrinus durabilis* Miller and Gurley, p. 48, pl. 4, figs. 14, 15.  
 1940. *Eupachyrcrinus irregularis* Sutton and Winkler, p. 551, pl. 66, figs. 8–10.  
 1940. *Intermediacrinus variabilis* Sutton and Winkler, p. 562, pl. 67, fig. 11.  
 1965. *Eupachyrcrinus germanus* Miller. Horowitz, p. 34, pl. 3, figs. 4–6.  
 1965. *Eupachyrcrinus spartarius* Miller. Horowitz, pp. 34, 35, pl. 3, figs. 10–12.  
 1965. *Eupachyrcrinus boydii* Meek and Worthen. Horowitz, pp. 35–37, pl. 3, figs. 16–18.

*Diagnosis.*—Greatest width of crown generally within dorsal cup; **IBrr**, **IIBrr**, and dorsal cup slightly to moderately tumid (Pl. 5, figs. 14–16).

*Remarks.*—The five species listed above are placed in synonymy with *E. boydii*. *E. durabilis* was differentiated based on its small size and short arms; it probably represents a juvenile (Burdick and Strimple, 1969). *E. germanus* is a small form that was differentiated on the shape of its crown, whereas *E. irregularis* was defined on its large size and the irregular development of 13 arms instead of 14. *E. spartarius* was characterized by the shape and size of its anal plates, and *E. variabilis* was defined both on the shape of its dorsal cup and the nature of its anal plates.

We believe that most of the above discriminating characteristics represent intraspecific variations or ontogenetic variations found in juveniles. Moreover, four of the five species placed in synonymy (*E. durabilis*, *E. germanus*, *E. irregularis*, and *E. spartarius*) were originally described from the Sloans Valley locality. Excepting the intraspecific and ontogenetic variations, we believe that all these species are generally so similar in appearance and occurrence as to warrant synonymy.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 1, 3, 5.

*Material.*—UK 115799, 115800–115802, all hypotypes.

Subclass FLEXIBILIA Zittel, 1879

Order TAXOCRINIDA Springer, 1913

Superfamily TAXOCRINACEA Angelin, 1878

Family SYNEROCRINIDAE Jaekel, 1918

Genus ONYCHOCRINUS

Lyon and Casseday, 1860

*Type species.*—*Onychocrinus exsculptus* Lyon and Casseday, 1860.

*Diagnosis.*—Round column widening toward cup (Pl. 6, figs. 1–4); **IBB** low but not hidden by column (Pl. 6, figs. 3, 4); C–D basal elongate; **RA** in upper oblique position between C–D basal and C radial or absent; three to six **IBrr** per ray (Pl. 6, fig. 1); arms divide heterotomously after first dichotomy (Pl. 6, figs. 1, 2); 10 main-arm trunks, rays widely separated above **IBrr**.

**Onychocrinus pulaskiensis**

Miller and Gurley, 1895

Plate 6, figures 1–4

1894. ?*Onychocrinus parvus* Miller and Gurley, p. 52, pl. 4, fig. 5.  
 1895. *Onychocrinus pulaskiensis* Miller and Gurley, p. 40, pl. 4, figs. 1, 2.  
 1920. *Onychocrinus pulaskiensis* Miller and Gurley. Springer, pp. 421, 437, pl. 74, figs. 1–10; pl. 75, figs. 15a–b.  
 1965. *Onychocrinus pulaskiensis* Miller and Gurley. Horowitz, pp. 39, 40, pl. 4, figs. 11, 12.

*Diagnosis.*—Column thicker than that of other species, with projecting, convex nodals (Pl. 6, fig. 3); crown large (Pl. 6, figs. 1, 2); one large **iBr** between each ray overlain distally by perisome; three **IBrr** per ray (Pl. 6, fig. 1); two to three **IIBrr** before first ramule (Pl. 6, fig. 1); ramules extend almost at right angles from the arms every two to three **Brr** (Pl. 6, figs. 1, 2); axillary **Brr** nodose to spiny, arms divergent; no **iBr** connecting ramules with arms; rays deeply rounded, **Brr** equidimensional.

*Remarks.*—*Onychocrinus pulaskiensis* Miller and Gurley, 1895, is a species that belongs to the *O. ramulosus* group of Springer (1920), and it is similar to other species in this group. In general, the arms of *O. pulaskiensis* are more divergent than the arms of other species in the group, and no interbrachials connect the ramules with the arms. *O. pulaskiensis* differs from *O. ramulosus* (Lyon and Casseday, 1859) in the presence of fewer and higher divergent ramules, in the absence of interbrachial plates between ramules and the main arm, and in the presence of spinose axillaries. *O. distensus* Worthen, 1882, is an earlier species with more widely spaced ramules and four primibrachials, rather than the three that characterize *O. pulaskiensis*. *O.*



*magnus* Worthen, 1875, has three to four primibrachials and has a greater number of smaller ramules in clusters. *O. liddelensis* Wright, 1954, and *O. wrighti* Springer, 1920, are both British forms that have pustulose ornamentation and lack spinose axillaries. *O. parvus* Miller and Gurley, 1894, is a juvenile with generalized, indistinguishable characters; it comes from the same locality as the holotype of *O. pulaskiensis*. As suggested by Springer (1920) and Horowitz (1965), the two forms probably represent the same species. Nonetheless, even though *O. parvus* has priority, it is technically a *species inquirerenda* because of its indistinguishable traits, and is not available as the species name.

**Occurrence.**—Upper Mississippian (Chesterian). Locality 3.

**Material.**—UK 115855–115863 (topotypes).

#### Family TAXOCRINIDAE Angelin, 1878

##### Genus TAXOCRINUS Phillips, in Morris, 1843

**Type species.**—*Cyathocrinus? macrodactylus* Phillips, 1841.

**Diagnosis.**—Column enlarges proximally (Pl. 6, fig. 7); **IBB** low, sometimes hidden by column; C–D basal elongate; **RA** in upper oblique position if present; eccentric anal opening at end of anal tube; anal tube formed by extension of perisome (Pl. 6, fig. 8), supported by vertical series of anal plates; tegmen composed of calcareous spicules embedded in pliant membrane; ambulacra extend from arms, between paired orals, to the open mouth; **iBrr** variable in number, but usually numerous (Pl. 6, fig. 5); rays do not abut above interrays; two to three **IBrr** (Pl. 6, figs. 5–7); arms are divergent and dichotomous, branching isotomously above main dichotom (Pl. 6, figs. 6, 7).

#### *Taxocrinus whitfieldi* (Hall, 1858)

##### Plate 6, figures 5–8

1858. *Forbesiocrinus whitfieldi* Hall, p. 632, text-fig. 104.  
 1860. *Forbesiocrinus cestriensis* Hall, p. 68.  
 1873. *Onychocrinus whitfieldi* (Hall). Meek and Worthen, p. 552, pl. 20, fig. 3.  
 1879b. *Forbesiocrinus parvus* Wetherby, p. 138, pl. 11, figs. 4a–b.  
 1895. *Taxocrinus wetherbyi* Miller and Gurley, p. 41, pl. 4, figs. 3–5.  
 1920. *Taxocrinus whitfieldi* (Hall). Springer, pp. 382, 408, pl. 60, figs. 1–11.  
 1973. *Taxocrinus cestriensis* (Hall). Burdick and Strimple, pp. 227, 228, text-figs. 1a–3, text-figs. 2b–c.

**Diagnosis.**—Column enlarged proximally, composed of very thin plates proximally, thicker plates distally (Pl. 6, fig. 7); medium-size species with a broad, short crown (Pl. 6, figs. 6, 7); inward curvature starts

at **IVBrr** (Pl. 5, figs. 6, 7); height-to-width ratio about 1:2 in mature specimens; calyx continuous to level of **IIBrr** except on posterior side (Pl. 6, figs. 5–7); **IBB** low; **BB** large and may contact **IBrr** in some interrays; two to three **IBrr** per ray, typically three (Pl. 6, figs. 5–7); one to three **IIBrr** per ray, typically two and three; **IBrr** and **IIBrr** wholly incorporated into calyx wall (Pl. 6, figs. 5–7); two to three **IIIBrr** in inner arms and three to four in outer arms (Pl. 6, figs. 6, 7); approximately four bifurcations per ray, fourth occurs near inward flexure of arms (Pl. 6, figs. 6, 7); free arms small and delicate; suture between **Brr** sinuous; **iBrr** only slightly depressed and larger in lower three levels; fourth-level **Brr** are smaller and connected to perisome.

**Remarks.**—*Taxocrinus whitfieldi* (Hall, 1858) is one of a group of four closely-related species also including *T. giddingsei* (Hall, 1858), *T. shumardianus* (Hall, 1858), and *T. huntsvillae* Springer, 1920. *T. giddingsei* is easily distinguished from the other three species by the presence of strong plates on either side of the anal tube. The remaining three species exhibit a perisome of very small plates surrounding the tube. However, these three species are more difficult to differentiate from each other, and *T. whitfieldi* may share characteristics with all of them.

The crown of *T. shumardianus* is generally smaller, interbrachials are fewer in number, and the basals make contact with the first interbrachials in all rays. *T. huntsvillae*, on the other hand, has narrower, more elevated rays rather than the low, rounded rays of *T. shumardianus* and *T. whitfieldi*; like *T. shumardianus*, basals make contact with the first interbrachials.

*Taxocrinus whitfieldi* is generally a larger form with a low, broad crown, which exhibits a larger number of more robust interbrachial plates; the anal tube is surrounded by perisome. In some specimens, basals in up to three interrays may make contact with first interbrachials. The other three species generally have three secundibrachials per ray, whereas *T. whitfieldi* typically exhibits only two, although a few rays in three of our specimens exhibit three secundibrachials. This same character was used by Burdick and Strimple (1973) to resurrect the species *T. cestriensis* (Hall, 1860). According to Burdick and Strimple (1973), forms placed in *T. whitfieldi* with one or more rays exhibiting three secundibrachials should be placed in the species *T. cestriensis*. However, we follow the practice of Springer (1920) and place *T. cestriensis* in synonymy with *T. whitfieldi* because our assemblage shows both variations, leading us to conclude that they are intraspecific.

Throughout the species as a whole, nearly any combination of two to three primibrachials, one to three secundibrachials, and contact of up to three basals with the first interbrachials, may occur. In effect, this sug-



gests that the species was very flexible for these characteristics, and that any use of combinations of these characters may be inadequate for species differentiation.

Our assemblage of *T. whitfieldi* supports the observations of Burdick and Strimple (1971) and Horowitz and Strimple (1974) regarding a systematic reduction in the number of secundibrachials through time. Most of our specimens exhibit only the two secundibrachials characteristic of the late Middle Chesterian populations referred to *T. whitfieldi*. While we believe that specimens with combinations of two and three secundibrachials, referred to *T. cestriensis*, are intermediate between *T. shumardianus* (mostly three secundibrachials) and *T. whitfieldi* (mostly two secundibrachials), we do not believe that the differences between *T. cestriensis* and *T. whitfieldi* are sufficient to warrant two separate species. Even in our assemblage, specimens referable to *T. cestriensis* are present, and we think they are little more than intraspecific variants. Clearly, the above evolutionary trend is apparent in assemblages of specimens, and hence we can designate our assemblage *T. whitfieldi* despite the presence of a few forms that considered in isolation might be referred to *T. cestriensis*. However, what happens when one is not dealing with an assemblage, but rather one or two specimens? Then one is reduced to reliance on some arbitrarily-defined number of secundibrachials, which we know may vary, or worse yet, on stratigraphy, to define taxa.

We believe that some more substantial differences, such as those found in *T. shumardianus* (number of interbrachials and relationship between basals and intrabrachials) are necessary to separate the species. However, because the number of secundibrachials may have biostratigraphic value, workers may find it useful to continue using the names "*cestriensis*" and "*whitfieldi*" within the species *T. whitfieldi*, as varieties or subspecies.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 3, 5, 6.

*Material.*—UK 115577, 115864, 115866–115874, 115876–115887; UK 115577, 115881, and 115885 are hypotypes.

Subclass CAMERATA

Wachsmuth and Springer, 1885

Order MONOBATHRIDA

Moore and Laudon, 1943

Suborder COMPSOCRININA Ubaghs, 1978

Superfamily HEXACRINITACEA

Wachsmuth and Springer, 1885

Family DICHOOCRINIDAE Miller, 1889

Subfamily TALAROCRININAE Ubaghs, 1953

Genus PTEROTOCRINUS

Lyon and Casseday, 1859

*Type species.*—*Asterocrinus capitalis* Lyon, 1857.

*Diagnosis.*—Column round, small; dorsal cup saucer- to bowl-shaped, wider than high, tegmen pyramidal, higher than cup; two **BB**, pentagonal in outline and **B** circlet excavated at C–D side for the single anal plate and on anterior side for anterior A radial; one small, triangular **IBr** occurs on each **R** and may be hidden from external view; each **IBr** supports two axillary **IIBrr**; these **IIBrr** meet above **IBr**, rest laterally on **R**; **IIBrr** support two **IIIBrr**, one above does not touch **R**, whereas outer one rests laterally on **R**. Primanal or tergal typically elongate, smaller than **RR**. Species of the genus typically have 20 short, biserial arms; each ray, consisting of four or six arms, is divided into two groups by one of five tegminal appendages or "wing plates". Nearly central anus surrounded by many tiny plates that form small protuberance or cone; large oral plates rest directly upon uppermost **iambb**; posterior oral plate wedged between other four.

*Remarks.*—The best known features of *Pterotocrinus* are the tegminal appendages called "wing plates". They show great variation in form and size between species and even within single assemblages. Even though we have placed in synonymy all the form species based on wing plate shape and size, workers may find it useful to continue using the various names applied to individual forms of wing plates within the two species we recognize, perhaps like varieties, because some of the plate forms appear to be stratigraphically restricted. These wing plates are the most common remains of *Pterotocrinus* as a fossil. In fact, we have found some beds composed almost wholly of *Pterotocrinus* wing plates. The great variation in wing plates and their rapid evolutionary changes have been utilized by stratigraphers to differentiate and identify the Lower and Middle Chesterian formations in the Illinois Basin (Sutton, 1934) and Middle Chesterian formations in the Appalachian Basin in Kentucky. *Pterotocrinus* appears to be restricted to the Chesterian Series, first appearing in the Renault Limestone (lowermost Chesterian) and continuing at least through the Kinkaid Limestone (Upper Chesterian).

Almost every specimen of *Pterotocrinus* in this study was found with a coprophagous platycerid gastropod attached to the upper tegminal surface over the anal cone (Pl. 6, fig. 12; Pl. 7, fig. 8). Wachsmuth and Springer (1897) stated that in their specimens the anterior margin of the gastropod shell is oriented to the posterior side of the tegmen.



***Pterotocrinus acutus* Wetherby, 1879**  
 Plate 6, figures 9–14; Plate 7, figures 1–24;  
 Text-figure 16A

- 1879a. *Pterotocrinus acutus* Wetherby, p. 134, pl. 2, figs. 2a–c.  
 1879a. *Pterotocrinus bifurcatus* Wetherby, p. 136, pl. 2, figs. 1a–c.  
 1879b. *Pterotocrinus spatulatus* Wetherby, p. 137, pl. 2, figs. 3a–c.  
 1897. *Pterotocrinus acutus* Wetherby. Wachsmuth and Springer, p. 799, pl. 79, figs. 3a–g.  
 1897. *Pterotocrinus bifurcatus* Wetherby. Wachsmuth and Springer, p. 801, pl. 79, figs. 9a, b.  
 1926. *Pterotocrinus acutus* Wetherby. Springer, p. 50, pl. 13, fig. 16.  
 1926. *Pterotocrinus bifurcatus* Wetherby. Springer, p. 50, pl. 14, fig. 5.  
 1934. *Pterotocrinus acutus* Wetherby. Sutton, p. 411, pl. 50, figs. 10–13.  
 1934. *Pterotocrinus bifurcatus* Wetherby. Sutton, p. 412, pl. 50., figs. 14–16.  
 1934. *Pterotocrinus spatulatus* Wetherby. Sutton, p. 410, pl. 50, figs. 5–8.  
 1965. *Pterotocrinus acutus* Wetherby. Horowitz, p. 42, pl. 5, figs. 7–9.  
 1965. *Pterotocrinus bifurcatus* Wetherby. Horowitz, p. 41, pl. 4, figs. 5–10.  
 1965. *Pterotocrinus spatulatus* Wetherby. Horowitz, p. 44, pl. 5, figs. 14, 15.  
 1965. *Pterotocrinus* sp. B. Horowitz, p. 48, pl. 5, figs. 4, 6.  
 1965. *Pterotocrinus* sp. C. Horowitz, p. 49, pl. 5, fig. 20.

**Diagnosis.**—*Pterotocrinus* with lobate dorsal cup outline at level of **III Brr** in plane view from base (Pl. 7, figs. 1, 5, 6), dorsal cup somewhat conical (Pl. 7, figs. 2, 4, 7); tegminal wing plates elongate and generally acutely pointed (Pl. 6, figs. 9–14); however, many variations in shape may occur: some are flat in different planes, some are pointed, some bifurcate in different planes, and some are spoon-shaped (Pl. 7, figs. 9–24); most wing plates undergo marked thickening proximally (Pl. 7, figs. 3, 8, 9–24); wing plate attachment base generally triangular, as is wing plate scar on tegmen; larger specimens may exhibit small spines on lower **III Brr** and again higher up on the arms at about four-fifths of their length (Pl. 7, fig. 2); 19 to 20 arms (Pl. 7, fig. 1).

**Remarks.**—Most species of *Pterotocrinus* are based on the shape of isolated wing plates, a character that we and others (e.g., Broadhead, 1981, 1985) believe is unrealistic and subject to much intraspecific variation. As a result, many species of *Pterotocrinus* have little or no biologic integrity (Broadhead, 1981). The conditions that have led to this situation, however, are understandable. Until recently, few calyces and crowns were known; for the most part, only isolated wing plates were found. During the course of our study, nearly a dozen complete or nearly complete crowns, a number of calyces, and many wing plates were found. Our examination of the crowns and calyces indicates that *P. acutus* Wetherby, 1879a, *P. bifurcatus* Wetherby, 1879a, and *P. spatulatus* Wetherby, 1879b, should be placed in synonymy. The calyces and crowns are identical in

every way except for the shape of the wing plates. Although some differences in the height and shape of the cups and plates have been reported in the literature, we believe that they are largely the product of different ontogenetic stages, preservation, or intraspecific variation. Sutton (1934) also recognized the close relationship between these three species, and grouped them together in the same “gens” or evolutionary line.

We also have noted many variations and intergradations between the three basic shapes of wing plates that characterize the three previously-described species. Many different intergradations occur between the acutely-elongate “*acutus*” (Pl. 6, figs. 9–14) and laterally-compressed “*spatulatus*” forms (Pl. 7, fig. 14). Some of the acutely-elongate forms become laterally compressed, like “*spatulatus*” (Pl. 7, fig. 9); others exhibit two to four processes compressed in the vertical plane (Pl. 7, figs. 11, 13). Some “*acutus*” forms bifurcate in the vertical plane (Pl. 7, fig. 20), thus approaching the “*spatulatus*” form, whereas others exhibit one or more bifurcations in a horizontal plane (Pl. 7, figs. 17, 18, 22, 23), approaching the “*bifurcatus*” form. Yet others are flattened in the horizontal plane (Pl. 7, figs. 10, 24), and a few bifurcate in both horizontal and vertical planes (Pl. 7, figs. 15, 19, 22).

The only two species that occur in the Sloans Valley member, *P. acutus* and *P. depressus* Lyon and Casse-day, 1860, are easily distinguished from each other. The wing plates of *P. acutus* generally exhibit a thickened proximal portion with a triangular attachment scar (Pl. 7, figs. 12, 13), and have a narrow blade that expands outward, perpendicular to the calyx. Moreover, the cup of *P. acutus* is somewhat conical and generally lobate at the level of the tertibrachials so that the arms of each ray are separated from the arms of other rays by an invagination in the cup (Pl. 7, fig. 1). Also, the arms are generally reflexed outward at the level of the wing plates (Pl. 7, figs. 2, 4, 6, 7). Nearly every specimen of *P. acutus* has a platycerid gastropod on the tegmen (Pl. 6, fig. 12; Pl. 7, fig. 8).

In contrast to *P. acutus*, the wing plates of *P. depressus* exhibit a thin proximal portion with a lanceolate attachment scar (Pl. 8, figs. 5, 6). The wing plates have greatly-expanded blades that do not expand as far outward from the calyx as the blades of *P. acutus* do. The cup has a broad, dish-like shape (Pl. 8, figs. 2, 4, 6) and is completely circular at the level of the tertibrachials (Pl. 8, fig. 3). The arms generally flex completely over the tegmen with no outward reflex (Pl. 8, fig. 2). Platycerid gastropods are rare on the tegmina of *P. depressus*.

One specimen of *P. acutus* with spoon-shaped wing plates (UK 115907) was found with the upper surfaces of the wing plates preserved and a centered platycerid gastropod exposed (Text-fig. 16A); the specimen was



located on the upper bedding surface of a thin grainstone bed. Upon removal of the crown, a small, round stem, 2 mm in diameter, was found in the matrix at the position of the basals. The matrix was broken away to follow the stem, which disappeared laterally into the matrix. The stem was found to be at least 6.3 cm long and was 1.5 cm below and parallel to the bedding surface (Text-fig. 16A). The arms of the specimen flexed outward at the level of the wing plates for half the length of the free arms, which suggests that the arms were bounded by sediment up to this level in life. Ettensohn (1975b) showed that *Agassizocrinus lobatus* Springer, 1926, with a similar outward flexure of the arms, lived partially buried in the sediment. The small size of the stem compared to the calyx, the buried stem and orientation of the calyx, and the flexure of the arms suggest that the crinoid may have lived in the substrata up to the level of the wing plates (Chesnut and Ettensohn, 1984). If this were the case, the role of the wing plates in *P. acutus* could have been to protect the outstretched arms lying on the substrate, to form eddying currents, to keep the crinoid from moving in a high-energy environment (the specimen was found in a grainstone), to support the crinoid on the substrate, and to protect it against shell-crushing and nipping fishes (see Welch, 1978). Baumiller and Plotnick (1985) also suggested that the wing plates may have stabilized and oriented stemmed crowns elevated in rheophilic conditions.

*P. acutus* is most commonly found in calcarenites, suggesting a preference for firm, sandy substrata.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 1, 2, 3, 5, 7.

*Material.*—UK 115573, 115574, 115889–115902, 115904–115908, 115919, 115921, 115922, 115924, 115928, 115929, 15931; USNM S-1557. UK 115899–115892, 115896–115897, 115899–115902, and 115921–115922, and USNM S-1557 are topotypes, whereas UK 115898, 115904, and 115912, and USNM S-1557 are hypotypes.

### *Pterotocrinus depressus*

Lyon and Casseday, 1860

Plate 8, figures 1–12; Text-figure 16B

1860. *Pterotocrinus depressus* Lyon and Casseday, p. 68.  
 1873. *Pterotocrinus depressus* Lyon and Casseday. Meek and Worthen, p. 599, pl. 21, fig. 13.  
 1895. *Pterotocrinus wetherbyi* Miller and Gurley, p. 44, pl. 4, figs. 6–9.  
 1897. *Pterotocrinus depressus* Lyon and Casseday. Wachsmuth and Springer, p. 796, pl. 79, figs. 2a–e.  
 1920. *Pterotocrinus menardensis* Weller, p. 373, pl. 11, fig. 9.  
 1926. *Pterotocrinus depressus* Lyon and Casseday. Springer, p. 50, pl. 14, figs. 4, 4a.  
 1934. *Pterotocrinus depressus* Lyon and Casseday. Sutton, pp. 403–405, pl. 49, figs. 7, 8, 40–44.

1934. *Pterotocrinus menardensis* Weller. Sutton, p. 405, pl. 49, figs. 47–49.  
 1934. *Pterotocrinus clorensis* Sutton, pp. 405, 406, pl. 49, figs. 52, 53.  
 1934. *Pterotocrinus vannus* Sutton, p. 408, pl. 49, figs. 9, 10.  
 1934. *Pterotocrinus wetherbyi* Miller and Gurley. Sutton, p. 416, pl. 50, figs. 1–4.  
 1965. *Pterotocrinus* sp. A. Horowitz, pp. 46–48, pl. 5, figs. 1–3.  
 1965. *Pterotocrinus depressus* Lyon and Casseday. Horowitz, pp. 45, 46, pl. 5, figs. 16–19.  
 1965. *Pterotocrinus vannus* Sutton. Horowitz, pp. 43, 44, pl. 5, figs. 10–13.

*Diagnosis.*—*Pterotocrinus* with dorsal cup outline circular at level of **IIIBrr** (Pl. 8, fig. 3), dorsal cup broadly dish-shaped (Pl. 8, figs. 2, 4, 6); tegminal wing plates generally oval to elongate oval, thin, and becoming knife-like distally (Pl. 8, figs. 1, 2, 4), highly variable in shape; wing plate attachment base and corresponding wing plate scar on tegmen is lanceolate (Pl. 8, figs. 5, 6); 20 arms, generally flexing over and resting against the tegmen (Pl. 8, figs. 1, 2).

*Remarks.*—*Pterotocrinus menardensis* Weller, 1920, *P. wetherbyi* Miller and Gurley, 1895, and *P. clorensis* Sutton, 1934, are almost certainly synonymous with *P. depressus*. *P. vannus* Sutton, 1934, and *P. vannus* of Horowitz (1965) also are synonymous with *P. menardensis*.

Sutton (1934) placed all three of the above species in the “*depressus*” evolutionary line or “gens”, and in our assemblage we have noted considerable variation in wing plate shape, ranging from *vannus*-like (Horowitz, 1965) to *clorensis*- and *menardensis*-like forms, as well as the more typical *depressus* forms. *P. wetherbyi* represents another variation of the “*depressus*” type, based on the thickness of the wing plates; the type specimen is from the Sloans Valley locality. The above considerations lead us to conclude that these wing plate forms are merely intraspecific variations.

A comparison with *P. acutus* is given in the *Remarks* section for *P. acutus*. *P. depressus* was found most commonly in shales and muddy carbonates, suggesting a preference for muddy substrates. The isolated wing plates commonly served as stable substrates for small epifaunal benthos on the muddy substrates.

*Occurrence.*—Mississippian (Chesterian). Localities 1, 3, 5, 7.

*Material.*—UK 5753, 115909–115915, 115918, 115922, 115923, 115925–115927, 115929–115930. UK 115909, 115911, 115913, 115915, and 115925 are hypotypes.

### Genus TALAROCRINUS

Wachsmuth and Springer, 1881

*Type species.*—*Dichocrinus cornigerus* Shumard, 1857.

*Diagnosis.*—Like *Dichocrinus* Münster, 1839, except



plates more massive; tegmen generally as high as cup; large central oral; arms branch on first **IBr**, biserial, four in each ray.

**Talarocrinus decornis**  
Wachsmuth and Springer, 1897  
(not figured)

1897. *Talarocrinus decornis* Wachsmuth and Springer, p. 788, pl. 3, fig. 19; pl. 78, figs. 3a-c.

*Diagnosis.*—Calyx elliptical in outline; dorsal cup higher than tegmen, plates in dorsal cup compact; sutures slightly impressed; tegmen has a single large nodose oral at the summit, other orals apparently missing; no tegminal spines.

*Remarks.*—No specimens of *Talarocrinus* were found during the course of our study, but two specimens were noted and described by Wachsmuth and Springer (1897). Their locality and stratigraphic data are imprecise, but the locality was probably close to our locality 3 (Text-fig. 1), and the stratigraphic horizon (upper St. Louis Group) probably is lithostratigraphically equivalent to the Glen Dean Member or lower Pennington Formation.

*T. decornis* differs from other dichocrinids found during our study in the number of primibrachials (one) and in the nature of the tegmen. The presence of only one oral and the absence of tegminal spines differentiate this from other species of *Talarocrinus*.

Not all workers are convinced that *Talarocrinus* is present as high as the Glen Dean Limestone (Horowitz and Strimple, 1974; Horowitz, written commun., 1985), and it is possible, because of the imprecise stratigraphic and locality data, that *T. decornis* may come from lower in the section. *Talarocrinus* is generally considered to be an Early Chesterian genus, but in addition to *T. decornis*, we are aware of an undescribed species of Golconda age from eastern Kentucky. Nonetheless, Middle Chesterian species of *Talarocrinus* probably are rare.

*Occurrence.*—Upper Mississippian (Chesterian).

*Material.*—USNM S-1528A (holotype), and USNM S-1528B (paratype).

Subfamily **DICHOCCRININAE** Miller, 1889

Genus **HYRTANECRINUS**  
Broadhead and Strimple, 1980

*Type species.*—*Hyrtanecrinus diabolus* Broadhead and Strimple, 1980.

*Diagnosis.*—Dichocrinid with 20 pendant arms; **IBrr** and **IIBrr** uniserial; proximal **Brr** incorporated with tegmen; **IIIBrr** biserial; **BB** with thickened proximal rim or platform only partly occupied by small column.

**Hyrtanecrinus pentalobus**  
(Casseday and Lyon, 1862)  
Plate 8, figures 13, 14

1862. *Cotyledonocrinus pentalobus* Casseday and Lyon, p. 26.

1897. *Dichocrinus pentalobus* (Casseday and Lyon). Wachsmuth and Springer, p. 775, pl. 78, figs. 1a-c.

1981. *Hyrtanecrinus pentalobus* (Casseday and Lyon). Broadhead, pp. 132, 133, pl. 11, fig. 12; pl. 12, figs. 5, 9, 11, 12, 15-17.

*Diagnosis.*—Calyx elongate; dorsal cup with thin, unornamented plates (Pl. 8, figs. 13, 14); large **BB** broadly conical (Pl. 8, fig. 14); **RR** twice as high as wide, almost vertical, and slightly convex outer surface with a small angularity along median line (Pl. 8, fig. 14); **R** facets deeply excavated and occupying full width of **R**; second **IBrr** and **IIBrr** divided by medial process.

*Remarks.*—The most outstanding characteristic of *H. pentalobus* is its recumbent arms (Pl. 8, fig. 13). The only other dichocrinid genus with recumbent arms is *Strimplecrinus* Broadhead, 1981, and only one species, *S. pendens* (Wachsmuth and Springer, 1897), exhibits the character (Broadhead, 1981). *S. pendens*, however, has a lower ovoid cup and is ornamented with delicate striae; it is an older species occurring in the Burlington Limestone (Middle Mississippian). *S. pendens* also lacks the columnar platform formed from the proximal basals.

Two other dichocrinid species also occur in the studied interval; they are *S. superstes* (Wachsmuth and Springer, 1897) and *Camptocrinus cirrifer* (Wachsmuth and Springer, 1897). *S. superstes* differs from *H. pentalobus* by having an obconical dorsal cup, thick plates, no columnar platform, and irregular radials. *S. superstes* also has only slight excavations on the upper surfaces of the radials, and has only ten heavy arms, all of which are erect. *C. cirrifer* differs by having a coiled stem, 10 uniserial arms, and very low, irregular basals.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 3, 5, 7.

*Material.*—USNM S-1509 (lectotype), UK 115567, UK 115575 (hypotype), and UK 115963 (topotype).

Genus **STRIMPLECRINUS** Broadhead, 1981

*Type species.*—*Dichocrinus plicatus* Hall, 1861a.

*Diagnosis.*—Dichocrininae with subcylindrical, low hemispherical, or conical dorsal cups; 10 stout arms; **IIBrr** biserial.

**Strimplecrinus superstes**  
(Wachsmuth and Springer, 1897)  
Plate 8, figure 15

1897. *Dichocrinus superstes* Wachsmuth and Springer, p. 766, pl. 76, fig. 12.

1981. *Strimplecrinus superstes* (Wachsmuth and Springer). Broadhead, pp. 142, 143, pl. 13, fig. 8.



*Diagnosis.*—Subconical cup, higher than wide, unornamented (Pl. 8, fig. 15).

*Remarks.*—No specimens of *Strimplecrinus* were found during the course of our study, but the only known specimen, the holotype (USNM S-4159) found earlier at the Sloans Valley locality, was examined at the U. S. National Museum [see *Remarks for Hyrtanecrinus pentalobus* (Casseday and Lyon, 1862)].

*Occurrence.*—Upper Mississippian (Middle Chesterian).

*Material.*—USNM S-4159 (holotype).

Subfamily CAMPTOCRININAE Broadhead, 1981

Genus CAMPTOCRINUS

Wachsmuth and Springer, 1897

*Type species.*—*Camptocrinus myelodactylus* Wachsmuth and Springer, 1897.

*Diagnosis.*—Crown like *Dichocrinus* Münster, 1839; bilaterally symmetrical stem is coiled and bears cirri generally along the margins of the flattened columnal sides; 10 arms.

**Camptocrinus cirrifer**

(Wachsmuth and Springer, 1897)

Plate 8, figures 16–19

1897. *Dichocrinus* (*Camptocrinus*) *cirrifer* Wachsmuth and Springer, p. 780, pl. 76, figs. 13 a–c.  
 1926. *Camptocrinus cirrifer* (Wachsmuth and Springer). Springer, p. 32, pl. 8, figs. 10, 10a.  
 1926. *Camptocrinus multicirrus* Springer, p. 31, pl. 8, figs. 4–9.  
 1968. *Camptocrinus beaveri* Moore and Jeffords, p. 48, pl. 5, figs. 10a–d, pl. 6, figs. 4a–d.  
 1981. ?*Camptocrinus alabamensis* Strimple and Moore. Broadhead, p. 145.  
 1981. *Camptocrinus multicirrus* Springer. Broadhead, p. 145.  
 1985. *Camptocrinus multicirrus* Springer. Broadhead, p. 214.  
 1985. *Camptocrinus beaveri* Moore and Jeffords. Broadhead, p. 214.  
 1985. *Camptocrinus alabamensis* Strimple and Moore. Broadhead, p. 214.

*Diagnosis.*—Stem long, tapers distally, becoming round and slender; middle part of stem strongly elliptical and maintains uniform width (Pl. 8, fig. 17); cirri doubled or in clusters of three, and extend from each end of pairs of short nodals (Pl. 8, figs. 16, 18); cirri-bearing nodals commonly coalesce to appear as one ossicle, and alternate with a long internodal; rudimentary cirri also form on the convex side of stem; in more distal portion of stem, rudimentary cirri form well-defined whorls; calyx small (Pl. 8, figs. 16, 18, 19); short **B** circlet, not over one-fourth the height of cup; **IBrr** broad, short.

*Remarks.*—*Camptocrinus cirrifer* (Wachsmuth and Springer, 1897) was divided by Springer (1926) into *C. cirrifer*, from the “Glen Dean” of Pulaski County, Kentucky, and Bland County, Virginia, and into *C. multicirrus* Springer, 1926, from the lower part of the

Chesterian (O’Hara and Renault formations) in Alabama and Illinois.<sup>4</sup> The only differences between these two species, according to Springer (1926), are that in *C. cirrifer* the cirri are more attenuate, the cirri-bearing nodals tend to coalesce, and the rudimentary cirri near the distal end form well-defined whorls. *C. cirrifer* also occurs in younger strata.

The calyxes of these forms are identical insofar as they are known. The slight differences in the stem do not seem to us sufficient to erect a separate species, as even Springer (1926, pp. 32, 33) recognized.

*C. alabamensis* Strimple and Moore, 1973a, is placed in synonymy, based on the work of Broadhead (1981, p. 145). Broadhead suggested that the cup of *C. alabamensis* is essentially the same as that of *C. cirrifer*. *C. alabamensis* was distinguished based on its tegminal structures, and the tegminal structure of *C. cirrifer* is not known with certainty. It is possible that the tegmina could be different, even with similar dorsal cups. Because of this, we tentatively place *C. alabamensis* in synonymy with *C. cirrifer*. *C. beaveri* Moore and Jeffords, 1968, appears to represent the isolated columnals or columnal pairs of *C. cirrifer*.

*Occurrence.*—Upper Mississippian (Meramecian–Chesterian). Locality 5.

*Material.*—UK 115570, USNM S-1516A (holotype), USNM S-1516B (paratype), USNM S-1516 (topotype), and USNM S-1519, USNM S-1520 (syntypes of *C. multicirrus*).

Family ACROCRINIDAE

Wachsmuth and Springer, 1885

Subfamily ACROCRININAE

Wachsmuth and Springer, 1885

Genus ACROCRINUS Yandell, 1855

*Type species.*—*Acrocrinus shumardi* Yandell, 1855.

*Diagnosis.*—Stem homeomorphic, composed of very thin columnals; calyx urn-shaped (Pl. 9, figs. 1, 2, 4); two large **BB**; circlets of intercalaries between **B** and **R** circlets; very low, wide **RR** and primanal; upper surface of **R** supports a tiny axillary **IBr** and two **IIBrr** on either side, each followed by an axillary **IIBrr**; uppermost circlet of intercalaries contains 10 small subradials in groups of two; eight interradial intercalaries; two intercalaries under each side of the primanal; two small subanal intercalaries; arms erect.

**Acrocrinus shumardi** Yandell, 1855

Plate 9, figures 1–7

1855. *Acrocrinus shumardi* Yandell, in Yandell and Shumard. p. 135.  
 1897. *Acrocrinus shumardi* Yandell. Wachsmuth and Springer, p. 806, pl. 80, figs. 1–3.

<sup>4</sup> Strimple and Moore’s (1973a) article on *Camptocrinus* gave reversed localities and formations for *C. cirrifer* and *C. multicirrus*.



1926. *Acrocrinus shumardi* Yandell. Springer, p. 45, pl. 12, figs. 6, 7.  
 1943. *Acrocrinus shumardi* Yandell. Bassler and Moodey, p. 266.  
 1943. *Acrocrinus urnaeformis* Hall, 1858. Bassler and Moodey, p. 266.  
 1969. *Acrocrinus shumardi* Yandell. Moore and Strimple, pp. 7, 8, text-fig. 2, figs. 1-3.

*Diagnosis.*—Most distal circlet of intercalaries includes eight plates in interradian positions and 10 in subradial position; radials wide; arms erect.

*Description.*—Stem round, proximal portion consists of very thin columnals; secondary nodals very thin and sharp-edged; primary nodals are wedge-shaped with thick side producing a cirrus (Pl. 9, fig. 3); wedge forms at expense of lesser columnals; characteristics of dorsal cup as in genus; height of calyx about twice as great as width (Pl. 9, figs. 1, 4); intercalaries subequal, small, smooth-surfaced; tegmen flat on upper surface at level of upper surface of arms near attachment, ridged near arms (Pl. 9, figs. 5-7); tegmen composed of many small plates, those on ridges near arms are knobby or almost spherical (Pl. 9, figs. 6, 7), other tegmental plates smooth to slightly tumid; anal area of tegmen is off-center toward posterior edge of upper surface of tegmen (Pl. 9, fig. 6); small, very low cone (or mound) of very small plates with a central anal opening makes up the anal structure; arms radiate outward and quickly flex upward to a height almost equal to height of dorsal sac (Pl. 9, figs. 1, 2, 4), then may flex inward (Pl. 9, figs. 1, 2); pinnules are moderately long and closely adjoin each other (Pl. 9, fig. 2); ossicles in pinnules are all the same length with sutures at the same distances from the arm, giving the appearance that they are all oriented in rows down the arm (Pl. 9, fig. 2).

*Remarks.*—This is a well-defined and easily distinguished species. It is most similar to *Amphoracrocrinus amphora* (Wachsmuth and Springer, 1897), but *A. amphora* is taller and has narrower radials, a single distal intercalary below each radial, and pendant arms.

Three of our specimens (UK 115940, 115951, and 115953) included specimens of *Platyceras* Conrad, 1840, on the tegmina. The gastropods are larger than those found on *Pterotocrinus* Lyon and Casseday, 1859.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 1, 3, 5, 6.

*Material.*—UK 115569, 115937-115960, 115962. UK 115569, 115939, 115941, and 115943 are hypotypes.

Class BLASTOIDEA Say, 1825

Order SPIRACULATA Jaekel, 1918

Family PENTREMITIDAE d'Orbigny, 1851

Genus PENTREMITES Say, 1820

*Type species.*—*Encrina godonii* DeFrance, 1819.

*Diagnosis.*—Club-shaped to subpyriform theca; radials overlap deltoids; lancet plate widely exposed, forms petaloid ambulacrum; one pore between side plates along the deltoid and radial margins; four spiracles and an anispiracle around mouth; anispiracle excavated in divided or undivided anal deltoid plate; three to seven or more hydrospire folds on both sides of ambulacrum; mouth, spiracles, anus covered by many imbricate plates.

*Remarks.*—Four species of *Pentremites*, *P. tulipaeformis* Hambach, 1903, *P. elegans* Lyon, 1860, *P. robustus* Lyon, 1860, and *P. pyriformis* Say, 1825, are recognized from the Sloans Valley member in this study. Although Bassler and Moodey (1943) recognized 10 species or subspecies from the same interval in the same area, most have since been placed in synonymy with the above four species. Our synonymies not only reflect all of the above species, but also certain species not reported from the Sloans Valley but included in the undocumented synonymy of Horowitz, Macurda, and Waters (1981).

For two of the species cited by Bassler and Moodey (1943) we can find no other reported occurrence from the Sloans Valley member, and we believe that the reports are in error. The report of *P. spicatus* Ulrich, 1918, is based on the incorrect interpretation of a statement by Ulrich (*in* Butts, 1918) on correlation in the Glen Dean Limestone. With the other species, *P. angularis* Lyon, 1860, we can find no substantiating report whatsoever for its occurrence in the Glen Dean Limestone or Pennington Formation of the Sloans Valley area.

***Pentremites tulipaeformis* Hambach, 1903**

Plate 9, figures 8, 9

1903. *Pentremites tulipaeformis* Hambach, pl. 4, figs. 10, 11.  
 1918. *Pentremites tulipaeformis* Hambach. Ulrich *in* Butts, p. 100, pl. 24, fig. 5.  
 1918. *Pentremites brevis* Ulrich *in* Butts, pl. 100, pl. 24, fig. 6.  
 1957. *Pentremites tulipaeformis* Hambach [*sic*]. Galloway and Kaska, p. 67, pl. 6, figs. 16, 17.  
 1957. *Pentremites godonii abbreviatus* (Hambach). Galloway and Kaska, (*partim*), p. 49, pl. 3, figs. 16, 17.  
 1981. *Pentremites platybasis* Weller. Horowitz, Macurda, and Waters, p. 281.  
 1981. *Pentremites brevis* Ulrich. Horowitz, Macurda, and Waters, p. 281.  
 1981. *Pentremites tulipaeformis* Hambach [*sic*]. Horowitz, Macurda, and Waters, p. 281.

*Diagnosis.*—Calyx ovoid to globular, small- to medium-size, greatest width suprabasal (Pl. 9, figs. 8, 9); length-to-width ratio is 1:1.1; vault nearly straight-sided to paraboloid, truncate to slightly concave summit; pelvis short, vault-to-pelvis ratio is 2.1:5; basal plates may be nodose; stem facet may lie in depression;



pelvic angle 100 to 150 degrees, averaging 120 degrees; ambulacra deeply concave, rims low and narrow, interambulacra slightly concave; deltoids 5 to 10 mm long, extend 0.5 mm above mouth, do not flare outward.

*Remarks.*—By far the most common species of *Pentremites* found in the Sloans Valley member is this small, globular, low-based, sulcate form. Approximately 160 specimens were found as compared to 68 of the next most common species, *P. elegans* Lyon, 1860.

Many specimens exhibited brachioles (Pl. 9, figs. 8, 9), and a few specimens exhibited oral cover plates.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 1, 2, 3, 5, 6.

*Material.*—UK 115566, 116017–116025, 116051–116057, 116057, 116060. UK 115566 and 116022 are hypotypes in this paper.

***Pentremites elegans* Lyon, 1860**  
Plate 9, figures 10–13

1860. *Pentremites elegans* Lyon, p. 632, pl. 20, figs. 4a–c.  
1918. *Pentremites canalis* Ulrich, p. 262, pl. 7, figs. 23, 26.  
1957. *Pentremites elegans* Lyon. Galloway and Kaska, p. 64, pl. 5, figs. 28–30; pl. 6, figs. 1–4.  
1981. *Pentremites calycinus* Lyon, 1860. Horowitz, Macurda, and Waters, p. 281.  
1981. *Pentremites elegans* Lyon. Horowitz, Macurda, and Waters, p. 281.  
1981. *Pentremites springeri* Ulrich, 1918. Horowitz, Macurda, and Waters, p. 281.  
1981. *Pentremites canalis* Ulrich. Horowitz, Macurda, and Waters, p. 281.

*Diagnosis.*—Calyx pyriform to ovoid, short to medium-size in height, greatest width is sub-medial (Pl. 9, fig. 10); length-to-width ratio is 1.2:1.5; vault is broad, paraboloid to nearly hemispherical in larger forms; pelvis nearly straight-sided to very slightly concave; vault-to-pelvis ratio is 0.5:1.3; pelvic angle ranges from 66 to 90 degrees; ambulacra moderately concave, with narrow, low rims; interambulacra nearly flat to slightly concave; short deltoids almost extend to summit, do not flare.

*Remarks.*—Several specimens exhibit brachioles (Pl. 9, figs. 10, 11), and one specimen had oral cover plates (Pl. 9, fig. 13). Another specimen from the U. S. National Museum (USNM S-5307; Pl. 9, fig. 12), designated *P. canalis* by Ulrich (1918), is one of the few examples of a complete theca with attached stem and holdfast.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 2, 3, 5, 6, 7.

*Material.*—UK 116026–116031, 116033–116035, 116046–116049, USNM S-5307 (topotype of *P. canalis*). UK 116026 and 116032, and USNM S-5307 are hypotypes in this study.

***Pentremites robustus* Lyon, 1860**  
Plate 9, figures 14, 15

1860. *Pentremites robustus* Lyon, p. 629, pl. 20, figs. 2a–c.  
1905. *Pentremites fohsi* Ulrich, p. 64, pl. 7, figs. 5–9.  
1918. *Pentremites fohsi* Ulrich. Butts, p. 101, pl. 24, fig. 21.  
1920. *Pentremites fohsi* Ulrich. Weller, pp. 370, 371, pl. 10, fig. 4.  
1957. *Pentremites robustus* Lyon. Galloway and Kaska, p. 66, pl. 6, figs. 14, 15.  
1957. *Pentremites fohsi* Ulrich. Galloway and Kaska, p. 66, pl. 6, figs. 11–13; pl. 13, fig. 16.  
1981. *Pentremites chesterensis* Hambach. Horowitz, Macurda, and Waters, p. 281.  
1981. *Pentremites fohsi* Ulrich. Horowitz, Macurda, and Waters, p. 281.  
1981. *Pentremites fohsi marionensis* Ulrich. Horowitz, Macurda, and Waters, p. 281.  
1981. *Pentremites hambachi* Butts. Horowitz, Macurda, and Waters, p. 284.  
1981. *Pentremites hemisphericus* Hambach. Horowitz, Macurda, and Waters, p. 281.

*Diagnosis.*—Calyx large, globular or ovoid (Pl. 9, figs. 14, 15); greatest width submedial; length-to-width ratio from 1:1 to 1.3:1; vault subspheroidal to parabolic, strongly-curved sides; pelvis, short with concave, sigmoidal, or straight sides; vault-to-pelvis ratio from 1.7:1 to 4:1; pelvic angle is 90 to 126 degrees; ambulacra concave, rims low, without prominent flanges; interambulacra moderately concave to flat (Pl. 9, fig. 15); deltoids long.

*Remarks.*—The pelvic angles of examined specimens range from 90 to 126 degrees. The specimens ranged in height from 29.5 mm to 55 mm and are fairly large for *Pentremites*. Using Galloway and Kaska's (1957) classification, 12 specimens (UK 116042–UK 116045) would be assigned to *P. fohsi* because of their small pelvic angles (90 to 98 degrees). In this study, however, these specimens are assigned to *P. robustus*.

Some juvenile forms (Pl. 9, fig. 14) from our assemblage of *P. robustus* approach the pyriform shape of *P. elegans* Lyon, 1860. However, a broader pelvic angle can be used to differentiate them. Although Waters, Horowitz, and Macurda (1985) inferred that *P. robustus* was probably derived from *P. tulipaeformis* Hambach, 1903, Horowitz (written commun., 1985) indicated that it may have been derived from *P. elegans*, suggesting that *P. robustus* may be polyphyletic. Despite recent advances in understanding the evolution and taxonomy of *Pentremites*, many problems still require resolution.

*Occurrence.*—Upper Mississippian (Chesterian). Localities 2, 3, 5, 6, 7.

*Material.*—UK 116036–116049. UK 116049 and 116038 are hypotypes in this study.

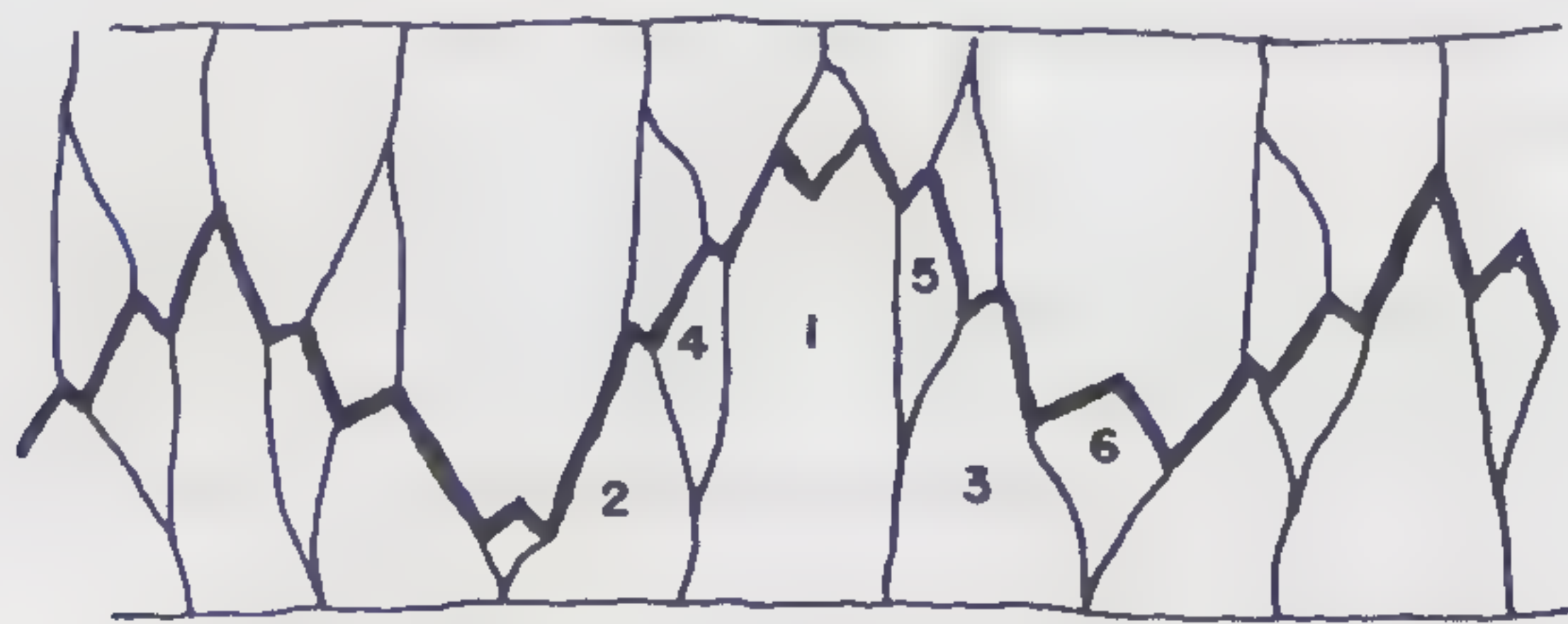


**Pentremites pyriformis** Say, 1825  
Plate 9, figures 16, 17

1825. *Pentremites pyriformis* Say, p. 294.  
1835. *Pentremites pyriformis* Say. Troost, p. 228, pl. 10, fig. 8.  
1905. *Pentremites pyriformis* Say. Ulrich, p. 57, pl. 6, figs. 9-12.  
1905. *Pentremites pyramidatus* Ulrich, p. 64, pl. 7, figs. 12-14.  
1918. *Pentremites pyriformis* Say. Ulrich, p. 257, pl. 6, figs. 3-6, 8, 9.  
1918. *Pentremites patei* Ulrich, p. 261, pl. 7, figs. 17-22.  
1920. *Pentremites okawensis* Weller, p. 357, pl. 10, figs. 5-7.  
1920. *Pentremites pyramidatus* Ulrich. Weller, p. 325, pl. 4, figs. 21-24.  
1957. *Pentremites pyriformis* Say. Galloway and Kaska, p. 56, pl. 4, figs. 32-37; pl. 13, figs. 2, 3.  
1957. *Pentremites patei* Ulrich. Galloway and Kaska, p. 57, pl. 5, figs. 1, 2.  
1957. *Pentremites pyramidatus* Ulrich. Galloway and Kaska, p. 57, pl. 5, figs. 3, 4; pl. 13, fig. 7.  
1981. *Pentremites arctibrachiata huntsvillensis* Ulrich. Horowitz, Macurda, and Waters, p. 281.  
1981. *Pentremites girtyi* Ulrich. Horowitz, Macurda, and Waters, p. 281.  
1981. *Pentremites lyoni* Ulrich. Horowitz, Macurda, and Waters, p. 281.  
1981. *Pentremites lyoni gracilens* Ulrich. Horowitz, Macurda, and Waters, p. 281.  
1981. *Pentremites patei* Ulrich. Horowitz, Macurda, and Waters, p. 281.  
1981. *Pentremites pyramidatus* Ulrich. Horowitz, Macurda, and Waters, p. 281.

*Diagnosis.*—Medium-size to large, pyriform calyx (Pl. 9, figs. 16, 17); greatest width medial; length-to-width ratio from 1.1:1 to 2:1; parabolic to pyramidal vault; pelvis pyramidal, generally with straight sides; vault-to-pelvis ratio from 0.8:1 to 1.8:1; pelvic angle is 50 to 110 degrees; ambulacra flat to slightly convex with either low, narrow rims or no rims; interambulacra flat to slightly concave; deltoids generally do not reach summit.

*Remarks.*—Using Galloway and Kaska's (1957) classification, a specimen with a pelvic angle of 72 degrees (UK 116059) would have been assigned to *P. pyramidatus* Ulrich, 1905. Similarly, two specimens with pelvic angles of 68 degrees and 69 degrees (UK 116060) would have been assigned to *P. patei* Ulrich, 1918, and two other specimens (UK 116061, UK 116062) would have been assigned to *P. okawensis* Weller, 1920. In this study, differences between these



Text-figure 25.—Cover-plate arrangement in *Lepidodiscus laudoni*. Six plates are included in each cycle.

species are considered to reflect intraspecific variations of *P. pyriformis* Say, 1825. One specimen exhibits brachioles (UK 116064).

*Occurrence.*—Upper Mississippian (Chesterian). Localities 1, 3, 6, 7.

*Material.*—UK 116059-116066. UK 116061 and 116065 are hypotypes in this paper.

Class **EDRIOASTEROIDEA** Billings, 1858

Order **ISOROPHIDA** Bell, 1976

Suborder **ISOROPHINA** Bell, 1976

Family **AGELACRINITIDAE** Clarke, 1901

Genus **LEPIDODISCUS**

Meek and Worthen, 1868

*Type species.*—*Agelacrinites squamosus* Meek and Worthen, 1868.

*Diagnosis.*—Theca may be highly convex, domal, or clavate in form; numerous small orals, with primary orals undifferentiated; hydropore structure large, elongate, and separate from central oral rise; posterior side of hydropore formed by many plates; ambulacra long, curved; ambulacra I through IV curve counterclockwise, V (right posterior) curves clockwise (Pl. 10, fig. 7); ambulacral coverplates composed of six-plate cycles; interambulacrals may be squamose and imbricate, or polygonal and tessellate; anal structure valvular, formed by two anal-plate circlets (Pl. 10, fig. 8; Text-fig. 26).

*Remarks.*—Three closely-related clavate genera exhibit retractable, pedunculate aboral zones: *Discocystis* Gregory, 1897, *Ulrichidiscus* Bassler, 1935, and *Lepidodiscus*. *Discocystis* has ambulacral coverplates composed of three- or four-plate cycles, and has a hydropore structure formed by at least three large plates on the posterior side. The ambulacra curve as in *Lepidodiscus*. *Lepidodiscus* has coverplates with six-plate cycles (Pl. 10, figs. 4, 5, 7; Text-fig. 25). *Ulrichidiscus* has ambulacra that curve in a contrasolar direction, and has coverplates arranged in a seven-plate cycle. The anterior plates of the hydropore do not reach the perradial oral midline. The plates of the pedunculate zone in *Ulrichidiscus* are irregular in size and shape and do not form regular vertical columns, whereas the same plates in *Discocystis* are regular in size and shape, and form regular vertical columns (Pl. 10, fig. 6), as in *Lepidodiscus laudoni* (Bassler, 1936). Both *Lepidodiscus* and *Ulrichidiscus* occur in the Sloans Valley member.

**Lepidodiscus laudoni** (Bassler, 1936)

Plate 10, figures 1-9; Text-figures 25, 26

1936. *Discocystis laudoni* Bassler, p. 21, pl. 3, figs. 7, 8.

1943. *Discocystis laudoni* Bassler. Bassler and Moodey, p. 201.

1958. *Discocystis laudoni* Bassler. Ehlers and Kesling, pp. 265-272, pls. 1-3.



1976. *Lepidodiscus laudoni* (Bassler). Bell, pp. 257, 267, text-figs. 52-54; pls. 49, 50, pl. 51, figs. 1-10.

1977. *Lepidodiscus laudoni* (Bassler). Bell, text-fig. 9.

**Diagnosis.**—Theca large, clavate (Pl. 10, figs. 1, 2, 7); pedunculate zone composed of numerous very thin imbricate, subrectangular plates arranged in vertical columns (Pl. 10, fig. 6); ambulacral coverplates rise perradially, forming small perradial ridges (Pl. 10, figs. 4, 5); ambulacral floorplates abut equally against adjacent floorplates (Pl. 10, fig. 8); two lateral protuberances occur on lower surface of each floorplate (Pl. 10, fig. 8); central interambulacrals polygonal, tessellate (Pl. 10, figs. 1, 2, 4, 5, 7).

**Remarks.**—Two other species of *Lepidodiscus* are *L. squamosus* Meek and Worthen, 1868, which is non-clavate, and *L. sampsoni* (Miller, 1891), which is clavate and exhibits irregularly-arranged pedunculate plates. *Discocystis kaskaskiensis* (Hall, 1858) appears to be closely related to *L. laudoni* (Bassler, 1936) on the basis of pedunculate zones, which are regular in size and shape, and form regular vertical columns, as in *L. laudoni*. In fact, on this basis the variation between *D. kaskaskiensis* (the only species of *Discocystis*) and *L. laudoni* is less than the difference between the three species of *Lepidodiscus*. The major differences between *Discocystis* and *Lepidodiscus*, however, are in the ambulacral coverplate arrangement and in the hydropore structure (Bell, 1976).

Although *D. kaskaskiensis* was reported from the Sloans Valley area by Bassler and Moodey (1943), theirs is the only report of the species from this area, and we have not been able to find the specimens or any other citation. We suspect that they were really reporting undescribed specimens of *L. laudoni*, a species that was relatively new and not well known at the time.

All of our specimens exhibited at least a few peduncular plates, but showed various stages of extension

and compression of the peduncular zone. Specimen UK 116015 was preserved in the extended state with a total height of 51 mm (Pl. 10, fig. 6). Two specimens (UK 116001 and 116005) show the peduncle in a contracted state (Pl. 10, figs. 3, 9).

Specimen UK 116016 provides an excellent internal view of the oral surface (Pl. 10, fig. 8; Text-fig. 26). It shows abutting floorplates with two lateral protuberances, the oral frame with the stone canal, and the anal structure.

Various specimens show evidence of attachment to a column of *Archimedes* Owen, 1838, a fenestellid frond, and the brachiopod *Cleiothyridina sublamellosa* (Hall, 1858).

A gregarious nature may be indicated by a slab that exhibited 11 specimens on the same surface (UK 116000).

**Occurrence.**—Mississippian (Kinderhookian–Chesterian). Localities 3, 5, 6, 7.

**Material.**—UK 115580, 115582, 116000–116016. UK 115580, 115582, 116001, 116005, 116015, and 116016 are hypotypes in this paper.

#### Genus *ULRICHIDISCUS* Bassler, 1935

**Type species.**—*Agelacrinus pulaskiensis* Miller and Gurley, 1894.

**Diagnosis.**—Subclavate or high-domed theca (Pl. 10, figs. 10, 11); many undifferentiated oral plates (Pl. 10, fig. 10); all ambulacra curved contrasolar (Pl. 10, fig. 10); interambulacrals may be tessellate or slightly imbricate (Pl. 10, fig. 10); large hydropore structure separated from central oral rise (Pl. 10, fig. 10); anal structure valvular with two circlets of plates (Pl. 10, fig. 10).

**Remarks.**—See *Remarks* under the genus *Lepidodiscus* Meek and Worthen, 1868.

*Ulrichidiscus* is known only from four specimens, all from the Sloans Valley area.

#### *Ulrichidiscus pulaskiensis* (Miller and Gurley, 1894) Plate 10, figures 10, 11

1894. *Agelacrinus pulaskiensis* Miller and Gurley, p. 16, pl. 3, fig. 18.

1935. *Ulrichidiscus pulaskiensis* (Miller and Gurley). Bassler, p. 8, pl. 1, fig. 7.

1943. *Ulrichidiscus pulaskiensis* (Miller and Gurley). Bassler and Moodey, p. 209.

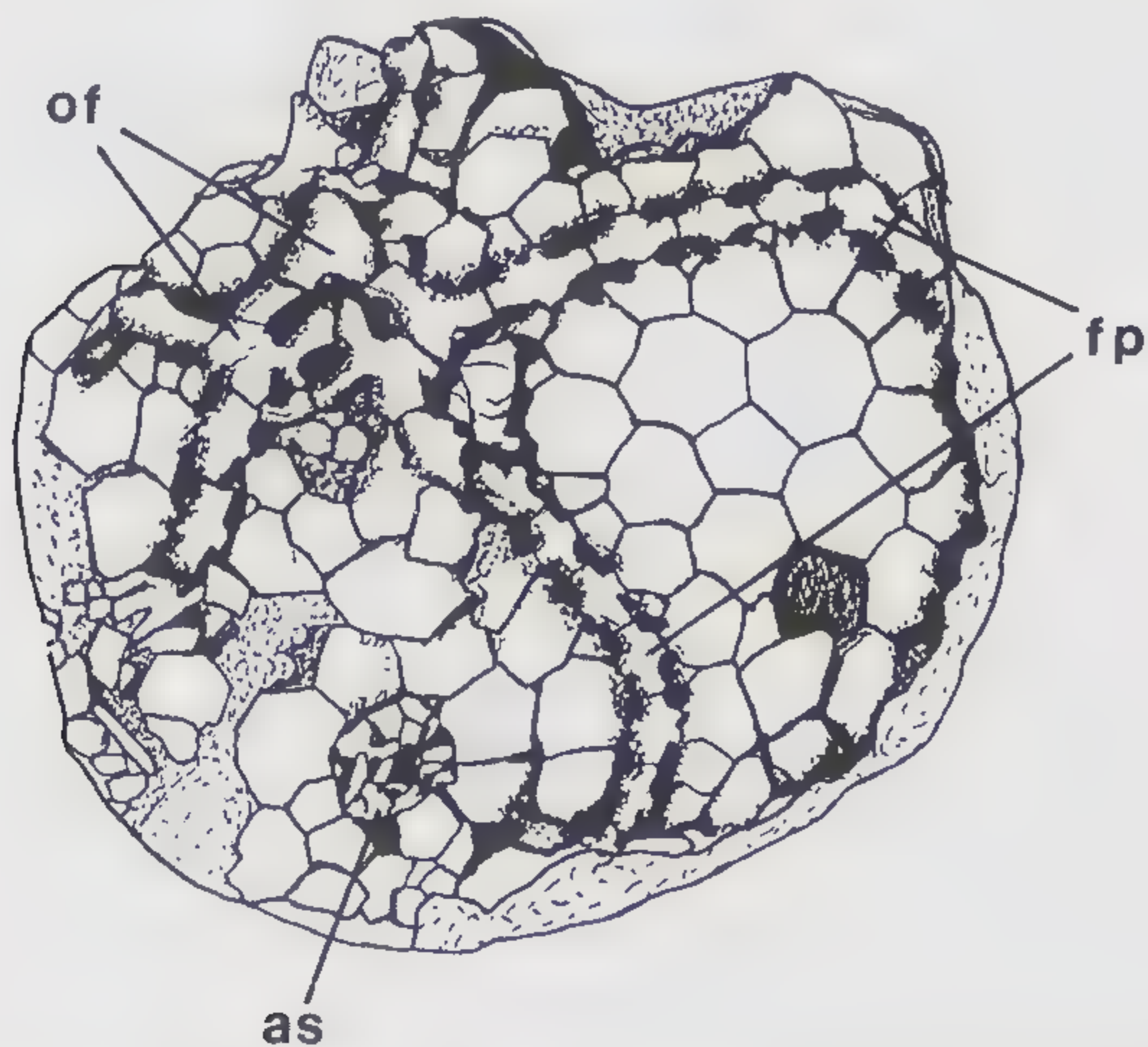
1976. *Ulrichidiscus pulaskiensis* (Miller and Gurley). Bell, pp. 271–277, text-figs. 56–58; pl. 53, pl. 54, figs. 1–7.

**Diagnosis.**—Coverplates in seven-plate cycles.

**Remarks.**—No specimens were found during our study, but three of the four known specimens were examined at the U. S. National Museum.

**Occurrence.**—Upper Mississippian (Chesterian).

**Material.**—USNM S-3193A, B, C (topotypes).



Text-figure 26.—Internal plate arrangement in *Lepidodiscus laudoni*. of = oral frame; as = anal structure; fp = ambulacral floor plates.



## Class ECHINOIDEA Leske, 1778

## Subclass PERISCHOECHINOIDEA M'Coy, 1849a

## Order ECHINOCYSTITOIDA Jackson, 1912

## Family LEPIDESTHIDAE Jackson, 1896

## Genus LEPIDESTHES

Meek and Worthen, 1868

*Type species.*—*Lepidesthes coreyi* Meek and Worthen, 1868.

*Diagnosis.*—Test high, with strongly imbricate plates (Pl. 11, fig. 1); ambulacra do not enlarge adorally, composed of plates forming many columns (Pl. 11, fig. 1); few columns of interambulacra (Pl. 11, fig. 1); no primary tubercles.

***Lepidesthes formosa* Miller, 1879**

Plate 11, figures 1–3

1879. *Lepidesthes formosa* Miller, pp. 41, 42, pl. 8, fig. 4.1912. *Lepidesthes formosa* Miller. Jackson, pp. 418–420, pl. 66, figs. 4–7; pl. 68, figs. 3–14.

*Diagnosis.*—Eight rows of imbricating ambulacral plates at mid-zone; five rows of imbricating interambulacral plates at mid-zone.

*Description.*—Test small, spheroidal to slightly ellipsoidal; ambulacra twice as wide as interambulacra (Pl. 11, fig. 1); at mid-zone, eight columns of small, rhombic ambulacral plates (Pl. 11, fig. 1); plates bevel under the adambulacrals and imbricate over each other adorally (Pl. 11, fig. 1); pore pairs located along median line of plates or slightly off-center towards nearest interambulacral; pores slightly above the middle of each plate (Pl. 11, fig. 1); interambulacra contain five columns at the midzone, composed of plates imbricating strongly aborally and over the ambulacrals (Pl. 11, fig. 1); in dorsal region interambulacrals impinge broadly upon oculars on both sides; peristome covered only with ambulacral plates; oculars separate the genitals and are relatively large, with two pores; wide genitals do not form elongate ventral apex; two to four pores per genital plate (Pl. 11, fig. 3), madreporic pores in one plate; wide-angled pyramids with moderately deep foramen magnum, plicate ridges on lateral wings of pyramids; teeth are grooved (Pl. 11, fig. 3).

*Remarks.*—*Lepidesthes formosa* is the only species with a combination of eight columns of ambulacral plates and five columns of interambulacral plates at the midzone. The holotype is from the "Glen Dean" (most likely the Sloans Valley member) of Sloans Valley, Pulaski County, Kentucky. Only two previously-described species are known from the Chester Series: *L. formosa* Miller, 1879, from the "Glen Dean" and the Chesterian undifferentiated, and *L. spectabilis* (Worthen and Miller, 1883), from the Chesterian of Illinois. *L. spectabilis* has 10 or more rows of ambu-

lacral plates and five rows of interambulacral plates at the midzone.

Jackson (1912) indicated that the number of pores on the genital plate varies from two to three, but one of our specimens exhibits four pores in the probable genital plate (Pl. 11, fig. 3).

*Occurrence.*—Upper Mississippian (Chesterian). Locality 3.

*Material.*—UK 115988, 115996, USNM S-3858(8020), all topotypes. UK 115988 and USNM S-3858(8020) are hypotypes.

## Order PALAEOCHINOIDA Haeckel, 1866

## Family PALAEOCHINIDAE M'Coy, 1849a

## Genus PALAEOCHINUS M'Coy, 1844a

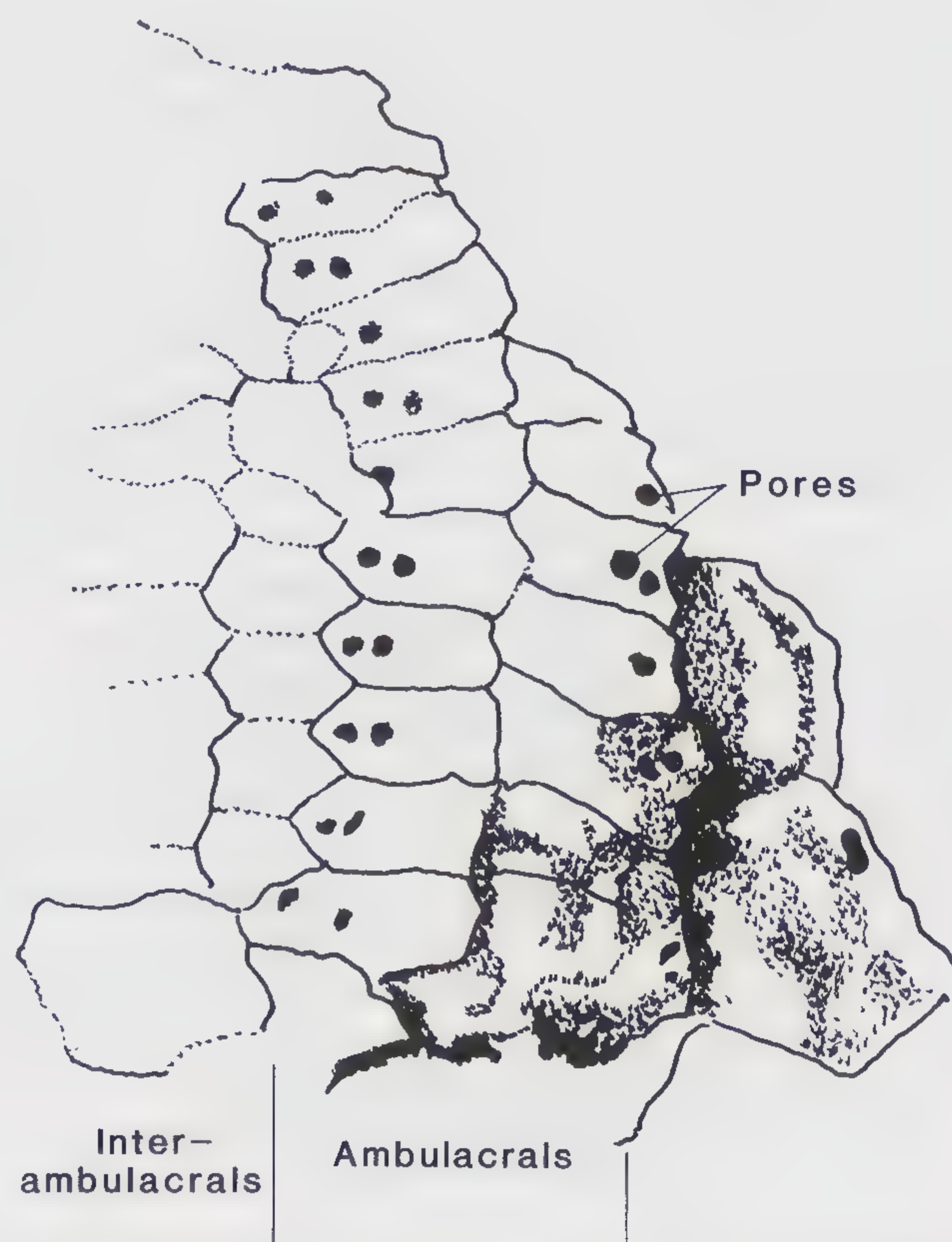
*Type species.*—*Palaechinus ellipticus* Lambert and Thiery, 1910.

*Diagnosis.*—Two columns of plates in ambulacrum; pore pairs uniserial or slightly biserial.

***Palaechinus jacksoni*, new species**

Plate 11, figure 4; Text-figure 27

*Etymology of Name.*—The species name honors Robert Tracy Jackson, who was a pioneer in the work on Paleozoic echinoids.



Text-figure 27.—Ambulacrum from *Palaechinus jacksoni*, n. sp., ambulacrals with uniserial pore pairs. Pitting on interambulacrals is not shown.



*Diagnosis.*—Four columns of interambulacrals at mid-zone (Pl. 11, fig. 4); interambulacrals bear numerous pits formed by circular arrays of apparently coalescing tubercles (Pl. 11, fig. 4); ambulacral plates are primary at mid-zone and appear to be regularly-shaped throughout.

*Description.*—Most of the test is crushed and disturbed so that shape of the test and nature of the apical and peristomal systems cannot be discerned. Ambulacra are narrow with two columns of primary plates and two to three plates equal to the height of the interambulacral plates (Text-fig. 27). Pore pairs are regularly uniserial. Tubercles are present, but plates are too worn to determine patterns. Interambulacra are wide with four columns of plates at mid-zone (Pl. 11, fig. 4). Plates typically are hexagonal and wider than high. Plates bear pits arranged in horizontal rows (Pl. 11, fig. 4) formed by circular arrays of apparently coalescing tubercles; plates bear eight to 12 pits, but pits decrease in number toward ambulacra. Pits may bear even smaller pits formed by smaller tubercles and may be shared by adjacent plates.

*Remarks.*—*P. jacksoni*, n. sp., is distinguished from other species through the presence of numerous pits formed by the arrangement of tubercles on the interambulacral plates.

*P. jacksoni* is only the second species of the genus to be found in North America. *P. (?) minor* Jackson, 1912, may be a species of *Maccoya* Pomel, 1869. *Palaechinus canadensis* Kier, 1953, and the newly-described *P. jacksoni* are the only members of the genus from North America. Both *P. (?) minor* and *P. canadensis* are Lower Mississippian species. The new species is Middle Chesterian in age and is the latest occurrence of the genus in North America and possibly in the world.

The holotype is the only known specimen (USNM 372191) and was found in the Springer collection during our study.

*Occurrence.*—Upper Mississippian (Middle Chesterian). Locality 1.

*Material.*—USNM 372191 (holotype).

#### Order CIDAROIDA Claus, 1880

#### Family ARCHAEOCIDARIDAE M'Coy, 1844a

#### Genus ARCHAEOCIDARIS M'Coy, 1844a

*Type species.*—*Cidaris urii* Fleming, 1828.

*Diagnosis.*—Subspherical test, probably flattened adorally and adapically; ambulacrals tend to have triad cycles, each third plate enlarged; four columns of interambulacrals at midzone, interradial plates imbricate over adradial plates, which imbricate over the ambulacral plates; primary spines not clavate terminally,

lacking discoid shaft, cortex of spines reduced or absent, medulla hollow.

#### *Archaeocidaris hemispinifera*, new species

Plate 11, figures 5–9; Text-figure 28

*Etymology of Name.*—The species is so named because the oral hemisphere is the only hemisphere with primary spines.

*Diagnosis.*—Ambulacra straight; primary spines without spinules; apical hemisphere lacking primary spines; apical interambulacra with one or two extra columns of plates beveled laterally and inserted beneath other interambulacral plates; oral hemisphere typical with four columns of interambulacral plates and primary spines.

*Description.*—The test is probably depressed apically and orally (Pl. 11, fig. 5; Text-fig. 28B). Ambulacra are moderately narrow and straight (Pl. 11, figs. 5–7; Text-fig. 28A). All ambulacral plates reach radial suture. Every third ambulacral plate is enlarged and equals the perradial length of the opposing two smaller ambulacrals to form a three-plate combination that tapers evenly and alternately (Text-fig. 28A). The third ambulacral gains its size by a perradial enlargement that contains one perforate tubercle. Despite the unequal size of the ambulacral plates, the pores in each column line up perfectly. The spines belonging to these tubercles are at least 2 or 3 mm long (broken?), and are small, striate, and straight. Each ambulacral plate is beveled and overlapped by the outer interambulacrals (Pl. 11, fig. 7). The nature of the apical and oral ambulacrals is not clear in the holotype or in the paratype, because the imbricating plates have been compressed and their positions are unclear. The interambulacral plates of the oral hemisphere are generally typical of other species of *Archaeocidaris*; they are wider than high. The inner interambulacrals are hexagonal and imbricate over the outer interambulacrals (Pl. 11, fig. 5). The outer interambulacrals of the oral hemisphere are pentagonal. The primary tubercle is perforate (Pl. 11, fig. 5); some are moderately high. The scorbicule is smooth; there are no ridges formed from the secondary tubercles entering the scorbicular region. Secondary tubercles are formed around the surficial margin of the plates (Pl. 11, fig. 5) (the beveled portion overlapped by more oral imbricating plates is smooth, but where the plates meet at the surface, tubercles are formed at the edge of each plate). Many of the secondary tubercles are perforate. The primary spines are broken in all specimens, and the maximum length of any spine is 6 mm (Pl. 11, fig. 8). The spines are finely-striate, possibly hollow, and taper above the milled ring. Spinules are absent. The secondary spines of the interambulacral plates are like those of the ambulacra. The interambulacrals of the apical hemisphere are quite



different; these plates are subquadrangular, squamose, elongate adapically, and without primary tubercles (Pl. 11, fig. 7; Text-fig. 28A). They appear to be more strongly imbricate than the plates of the other hemisphere (Pl. 11, fig. 7). The central portion of the plates is smooth. Zero to three perforated tubercles are present along the adapical and adradial margins of the plates. An unusual feature of the apical hemisphere interambulacra is the number of columns. Where a complete interambulacral section is preserved, there appear to be five to six columns of plates (Pl. 11, fig. 7; Text-fig. 28A). The centralmost column or columns do not imbricate over the other interambulacrals but are overlapped by them. Therefore, the centermost column appears to be depressed. In the holotype (UK 115989), several dislocated plates with two pores each appear to be genital plates. The nature of the apical region is relatively uncertain, due to compression of the specimen.

The pyramids appear to have moderately deep foramen magnum and deep muscle pits. Cidaroid teeth are strongly grooved toward the top (Pl. 11, fig. 7). The angle between wings is approximately 45 degrees.

*Remarks.*—The ambulacra of *A. immanis* Kier, 1958, *A. worthenia* Hall, 1858, and *A. rossica* (Buch, 1842) are sinuous. *A. hemispinifera*, n. sp., has straight ambulacra. The ambulacra of *A. lagrandensis* Miller and Gurley, 1890b, and *A. blairi* (Miller, 1891) are not known. Many of the ambulacral plates of *A. immanis* do not reach the perradial line. All ambulacrals reach the perradial line in other species in which ambulacra are known, including *A. hemispinifera*. *A. agassizi* Hall,

1858, *A. urii* (Fleming, 1828), and *A. rossica* have primary spines with spinules. *A. hemispinifera* lacks spinules on its spines. The interambulacral plates of *A. aliquantula* Kier, 1958, contain coarse plications that extend from the basal terrace to the margin of the plates. Extremely fine radial plications are found on the edge of the basal terrace of *A. blairi*. *A. hemispinifera* is the only species in which nontuberculate (primary) interambulacrals occupy half of the test. *A. immanis* is probably closest to *A. hemispinifera* in this respect. *A. immanis* has primary spines on most of the test except the most apical interambulacrals. *A. immanis* also has an extra column in the apical interambulacra made up of small plates.

Five specimens of *A. hemispinifera* on two slabs were found with *Tholocrinus* Kirk, 1939. One specimen occurs with *Taxocrinus* Phillips, in Morris, 1843.

*Occurrence.*—Upper Mississippian (Middle Chesterian). Localities 3, 5.

*Material.*—UK 115989 (holotype); UK 115990 and 115992 (topotypes); UK 115584, 115987, 115991, 115993–115995. UK 115995 is a hypotype in this study.

Subphylum ASTEROZOA Zittel, 1895

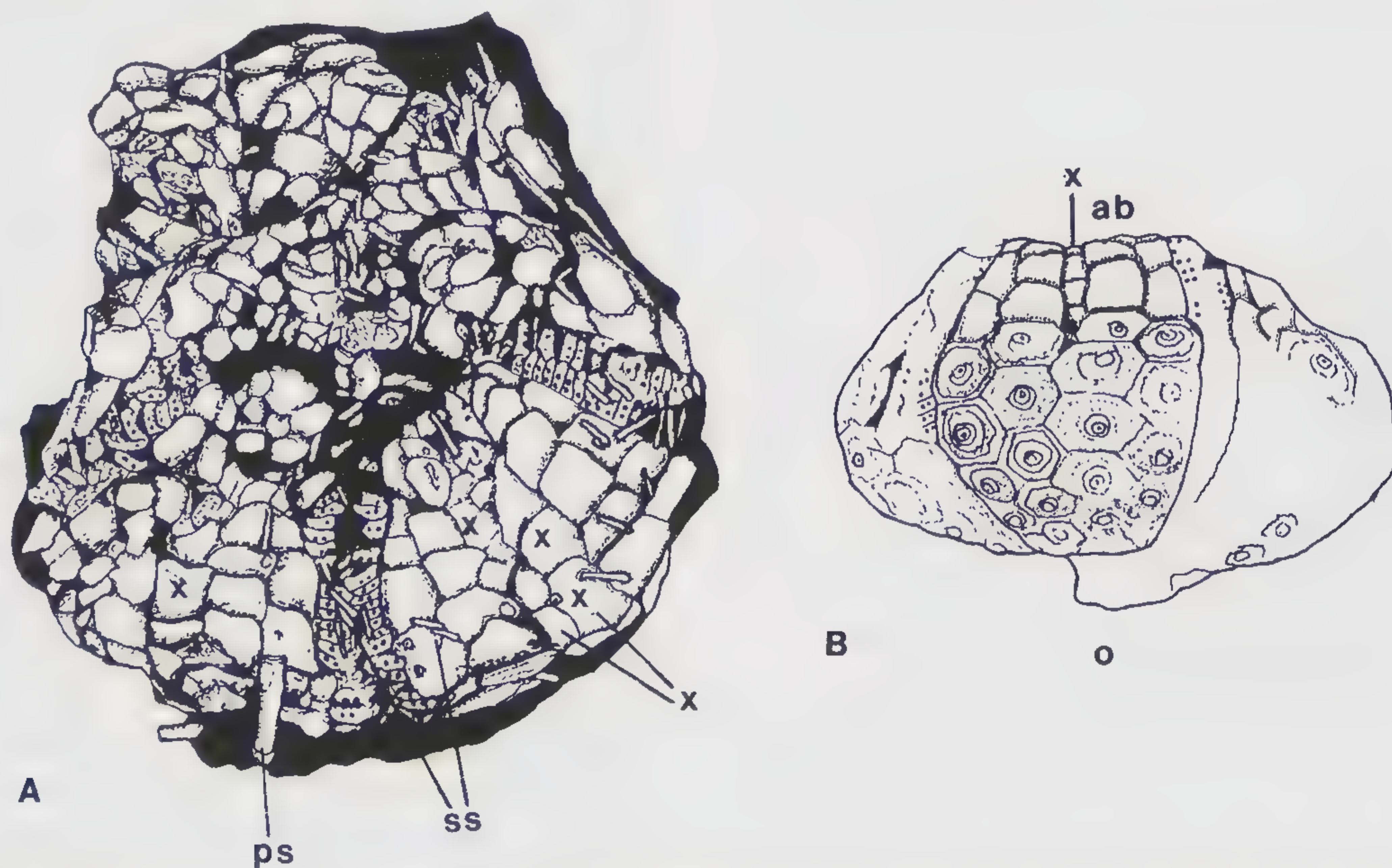
Class STELLEROIDEA Lamarck, 1816

Subclass OPHIUROIDEA Gray, 1840

Order PHRYNOPHIURIDA Matsumoto, 1915

Suborder EURYALINA Lamarck, 1816

Family ONYCHASTERIDAE Miller, 1889



Text-figure 28.—Plate arrangement for *Archaeocidaris hemispinifera*, n. sp. A. Lateral view. B. Dorsal view. ps = primary spines; ss = secondary spines (ambulacral and interambulacral); x = extra row of interambulacrals produced in the aboral hemisphere; ab = aboral pole; o = oral pole.



Genus **ONYCHASTER**  
Meek and Worthen, 1868

*Type species.*—*Onychaster flexilis* Meek and Worthen, 1868.

*Diagnosis.*—Disc small; disc and arms covered by thick integument with or without granules; five arms; laterals small.

**Onychaster strimplei**  
Bjork, Goldberg, and Kesling, 1968  
Plate 12, figures 1, 2

1968a. *Onychaster strimplei* Bjork, Goldberg, and Kesling, pp. 197–200, pl. 34, figs. 1–6; text-fig. 1.

1968b. *Onychaster strimplei* Bjork, Goldberg, and Kesling. Bjork, Goldberg, and Kesling, pp. 50–57, pl. 4, figs. 1–3, text-fig. 4.

1970. *Onychaster strimplei* Bjork, Goldberg, and Kesling. Strimple, p. 42.

*Diagnosis.*—Disc small with five arms, tapering and flexible; arms may curl up under disc; integument on arms consists of small imbedded ossicles generally arranged in hexagonal pattern (Pl. 12, figs. 1, 2); vertebrae formed by weakly-fused pairs of ambulacrals; denticles of mouth frame large and elevated as a dome; torus rounded, short, subrectangular with denticle suture only slightly depressed; mouth angle-plates large, each pair narrowly separated.

*Remarks.*—*Onychaster strimplei* Bjork, Goldberg, and Kesling, 1968a, has marked differences in vertebrae and mouth frame from the other two species of *Onychaster*. These other species are dealt with by Bjork, Goldberg, and Kesling (1968a, 1968b). The integument is different also: *O. barrisi* (Hall, 1861b) has thin ossicles arranged irregularly; *O. flexilis* Meek and Worthen, 1868, has close-set, rounded ossicles in a tessellate pattern; and *O. strimplei* has small, rounded ossicles forming a hexagonal tessellate pattern. *O. strimplei* has been found in the Middle Chesterian Golconda Formation, and the Sloans Valley occurrence extends its range higher into the Chesterian. The other two species are found in the Lower Mississippian.

The specimens found in this study were found wrapped around the anal sacs of the crinoid *Pulaskiocrinus campanulus* (Pl. 12, figs. 1, 2). We believe that the ophiuroid was probably coprophagous on the crinoid. However, Bjork, Goldberg, and Kesling (1968b) stated:

it occurs to us that the vulnerability of the stomach and other internal organs, inadequately armored on the aboral side, may have been a factor inducing *Onychaster* to seek protection within the arms of crinoids.

Later in the same article, they stated:

The association of *Onychaster flexilis* with crinoid calyxes has been widely publicized. We have also seen one specimen of *O. barrisi* on a crinoid tegmen. Brittle-stars which do not burrow into the bottom

sediments and ingest quantities of mud evolved two methods of acquiring sufficient nourishment. In the keen competition with one another and with other animals for the rain of detritus settling in marine waters, one group developed branching of the arms, wherewith these "basket-stars" proliferated the ambulacral area into a great food-collecting network. The other group, which includes *Onychaster* and certain of the living Phrynophiurida, solved the problem by climbing upon crinoids and other sessile bottom forms to intercept the food supply before it reached the congested bottom area and to take advantage of any food-collecting currents set up by their hosts. The well-developed masticatory apparatus and the restricted oral intake argue strongly against *Onychaster* being coprophagous.

On the other hand, the feeding of crinoid and brittle-star were different. Lacking any structures for biting, chewing, or grinding, the crinoid sifted and selected particles of the proper minute size for ingestion. The brittle-star, as indicated by its mouth-frame, was equipped to eat large and even hard materials. *Onychaster* may very well have taken up residence on the crinoid calyx both for protection and for taking advantage of large food particles rejected by the crinoid. The relationship appears actually commensal.

The separate species of *Onychaster* appear to restrict themselves to only a few species of crinoids. *O. flexilis* is found on *Actinocrinus multiramosus* Wachsmuth and Springer, 1897, *Scytalocrinus robustus* (Hall, 1861a), and *Barycrinus hoveyi* (Hall, 1861a). Each of these crinoids is the only host of *Onychaster* in its respective stratigraphic formation. *Onychaster*, in fact, is rarely found by itself (Wachsmuth and Springer, 1897). *Onychaster barrisi* has been found on a crinoid tegmen (genus and species not disclosed) by Bjork, Goldberg, and Kesling (1968b). However, *Onychaster strimplei* has not been found associated with a crinoid tegmen until now.

The only observable plates were the integument ossicles, which cover the arms and the central disc. The ossicles are arranged in a hexagonal pattern. The length of the arms cannot be determined, because they intertwine around the anal sac of the crinoids. The diameter of several arms near the disc is 6 mm. In specimen UK 115998 (Pl. 12, fig. 1), the disc appears to have a diameter of about 14 mm. The typical integument ossicle has a diameter of about 0.5 mm.

*Occurrence.*—Upper Mississippian (Chesterian). Locality 3.

*Material.*—UK 115997 and 115998, the latter a hypotype in this study.

Order **OEGOPHIURIDA** Matsumoto, 1915

Suborder **LYSOPHIURINA** Gregory, 1896

?Family **ENCRINASTERIDAE** Schuchert, 1914

unidentifiable ophiuroid genus and species  
Plate 12, figure 3

*Description.*—Oral disc well developed (Pl. 12, fig. 3), probably with marginal frame; halves of vertebrae appear to be alternating (Pl. 12, fig. 3); laterals subventral with broad oral face, elongate transversely; oth-



er features too poorly preserved to describe at generic level.

*Remarks.*—The alternating vertebrae, a well-developed disc with prominent marginal frame, and subventral laterals suggest that this is an encrinasterid ophiuroid.

*Occurrence.*—Upper Mississippian (Chesterian). Locality 3.

*Material.*—UK 115583 (hypotype).

Subclass ASTEROIDEA Blainville, 1830

Order SPINULOSIDA Perrier, 1884

Suborder EUGNATHINA

Spencer and Wright, 1966

Family TAENIACTINIDAE Spencer, 1927

Genus CALYPTACTIS Spencer, 1930

*Type species.*—*Calyptactis spinosus* Spencer, 1930.

*Diagnosis.*—Five arms, typically enrolled (Pl. 12, figs. 4–7); apically, median row of radial plates on each arm bordered on each side by a row of supramarginals (Pl. 12, figs. 5–7); adambulacrals below and commonly hidden by supramarginals, are short, broad, forming a very narrow edge and bearing long spines in line at right angles to the arm; spines of adambulacrals flat, not conical; most ossicles fairly stout; no apical plates bear ridges; ambulacrals are an advanced form of the flooring-plate type; mouth-angle plates very prominent, with deep grooves for water and nerve rings; high, erect apophysis; proximal ambulacral, open V-type.

*Remarks.*—*Onychaster* Meek and Worthen, 1868, *Calliasterella* Schuchert, 1914, and *Calyptactis* have “bird claw”-type ventral enrollment of the arms. *Onychaster* is an ophiuroid. *Calliasterella*, however, has a similar plate arrangement to *Calyptactis*. Spencer (1930, p. 395) stated:

None of the apical plates (of *Calyptactis*) bears ridges, and in this character the forms differ unmistakably from *Calliasterella*, which also has “*Onychaster*”-like arm foldings . . . .

Considering the manner in which spines are borne, he stated (p. 401):

The apical plates of *Calliasterella* have stout ridges, and the spines are set on the lateral edges of these ridges.

He additionally stated (p. 396):

This frame [mouth-frame of *Calyptactis*] contrasts strongly with the frame of *Calliasterella*, which is of the closed ring type, with very prominent first ambulacrals and mouth-angle plates small in comparison.

Furthermore (p. 398), he wrote:

There seems to be an odontophor [axillary] in the angles between arms IV and V [of *Calyptactis spinosus*]. The plate is elongated in a horizontal position, not vertically, as in *Calliasterella*.

### *Calyptactis spenceri*, new species

Plate 12, figures 4–7; Text-figures 18, 29

*Etymology of Name.*—The species name honors W. K. Spencer, who has done much work with Paleozoic asterozoans.

*Diagnosis.*—Plates of the disc are stellate (Pl. 12, figs. 5, 6); one very short, stubby, conical spine (Text-fig. 29) centrally located on all radials; each supramarginal (except Sm1) bears one small spine near the distalmost corner of the plate; spines as on radials.

*Description.*—The five arms are fairly long and enrolled ventrally (Pl. 12, figs. 4–7); diameter of arms (about 5 mm) is approximately one-half the diameter of the disc (about 10 mm). The aboral surface of the disc is flat-topped, with a shallow depression in the center formed by the imbrication of somewhat robust outer plates (primary radials and Sm1) upon less robust inner plates (centroradials and the centrale) (Pl. 12, figs. 5, 6; Text-fig. 29). The sides of the disc are declivitous from the central disc, the angles of which are formed by the five primary radials. The plates distal of the primary radial and Sm1 descend and form the sides. The arms are almost perpendicular to the flat-topped disc (Text-fig. 29B).

The plates of the disc are stellate and imbricate (Pl. 12, fig. 5; Text-fig. 29B). The upper surface of the centrale (C) is slightly convex (Text-fig. 29A). It has a stellate, pentagonal form due to the moderate concavities on its sides. It appears that the C imbricates over a circlet of five small, surrounding centroradials (cR) (Text-fig. 29B). The form of these is unclear because their edges are covered by the overlying plates. Surrounding the centroradials is a circlet of five primary radials (R1) alternating with five Sm1 (Pl. 12, figs. 5, 6; Text-fig. 29). Both of these imbricate over the centroradials, while the primary radials imbricate over the Sm1. The R1 are slightly more distal than the Sm1. The R1 and the Sm1 are somewhat more stellate than the C, but are about the same size. The Sm1 have the same degree of convexity as the C, but the R1 are all much more convex and robust than either of the other two, and have small circular depressions in the center of the plates that supported single spines (none of which are preserved). The Sm do not have these spine scars. The R1 are hexagonally stellate, with one of the points directed proximally (Pl. 12, fig. 5; Text-fig. 29). The shapes and sizes of the Sm2 and Ax are unclear.

The R2, R3, etc., are elongate hexagonal, but the form becomes progressively exaggerated distally into a rectangular shape, with the short axis parallel to the ray (Pl. 12, fig. 6; Text-fig. 29A). All of the radials are very convex. It appears that the R1 imbricates over the R2. The R2 is in contact with the R3, but from that point, the RR do not touch, and ride upon the

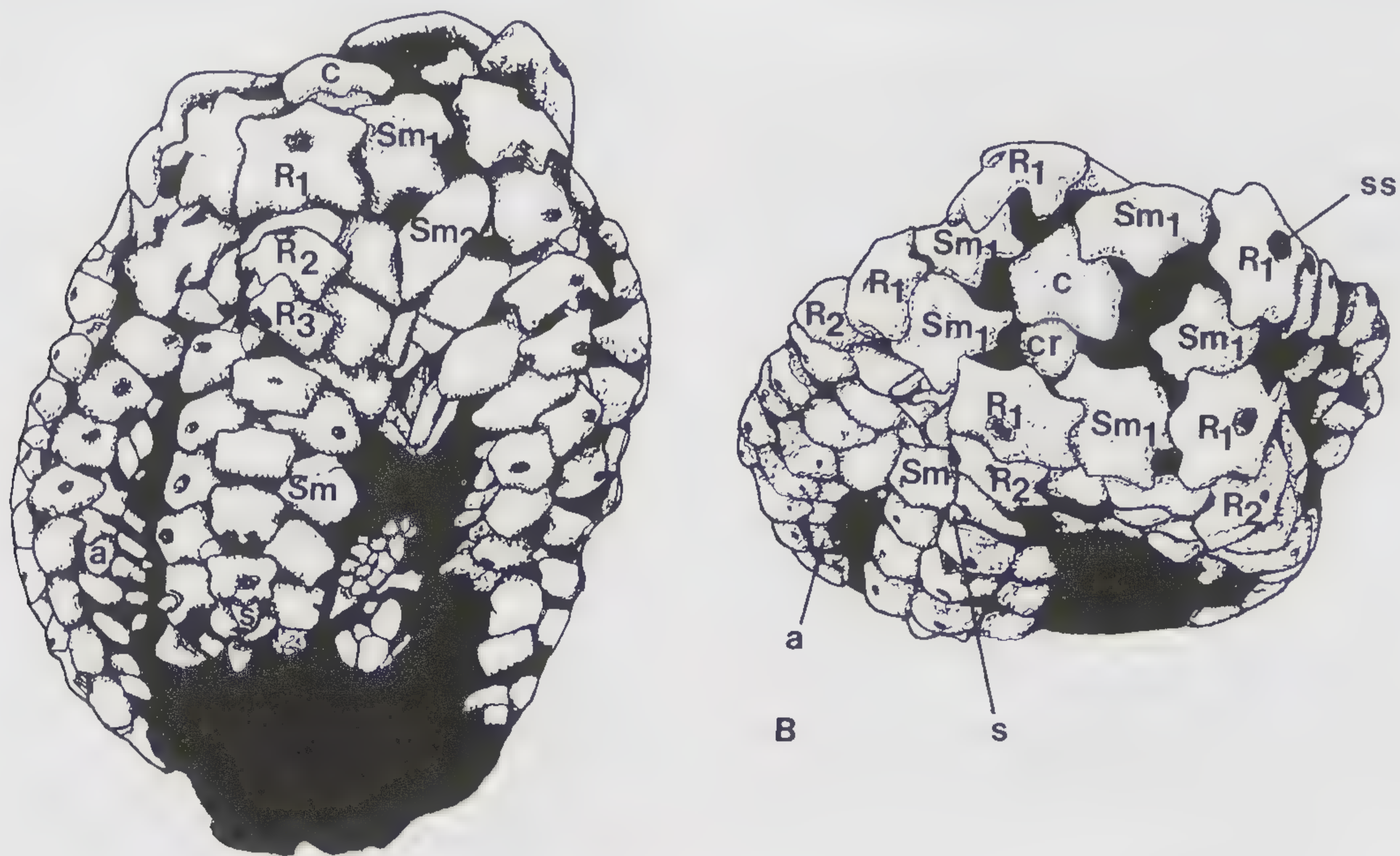


contact between the **Sm**. The **R2** still has a somewhat stellar form, but the side concavity diminishes in more distal **RR**. Both the distal axial point and the proximal axial point of the stellate **RR** are reduced, but still discernable. The **RR** bear small, circular spine scars centrally on each plate. The associated spines, when preserved, are very short, stubby, conical forms with a rounded base (Text-fig. 29). Their length is less than the shortest axis on the radial plate. They appear to be more like pointed knobs than spines.

The **Sm** of the arms are shaped like irregular subparallelograms with the longest axis directed at an angle of 40 to 60 degrees distally from the ray axis (Pl. 12, fig. 6; Text-fig. 29A). There is a matched pair on either side of the radials with their midline occurring between each radial plate. The **RR** imbricate over the **Sm**. Distally, the **Sm** become comparatively larger than the **R** plate over them. Each **Sm** bears a small circular spine scar, and, if preserved, a small knob-like spine, near the farthest and most distal edge of the plate (Pl. 12, figs. 4, 7; Text-fig. 29). The convex **Sm** curve toward the ventral side of the ray and form the sides. Each **Sm** is in contact with one or two ventrally-directed adambulacrals. The **Sm** slightly overhangs the **Ad** and commonly hides them from dorsal view of the ray (Text-fig. 29). In side view, the adambulacrals are subrectangular, directed at an angle with the longest axis ventral and distal. The adambulacrals support one (or more?) ventrally-directed small spines (Text-fig.

29A), comparatively longer than the knoblike spines of the other plates. No ambulacral or oral structure is observed in the two specimens, due to enrollment of the arms.

*Remarks.*—The species of *Calyptractis* are differentiated by the types and positions of the spines. *C. confragosus* (Miller, 1892) has numerous long spines on both radials and supramarginals (Spencer, 1930, p. 396). According to Miller (1892), all the radial plates are sculptured by spine scars and several spine scars appear on each disc plate, with ridges separating the scars. Spencer stated that *C. confragosus* is covered with spines (p. 394); however, the only disc plates bearing spines in *C. spenceri*, n. sp. are the radials, and these have only one spine each. No ridges separate spine scars, and the radial plates are not sculptured by spine scars. *C. demissus* (Miller, 1892) has angular arms with prominent spines on the primary radials of the disc and on the radials of the arms only. *C. spenceri* has spines on the radials and on the supramarginals. The spines are not prominent, however. *C. spinosus* carries isolated long spines on occasional radials and supramarginals (Spencer, 1930, p. 396). *C. perarmatus* (Whidborne, 1896) has no spines on the apical arm surface. *Calliasterella americana* Kesling and Strimble, 1966, is actually a species of *Calyptractis*. The excellent photographs of this species indicate that it is closely related to *Calyptractis spenceri*. However, there are no obvious large spine scars on the plates as in *C.*



A

Text-figure 29.—Plate arrangement for *Calyptractis spenceri*, n. sp. A. Lateral view. B. Dorsal view. c = central; cr = centroradials(?); R1 = primary radials; Sm1 = first supramarginals; R2 = secondary radials; R3 = tertiary radials; a = adambulacrals; s = spine; ss = spine scar.



*spenceri*. According to Kesling and Strimple (1966), this species probably had many small spines attached to numerous tubercles on the plates.

Kesling and Strimple (1966, p. 1164) described the possible paleobiology of their asteroid, *Calliasterella americana* (herein considered *Calyptactis americana*). They gave several reasons why it did not feed on bivalves: the structural nature of the arms was apparently not strong enough to exert a strong pull, and the podia, which are longer than the adambulacral spines, would have been too long for good pulling action. They suggested that the many small spines of the aboral surface provide an "insulating shield" to hold sediment away from the body of the starfish. They believed that the long adambulacral spines served as sediment rakes and that they possibly formed tunnels for passage of food particles when the animal was partially buried by sediment. However, the common occurrence of *C. spenceri* with fenestrate bryozoans (even within the ambulacra) (Pl. 12, figs. 4, 6, 7) suggests that the species may have fed on bryozoans (Text-fig. 18).

*Occurrence.*—Upper Mississippian (Middle Chesterian). Locality 3.

*Material.*—UK 115999 (holotype); USNM 441445 (topotype).

unidentifiable order

unidentifiable suborder

unidentifiable family

unidentifiable asterozoan genus and species

Plate 12, figures 8, 9

*Description.*—Mouth frame probably adambulacral; probable adambulacrals alternating, arranged in transverse rows, approximately rectangular, becoming wedge-shaped toward ambulacral groove (Pl. 12, figs. 8, 9); ambulacrals not visible; interradiar arc even, apparently without axillary; arms broad proximally and tapering evenly distally.

*Remarks.*—The specimen is poorly preserved, and the above characteristics do not seem sufficient to classify it below the subclass level.

This specimen occurs on a slab with a crinoid described and illustrated by Kirk (1942b) as *Ampelocrinus berhardinae* Kirk, 1942b (Pl. 12, fig. 8). Along with the crinoid, Kirk illustrated the above-mentioned starfish, but provided no identification.

*Occurrence.*—Upper Mississippian (Chesterian).

*Material.*—USNM S-4402B (hypotype).

#### APPENDIX 1

##### Reference Section

##### Sloans Valley member of the Pennington Formation

Roadcuts on U.S. Highway 27 at Sloans Valley, Kentucky, between Sloans Valley Post Office and small roadcut (east side of road) just north of junction with Dixie Bend Road; Pulaski County, Burnside Quadrangle, 800 ft FEL × 1800 ft FSL, 18-F-60. Reference section for Sloans Valley member (Ettensohn *et al.*, 1984).

unit	description	thickness	
		meters	(ft)
Lee Formation			
4.	Shale, dark; siderite nodules	0.46	(1.5)
3.	Coaly horizon, sandy	0.30	(1.0)
2.	Shale, very sandy, organic-rich	0.61	(2.0)
1.	Sandstone interbedded with shale	0–3.66	(0–12.0)
Disconformity from unit 21 to 2.7 m (9 ft) from top of unit 17 of upper shale member			
Pennington Formation			
upper shale member			
21.	Shale, green, weathered; missing laterally due to channeling	0.10	(0.3)
20.	Dolostone, silty; with some ironstone	1.00	(3.3)
19.	Shale	0.43	(1.4)
18.	Siltstone, dolomitic; current ripples	0.37	(1.2)
17.	Shale, red and green	5.12	(16.8)
16.	Siltstone, dolomitic, very thin and irregularly bedded; some burrowing	2.00	(6.7)
15.	Shale, maroon and green, clayey, with thin dolostone stringers and nodules	2.2	(7.2)
Covered interval. Dixie Bend Road			
14.	Siltstone, dolomitic	0.46	(1.5)
13.	Shale, dark-greenish-gray	0.61	(2.0)
12.	Dolostone, silty	0.15	(0.5)
11.	Shale, dolomitic	0.18	(0.6)
10.	Dolostone, silty, massive	0.30	(1.0)
9.	Shale, dark-greenish-gray	0.24	(0.8)
8.	Dolostone, laminated	0.43	(1.4)
7.	Shale, greenish- to reddish-gray, with zone of brecciated dolostone 0.3 m (1.0 ft) from top	1.28	(4.2)
6.	Sandstone, fine-grained, to siltstone; lower portion rippled, flaser-bedded; upper 0.15 m (0.5 ft) cross-bedded; grades into overlying shale	0.58–0.82	(1.9–2.7)
5.	Dolostone, brown, weathers orangish-brown; with fossil and shale clasts; burrowed; concretionary	0.21	(0.7)
4.	Shale, silty, red and green, chunky, with dolomitic nodules; top portion red, lower portion green; no fossils?	2.87	(9.4)
3.	Shale, dark-gray to black, clayey; 0.91 m (3.0 ft) from top is 2.5 cm of black, carbonaceous, brittle shale with abundant productid brachiopods	4.33	(14.2)
2.	Limestone, calcarenite, shaly, cross-bedded, rippled, irregular, thin, interbedded with shale, fossiliferous (brachiopods, bryozoans)	0.30	(1.0)
1.	Shale, clayey, black, laminated	1.62	(5.3)
Total upper shale member		28.8–29.2	(94.7–95.5)
limestone member			
1.	Limestone, crinoidal calcarenite; ooids; overlies and fills a burrowed,		



irregular surface on dolostone below; <i>Agassizocrinus</i> , <i>Pterotocrinus</i> , <i>Zaphrentoides?</i> , <i>Anthracospirifer</i> , crinoid columnals	0.24–0.30	(0.8–1.0)	4. Shale, marly, and interbedded nodular limestone, very fossiliferous	1.09	(3.6)
Total limestone member	0.24–0.30	(0.8–1.0)	3. Interbedded shale and thin-bedded limestone, fossiliferous	1.0	(3.3)
dolostone member			2. Limestone, massive skeletal and oolitic calcarenite, pinches out in both northwest and southeast directions, cross-bedded (109°), channeling, scouring	0–4.88	(0–16.0)
17. Dolostone to limestone, dolomitic, massive, vuggy; some laminae; forms ledge with limestone member above; upper 0.61 m (2.0 ft) brownish, rest light gray; upper 0.76 m (2.6 ft) thinner bedded with shale partings	2.19	(7.2)	1. Interbedded shale and thin-bedded limestone, very fossiliferous, crinoids, <i>Pterotocrinus</i> , <i>Zaphrentoides</i> , brachiopods, bryozoans, unit thins where overlying limestone thickens	1.4–2.13	(4.5–7.0)
16. Shale, gray; three thin dolostone beds in upper 0.40 m (1.3 ft); burrowed calcisiltite bed (0.25 m [10 in]) (dolomitic?); calcisiltite, rippled, 0.18 m (0.6 ft) thick, 0.3 m (1.0 ft) above base	2.04	(6.7)	Total Sloans Valley member	6.3–12.0	(20.8–39.3)
15. Limestone, laminated with some pebbles, brachiopodal and pelecypodal; convex-up shells, small pelecypods, <i>Orthotetes</i> , other brachiopods, burrows	0.18	(0.6)	Bangor Limestone		
14. Shale, greenish-gray	0.37	(1.2)	6. Limestone, medium- to thin-bedded, skeletal calcarenite, thin shale partings	5.33	(17.5)
13. Limestone, calcilutite, irregular, rubbly, uppermost 0.5 m (1.6 ft) brecciated and filled with dark-greenish shale and quartz pebbles	0.91	(3.0)	5. Limestone, thin- to medium-bedded, skeletal calcarenite, with shale partings	2.13	(7.0)
12. Shale, dolomitic	0.12	(0.4)	4. Limestone, cross-bedded, skeletal calcarenite, intraclasts, <i>Zaphrentoides</i> , crinoids, <i>Agassizocrinus</i> , <i>Pentremites</i>	0.88	(2.9)
11. Dolostone, massive, rubbly and brecciated at top	0.37	(1.2)	3. Limestone, crinoidal calcarenite, grading up into shale horizon	0.55	(1.8)
10. Shale, dolomitic	0.55	(1.8)	2. Limestone, shaly, calcarenite	0.12	(0.4)
9. Dolostone, laminated, mud chips, contorted bedding, birdseyes	0.30	(1.0)	1. Limestone, fossiliferous calcarenite, <i>Agassizocrinus</i>	0.30	(1.0)
8. Shale, with fossiliferous limestone lenses	0.30	(1.0)	Total Bangor Limestone	9.3	(30.6)
7. Limestone, fine-grained calcarenite, fossiliferous, brecciated at top of exposure zone	0.15	(0.5)	Hartselle Formation (incomplete)		
6. Shale	0.03	(0.1)	2. Limestone, dolostone, calcisiltite, productid brachiopods	0.15	(0.5)
5. Limestone, silty, some fossils, locally dolomitic	0.58	(1.9)	1. Shale, silty, gray-green, chunky	1.10	(3.6)
4. Shale, dolomitic	0.09	(0.3)			
3. Limestone, calcarenitic, crinoidal and ooid grains, cross-bedded, dolomite-filled burrows	1.16	(3.8)			
2. Dolostone, massive, vuggy, large stylolites; lower 0.8 m (2.6 ft) may be rubbly, shaly dolostone that pinches out into dolostone	0.98	(3.2)			
1. Dolostone and limestone, dolomitic, massive; some laminae, vuggy, some fossil fragments	1.34	(4.4)			
Total dolostone member	11.7	(38.3)			
Sloans Valley member					
7. Shale, gray to black, fissile, bryozoans, brachiopods, <i>Archimedes</i> , <i>Pterotocrinus</i>	0.61	(2.0)			
6. Limestone, skeletal calcarenite, cross-bedded, brownish-gray, <i>Composita</i> , <i>Pterotocrinus</i> , <i>Agassizocrinus</i> , <i>Lycopora</i>	0.61	(2.0)			
5. Shale, calcareous, brownish- to greenish-gray, with a few limestone lenses, both very fossiliferous (flattened fenestrites, brachiopods)	1.65	(5.4)			

## APPENDIX 2

## Locality Register and Section Descriptions

Collections for this study were made at seven localities, listed below and shown on Text-figure 1. Collection sites are located on 7.5' topographic quadrangle maps using the Carter coordinate system, an alphanumeric grid system used throughout Kentucky. Descriptions of the sections at each locality are given below.

Most collecting at the quarry localities was done from spoil piles of discarded shale and limestone of the Sloans Valley member of the Pennington Formation. These dumps provided specimens that were better exposed in or weathered free from the matrix; however, it was difficult to determine from which beds such fossils came. Because the Sloans Valley member weathers so quickly, most outcrop and quarry exposures soon become covered and poorly exposed.

*Locality 1.*—Cincinnati–Southern Railroad cut (old bed) near Sloans Valley, Pulaski County, Burnside Quadrangle; Carter coordinate location 1200 ft FNL



× 2400 ft FEL, 14-F-60, and along the eastern part of 14-F-60 and the southwestern part of 13-F-60. This is the famous collection locality. The reference section is nearby. Very little material is found here now; the banks are all overgrown.

*Locality 2.*—Southern Railroad cut (new bed), where Garland Road crosses over railroad, near Tatesville, Pulaski County, Burnside Quadrangle, 1200 ft FWL × 2400 ft FSL, 16-F-60.

unit	description	thickness meters	(ft)
Pennington Formation			
dolostone member (lowest bed only)			
1.	Limestone, dolomitic, to dolostone, massive, some fossils ( <i>Pentremites pyriformis</i> , <i>Composita</i> , fenestellids)	0.61	(2.0)
	Total measured dolostone member	0.61	(2.0)
Sloans Valley member			
7.	Shale, greenish-brown, somewhat fossiliferous at southern end of exposure, very fossiliferous at northern end; <i>Pterotocrinus</i> spp. ( <i>P. depressus</i> , very abundant, <i>P. acutus</i> , abundant), <i>Tholocrinus</i> , <i>Pentremites</i> , crinoid columnals, <i>Cleiothyridina</i> , <i>Zaphrentoides</i> , <i>Archimedes</i> , ramose bryozoans	0.76–1.45	(2.5–4.75)
6.	Limestone, irregularly bedded to nodular-bedded, skeletal calcarenite, shale clasts, internal bedding contorted, very fossiliferous, commonly good preservation of crinoids, <i>Archimedes</i>	0.18–0.30	(0.6–1.0)
5.	Shale, fossiliferous ( <i>Pterotocrinus depressus</i> , <i>Archimedes</i> , <i>Cleiothyridina</i> )	0.08–0.23	(0.25–0.75)
4.	Limestone, as in bed 6, <i>Agassizocrinus</i> , other crinoids, crinoid columnals, <i>Lyropora</i> , <i>Archimedes</i> , <i>Anthracospirifer</i> , <i>Zaphrentoides</i>	0.30–0.46	(1.0–1.5)
3.	Shale, calcareous, medium-gray, with some limestone stringers and nodular-bedded limestone, both highly fossiliferous; <i>Pterotocrinus depressus</i> (more abundant in this shale than at any other locality); <i>Archimedes</i>	0.3–0.76	(1.0–2.5)
2.	Limestone, crinoidal calcarenite; at southern end it is massive, cross-bedded, and contains ooids; grades laterally northward into limestone with interbedded shale; one limestone bed (0.3 m from bottom) is a <i>Pterotocrinus coquina</i> ; other abundant fossils include: <i>Archimedes</i> , <i>Cleiothyridina</i> , <i>Anthracospirifer</i> , <i>Zaphrentoides</i> , <i>Pentremites</i> , <i>Acrocrinus</i> , <i>Tholocrinus</i> , <i>Pterotocrinus</i>	0.9–1.52	(3.0–5.0)
1.	Shale with some thin limestone beds; shale, calcareous; limestone and shale fossiliferous	0.9	(3.0)
	Total Sloans Valley member	4.4	(14.5)

Bangor Limestone (incomplete)

2.	Limestone, argillaceous, with thin shale partings; grades into shale above and massive limestone below; very fossiliferous, with crinoids, brachiopods, and bryozoans	0.46	(1.5)
1.	Limestone, argillaceous, crinoidal; some chert; massive- to medium-bedded	7.47	(24.5)
	Total Bangor Limestone	7.93	(26.0)

*Locality 3.*—Strunk Construction Company Quarry near Tatesville, Pulaski County, Burnside Quadrangle, 2200 ft FWL × 2200 ft FSL, 15-F-60.

unit	description	thickness meters	(ft)
Pennington Formation			
dolostone member (lowest bed only)			
1.	Dolostone to dolomitic limestone, skeletal calcarenite, massive, dark-gray, finely laminated when not bioturbated; abundant vugs as large as 0.3 m containing dogtooth spar calcite, dolomite, barite, celestite, strontiantite; large styolites up to 0.15 m (0.5 ft) high	1.37–4.42	(4.5–14.5)
	Total dolostone member	1.37–4.42	(4.5–14.5)
Sloans Valley member			
11.	Shale, clayey, fissile, dark-gray, fossiliferous with impressions of fenestellids and <i>Aviculopecten</i> ?; lower half contains fossils and irregular lenses of fossiliferous limestone with <i>Lyroporella</i> , <i>Archimedes</i> , <i>Agassizocrinus</i> , <i>Tholocrinus</i> , <i>Pterotocrinus</i> spp., <i>P. depressus</i> , and <i>P. acutus</i>	0.46–0.9	(1.5–3.0)
10.	Limestone and shale interbedded; limestone very fossiliferous, shale marly; may change laterally	0.15	(0.5)
9.	Shale	0.15	(0.5)
8.	Interbedded limestone and shale; limestone, thin-bedded, calcarenite with pelmatozoans; may change laterally	0.46	(1.5)
7.	Limestone, dolomitic, wackestone-packstone, abundant fossil fragments (bryozoans, echinoderms); may change laterally	0.40–0.61	(1.3–2.0)
6.	Shale, clayey, fossils sparse	0–0.69	(0–2.25)
5.	Shale with limestone interbeds; limestone irregular, lenses in and out; fossils in both; changes laterally	0.46	(1.5)
4.	Limestone, calcirudite; changes laterally	0.30	(1.5)
3.	Shale	0.08	(0.25)
2.	Limestone, calcirudite–calcisiltite, fossiliferous; <i>Pterotocrinus</i> , crinoid columnals, <i>Zaphrentoides</i> ; may change laterally	0.46	(1.5)
1.	Shale, medium-dark gray, clayey, fissile, with limestone stringers lensing		



in and out; may change laterally 0.30 (1.0)  
 Total Sloans Valley member 3.5-4.2 (11.5-13.8)

Bangor Limestone (incomplete)

1. Limestone, bluish-gray, massive, argillaceous in part, some chert; top surface rich in fossils, including crinoid debris, brachiopods, ramose bryozoans, *Archimedes*, and other fenestellids 9.22 (30.25)  
 Total Bangor Limestone 9.22 (30.25)

*Locality 4.*—Somerset Stone Company Quarry (Bangor and Pennington strata no longer present because of quarrying), Pulaski County, Somerset Quadrangle; Carter coordinate location 700 ft FWL × 2500 ft FSL, 25-H-60. The Sloans Valley member was removed before the section could be measured.

*Locality 5.*—Laurel County Quarry (now abandoned and flooded); Laurel County, Billows Quadrangle; Carter coordinate location 300 ft FNL × 1800 ft FWL, 3-H-63.

unit	description	thickness	
		meters	(ft)
Pennington Formation			
dolostone member (only lower part exposed)			
	3. Interbedded dolostone and shale, no fossils?	0.91	(3.0)
	2. Dolostone, massive, bluish-gray, weathers yellowish-buff, bioclastic, somewhat arenaceous, with crinoid columnals, <i>Agassizocrinus</i> , <i>Pentremites pyriformis</i> , <i>Composita</i> , <i>Anthracospirifer</i> , and productids	0.46-0.61	(1.5-2.0)
	1. Interbedded dolostone and shale; basal dolostone fossiliferous with <i>Agassizocrinus</i> , <i>Composita</i> , <i>Anthracospirifer</i> , <i>Archimedes</i> , <i>Lyropora</i> , and other fenestrates; undersides of slabs have numerous horizontal burrows	0-0.99	(0-3.25)
	Total measured dolostone member	2.36-2.51	(7.75-8.25)
Sloans Valley member			
	18. Shale, clayey, light-brown, fissile; few fossils	0.58-0.76	(1.9-2.5)
	17. Shale with some limestone interbeds; shale marly, bluish-gray, highly fossiliferous ( <i>Composita</i> , <i>Anthracospirifer</i> , crinoid fragments, and bryozoans); limestone 5-8 cm thick, argillaceous, bioclastic calcarenite, may be irregularly bedded, with fenestrate and ramose bryozoans, <i>Anthracospirifer</i> , other brachiopods, crinoids, sharks' teeth; grades laterally into unit 16	0.30-1.07	(1.0-3.5)
	16. Limestone, argillaceous, arenaceous, poorly sorted, indistinct to irregular bedding, rubbly weathering; in part highly encrinal; very fossiliferous, crinoids, sharks' teeth, <i>Anthracospirifer</i> , and fenestrate bryozoans; grades laterally and into unit 17	0.38-1.40	(1.25-4.6)

15. Shale, marly, bluish-gray, irregular rubbly weathering, fossil fragments throughout; some layers encrinal, other layers with fenestrate bryozoans	0-0.38	(0-1.25)
14. Limestone to dolomitic limestone, massive, arenaceous, bioclastic, bluish-gray, with crinoid debris, <i>Pterotocrinus</i> , <i>Agassizocrinus</i> , <i>Anthracospirifer</i> , <i>Composita</i> , <i>Zaphrentoides</i> , and fenestrate bryozoan fragments; lower 10 cm contains abundant clasts of calcilutite, phosphate pebbles, and transported fossils, large calcilutite lithoclasts are in irregular shapes up to 10 cm in width and are rounded; these lithoclasts contain fossils of bellerophonitids, other large gastropods, a straight nautiloid, trilobite pygidia, and corals; pebbles are rounded and transported, some are worn sharks' teeth; transported fossils include bryozoans, crinoid columnals, <i>Agassizocrinus</i> infrabasal cones, <i>Pterotocrinus</i> wing plates, predominantly <i>P. acutus</i> , and brachiopods; pyrite is also present	0.40	(1.3)
13. Limestone, bioclastic, arenaceous, dark-gray, friable, very fossiliferous; no whole fossils; fossils transported and include <i>Agassizocrinus</i> infrabasal cones, <i>Pterotocrinus</i> wing plates, predominantly <i>P. acutus</i> , crinoid columnals, <i>Zaphrentoides</i> , single <i>Anthracospirifer</i> valves, and rounded phosphatic pebbles; pyrite present, unit is iron-stained	0-0.27	(0-0.9)
12. Shale, clayey, fissile, few fossils; upper 2.5 cm may have abundant <i>Pterotocrinus</i> wing plates; in the eastern portion of the quarry this unit thickens and contains flaser bedding; shale is silty	0.30-0.34	(0.1-1.1)
11. Limestone, bluish-gray, massive, coarse-grained, bioclastic, with <i>Agassizocrinus</i> , <i>Pterotocrinus</i> , and <i>Anthracospirifer</i> fragments; lower 12.5 cm in western end is cross-bedded; in eastern end irregular bedding	0.40-0.70	(1.3-2.3)
10. Shale, clayey to silty; in the eastern part of quarry unit thickens; minor flaser bedding in lower 0.3 m (1 ft)	0.07-0.84	(0.25-2.75)
9. Limestone, arenaceous, calcarenite, laminated, no fossils, found only in western part of quarry	0.08	(0.25)
8. Shale, siltstone, and sandstone interbedded, flaser-bedded; unusual surface markings (tool markings?) on some flaser beds; some pyrite, many dark carbonaceous fragments scattered over the bedding surface; irregular asymmetric ripple marks; abundant and diverse trails on surface	0.15-0.30	(1.5-1.0)
7. Sandstone, calcareous, to arenaceous limestone, white to light-gray; well-		



developed cross-bedding; contains flat clay pebbles (1–2 cm); upper surface with irregular ripple marks; sandstone is calcareously cemented and contains marine fossils; grades laterally into very arenaceous limestone, containing fossils	0.15–0.46	(0.5–1.5)
6. Shale, siltstone, and sandstone; flaser-bedded, as in unit 8	0.03–0.15	(0.1–0.5)
5. Sandstone, calcareous, to arenaceous limestone; in eastern portion it is cross-bedded, irregularly bedded with 5 cm shale parting in middle; in western portion sandstone is much thinner and has horizontal burrows	0.03–0.53	(0.1–1.75)
4. Shale	0.3	(0.1)
3. Limestone, light-gray, biocalcirudite; occurs in western part of quarry	0–0.15	(0–0.5)
2. Limestone, argillaceous, medium-gray, irregularly bedded to pseudonodular; internal bedding contorted; very fossiliferous; <i>Anthracospirifer</i> , crinoids, found in western part of quarry	0–0.30	(0–1.0)
1. Shale, clayey, dark-gray, fissile, sparsely fossiliferous, fenestellids	0.30–0.46	(1.0–1.5)
Total Sloans Valley member	7.0	(23.0)
Bangor Limestone (incomplete)		
2. Interbedded limestone and shale, very fossiliferous, delicate fossils, echinoids, crinoids, brachiopods, bryozoans, trilobite pygidia, some pyrite;		

unit is gradational between the Bangor Limestone and the Sloans Valley member	0–0.08	(0–0.25)
1. Limestone, argillaceous, bluish-gray, massive, skeletal calcarenite; dolomite- or calcite-filled vugs; some chert; upper surface may contain <i>Archimedes</i> and crinoid columnals; surfaces below shale partings reveal <i>Archimedes</i> , large ramose bryozoans, fenestellids, large rugose corals, <i>Anthracospirifer</i> , <i>Composita</i> , and a few crinoid columnals	7.0+	(23.0+)
Total measured Bangor Limestone	7.1+	(23.2+)

*Locality 6.*—Exposure above small, man-made farm pond at Clover Bottom. The thin, incomplete section probably occurs near the base of the Sloans Valley member, but could not be placed exactly for lack of a marker horizon; the section was not measured or described. Jackson County, Big Hill Quadrangle; 2400 ft FSL × 300 ft FEL, 21-M-64.

*Locality 7.*—Small roadcut on Long Branch Road, approximately 3.5 km (2.2 mi) from its junction with U. S. Highway 421, southeast of Morrill. The thin, incomplete section in the Sloans Valley member occurs just above the Bangor Limestone; the section was not measured or described. Jackson County, Big Hill Quadrangle; 200 ft FWL × 1100 ft FSL, 16-M-65.

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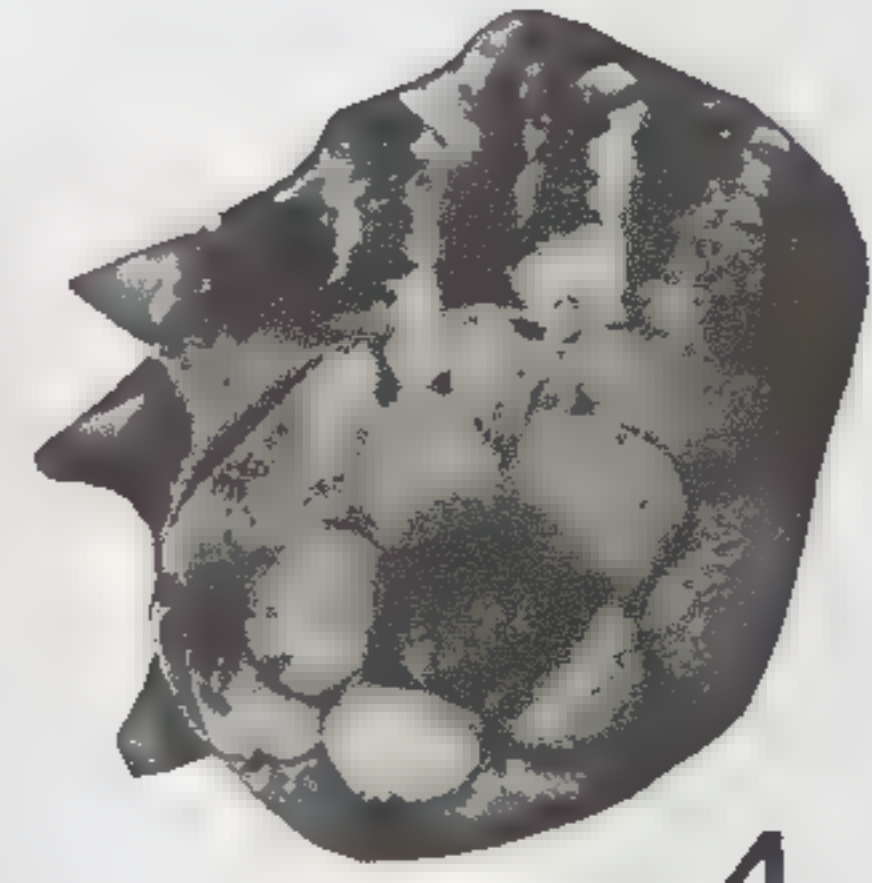
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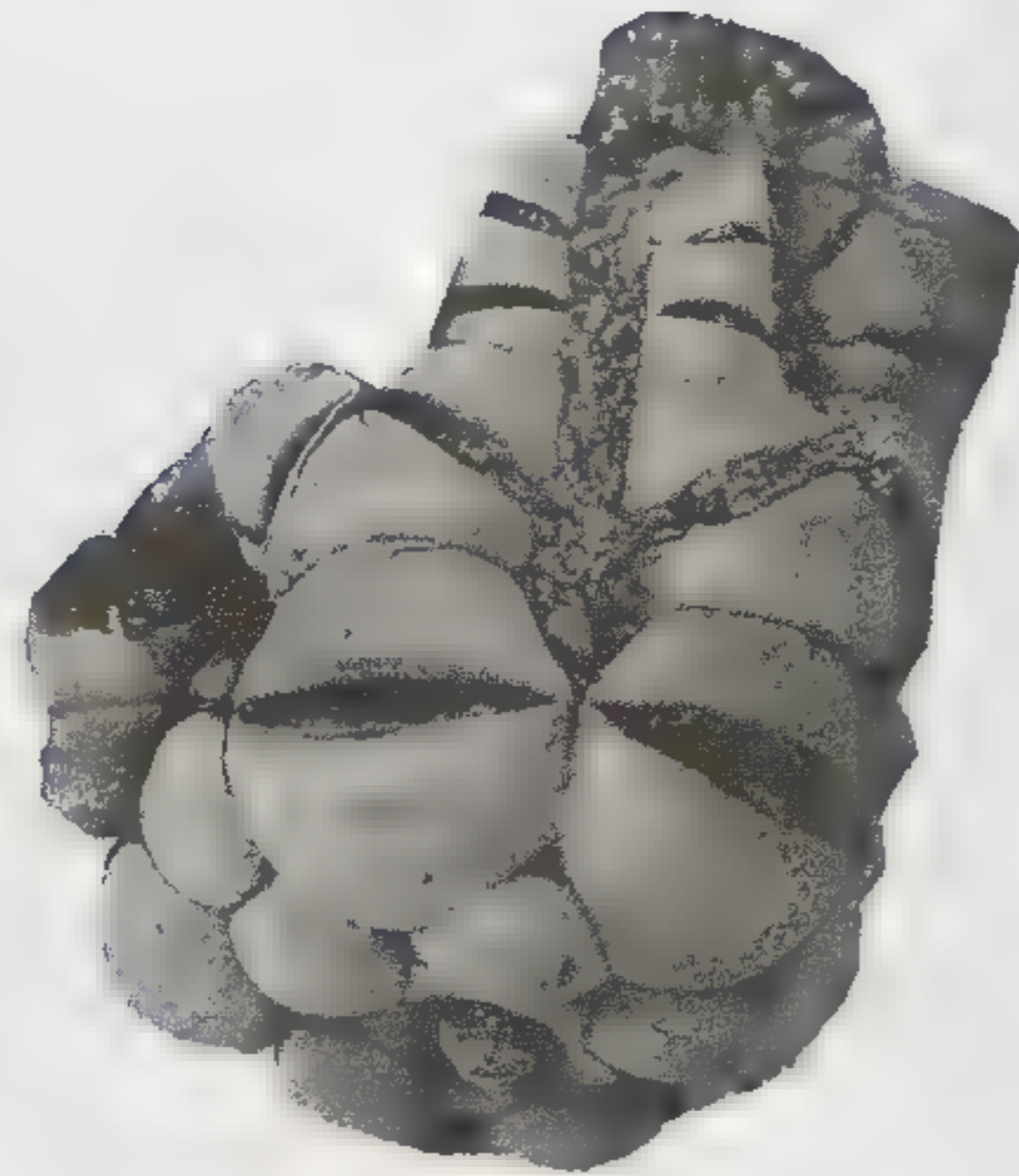
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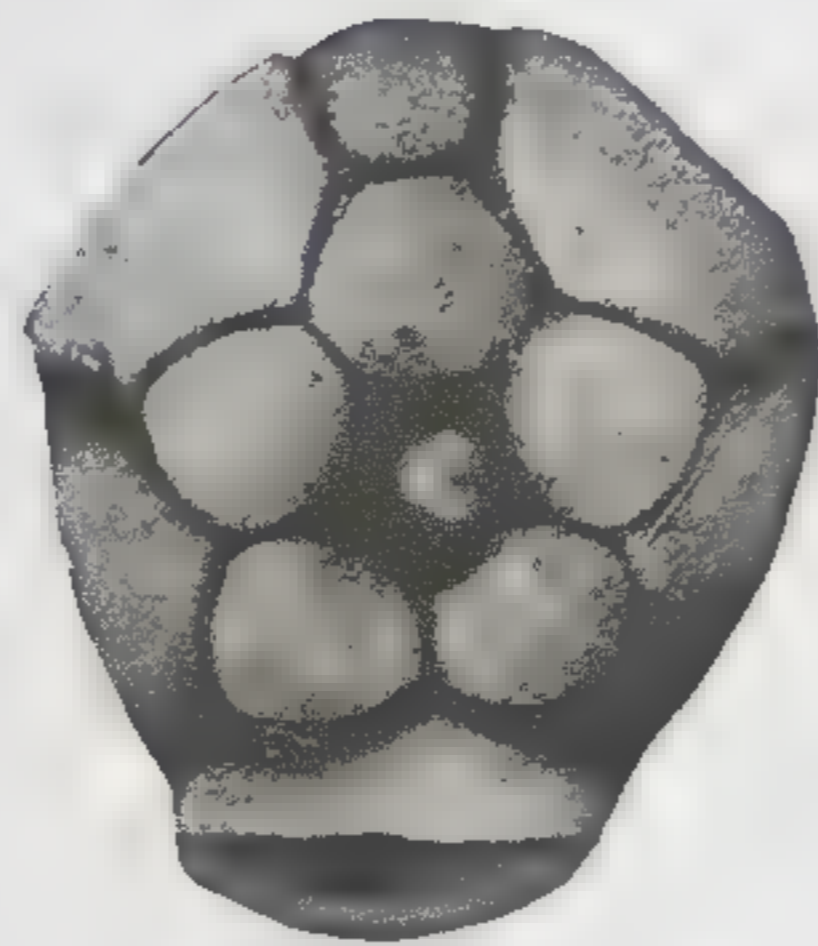
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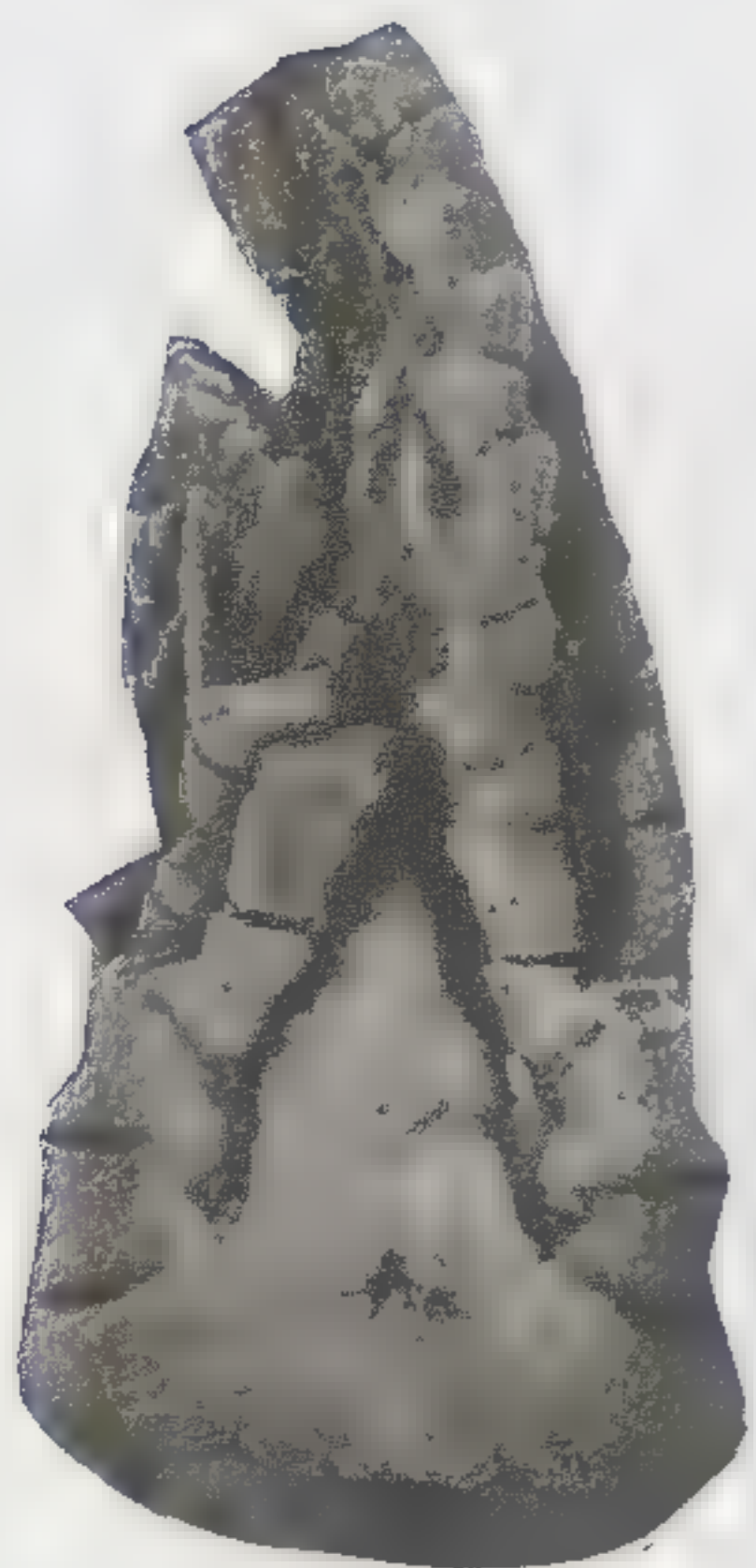
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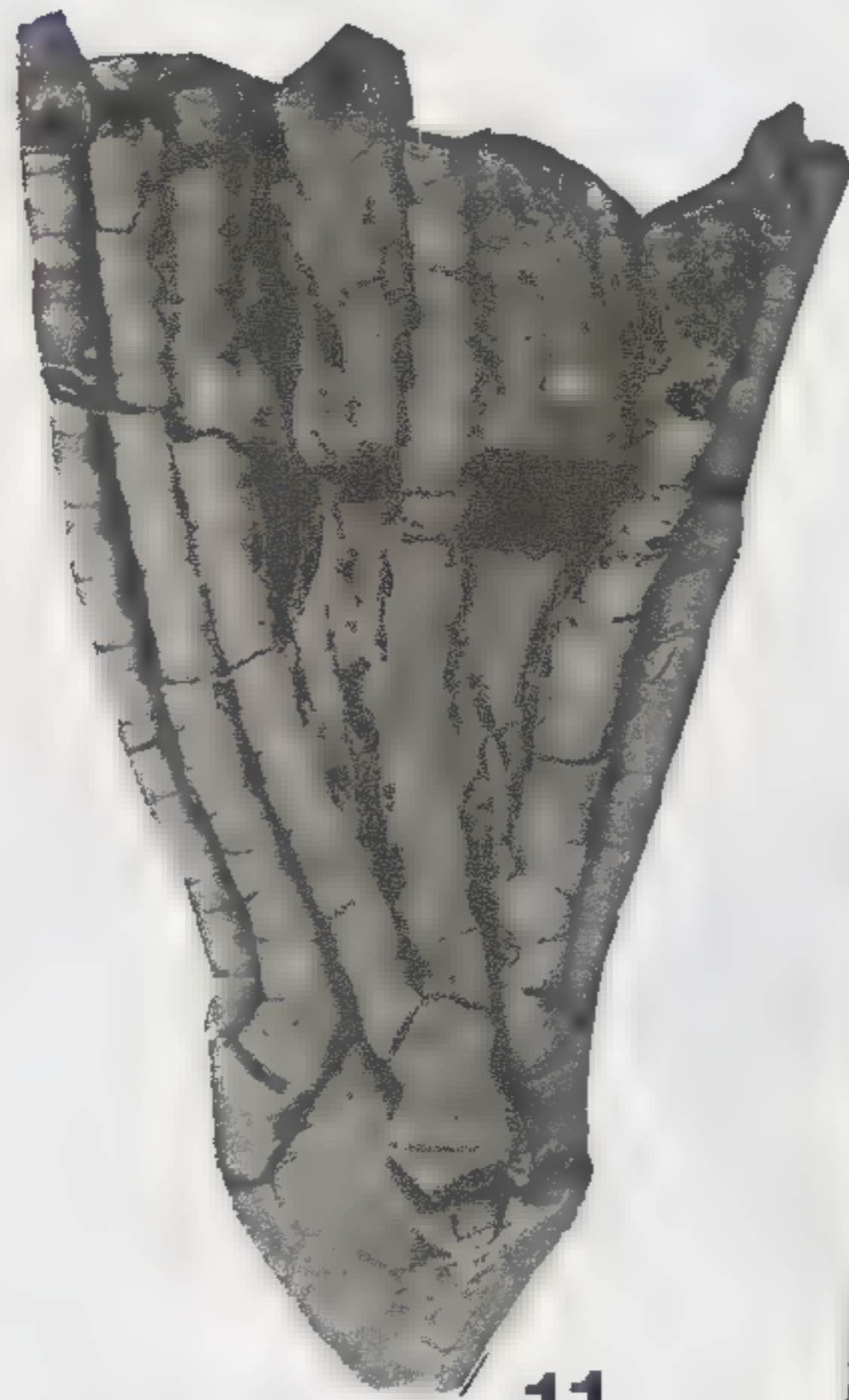
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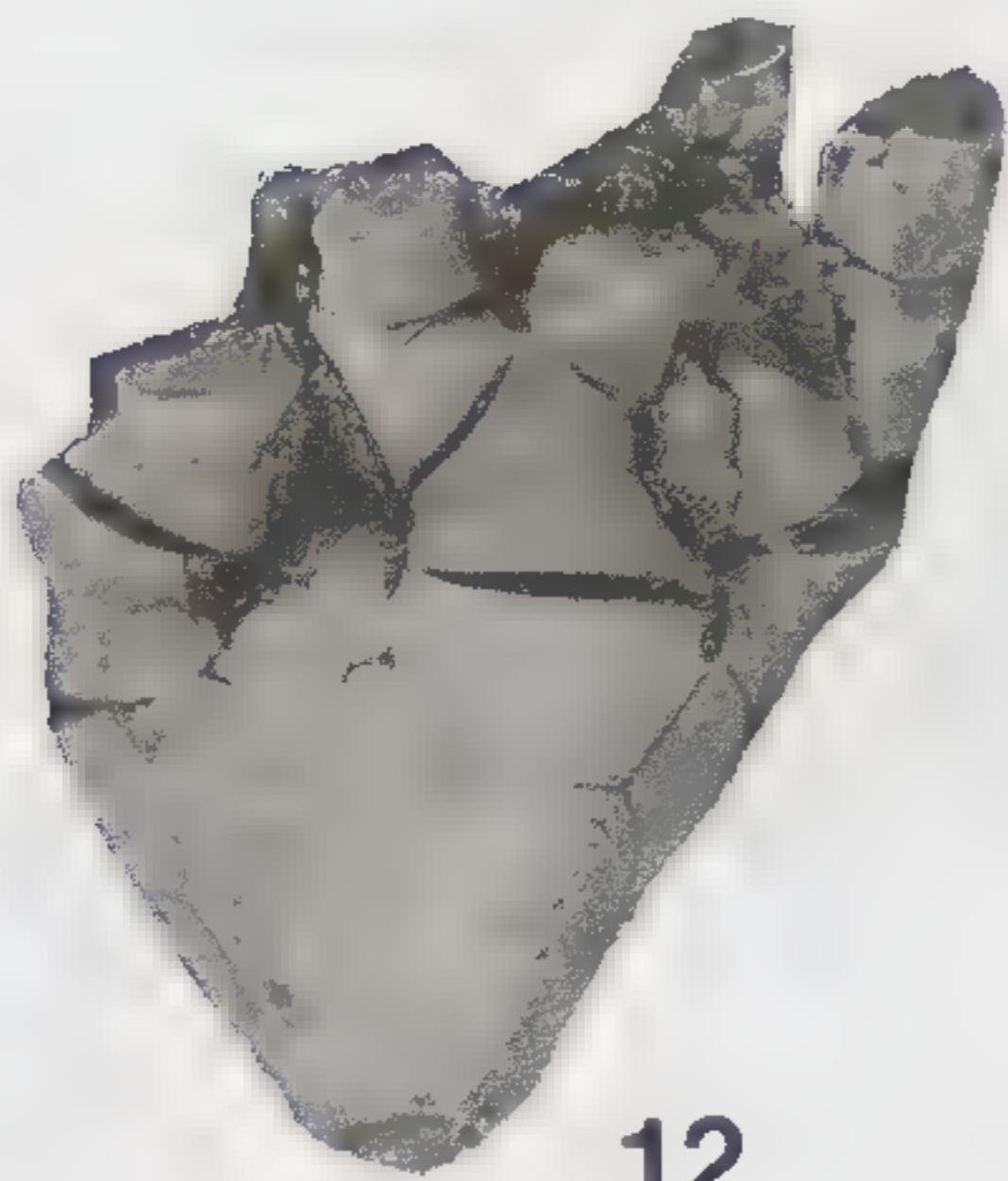
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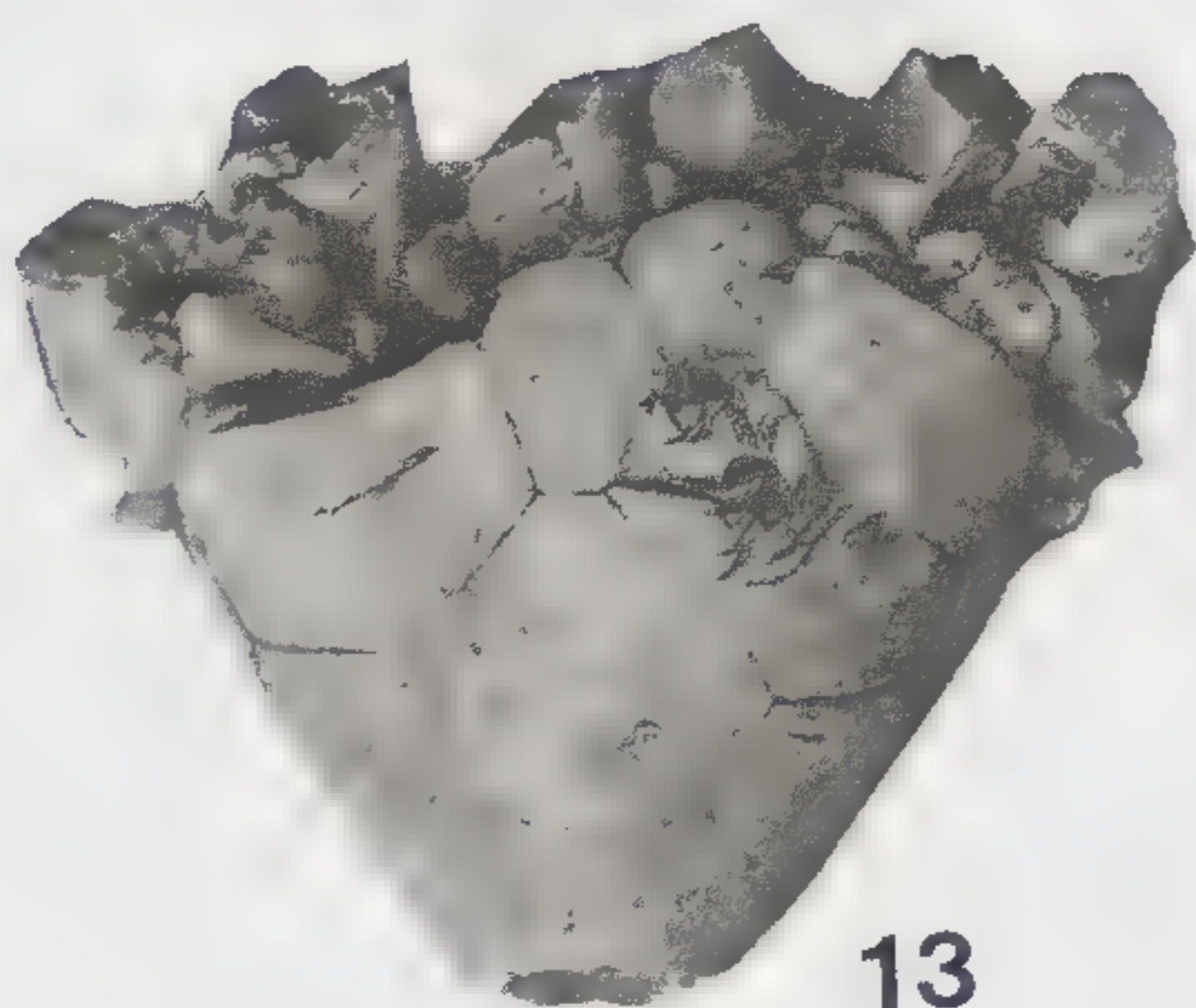
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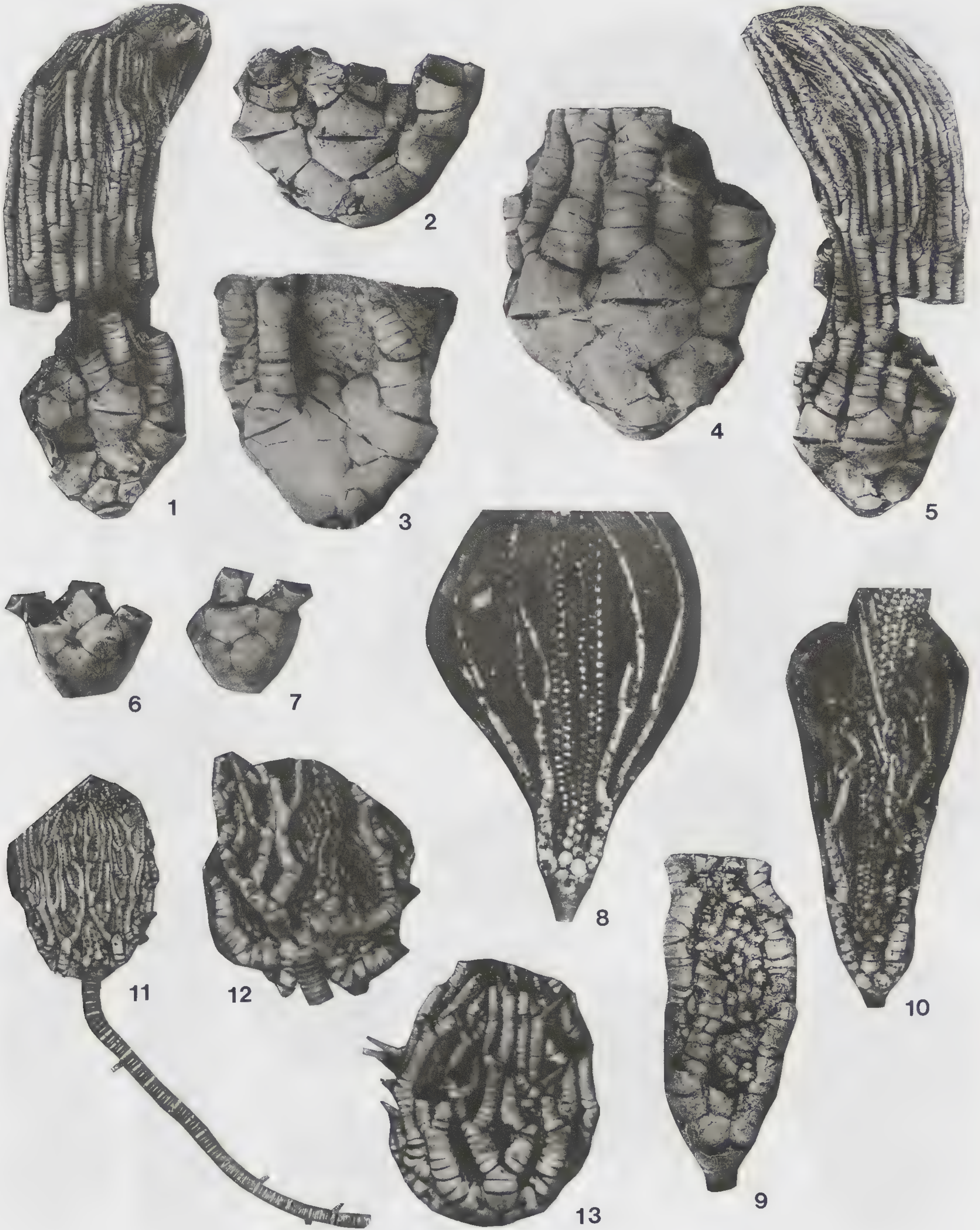
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## EXPLANATION OF PLATE 4

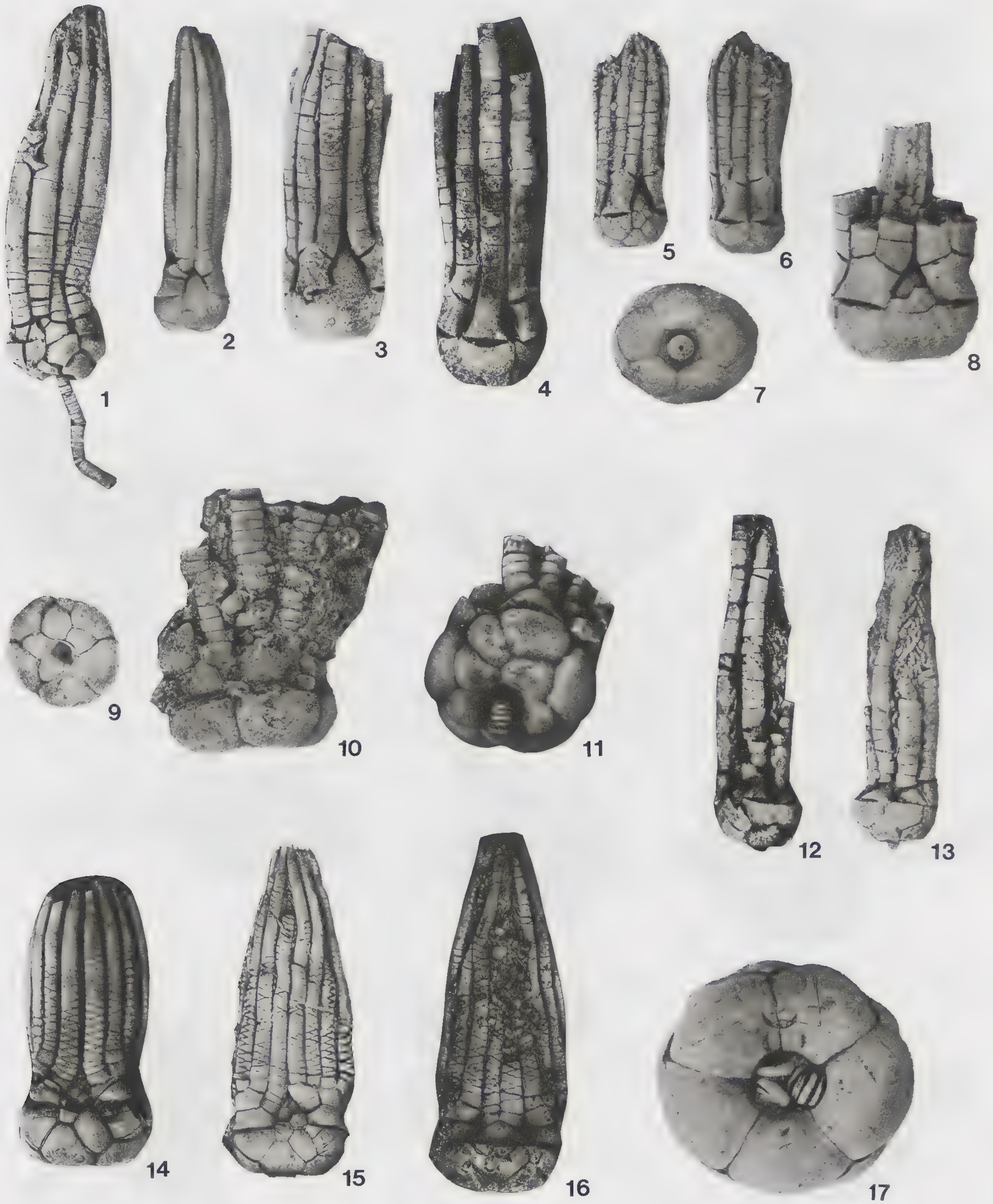
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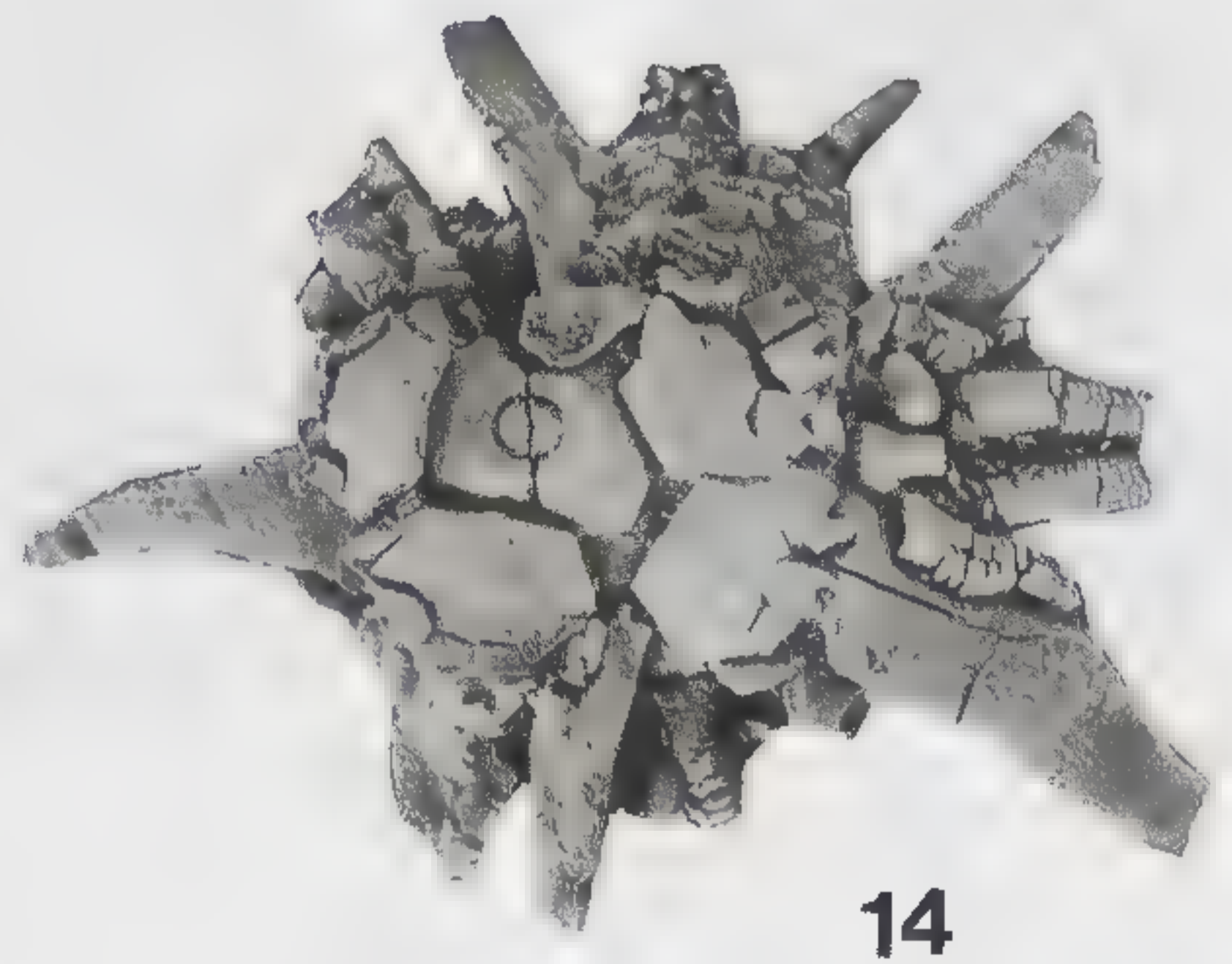
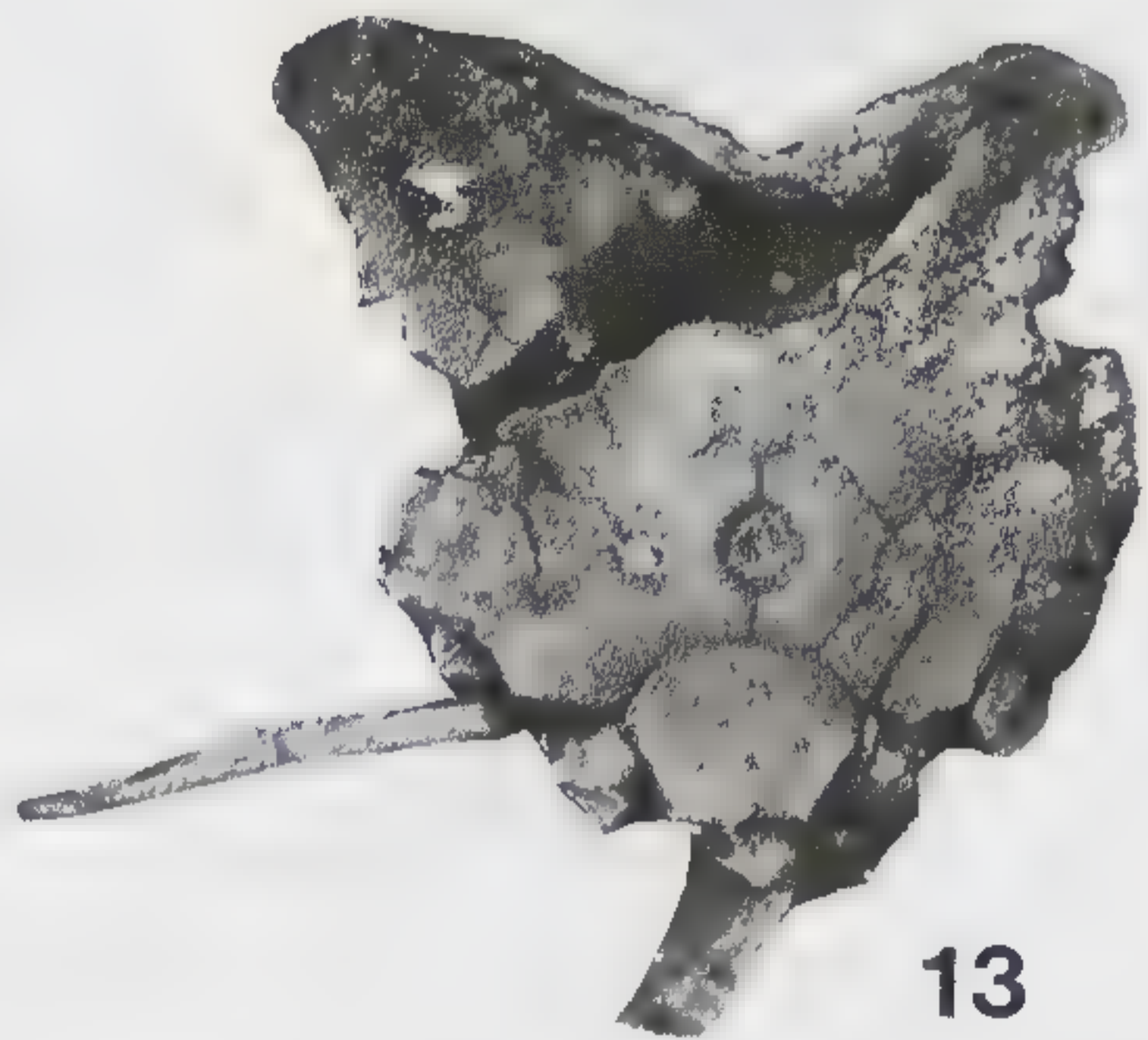
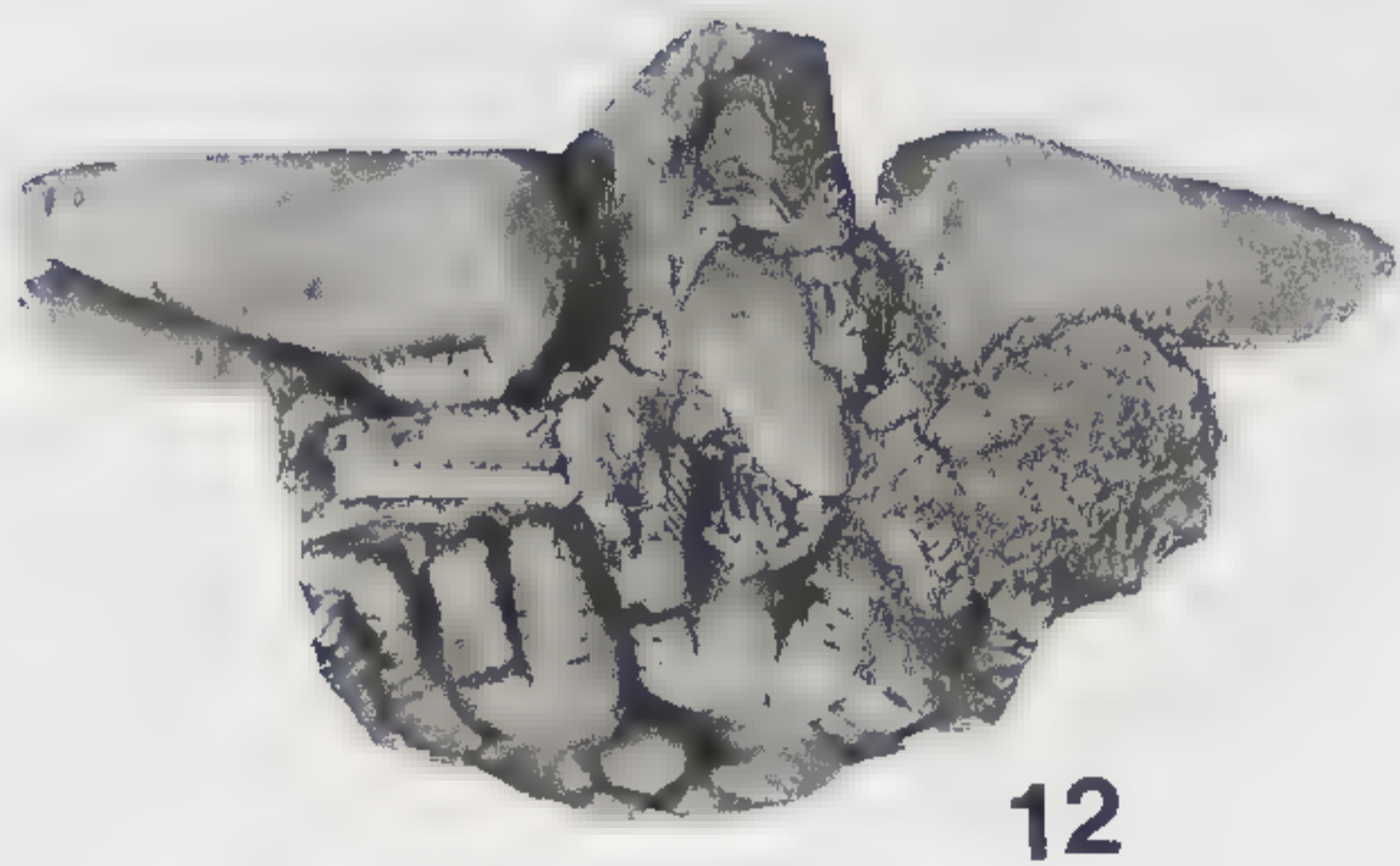
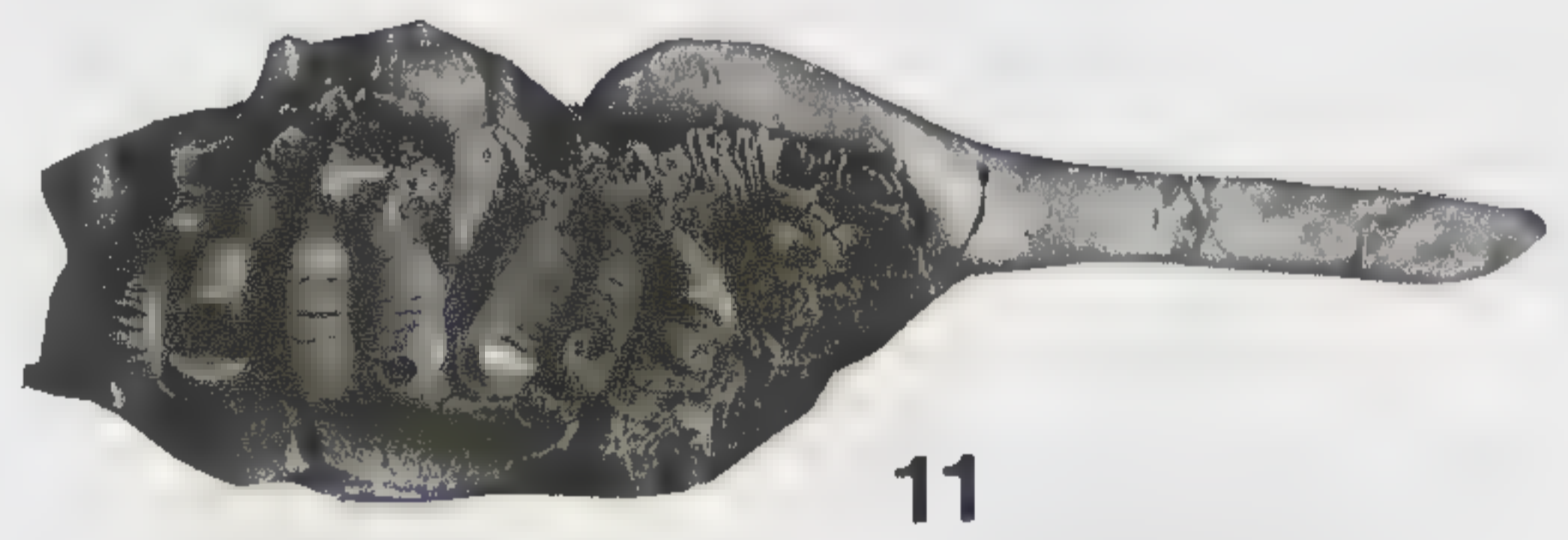
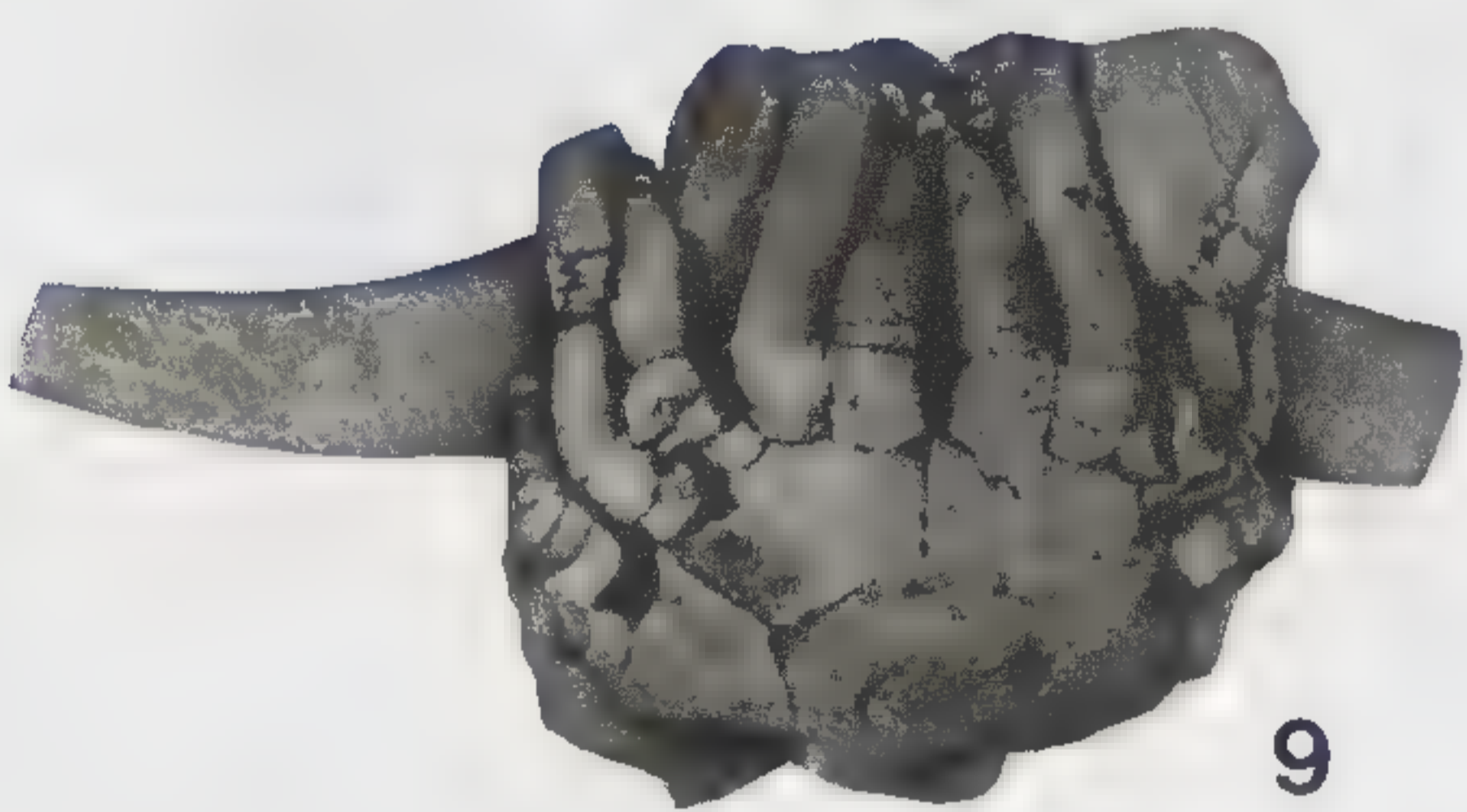
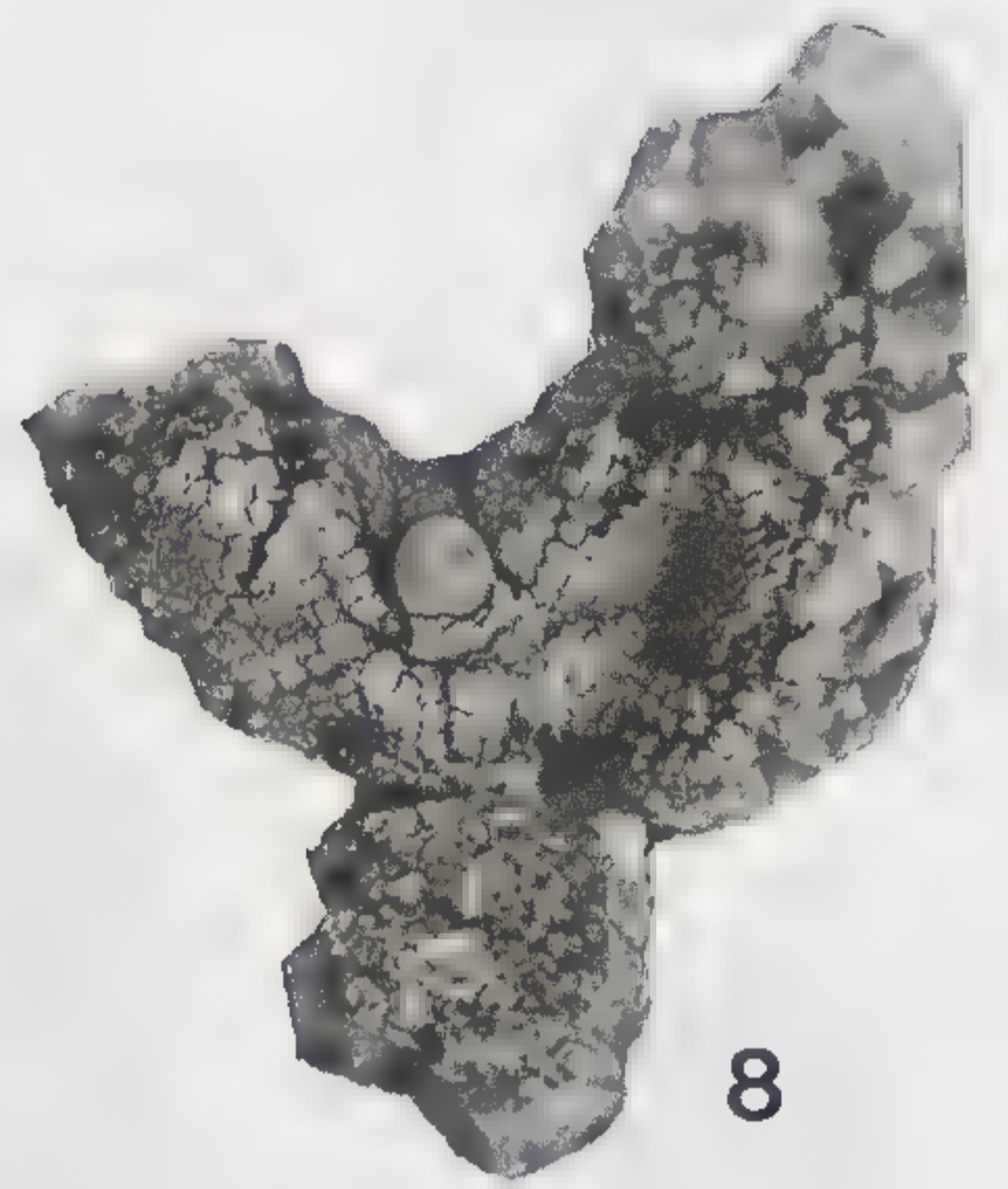
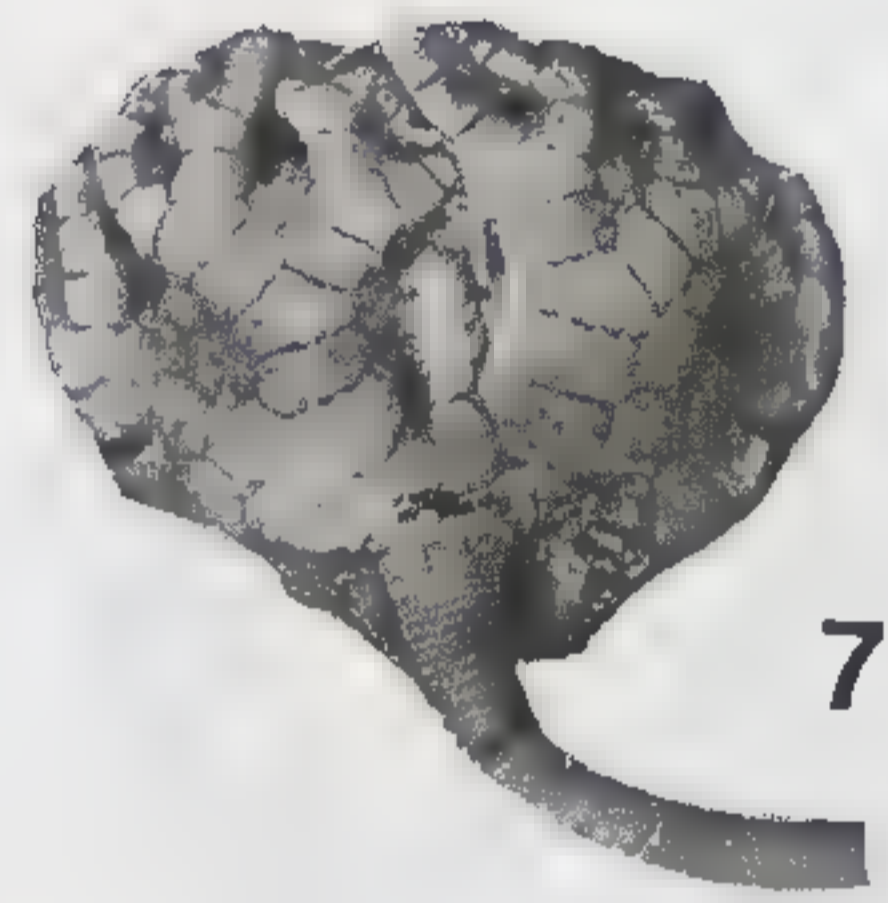
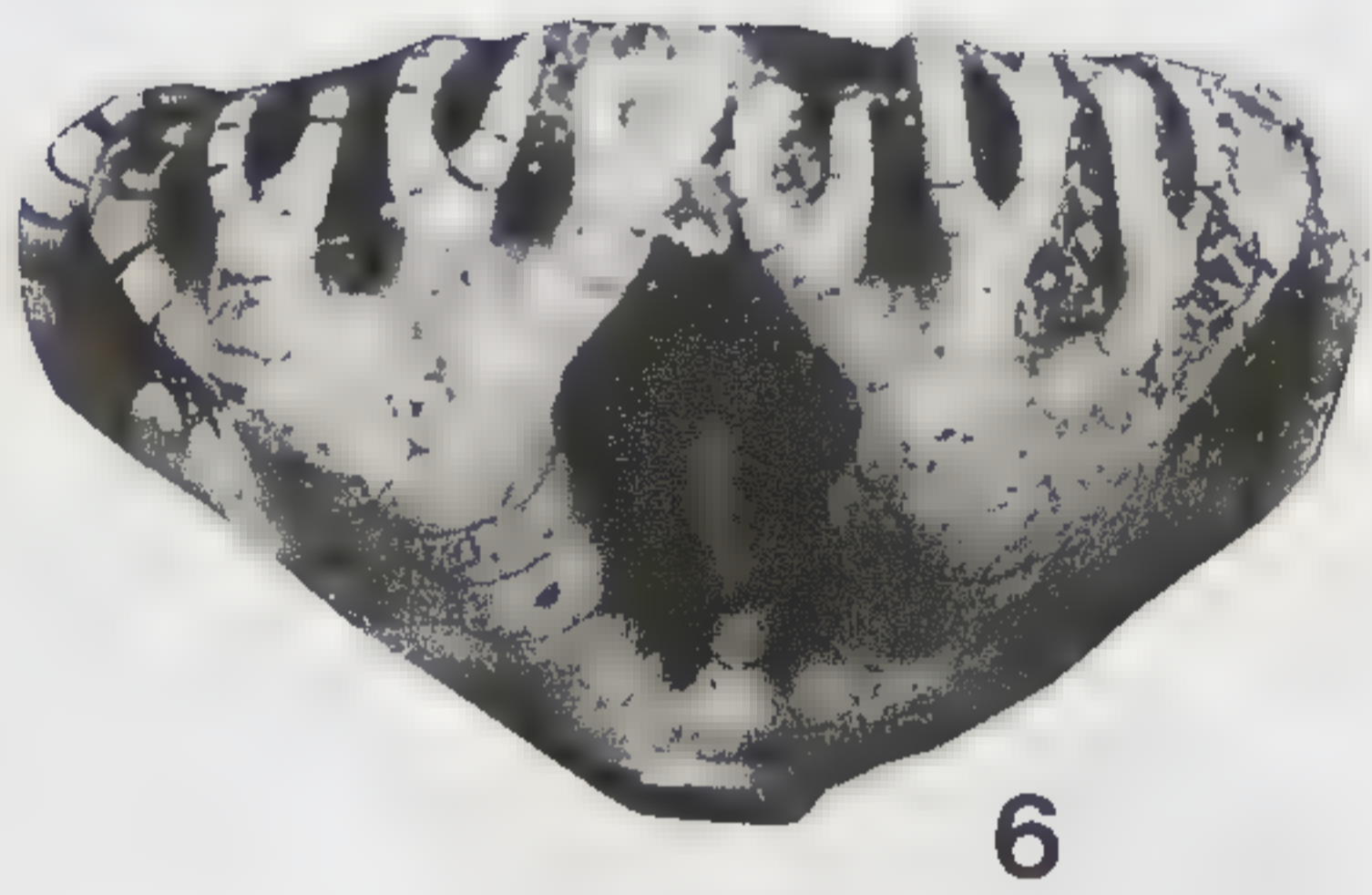
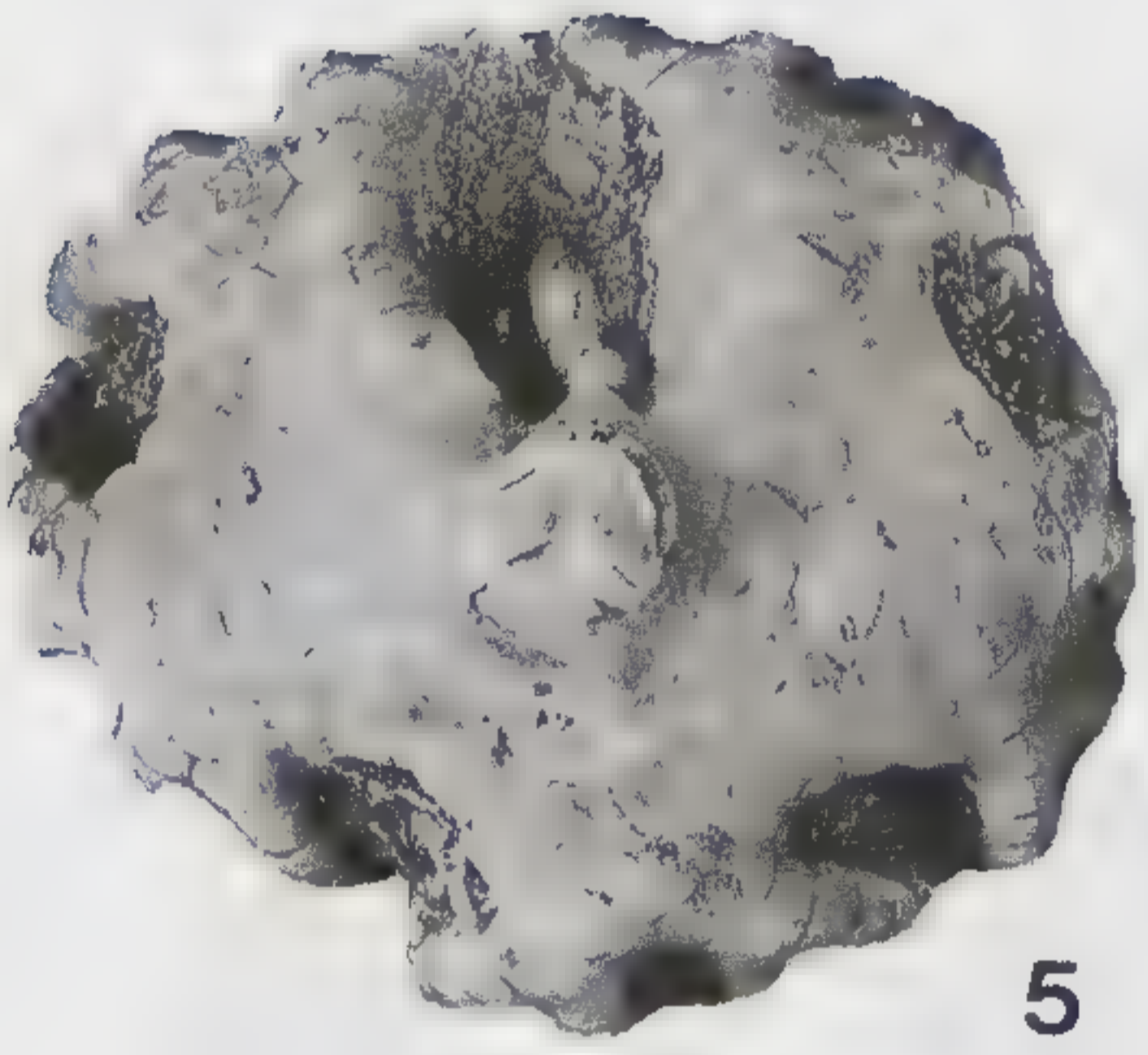
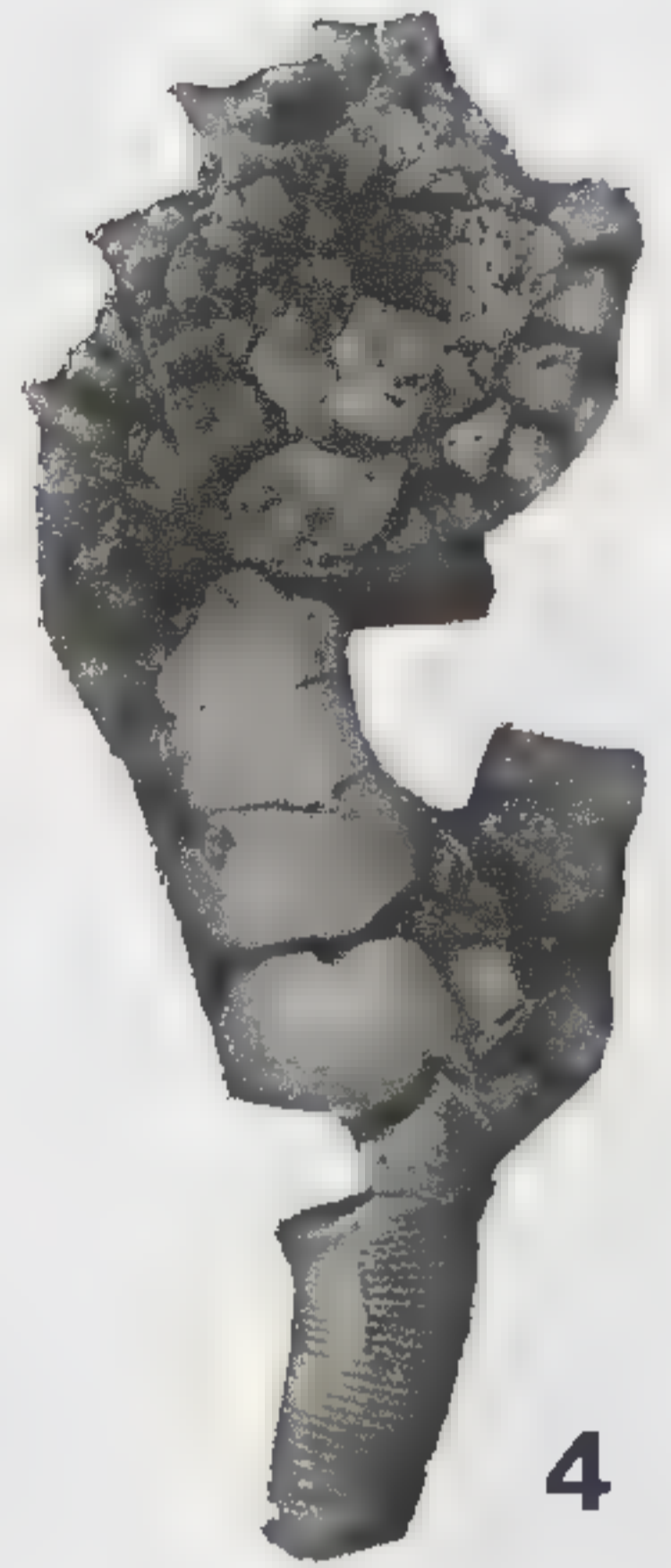
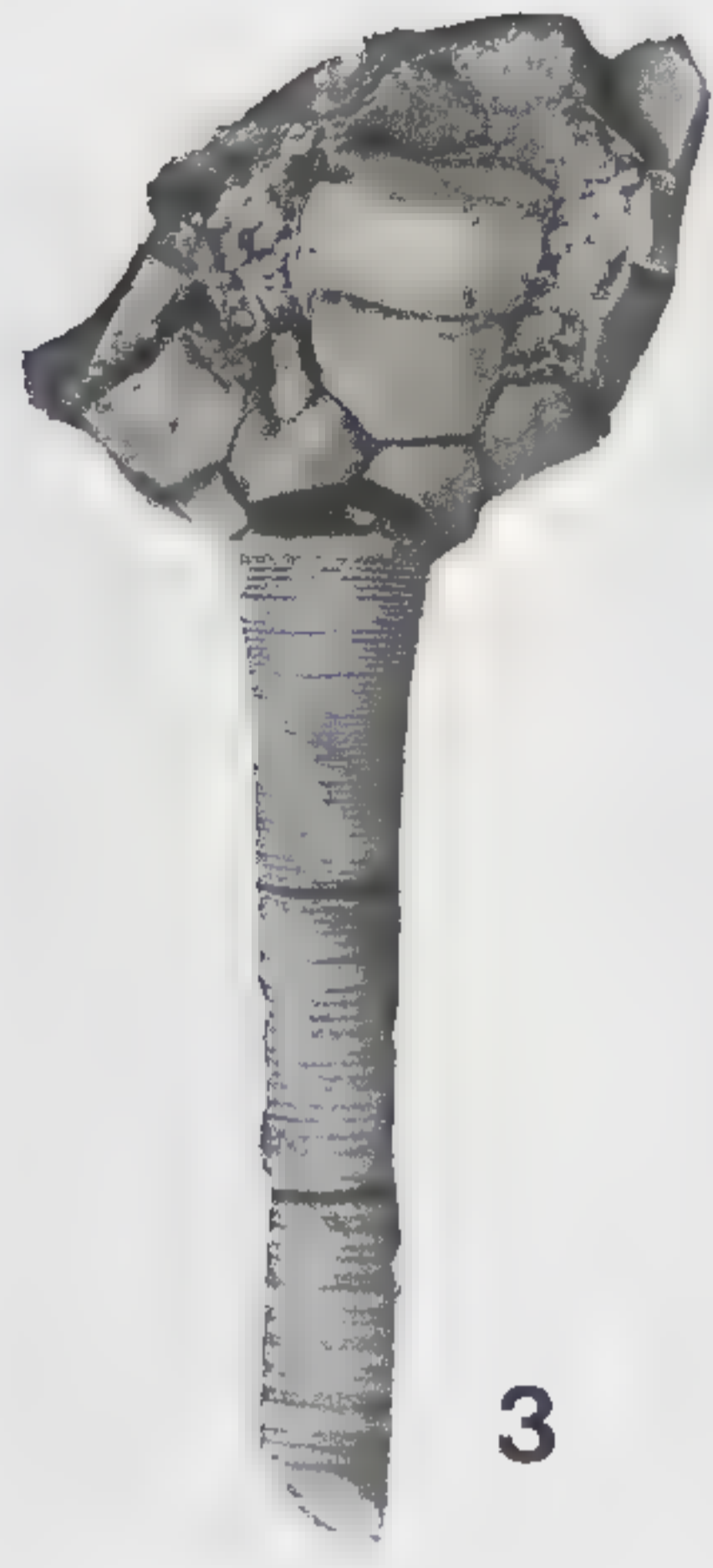
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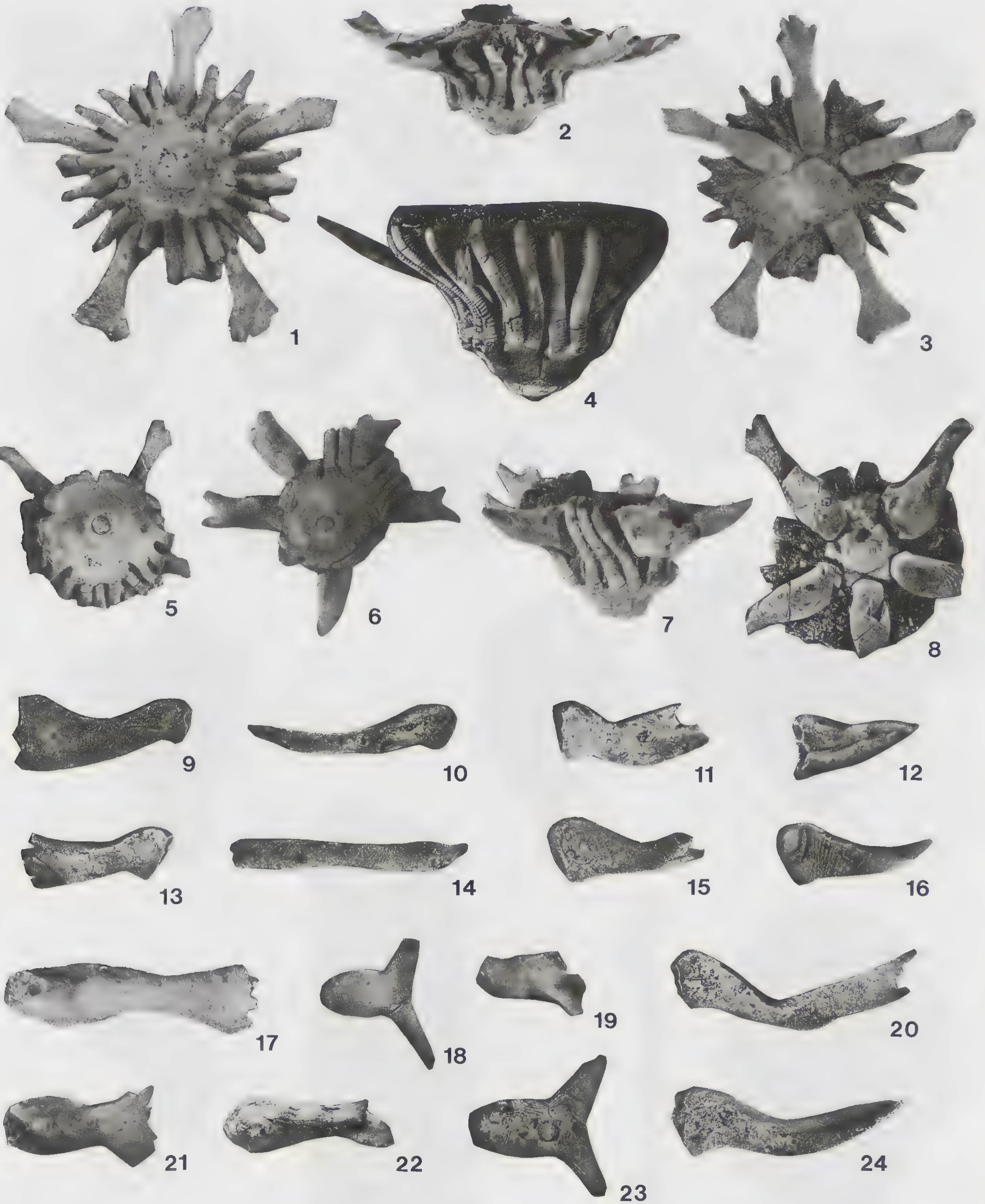
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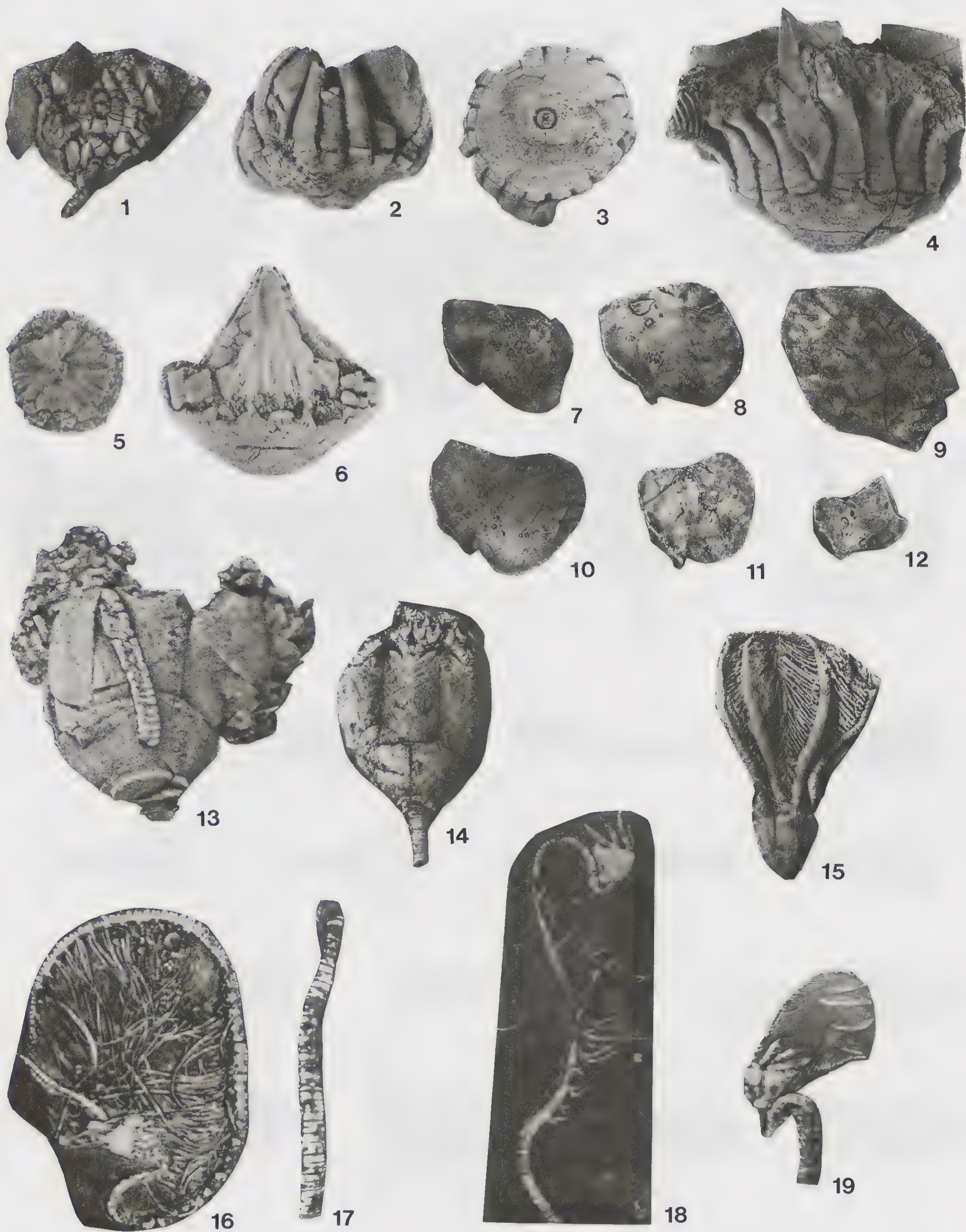
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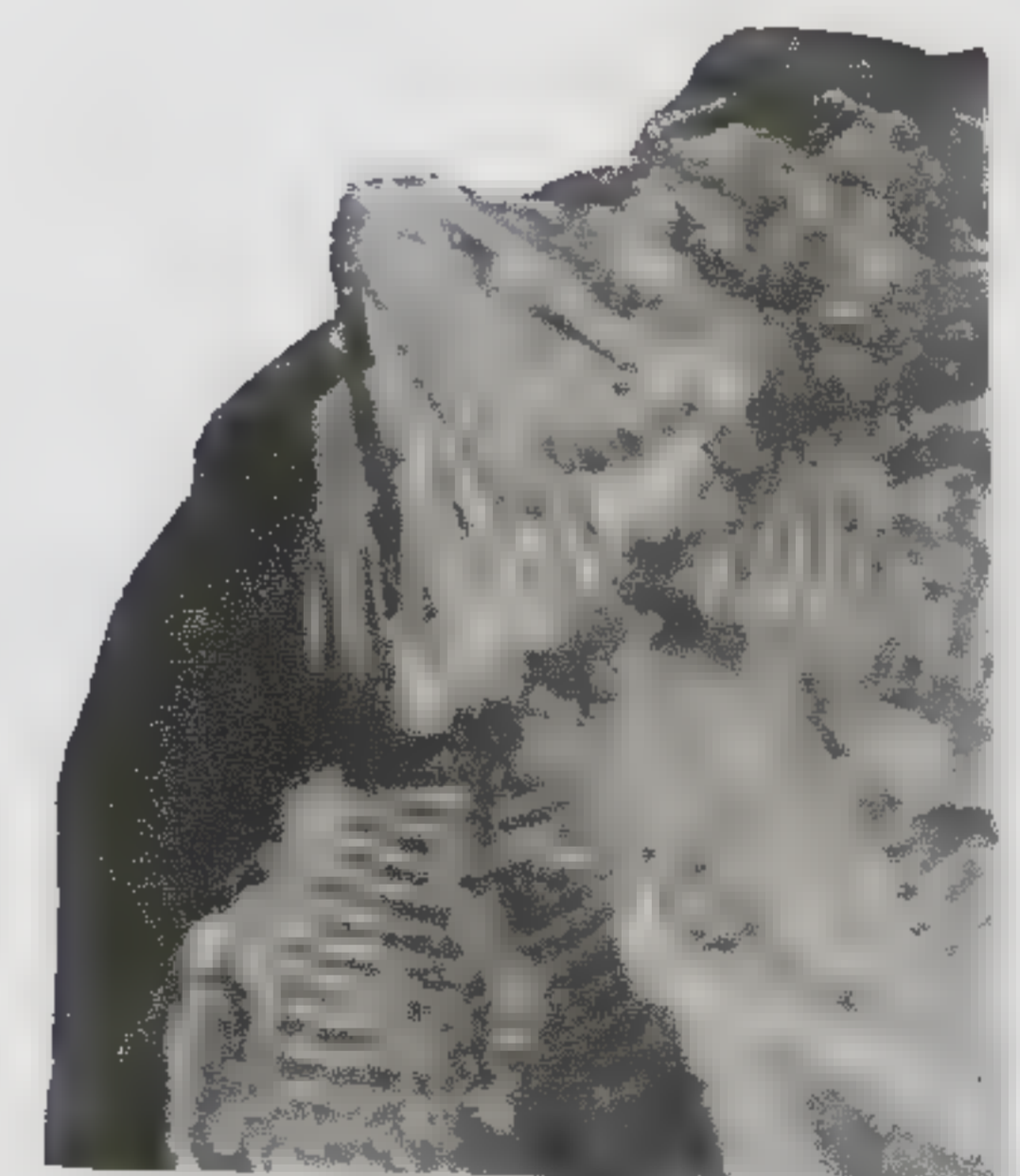
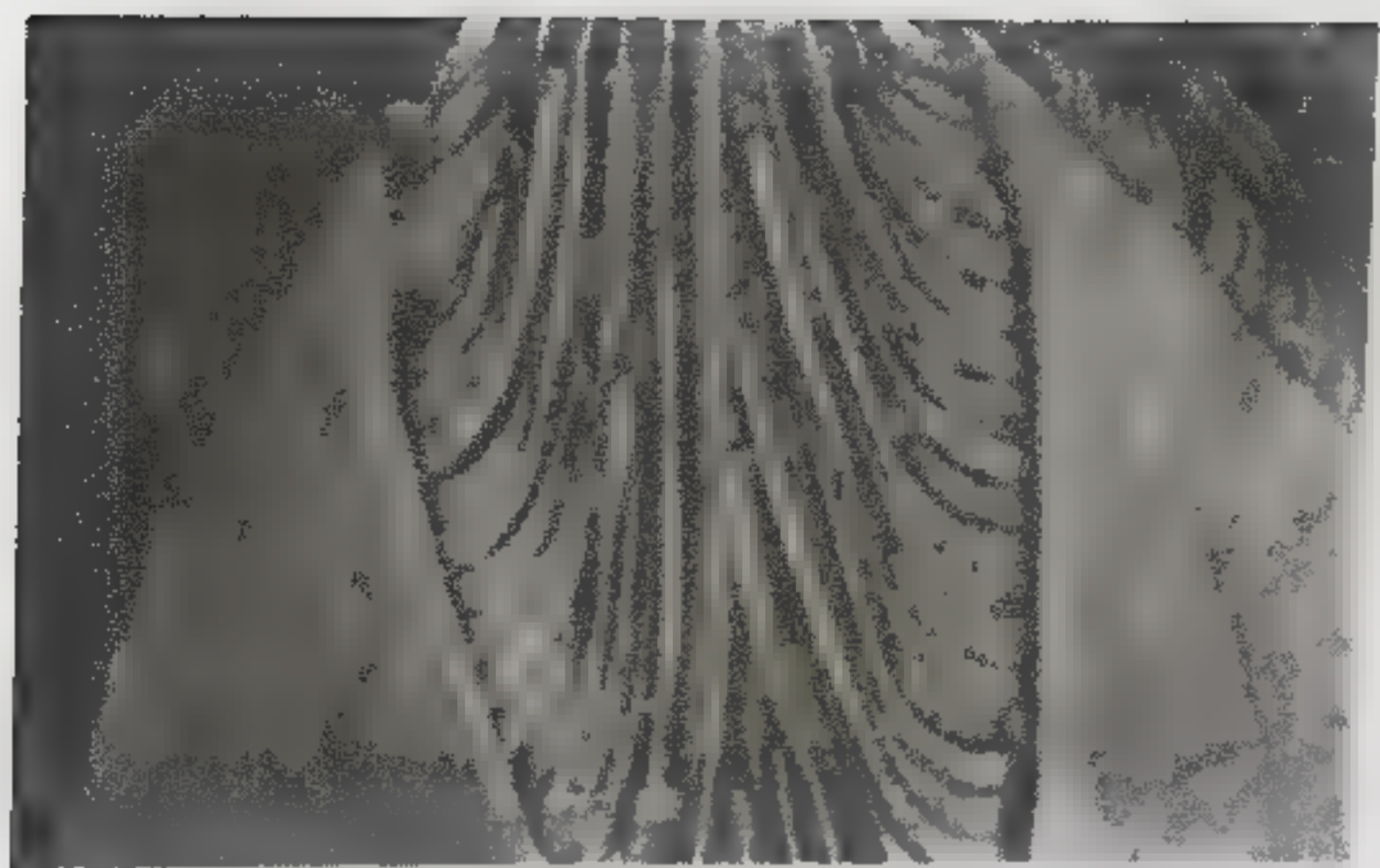
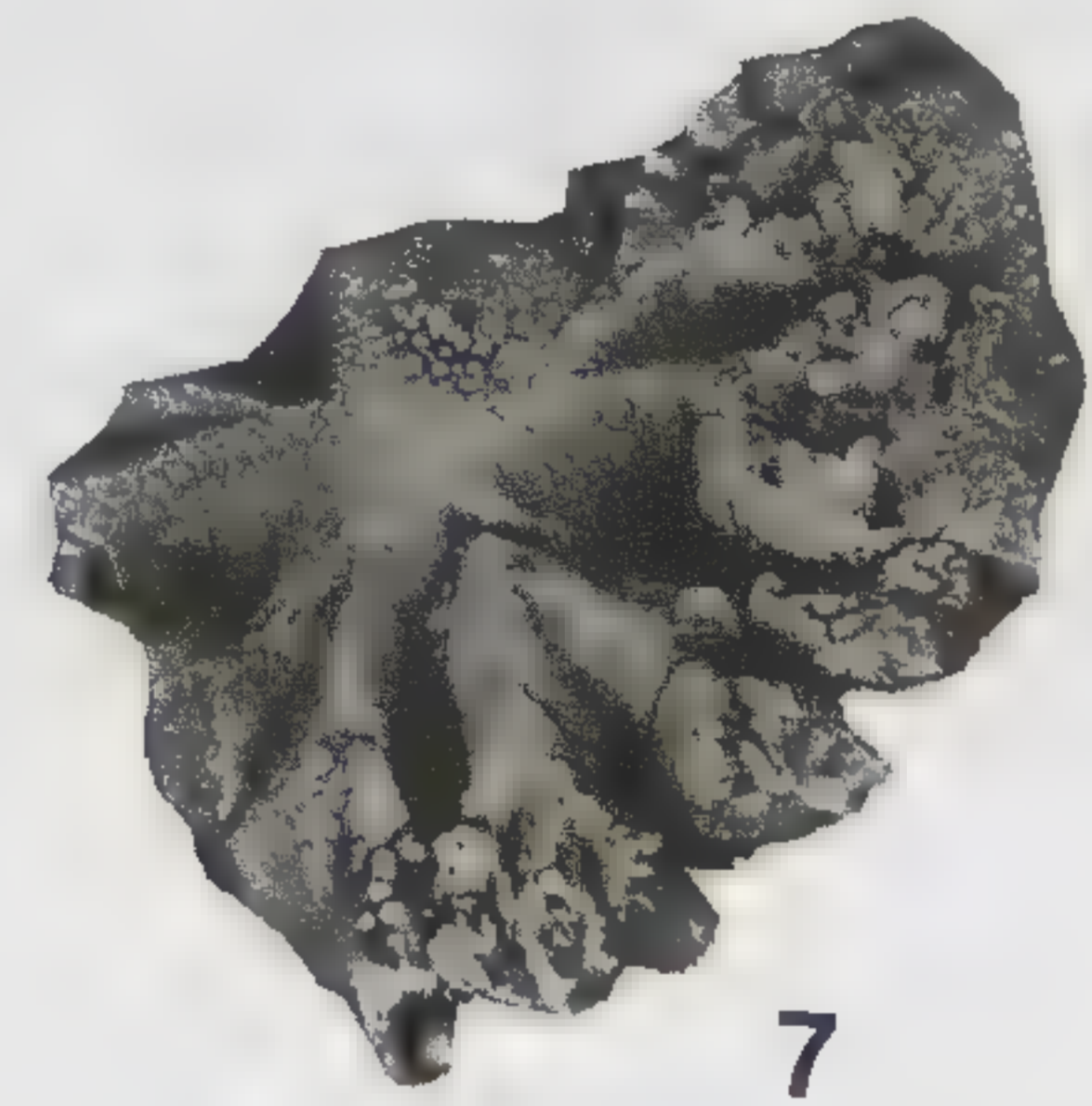
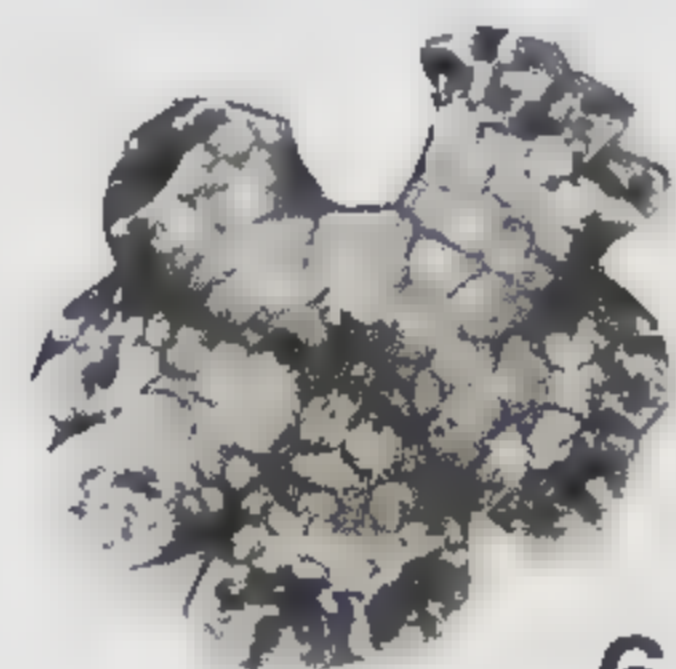
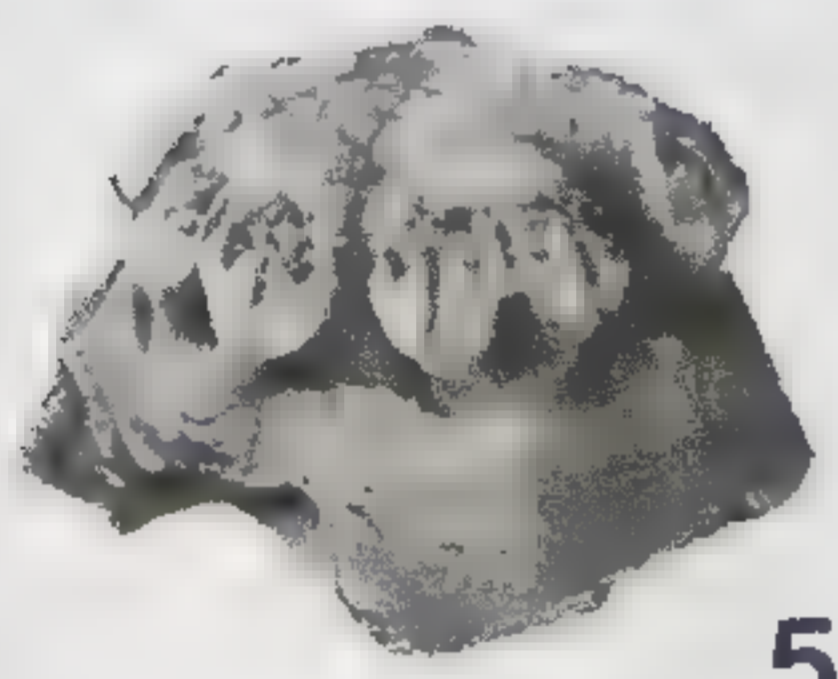
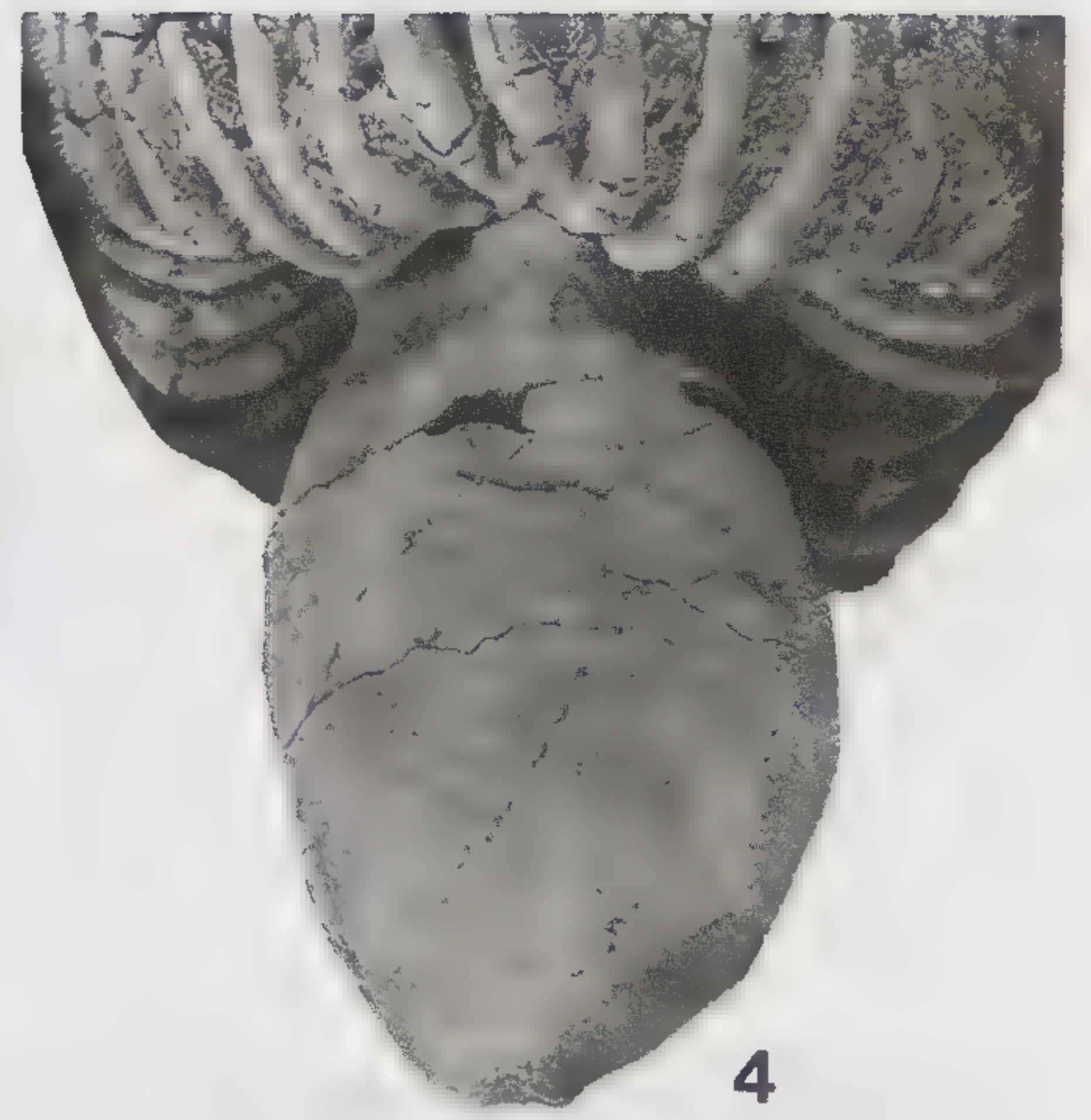
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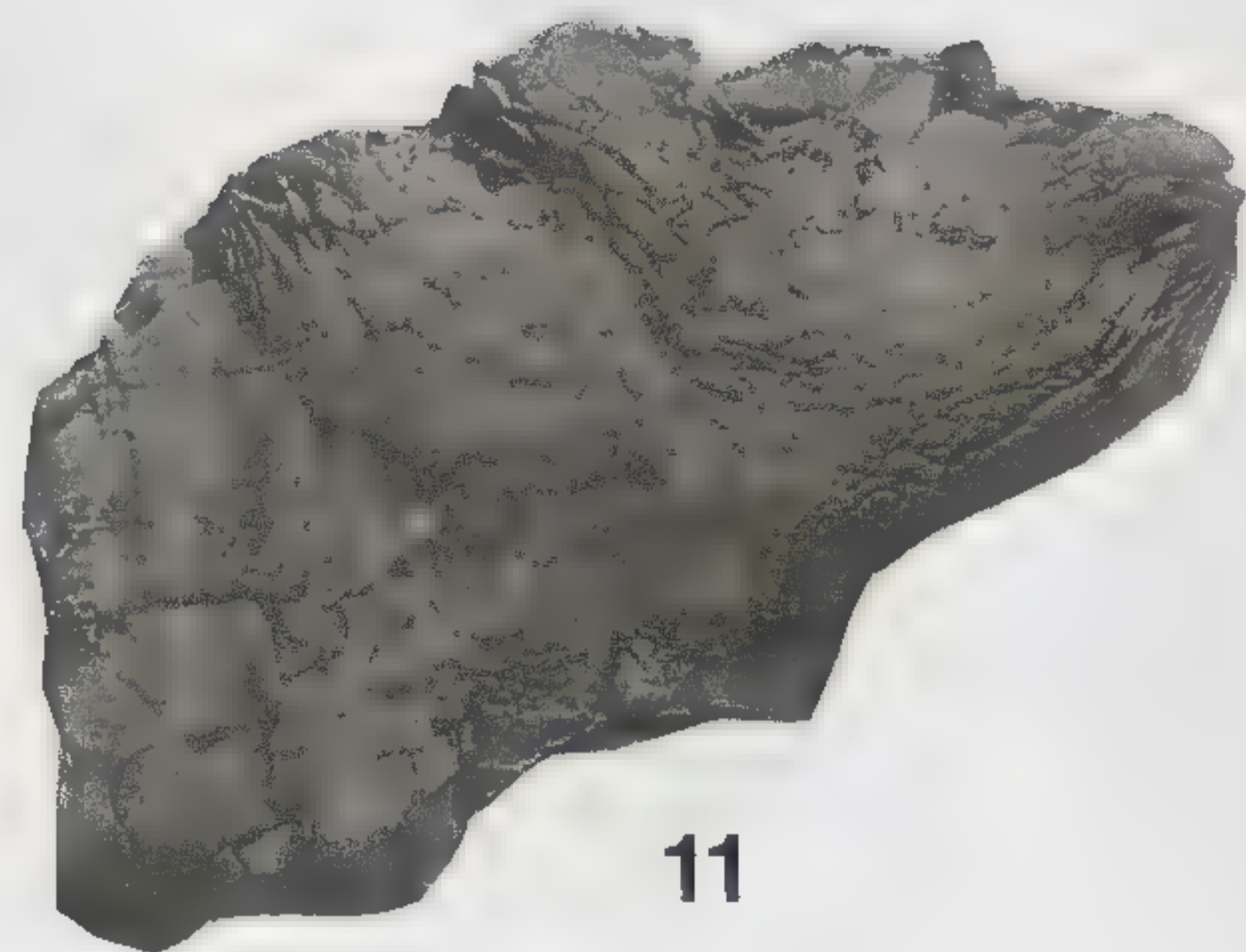
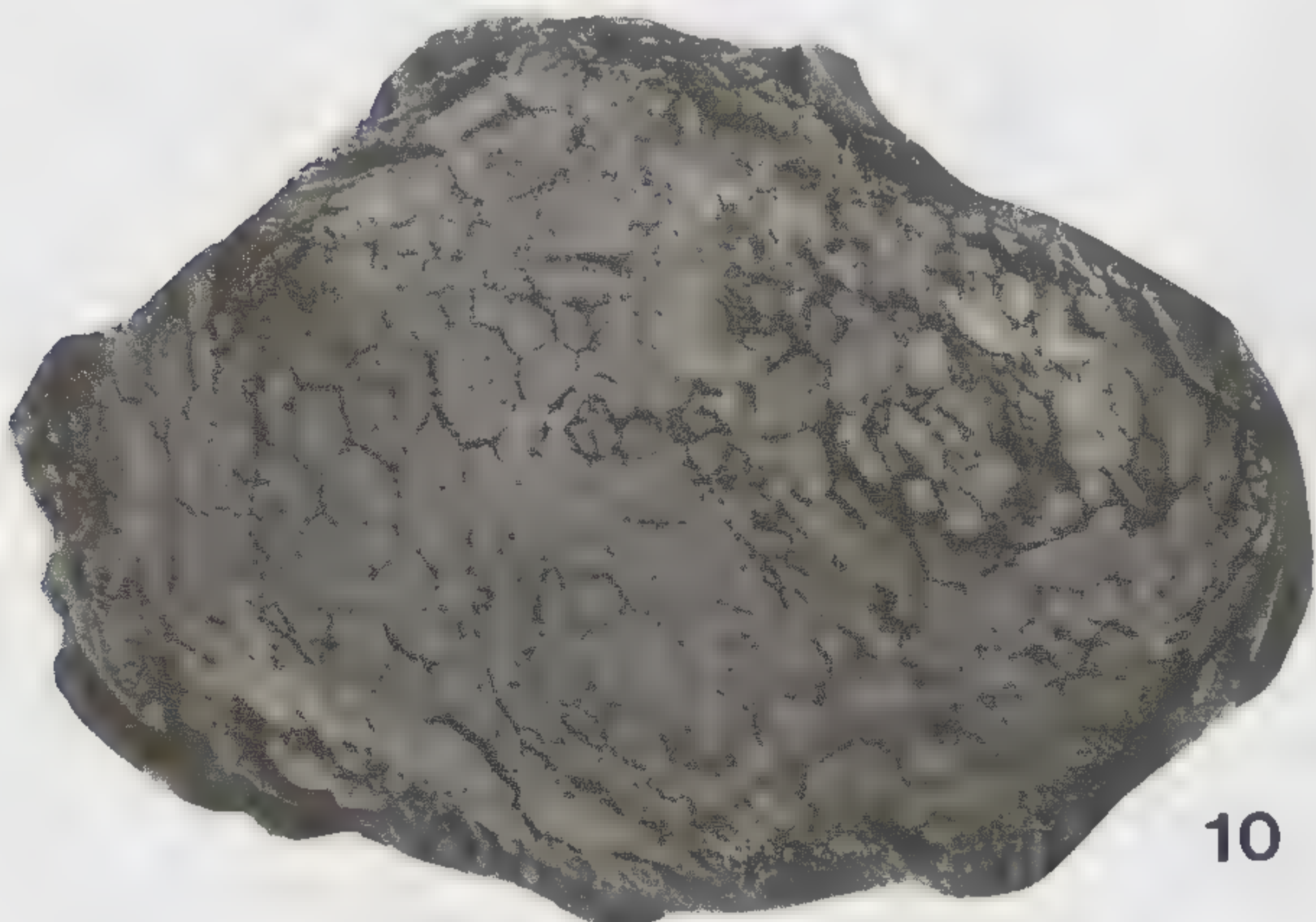
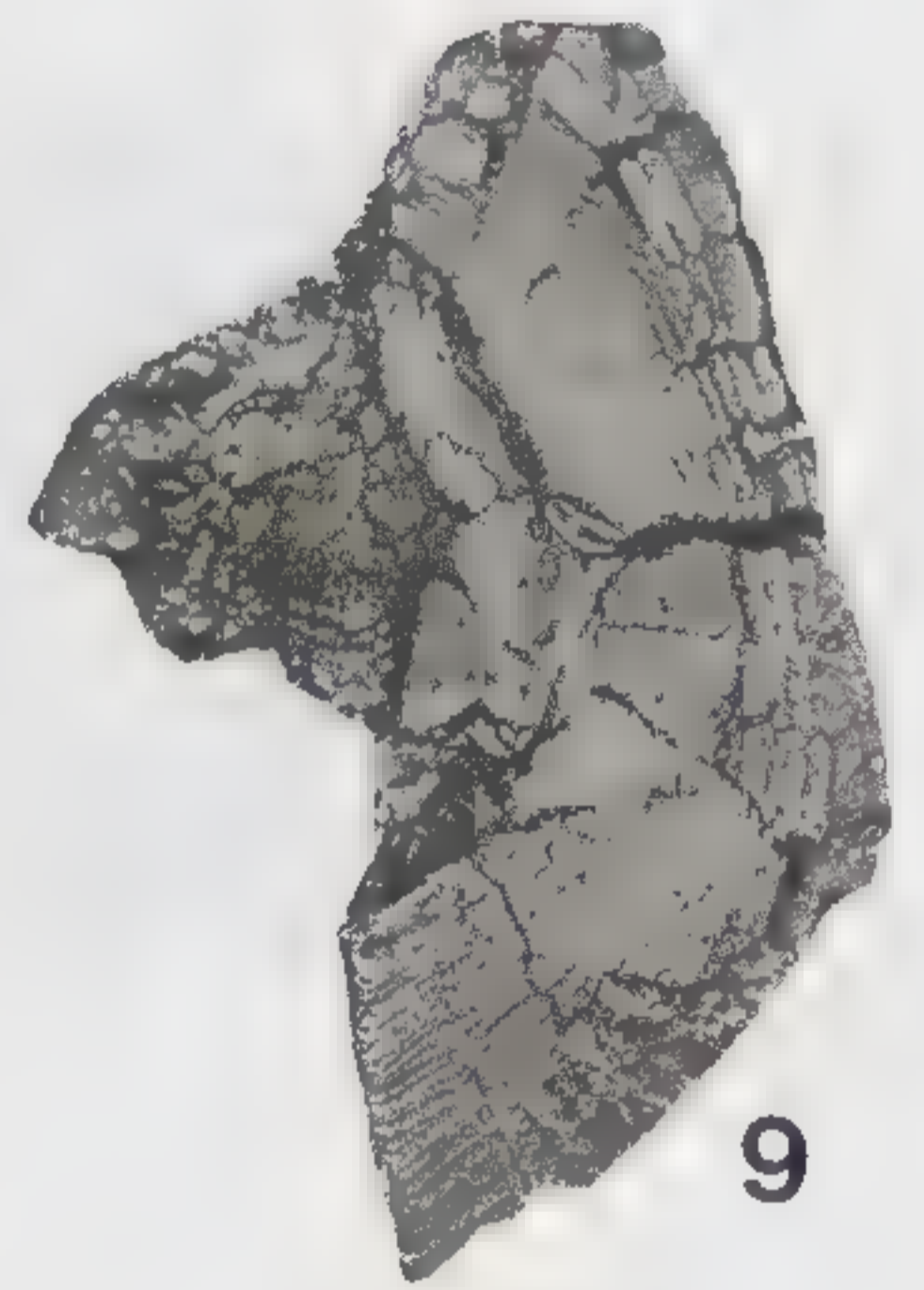
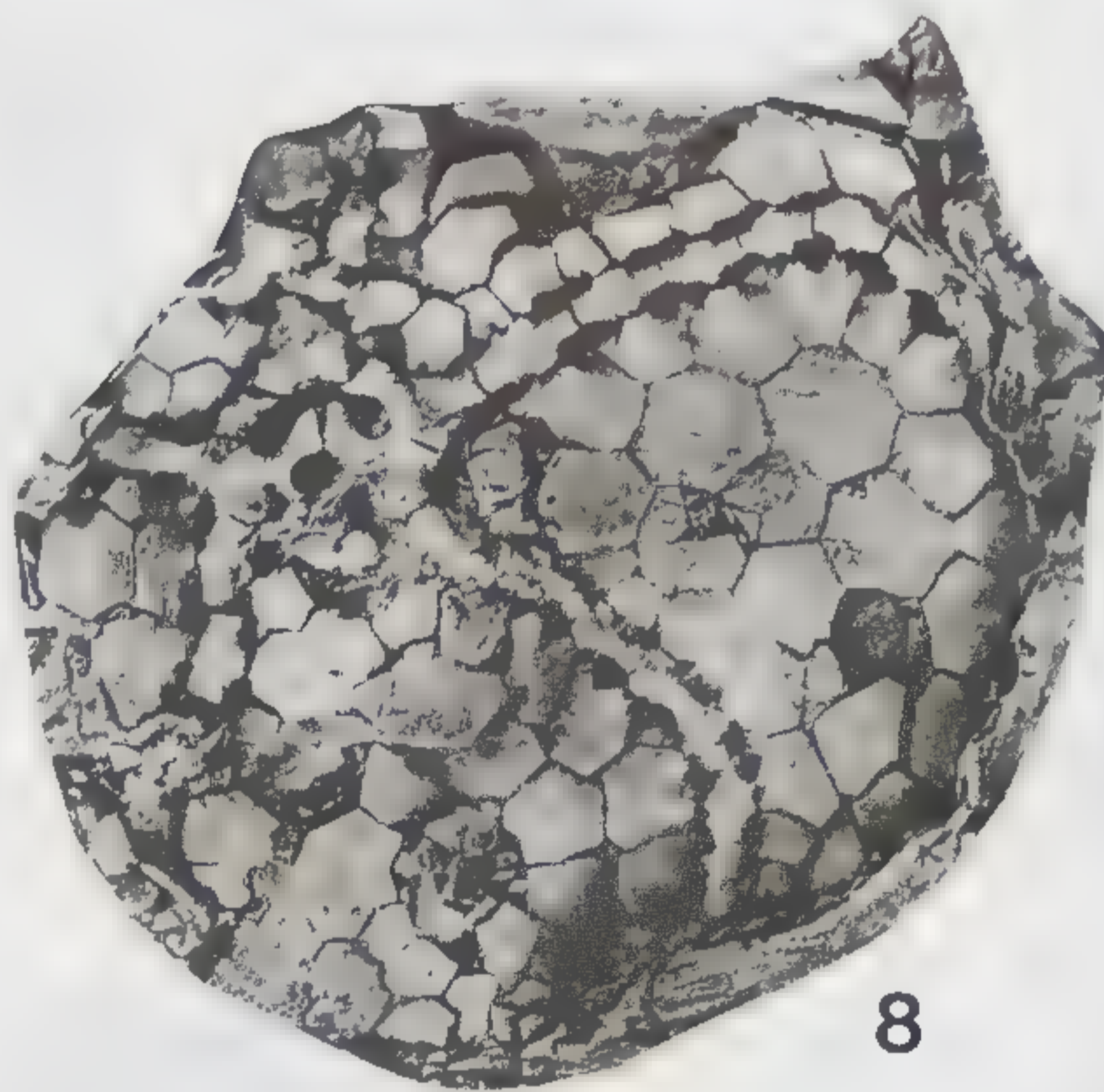
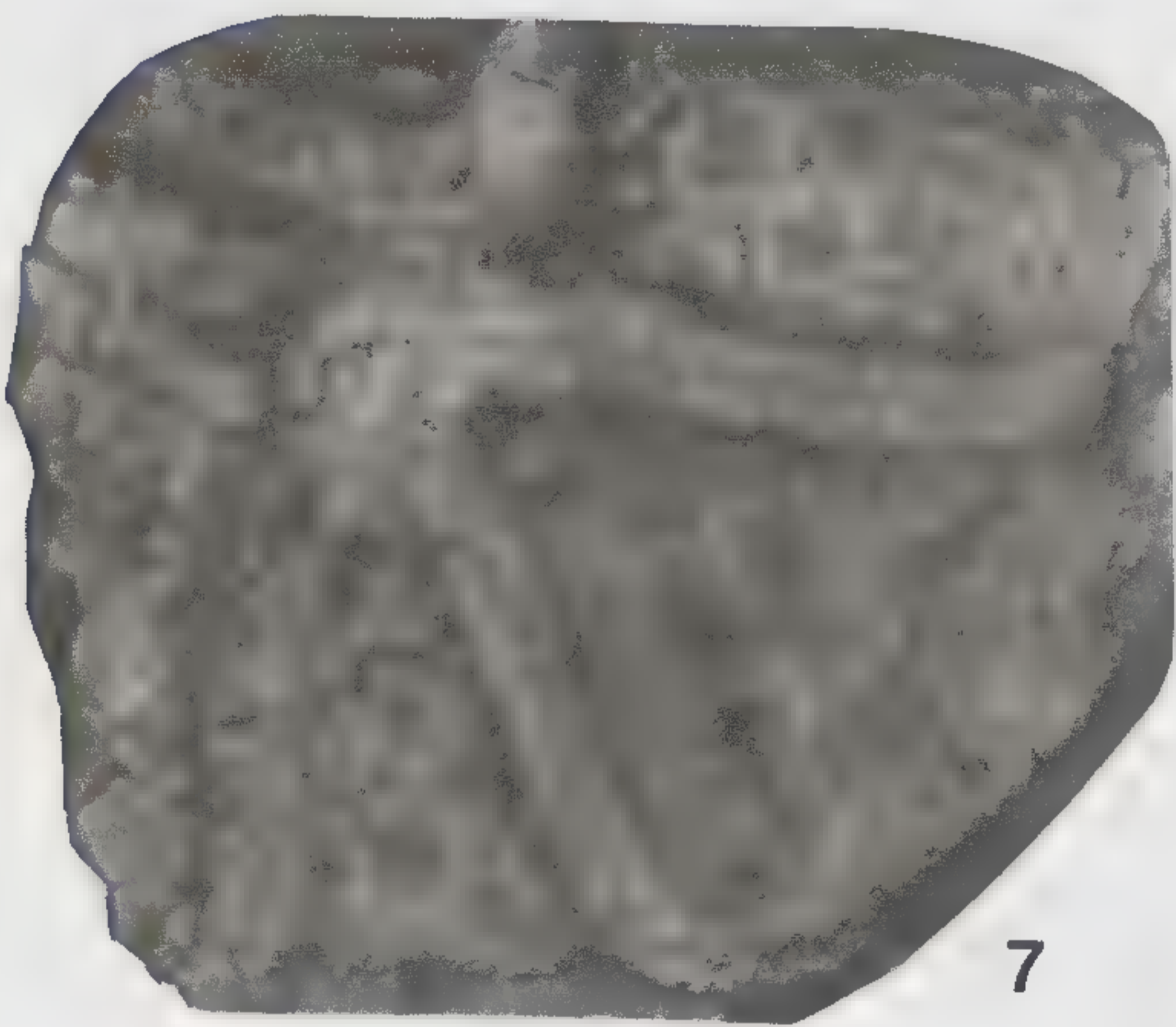
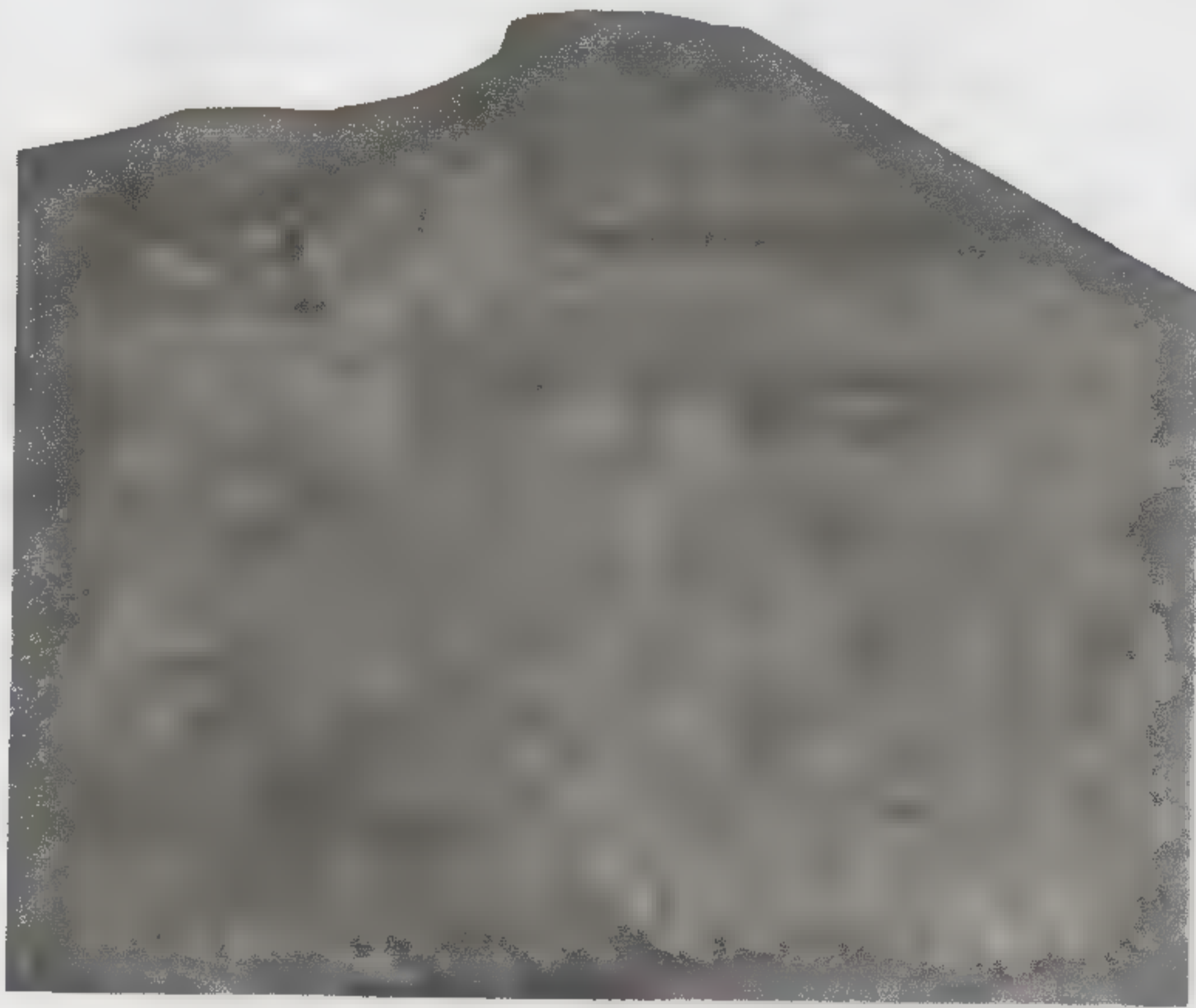
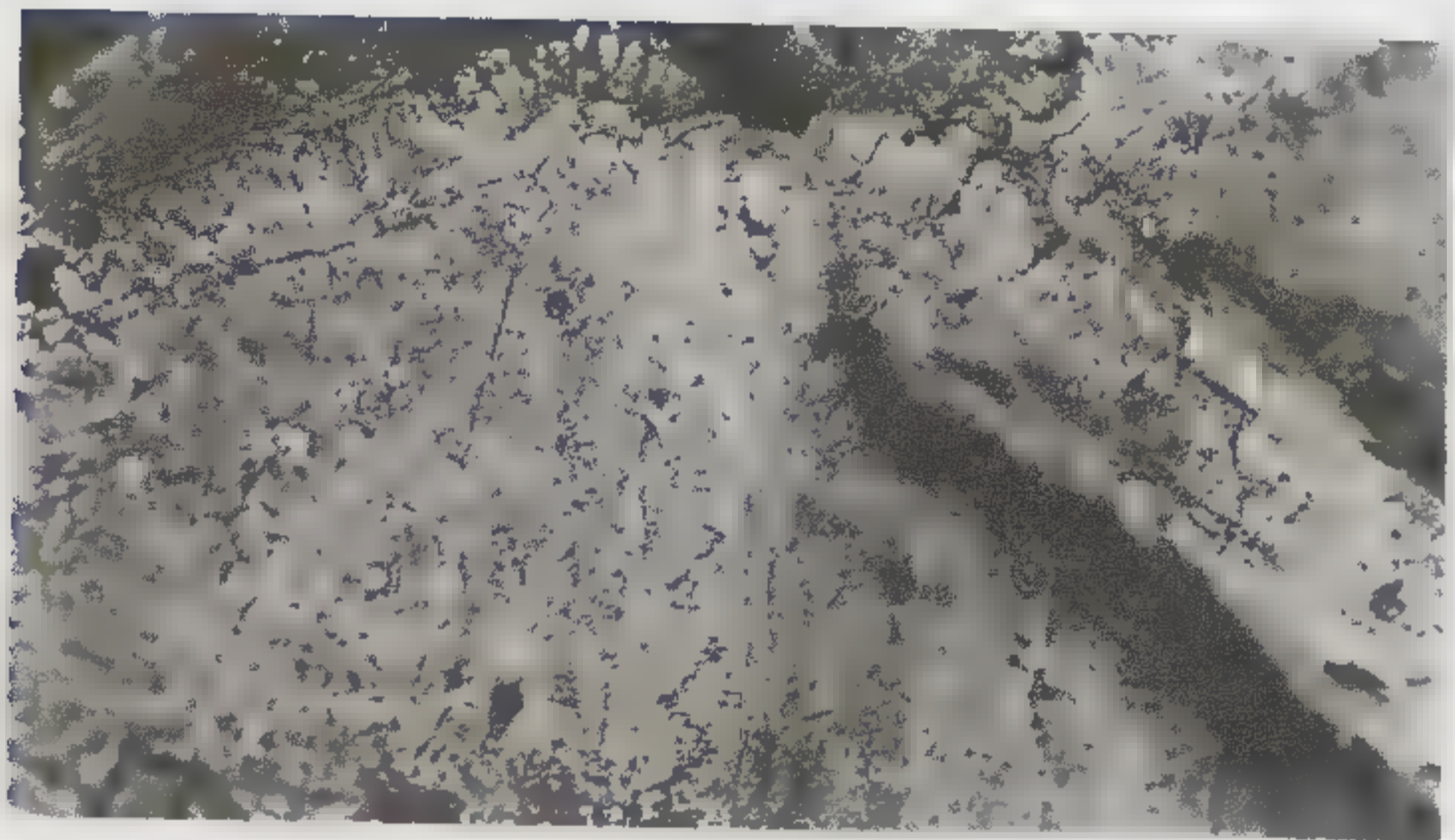
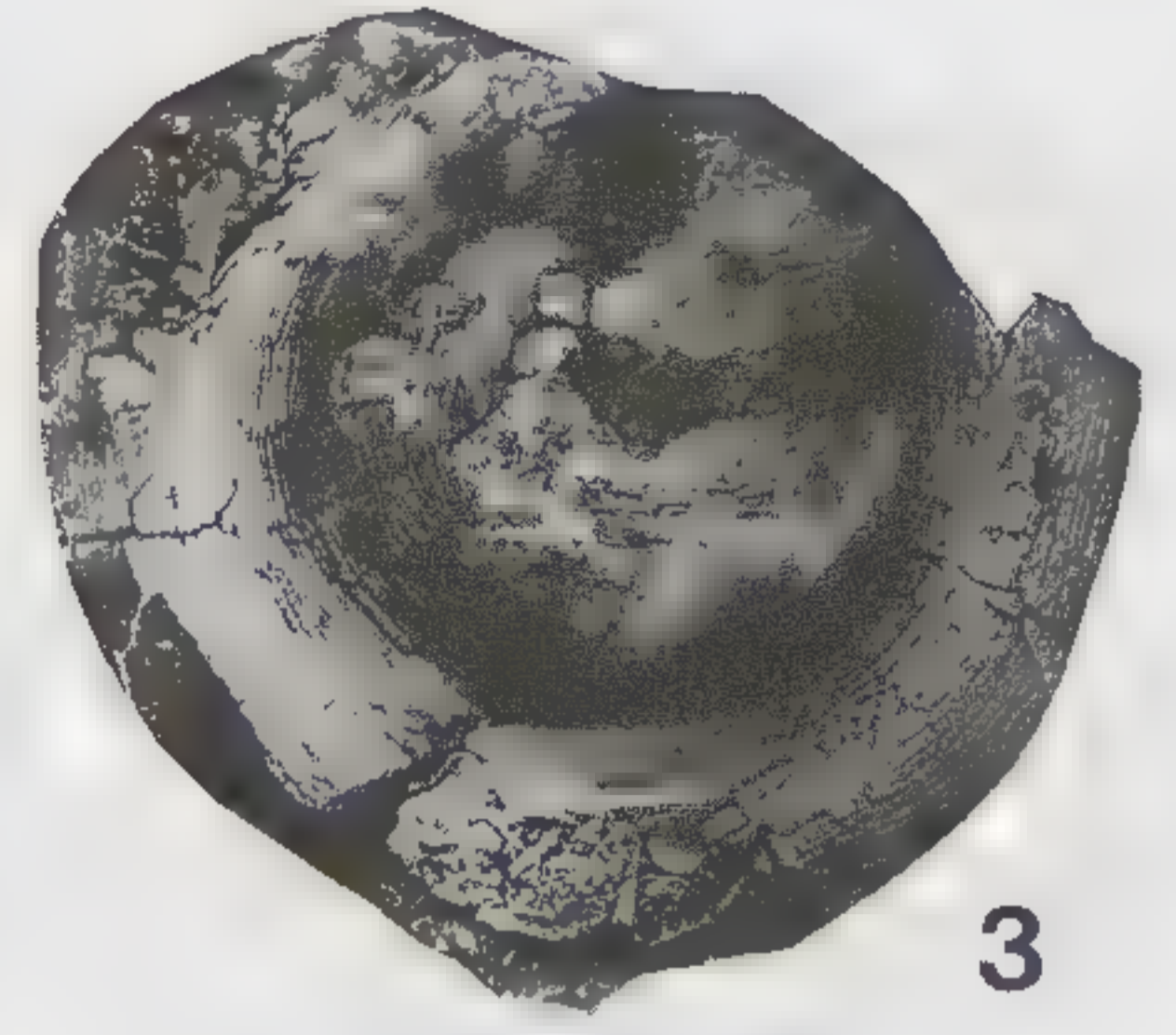
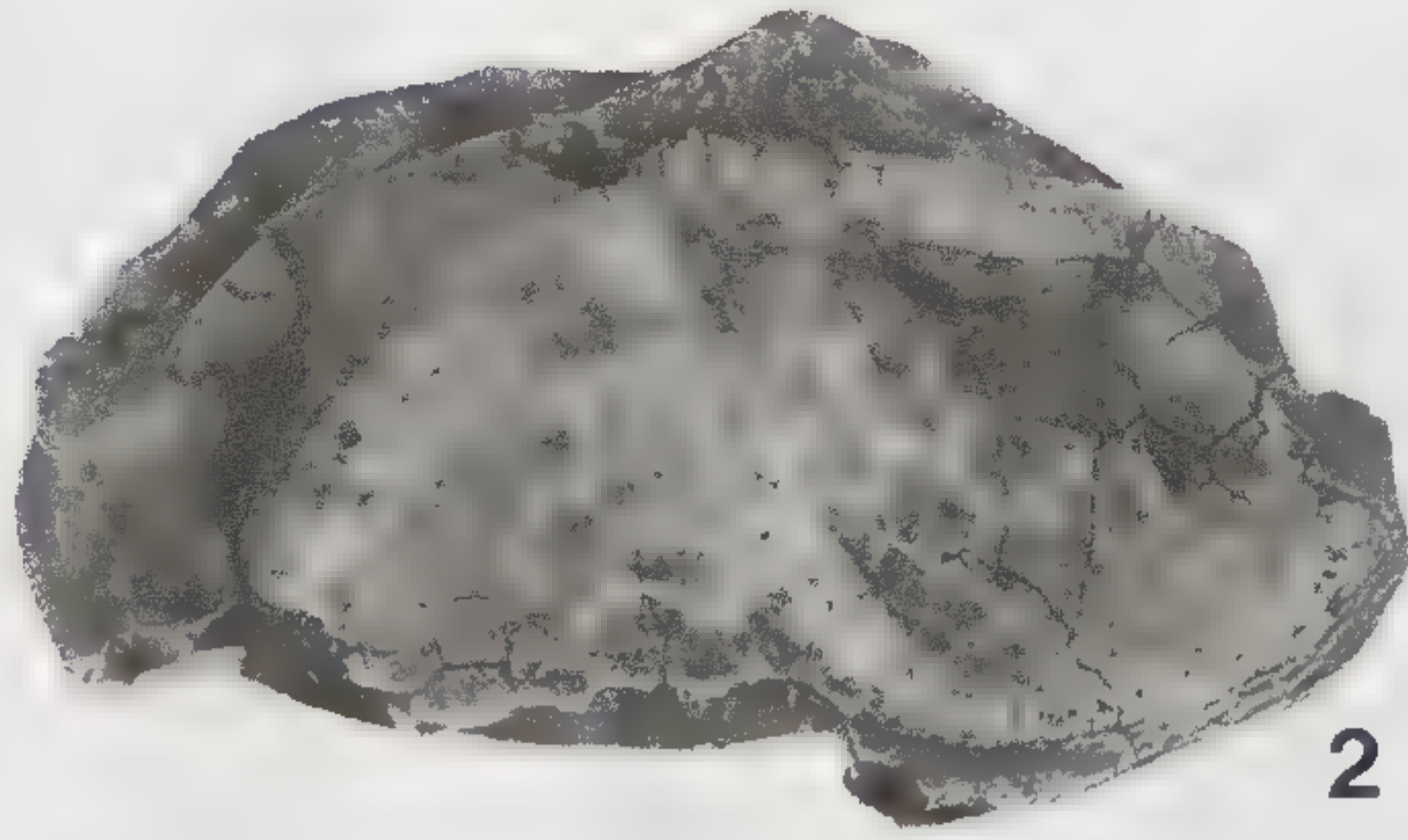
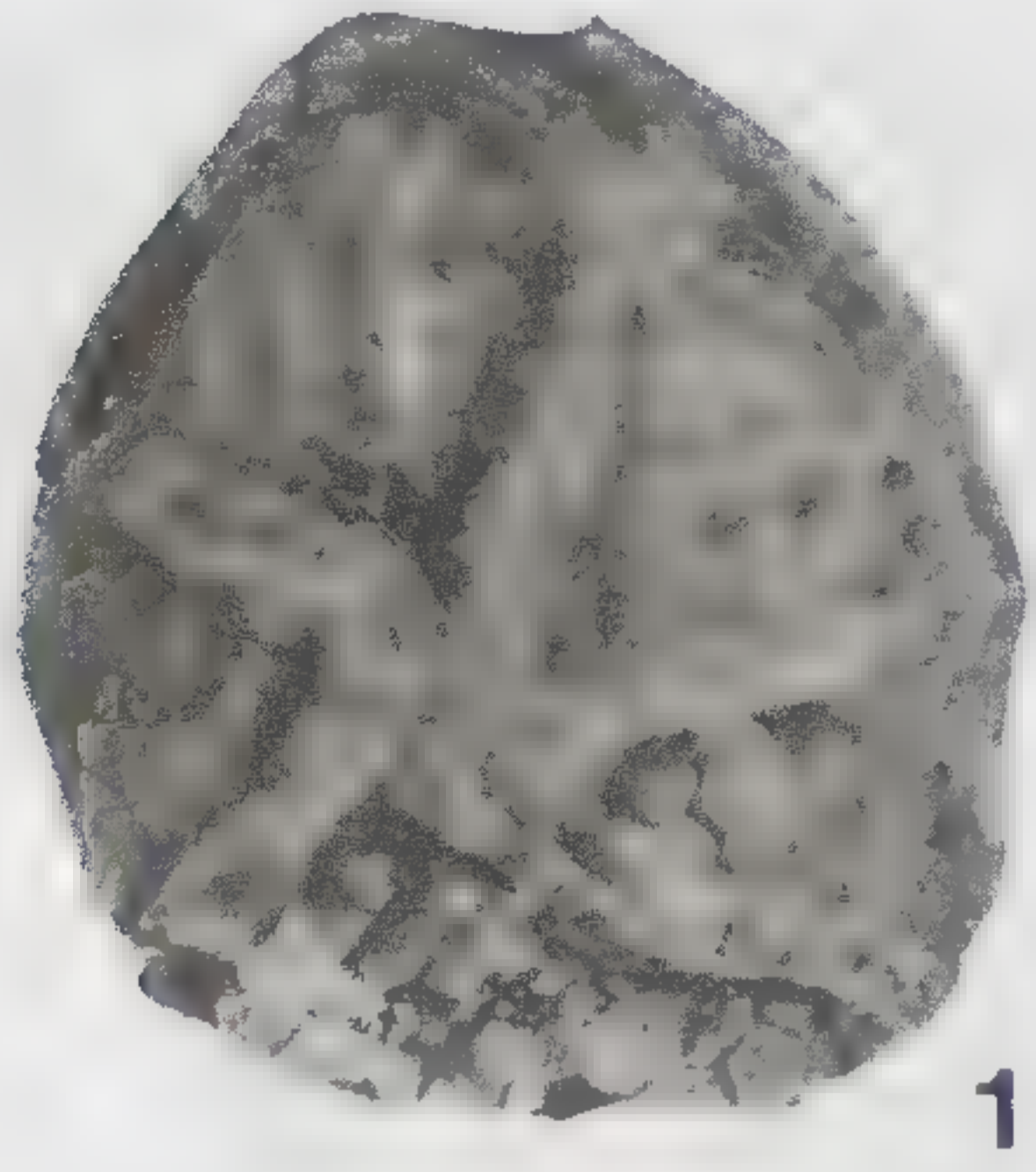
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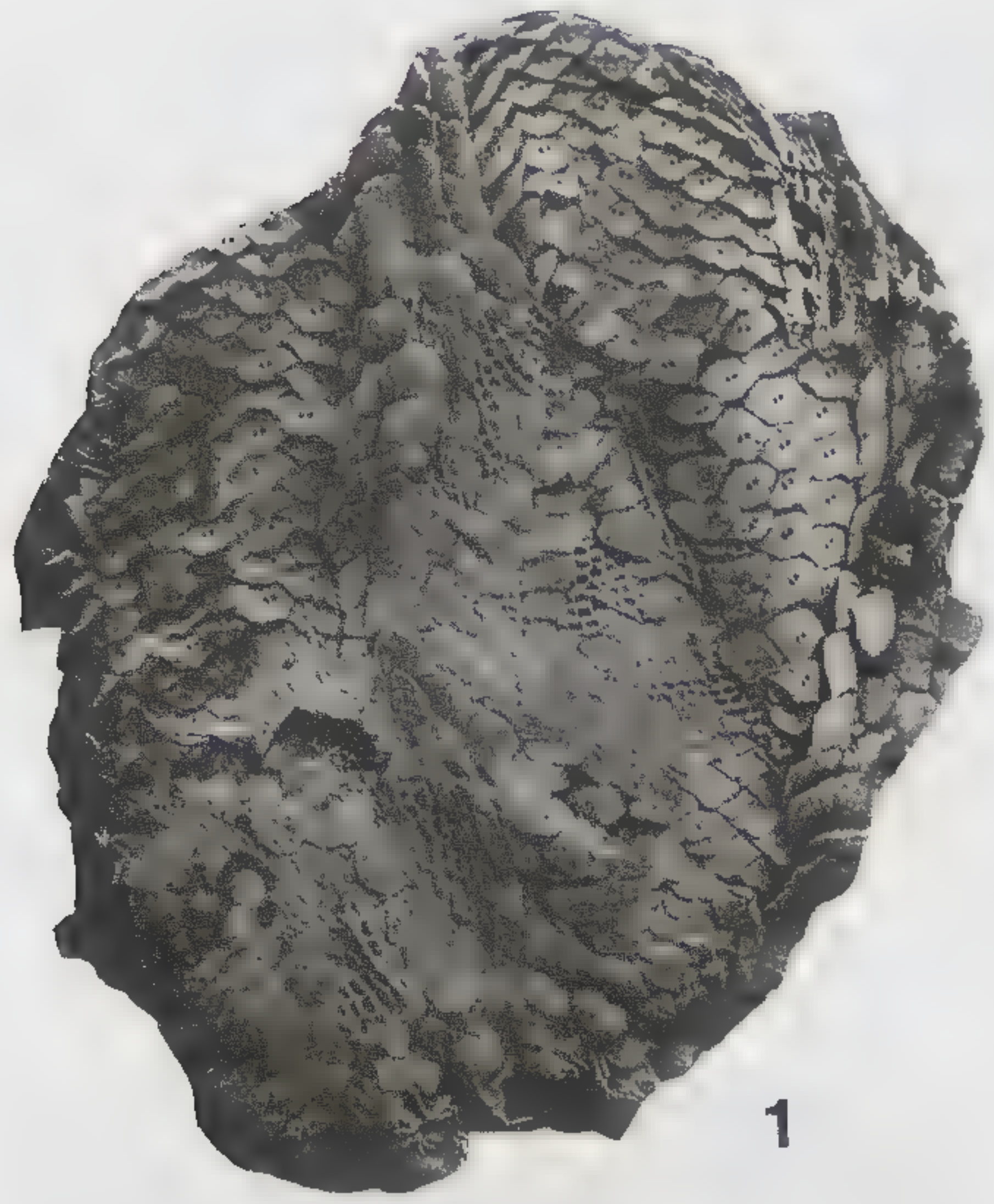
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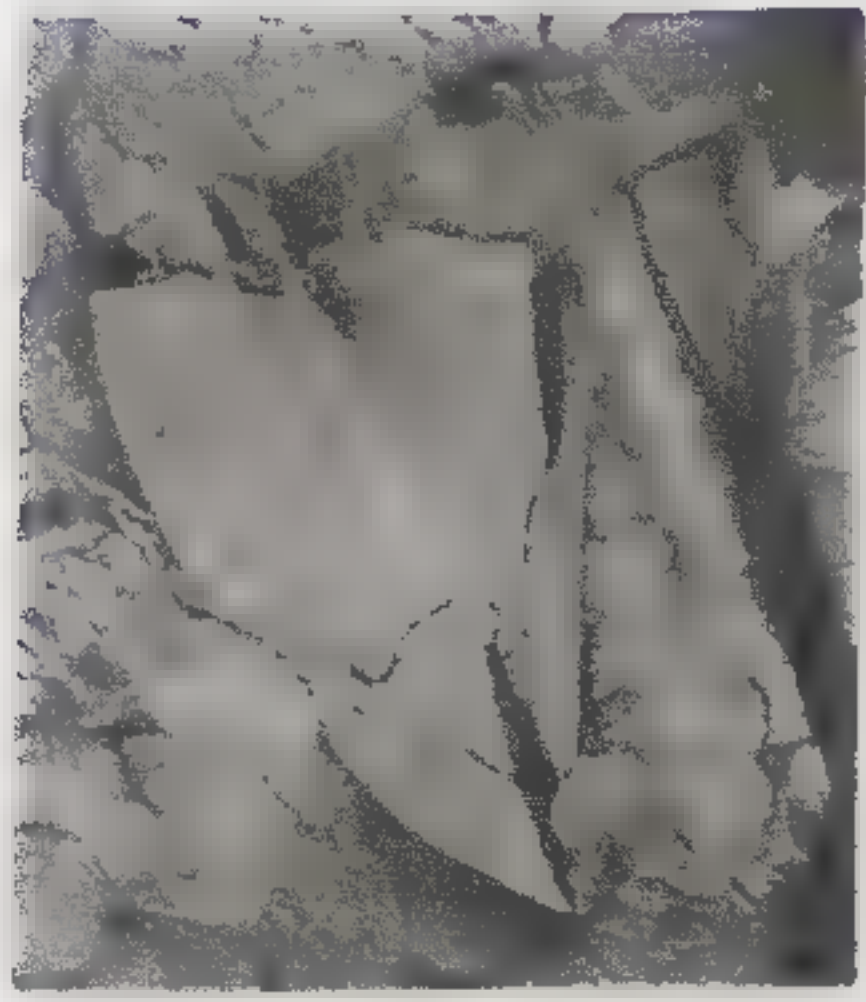
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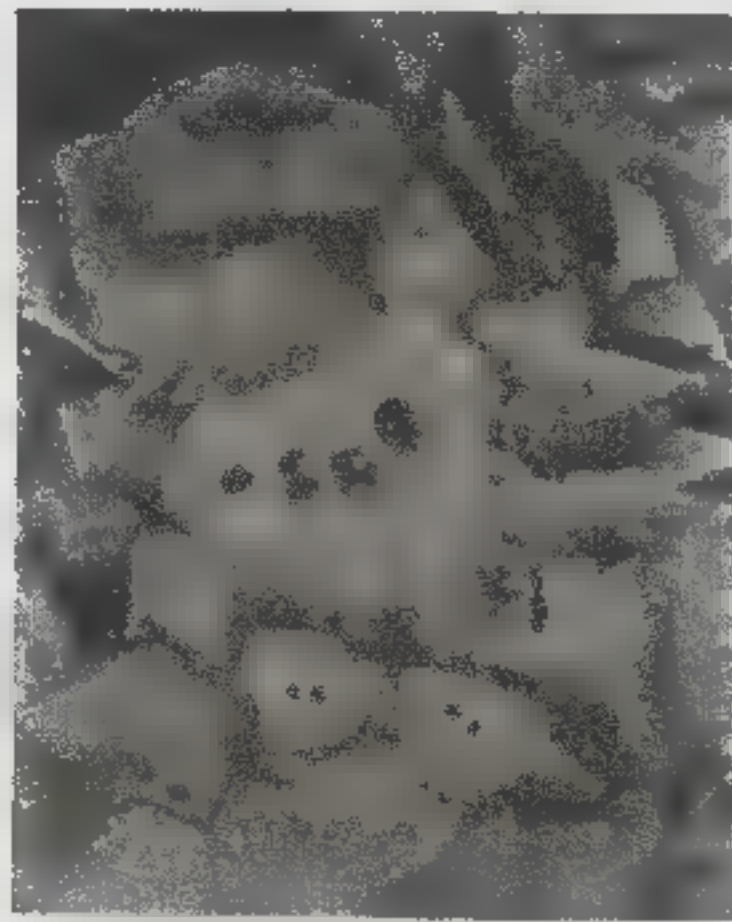




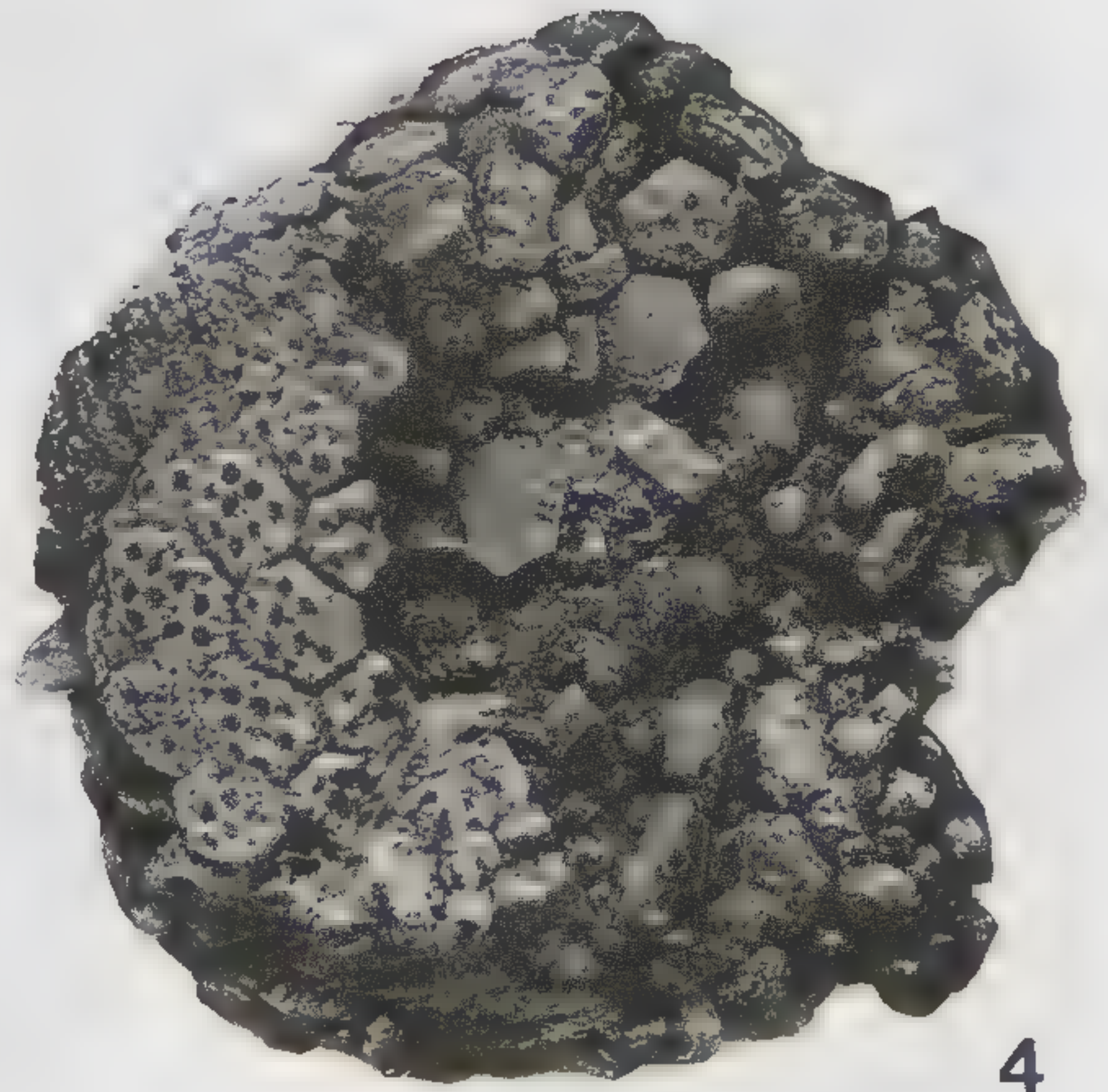
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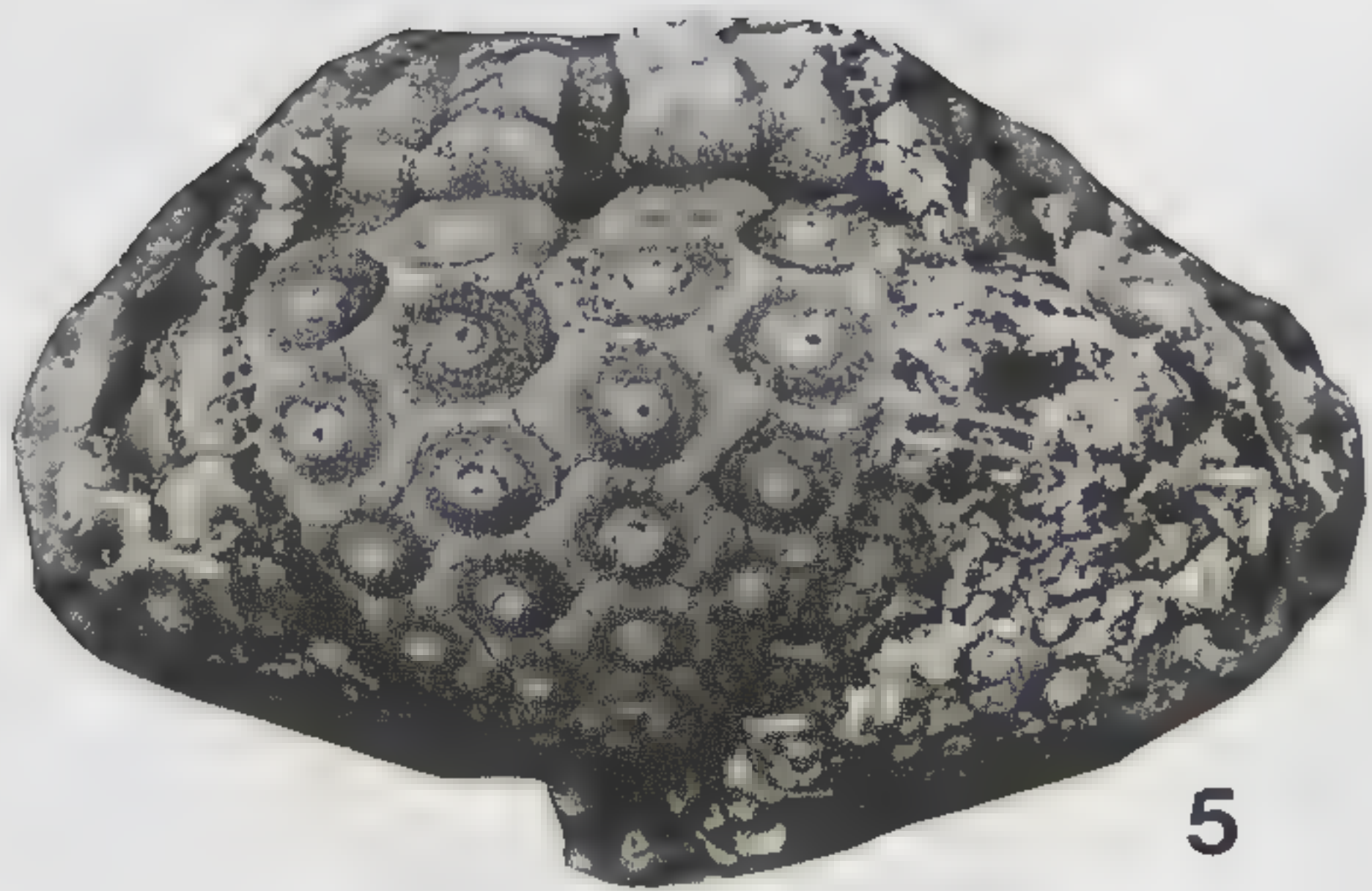
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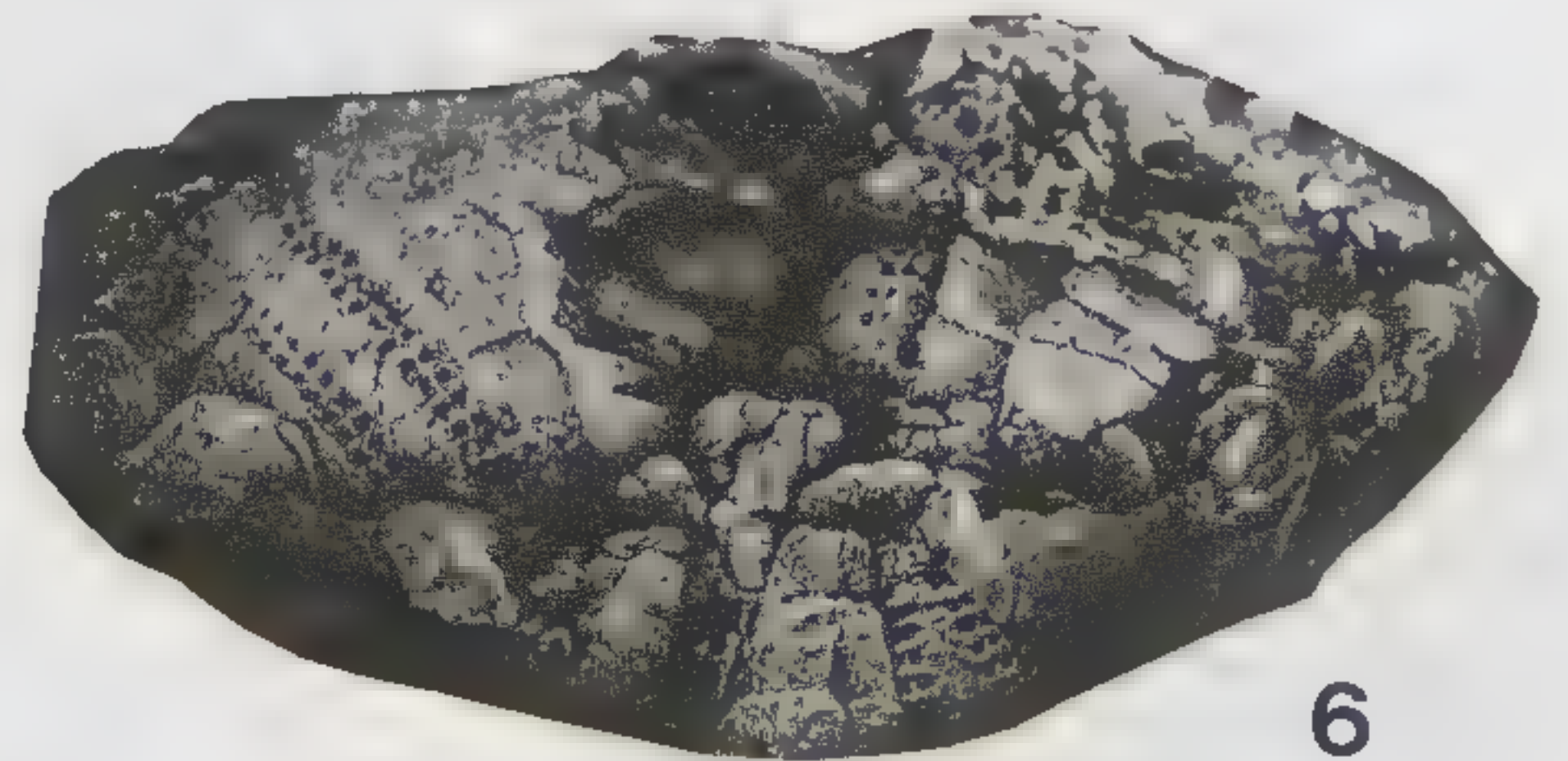
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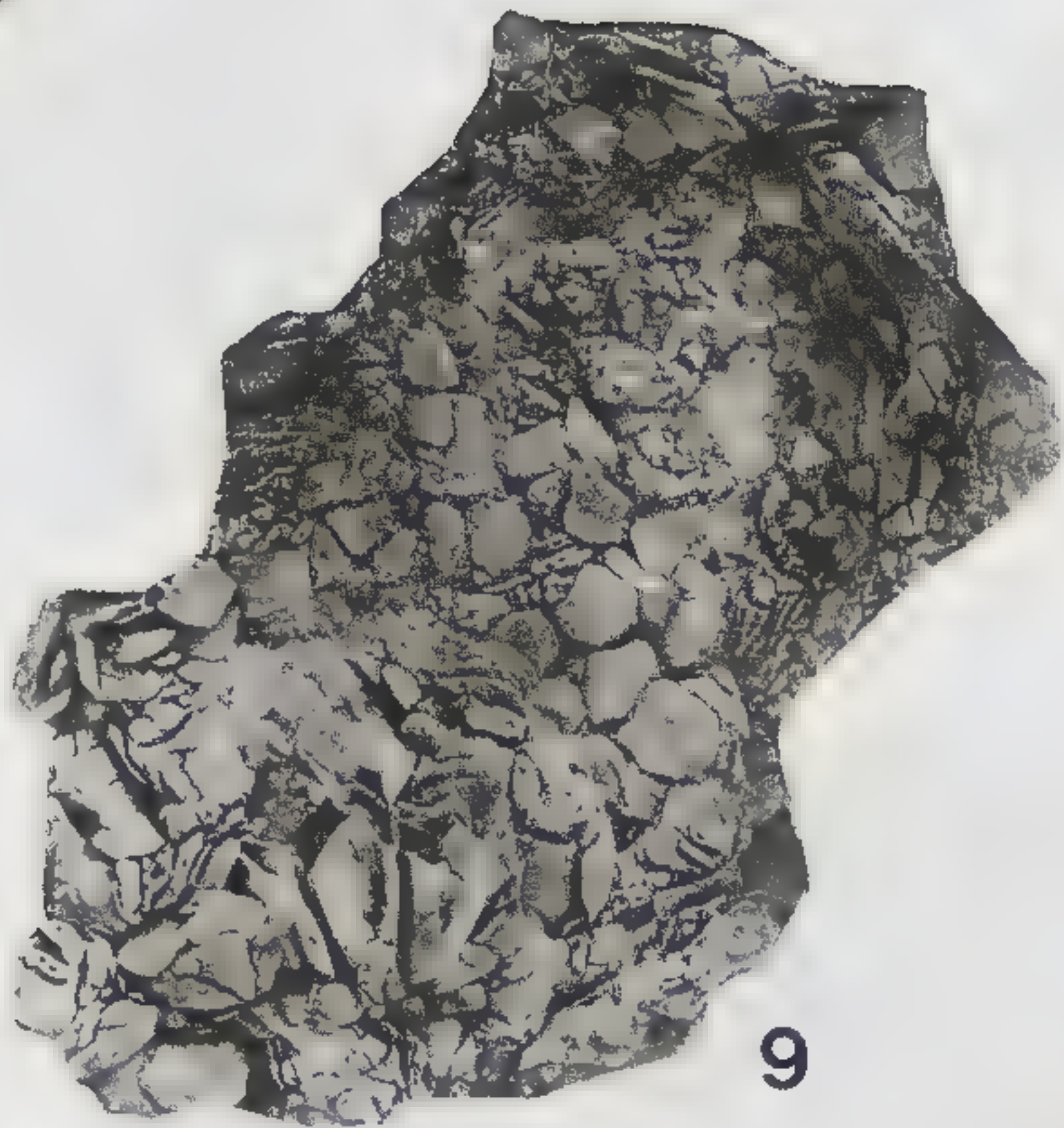
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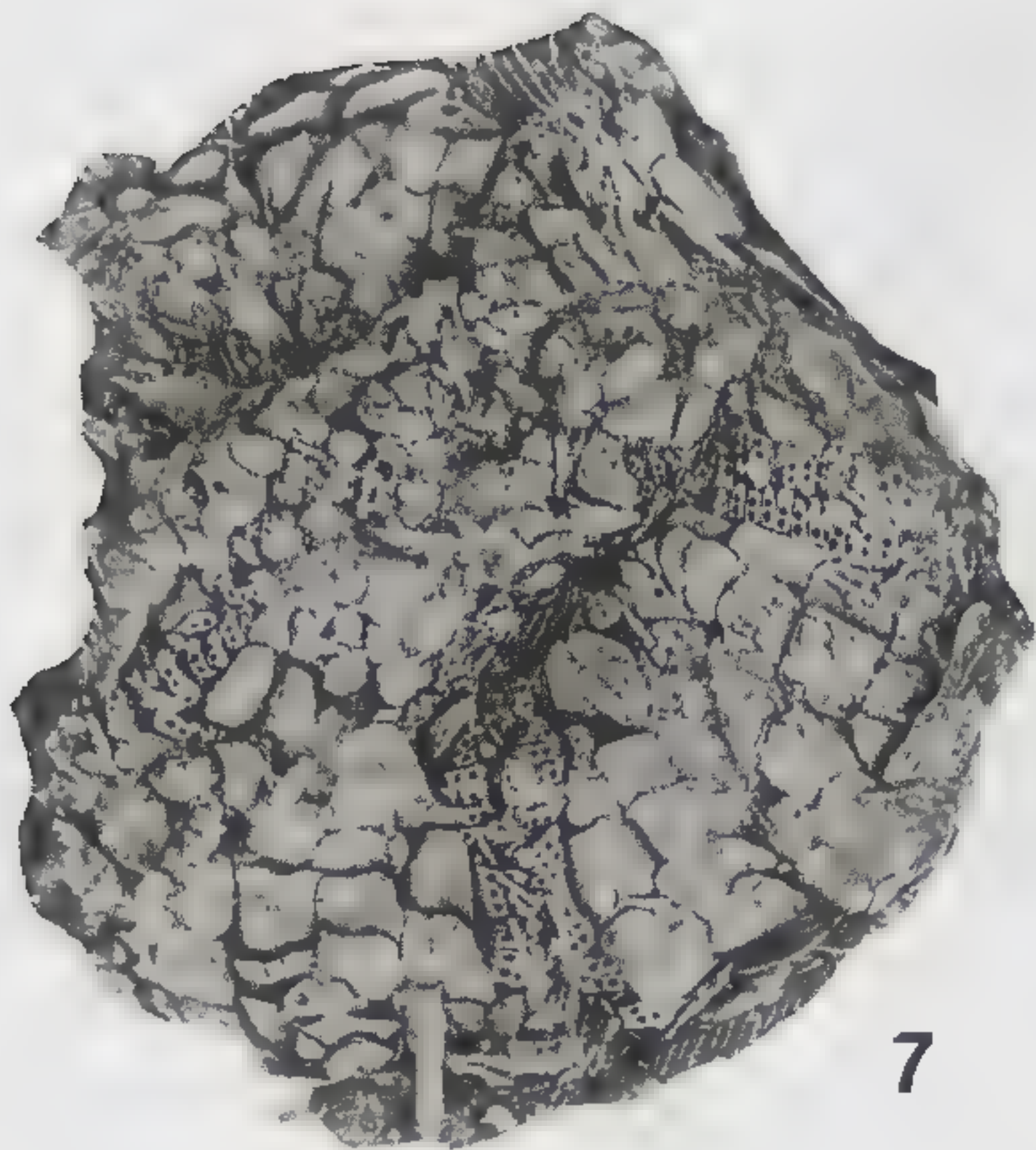
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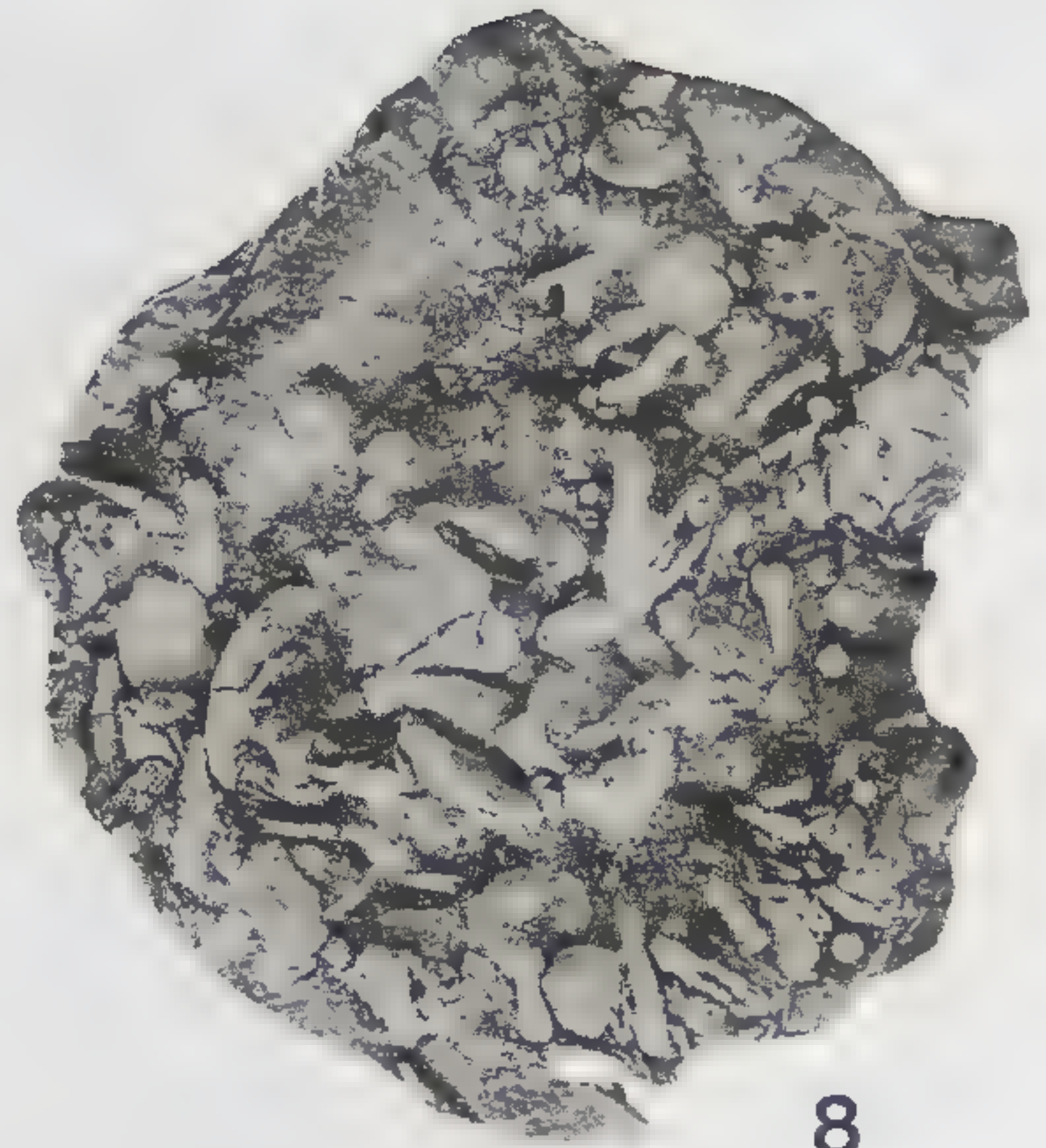
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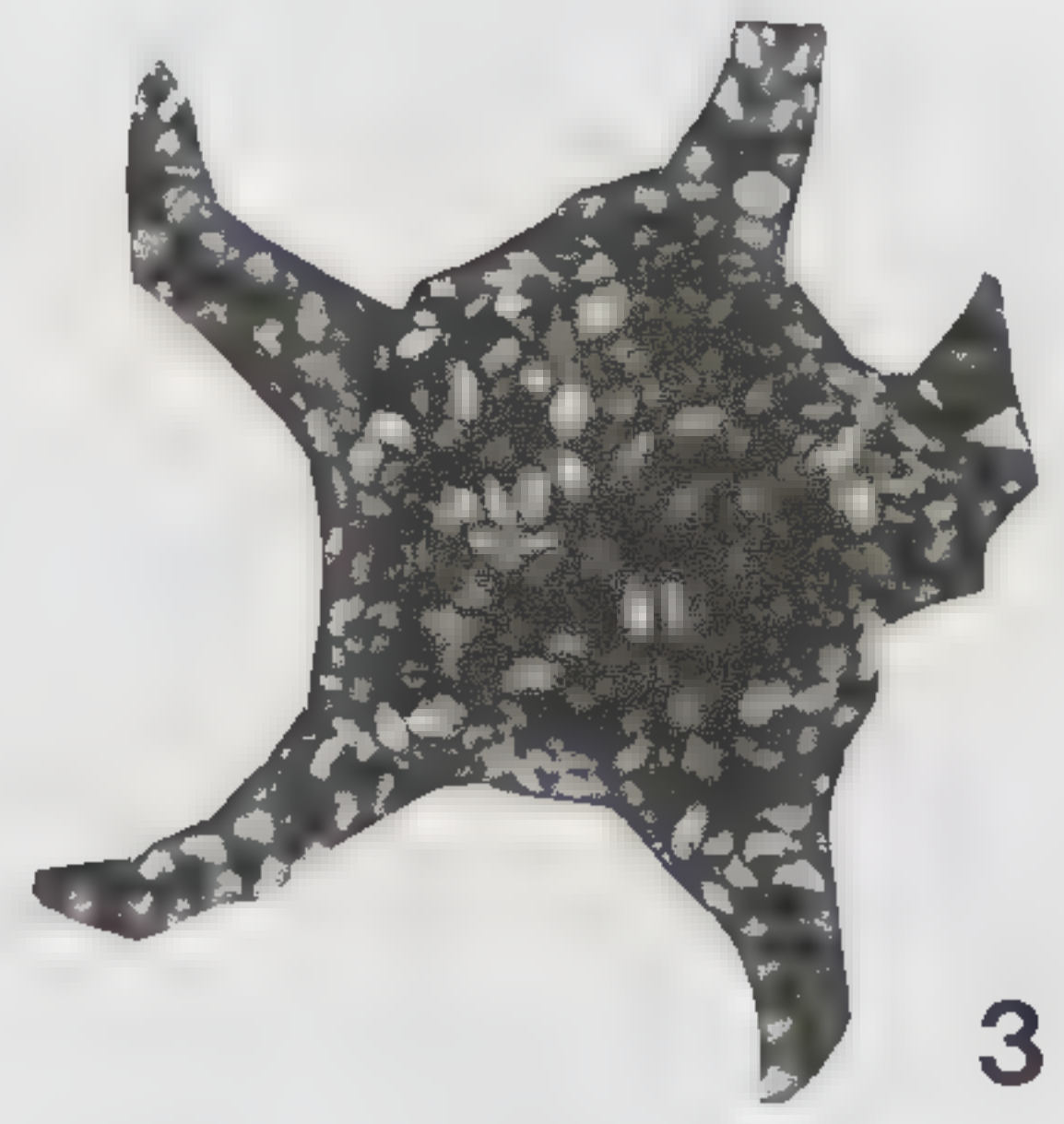




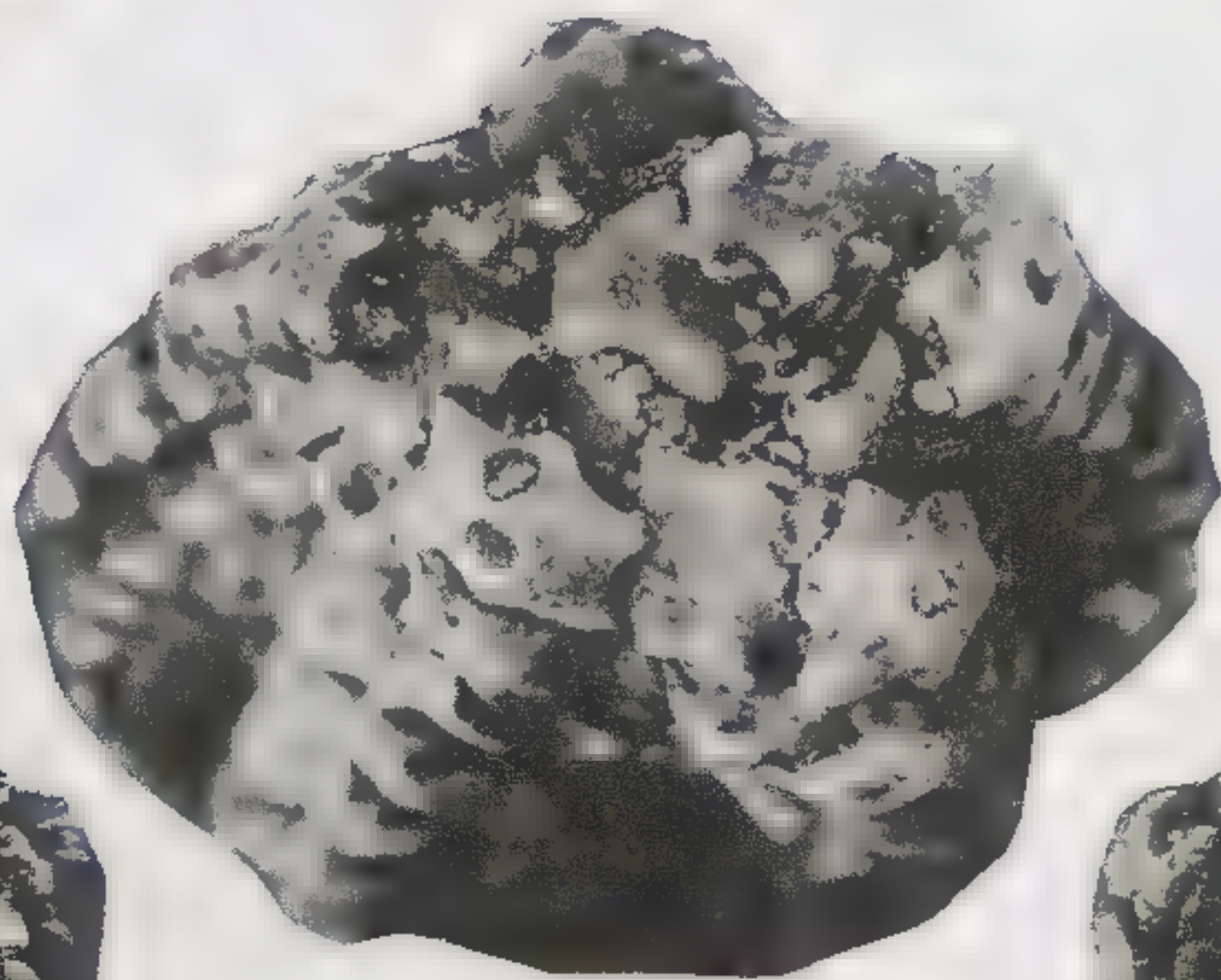
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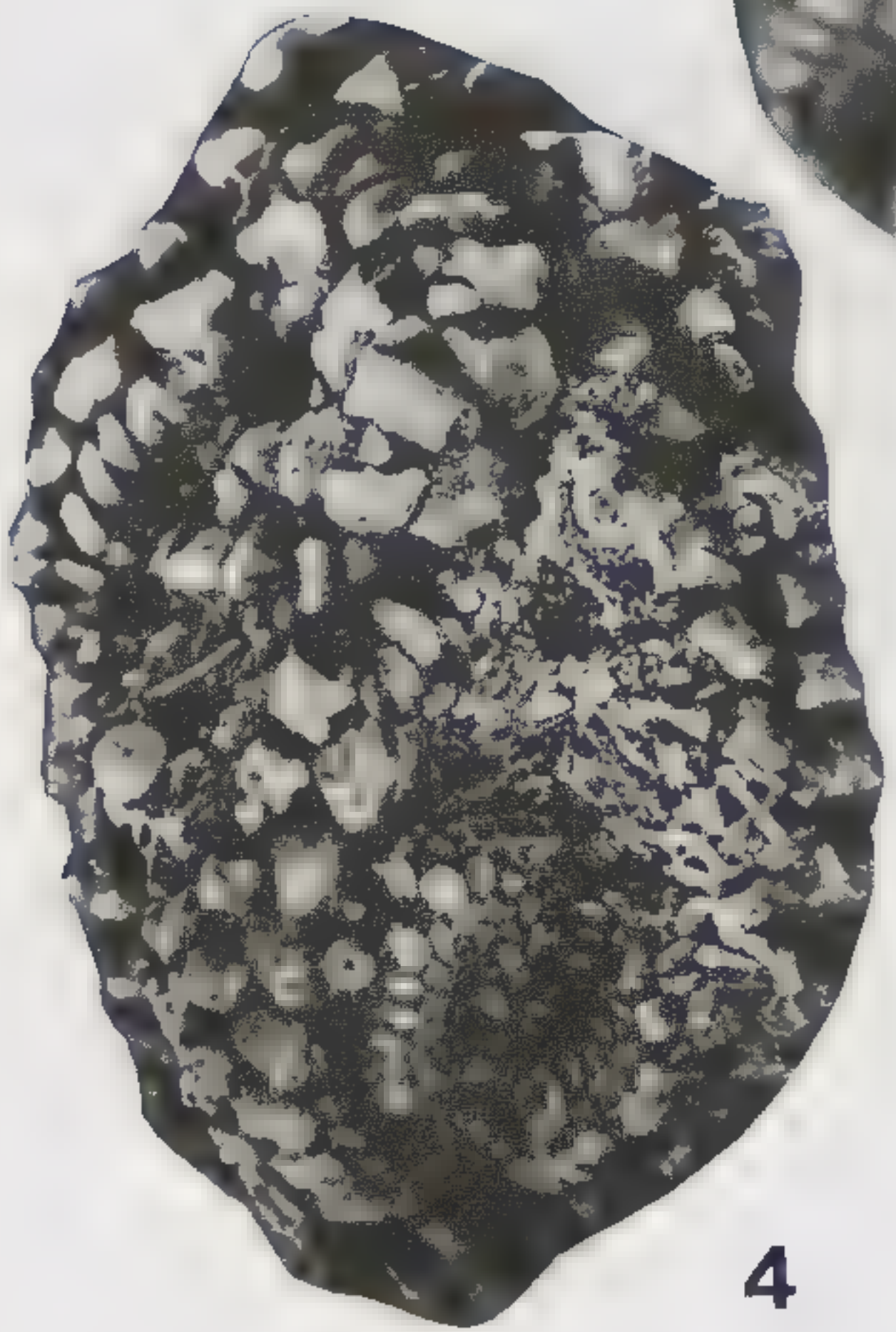
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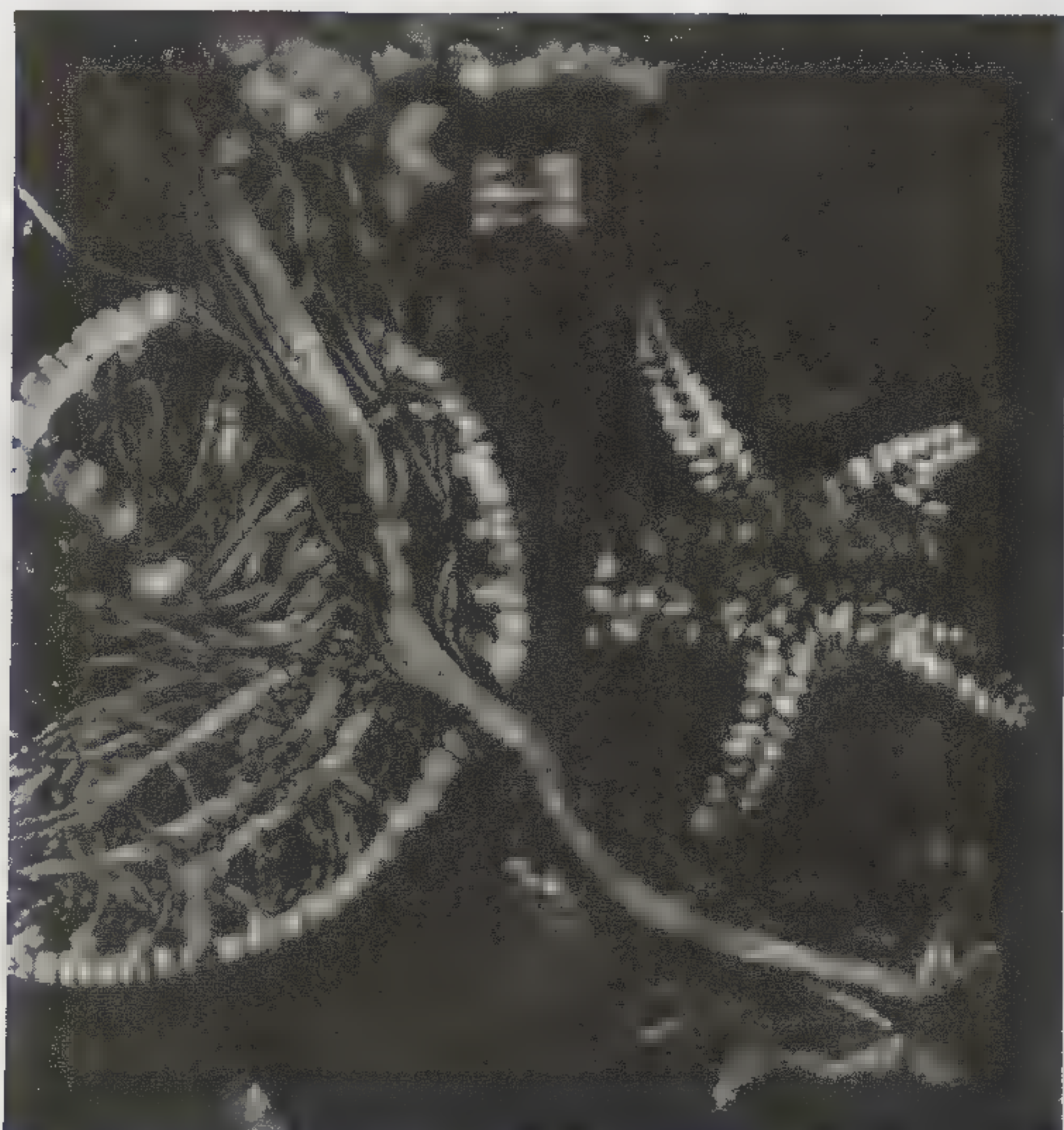
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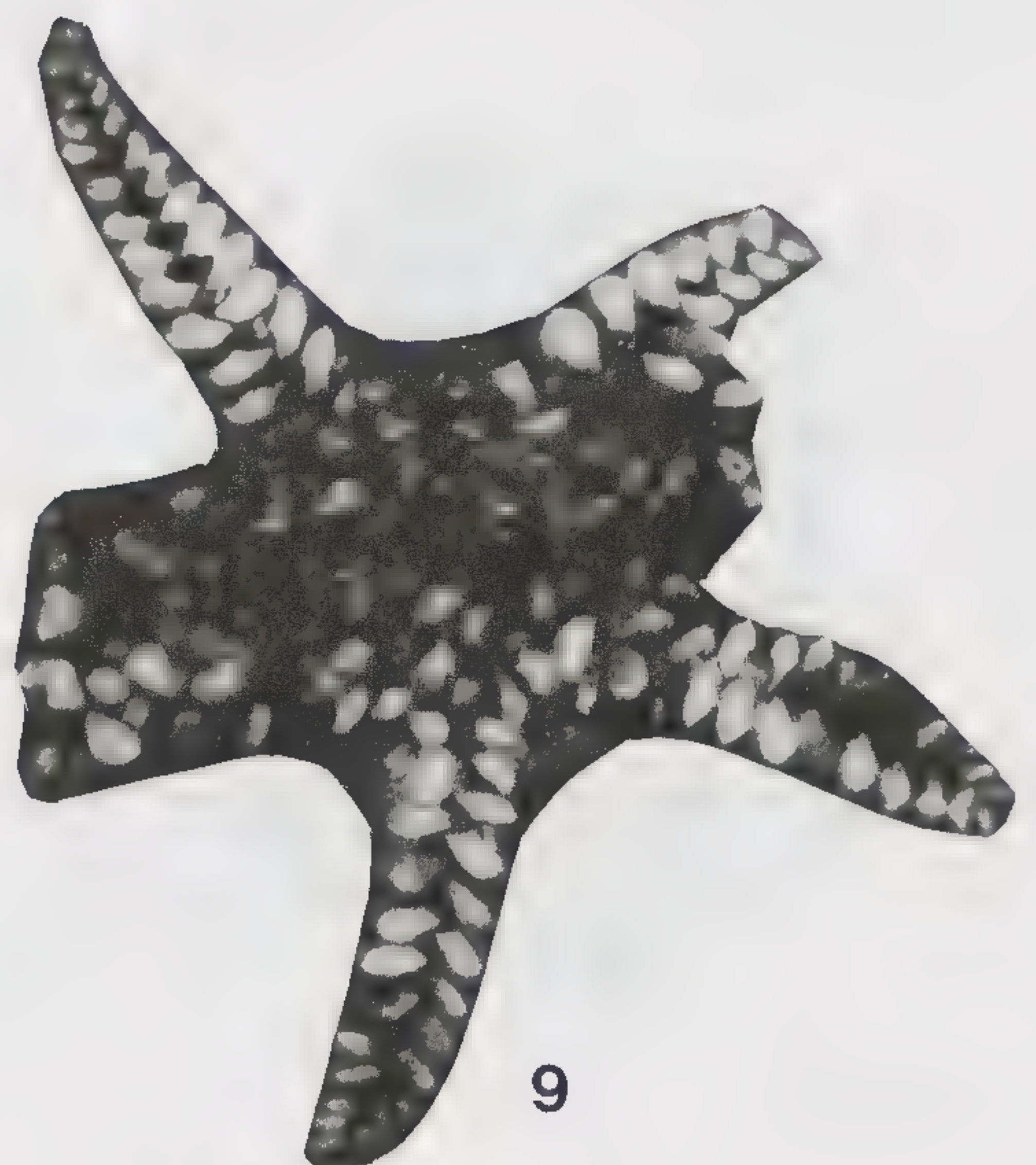
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Table 6.—Explanation of symbols used in the taxonomy section. Parentheses denote plural usage. A numerical suffix indicates the specific plate within the series.

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Crinoidea

- B(BB)** = basal(s)  
**Br(Brr)** = brachial(s)  
**iamb(iambb)** = interambulacral(s)  
**IB(IBM)** = infrabasal(s)  
**iBr(iBrr)** = interbrachial(s)  
**R(RR)** = radial(s)  
**RA** = radianal  
**RX** = right tube plate  
**IBr(IBrr)** = primibrachial(s)  
**IIBr(IIBrr)** = secundibrachial(s)  
**IIIBr(IIIBrr)** = tertibrachial(s)  
**IVBr(IVBrr)** = quartibrachial(s)

Stelleroidea

- Ad** = adambulacral  
**Ax** = axillary, or odontophore  
**C** = centrale  
**cR** = centroradial  
**R** = radial  
**Sm** = supramarginal
-



## PREPARATION OF MANUSCRIPTS

*Bulletins of American Paleontology* usually comprises two or more separate monographs in two volumes each year. This series is a publication outlet for significant longer paleontological monographs for which high quality photographic illustrations and the large quarto format are a requisite.

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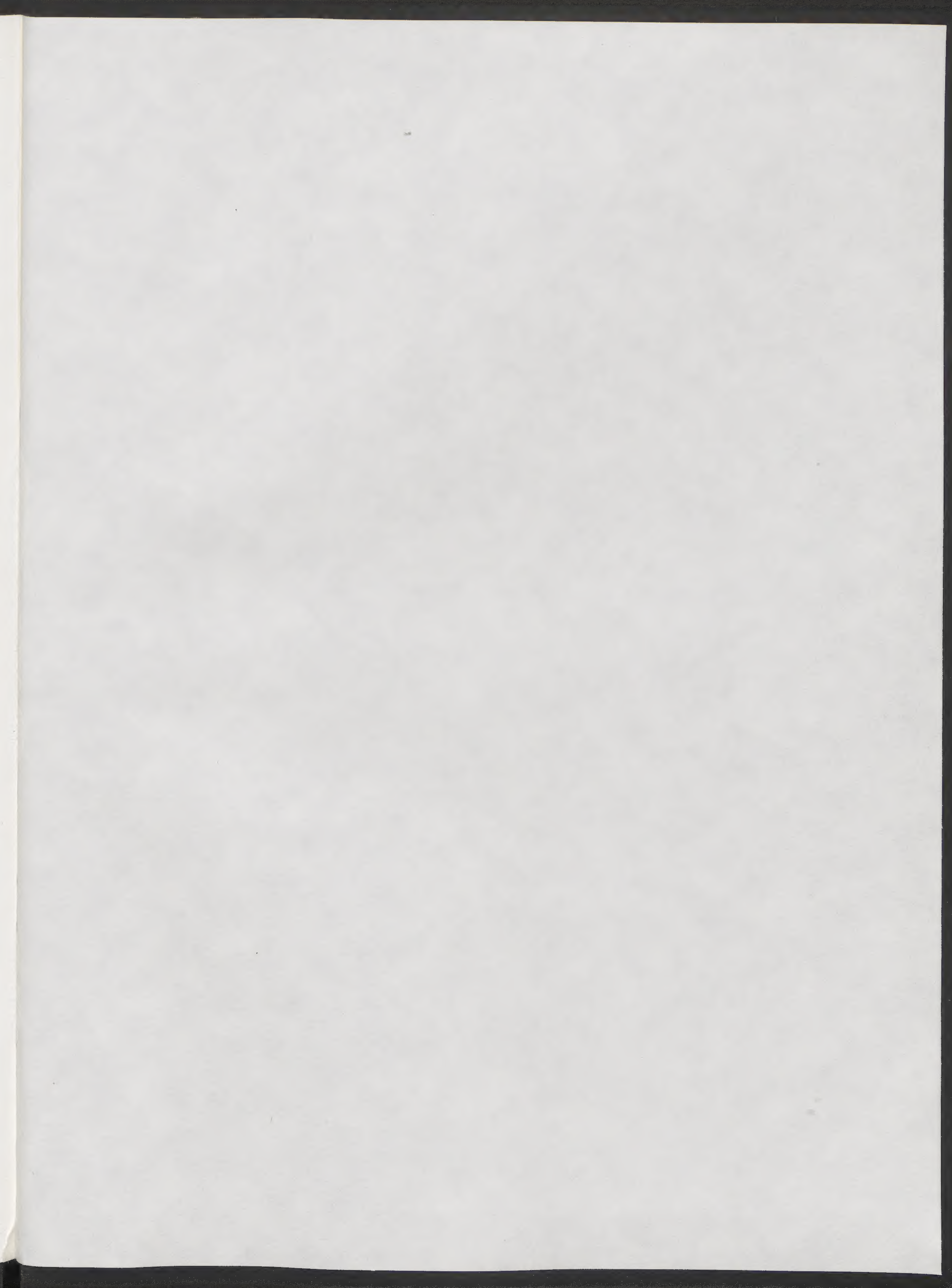




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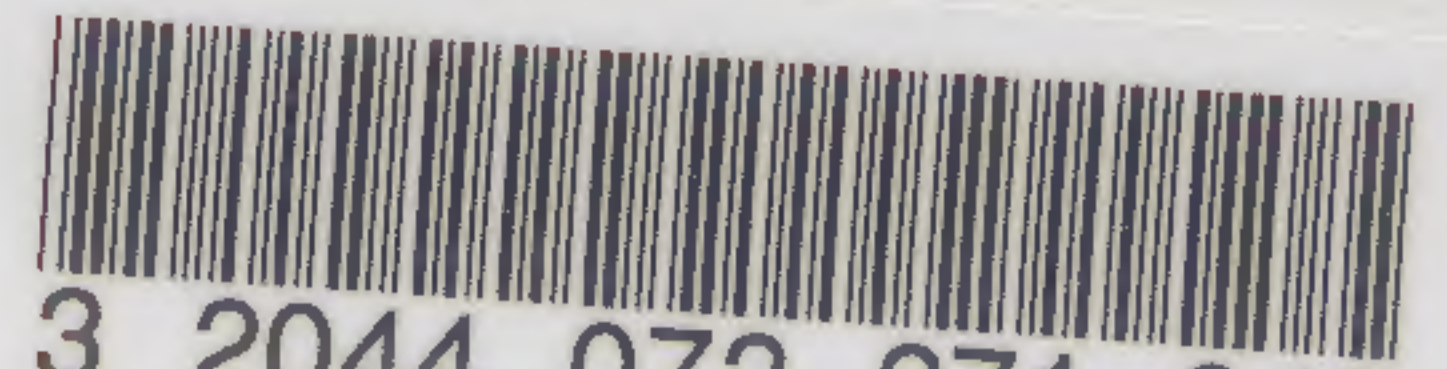












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