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Echinodermata of the Middle Ordovician Lebanon Limestone, Central Tennessee

by

Thomas Edgar Guensburg

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ECHINODERMATA OF THE MIDDLE ORDOVICIAN LEBANON LIMESTONE, CENTRAL TENNESSEE

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ABSTRACT

Representatives of six classes of echinoderms, the Crinoidea, Paracrinoidea, Rhombifera, Asteroidea, Edrioasteroidea, and Echinoidea are present in the Middle Ordovician Lebanon Limestone of central Tennessee. Crinoids are the most abundant and diverse class present and include the following new taxa: Tornatilicrinidae, new family; Tryssocrininae, new subfamily; *Tornatilicrinus, Tryssocrinus,* and *Gustabilicrinus,* all new genera; *Cleiocrinus springeri, Reteocrinus polki, R. variabilicaulis, R. fenestratus, Gustabilicrinus plektanikaulos, G. latomium, Archaeocrinus snyderi, Abludoglyptocrinus gregatus, Tornatilicrinus longicaudis, ?Anomalocrinus antiquus, Tryssocrinus endotomitus, Doliocrinus monilicaulis, Porocrinus lebanonensis,* and *Hybocrinus bilateralis,* all new species. *Reteocrinus* Billings, 1859, is revised and *Traskocrinus* Kolata, 1975, is suppressed and reassigned to *Reteocrinus. Columbicrinus crassus* Ulrich, 1925, is redescribed based on more complete new material and *Praecursoricrinus* Frest, Strimple, and McGinnis, 1979, is suppressed and reassigned to *Columbicrinus* Ulrich, 1925. Of other echinoderms, *Oklahomacystis trigonis* (Paracrinoidea); *Praepleurocystis ranaformis, Amecystis nanus,* and *Tanaocystis sprinklei* (Rhombifera); *Schuchertia darwini* (Asteroidea); *Unibothriocidaris kieri* and *Bothriocidaris vulcani* (Echinoidea) are new. Previously unknown features include crinoid and paracrinoid columns and holdfasts and a partial peristome of *Unibothriocidaris* Kier, 1982.

Echinoderms indicate a middle to late Blackriveran age for the Lebanon, an interpretation in approximate agreement with ages based on conodonts and brachiopods.

Other major faunal groups in the Lebanon are brachiopods, bryozoans, and arthropods. Dominant lithologies include pellet biocalarenites, brachiopod, bryozoan, echinoderm biocalcirudites, calcisiltites, and calcilutites. Paleontologic and sedimentologic evidence indicates the Lebanon was deposited in a moderate-energy normal marine shelf environment ranging from mean low water to 20 to 30 m in depth.

INTRODUCTION

In recent years, several monographic and smaller works have greatly enhanced our knowledge of Middle Ordovician echinoderms. Most notable among these are Brower and Veinus (1974) on echinoderms from Chazyan and Blackriveran rocks of east Tennessee; Kolata (1975) on both Blackriveran and Trentonian echinoderms from northern Illinois and southern Wisconsin; Brower and Veinus (1978) on the Blackriveran and Trentonian faunas from the Minneapolis–St. Paul area, Minnesota; and Sprinkle (1982e) on Blackriveran faunas from the Arbuckle Mountains area, south-central Oklahoma. These studies add to prior knowledge of Middle Ordovician echinoderms that was in large part a result of the efforts of Billings (1854, 1857, 1858, 1859), who studied Trentonian echinoderms from the Ottawa area, Ontario, and Springer (1911), who studied similar Trentonian faunas from the Kirkfield area, Ontario.

Over 300 well-preserved and commonly almost complete specimens were collected for this study. These, augmented by a few previously collected specimens, constitute a rich and diverse Blackriveran echinoderm fauna from the Lebanon Limestone of central Tennessee. This fauna adds significantly to available information on Middle Ordovician echinoderms, permits a detailed analysis of the functional morphology of many forms, and aids in interpreting the phylogenetic history of many groups. The new fauna includes at least 32 genera in six classes: the Crinoidea, Paracrinoidea, Rhombifera, Asteroidea, Edrioasteroidea, and Echinoidea.

The purposes of this study are threefold: 1) to describe all known Lebanon Formation echinoderms and document their stratigraphic positions; 2) to determine the paleoenvironmental setting of the Lebanon Limestone; 3) to realize the regional biostratigraphic potential of echinoderms.

ACKNOWLEDGMENTS

I am grateful to a number of people for help during this study, which is based on my Ph.D. dissertation at the University of Illinois. I would especially like to thank my advisor, Daniel B. Blake, for his many helpful suggestions and ideas, and his critical reading of the manuscript. Albert V. Carrozzi, Ralph L. Langenheim, Philip Sandberg, and Daryl Sweeney, all of the University of Illinois, and Dennis R. Kolata, of the Illinois State Geological Survey, read the manuscript, offered suggestions, and served on my dissertation committee. James Sprinkle, University of Texas, and Ronald Parsley, Tulane University, and Dennis Kolata reviewed a revised manuscript, offered many suggestions, and assisted in other ways. All of the above increased the quality of the resulting monograph.

Thomas E. Bolton of the Geological Survey of Canada (GSC), Ottawa, Ontario, Canada; Porter M. Kier of the United States National Museum (USNM, USNM S), Washington, D.C.; David L. Meyer of the University of Cincinnati (UC), Cincinnati, Ohio; Eugene S. Richardson of the Field Museum of Natural History (FM(UC)), Chicago, Illinois; and Harrell Strimple of the University of Iowa (SUI), Iowa City, Iowa, arranged for the loan of specimens by their respective institutions.

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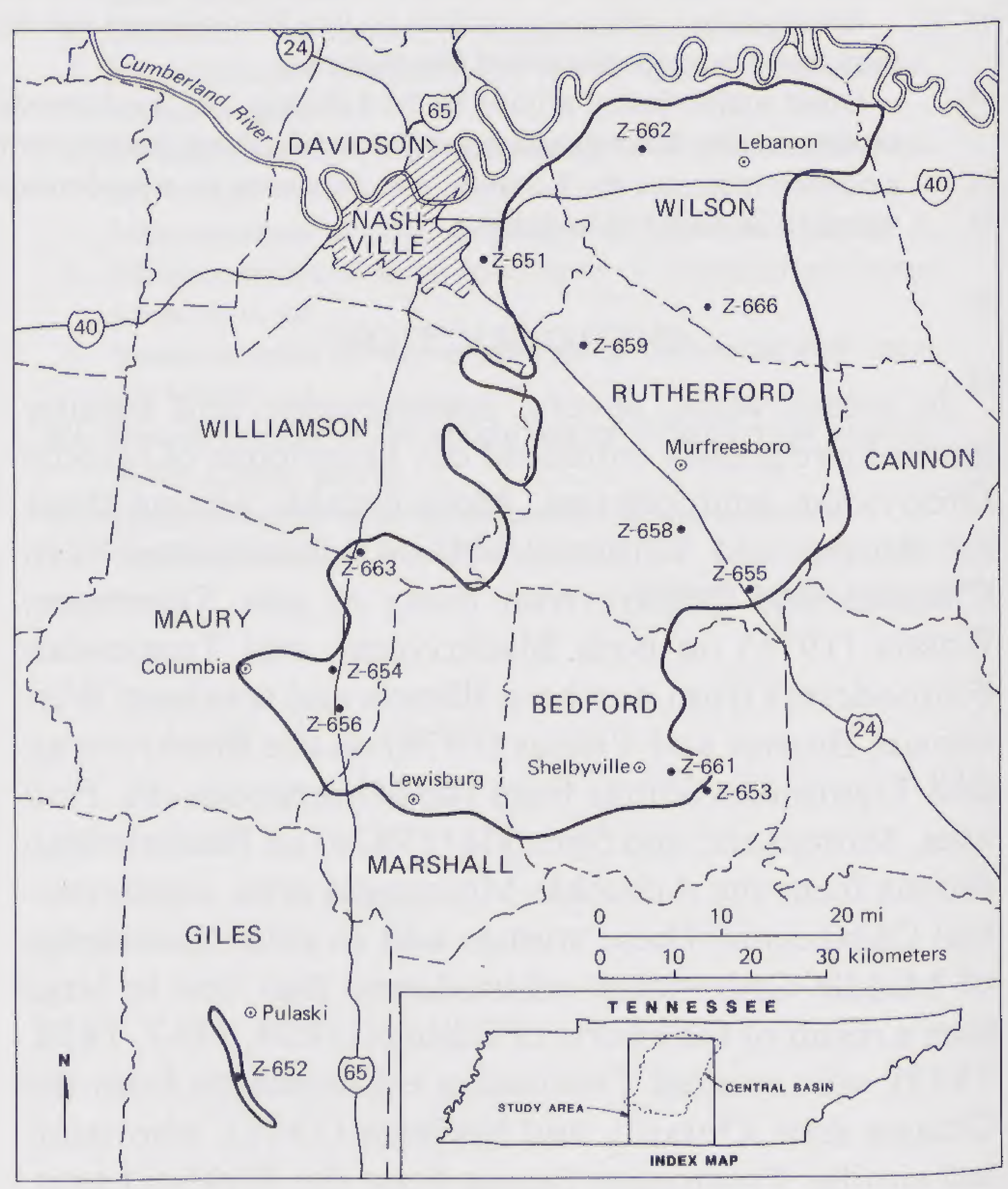
THE LEBANON LIMESTONE

GEOLOGIC AND PALEOGEOGRAPHIC SETTING

The study area is the Central Basin of Tennessee, a topographic feature occupying much of central Tennessee. Nashville, the only major population center in the basin, is situated on its northwest edge (Text-fig. 1). The Central Basin is approximately oval with dimensions of approximately 120 by 80 km; the major axis trends north-northeast. The basin is surrounded by the topographically higher Highland Rim. Structurally, the basin is underlain by the deeply dissected Nashville Dome, which is the southern continuation of the Cincinnati Arch and Jessamine Dome of Ohio and Kentucky. The Cumberland Saddle separates the Jessamine and Nashville domes. Strata generally dip at low angles away from the central part of the Nashville Dome in all directions, and small scale folding and faulting upon the dome is widespread. Silurian through Carboniferous strata are exposed around the edges of the dome, along the Highland Rim, and on resistant inliers.

Ordovician strata form most of the bedrock topography within the Central Basin itself, and in an upfaulted outlier along the southern edge of the Nashville Dome, where younger strata are eroded. The Lebanon Limestone is less resistant than the over- and underlying formations and therefore tends to form topographic lows. Soil cover, however, is thin over much of the Lebanon Limestone outcrop belt so that natural exposures are abundant and form what are locally known as glades. Most natural exposures are deeply eroded, however, and many exposed fossils are extensively damaged by dissolution. Fresh exposures of the Lebanon Limestone, mainly quarries and roadcuts, are also numerous; 12 of these have yielded the echinoderms studied here (*see* Appendix).

During the Middle Ordovician time, the Central Basin region of Tennessee was a southern part of the large cratonic carbonate shelf that occupied most of present-day eastern North America. The continental margin was approximately 200 to 300 km to the south and east and the shallow shelf extended to the north and west from the Central Basin. To the east of the Central Basin in what is now the Sequatchie Valley of Tennessee, and to the north on what is now the Jessamine Dome of Kentucky, the Lebanon Limestone and equivalent-age rocks (Camp Nelson Formation) indicate supratidal, intertidal, and subtidal environments (Cressman and Noger, 1976; Bennedict, 1974). The Central Basin was approximately 20 to 25 degrees latitude south of the equator during the Middle Ordovician (Bambach, Scotese, and Ziegler, 1980, p. 30).



Text-figure 1.—Map of study area showing localities where Lebanon echinoderms were collected. Location of study area is shown on inset map of Tennessee. Heavy line = maximum extent of Lebanon outcrop belt; dashed line on inset = approximate boundary of the Central Basin/Nashville Dome area.

Stratigraphic Setting

The Lebanon Limestone is part of the lower to middle Champlainian Stones River Group. In the Central Basin of Tennessee, this sequence is divided into five formations including, in ascending order, the Murphreesboro Limestone, Pierce Limestone, Ridley Limestone, Lebanon Limestone, and Carters Limestone. The Lebanon Limestone is a relatively argillaceous, thin- to medium-bedded interval between the more massive Carters Limestone and Ridley Limestone (Wilson, 1949). The Lebanon averages approximately 28 m thick in the Central Basin (Wilson, 1949).

The Ridley - Lebanon contact as exposed is conformable (Wilson, 1949, p. 37; pers. observ.). Over most of the study area (including locs. Z-652, Z-658, Z-665, and Z-667) the top of the Ridley Limestone is marked by a 1.5 to 2.0 m thick pelletoidal biocalcarenite.

Wilson (1949, pp. 43, 54) postulated an unconformity between the Lebanon Limestone and the Carters Limestone, and cited several mostly indirect lines of evidence to support this conclusion. The upper member of the Lebanon Limestone and lower part of the overlying lower member of the Carters Limestone both generally thicken away from the axis of the Nashville Dome. This was interpreted by Wilson to have resulted from slight uplift and erosion of the dome immediately following Lebanon deposition and subsequent Carters deposition first about the dome edges, then over the entire area (resulting in a thicker section of Carters Limestone around the margins of the dome). Some beds occurring at or near the top of the Lebanon were observed to have a "pinkish peripheral zone" indicating oxidation; this was interpreted as evidence for subaerial exposure of the Lebanon before Carters deposition. The contact between the Lebanon and Carters is abrupt. A local angular unconformity between the Lebanon and Carters formations was believed to have been observed by Wilson (1949, p. 56) on the far southern flank of the Nashville Dome along Richland Creek, 1.6 km south of Milky Way Station, Giles County, Tennessee.

I have found Wilson's arguments unconvincing for the following reasons. As pointed out by Hofstetter (1965b, p. 57), the thinning of the Lebanon could as readily have been caused by differential rates of deposition. Beds with a pinkish cast are typically calcarenites or calcirudites. They occur at many levels in the Lebanon Limestone and are most common near the middle of this formation, not concentrated at or near the top, as was indicated by Wilson. There is also no evidence (*e.g.,* vadose crusts, desiccation cracks, or local relief on top of the Lebanon) that the oxidation of these horizons occurred during times of subaerial exposure. An abrupt contact need not indicate an unconformity. The abruptness of the Lebanon - Carters contact is due to the rapid change from many argillaceous and (or) dolomitic interbeds in the Lebanon to fewer of these in the Carters; the change is accentuated by weathering. I visited the site of the above stated local angular unconformity and found no angular relationship between the Lebanon and Carters formations. This exposure is poor, and the Carters Limestone is deeply weathered. G. L. Bennedict and L. Alberstadt visited the locality several times and were also unable to discern an angular relationship between the Lebanon and Carters (Bennedict, oral commun., 1981). I found no indication of an unconformity at better nearby exposures (*e.g.,* loc. Z-652).

Bassler (1932) believed a considerable diastem (lasting from early Chazyan to Blackriveran) separates the Lebanon and the Carters (called "Carters Member of the Lowville Formation" by Bassler, 1932) limestones. Others, including Wilson (1949) and Cooper (1956), have ignored Bassler's published interpretation. Bassler apparently based his conclusion on faunal differences alone (particularly corals) because he states (p. 58) that the Lebanon and Carters limestones "appear to be in conformable relationship." Neither Cooper (1956, chart 1), using brachiopods, nor Sweet and Bergström (1976, p. 133), using conodonts, were able to recognize a significant diastem between the Lebanon and Carters formations. During this study, two guide fossils characteristic of the lower Carters Limestone, *Foerstephyllum halli* Nicholson, 1879, and *Streptelasma profundum* (Conrad, 1843) were collected in the upper Lebanon Formation. Based on brachiopods, conodonts, and corals, therefore, the Lebanon Limestone appears to be only slightly older than the Carters Limestone.

No physical evidence of an erosional unconformity between the Lebanon and Carters formations, such as widespread scoured or corroded surfaces, basal lag deposits, or weathering features such as dissolution or vadose crusts, were observed during this study. Instead, the contact investigated at several localities in this study (locs. Z-651, Z-653, Z-654, Z-657, and Z-662, among others) proved to be a change in bedding. Contact recognition in fresh exposures (such as at loc. Z-651) can be difficult and somewhat arbitrary (Pl. 16, fig. 4). The change in bedding results from the fewer argillaceous and (or) dolomitic interbeds in the Carters. Because of basic lithic and paleontologic continuity, I believe that no major unconformity or diastem exists between the Lebanon and Carters formations. The primary lithologic difference between the two units is decreased clastic input during Carters deposition; the causes for this change have not yet been identified.

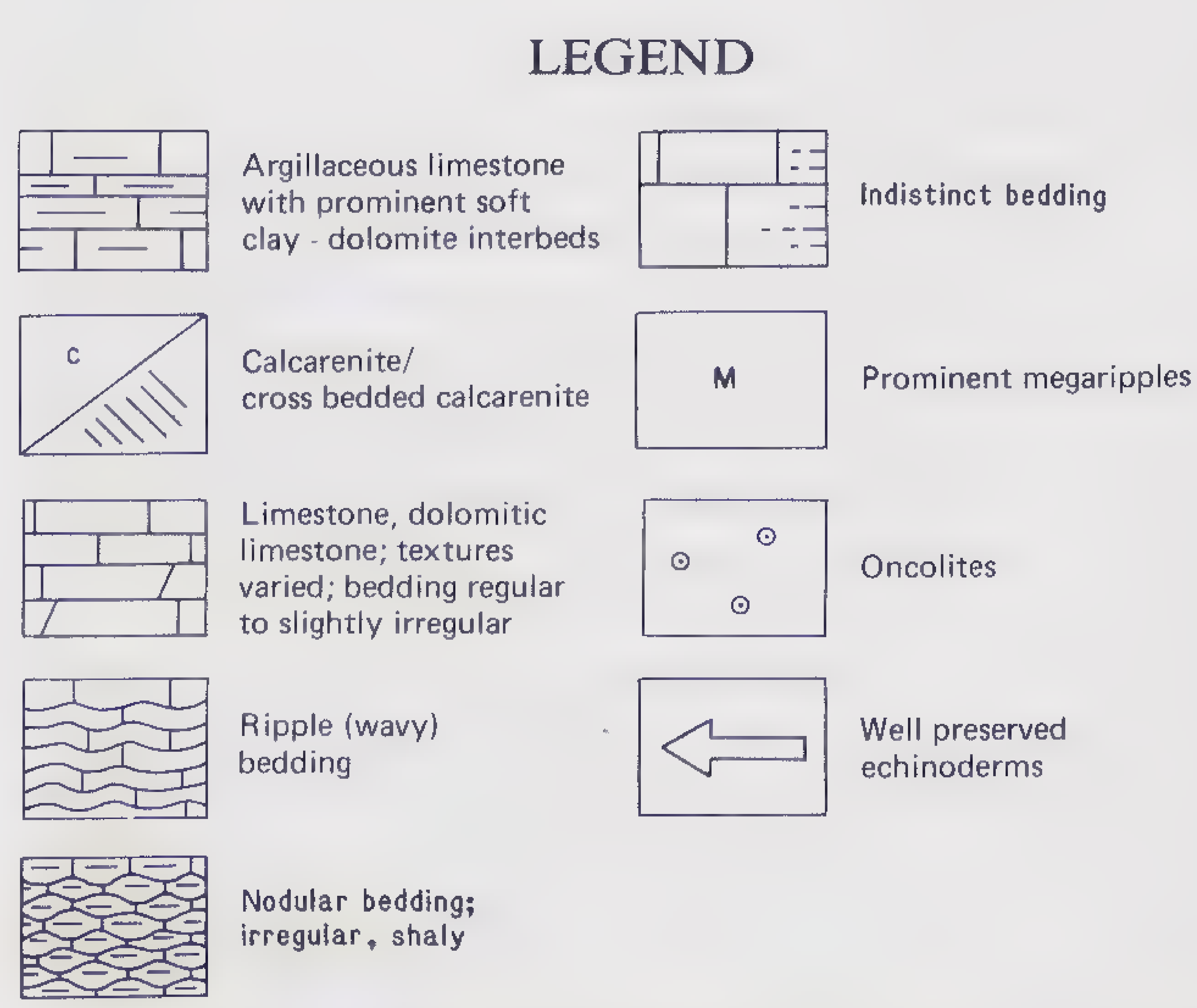
Wilson (1949) subdivided the Lebanon Limestone into three rock-stratigraphic subunits informally termed "lower," "massive," and "upper" members. The lower member is thin-bedded and averages approximately 18 m thick. The massive member is near the middle of the Lebanon; it is massive and averages approximately 1.6 m thick. The upper member is again thin-bedded, and averages approximately 10.6 m thick.

Where the massive member thins (it is approximately 0.5 m thick at loc. Z-651 [Pl. 16, fig. 1]) and where other massive strata occur locally in the Lebanon section, it can be difficult to recognize (Hofstetter, 1965b; Bennedict, 1974; pers. observ.). Because of these subtleties, Hofstetter (1965b, p. 15) referred to the massive member as the "massive weathering member" rather than the "massive member," and Bennedict (1974) did not use the three member concept of Wilson. Bennedict, however, studied only three exposures and one well core in the Central Basin in detail, and his emphasis was on lithofacies analysis and not stratigraphy. I found the massive member at all sections where the middle interval of the Lebanon Limestone is exposed; although the member is difficult to discern in places. The middle interval was located by visual observation of upper or lower formation contacts, from elevations and contacts on published geologic quadrangle maps, and by identification of the *Sowerbyella - Diplograptus* horizon (see discussion below). The massive member is typically a single bed in the north and central parts of the Central Basin. It is approximately 1.6 m thick at locality Z-651 near Nashville but only 0.5 m thick at locality Z-654 near Columbia, Maury County. In the southernmost part of the study area, south of Pulaski, Giles County, the member is approximately 3 m thick and consists of several thick to thin beds. Lithologically, the middle massive bedded member is characteristically a bioturbated pellet biocalcarenite (lithofacies 2 under Lithology); locally it contains oncolites in a calcilutite matrix. The member is whitish brown to whitish pink in fresh exposures, which contrast with the grey adjacent strata. Because the massive member is continuous over the entire Central Basin and is readily recognizable over most of this area, it is here utilized as a marker unit.

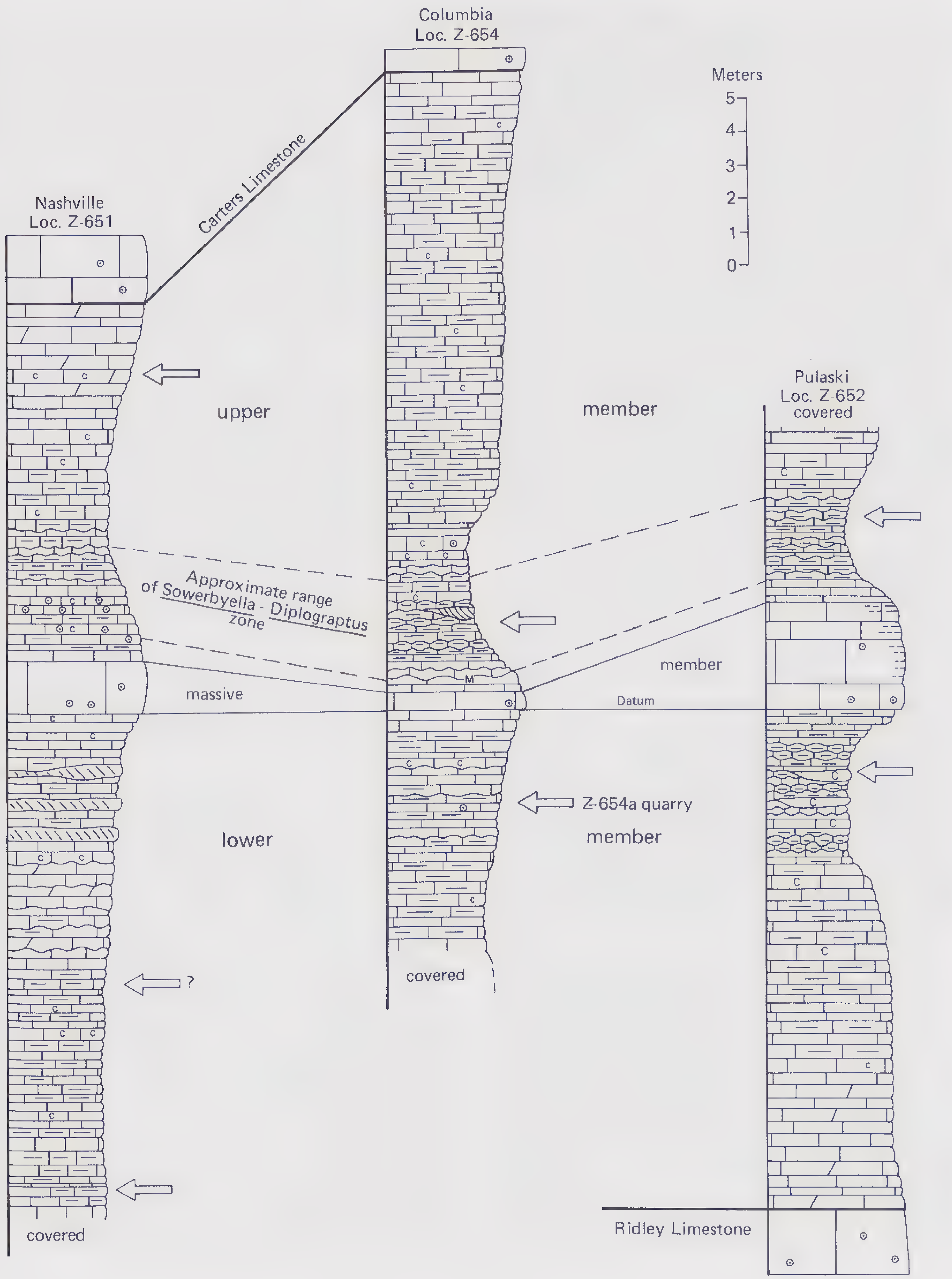
The massive member is also identified by the presence immediately above it of a zone containing the graptolite *Diplograptus multidens* Elles and Wood, 1907, and abundant brachiopods of the species *Sowerbyella lebanonensis* Bassler, 1935. This interval is here referred to as the *Sowerbyella - Diplograptus* Zone of the upper member. It is located from 0.8 to 3.0 m above the massive member. Graptolites have not been found at any other horizon in the Lebanon and *Sowerbyella* Jones, 1928, does not occur above this zone. This zone locally contains prominent megaripples near its base and it is more argillaceous than under- and overlying strata. Stratigraphic columns of three thick, well-exposed sections are presented in Text-figure 2. The columns are approximately aligned in a north-south direction across the Central Basin; the farthest-separated sections are approximately 120 km apart. Although the columns differ in detail, the overall sequences including the positions of the middle massive bedded member and *Sowerbyella - Diplograptus* Zone are similar.

LITHOLOGY

General features.—The Lebanon consists principally of thin- to medium-bedded (rarely thick-bedded) light to dark grey limestone with thin interbeds of calcareous shale or dolomite (bedding classification after Ingram, 1954). Beds are typically between 5 and 20 cm thick but attain a maximum thickness of 170 cm; deeply-weathered exposures appear more thinly-bedded than fresh ones. Interbeds range from approximately 1 mm to 2.5 cm thick. Dolomitic interbeds weather to light buff or yellow. Beds are subplanar, irregular, wavy (rippled), and nodular; their lateral extent is from a meter or less, to (rarely) kilometers. Stylolites are common. The Lebanon becomes more argillaceous toward the south and west sides of the Nashville Dome, and, in addition, clay content decreases near the formational



Text-figure 2.—Three lithostratigraphic sections of the Lebanon Limestone. The localities are near Nashville, in the north (Z-651); near Pulaski, in the south (Z-652); and east of Columbia, approximately midway between the first two (Z-654). See Text-figure 1 and the Appendix for more detailed locality information.



Columbia
Loc. Z-654
Meters
5
4
3
2
1
0
Nashville
Loc. Z-651
Carters Limestone
upper
member
Pulaski
Loc. Z-652
covered
Approximate range
of Sowerbyella - Diplograptus
zone
massive
member
Datum
Z-654a quarry
lower
member
?
covered
covered
Ridley Limestone
covered

contacts and in the massive member. Dolomite appears to increase toward formational contacts.

Lithofacies.—Bennedict (1974) divided the Lebanon into five end member lithofacies based primarily on petrographic characteristics; four of these occur in the Central Basin and one occurs only in the Sequatchie Valley in eastern Tennessee. The same lithofacies can be recognized on the basis of field observation, hand samples, and limited thin-section and acetate-peel analysis. Bennedict's Central Basin lithofacies, therefore, are here summarized with a few modifications. The carbonate classification used is that of Carozzi (1972) and differs from that of Bennedict, who used a combination of the classifications of Dunham (1966) and Folk (1959).

Lithofacies 1 (Pl. 15, fig. 4) is a poorly- to well-sorted fine to coarse pelletal and pelletoidal calcarenite (pelletal or pelletoidal grainstone of Bennedict, 1974). The matrix is typically sparite but can be mud (calcilutite). The color is medium to dark brownish-grey, occasionally brownish-white. External bedding typically is thin, occasionally medium or thick. Internally, beds are thinly- to thickly-laminated or cross-laminated, but occasionally structureless and bioturbated. Pellets and pelletoids range in diameter from approximately 0.1 to 1.0 mm. Many larger pelletoids show faint shapes within them and appear to be micritized skeletal fragments. Some pellets could be fecal in origin, as indicated by their relatively constant diameter. Fossils are broken, abraded and rounded, and many have distinct micrite coatings. They are concentrated in stringers or scattered more or less homogeneously through the sediment. Common fossil groups include ostracods, gastropods, trilobites, brachiopods, and bryozoans. Angular to subrounded intraclasts of pellets and calcilutite are locally common. Oncolites are locally common and are constructed of tubes of the blue-green algae *Girvanella* Nicholson and Etheridge, 1880. They nucleate around bioclasts or intraclasts. Horizontal and vertical burrows are locally common.

Lithofacies 2 is an oncolitic biocalcirudite with a sparite or calcarenite matrix (oncolithite of Bennedict, 1974). The calcarenite matrix is composed either of pelletoids or skeletal fragments (mainly of brachiopods and echinoderms). Most oncolites are 5–10 mm in diameter but are rarely greater than 30 mm in diameter. They are composed of a skeletal grain or pellet nucleus surrounded by concentric laminae of *Girvanella* tubes. This lithofacies is rare and occurs in lenses or pods in beds comprised primarily of lithofacies 1 and 4 (Pl. 15, fig. 5). Bennedict reported it from a few horizons in exposures in the southwestern part of the Central Basin in Maury and Giles counties. I have also collected a sample from locality Z-651 near Una, Davidson County, in the northwest part of the Central Basin.

Lithofacies 3 (Pl. 15, fig. 6) is a bioturbated biocalcilutite (massive micrite of Bennedict, 1974). Bedding is thin to medium and irregular or nodular. Beds are internally unstratified to finely-laminated and of medium-grey to whitish-grey color. Much of the calcilutite appears to be comprised of micritized microscopic fossil fragments. Megafossils typically are uncommon but locally can be rare to abundant. Fossils commonly are whole and unabraded and can be exquisitely preserved. Common forms include ostracods, particularly *Eoleperditia* Swartz, 1949, gastropods, and trilobites. Less commonly, a more diverse fauna is present, often in lenses of bioaccumulated limestone surrounded by less fossiliferous micrite. These lenses contain brachiopods (particularly strophomenids), bryozoans, bivalves, sponges and echinoderms. Two types of bioturbation are recognizable. The first is represented by discrete dolomite-filled burrows. The dolomite weathers more rapidly than the adjacent limestone, yielding irregular, often intersecting tunnels. The second consists of swirl structures caused by orientation of fine fossil debris and is usually accompanied by mottling of the calcilutite (micrite) matrix. Lithofacies 3 is common throughout the Central Basin of Tennessee. One to 2.5 m thick intervals consisting primarily of this lithofacies occur in the lower Lebanon Limestone at localities Z-652 and Z-655 and beds of this lithology also occur in the *Sowerbyella - Diplograptus* Zone in Maury County (*e.g.,* at loc. Z-654).

Lithofacies 4 (Pl. 15, figs. 2, 3) ranges from a well-sorted, fine to coarse biocalcarenite with a sparite matrix, to a well- to poorly-sorted biocalcirudite with sparite or micrite matrix [bioclastic lithologies of Bennedict (1974) including grainstones and packstones]. The color is medium to dark grey, and may have a pink or reddish cast. The former rock type is thin- to medium-bedded and beds are finely- to coarsely-laminated, occasionally cross-laminated. The latter lithology is thin- to medium-, rarely thick-bedded externally and coarsely laminated to thin-bedded internally. Cross-bedding and graded bedding are common. Beds of both rock types commonly occur as lens-shaped, small, temporary channels or more widely-extended subtabular beds, many characterized by ripple marks. Larger ripple marks to small scale dunes (Pl. 16, fig. 2) are associated with the calcirudites and have maximum wavelengths ranging from 0.8 to 1.0 m, and a ripple index (wavelength ÷ amplitude) of 10 to 20. Smaller ripples are typically associated with the calcarenites and usually have wavelengths of 15 to 25 cm. Fossils are most commonly extensively abraded and rounded, and when identifiable typically consist of echinoderms and brachiopods. Calcirudites typically contain whole unabraded to slightly abraded fossils, mainly brachiopods, that may form coquinites. Oncolites, pellets and pelletoids are commonly abundant.

Intraclasts of lithofacies 1, 3, or 4 are locally common in the calcirudites and uncommon in calcarenites. The intraclasts typically are highly angular, and range in size from coarse sand to (rare) pebbles over 8 cm in diameter. Dolomite-filled trace fossils are also locally common, especially in the calcarenites. Lithofacies 4 is common throughout the Central Basin but is most common on the west side of the major axis of the Nashville Dome.

Mixing and rapid changes of lithofacies over short lateral and vertical distances are common (Pl. 15, fig. 5) and many samples are varied, indicating a complex interweaving of the various subenvironments implied by the lithofacies. As also noted under "Stratigraphic Setting", the massive member consists primarily of lithofacies 1 (pellet and pelletoidal calcarenites). Both upper and lower members are comprised predominantly of lithofacies 1, 3, and 4.

FAUNA AND FLORA

Fauna Other than Echinoderms

The Lebanon contains an abundant and diverse invertebrate shelly fauna dominated by bryozoans, brachiopods, and echinoderms. Taxonomic studies of Lebanon Limestone fossils are few, however. The most comprehensive works on these fossils to date are by Cooper (1956), who included Lebanon brachiopods as part of his larger work on Chazyan brachiopods and Coryell (1921) who studied Lebanon bryozoans as a portion of his Stones River Group bryozoan work. Hofstetter (1965a) reported the graptolite *Diplograptus multidens* Elles and Wood, 1907; Bassler (1935) briefly described the brachiopod *Sowerbyella lebanonensis* Bassler, 1935, and two ichnofossil species; and Troost (*in* Wood, 1909), Springer (1911), Schuchert (1912), and Ulrich (1925), each described or reported an echinoderm species (for details see "Echinoderm Fauna" and "Systematic Paleontology"). Safford (1869), Coryell (1921), Bassler (1932), and Wilson (1949) all provided faunal lists for the Lebanon Limestone, but taxonomic revisions of many taxa, especially bryozoans, corals, sponges and arthropods, are needed for such lists to be meaningful. A large macrofossil collection made during this study contains over 120 species, many of which are previously unrecorded and undescribed. At least 10 genera of trilobites were collected, of which only three were included in previous faunal lists. Because of these problems, no compendium of species from the Lebanon Limestone is provided here. Macrofossil groups are discussed below, however, and relative abundances (i.e., abundant, common, uncommon, rare) of taxa within groups are based upon field observations. Abundances given are rough approximations only. *Abundant* indicates that many specimens of the taxon in question can be collected from most exposures in the Central Basin of Tennessee. *Common* indicates that several specimens can be collected from each exposure in the study area. *Uncommon* indicates fossils that are widespread over the study area, but occur in small numbers and require intensive search to find. *Rare* fossils are those of which only a few specimens were found; these usually occur only at one or two localities. Field impressions of abundances gathered here are biased in favor of specimens that tend to be most visible on bedding planes or that easily weather free, such as brachiopods, bryozoans, trilobites, and echinoderms. Whole fossils or well-preserved fossils were usually collected in favor of fossils that were broken or poorly preserved. A deliberate effort was made to collect rare or unusual specimens and, therefore, actual numbers of specimens in collections are also biased.

Sponges.—Poriferans are common in the Lebanon Limestone; there are a minimum of four genera, including 1 stromatoporoid. Calcisponges are uncommon in the lower member of the Lebanon Limestone at localities Z-651, Z-652, Z-654, and other non-listed localities. One calcisponge is tentatively identified as *Zittelella* Miller, 1889 (Bassler, 1932). Bennedict (1974) found abundant pyritized hexacton sponge spicules in the *Sowerbyella - Diplograptus* Zone of the upper member, Lebanon Limestone.

Corals.—Corals are usually rare to locally common (at the top of the Lebanon Limestone at locality Z-651). At least two genera of tabulates including *Foerstephyllum* Bassler, 1941, and *Tetradium* Dana, 1846, and two kinds of solitary rugosans including *Streptelasma* Hall, 1847, are present. Fragments of conularids are rare in shaly interbeds.

Bryozoans.—Bryozoans are abundant and diverse; at least 20 species occur in the Lebanon Limestone. Ptylodictyoids (bifoliate cryptostomes) are probably numerically most abundant. The thin ribbon-like (basally articulated and non-articulated) genera such as *Stictopora* Hall, 1847, and *Escharopora* Hall, 1847, are most abundant. Large species with ribbon-like, foliose, and reticulate growth modes also occur. Other common to abundant cryptostomes include arthrostylids, of which articulated genera such as *Arthroclema* Billings, 1865, and *Ulrichostylus* Bassler, 1952, are most common. Fenestrate bryozoans are represented by common phylloporinids, of which at least two species are represented. Trepostome bryozoans are common and diverse. Most forms have a massive or low encrusting growth habit; a few species with erect dendroid growth habit are also present. Common trepostome genera (Bassler, 1932) include *Homotrypa* Ulrich, 1882, *Nicholsonella* Ulrich, 1889, *Ceramoporella* Hall, 1851, and *Monticulipora* d'Orbigny, 1849a. Both cystoporate and cyclostome bryozoans were rarely encountered.

Brachiopods.—Inarticulate brachiopods are rare to uncommon. At least three genera are represented, including *Acanthocrania* Williams, 1943 (two species), *Conotreta* Walcott, 1889, and *Lingulops* Hall, 1872. Articulate brachiopods are abundant; Cooper (1956) lists 22 species and 18 genera. Strophemenids are the most abundant order and include *Strophemena* de Blainville, 1825, *Oepikina* Salmon, 1942, and *Sowerbyella* Jones, 1928. Orthids are also abundant, particularly *Doleroides* Cooper, 1930; other common orthids include *Pionodema* Foerste, 1912, *Hesperorthis* Schuchert and Cooper, 1931, *Skenidioides* Schuchert and Cooper, 1931, and *Multicostella* Schuchert and Cooper, 1931. Abundant rhynchonellids and spiriferids include *Rostricellula* Ulrich and Cooper, 1942, and *Zygospira* Hall, 1862, respectively.

Mollusks.—Mollusks are common to locally abundant. Most occur as poorly preserved molds or sparfilled casts in fine-grained matrices, making identification difficult. Gastropods are locally abundant and diverse. Common genera (from Bassler, 1932) include *Maclurites* Le Sueur, 1818, *Subulites* Emmons, 1842, *Phragmolites* Conrad, 1838, *Lophospira* Whitfield, 1886, and others. Bivalves are rare; one unidentified species, at least, is represented. Cephalopods are uncommon; forms include a large endocerid and small nautiloids.

Trilobites.—Trilobites are common and diverse although complete or near complete specimens are very rare. At least 10 genera were identified during this study. The most common genera appear to be ?*Ceraurus* Green, 1832, *Isotelus* DeKay, 1824, *Encrinurus* Emmrich, 1844, *Illaenus* Dalman, 1827, *Thaelops* Conrad, 1843, and *Dolichoharpes* Whittington, 1949.

Other faunal elements.—The graptolite, *Diplograptus multidens* Elles and Wood, 1907 (*see* Hofstetter, 1965a), is abundant in and confined to the *Sowerbyella - Diplograptus* Zone, upper member, Lebanon Limestone. One specimen of a possible dendroid graptolite was found in the upper member at locality Z-653. Cornulitids are rare. Scolecodonts (annelid jaw parts) are common and locally abundant.

Trace fossils.—Burrows are common to abundant in the Lebanon Limestone. Most within limestone beds tend to retain their shape whereas those in shaly interbeds are typically flattened by compaction. Most appear to be horizontal or subhorizontal irregular feeding structures. Feeding burrows (*Phycodes* Richter, 1850) are locally common as are vertical dwelling burrows. Other trace fossils include *Cruziana* d'Orbigny, 1842, and several unidentified trails or burrows. Bennedict (1974) has noted possible fungal borings in brachiopod fragments from biocalcirudite lithofacies (lithofacies 4).

Flora

Calcareous algae are common in the Lebanon Limestone. Several types were observed in thin sections or reported from thin sections by Bennedict (1974), including the blue-green alga *Girvanella* Nicholson and Etheridge, 1880, which is locally abundant, and the red alga *Solenopora* Dybowski, 1877, and two or more green algae including *Vermiporella* Stolley, 1893, which are uncommon but widespread. Fragments of *Nidulites* Salter, 1851, are uncommon in hand samples, and a single specimen each of a calathid alga and an undetermined large (?)alga were found.

Echinoderm Fauna

Disarticulated echinodermal debris is one of the dominant constituents in the Lebanon Limestone; articulated specimens are uncommon overall and only locally common, however. Approximately 300 partial to complete echinoderms were collected during this study. Most articulated specimens were collected from the lower member between 4 and 12 m above the contact between the Lebanon and Ridley limestones. Other specimens are from the upper member, particularly the *Sowerbyella - Diplograptus* Zone. No specimens were found in the massive member. Specimens occur both as isolated individuals and in clusters. Approximately 80 percent of the echinoderms studied are from localities Z-651, Z-652, Z-654, Z-654a, and Z-655; approximately one-third of all specimens were found in a shaly interbed at locality Z-654a (see below). Disarticulation of fossils precluded determination of stratigraphic ranges within the Lebanon Limestone for most species. *Archaeocrinus snyderi* n. sp., *Cleiocrinus tessellatus* (Troost, *in* Wood, 1909), *Quinquecaudex* sp. A, and *Porocrinus lebanonensis* n. sp. range throughout most of the Lebanon Limestone. *Praepleurocystis ranaformis* n. sp. was not found above the *Sowerbyella - Diplograptus* Zone, upper member, and *Praepleurocystis* sp. cf. *P. watkinsi* (Strimple, 1948) was not observed at or below this horizon.

Four species of echinoderm previously described from the Lebanon Limestone of central Tennessee include three crinoids and a single sea star. Previously described crinoids include *Cleiocrinus tessellatus* (Troost, *in* Wood, 1909), *Cleiocrinus laevus* Springer, 1911, and *Columbicrinus crassus* Ulrich, 1925. Schuchert (1915) referred a Lebanon Limestone asteroid to *Hudsonaster narrawayi* (Hudson, 1912). At least 40 species and 32 genera of Lebanon Limestone echinoderms were identified during this study. The complete list of known Lebanon Limestone echinoderm species is as follows:

Class Crinoidea
- *Cleiocrinus tessellatus* (Troost, *in* Wood, 1909)
- *Cleiocrinus laevus* Springer, 1911
- *Cleiocrinus springeri* n. sp.
- *Reteocrinus variabilicaulis* n. sp.
- *Reteocrinus polki* n. sp.
- *Reteocrinus fenestratus* n. sp.
- *Reteocrinus* sp. cf. *R. variabilicaulis*
- *Reteocrinus* sp.
- *Gustabilicrinus plektanikaulos* n. gen. et sp.
- *Gustabilicrinus latomium* n. sp.
- *Archaeocrinus snyderi* n. sp.
- *Abludoglyptocrinus gregatus* n. sp.
- ?*Diabolocrinus* sp. A
- Rhodocrinitid sp. A
- Rhodocrinitacid sp. A
- *Apodasmocrinus* sp. cf. *A. daubei* Warn and Strimple, 1977
- *Cremacrinus* sp. cf. *C. punctatus* Ulrich, 1886
- *Columbicrinus crassus* Ulrich, 1925
- *Doliocrinus monilicaulis* n. sp.
- *Tryssocrinus endotomitus* n. gen. et sp.
- *Tornatilicrinus longicaudis* n. gen. et sp.
- *Anomalocrinus antiquus* n. sp.
- *Hybocrinus bilateralis* n. sp.
- *Carabocrinus* sp.
- *Porocrinus lebanonensis* n. sp.
- *Cupulocrinus* sp. cf. *C. gracilis* (Hall, 1847)
- *Cupulocrinus* sp.
- *Quinquecaudex* sp. A

Class Paracrinoidea
- *Oklahomacystis trigonis* n. sp.
- *Oklahomacystis* sp. aff. *O. trigonis* n. sp.

Class Rhombifera
- *Tanaocystis sprinklei* n. sp.
- *Praepleurocystis ranaformis* n. sp.
- *Praepleurocystis* sp. cf. *P. watkinsi* (Strimple, 1948)
- *Amecystis nanus* n. sp.

Class Asteroidea
- *Hudsonaster* sp. cf. *H. narrawayi* (Hudson, 1912)
- *Salteraster* sp. cf. *S. grandis* (Meek, 1872)
- juvenile *Salteraster* sp.
- *Schuchertia darwini* n. sp.

Class Edrioasteroidea
- ?*Edrioaster* sp. A
- ?*Cyathocystis* sp.
- indeterminate isorophid

Class Echinoidea
- *Unibothriocidaris kieri* n. sp.
- ?*Unibothriocidaris* sp.
- *Bothriocidaris vulcani* n. sp.
- ?*Neobothriocidaris* sp.

The Lebanon Limestone echinoderm fauna is dominated by camerate and disparid inadunate crinoids. Dominant camerate genera include *Archaeocrinus* Wachsmuth and Springer, 1881, *Reteocrinus* Billings, 1859, *Gustabilicrinus* n. gen. (Anthracocrinidae), and *Abludoglyptocrinus* Kolata, 1982; thick-plated rhodocrinitids are conspicuously scarce (only ?*Diabolocrinus* sp. A is known). The most often encountered and widespread disparid inadunate is *Columbicrinus* Ulrich, 1925. Pleurocystid rhombiferans and amygdalocystid paracrinoids are also locally found.

DEPOSITIONAL ENVIRONMENT

The lithology, primary sedimentary structures, trace fossils, flora, and fauna of the Lebanon Formation indicate a well-lit, normal marine, subtidal environment of moderate energy. Depth ranged from mean low water to 20 or 30 m. Sediment was primarily locally-derived, biogenically-precipitated calcareous debris with minor amounts of clay derived from outside the depositional area. The origin of the lime mud is largely unknown but some is micritized fossil skeletal fragments. Both physical and biological processes were important influences on fabric and texture in the Lebanon Limestone. Abundant broken and well-rounded current laminated or bedded bioclastic debris and local oncolites indicate considerable reworking of sediment before final burial. Transport mechanisms included waves (perhaps storm-generated), as indicated by abundant symmetrical ripples and megaripples, and poorly channelized bottom currents, as indicated by lenses of coarse to fine, poorly- to well-sorted, often cross-laminated or cross-bedded bioclastic debris (Bennedict, 1974; pers. observ.), and current ripples. Intervals dominated by calcilutites and few associated bioaccumulated limestones were likely areas of quieter water deposition, perhaps in subtle topographic lows or where significant baffling from plants or animals occurred, because low current energies would have allowed lime mud to settle. Bioturbation was important, particularly in pellet and pelletoid calcarenite and calcilutite microfacies, and in the shaly interbeds. Bioturbation produced some of the common mixed lithologies and pellets in the Lebanon Formation, and also contributed to the breakage of fossils.

Firm, perhaps cemented substrates were common in the Lebanon Limestone; these substrates are primarily developed on calcarenites and calcirudites and the associated substrate topography varies from irregular to subplanar. Evidence indicating firm or cemented substrates includes holdfasts or entire colonies of ptylodictyoid or trepostome bryozoans, encrusting holdfasts, attachment discs of echinoderms (crinoids and edrioasteroids), and vertical borings (*Trypanites* Mägdefrau, 1932). In addition, intraclasts of various lithologies including calcarenites are common, indicating partial cementation before reworking. Insofar as can be compared, the fauna of the firm substrates is similar to the faunas of "hardgrounds" reported by Palmer and Palmer (1977) from the Trentonian Galena Group of Iowa, and by Brett and Liddell (1978) from the Trentonian Bobcaygeon Limestone near Kirkfield, Ontario.

Depositional conditions apparently varied only slightly with time. The massive member is lithologically similar to the upper Ridley Limestone and possibly the lower Carters Limestone (immediately below and above the Lebanon, respectively, and represents a brief time of decreased clastic input and dominant pellet and pelletoid deposition. The *Sowerbyella - Diplograptus* Zone was deposited during times of slightly increased clastic input.

The estimated paleobathymetric range of mean low water to roughly 20 to 30 m is derived from the combined overlap of known physical and biological indicators present in the Lebanon Limestone (see Bennedict and Walker, 1978, p. 583 for a summary table of Paleozoic bathymetric indicators). The most diagnostic such indicators in the Lebanon Limestone are megaripples, oncolites, and an abundant flora containing blue-green, red, and green algae.

TAPHONOMY OF AN ECHINODERM ASSEMBLAGE

Observations.—A remarkably large and diverse faunule of relatively complete invertebrates, including many echinoderms, was recovered from a dolomitic shale interbed in the lower member of the Lebanon Limestone along Interstate Route 65 near Columbia, Tennessee (loc. Z-654a). The taphonomy of this horizon is here evaluated in an attempt to better understand this unique occurrence, and the living and death conditions of the echinoderms.

The well-preserved echinoderms were collected along a 7 m horizontal interval exposed in a highway cut. The distribution of the highly fossiliferous part of the interbed probably was restricted. Although the interbed continues along the west side of the highway for at least 150 m, no complete specimens were observed beyond the 7 m interval. Further, only four less complete specimens from the same horizon were collected on the east (opposite) side of the highway. Although some specimens had weathered free of the matrix, most material was found on small quarried slabs. Because accessible bedding surfaces were discontinuous and relatively few, only approximately 1.5 m^2 of slab surface could be collected and it was impossible to reconstruct a large surface area.

The fossil-bearing interbed averages 1 to 3 cm thick. The well-preserved fossils occur in the thickest part of the interbed, in which the lithology is non-laminated, burrow mottled, dark grey, dolomitic shale. Dolomite content increases toward both upper and lower contacts of the interbed and is the dominant constituent immediately adjacent to both contacts. The dolomite is authigenic, consisting of discrete well-formed rhombs displacing and surrounded by clay. The interbed clay mineralogy was not determined. The interbed also contains abundant small fragments of both organic debris and calcareous skeletal elements (Pl. 15, fig. 1). Small amounts of finely-disseminated pyrite and occasional secondary gypsum occur along weathered surfaces.

Directly below the interbed is a poorly-sorted intraclastic oncolite biocalcirudite with a sparite and micrite matrix (Pl. 15, fig. 1). The interface between the shaly interbed and the calcirudite below is sharp but poorly exposed. Poor exposure is a result of the large amount of weathering-resistant dolomite in the lower part of the shaly interbed that adheres to the interface below. The interface is slightly irregular and covered with bioclastic debris. No sign of intensive scouring is present. A few of the fossils within the shaly interbed are impressed into the calcirudite, indicating this layer was not completely lithified at the time of deposition. The overlying bed is a poorly-sorted biocalcirudite with a calcilutite matrix and has a sharp interface with the interbed below.

The distribution and orientation of fossils within the interbed is important to understanding their taphonomy. Whole fossils and fossil debris in the interbed are concentrated just above the lower interface; fossils rarely contact the interface itself. Thus material in the interbed is crudely graded. No fossils in the interbed were found attached to the underlying calcirudite. Large and small fossils of various taxa are mixed indiscriminately, with two exceptions (discussed below). The distribution of fossils is uneven, with some slabs having several specimens, whereas roughly equal areas of other slabs have few. Fossils apparently are not current-oriented. Long crinoid columns, with crowns attached, often cross one another at nearly right angles. A few fossils are preserved in orientations that clearly do not represent living positions. For example, trepostome bryozoan fragments lie on crinoid crowns, and one large sea star, *Salteraster* sp. cf. *S. grandis* (Meek, 1872) is inverted over a crinoid crown. Only two fossils in the interbed were obviously in life position: small specimens of *Doleroides* Cooper, 1930, commonly are preserved in small clusters of approximately 10 to 15 specimens and distal columns of *Gustabilicrinus* n. gen. are often found wrapped around the columns of other crinoids.

The condition of the fossils, particularly that of the echinoderms, varies greatly. A few crinoids are essentially complete skeletons with articulated crown, column, and holdfast. Most specimens, however, are partially dismembered and (or) slightly disarticulated. Dismemberment occurs in different ways and varies in extent. For example, many crinoids and paracrinoids are complete except for arms or arm tips whereas others are reduced to parts of cups with attached arms, column sections, or isolated arms with attached partial to complete pinnules, or armlets. Dismembered parts, particularly thin-plated cup fragments, are common. These can be broken across, rather than along, plate boundaries. Specimen completeness generally is related to organism type. The relatively sturdy disparid inadunates, including *Tryssocrinus* n. gen. and *Columbicrinus* Ulrich, 1925, and the stout-plated camerate *Reteocrinus* Billings, 1859, are typically little dismembered or disarticulated. Most specimens of *Hybocrinus* Billings, 1857, and *Oklahomacystis* Parsley and Mintz, 1975, possess complete calices (thecae), but their columns and arms are partial or missing. Thin-plated crinoids, however, such as the camerate *Gustabilicrinus* n. gen. and the inadunate *Carabocrinus* Billings, 1857 typically were reduced to partial cups, crowns, or isolated column segments. Fragments of dismembered and disarticulated specimens are isolated, without missing parts lying nearby, suggesting disruption occurred before final burial. In addition to being dismembered and slightly disarticulated, many echinoderms are in distorted positions. No fossils from the interbed show signs of pre-burial mechanical abrasion.

Sand- or silt-sized calcareous fossil debris is common in the interbed. Identifiable fragments primarily are smaller pieces of the more complete fossils: *Doleroides* Cooper, 1930, and echinoderm plates are particularly common.

Subhorizontal feeding burrows are common in the interbed. They are light grey rather than the dark grey of the surrounding rock and vary from approximately 5 to 10 mm in maximum diameter. Burrows rarely disrupt fossils even though they often occur among them. A few burrows are filled with bioclastic debris.

Many fossils and all burrows were flattened by compaction. Burrows average five times wider than high; assuming that these were originally circular, this shape suggests considerable compaction occurred after the time of burrowing (presumably shortly after deposition). Crinoid columns and thick-plated calices such as those in the disparid inadunates are typically uncrushed, and occasionally have small-scale slickensides caused by compaction of adjacent clay.

Some specimens, though well preserved overall, show corrosion on surfaces that contact the subjacent limestone bed. Corrosion is most prevalent in thin-plated or pore-bearing genera, including *Cleiocrinus* Billings, 1857, *Carabocrinus,* and *Oklahomacystis.* Associated finely-disseminated pyrite suggests the corrosion took place in reducing microenvironments.

Interpretations.—The interbed fossils of sessile organisms were torn from their attachment sites. They are often dismembered but only slightly disarticulated and none of the fossils are attached to the substrate below; holdfasts are always broken or torn loose. Thus, the fossils must have been transported before burial.

The Lebanon Limestone depositional environment apparently was well oxygenated and presumably contained many scavenging organisms. The exceptional completeness of many echinoderms and other interbed fossils reflects rapid deposition, shortly after detachment from life sites. Taphonomic studies of modern echinoderms particularly well illustrate this. For example, Liddell (1975) and Meyer (1971), among others, have studied postmortem decay and disarticulation of modern crinoids and found this to be rapid, requiring from one to six days for complete disarticulation under well-oxygenated conditions. Delicate skeletal structures such as cirri or pinnules can be lost only a few hours after death whereas more rigidly articulated elements such as cup plates require much longer. The apparent lack of mechanical size sorting and current orientation of fossils, as well as concurrent deposition of nonlaminated clay and other fine particles indicate quiet water deposition. Coarser particles, including the fossils, are concentrated near the bottom of the interbed, indicating specific gravities and settling velocities at the time of deposition averaging slightly greater than clays in the interbed. After burial, the fossils remained largely undisturbed by burrowing.

The most reasonable causal agent for the interbed is a storm. A storm could provide sufficient energy to detach, dismember the creatures and transport them with accompanying fine sediment. A rapid energy decrease such as occurs after a storm passes would account for the absence of both current orientation and size sorting, as well as the occurrence of the fossils in a single thick clay blanket and the crude graded bedding of the interbed. The rapid deposition under such circumstances would help explain the exceptional preservation. The faunule is thus considered to be a transported death assemblage (*sensu* Craig and Hallam, 1963). The postulated tropical Lebanon Limestone paleoenvironment was shallow enough to be affected by major storms (see "Depositional Environment"), and the paleolatitude of 20 to 25°S compares well with latitudes of worldwide modern tropical storm tracks (Jordan, 1966).

Few observations concerning the living relationships of the interbed assemblage can be made because of its disrupted nature. Biases acting upon the assemblage may have included selective removal, transport, and mixing of various life assemblages. Evidence from fossils in the interbed, as listed below, suggests a single life assemblage is represented.

1. There is no apparent size sorting of fossils.

2. The most abundant and diverse megafossils in the Lebanon Formation are the brachiopods and bryozoans. In contrast, brachiopods and bryozoans in the interbed have low diversities but high abundances. (See bryozoans and brachiopods under "Fauna other than Echinoderms," herein, for partial listing of many species from the Lebanon Limestone.) Approximately seven species of bryozoans, including two arthrostylids, two bifoliates and three trepostomes, and a single brachiopod species (*Doleroides* sp.) were found in the interbed. Mixing of the Lebanon Limestone assemblages would presumably have produced a much greater diversity of these groups.

3. The life modes of the various interbed fossils is compatible insofar as can be determined. Nearly all interbed echinoderms appear to have lived fixed to a firm substrate. An exception, the sea star *Salteraster* sp. cf. *S. grandis* (Meek, 1872), was probably vagrant. At least four crinoid genera possessed small discoid encrusting holdfasts. *Doleroides* was pedically attached and bryozoans were either attached by smaller cemented holdfasts (*e.g.*, arthrostylids, bifoliates) or simply were cemented to or rested on the substrate (*e.g.*, trepostomes). Other bottom-dwelling groups present in the interbed include at least one unidentified trilobite, annelids (represented by scolecodonts), and conularids (fragments), all of which probably could have occupied a firm substrate. Organisms thought to have inhabited soft bottoms, such as crinoids with rootlike holdfasts and strophomenid brachiopods such as *Oepikina* Salmon, 1942 and *Strophomena* de Blainville, 1825, are absent from the interbed. Strophomenid brachiopods are abundant in the Lebanon Limestone as a whole.

The occurrences of distal columns of *Gustabilicrinus* n. gen. coiled about columns of other crinoids, and small specimens of *Doleroides* Cooper, 1930, in clusters, are preserved remnants of probable living occurrences of these organisms. The *Doleroides* cluster attachment sites (?algal) are no longer preserved and apparently decayed after burial.

AGE AND CORRELATION

Information from both brachiopods and conodonts suggests that the Lebanon Limestone belongs in the upper part of the Middle Ordovician Blackriveran Stage. Based on their conodont faunas, Sweet and Bergström (1976, p. 133) suggested the following as approximate lateral equivalents to the Lebanon Limestone (see Table 1): the upper Pooleville Member of the Bromide Formation, Oklahoma, the Camp Nelson Formation, central Kentucky, the Glenwood Formation of Iowa and Minnesota, and the Watertown Formation of the type Blackriveran section in New York. Based on brachiopods, Cooper (1956, p. 102 and chart 1) assigned the Lebanon Limestone to his Wilderness Stage [early Trenton or latest Blackriveran] and listed the Witten Formation (uppermost Ottosee Group) of east Tennessee, possibly the Rockland (Selby, in part) Formation of New York, and the Grand Detour Formation of Illinois as approximate lateral equivalents (see Table 1).*

A single graptolite, *Diplograptus multidens* Elles and Wood, 1907, has been identified in the Lebanon Limestone. This species ranges from the Blackriveran through the middle Trentonian- (Kirkfieldian) age rocks (Sweet and Bergström, 1976, p. 134) in North America and also occurs in the upper Dalbyan and lower Moldan stages in Sweden. These two Swedish stages have been correlated with the Idaverian and Jöhvian stages in Estonia (Jaanussen, 1976, p. 320).

The Lebanon Limestone echinoderm fauna is similar to several previously described Blackriveran and classical Trentonian faunas. Although most similarities are at the generic level, many species are clearly closely related as well.

The Blackriveran Bromide Formation of Oklahoma (see Sprinkle, 1982a) contains a large number of genera and probably one species (*Apodasmocrinus daubi* Warn and Strimple, 1977) in common with the Lebanon Limestone (see Table 2). In addition, two Lebanon Limestone species, *Archaeocrinus snyderi* n. sp. and *Columbicrinus crassus* Ulrich, 1925, appear to be closely related to *Archaeocrinus subovalis* Strimple, 1953, and *Columbicrinus sulphurensis* (Frest, Strim-

* The Trenton Stage, retained here, has in recent years been subdivided by some workers into three stages; Rockland, Kirkfield, and Sherman, from oldest to youngest. In addition, the latest Trenton, or Cobourg Substage, is considered by these workers as the basal Edenian Stage. These new terms are here included in parentheses for further clarity when possible.

Table 1.—Correlation of selected Champlainian (Black River and Trenton) units (modified from Sweet and Bergström, 1976, and Cooper, 1956). The Hull Member of the Ottawa Formation is equivalent in age to the Kirkfield and Bobcaygeon limestones (not shown) of the Kirkfield, Ontario area.

SERIES	STAGE	CENTRAL TENNESSEE		UPPER MISSISSIPPI VALLEY		SOUTH CENTRAL OKLAHOMA		EAST TENNESSEE-SOUTHWEST VIRGINIA		SOUTHEAST ONTARIO-NORTHERN NEW YORK		CENTRAL KENTUCKY	
CHAMPLAINIAN	TRENTON	HERMITAGE FORMATION		GALENA GROUP						OTTAWA FORMATION	COBOURG MEMBER	LEXINGTON LIMESTONE	
CHAMPLAINIAN	TRENTON	HERMITAGE FORMATION		GALENA GROUP						OTTAWA FORMATION	SHERMAN FALL MEMBER	LEXINGTON LIMESTONE	
CHAMPLAINIAN	TRENTON	HERMITAGE FORMATION	CURDSVILLE MEMBER	GALENA GROUP						OTTAWA FORMATION	HULL MEMBER	LEXINGTON LIMESTONE	CURDSVILLE MEMBER
CHAMPLAINIAN	TRENTON			GALENA GROUP	DECORAH SUBGROUP								
CHAMPLAINIAN	BLACK RIVER									SELBY FORMATION			
CHAMPLAINIAN	BLACK RIVER	STONES RIVER GROUP	CARTERS LIMESTONE	PLATTEVILLE GROUP									
CHAMPLAINIAN	BLACK RIVER	STONES RIVER GROUP	CARTERS LIMESTONE	PLATTEVILLE GROUP	GRAND DETOUR FORMATION			OTTOSEE GROUP	WITTEN FORMATION	WATERTOWN FORMATION			
CHAMPLAINIAN	BLACK RIVER	STONES RIVER GROUP	LEBANON LIMESTONE	PLATTEVILLE GROUP	MIFFLIN FORMATION	BROMIDE FORMATION	POOLEVILLE MEMBER	OTTOSEE GROUP	WARDELL FORMATION			CAMP NELSON FORMATION	
CHAMPLAINIAN	BLACK RIVER	STONES RIVER GROUP	RIDLEY LIMESTONE	GLENWOOD FORMATION		BROMIDE FORMATION	MOUNTAIN LAKE MEMBER	OTTOSEE GROUP	BENBOLT FORMATION				
CHAMPLAINIAN	BLACK RIVER	STONES RIVER GROUP	PIERCE LIMESTONE			BROMIDE FORMATION	MOUNTAIN LAKE MEMBER	OTTOSEE GROUP	BENBOLT FORMATION				
CHAMPLAINIAN	BLACK RIVER	STONES RIVER GROUP	MURPHREESBORO LIMESTONE			BROMIDE FORMATION		OTTOSEE GROUP					

ple, and McGinnis, 1979), respectively, from the Bromide Formation. Camerate crinoids, rhombiferans, and echinoids, most closely resemble forms occurring in the upper or Pooleville Member of the Bromide Formation whereas the long-armed disparid inadunates better correlate with forms from the lower or Mountain Lake Member. Overall, the closest resemblance seems to be with Pooleville Member forms.

Lebanon Limestone echinoderms are also similar to those of the Blackriveran Platteville Group and overlying early Trentonian (Rocklandian) Decorah Subgroup of the upper Mississippi Valley (Kolata, 1975; Brower and Veinus, 1978; see Table 2). Similarities are greatest with the Platteville Group because *Cupulocrinus gracilis* (Hall, 1847), *Abludoglyptocrinus* Kolata, 1982, *Quinquecaudex* Brower and Veinus, 1982, *Praepleurocystis* Paul, 1967a, ?*Tanaocystis* Sprinkle, 1982b, and *Unibothriocidaris* Kier, 1982, are known only in this interval.

The mid to late Trenton faunas from the Hull, Sherman Falls, and Cobourg members of the Ottawa Formation and equivalent units, southeast Ontario, are similar to the Lebanon Limestone faunas (Table 2). Most species from the two areas, however, do not appear to be closely related. Both rhombiferans and paracrinoids from the Trenton faunas are generically distinct.

The Lebanon Limestone fauna shows few similarities with nearby Blackriveran to (?)Chazyan-age formations of the Ottosee Group (Benbolt, Hogskin, Lincolnshire, and Wardell formations) and related rocks in east Tennessee and southwest Virginia (Table 2). The east Tennessee faunas are characterized by thick-plated rhodocrinitids such as certain species of *Archaeocrinus* Wachsmuth and Springer, 1881, and *Diabolocrinus* Wachsmuth and Springer, 1897, hybocrinids (of which *Hybocrinus* Billings, 1857, is most common), and platycystitid paracrinoids, which are represented by *Platycystites* Miller, 1889, and allied forms. Of these, only *Hybocrinus* is present in the Lebanon Limestone.

The stratigraphic distribution of echinoderms within other formations of central Tennessee and adjacent areas aids in determination of the age of the Lebanon. The Pierce Limestone is the second unit below the Lebanon in the Stones River Group of the study area. Three echinoderms identified thus far from this unit are *Paleocrinus* sp. (Bassler, 1932), *Hybocrinus punctatus* (Miller and Gurley, 1895), and *Diabolocrinus* sp. (Brower and Veinus, 1974); all three taxa are known

Table 2.—Occurrence of Lebanon Limestone echinoderm taxa and related species in Eastern North America.

Region; approximate age; stratigraphic unit / Classes / Genera / Species	Upper Mississippi Valley (from Kolata, 1975) Blackriveran, Platteville Gr.	Upper Mississippi Valley (from Kolata, 1975) Trentonian, Galena Gr. including Decorah Subgr.	Arbuckle Mountains South Central Oklahoma (from Sprinkle, 1982e) Blackriveran Bromide Fm., Mountain Lake Mbr.	Arbuckle Mountains South Central Oklahoma (from Sprinkle, 1982e) Blackriveran Bromide Fm., Pooleville Mbr.	East Tennessee–Southwest Virginia (mainly from Brower and Veinus, 1974) Chazyan–Blackriveran, Ottosee Group; Benbolt Fm. and other fms.	Southeast Ontario (from Wilson, 1946; Springer 1911) Trentonian, Ottawa Fm. and other fms.	Central Tennessee (Original, herein) Blackriveran, Lebanon Limestone
Crinoidea							
Abludoglyptocrinus							
A. spp.				X		X	
*A. gregatus**							X
*A. charltoni**	X						
Archaeocrinus							
A. spp.			X		X	X	
*A. snyderi**							X
*A. subovalis**				X			
Apodasmocrinus							
A. spp.					X		
A. daubi			X				X
Carabocrinus spp.	X	X	X		X	X	X
Cleiocrinus							
C. spp.	? X[1]				X	X	
*C. laevus**							X
*C. bromidensis**			X	X			
Columbicrinus							
*C. crassus**							X
*C. sulphurensis**			X				
Cremacrinus							
C. spp.	X	X		X		X	
*C. punctatus**		X					X
*C. sp.**[2]							
Cupulocrinus							
C. spp.	X	X				X	
C. gracilis	X						X
Doliocrinus spp.			X				X
Hybocrinus spp.		X	X	X	X	X	X
Porocrinus							
P. spp.	X			X		X	
*P. lebanonensis**							X
*P. elegans**		X					
Quinquecaudex spp.	X			X			X
Reteocrinus spp.	X	X	X			X	X
Paracrinoidea							
Oklahomacystis spp.			X				X
Rhombifera							
Tanaocystis spp.	? X			X			X
Praepleurocystis spp.	X			X	X		X
Amecystis spp.		X			X	X	X
Asteroidea							
Hudsonaster spp.	X		X				X
Salteraster spp.						X	X
Schuchertia spp.						X	X
Edrioasteroidea							
Edrioaster spp.		X	? X			X	X
Cyathocystis spp.			X	X	X		X
Echinoidea							
Unibothriocidaris							
U. sp.[3]	X						
*U. bromidensis**				X			
*U. kieri**							X
Bothriocidaris							
B. spp.				X			
*B. solemi**	X						
*B. vulcani**							X
Neobothriocidaris spp.	X	X					X

[1] Undescribed specimen of Kolata (oral commun., 1981).
[2] *Cremacrinus* sp. of Kolata (1975, p. 24).
[3] = genus and species unknown of Kolata (1975, p. 68).
* Denotes closely related species within the genus.

from the Ottosee Group of east Tennessee and similar forms occur in the Mountain Lake Member of the Bromide Formation, Oklahoma. The Curdsville Limestone Member of the Lexington Limestone of Kentucky extends to the edges of the Central Basin, where it is only 0.5 to 3 m thick and is referred to as the Curdsville Member at the base of the Hermitage Formation. The Hermitage is the second formation above the Lebanon and is the basal unit of the Nashville Group, which is separated from the Stones River Group by an unconformity (Wilson, 1949). The Curdsville, therefore, is significantly younger than the Lebanon. The Curdsville Member in Kentucky has produced a diverse echinoderm fauna that, among other species, includes *Amygdalocystites florealis,* Billings, 1854, *Cupulocrinus jewetti* Billings, 1859, *Reteocrinus alveolatus* Miller and Gurley, 1894, *Carabocrinus radiatus* Billings, 1859, and *Paleocrinus angulatus* Billings, 1857, all of which are also known from the mid to late Trenton of Ontario.

Based on echinoderms from the Lebanon Formation, and from overlying and underlying formations, the Lebanon seems to be middle to late Blackriveran in age. The Lebanon Limestone faunas are clearly older than those of the Trentonian of Kentucky and Ontario and younger than most of the Ottosee Group of east Tennessee and the Mountain Lake Member of the Bromide Formation, Oklahoma. This age is in approximate agreement with correlations based on conodonts (Sweet and Bergström, 1976), and is approximately equivalent to slightly older than correlations based on brachiopods (Cooper, 1956).

SYSTEMATIC PALEONTOLOGY

INTRODUCTION

The classification, arrangement, and terminology of echinoderms used herein are as listed below. Class division and arrangement only is from Sprinkle (1980, p. 26). Crinoid classification follows part T of the *Treatise on Invertebrate Paleontology* except that the Archaeocrinidae is rejected (see Kolata, 1982) and the classification of the Disparida is accepted, but with reservations (see Remarks, Order Disparida). In addition, the term "interradial," rejected in the *Treatise,* is retained herein for use with certain camerate crinoids. Paracrinoid classification and terminology follow Parsley and Mintz (1975). Glyptocystid rhombiferans are classified and described after Sprinkle (1982b), and pleurocystid rhombiferans after Parsley (1970), except that quotes are deleted from certain oral and radial plate acronyms. Sea stars (Asteroidea) are not classified to order (*see* Remarks, Class Asteroidea); Spencer and Wright (1966) were followed for familial and generic classifications and the terminology is after Blake (1973; oral commun., 1980–1981). Edrioasteroids were classified and described following Bell (1976, 1980). Echinoid classification and terms are from Durham (1966) and Kier (1982).

Because crinoids are numerically the most common and taxonomically the most diverse echinoderm class in the Lebanon Limestone, this group was the most intensively studied. Many species fit well into pre-existing classifications; a few species and higher level taxa, however, required emendation or redescription. Suprageneric revision of the Disparida, although needed, was not undertaken during this study. Nearly all non-crinoid echinoderms were readily incorporated into existing classifications. One sea star specimen, however, was described. Sea star orders were not revised, although this also is badly needed.

Exact synonymies are given for the various previously described taxa. Only the most important synonyms are typically listed; in particular, bibliographic (such as Bassler and Moodey, 1943) and other short references are commonly omitted.

Explanations of acronyms used in the taxonomic section are given in Table 12.

PHILOSOPHICAL CONSIDERATIONS

The modern biological concept of a species is based on an organism's having the potential to interbreed and produce fertile offspring in natural conditions. Modern metazoan species are thus nearly always readily defined (clines and ring species are problems). This concept is, of course, untestable using fossils and fossil species are defined by comparative methods utilizing preserved parts. Modern relatives aid in development of criteria for recognition of fossil species. The species concept in paleontology is therefore somewhat arbitrary but nevertheless does offer a reasonable approximation of biological species boundaries. Further, this system is amenable to criticism and revision. (For a detailed discussion of fossil species and their relationship to modern species, *see* Raup and Stanley, 1978.)

Species concepts adopted in this monograph are those established by early workers and generally followed by modern students of fossil echinoderms. The echinoderm skeleton, due to its unique articulated construction and complexity, serves as an excellent and primary taxobasis within this diverse group. In few (perhaps no) other phyla is the nature of the overall morphology, soft part anatomy, and functional morphology so well revealed by hard (preservable) parts alone. Indeed the nature of the skeleton is a primary taxobasis for modern echinoderms as well as for fossils, and studies of recent species confirm the overall usefulness of the skeleton for differentiating species as well as higher taxa (*see, e.g.,* Clark, 1915; Fisher, 1911). Characters most commonly of taxonomic value are: thecal (or body) shape; position and nature of openings and appendages, and plate morphology, number, arrangement, size and ornament. New species (and higher level taxa) are herein based on clear consistent differences from preexisting taxa in one or more of these characters, though plate ornament alone is generally not a good taxobasis. The overall goal of the following taxonomic section is to approximate, as well as possible, biological species for the Lebanon echinoderms. I consider my taxonomic assignments to be near the midrange in the spectrum of modern workers' species philosophies, between those known either as "lumpers" or "splitters."

Fossil echinoderms are rarely complete, and specimens are few. This is a major hindrance to their study. The typical excellent preservation, and relatively large assemblages of Lebanon Limestone echinoderms offer a rare opportunity for such detailed observations.

Abbreviations of Repository Institutions

All specimens collected during this study are reposited in the collections of the Department of Geology, University of Illinois. Acronyms and addresses of other cited specimen repositories are listed below:

BMNH:	Burpee Museum of Natural History, Rockford, IL
FM (UC):	Walker Museum Collection, Field Museum of Natural History, Chicago, IL
GSC:	Geological Survey of Canada, Ottawa, Ontario, Canada
MCZ:	Museum of Comparative Zoology, Harvard University, Cambridge, MA
SUI:	University of Iowa, Iowa City, IA
UC:	University of Cincinnati Geology Museum (Kopf Collection), Cincinnati, OH
UI X:	University of Illinois, Urbana, IL
USNM:	United States National Museum, Washington, DC
USNM S:	United States National Museum (Springer Collection), Washington, DC

Subphylum **CRINOZOA** Matsumoto, 1929

Class **CRINOZOA** Miller, 1821

Subclass **CAMERATA**
Wachsmuth and Springer, 1885

Order **DIPLOBATHRIDA**
Moore and Laudon, 1943

Suborder **ZYGODIPLOBATHRA** Ubaghs, 1953

Family **CLEIOCRINIDAE** Miller, 1889

Genus **CLEIOCRINUS** Billings, 1857

Type species.—*Cleiocrinus regius* Billings, 1857, p. 276.

Cleiocrinus tessellatus (Troost)
Plate 1, figures 3, 5–9, 11–17, 19–21

Campanulites tessellatus Troost, 1849, p. 419 (*nom. nud.*).
Cleiocrinus tessellatus (Troost). Wood, 1909, p. 100, pl. 7, fig. 11.

Diagnosis.—A species of *Cleiocrinus* characterized by large, elongate, steep-sided conical to funnel-shaped cup; cup sides diverging at approximately 10 to 30° from vertical at level of **IBrr**, then flaring slightly, usually at level of **IIBr**$_{2,3}$, to approximately 25 to 35°. Cup plates flat to slightly convex. Exospires of parallel rows of tiny pores forming subrhombic to subpolygonal patterns at plate surfaces; small central area of plates usually without pores.

Description.—Cup moderately large, conical, steep cup sides diverge at approximately 10 to 30° from vertical at level of **IBrr**$_1$, then usually flare slightly to 25 to 35° approximately at level of **IIBrr**$_{2,3}$, flare can reach 45°, at least, adorally. Lower cup shape varies from round, without median ray ridges to subpentagonal, with low median ray ridges; ridges usually disappear by **IIIBrr**. Lower cup plates thickened, tightly articulated, possibly ankylosed, sutures indistinct. Lower anal series can be slightly protuberant (UI X-5902; Pl. 1, fig. 20). Cup plates usually flat, can be slightly convex; sutures usually flush, can be slightly impressed.

Exospires externally of subequally-spaced parallel rows of tiny pores; pore rows perpendicular to, bisected by, and abutting across plate sutures; forming subrhombic or other subpolygonal patterns on plate surfaces. Pore rows lead internally to slit-like channels (Pl. 1. figs. 5, 7, 12, 16); channels oblique to plate surfaces (usually about 45°). Alternating thick and thin vane-like walls separate channels; thin walls extend only a short distance internally so that channels separated by thin walls merge below (Pl. 1, fig. 16), thick walls extend below to main body of plate, except at plate margins. Channels open along plate margins into interarticular canals. Canals formed equally by opposing articulating plates, expanding toward plate corners; canal can be continuous across facet face forming low inverted V-shape in lateral view, or divided at center of facet face into two separate halves. Canals connected to coelomic cavity *via* subcircular to suboval pores at inner plate corners.

Inside of cup with wide, radially-positioned grooves; these extending axially down each ray, and ray bifurcation. Pores, connecting to exospires, open on ridges between grooves (Pl. 1, fig. 13).

External plate surfaces with indistinct stellate pattern formed by non-pore-bearing plate centers, narrow rays radiating to plate corners; in some specimens additional rays extend to midpoints between plate corners; rays abut across adjacent plates. Plate centers small, usually approximate plate outline in shape, slightly convex to flat; can have fine, faint, subconcentric ridges and grooves, small shallow central depression divided by low vertical ridge. Uncommonly, specimens have non-pore-bearing centers, no distinguishable rays. Articulation surfaces between cup plates finely crenulate (Pl. 1, fig. 7).

IBB five, wider than tall in one specimen where visible, confined to basal concavity; axial canal large, subpentagonal. Columnal articular surface forms faint to prominent notch in basal concavity; either smooth or with faint radially disposed crenulae. **BB** five, small, apparently subpentagonal to suboval, wider than tall; alternating with **RR** that form a circlet of ten plates, at least; circlet projects over, below **IBB**. One specimen (UI X-5902) appears to have supernumerary plates intercalated into basal-radial circlets. **RR** small, subpentagonal, wider than tall, widest distally, much smaller than **IBrr**. **IBr**$_{1,2}$ axillary, wider than tall. Succeeding axillaries known on **IIBrr**$_{4-6}$ and **IIBr**$_7$. **IIBrr** slightly wider than tall to nearly as tall as wide. Proximal anal plates known in one specimen (UI X-5902; Pl. 1, fig. 21); subhexagonal, arranged in vertical row. Anal plates 1, 2 (counting from base of cup) wider than tall, anal plate 3 about as wide as tall. Distal cup, free arms, tegmen known.

Column long, tapering proximally; wide to very wide in preserved columnals, ratio of height to width varies from approximately 1:5 to 1:8; columnals 7 to 9 mm in diameter, cup column articular facets 4 to 5 mm in diameter indicating proximal column of this width. Columnals straight-sided, smooth to pitted (pitted surfaces could be weathered). Columnals of pentameres; pentameres articulate laterally along crenulate margin; zygum divided into outer narrow crenularium, wider attenuated inner areola. Areolae with vermicular ridges and grooves, confluent with crenulae ridges and grooves. Shallow, triangular, smooth-bottomed notches interrupt crenulae, areola ridges and grooves; notches bisected by pentamere articulations. Lumen large, subpentagonal, pentagon corners at mid-points of pentameres. Holdfast unknown.

Discussion.—*Cleiocrinus regius* Billings, 1857, and *C. magnificus* Billings, 1859, both from the latest Trentonian Cobourg Member, Ottawa Formation, Ontario, differ most conspicuously from *C. tessellatus* in that the former has well-developed median ray ridges and external exospires of short channels (slits), whereas the latter has a larger, wider, more rapidly expanding cup. *C. sculptus* Springer, 1911, from the middle Trentonian (Kirkfieldian) Curdsville Limestone, Kentucky, and *C. springeri* n. sp. from the Lebanon Limestone, both differ in having highly ornamented cup plates with distinctly raised plate centers. The poorly known *C. ornatus* Kolata, 1982, from the Blackriveran Pooleville Member, Bromide Formation, Oklahoma, differs in having exospires of rows of channels rather than pore rows. Deeply weathered *C. tessellatus* plates show a pattern of channels similar to that in *C. ornatus* (compare pl. 16, figs. 11, 12 of Kolata, 1982, with Pl. 1, fig. 16). *C. laevus* Springer, 1911, also from the Lebanon Limestone, *C. perforatus* Hudson, 1911, from the Chazyan Valcour Limestone, New York, and *C. bromidensis* Kolata, 1982, from the Bromide Formation all have exospires of pores along sutures only.

Three crown fragments of *C. tessellatus* from different localities were found associated with similar column segments of large diameter; no other identifiable echinoderms were associated with these specimens. Further, the morphology is similar to that of specimens of *C. regius* (Springer, 1905, pl. 1, fig. 3). These column fragments are therefore considered to belong to *C. tessellatus*; they indicate a heteromorphic, proximally tapering column. Final confirmation, however, must await discovery of an attached crown and column.

Cleiocrinus libanus Safford, 1869 (p. 285; *nom. nud.*), was placed in synonymy with *C. tessellatus* by Bassler and Moodey (1943, p. 365). Safford's material is now missing (Alberstadt, oral commun., 1980), making verification of Bassler's identification impossible.

Types and occurrence.—The holotype, USNM 39910, is from an unspecified horizon in the Lebanon Limestone along the Duck River near Columbia, Maury County, Tennessee. Twenty-one hypotypes include UI X-5894 through 5911, 5917; USNM 166816; and USNM 42271. UI X-5894 is from the upper member at locality Z-653. UI X-5895, 5899, 5902, and 5903 are all from the lower member at locality Z-651 and UI X-5904 through 5907 are from the upper member at locality Z-651. UI X-5896 is from the lower member at locality Z-654a and UI X-5908 is from the lower member at locality Z-654. UI X-5898, 5899, and 5909 are all from the lower member at locality Z-652. UI X-5900 and 5901 are both from the lower member at locality Z-656 and UI X-5910, 5911 are from the lower member at locality Z-658. USNM 42271 is from an unknown horizon in the Lebanon at Shelbyville, Tennessee, and USNM 166816 is from an unspecified horizon in the Lebanon northwest of Woodbury, Cannon

County, Tennessee. Figured specimens are the holotype USNM 39910 and hypotypes UI X-5895, 5897, 5898, 5900, 5902, 5903, 5908, 5917; USNM 42271 and 166816.

Cleiocrinus springeri new species
Plate 2, figures 4, 8, 9

Etymology of name.—The specific nomen honors Frank Springer, well-known student of fossil echinoderms.

Diagnosis.—A species of *Cleiocrinus* characterized by a steep-sided, conical cup. Cup plates highly ornamented, having high relief; exospires externally of rows of parallel, discontinuous slit-like channels forming subrhombic to subpolygonal patterns on plate surfaces; cup plate margins upraised slightly, centers protuberant, without slits; ridges radiate off plate center protuberances toward plate corners, most abut across plates.

Description.—Cup moderately large, tall, funnel-shaped (Pl. 2, figs. 8, 9); expansion angle approximately 10° from vertical at level of **IBr**$_1$, expanding to approximately 20 to 30° at level of **IIIBrr**. Basal concavity wide. Cup plates with prominent ornament (Pl. 2, fig. 4), high relief; plates of lower part of cup thick, tightly sutured (perhaps fused), plate boundaries obscure. Exospires of discontinuous channel-like slits separated by irregular vane-like walls. Slits perpendicular to, bisected by, or abutting across sutures; forming subrhombic or other subpolygonal patterns on plate surfaces. Slits increase in size, decrease in frequency proximally on cup; approximately 60 slits per 5 mm on **IIIBr**$_3$, approximately 30 slits per 5 mm on distal **IBr**$_1$ margin. Plate margins forming elevated ridges along plate sutures. Plate centers protuberant, without slits, roughly approximating plate outline in shape; ridges radiate from protuberances toward and often abut across plate corners; smaller ridges commonly radiate from protuberances at right angles to plate faces.

IBB apparently five, boundaries obscure. **BB** five, alternate in circlet of ten plates with **RR**; apparently small, shape uncertain. **RR** five, small, much smaller than **Brr**; each with wide medial vertical ornamenting ridge, single depression on either side. **IBrr**$_1$ apparently axial, pentagonal, much wider than tall. **IIBr**$_4$ axillary; **IIBrr** wider than tall. Proximal **IIIBrr** wider than tall; cup unknown beyond **IIIBr**$_4$. Anal plates known through anal plate 10, form vertical series. Anal plates 1 to 5 wider than tall; anal plates 5 to 10 taller than wide. Tegmen, arms, column unknown.

Discussion.—The new species closely resembles *C. tessellatus* (Troost, *in* Wood, 1909), also from the Lebanon Limestone, in cup shape and plate arrangement. The new species differs most conspicuously, however, in possessing prominent cup plate relief including central protrusions and upraised margins. *C. sculptus* Springer, 1911, from the Trentonian Curdsville Limestone of Kentucky differs from *C. springeri* n. sp. in having a much wider basal concavity and non-raised plate margins. The new species differs from all other species in possessing discontinuous pore slits and high plate relief.

The E ray side of the holotype was buried facing downward, touching the bedding plane below. This area has undergone differential dissolution, obliterating plate relief (Pl. 2, fig. 8). The degree of dissolution decreases gradually away from the E ray and is inversely proportional to distance from the bedding plane.

Type and occurrence.—The holotype and only known specimen, UI X-5918, a partial cup, is from the lower member, Lebanon Limestone, at locality Z-654a.

Cleiocrinus laevus Springer
Plate 2, figures 1–3, 6, 7; Text-figure 3

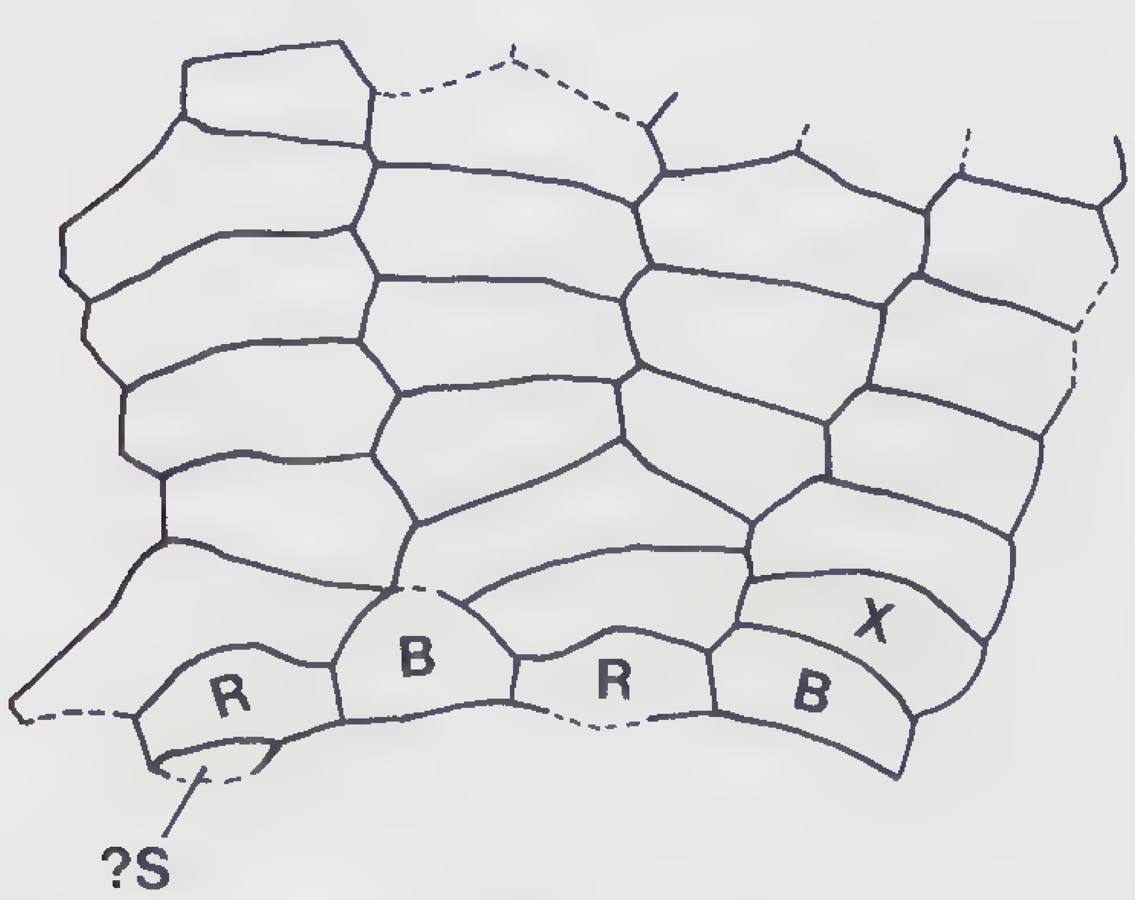
Cleiocrinus laevus Springer, 1911, p. 44, pl. 5, figs. 11a–c.
Cleiocrinus tessellatus (Troost). Bassler and Moodey, 1943, p. 365.
Cleiocrinus tessellatus (Troost). Ubaghs, 1978b, fig. 174, nos. 6–8.

Diagnosis.—A species of *Cleiocrinus* characterized by a rapidly expanding funnel-shaped cup (Pl. 2, figs. 1, 2, 6, 7); expansion angle of about 10 to 20° from vertical at level of **BB-RR** circlet, increasing to about 60 to 70° at **IIIBrr**. Exospires of rows of pores along plate sutures, about 18 pores per 5 mm at level **BB-RR** circlet, increasing to about 37 pores per 5 mm at level of **IIIBrr**. Plates nearly flat with very fine, irregular, anastomosing, concentric ridges and grooves. **BB-RR** circlet forms thin attenuated collar extending downward over proximal column.

Emended description.—Aboral cup rapidly expanding funnel (Pl. 2, figs. 1, 2, 6, 7), expansion angle about 10 to 20° from vertical at level of **BB-RR** circlet, increasing to about 60 to 70° at level of **IIIBrr**. Exospires of rows of sutural pores (Pl. 2, fig. 3), about 18 pores per 5 mm at level of **BB-RR** circlet, increasing to about 37 pores per 5 mm at level of **IIBrr**; pores extend internally to interarticular canals. Two canals per plate facet, each extends internally and laterally from near midpoint of facet to nearest corner. Canals connect at plate corners to large pores, which open in inside of cup. Inside of cup with wide grooves extending longitudinally out each ray, and ray bifurcation. Large pores enter inside of cup in high areas between grooves. Lower cup obscurely subpentagonal, with faint median ray ridges. Plates nearly flat except for ray ridges, with fine irregular anastomosing subconcentric ridges and grooves (Pl. 2, fig. 3). **Brr** can have shallow central depression divided by vertical ridge, faint grooves extending in stellate pattern away from plate centers. Basal concavity large, subround in outline.

IBB five (damaged in available material), deeply inset in basal concavity, wider than either **BB** or **RR**; column articular facet with fine crenulae; circlet undulant, with highs adjacent to **RR**. Narrow shallow channel between articular facet, **BB-RR** circlet. **BB**, **RR** each five, alternate in circlet of 10 plates, forming attenuated collar projecting downward over anteriormost column; lower edge of collar with **RR** projecting slightly farther downward than **BB**. **BB** subpentagonal, usually wider than high, can be about as wide as high; size variable, average slightly larger than **BB**. **RR** wider than high, subpentagonal. Small wedge-shaped ?supernumerary plate below E ray **R** in holotype. $\mathbf{IBr}_{1,2}$ axillary, $\mathbf{IBr}_1$ axillary in B and D rays of holotype. **IBrr** much wider than high, lateral margins usually diverge rapidly distally to accommodate rapid cup expansion. $\mathbf{IBrr}_2$ inverted V-shape. $\mathbf{IIBrr}_{3\text{ or }4}$ axillary; **IIBrr** much wider than tall. Secundaxillaries subpentagonal, usually with slight indentation along lower margin. Proximal **IIIBrr** wider than tall. Anal plates form single vertical row; anal plates 1 to 5 much wider than tall, anal plate 6 wider than tall. Distal cup, tegmen, arms, column, holdfast unknown.

Discussion.—*C. laevus* is distinguished from most other species of *Cleiocrinus* by its exospire openings of sutural pores. Both *C. bromidensis* Kolata, 1982 from the Blackriveran Bromide Formation, Oklahoma and *C. perforatus* Hudson, 1911 from the Chazyan Valcour Limestone, New York have similar exospire morphologies. The former differs from *C. laevus* in having a relatively smaller basal concavity, a less attenuated **BB-RR** circlet, and a more regular arrangement of fine concentric ridges and grooves on cup plates. The latter species is known only from a few patches of apparently deeply weathered cup plates; it appears to differ from *C. laevus* in possessing fewer, larger sutural pores.



Text-figure 3.—*Cleiocrinus laevus* Springer, drawing of lower part of cup. Shows CD interray (right), D ray (center), and E ray (left) of holotype (USNM 50045); ?S = possible supernumerary cup plate, approximately ×4.

Types and occurrence.—Only the holotype, USNM 50045, was available for study and is refigured here. Springer (1911) lists the specimen as being from an unspecified horizon of the Lebanon at Shelbyville, Bedford County, Tennessee.

columns of **Cleiocrinus** species
Plate 1, figures 1, 2, 10, 25

Remarks.—Two column fragments are here assigned to *Cleiocrinus* sp. Both were found as isolated specimens. Generic assignment is based on great similarity of morphology to fragments assigned to *C. tessellatus* (Troost *in* Wood, 1909) from the Lebanon and *C. regius* Billings, 1859, and *C. magnificus* Billings, 1859, both from the Trenton of Ontario (Billings, 1859, pl. V, figs. 1, 3; Springer, 1905, pl. 1. figs. 1–3, 12). The zygum morphology of column fragments assigned to *C. tessellatus* is distinctive and unlike that of any other known Lebanon crinoid (see *Cleiocrinus tessellatus* description herein). The fragments assigned here have similar zygal morphology but differ in other details. UI X-5916 (Pl. 1, figs. 10, 25) differs from column segments assigned to *C. tessellatus* in having a subpentagonal column outline, a smaller column diameter (6.8 mm), a slightly smaller columnal height to width ratio of about 1:10, and columnals with slightly concave latera at angles of subpentagonal outline. UI X-5915 (Pl. 1, figs. 1, 2) differs in having a wider column diameter (about 12 mm), a subpentagonal column outline, a much smaller columnal height to width ratio of about 1:20, and small lens-shaped ossicles intercalated at irregular intervals between columnals, approximately at mid-points between lateral articulations of pentameres. The column in *C. regius* is heteromorphic and it is probably also heteromorphic in *C. tessellatus* (see *Remarks* under *C. tessellatus*); one or both fragments could therefore belong to the latter species, and the differences in morphology could reflect only position along the column. UI X-5915 bears a strong similarity to distal column in *C. regius* (compare Pl. 1, figs. 1, 2 with pl. 1, fig. 3e of Springer, 1905). It is also possible that the fragments belong to another Lebanon species of *Cleiocrinus,* either *C. springeri* n. sp. or *C. laevus* Springer, 1911. The column is unknown in both of these rare species. These column fragments are therefore not specifically assignable.

The two column fragments also differ in that UI X-5915 has lateral pentamere articulations at the angles of the subpentagonal column, whereas the articulation points of UI X-5916 are midway between the angles.

Types and occurrence.—Figured specimens UI X-5916 and UI X-5915 are from the lower member, Lebanon Limestone, at localities Z-656 and Z-652, respectively.

holdfasts of ?**Cleiocrinus** species
Plate 1, figures 4, 18

Remarks.—Four encrusting holdfasts are here tentatively assigned to *Cleiocrinus*. All are large, varying from 30 to 43 mm in maximum diameter. The specimens have a low to high cone-shaped upper surface; UI X-5914 is nearly round in outline, UI X-6012 is suboval, and UI X-5912 and UI X-5913 (Pl. 1, fig. 18) are subround with short lobate radicles. Upper surfaces are composed of very thick, flat or near flat, tightly sutured, flush, subpolygonal plates. UI X-5914 (Pl. 1, fig. 4) and UI X-6012 have a thin lower disc with numerous radiating septa extending upward into the holdfast lumen. All specimens have a large holdfast lumen; none of the specimens has a well-preserved column facet. The column lumen diameter was apparently large, approximately 10 to 20 mm.

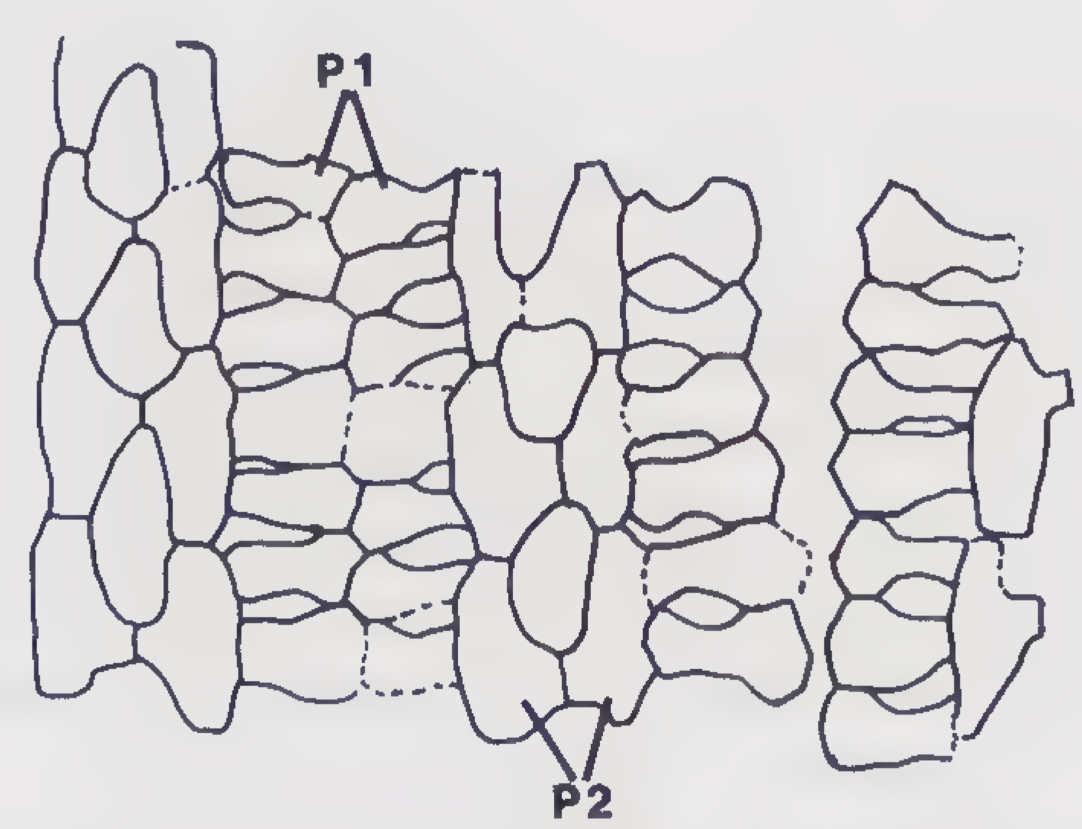
Generic assignment is based on large size and similar morphology to holdfasts of *Cleiocrinus regius* Billings, 1859, from Trenton rocks of Canada (Springer, 1905, pl. 1, figs. 3a–3e). Upper surfaces in all species as well as the basal disc morphology in UI X-5914 and UI X-6012 are also very similar to those of *Cleiocrinus* sp. from the middle Trentonian Bobcaygeon Limestone, Ontario (Brett and Liddell, 1978, p. 339, fig. 6). The distalmost column lumen in the Lebanon specimens appears to have been very wide (about 10 to 20 mm), indicating a wide distal column. *Cleiocrinus* is the only Lebanon echinoderm known to have possessed a distal column and lumen of such large diameter. The Lebanon specimens are also similar to those of Brett and Liddell in having variable morphology of the holdfast, depending on the substrate topography. UI X-5914 (Pl. 1, fig. 4) is attached to a relatively flat substrate and is circular in outline without short lobate extensions. In contrast, UI X-5913 (Pl. 1, fig. 18) has short lobate extensions that conform to the irregular topography upon which it attached.

Types and occurrence.—UI X-5913 is from the (?)upper member of the Lebanon Limestone at locality Z-661; UI X-5912 and UI X-5914 are from the lower member, Lebanon Limestone at localities Z-656 and Z-658, respectively; and UI X-6012 is from the upper member, Lebanon Limestone, approximately one m above the massive member at locality Z-651. UI X-5913 and UI X-5914 are figured.

?tegmen of ?**Cleiocrinus** species
Plate 1, figures 22–24; Text-figure 4

Description.—Fossil shape low, conical, with rounded subcentral apex; outline subcircular. Fossil constructed of tightly sutured, possibly locally fused array of at least two basic types of small plates that enclose internal network of tunnels (Pl. 1, fig. 22). Plates relatively massive toward cone apex, thinning toward periphery. Tunnels ovate to subcircular in cross-section, radiating from apex and bifurcating at least three or four times distally, approximately (?)five tunnels near apex and approximately 100 about periphery. Tunnels decrease in diameter from approximately 1.0 mm at center apex to 0.5 mm near periphery; spaced at intervals equal to or slightly wider than tunnel widths. Cone apex damaged, features obscure. Small subcircular area developed adjacent to apex constructed of small closely packed, thick plates (Pl. 1, fig. 24).

Exposed surface other than small subcircular area of above constructed of two plate types (Text-fig. 4). Type 1 arranged in alternating to nearly opposing biseries that covers tunnels. Type 2 arranged in opposing biseries of attenuated wall-forming plates above and between tunnels. Type 1 plates transversely elongate, dumbbell-shaped, abutting medially above tunnels along a straight or more commonly zigzag surface. Type 1 plate medial constrictions producing longitudinal rows of sutural pores along each row of the biseries; pores apparently opening into tunnels below. Type 2 plates forming peaked walls; each **T**-shaped as seen from above; each abuts laterally along short arm with opposing type 2 plate, forming **H**-shaped pair; opposing plate pairs connected longitudinally in series to form ladder-like pattern with deep subrectangular to



Text-figure 4.—?tegmen of ?*Cleiocrinus* sp., tracing of portion of specimen. Type 1 plates (P1) cover tunnels, articulate laterally with type 2 plates (P2); approximately ×4.5.

suboval depressions in gaps between plates. Type 1 plates tightly abut type 2 plates approximately above lateral margins of tunnels; articulation location alternates from mid-point of each type 2 plate longitudinal wall to point of contact between adjacent longitudinal walls of type 2 plates.

Remarks.—The radiating pattern of enclosed tunnels in this fossil is unlike other echinoderms, but resembles the internal ambulacral tracts in many camerate crinoids in which the ambulacral grooves and ambulacral plates are found below the outer plate surface along the inner side of the tegmen. Some camerates have subcircular tubes comprised of numerous plates that extend from the arm bases along the inside of the tegmen and probably contained the food grooves (Ubaghs, 1978b, p. T179). Tunnels in the ?tegmen described here are similarly thought to have been food grooves. Sutural pores between type 1 plates are inferred to have been communication avenues (for respiration, nutrients, or nervous tissue?) to supply tissues lining the tunnels. The small subcircular area of closely packed plates adjacent to the central area might, by analogy with camerate crinoids, have been the anal structure. The large number of equally spaced tunnels arrayed about the margin of the ?tegmen likely reflects the arrangement of arms about the calyx. Among the known Lebanon crinoids only *Cleiocrinus* possesses such an arm arrangement. The large size of the ?tegmen is also compatible for *Cleiocrinus.* Final evaluation must await discovery of an associated dorsal cup and tegmen.

The exposed side of this fossil is presumed to be internal because of the exposed complicated framework containing numerous pores, deep depressions, and attenuated walls. Channels were revealed by polishing a vertical surface broken through the side of the specimen. Plates are generally tightly sutured, possibly fused. Gaps in the specimen most often occur as fractures through plates rather than along their margins. The morphology and preservation of the specimen, therefore, suggest that it formed a rigid structure that offered protection and support for the network of radiating tunnels at the top of the calyx. The specimen shows no sign of significant distortion due to compaction.

The occurrence of this ?tegmen as an isolated entity is unusual. A partial explanation may be found in the fact that the edges of the specimen are thin, indicating a zone of relative weakness. The adoral part of the cup and arm bases in Lebanon species of *Cleiocrinus* have never been found despite the relatively large number of lower cup portions, suggesting fragile construction near the arm bases.

The ?tegmen morphology is superficially suggestive of the inside of the aboral cup in *Cleiocrinus.* It differs most conspicuously in its slightly concave shape (which would literally require the specimen to be turned inside out if it were a cup), the absence of a central axial canal at the apex, which would be the column position if the fossil were an aboral cup, and the presence of internal tunnels rather than the open grooves typical of *Cleiocrinus* cups (Pl. 1, fig. 22).

Types and occurrence.—The figured single specimen, UI X-5919, is from the lower member, Lebanon Limestone, approximately 8 m above the base of the Lebanon at locality Z-652.

Suborder **EUDIPLOBATHRINA** Ubaghs, 1953

Superfamily **RHODOCRINITACEA** Roemer, 1855

Family **RETEOCRINIDAE**
Wachsmuth and Springer, 1885

Diagnosis.—Calyx obconical, bilaterally symmetrical across the A/CD plane. Calyx with strong median ray ridges. Arms uniserial, pinnulate or non-pinnulate. Anal area with prominent sagittal anal series. Interbrachial areas depressed, filled with numerous small plates.

Discussion.—Ubaghs (1978a, p. T414) lists three genera in the Reteocrinidae; *Reteocrinus* Billings, 1859, and *Traskocrinus* Kolata, 1975, from the Middle Ordovician and *Gaurocrinus* Miller, 1883, from the Upper Ordovician. As discussed under *Remarks* on *Reteocrinus, Traskocrinus* is here synonymized with *Reteocrinus. Gaurocrinus* differs from *Reteocrinus* in being pinnulate and in not having either interbasal or interinfrabasal gaps. In addition, *Gaurocrinus* has proportionately smaller **IBB** and fewer arm branchings.

Genus **RETEOCRINUS** Billings, 1859

Type species.—*Reteocrinus stellaris* Billings, 1859.

Diagnosis.—A reteocrinid with steep-sided to widely flaring convex-sided cup; sides of cup with greatest curvature approximately at level of radials. Major cup plates large, deeply cleft (*i.e.,* multilimbed), forming prominent reticulated framework with interbasal gaps (spaces between major cup plates), small gaps or depressions on primary plate surfaces in interinfrabasal areas. Interbasal gaps, possibly interinfrabasal gaps (when present), interbrachial areas, occupied by small, irregular, loosely articulating plates. Secondary plate fields depressed below level of primaries; apparently embedded in flexible integument in life (Kolata, 1975, p. 47; Brower, 1974, p. 23). Posterior crown of large pentaxial basal followed by prominent sagittal anal series extending nearly to top of, and confluent with, tegmen where known. Tegmen vaulted, sac-like, flexible; not known to extend beyond arm tips. Arms non-pinnulate, branching isotomously at least three times. Column round or pentagonal; where known, lumen usually wide, quinquelobate. Articulae cryptosymplectial.

Description.—A reteocrinid with small to large adult crown, cup nearly straight-sided, steeply conical to widely flaring, convex-sided with greatest curvature approximately at level of **RR**. Major cup plates deeply cleft (*i.e.,* multilimbed), forming prominent reticulate framework, with gaps in interbasal areas, with depressions or small gaps in interinfrabasal areas; plates evenly rounded, somewhat flattened, or slightly distended. Keels may radiate from plate centers onto plate limbs, and may abut keels from adjacent plates. Other surface ornamentation can be smooth, reticulated, striated, or warty. **RR** and **Brr** can bear lateral projections that extend into interbrachial areas. **IBB** five, relatively large, open **U**-shaped in species with interinfrabasal depressions, low **x**-shaped in species with interinfrabasal gaps. One small plate can occupy interinfrabasal gaps. **BB** five, large, **x**-shaped; commonly higher than wide, wider distally than proximally. CD **B** pentiaxial with distal vertical extension supporting primanal. Each **B** articulates with two **iBB**, two **RR**, numerous small interbasal, **iBr** plates. **BB** form sides of interbasal gaps, bottom of interbrachial areas, upper margin of interinfrabasal depression or gap. Interbasal gaps generally large, filled with small, depressed plates similar to those in interbrachial areas. **RR** five, with low, inverted **Y**-shape, each articulates with two **BB**, **IBr**$_1$, small interbasal, interbrachial plates. **RR** form upper margin of interbasal gap, lower margins of interbrachial area. Posterior of prominent tall sagittal anal series extending nearly to top of tegmen where known. Proximal anals usually resemble primibrachs in size, shape, but can be smaller. Anal series generally symmetrically disposed in CD interray, confluent with tegmen, bordered on either side by depressed interbrachial fields. Arms non-pinnulate, branching isotomously at least three times. **IBrr**$_{1-6}$, or rarely **RR**, axillary. Interbrachial areas depressed, filled with small, loosely articulating plates, confluent with tegmen; apparently imbedded in a flexible integument in life. Tegmen vaulted, sac-like, not known to extend beyond arm tips; web-like extensions connect to sides and ventral surfaces of arms (Kolata, 1975, p. 47). Anal opening on tegmen near top of anal series (Kolata, 1975, p. 47; Pl. 5, fig. 4). Column round or pentagonal, ?homeomorphic or xenomorphic, usually broad. Columnals heteromorphic, often thin, highly varied in some species, can be constructed distally of pentameres. Articulations cryptosymplectic or rarely ankylosed; lumen quinquelobate where observed, terminations radially disposed. Column can terminate as multiplated subconical encrusting holdfast.

Discussion.—*Reteocrinus* is now known from 10 species, three of which are new. Characters most useful in species recognition include shape of aboral cup, plate ornament, nature of interinfrabasal areas, shape of **IBB**, number of **IBrr**, and column features. Characters less consistently useful are the shape and relative size of the **RR** and **BB**, size of the interbasal gaps, size and shape of the anals, and nature of the **iBrr** plates. Known species of *Reteocrinus* are compared in Table 4.

Terminology for the lateral projections found on the **RR** and **Brr** of many *Reteocrinus* species varies among authors. These have been called *lateral buttresses* (Springer, 1911, p. 11), *sharp girders* (Raymond, 1931, p. 203), and *lateral spines* (Kolata, 1975, p. 45). Because these are apparently homologous structures, they are here all referred to as *lateral projections* and are differentiated by adding modifiers (*e.g.,* wedge-shaped, hemispherical, etc.). This new terminology is used because none of the previously used terms describe all of the shapes seen.

Traskocrinus Kolata, 1975 was first described as a monotypic genus whose principal diagnostic character was considered to be the presence of large interbasal gaps filled with small plates similar to those present in the interbrachial areas. In reexamining type and topotype specimens of all species of *Reteocrinus,* I found proportionately large interbasal gaps similar to those in *Traskocrinus* in all species except *R. depressus* Kolata, 1982, and *R. rocktonensis* Kolata, 1975, and relatively smaller gaps in these species. This finding differs from that of Wachsmuth and Springer (1883, p. 262–263, fig. 1; 1897, p. 178), who thought that *Reteocrinus* had interbasal depressions rather than gaps. Subsequently, Ubaghs (1978a, p. T414) described *Reteocrinus* as generally having spaces (*i.e.,* gaps) in the infrabasal areas. I have identified plates in the interbasal gaps similar to those in the interbrachial areas in *Reteocrinus stellaris* Billings, 1859 (the type species of *Reteocrinus*), *R. alveolatus* Miller and Gurley, 1894, *R. polki* n. sp., and *R. variabilicaulis* n. sp. I further believe that most or all of the remaining species of *Reteocrinus* had such plates because the interbasal gaps and adjacent cup plates are similar among all species of *Reteocrinus.* Incomplete preservation or highly indurated matrices in the available material precludes conclusive determination of this point in *R. depressus* Kolata, 1982, *R. elongatus* Raymond, 1931, *R. fenestratus* n. sp., *R. rocktonensis* Kolata, 1975, and *R. spi-*

Table 3.—Measurements (in mm) of specimens of *Reteocrinus* from the Lebanon Limestone.

	Crown height	Cup height at tops of **RR**	Cup width at tops of **RR**	**IB** Height	**IB** Width	**B** Height	**B** Width	**R** Height	**R** Width	Column diameter at base of cup
R. fenestratus										
UI X-5690	—	9.5	8.9*	2.9	3.6	3.9	3.4	3.9	3.4	—
UI X-5695	—	—	—	2.9	3.4	3.2	2.9	3.2	2.9	—
R. variabilicaulis										
UI X-5805	39	6.3	9.5*	1.6	2.9	3.0	2.5	2.6	2.9**	4.3
UI X-5411	42	7.5	11*	2.7	4.0	4.0	3.4	3.4	3.8	6.8
UI X-5412	28	7.7	4.9*	1.2	2.1	2.6	2.0	2.1	2.0	3.7
UI X-5409	20	4.6	6*	1.2	2.1	2.6	2.2	2.4	2.8	4.0
R. polki										
UI X-5790	41	10	20*	—	—	5.1	4.8	4.8	5.0	10.4*
UI X-5417	22	5.2	9*	1.2	2.1	2.6	2.2	2.4	2.8	4.0
UI X-5413	—	—	—	2.8	4.9	4.4	4.2	—	—	—
R. sp.										
UI X-5416	23	5	—	1.5	2.8	2.7	2.4	2.6	2.5	3.7
R. sp. cf. *R. variabilicaulis*										
UI X-5414	30	7.2	9*	1.7	2.7	—	—	2.8	2.8	3.8

* = estimated.
** = abnormal.

nosus Kolata, 1975. Each of these species is known from one to three specimens.

Other characters used in the definition of *Traskocrinus* include the number of **IBrr** per arm and crown size. Primibrach number in *Traskocrinus* lies within the range found within two species assigned to *Reteocrinus, R. spinosus* and *R. rocktonensis* (see Table 3). Primibrach number is a variable feature and has been used as a species characterization in *Reteocrinus* (Kolata, 1975, p. 41; Raymond, 1931, p. 203; herein). The crown of the one known specimen assigned to *Traskocrinus* is about 50% larger than that of any specimen traditionally assigned to *Reteocrinus.* Crown size among largest specimens of known species of *Reteocrinus* ranges from about 25 to well over 50 mm, a factor over 100% (Table 4). Size, therefore, seems to provide a weak generic criterion. Because of these similarities, I judge *Traskocrinus* and *Reteocrinus* to be congeneric and *Traskocrinus,* therefore, is herein synonymized with *Reteocrinus.*

The ontogeny of *Reteocrinus* is poorly known. The maximum range in crown size of a *Reteocrinus* species, in *R. polki* n. sp., is from 22 to 60 mm. Significant size ranges are also known from *R. alveolatus* Miller and Gurley, 1894 (see Springer, 1911, pl. 1, figs. 1–5) and *R. variabilicaulis* n. sp. (Table 2). Growth in *Reteocrinus* was anisometric. Smaller specimens typically differ from the larger ones in that multilimb extensions of primary cup plates, cup gaps and (or) depressions, and plate ornamentation, particularly the lateral projections on the **RR** and **Brr**, are disproportionately small. In species having a pentagonal column, the column increases in angularity with size. Branching increases at an essentially constant rate later in ontogeny and therefore branches are fewer in number in smaller specimens. Identification of smaller specimens can be difficult because features that develop late in ontogeny are often those most useful in species recognition.

Intraspecific variation is important in *Reteocrinus.* As summarized under the descriptions, all characters used for species definition were found to vary within populations (*e.g., R. polki* n. sp. and *R. variabilicaulis* n. sp.).

In addition to the three new species described here, the type species, *Reteocrinus stellaris* Billings, 1859, is herein redescribed. Remarks concerning the descriptions of several other species, including *R. alveolatus* Miller and Gurley, 1894, *R. elongatus* Raymond, 1931, *R. mahlburgi* (Kolata, 1975), and *R. spinosus* Kolata, 1975, are also provided. Specimens of *R. alveolatus* and *R. elongatus* are refigured.

Range and occurrence.—Middle Ordovician, ?Whiterockian, Blackriveran through Trentonian. North America; U.S.A. (Illinois, Kentucky, ?Nevada, Oklahoma, Tennessee, Wisconsin), Canada (Ontario, Quebec).

Mode of life.—One complete specimen of *R. variabilicaulis* n. sp. including crown, column, and holdfast, plus nearly complete specimens of *R. polki* n. sp. and *R. spinosus* were available for study. *R. variabilicaulis*

Table 4.—Summary comparison of species of *Reteocrinus*.

Species	Maximum known crown size in mm	Width vs. height of cup (in mm) at middle of **RR**[1]	Crown height[2] / width of cup (in mm) at middle of **RR**	Position of first arm branching	Nature of interinfrabasal areas
stellaris	>45	w ≫ h	3	**IBr**$_3$	d
alveolatus	>45	w > h	4	**IBr**$_{2-4}$	g
depressus	22	w ≫ h	2	**RR-IBr**$_2$	very small d
elongatus	>27	w > h	4	**IBr**$_{4-5}$	small d
fenestratus	—	w > h	—	—	g
mahlburgi	≃90	(?) w > h	4	**IBr**$_{5-6}$	d
polki	60	w ≫ h	3	**IBr**$_{3-?4}$	d
rocktonensis	23	w > h	3	**IBr**$_{4-6}$	g
spinosus	21	—	4	**IBr**$_{4-6}$	d
variabilicaulis	45	w > h	4	**IBr**$_{2-4}$	d
mutli-limbed fold plates of Sprinkle, 1971	—	—	—	—	g

[1,2] = estimated due to flattening; d = depressions, g = gaps.

and *R. spinosus* attached to the substrate by means of a dorsally polyplated encrusting holdfast. The holdfast was floored in *R. variabilicaulis* by an attachment disc. Total column length varies according to species; it is short in *R. variabilicaulis*; moderate in *R. polki* and *R. spinosus*; and long in *R. alveolatus*. A short, narrow column segment adjacent to the holdfast in *R. variabilicaulis* was probably flexible, because it is divided into loosely articulated pentameres. Flexibility is also suggested by the relatively strong curvature of preserved pentamere segments. Short distal columns in *R. polki* and *R. spinosus* are comprised of many small, irregular, subpolygonal, loosely articulated plates: these were also probably flexible. The proximal to medial columns in nearly every known species of *Reteocrinus* in contrast appear to have been only slightly flexible, as is indicated by the pervasive straight to slightly curved column attitudes and more importantly, the tight cryptosymplectial (or rarely intermittently ankylosed) articulations of the columnals. The columns in living *R. variabilicaulis, R. spinosus,* and *R. polki* were rigid except for movement at the short flexible distal sections. This overall column morphology is functionally very similar to the Lebanon Limestone disparid inadunates *Columbicrinus crassus* Ulrich, 1925, and *Tryssocrinus endotomitus* n. gen. et sp.

The crown, particularly the interbrachial areas, appear to have been pliant in *Reteocrinus* (Brower, 1974, p. 23; Kolata, 1975, p. 47; Ubaghs *et al.*, 1978, p. T285). Interbasal, interbrachial, and tegmen plates are subpolygonal with thin attenuated lateral margins, unlike the planar (zygosynostosial) lateral margins that are found in most other camerate taxa. These plates were presumably imbedded in and held together by a flexible integument.

Study of specimens of *R. alveolatus* from Ontario shows that the interbasal-interbrachial plates in these specimens are pierced by small holes arrayed around the plate centers (Pl. 4, fig. 7). Pierced plates were not found in other species of *Reteocrinus,* but those of *R. alveolatus* have scalloped margins so that gaps are present between plates. Extensive distribution of these pores about the interbasal, interbrachial, and tegmen regions suggests that the holes mark the sites of respiratory structures.

Reteocrinus stellaris Billings
Plate 4, figures 1–3

Reteocrinus stellaris Billings, 1859, p. 64, pl. 9, figs. 4a–c; Wachsmuth and Springer, 1882, pp. 262–263, fig. 1; Wachsmuth and Springer, 1897, p. 178, pl. 9, figs. 3a–c; Springer, 1911, p. 10, pl. 1, figs. 6, 7; Ubaghs, 1978a, p. T414, fig. 223, nos. 1a, b.

Emended diagnosis.—A species of *Reteocrinus* with aboral cup high, convex-sided, slightly wider than high at level of **RR**, relatively short arms, wide interray areas; keels radiate from axes along limbs of **IBB**, **BB**, **RR**; distal **RR** through **Brr** ornamented with sublongitudinal fine ridges, no lateral projections; interinfrabasal depressions medium-sized (relative to other species of *Reteocrinus*), much higher than wide, open below; **IBr**$_3$ axial. Proximal column round, columnals thin with narrow rounded epifacets.

Emended description.—Crown moderate to large, averaging approximately 45 mm high among known

Table 4.—Continued.

Width/height of **IBB**	Plate ornamentation: Keels on cup plates	Nature of surficial ornament	Locations of lateral projections on arms	Column shape
w > h	present	longitudinal striations	none	Round
w ≥ h	present	reticulate and (or) thick discontinuous striations	**RR-IIBrr** (not always present)	Pentagonal
w ≥ h	absent	smooth	none	Round
w ≫ h	absent	smooth	**RR-IIBrr**	Round
w ≥ h	absent	smooth to nearly smooth	**RR-IIBrr**	(?) Round
w > h	absent	reticulate, warty	none	—
w > h	absent	none or faintly reticulate	distal **IIBrr**-arm tips	Pentagonal
w > h	present	fine longitudinal striations	**IBrr**-(?) **IIBrr** (faint)	Subpentagonal
w > h	present	reticulate	**IBrr-IIBrr**	Subpentagonal
w > h	absent	reticulate	**RR-IIBrr** or **IBrr-IIBrr**	Round to subpentagonal
w > h	present	longitudinal striations	at least **RR** (anals)	—

specimens; cup high, convex-sided, slightly wider than high at level of radials; arms relatively short, interray areas relatively wide. Keels radiate from plate axes along limbs of **RR**, **BB**, **IBB**; abut at plate articulations. Sutures flush. **RR** through **Brr** ornamented with sublongitudinal fine ridges, usually four or five per plate, ridges abut across plate articulations. Surface of proximal cup can have additional small surface irregularities. Interinfrabasal depressions moderately large, deep, much higher than wide, open below. Interbasal gaps large, subround.

IBB large, up to two times wider than high. **BB** large, usually about as high as wide but variable. **RR** large, about 1.5 times higher than wide. Interbrachial-interbasal areas with depressed fields of small subround to subpolygonal plates having coarse stellate ornament (Pl. 4, fig. 2). **IBr**$_3$ axillary; **IBrr** much taller than wide, becoming less so distally. **IIBrr**$_{4-6}$ axillary, **IIBrr** higher than wide, becoming less so distally. **Brr** beyond **IIBrr** typically about as high as wide, variable. Arms branch at least four times in larger specimens. Proximal anals as much as five times higher than wide, becoming less so distally; distal anals unknown. Tegmen apparently sac-like, not extending beyond arm tips; poorly known. Only proximal 3 cm of column known; round, not tapering. Columnals very thin; epifacets narrow, margins rounded to attenuated; nodals separated by thin internode of several internodals, middle internodal is priminternodal. Articulae cryptosymplectial, lumen quinquelobate.

Remarks.—See Table 4 for comparison with other species of *Reteocrinus.*

Types and occurrence.—All original type material was available for study. GSC 1525 is here figured and designated the lectotype. GSC 1525b–e are designated paralectotypes and GSC 1525b is figured. GSC 1525f was not part of the hypodigm and is therefore designated a topotype. The specimens are from the late Trenton Cobourg Beds, Ottawa Formation, at Ottawa, Ontario, Canada.

Reteocrinus alveolatus Miller and Gurley
Plate 4, figures 5–7, 9, 14, 15

Reteocrinus alveolatus Miller and Gurley, 1894, pp. 46–47, pl. 11, fig. 22; Springer, 1911, pp. 10, 11, pl. 1, figs. 1–5; Ubaghs, 1978a, p. T414, fig. 223, nos. 1c, d.

Remarks.—The original description was based on a single individual from Kentucky. This specimen is coarsely silicified and lacks most details of plate ornament. Well-preserved material assignable to this species was later reported from Ontario (Springer, 1911). Additional Ontario specimens from approximately the same horizon and at a locality near Springer's are in the University of Cincinnati collections. I examined the holotype and referred specimens from Ontario and found no significant differences among them.

The following additions and corrections should be added to the largely accurate descriptions provided by Miller and Gurley (1894) and Springer (1911). The cup is high, with sides slightly convex in type specimen, slightly convex or possibly straight-sided in Canadian specimens. Interinfrabasal gaps are small, suboval; interbasal gaps are large and subcircular. **IBB**, **BB**, **RR** possess an interconnecting network of prominent keels radiating from plate centers; the keels are offset from limb axes. **RR** to **IIIBrr** typically have small to large wedge-shaped lateral projections.

The following additions were observed in Canadian specimens only; their absence in the holotype probably results from coarse silicification. Crown plate ornament is variable; can be on **RR** and **Brr** only, it consists of few subparallel sublongitudinal fine ridges to many irregular, sinuous, sublongitudinal, anastomosing fine ridges; the ridges typically abut across plates (Pl. 4, fig. 5). Interinfrabasal, infrabasal, as well as interbrachial fields are filled with small, irregular, subpolygonal plates; the plates have coarse stellate ornament ridges and numerous pores arrayed about plate centers between ridges (Pl. 4, figs. 7, 15). The column widens slightly near the crown; it is subpentagonal to round in small specimens and consists of nodals separated by an internode of six to eight columnals. Internodes typically have a medially disposed priminternodal flanked by secundinternodals. The column can also possess discontinuous longitudinal ridges along the pentagonal angles. Epifacets are narrow, margins attenuated, rounded, to nearly straight sided. Articulae are cryptosymplectial.

Types and occurrence.—The holotype FM(UC)-6045 is here refigured; it is from the middle Trentonian (Kirkfieldian) Curdsville Limestone, Mercer County, Kentucky. Referred and figured specimens in the Kopf Collection at the University of Cincinnati are from the middle Trentonian (Kirkfieldian) Hull Limestone, Kirkfield Quarry, Victoria County, Ontario, Canada; these are UC-35991, UC-36514, and UC-36006. Other referred specimens from the Hull Limestone near Kirkfield, Ontario, [USNM(S)] were not examined. (The Hull Limestone in the Kirkfield area is now redefined as Bobcaygeon and Kirkfield limestones.)

Reteocrinus elongatus Raymond
Plate 4, figure 4

Reteocrinus elongatus Raymond, 1931, pp. 203–204, pl. IV, fig. 5.

Remarks.—The following emendations are here made to Raymond's brief but accurate description. Interbasal gaps are large and interinfrabasal depressions are small and shallow. **RR**, **IBrr**, and **IIBrr** have small wedge-shaped lateral projections. [Raymond (1931, p. 203) referred to these as "sharp girders".] The column is round, tapering gradually away from the crown. It is composed of thin alternating nodals and internodals; nodals variably sized; largest columnals are intermittently distributed along column (usually every fourth or fifth columnal). Nodal epifacets are narrow with rounded margins.

The downward-projecting frills on proximal columnals inferred by Raymond were caused by differential weathering (Pl. 4, fig. 4) and are artifacts of preservation only.

Types and occurrence.—The holotype and only specimen, here refigured, is MCZ 3370 [formerly 3994] and it is from 2.5 mi east of Cumberland Gap, Tennessee. Raymond lists the specimen as occurring in the "Lebanon" Limestone, but this term is no longer applied to rocks east of Sequatchie Valley in Tennessee. The specimen could be from the Upper Ottosee Group, possibly the Witten or Wardell formations.

Reteocrinus fenestratus new species
Plate 2, figures 10–13, 18

Etymology of name.—*fenestratus* (L.) = window, and refers to the open nature of the cup in this species.

Diagnosis.—A species of *Reteocrinus* characterized by medium-sized crown for genus with steep, nearly straight-sided, cone-shaped cup, smooth or faint reticulate ornamentation on cup plates; relatively large high **IBB**, small interinfrabasal gaps, small wedge-shaped lateral projections on **RR**, **IBrr**, **IIBrr**, and with low rounded hemispherical to small wedge-shaped lateral projections on proximal anals. Column differentiated into at least proximal and medial parts; proximal columnals with narrow sharp epifacets, farther distal columnals straight-sided or with narrow straight-sided epifacets.

Description.—Moderate-sized crown for genus with steep-sided cone-shaped cup, slightly higher than wide at level of radials. Major cup plates slightly flattened, with smooth or faintly reticulate ornament. **RR**, **IBrr**, **IIBrr** with short lateral wedge-shaped projections; proximal anals with low hemispherical to small lateral wedge-shaped projections. Small typically subtriangular interinfrabasal gaps; interbasal gaps large. **IBB** slightly wider than high, forming relatively large part of sides as well as base of cup. **BB** largest plate in cup, slightly higher than wide. **RR** large, higher than wide. Anal plate 1 as much as four times higher than wide, succeeding lower anals becoming slightly higher than wide. **IBrr**$_{3,4}$ axillary (Pl. 2, fig. 11); **IBr**$_1$ higher than wide, succeeding **IBrr** becoming only slightly higher than wide. **IIBr**$_3$ axillary, **IIBrr** slightly higher than wide. Arms beyond **IIBrr** unknown. **iBrr** very small, with irregular stellate ornamentation. Column obscurely (?)pentagonal or round, columnals thin, epifacets narrow or absent, known over proximal (to approximately 20 mm below cup) and medial (at least 75 mm beyond proximal) portions. Proximal columnals with narrow attenuated epifacets; thicker, wider nodals alternate with two to three thinner narrow internodals; internode can have priminternodal, secundinternodals. Medial column an irregular series, generally of two to three similar straight-sided internodals separated by thicker nodals with gently convex or straight-sided epifacets (Pl. 2, fig. 18); nodals apparently consist of two to three ?ankylosed thin columnals, the median ?fused columnal often slightly wider, protruding. Articulae cryptosymplectial.

Remarks.—See Table 4 for comparisons.

Types and occurrence.—The holotype, UI X-5690, is from the lower Lebanon at locality Z-651. Paratypes UI X-5695 and UI X-5696 are from the lower Lebanon at localities Z-658 and Z-659, respectively. All specimens are figured, and UI X-5690 and UI X-5695 were measured.

Reteocrinus mahlburgi (Kolata)

Traskocrinus mahlburgi Kolata, 1975, pp. 46–47, text-fig. 14, pl. 8, figs. 1, 4–5.

Remarks.—This species is well described except for the inference of the presence of interinfrabasal gaps (Kolata, 1975, text-fig. 14; remarks under *Traskocrinus,* p. 46). The **IBB** are missing in the type and only known specimen. The lower margins of **BB** are depressed, meeting medially at vertices; this morphology is typical of species of *Reteocrinus* that lack interinfrabasal gaps (*R. polki* n. sp., *R. stellaris* Billings, 1859, *R. elongatus* Raymond, 1931). In contrast, species possessing interinfrabasal gaps have rounded inverted notches along their lower medial margins (*R. spinosus* Kolata, 1975, *R. rocktonensis* Kolata, 1975, *R. alveolatus* Miller and Gurley, 1894, *R. fenestratus* n. sp.).

Types and occurrence.—The holotype, BMNH Pk-48, is from the Blackriveran Grand Detour Formation, Northern Illinois.

Reteocrinus polki new species

Plate 2, figures 5, 17; Plate 3, figures 1–4, 11

Etymology of name.—The specific name honors James Knox Polk, eleventh President of the United States, whose home is near the collecting locality.

Diagnosis.—A species of *Reteocrinus* with convex-sided aboral cup, twice as wide as high at level of **RR**, primary cup plates smooth or very faintly reticulate, slightly distended or evenly rounded, with narrow shelves on latero-ventral margins adjoining interbasal gaps, interbrachial areas; interinfrabasal depression; interbasal gaps large, typically wider than high, $\mathbf{IBrr}_{3,4}$ axillary; **Brr** beyond **IIBrr** with prominent sharp wedge-shaped lateral projections. Column pentagonal, columnals extremely thin, with cryptosymplectial articulations.

Description.—Adult crown large (see Table 3); aboral cup convex-sided, twice as wide as high at level of **RR**. Major cup plates with large multilimbed extensions; evenly rounded or slightly distended, smooth or with faint reticulate ornament (Pl. 3, figs. 1, 3). **Brr** can have faint longitudinal ridges on proximal and distal margins. Sutures flush. Major cup plates with narrow shelves on ventro-lateral margins adjoining interbasal gaps, interbrachial areas. Interinfrabasal depressions small (Pl. 2, fig. 5), depressions shallow in small specimens (UI X-5417), larger, deeper, subtriangular in large specimens (UI X-5790). Interbasal gaps large for genus, typically wider than high. **Brr** beyond proximal **IIBrr** with prominent dorso-ventrally flattened wedge-shaped lateral projections; projections diminish in size away from **IIIBrr** (Pl. 3, fig. 1).

IBB five, at least two times wider than high. **BB**, **RR** largest plates in cup. **RR** five, about as high as wide. **iBr**, interbasal plates thin, small, irregularly subpolygonal, with thickened centers; arranged in loose mosaic; ornamented with fine ridges emanating in irregular stellate pattern from plate centers (Pl. 3, fig. 1). **iBrr** become thinner, more weakly calcified distally. $\mathbf{IBrr}_{3,4}$ axillary; $\mathbf{IBr}_1$ much higher than wide, $\mathbf{IBr}_{3\text{ or }4}$ only slightly higher than wide. $\mathbf{IIBrr}_{3,4}$ axillary. **Brr** beyond proximal **IIBrr** usually about as high as wide, variable; having prominent dorsoventrally-flattened wedge-shaped lateral projections (Pl. 3, fig. 1). Projections diminish in size away from **IIBrr**. Arms branch isotomously at least five times in adults. Ambulacral grooves apparently wide. Coverplates small, apparently of median biseries of small wedge-shaped plates (ambulacrals) flanked on either side by a single row of plates (adambulacrals). Proximal anals resemble $\mathbf{IBr}_1$ but can be much higher than wide. Tegmen sac-like, extending approximately to level of arm tips on one specimen (Pl. 3, fig. 1), covered by small, thin subpolygonal to suboval plates confluent with **iBrr**; plates become thinner, more weakly calcified distally. Web-like extensions of tegmen extend to **IIIBrr**.

Column pentagonal, much longer than crown height, at least 14.8 cm in holotype UI X-5790; heteromorphic, tapering slightly away from crown. Proximal and medial column of extremely thin columnals bearing very narrow rounded epifacets; alternating columnals with slightly more prominent epifacets; largest epifacets on columnals at variable intervals, generally every fourth or fifth columnal. Distal column of numerous tiny tightly fitting subequant plates forming mosaic (Pl. 3, fig. 11).

Remarks.—*Reteocrinus polki* n. sp. is compared with other species of *Reteocrinus* in Table 4.

Types and occurrence.—The holotype is UI X-5790; paratypes are UI X-5410, 5413, 5414, 5417; UI X-5413, 5417 and 5790 are figured and measured; UI X-5410 is figured. All specimens are from locality Z-654a.

Reteocrinus spinosus Kolata

Reteocrinus spinosus Kolata, 1975, pp. 45–46, text-fig. 13, pl. 8, figs. 3, 8.

Remarks.—Kolata's description is accurate except for the inference of interinfrabasal gaps. Additional preparation of the holotype and only known specimen shows the specimen had interinfrabasal depressions.

Types and occurrence.—The holotype, UI X-4881, is from the Blackriveran Grand Detour Formation, northern Illinois.

Reteocrinus variabilicaulis new species
Plate 2, figures 14–16, 20; Plate 3, figures 5–10, 13; Plate 4, figures 12, 13

Etymology of name.—*variabilis* (L.) = variable; *caulis* (L.) = tail, referring to the highly variable column morphology of this species.

Diagnosis.—A species of *Reteocrinus* characterized by a medium-sized (for genus) elongate crown with steep nearly straight to slightly convex-sided cup, cup slightly wider than high at level of **RR**, multilimbed extensions of cup plates relatively short. Small interinfrabasal depressions, large rounded lateral projections on **RR** to **IIBrr**, two to four **IBrr** per ray, and moderately large interbasal gaps. Column heteromorphic, relatively short; proximal, medial column with large round to subpentagonal nodals separated by variable internode series; nodals typically of two or three ankylosed columnals. Distal column of pentameres tapers rapidly toward subconical, polyplated, encrusting holdfast.

Description.—Crown moderate-sized (Table 3), slender. Aboral cup steeply conical, sides nearly straight to slightly convex, slightly wider than high at level of **RR**. Major cup plates relatively compact with short lateral multilimbed extensions, evenly rounded to slightly flattened, with ornament faint reticulate to smooth. UI X-5409 with faint keels on limbs of CD **B**. UI X-5412 and UI X-5694 possess supernumerary major cup plates (Pl. 2, fig. 20; Pl. 4, fig. 13). **RR-IIBrr** possess large subhemispherical lateral projections (Pl. 3, figs. 8, 10); projection size decreases away from **IBr**$_{1 \text{ or } 2}$. Interinfrabasal depressions small, can be open below. Interbasal gaps medium-sized for genus, typically taller than wide to about as tall as wide, variable.

IBB medium-sized, approximately twice as wide as high; often with small low node projecting from medial-adoral surface toward interbasal gap. **BB** five, higher than wide, widest distally. CD **B** pentaxial, higher than wide. **RR** five, large, slightly higher than wide. Two to four **IBrr** per ray. **IBr**$_{1,2}$ generally higher than wide, succeeding **IBrr** about as high as wide, variable. **IIBr**$_3$ typically axillary. Interbasal, **iBr** plates small, irregularly polygonal, with prominent ridges that generally radiate in stellate pattern from near plate centers. Proximal anals higher than wide, slightly narrower than **IBrr**. Tegmen poorly known, apparently sac-like, not extending to arm tips. Proximal tegmen covered with slightly smaller plates than interbrachials, with less pronounced or no stellate ornamentation. Arms uniserial, long, branching isotomously at least five times in bigger specimens.

Column short, about two-and-one-half times crown height, weakly tripartite, heteromorphic, highly varied along length among specimens. Column slightly thicker to subequal in thickness from crown to about middle column, then tapering rapidly to holdfast. Articulae pentagonal, cryptosymplectial; lumen quinquelobate.

Proximal, medial column sections composed of intervals of several internodals separated by single nodals; proximal columnals of both series more or less compressed. Nodals thick to thin; compound, typically of two to three ankylosed columnals; outline circular or obscurely pentagonal, with wide epifacets, straight to rounded margins (Pl. 3, figs. 5, 6). Straight-sided epifacets (Pl. 3, fig. 6) sculpted with irregular ridges, grooves encircling columnal; rounded epifacets smooth or pitted in distal medial column region. Internodes variable with five to eight columnals; columnals either low, subpentagonal throughout or approximate middle internodal is slightly (Pl. 3, figs. 5, 9) to greatly enlarged [*i.e.,* nodiform (Pl. 3, fig. 9)]; can obscure adjacent low internodals. Low subpentagonal internodals typically having low, thin sharply attenuated epifacets. Distal column narrow, rapidly tapering, of projecting rounded pentameres, circlets of which alternate slightly in size. Larger circlets replace nodals in sequence, smaller circlets replace internodals; circlets compressed distally, thin.

Holdfast encrusting, subconical, low, surface smooth; dorsally of tightly sutured (?fused) polygonal plates; ventral disc present.

Remarks.—See Table 4 for comparison of *R. variabilicaulis* with other species of *Reteocrinus.* The ankylosed columnals forming the nudinodals in *R. variabilicaulis* are an unusual feature among crinoids. Also of note in this species is the great individual variation in column morphology.

UI X-5415 (Pl. 2, fig. 16) is tentatively assigned to this species. It is a distorted crown and proximal column with badly corroded arm tips differing from other specimens assigned to this species in having thinner more attenuated lateral projections on the **IBrr** and **IIBrr**. I cannot be certain of the column shape, but the columnal morphology is similar to that of UI X-5408 (Pl. 2, fig. 15) and UI X-5694 (Pl. 4, fig. 13).

Types and occurrence.—Six specimens are designated types and are figured; the holotype, UI X-5411, and paratypes UI X-5408, 5409, 5412, 5805, and 5694, are all from the lower member, Lebanon Limestone at locality Z-654a. UI X-5409, 5411, 5412, and 5805 are measured. Referred, figured, and measured specimen UI X-5415 is from the lower member, Lebanon Limestone, at locality Z-651.

Reteocrinus species
cf. **R. variabilicaulis** new species
Plate 3, figure 12

Remarks.—A single small crown and proximal column, UI X-5414, is tentatively assigned to *R. variabilicaulis.* It differs from other specimens ascribed to this species principally in possessing a relatively narrower, more gradually tapering column; also columnals are thinner with narrower lower epifacets. I suspect the differences are due to ontogenetic and intraspecific variation.

Types and occurrence.—The single figured and measured crown, UI X-5414, is from the lower member, Lebanon Limestone, at locality Z-654a, where it cooccurs with both *R. variabilicaulis* and *R. polki.*

Reteocrinus species
Plate 2, figure 19

Remarks.—The single small partial crown with proximalmost column herein described (see Table 3 for measurements) is most similar to *R. fenestratus,* but differs in lacking interinfrabasal gaps, possessing four or five **IBrr** instead of (?)three or four, and having more angular lateral projections on distal cup plates (Pl. 2, fig. 19). Interinfrabasal gaps could develop later in ontogeny similar to interinfrabasal depression development in *R. polki* n. sp. and *R. variabilicaulis* n. sp. Small size supports this possibility. The other differences could be a result of intraspecific variation.

The specimen is also similar to specimens assigned to *R. variabilicaulis,* but the former differs in possessing thin homeomorphic proximal columnals, four to five **IBrr** instead of two to four, and more angular, in some cases subrectangular (Pl. 2, fig. 19) lateral projections on distal cup plates. It is possible, again, that the differences are due to intraspecific and ontogenetic variation.

Because of lack of information concerning ontogenetic and intraspecific variation, therefore, the specimen cannot be assigned although I suspect the specimen belongs to either *R. fenestratus* n. sp. or *R. variabilicaulis* n. sp.

Types and occurrence.—This single specimen, UI X-5416, is figured and measured, and is from the lower member approximately 8 m below the massive member at locality Z-651.

Family **ANTHRACOCRINIDAE**
Strimple and Watkins, 1955

Genus **GUSTABILICRINUS** new genus

Etymology of name.—*gustabilis* (L.) = appetizing; *crinum* (L.) = lily. The first element suggests one possible cause for the rarity of intact calyxes in this genus, a condition that probably is the result of relatively fragile construction.

Type species.—*Gustabilicrinus plektanikaulos* n. sp.

Diagnosis.—Anthracocrinidae with subconical cup, slightly higher than wide, median ray ridges faint to absent; sutures moderately depressed to flush; plates flat to slightly convex. **IBB**, aboral portion of **BB** form deep cylinder-like basal invagination, tightly appressed over proximal column. **BB** highly reflexed, form attenuated lower cup margin. All interrays apparently of nearly equal width; lateral interray consists of large interradial followed by two moderate-sized $\mathbf{iBrr}_1$; CD interray poorly known, of small primanal followed by two rows with two plates per row. Fixed **Brr** bifurcate isotomously twice; four arms per ray. Free arms uniserial, cuneate. Column heteromorphic, large, round, with slight gradual distal taper.

Remarks.—Features which place *Gustabilicrinus* n. gen. in the Anthracocrinidae are the deep basal concavity with concealed **IBB**, **iBrr** separated from tegmen by fixed pinnules, fixed **Brr** and pinnules forming web-like extensions of the cup at the arm bases, and CD interray apparently equisized with lateral interrays.

The new genus resembles *Anthracocrinus* Strimple and Watkins, 1955, but the latter differs in possessing 15 arms and a wide CD interray whose plates connect with the tegmen. *Hercocrinus* Hudson, 1907, and *Deocrinus* Hudson, 1907, differ in possessing a globular cup and apparently 10 arms (Hudson, 1907, pp. 121, 125, pls. 8, 9); *Hercocrinus* also has biserial arms. *Rheocrinus* Haugh, 1979, differs most conspicuously in possessing biserial arms and **BB** and **RR** alternating in a "bicirclet" along the lower edge of the cup.

Gustabilicrinus plektanikaulos new species
Plate 3, figures 1, 3; Plate 5, figures 2–5, 12, 13, 18, 20–22; Text-figure 5

Etymology of name.—*plektanos* (Gr.) = curly; *kaulos* (Gr.) = stem. This epithet refers to the commonly coiled column of the species.

Diagnosis.—A species of *Gustabilicrinus* character-

Table 5.—Measurements of specimens of two species of *Gustabilicrinus* n. gen. (in mm).

	G. plektanikaulos								*G. latomium*	
	UI X-5952			UI X-5943		UI X-5791	UI X-5962		UI X-5961	
Cup height		24		13*		—	6.5		11.4*	
Cup width		20*		11		—	6.2*		—	
B height	3.8		3.8	3.1	3.1	—	1.9	2.0	3.4	3.2
B width	4.3		3.5	3.1	3.6	—	1.4	1.5	3.2	2.9
R height	3.8	4.0	4.1	3.5	2.6	2.4*	0.9	1.1	2.1	2.1
R width	4.3	4.1	4.8	3.3	3.2	3.0	1.6	1.6	3.1	2.8
iR height	4.8	4.4	5.2	2.8	2.9	2.7	1.6	1.8	2.8	2.8
iR width	4.2	4.6	4.2	3.0	3.1	2.7	1.3	1.3	2.4*	2.2
Column diameter at base of cup		4.1*		3.9		—	1.9		4.3	

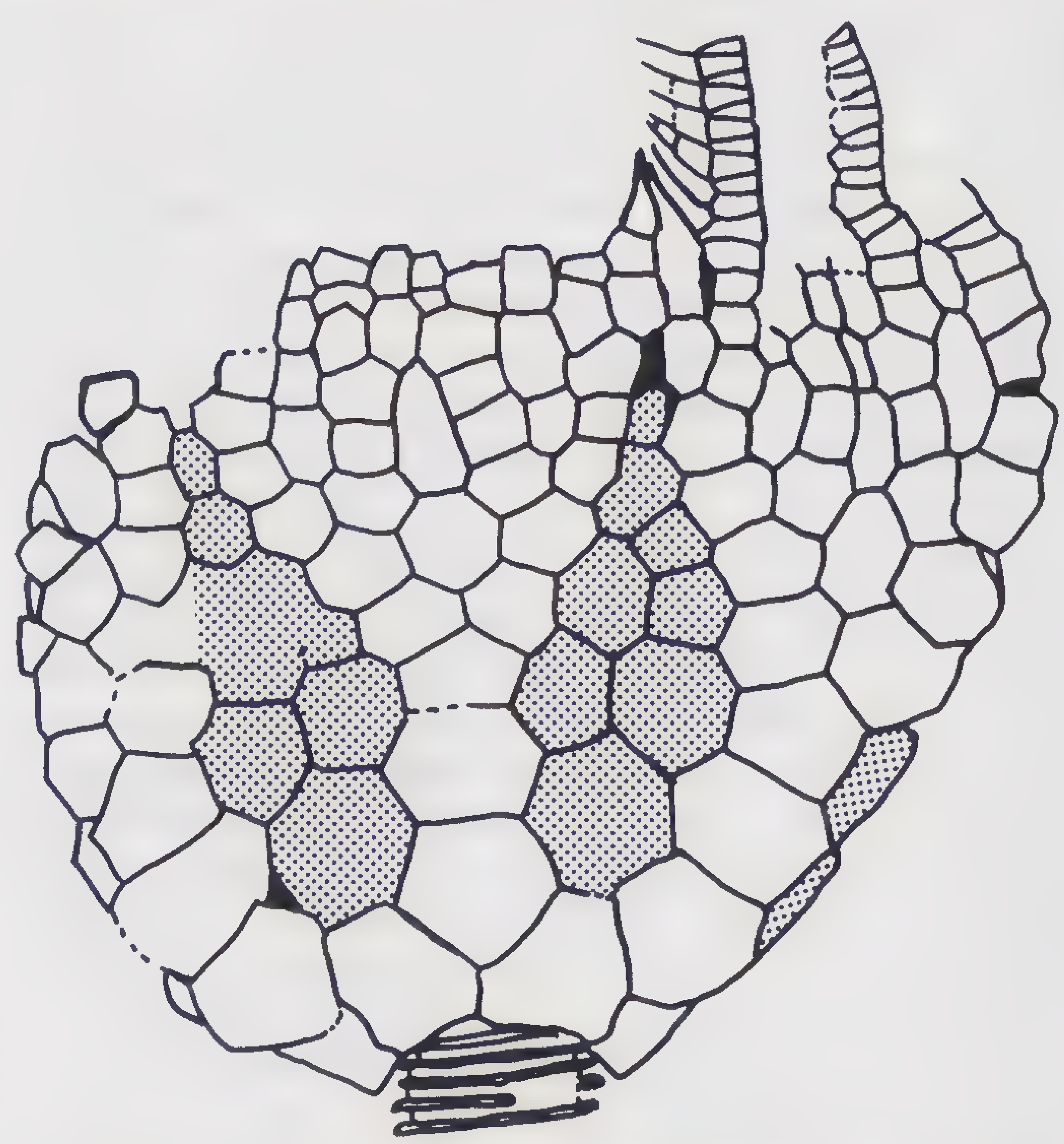
* = estimated; multiple measurements are of several plates.

ized by a moderate-sized to large, convex-sided cup about as high as wide; lateral interrays of relatively small **iR** followed by rows of two, then two or one **iIBrr**; **iRR** not contacting **Brr** above $\mathbf{IBr}_1$; **IBrr** slightly wider than high to wider than high; proximal column nodals with smooth, rounded latera.

Description.—Dorsal cup medium to large (Table 5), subconical, slightly higher than wide, cup sides slightly convex; deep cylinder-like basal concavity; concavity extends upward into coelomic cavity approximately to level of $\mathbf{IBr}_1$ or $\mathbf{IBr}_2$, appressed tightly against and concealing proximalmost column (Pl. 5, fig. 4). Cup plates flat to slightly convex, can have depressed centers; smooth or with fine pits; sutures flush to moderately depressed, depressed particularly at triple junctions, between adjacent **BB**, **RR**. Median ray ridges faint, low, wide, occasionally absent; where present gradually disappearing distally at **IBrr** or **IIBrr**. Dorsal surfaces of fixed **IIIBrr** to proximal five or six **IVBrr** can have faint longitudinal abutting keels.

IBB five, forming ventral half of basal concavity, large, taller than wide, pentagonal, sides diverge slightly distally away from column articular facet. **BB** five, articulate with two **IBB**, two **BB**, two **RR**, one **iR**; sharply reflexed medially, **V**- or **Y**-shaped in transverse section, form dorsal half of basal concavity, attenuated lower cup margin. **RR** five, pentagonal, large; each in contact with two **BB**, two **iRR**, $\mathbf{IBr}_1$. $\mathbf{IBrr}_1$ smaller than **RR**, hexagonal, wider than high; rarely pentagonal, axillary. $\mathbf{IIBrr}_2$ axillary, pentagonal, wider than tall, much smaller than **RR**. $\mathbf{IIBr}_1$ wider than high, irregularly pentagonal to hexagonal, smaller than **IBrr**. $\mathbf{IIBr}_2$ pentagonal, axillary; typically slightly smaller than $\mathbf{IIBr}_1$, can be nearly the same size, bears two arms; $\mathbf{IIIBr}_1$ hexagonal; $\mathbf{IIIBr}_2$ pentagonal or quadrangular; $\mathbf{IIIBrr}_3$ axillary, bear a single fixed pinnule, one **IVBr**. $\mathbf{IVBrr}_{1,2}$ non-pinnulate, $\mathbf{IVBr}_3$ can also be non-pinnulate. Succeeding **Brr** with single pinnules on alternating sides of arms. Two or three **iIIBrr**, aligned in vertical row, decreasing greatly in size distally. One to four **iIIIBrr**; aligned in vertical row.

Interrays narrow, typically of eight to 10 plates; not reaching tegmen (Text-fig. 5). **iRR** heptagonal, large, as large as or slightly larger than **RR**; followed by rows of two, then two or less commonly one subequal-sized **iIBrr**. One interray of UI X-5952 with unusually tall **iR** followed by row with two unequal **iIBrr** (Pl. 5, fig. 2), right **iIBr** of this row much taller than left **iIBr**, abuts **iR** along smaller facet than left **iIBr**. One interray of UI X-5943 has first row above **iR** with right **iIBr** taller, wider than left **iIBr** (Pl. 5, fig. 12); right bordering ray with $\mathbf{IBr}_1$ axillary. CD interray not defined; ap-



Text-figure 5.—*Gustabilicrinus plektanikaulos* n. gen. and sp., tracing of cup, anterior view, in holotype UI X-5952. Interray areas (**iRR**, **iIBrr**) are stippled (×3).

parently of approximately equal width to other interrays.

Tegmen poorly known, of many small plates with single spinose projections.

Arms 20, long, length greater than 1.5 times height of cup, tapering slightly proximally, more rapidly distally; cuneate, uniserial, densely pinnulate, free above **IVBr**$_{5,6}$. Pinnules closely spaced, large, flattened, with gradual distal taper; approximately 10–12 pinnulars per pinnule.

Column round, heteromorphic, long, greater than three times as long as crown height; distally tapering, commonly coiling (Pl. 5, fig. 21); of closely spaced thin nodals alternating with few thin internodals near crown; gradually changing to widely spaced nodals alternating with approximately four to six (most commonly five) internodals distally. Nodals with wide epifacets, rounded margins; radially arranged low ridges on upper, lower epifacet surfaces, do not reach margins (Pl. 5, fig. 22). Internodals with slightly convex, irregular latera. Articulations symplectial, crenularium narrow, lumen large, subpentagonal.

Remarks.—See remarks under *Gustabilicrinus latomium* n. sp. for comparison with *G. plektanikaulos* n. sp.

Mode of life.—Several distal columns of *Gustabilicrinus plektanikaulos* n. sp. were found coiled about columns of *Tryssocrinus endotomitus* n. gen. et sp., *Reteocrinus polki* n. sp., and *Hybocrinus bilateralis* n. sp. *Tryssocrinus endotomitus, H. bilateralis,* and probably *R. polki* were attached to the substrate by a holdfast. *Gustabilicrinus plektanikaulos* then, maintained its position by prehensile attachment to the columns of crinoids that were fixed to the substrate.

Types and occurrence.—The holotype is UI X-5952 and paratypes are UI X-5758, 5769 through 5773, 5791, 5792, 5802, 5811, 5940, 5943 through 5951, 5953 through 5960, 6048, 6049, 6051, 6054. UI X-5952, 5943, and 5791 are figured and measured; UI X-5758, 5773, 5792, 5951, and 5959 are figured. All specimens are from the lower member of the Lebanon Limestone at locality Z-654a.

Gustabilicrinus latomium new species
Plate 4, figures 8, 10, 11, 16, 17;
Plate 5, figures 1, 6

Etymology of name.—*latomium* (L.) = stone quarry. This epithet refers to the collecting locality.

Diagnosis.—A species of *Gustabilicrinus* with steep, nearly straight-sided cup; **IBrr** much wider than tall, wider to nearly as wide as interray areas; **iRR** relatively large, abut **IIBrr**$_1$. Presumed CD interray of small primanal followed by rows in series of two, two plates. Column round; nodals serrated along epifacet margins.

Description.—Cup small (Table 5), subconical, slightly higher than wide, cup sides straight, nearly vertical at level of **BB**, slightly convex, flaring above **BB**. Basal concavity deep, cylinder-like, extends into cup cavity to level of **IBr**$_1$, appressed tightly against, concealing proximalmost column. Cup plates flat to slightly convex, ornamented with fine pits, ridges and grooves; ridges and grooves can abut across sutures. Sutures flush; indentation in **BB** at junction with lower edge of each **R**. Median ray ridges faint, low; more prominent distally on cup.

IBB not observed. **BB** five, taller than wide, articulate with two **IBB**(?), two **BB**, two **RR**, one **iR**; sharply reflexed medially, Y-shaped in transverse section, form lower half of basal concavity, attenuated lower cup margin. **RR** five, pentagonal, wider than high, large, in contact with two **BB**, two **iRR**, one **IBr**$_1$. **IBr**$_1$ smaller than **RR**, much wider than high, subquadrangular to hexagonal; **IBrr**$_2$ axillary, pentagonal, much wider than high. **IIBrr** wider than high; **IIBr**$_1$ hexagonal, can be pentagonal; **IIBr**$_2$ axillary, pentagonal, bears two **IIIBr**$_1$. **IIIBr**$_1$ pentagonal; **IIIBr**$_3$ axillary; each bears one fixed pinnule, one **IVBr**. **IVBrr**$_{2,3}$ without fixed pinnules; succeeding **Brr** poorly known. Two to four **iIIBr** rows of single plate per row; **iIIBrr** decrease in size distally. One or two **iIIIBrr** between fixed **IIIBrr**.

Lateral interrays narrow, not contiguous with tegmen, of approximately three to five plates; **iR** large, in contact with one **B**, two **RR**, four **IBrr**, two **IIBrr**, two or less commonly one **iIBrr**. Presumed CD interray known in UI X-5962; narrow, apparently not reaching tegmen (Pl. 5, fig. 1) small (?)primanal not extending above mid-level of **IBr**$_1$ followed by at least two rows of two plates.

Tegmen poorly known, of small plates having single spine-like projections (Pl. 4, fig. 16). Arms poorly known, apparently 20, long; **Brr** wider than tall, cuneate uniserial, one pinnule per **Br**; pinnulars taller than wide, laterally compressed.

Column round, heteromorphic; proximal column of closely spaced nodals, distal column with nodals separated more widely. Nodals with wide epifacets; epifacets serrated, with numerous distally projecting short spinose processes (Pl. 4, fig. 10). Articulae symplectial, lumen moderately large, round.

Remarks.—*Gustabilicrinus latomium* n. sp. closely resembles *Gustabilicrinus plektanikaulos* n. sp., also from the Lebanon Limestone, but the latter can be distinguished by its relatively smaller **iRR** that do not abut **IBr**$_2$ or **IIBr**$_1$, relatively taller **IBrr** (compare Pl. 4, fig. 17 with Pl. 5, fig. 20), and nodals with smooth rounded latera. *G. latomium* is also similar to *Anthracocrinus primitivus* Strimple and Watkins, 1955, from the Blackriveran Pooleville Member, Bromide Formation, of Oklahoma but the latter has 15 arms instead of 20 and relatively wider interrays.

Types and occurrence.—The holotype, UI X-5961, and a single paratype, UI X-5962, are the only known specimens. Both are figured and measured; they are from the lower member, Lebanon Limestone, at locality Z-651.

Family **RHODOCRINITIDAE** Bassler, 1938

Genus **ARCHAEOCRINUS** Wachsmuth and Springer, 1881

Type species.—*Glyptocrinus lacunosus* Billings, 1859, p. 261.

Diagnosis (modified from Kolata, 1982, p. 181).—A rhodocrinitid crinoid with a high subconical cup, **IBB** small, hidden in basal concavity; **BB** large, forming lower half of basal concavity; lateral interrays of **iR** followed by two **iBrr**; CD interray widest, of primanal, followed by row of three **iIBrr**; arms 10, biserial branching isotomously several times; column large, round.

Archaeocrinus snyderi new species
Plate 5, figures 7–11, 14–17, 19;
Plate 6, figures 3, 5, 6

Etymology of name.—The specific epithet honors Edward M. Snyder who assisted the writer with field work, offered suggestions, and who discovered some of the type material.

Diagnosis.—A species of *Archaeocrinus* characterized by a large, relatively high cup with generally smooth flush plates; faint median ray ridges, large basal concavity; column wide, long, nodals with smooth rounded epifacets along proximal, medial column.

Description.—Aboral cup large (Table 6), height approximately equal to width, widest about level of $\mathbf{IIBr}_3$; cup sides moderately to slightly convex; circular in basal view; constricted slightly below level of free arm bases. Basal concavity large, funnel-shaped, of moderate depth, subpentagonal to subpentastellate in outline, with faint to prominent surrounding rim, involving **IBB**, **BB**. Median ray ridges low, narrow, faint, often discontinuous; extending from **BB** to convergence at **RR**; then extending distally along **IBrr**, diverging at axillary **IBrr**, extending along **IIBrr** to bases of free arms.

IBB five, small, pentagonal, generally wider than tall, restricted to basal concavity; proximal rim projects upward into body cavity for short distance, forms col-

Table 6.—Measurements of four specimens of *Archaeocrinus snyderi* n. sp. (in mm).

	UI X-5732	UI X-5740	UI X-5743	UI X-5750
Cup height	—	37.8	31.3*	25.2*
Cup width	—	37.6	31.5*	27.5*
B height	8.3	7.1	6.9	6.2
B width	10.8	9.2	8.3	7.8
R height	10.0	8.8	7.2	7.3
R width	10.7	9.1	7.2	8.2
iR height	10.8	9.7	7.5	7.6
iR width	11.4	10.0	8.0	7.5
Column diameter at base of cup	—	6.7	5.7	4.7

* = approximate (due to crushing).

lar continuous with column lumen. Column articular facet forms narrow, crenulate shelf. **BB** five, heptagonal (B ray **B** can be octagonal) slightly wider than high; inflected medially forming lower cup margin; articulating with two **IBB**, two **BB**, two **RR**, one **iR**. **RR** five, A, B, E ray **RR** inverted pentagons, D ray **R** hexagonal, C ray **R** pentagonal or hexagonal; about as high as wide; typically articulating with two **BB**, two **iRR**, and one **IBr**. $\mathbf{IBr}_1$ typically hexagonal, about as high as wide, nearly as large as **RR**. $\mathbf{IBr}_2$ generally heptagonal, about as high as wide, smaller than $\mathbf{IBr}_1$, axillary. **IIBrr** become progressively smaller distally, $\mathbf{IIBr}_1$ usually slightly taller than wide, hexagonal; followed at least by four fixed **IIBrr**. Second **IIBrr** of same ray separated by hexagonal **iIIBr** which is followed by rows of two, then three **iIIBrr**. **iRR** large, as large as **RR**, heptagonal, about as high as wide to slightly wider than high; followed by approximately five or six **iIBr** rows; row articulating **iR** usually with two plates, then followed by two rows with three plates each. **iIBrr** diminish in size distally. CD interray slightly wider than other interrays, with more numerous plates. Primanal large, usually hexagonal. UI X-5740 with two roughly equisized pentagonal plates occupying primanal position, both abutting **B** below (Pl. 5, fig. 15). Primanal followed by row with three **iIBrr**, then row with three or four (rarely five) **iIBrr** (Pl. 6, fig. 5) and five or six additional rows with five to eight plates per row. Anal series not distinct. Tegmen unknown.

Arms poorly known; ten, long, slender, gradually tapering, uniserial, free above $\mathbf{IIBr}_5$, branching isotomously at least three times, with evenly rounded dorsal surfaces. Free **IIBrr** wedge-shaped, articulating along sides of arms with modified first pinnulars, which are incorporated, fixed, into primary arm structure (Pl. 5, fig. 9); fixed pinnulars give rise to free pinnulars along zig-zag suture pattern. Free **IIIBrr** and beyond uniserial, slightly cuneate becoming non-cuneate, without fixed first pinnulars. Free **Br** articular surfaces crenulate. Pinnules begin with initial free **IIBr**, given off alternatively from arms one per **Br**. Pinnules long, delicate, laterally compressed with attenuated aboral margin; ambulacral groove narrow, covered by alternating biseries of tiny coverplates; coverplates meet medially along zigzag suture. Pinnulars taller than wide, many per pinnule.

Column long, greater than 13.5 cm in SUI 46910, wide, heteromorphic; regions intergrade gradually. Proximal, medial column greater than 13.5 cm in length in SUI 46910, diameter subequal. Proximal column of thin closely-spaced nodals separated by four or five internodals; thinner, thicker nodals alternate along column length (Pl. 5, figs. 8, 17). Medial column with equisized nodals widely separated by as many as 12 internodals (Pl. 5, figs. 7, 19). Distal column rapidly tapering, much narrower than proximal, medial regions, of relatively thick nodals separated by four to six internodals. Nodals thin, with wide epifacets, medial column nodals with rounded margins; thin proximal nodals with sharp, attenuated margins; distal column nodals with low, evenly spaced distolaterally nodelike projections (Pl. 5, fig. 10). Internodals straight-sided, without epifacets. Columnal articulations crenulate symplectial; lumen large, circular.

Remarks.—*Archaeocrinus snyderi* n. sp. is similar to *Archaeocrinus subovalis* Strimple, 1953, from the Blackriveran Pooleville Member, Bromide Formation of Oklahoma (see Kolata, 1982, p. 183 for redescription of this species). The latter species differs slightly in having a relatively smaller basal concavity, cup sides with a greater expansion angle, relatively smaller **BB**, **RR** and **iRR**, fine pustules or radiating ridges on some lower cup plates, and proximal column nodals with short, distally curving spines. *Archaeocrinus buckhornensis* Kolata, 1982, from the Upper Mountain Lake Member, Bromide Formation of Oklahoma, has a similar high cup with low median ray ridges, and thin smooth flush cup plates, but differs most conspicuously in possessing a relatively much smaller basal concavity and smaller **RR** and **BB**.

Types and occurrence.—The holotype UI X-5740, and paratypes UI X-5717 through 5739, and 5741 through 5749, are from the *Sowerbyella - Diplograptus* Zone of the upper member, Lebanon Limestone, at locality Z-654. Paratype UI X-5750 is from the lower member of the Lebanon Limestone at locality Z-651. Paratype SUI 56910 is from the upper member of the Lebanon Limestone approximately 3 m below the Carters Limestone at locality Z-662. UI X-5740, 5743, and 5750 are figured and measured; UI X-5737, 5739, 5741, 5742, 5744, and 5745 are figured; UI X-5732 is measured.

Rhodocrinitid species A
Plate 6, figures 7, 10, 11

Remarks.—One poorly preserved partial crown, UI X-5752, represents this species. The aboral cup is apparently bowl-shaped with a basal concavity and low faint median ray ridges. Cup plates are smooth and thin; sutures are flush. **IBB** are unknown. **BB** are large and reflexed, indicating a basal concavity. **RR** are poorly preserved and apparently large, $\mathbf{IBr}_2$ is axillary. Interbrachial areas are moderately wide and reach the tegmen. Arms are free above $\mathbf{IIBr}_3$; **iIIBrr** are present. Free arms are biserial and branch isotomously a short distance above the cup (Pl. 6, fig. 10). **Brr** are cuneate, wider than tall with medial transverse indentations and slightly impressed sutures (Pl. 6, fig. 7). The column is large with thin closely-spaced nodals having wide epifacets and rounded margins.

This specimen most closely resembles *Archaeocrinus* Wachsmuth and Springer, 1881, as far as can be observed. The **Brr** with medial transverse indentations and impressed sutures distinguish this form from the only known Lebanon archaeocrinid, *Archaeocrinus snyderi* n. sp. The specimen is too poorly preserved to allow generic and specific assignment.

Types and occurrence.—The figured single specimen, UI X-5752 is from the lower member, Lebanon Limestone, at locality Z-651.

Genus **DIABOLOCRINUS**
Wachsmuth and Springer, 1897

?**Diabolocrinus** species A
Plate 6, figures 1, 2, 4

Remarks.—This species is represented by four small crowns with proximal columns (Table 7). The calyx is globular. The cup is bowl-shaped, about as wide as high to slightly wider than high with small basal concavity. Cup plates are smooth in most specimens, but may have faint radiating ridges in UI X-5794, sutures are flush. Median ray ridges are faint; interray areas are slightly depressed.

IBB, if present, are very small. Five large, hexagonal **BB** are about as high as wide, and articulate with two **BB**, two **RR**, one **iR** and possibly one **IB**; **BB** are infolded, forming the basal concavity. The basal concavity rim is slightly thickened. The five **RR** are large, pentagonal, typically wider than tall in larger specimens and about as wide as tall in smaller specimens and some larger specimens. **RR** articulate with two **BB**, two **iRR**, and one $\mathbf{IBr}_1$. **RR** through **IBrr** decrease in size distally. $\mathbf{IBr}_1$ is hexagonal, wider than tall, and smaller than **RR**. $\mathbf{IBr}_2$ is pentagonal, wider than tall, axillary, and smaller than **IBr**$_1$. Lateral interrays reach the tegmen; they consist of a large hexagonal to heptagonal interradial followed by rows of two, and then two or three **iIBrr**. The CD interray is known in UI X-5853; it is continuous with tegmen, wider than lateral interrays (Pl. 6, fig. 4). The primanal is taller than wide, hexagonal, followed by small plates arranged in rows of three, then five plates. The tegmen is unknown.

Ten arms, with length twice cup height, are cuneate, uniserial, and pinnulate. Arms are free above **IBr**$_2$ or **IIBr**$_1$. **Brr** are wider than tall in larger specimens and about as wide as tall in smaller specimens. Pinnules are long, one per **Br** and laterally compressed; pinnules begin on the interradial side of **IIBr**$_2$. Pinnules are denser, longer in larger specimens.

The column is round, heteromorphic and distally tapering; proximally, the column consists of thick nodals with wide epifacets and convex margins closely spaced between a variable internode of few thin narrow internodals. Columnals in the distal column of UI X-5767 are taller than wide, straight-sided and cylinder-like.

IBB were not seen in any of the specimens; however, they are inferred to have been present because: 1) the **RR** are separated all around by **iRR**; 2) the **BB** have straight lower facets suggesting articulation with another circlet of plates; and 3) column articular facets on the **BB** are apparently absent.

These specimens are provisionally assigned to *Diabolocrinus*. They resemble other known species of *Diabolocrinus* in having a similar basal concavity, basic cup plate arrangement, and arm number. They differ in possessing a relatively higher cup, few if any supplementary plates in the interrays, non-protuberant arm bases, relatively thinner arms, and a smaller known crown size. Among *Diabolocrinus* species, the forms described here are most like *D. oklahomensis* Kolata, 1982, from the Pooleville Member, Bromide Formation, Oklahoma. Both forms have simple interrays of an **iR** followed by two **iBrr**, small crown size, cuneate uniserial arms, and no or faint median ray ridges. The Oklahoma species differs in having cup plate ornament of sinuous ridges, a relatively wider cup, and thicker arms with protuberant arm bases.

The specimens assigned here are immature, or a paedomorphic species that did not significantly exceed in size the largest preserved specimen (Table 7). Suggesting early ontogenetic stages are: small size; **IBr**$_2$ and **IIBr**$_1$ are the last fixed **Brr**; relatively large **RR**, and few **iBrr** (see Brower, Lane, and Rasmussen, 1978, pp. T245, T253). If the specimens are immature, they have not developed many of the potentially diagnostic features found in adults. However, the relatively simple cup plate arrangement and arm number of *Diabolocrinus* does not differ significantly from that seen in these specimens and this genus could have given rise to a paedomorphic form such as this species. Because of the above uncertainties, these specimens are not assigned to species and only provisionally assigned to genus.

Table 7.—Measurements of three specimens of ?*Diabolocrinus* sp. A (in mm).

	UI X-5853	UI X-5767	UI X-5794
Dorsal cup height	3.8*	2.7	3.3
Dorsal cup width	4.1*	2.7	—
B height	1.6	0.9	0.9
B width	1.7	0.9	1.3
R height	1.3	0.7	1.1
R width	1.9	0.8	1.3*
Arm length	10.0*	4.9	7.0*
Column diameter at base of cup	0.9	0.7	0.7*

* = estimated.

Types and occurrence.—Four specimens were available: UI X-5767, 5794, 5795, and 5853. UI X-5767 and 5853 are measured and figured; UI X-5794 is measured. All specimens are from the lower member, Lebanon Limestone, at locality Z-654a.

Family unknown

Rhodocrinitacid species A

Plate 6, figures 8, 9

Remarks.—This species is represented by one extensively corroded calyx, UI X-5753, and a cup plate, UI X-5754. The cup is large, bowl-shaped, probably slightly wider than high (?), widest at the level of **IIBr**$_3$. Median ray ridges are prominent and narrow. Low broad ridges radiate from centers of distal **iRR** and **iIIBrr**; ridges abut across plates. Plates are flat to slightly convex and ornamented with very fine parallel ridges and small pustules (Pl. 6, fig. 9); ridges are perpendicular to and abut across plate boundaries; pustules can also be arranged in rows that are perpendicular to and abut across plate boundaries. Plate sutures are flush. **IBB** and **BB** are unknown. **RR** are large, apparently pentagonal; the median ray ridges on the **RR** form an inverted Y shape. **RR** are separated by **iRR**. **IBrr** are taller than wide; **IBr**$_1$ is hexagonal; **IBr**$_2$ is axillary. There are approximately four fixed **IIBrr**. **IIBr**$_2$ has a small ridge bifurcating off the larger ray ridge; the small ridge then passes upward toward the tegmen. **IIBrr** are apparently separated by **iIIBrr**. Interrays are wide and reach the tegmen. They consist of a large octagonal **iR** followed by ? three **iIBrr**. The tegmen is highly arched and acuminate with a distal (?)anal opening. Convex

Table 8.—Measurements of three specimens of *Abludoglyptocrinus gregatus* n. sp. (in mm).

	UI X-5964	UI X-5969	UI X-5998
Cup height	17.5	16.5	—
Cup width	16.5*	14*	—
B height	1.5*	1.6	1.5
B width	3.0	2.6	2.5
R height	3.4	2.8	3.5
R width	4.9	4.4	4.7
Column diameter at base of cup	3.0	2.4	2.8*

* = estimated.

lobes extend from the sides of the tegmen toward the free arms.

This species is assumed to be dicyclic because **RR** are separated by **iRR**. This inference, the strong ray ridges, and interrays contacting the tegmen all indicate this species is a rhodocrinitacid. It resembles *Pararchaeocrinus* Strimple and Watkins, 1955, of the Rhodocrinitidae, in having a row of three **iIBrr** following the **iR**, prominent ray ridges, and a small secondary ridge branching from the primary ray ridge on $\mathbf{IIBr}_2$. The aboral cup differs, however, in being higher than in any known species of *Pararchaeocrinus* and having different cup plate ornament. Insufficient material precludes generic and specific assignment.

Types and occurrence.—UI X-5753 is figured and from the upper member, Lebanon Limestone, at locality Z-653; UI X-5754 is from the *Sowerbyella - Diplograptus* Zone of the upper member, Lebanon Limestone, at locality Z-654.

Order **MONOBATHRIDA** Moore and Laudon, 1943

Family **GLYPTOCRINIDAE** Zittel, 1879

Genus **ABLUDOGLYPTOCRINUS** Kolata, 1982

Type species.—*Glyptocrinus charltoni* Kolata, 1975, p. 49.

Emended diagnosis.—A glyptocrinid with 10 uniserial arms; arms free above $\mathbf{IIBrr}_{3-6}$; median ray, anal ridges, present; cup ornamented with small pustules and ridges or unornamented, smooth.

Remarks.—The original generic diagnosis is here altered slightly to encompass the new species. At the time of the original diagnosis, only species with free arms above $\mathbf{IIBrr}_{3-5}$ were known; the free arms in *A. gregatus* n. sp. arise above $\mathbf{IIBr}_{5,6}$.

Abludoglyptocrinus gregatus new species
Plate 6, figures 12–18

Etymology of name.—*gregatus* (L.) = to collect, or assemble. This refers to the occurrence of the hypodigm in a single "garden," or pod.

Diagnosis.—A species of *Abludoglyptocrinus* characterized by a bowl-shaped cup, slightly higher than wide; median ray, anal ridges low, rounded; **BB** small, much wider than tall; lateral interrays narrow, **iR** followed by rows of two, and one or two **iIBrr**.

Description.—Cup moderate-sized (Table 8), bowl-shaped, slightly higher than wide to nearly as wide as high. Cup plates flat, can be slightly convex, smooth flush sutures. Median ray ridges low, evenly rounded, become more prominent distally.

BB five, small, much wider than high. Sharp rim projects laterally from lower margin of each **B**; rims form flat subcircular surface lateral to column articular facet (Pl. 6, figs. 13, 18). **RR** five, largest plates in cup, wider than tall, heptagonal, contacting two **BB**, two **RR**, two **iRR**, one **IBr**. $\mathbf{IBr}_1$ hexagonal or pentagonal, wider than high. $\mathbf{IBr}_2$ axillary, wider than high to about as high as wide, pentagonal or hexagonal. $\mathbf{IIBr}_1$ through $\mathbf{IIBr}_{5\,or\,6}$ fixed, wider than high; $\mathbf{IIBr}_2$ with fixed pinnule branching off interray side; small ridge runs longitudinally, medially along each fixed pinnule, ridge abuts median ray ridge at $\mathbf{IIBr}_2$. **iIIBrr** small, arrangement variable: can be in rows of: one, two, and two; one, one, and two; one, one, and one; two, one, and two plates. Lateral interrays flat to slightly depressed, relatively narrow (Pl. 6, figs. 13, 18), of 10 to 12 plates at least; **iR** large; followed by rows of two or rarely one, then two or less commonly one **iIBrr**. CD interray wide, median anal ridge low, wide, of six or seven plates (including primanal) in longitudinal series, gradually diminishing in size distally, extending to tegmen. Ridge bifurcates aborally, extends faintly onto C,D ray **RR**. Primanal large, heptagonal to hexagonal; plates above primanal arranged in rows of three or four, four, and then six plates. Tegmen poorly known, of many small subpolygonal convex plates.

Arms ten, longer than cup height, uniserial, densely pinnulate (Pl. 6, fig. 16). **Brr** evenly rounded, cuneate, much wider than high; articulation surfaces between **Brr** crenulate. Pinnules slender; pinnulars taller than wide, compressed.

Column round, long, heteromorphic. Proximal column of thin nodals closely spaced between thin internode; nodals with wide epifacets, attenuated margins; internode of few thin straight-sided secundinternodals subequally disposed on either side of single priminternodal (Pl. 6, fig. 15); priminternodals resemble nodals but thinner with narrower epifacets; internode can be of few straight-sided internodals only. More distal column of thin nodals widely separated by eight to 17 thin internodals. Nodals with wide epifacets; margins rounded with numerous low distally (?) curving low projections (Pl. 6, fig. 17). Internodals with straight sides, no epifacets. Articulations symplectial; distal lumen pentastellate; angles rounded.

Remarks.—Abludoglyptocrinus gregatus n. sp. is similar to *A. charltoni* (Kolata, 1975), from the Blackriveran Platteville Group of northern Illinois. The latter species differs in possessing a slightly wider, lower cup, wider lateral interrays; and in having lateral interrays arranged in one, two, three plates per row pattern instead of a one, two, two or one, one, two pattern. The two species are remarkably similar in all other respects.

A. ornatus (Billings, 1857) from the Trenton Ottawa Formation at Ottawa and Kirkfield, Ontario, differs in possessing fine ridges on cup plates; the ridges radiate from plate centers in stellate patterns. *Abludoglyptocrinus insperatus* (Rowley, 1904) from the lower Silurian Edgewood Limestone, Pike County, Missouri, differs in having larger, taller **BB** with elevated **Y**-shaped ray ridges and the **iRR** have a single centrally-located pustule. *A. pustulosus* (Kolata, 1975) from the Platteville Group, northern Illinois, has a narrow conical cup and prominent pustulose plate surfaces in areas between prominent median ray ridges. *A. laticostatus* Kolata, 1982, from the Pooleville Member, Bromide Formation, Oklahoma, is also similar to the new species but differs most conspicuously in possessing highly elevated median ray ridges and pustulose ornamentation in depressed areas between ridges.

Types and occurrence.—The holotype, UI X-5964, and paratypes UI X-5963, 5965 through 5973, and 5994 through 6003 are from the upper member, Lebanon Limestone, at locality Z-653. UI X-5964, 5969, and 5998 are figured and measured; UI X-5995 through 5997 are figured. Columnals probably referable to this species occur at many localities and horizons in the Lebanon Limestone.

Subclass **INADUNATA**
Wachsmuth and Springer, 1885

Order **DISPARIDA** Moore and Laudon, 1943

Remarks.—The classification of the Disparida used in the *Treatise on Invertebrate Paleontology* (Moore *et al.*, 1978) and by most modern workers is that of Moore (1962b), who divided this diverse group into superfamilies based on planes of symmetry within the cup. Symmetry planes are determined using the number and position of biradials. Recently, Frest, Strimple, and McGinnis (1979, p. 412) criticized this approach. They cite examples among the Disparida of 1) a genus (*Abyssocrinus* Strimple, 1963) having variable numbers of biradials, 2) lineages, based on other characters, such as cup shape, that apparently lose infraradials (*Apodasmocrinus* Warn and Strimple, 1977 - *Difficilicrinus* Frest, Strimple, and McGinnis, 1979), and 3) genera that have simple **RR**, which are shown to be comprised of fused biradials because the plates retain signs of sutures. Frest, Strimple, and McGinnis also incorporate *Difficilicrinus* into the Homocrinacea even though the genus has compound **RR** in the B and E rays only, rather than in B, C, and E rays, as typical of homocrinaceans (*sensu* Moore, 1962b). *Tryssocrinus* n. gen. from the Lebanon supports the views of Frest, Strimple, and McGinnis, in that this genus closely resembles *Daedalocrinus* Ulrich, 1925 (Trentonian, Ontario) in cup shape, and column and arm morphology but differs in the number and position of biradials. (*Tryssocrinus* has biradials in the C and E rays; *Daedalocrinus* has them in the B, C, and E rays.) In accordance with the concepts of the *Treatise*, the two genera would be placed in different superfamilies even though they are similar in other characters. Position and number of compound radials, therefore, appears to be a more variable feature than previously thought and as a result the superfamilial classification based essentially on this feature alone apparently does not reflect natural groupings of the disparids. Revision of the Disparida is needed and suprageneric classification should incorporate such other characters as cup shape, arm and column morphology as well as number and position of biradials. Such a revision, however, demands extensive research that goes far beyond the scope of this study and therefore the *Treatise* classification has been used here for the Lebanon disparids.

Superfamily **HOMOCRINACEA** Kirk, 1914

Family **HOMOCRINIDAE** Kirk, 1914

Genus **APODASMOCRINUS**
Warn and Strimple, 1977

Type species.—Apodasmocrinus daubei Warn and Strimple, 1977.

Apodasmocrinus species cf. **A. daubei**
Warn and Strimple, 1977
Plate 7, figures 6, 14, 15

Apodasmocrinus daubei Warn and Strimple, 1977, pp. 93–96, text-figs. 21, 22a–c; Warn, 1982, pp. 78–81, pl. 4, figs. 13–30.

Remarks.—A single well-preserved crown, with column attached and largely buried in a hard matrix is referred to this species. The Lebanon specimen is similar to the type and referred specimens from the middle and upper Mountain Lake Member, Bromide Formation, Oklahoma (see Warn, 1982). It differs from most Oklahoma specimens in possessing shorter **RR**. Oklahoma specimens are described as having simple **RR** approximately 1.25 times taller than wide (Warn, 1982, p. 80) whereas the D ray simple **R** in the Lebanon Limestone specimen is approximately 1.25 times wider than tall. This feature is variable among Oklahoma specimens, however, and Warn (1982, pl. 4, figs. 15–16) figures a specimen with approximately the same simple **R** width to height ratio (1.25) as the Lebanon specimen. The Lebanon Limestone specimen apparently also differs from Oklahoma specimens in possessing a subround rather than subpentagonal proximalmost column. As far as can be compared, the Lebanon specimen otherwise closely resembles those from Oklahoma. These differences are considered insufficient for erection of a new species.

The Lebanon Limestone specimen possesses a column known over a greater length than other specimens of *A. daubei*; 7.5 cm is preserved, and it appears to be nearly complete (Pl. 7, fig. 14). The column is heteromorphic and gradually changing. It is of moderate length, greater than 2.5 times the approximate crown height; wide, about two-thirds as wide as the cup proximally; tapering gradually away from the second nodal below the cup. The columnals are apparently solid proximally within 1 cm of the crown, divided into pentameres from 1 to 6.5 cm beyond the crown, and apparently solid in the remaining distal 1 cm of preserved column. The medial column from approximately 3 to 5.5 cm below the crown has longitudinal striations adjacent to and symmetrically disposed across lateral pentamere articulation surfaces: there are two striations per articulation surface proximally and increasing to four distally. Within the first cm from the crown, nodals are subround to subpentagonal with wide rounded latera. They gradually become rounded, pentalobate from approximately 1.5 to 6 cm below the crown with lateral pentamere sutures in the depressed regions between the lobes. Lobes become lower, less protruding distally. Internodes vary in thickness from much thinner than adjacent nodals near crown, to slightly thicker than adjacent nodals in the medial column region, to slightly thinner than adjacent nodals in the distal column region. There are typically three internodals per internode in the medial column and these consist of two pentagonal, nearly straight-sided secundinternodals separated by a thicker wider subpentalobate priminternodal. Distal internodes are composed of a single convex internodal. The distalmost 1 cm of column as preserved is composed of subequal-sized and -shaped pentagonal columnals that are slightly convex-sided and have slightly impressed sutures between adjacent columnals. Articulae appear to be cryptosymplectial. No holdfast is visible.

Measurements (in mm).—Cup height = 4.6; cup width = 4.5; DE **B** height = 1.5; DE **B** width = 2.1; D **R** height = 2.2; D **R** width = 2.8; E **iR** height = 1.2; E **iR** width = 2.4; E superradial height = 2.0; E superradial width = 2.3; column diameter at base of cup = 2.1.

Types and occurrence.—The single figured and measured specimen, UI X-5714, is from the *Sowerbyella* - *Diplograptus* Zone, upper member, Lebanon Limestone, locality Z-652.

Superfamily **CALCEOCRINACEA**
Meek and Worthen, 1868

Family **CALCEOCRINIDAE**
Meek and Worthen, 1868

Genus **CREMACRINUS** Ulrich, 1886

Type species.—*Cremacrinus punctatus* Ulrich, 1886, pp. 106–107, fig. 1.

Cremacrinus species cf. **C. punctatus** Ulrich
Plate 7, figures 1, 2, 7

Cremacrinus punctatus Ulrich, 1886, pp. 106–107, fig. 1; Sardeson, 1928, p. 35, pl. 1, figs. 6–8; Moore, 1962a, pl. 21, figs, 3a, b; Brower and Veinus, 1978, pp. 467–470, pl. 18, figs. 1–10.

Remarks.—Two specimens are assigned to this species, UI X-5891 and UI X-5892. UI X-5892 (Pl. 7, figs. 1, 2) is a crown with distal arms missing; UI X-5891 (Pl. 7, fig. 7) is a crown and proximal column largely buried in hard matrix. UI X-5891 differs from UI X-5892 in having more tumid cup plates, and a thicker E ray; the two specimens are otherwise similar insofar as can be compared. Kolata (1975, pp. 21, 23) has noted considerable intraspecific variation among specimens of *Cremacrinus arctus* Sardeson, 1928, from the Platteville Group, northern Illinois. Both Kolata (1975, pp. 21, 23) and Brower and Veinus (1978, p. 459) studied ontogeny in *Cremacrinus arctus* from northern Illinois and the Minneapolis–St. Paul area of Minnesota, respectively. They found that cup and arm plates in this species become relatively thicker, more tumid in older, larger specimens. Because of these studies, it is here considered that the differences between the Lebanon specimens are probably due to intraspecific and (or) ontogenetic variation. It is possible, however, that the specimens belong to two closely related species.

UI X-5892 differs in no significant way from specimens assigned to *Cremacrinus punctatus* Ulrich, 1886, from the early Trentonian Decorah Shale, Minneapolis, Minnesota, and Escanaba, Michigan whereas UI X-5891 is also similar except for the unusually thick E ray (Pl. 7, fig. 7). *Cremacrinus* sp. described by Kolata (1975, p. 24) from the Blackriveran Grand Detour Formation, northern Illinois, closely resembles UI

X-5891 in possessing a thick E ray. The Illinois specimen differs slightly from both Lebanon specimens in possessing thicker arms other than in the E ray as well as slightly coarser punctate ornament. Kolata noted the resemblance of his specimen to *C. punctatus*.

Types and occurrence.—UI X-5891 is from the lower member, Lebanon Limestone, at locality Z-652 and UI X-5892 is from the (?)upper member of the Lebanon Limestone at locality Z-651. Both specimens are figured.

Superfamily **CINCINNATICRINACEA** Warn and Strimple, 1977

Remarks.—The description and diagnosis of the superfamily by Warn and Strimple (1977, p. 28) is accepted as given except for additions made necessary by new forms described herein. Radials are typically of regular pentagonal shape with one vertex pointed downward, but can be other shapes such as asymmetrical hexagons, heptagons (as in, *e.g., Tryssocrinus* n. gen.). Branching of the arms beyond the initial isotomous bifurcation can be isotomous, alternating heterotomous, or endotomous heterotomous (*Tryssocrinus* n. gen.).

Modes of life.—Two Lebanon Limestone cincinnaticrinaceans, *Tryssocrinus endotomitus* n. gen. et sp. and *Columbicrinus crassus* Ulrich, 1925, are known from complete composite reconstructions. They had similar life modes that differ significantly from that postulated for *Cincinnaticrinus* Warn and Strimple, 1977 (Warn and Strimple, 1977, p. 53). The latter genus apparently broke free (autotomized) from an encrusting discoidal type holdfast and as an adult was free living, trailing a long column as a stabilizer. *Tryssocrinus* and *Columbicrinus* as adults had long columns (approximately 15 to 20 cm in *Tryssocrinus endotomitus* and approximately 40 to 50 cm in *Columbicrinus crassus*) that were attached by a dorsally multiplated holdfast ("*Podolithus*" type of Sardeson, 1908, and type 1C of Lewis, 1982). The proximal eight- to nine-tenths of the column in these forms is composed of solid columnals or pentamere circlets that are tightly articulated and are typically preserved intact with little or no curvature. The articulae are cryptosymplectial and the lumen is small. The distalmost column in these species is composed of five relatively loosely-articulated vertical series of plates; the plates alternate with laterally adjacent plates forming zigzag sutures; the lumen is large, the articulae are cryptosymplectial. The distal columns were often disarticulated or broken before burial and typically show more curvature than the proximal columns. The evidence suggests, therefore, that orientation of the crown in *Tryssocrinus* and *Columbicrinus* was accomplished mainly through flexure of the distal column and that the long semi-rigid proximal column section enabled the crown to reach higher feeding levels.

Family **CINCINNATICRINIDAE** Warn and Strimple, 1977

Subfamily **CINCINNATICRININAE** Warn and Strimple, 1977

Genus **DOLIOCRINUS** Warn, 1982

Type species.—*Doliocrinus pustulatus* Warn, 1982.

Emended diagnosis.—Cincinnaticrininae with a relatively broad low conical to subconical nearly straight- to slightly convex-sided cup; cup plates tumid to slightly convex, smooth or with coarse pustulose ornament, sutures impressed to flush; AB ray **B** symmetrical pentagonal, other **BB** typically slightly asymmetrical pentagonal; compound **RR** relatively short, about as tall as wide to slightly taller than wide; small **iBrr** between **IBrr**$_1$, proximal AB **iR**, abuts both A and B ray **RR** along short sutures; arms non-pinnulate, isotomously branching. **IBrr**$_3$ axillary.

Remarks.—The generic diagnosis provided by Warn (1982) is emended to accommodate the new species described here and to more fully differentiate the genus. *Doliocrinus* closely resembles *Isotomocrinus* Ulrich, 1925, in the nature of the primary cup plate arrangement and arm branching pattern. The former differs, however, in possessing a relatively wider cup and shorter compound **RR**, in having small **iBrr** (particularly prominent in the AB interray), and in having the first arm bifurcation on **IBrr**$_3$ (in *D. monilicaulis*, at least) instead of **IBrr**$_{4\ to\ 6}$.

Doliocrinus monilicaulis new species

Plate 7, figures 8, 9; Text-figure 6

Etymology of name.—*monilis* (L.) = necklace, string of pearls, *caulis* (L.) = stem; the specific epithet refers to the nature of the column in this species.

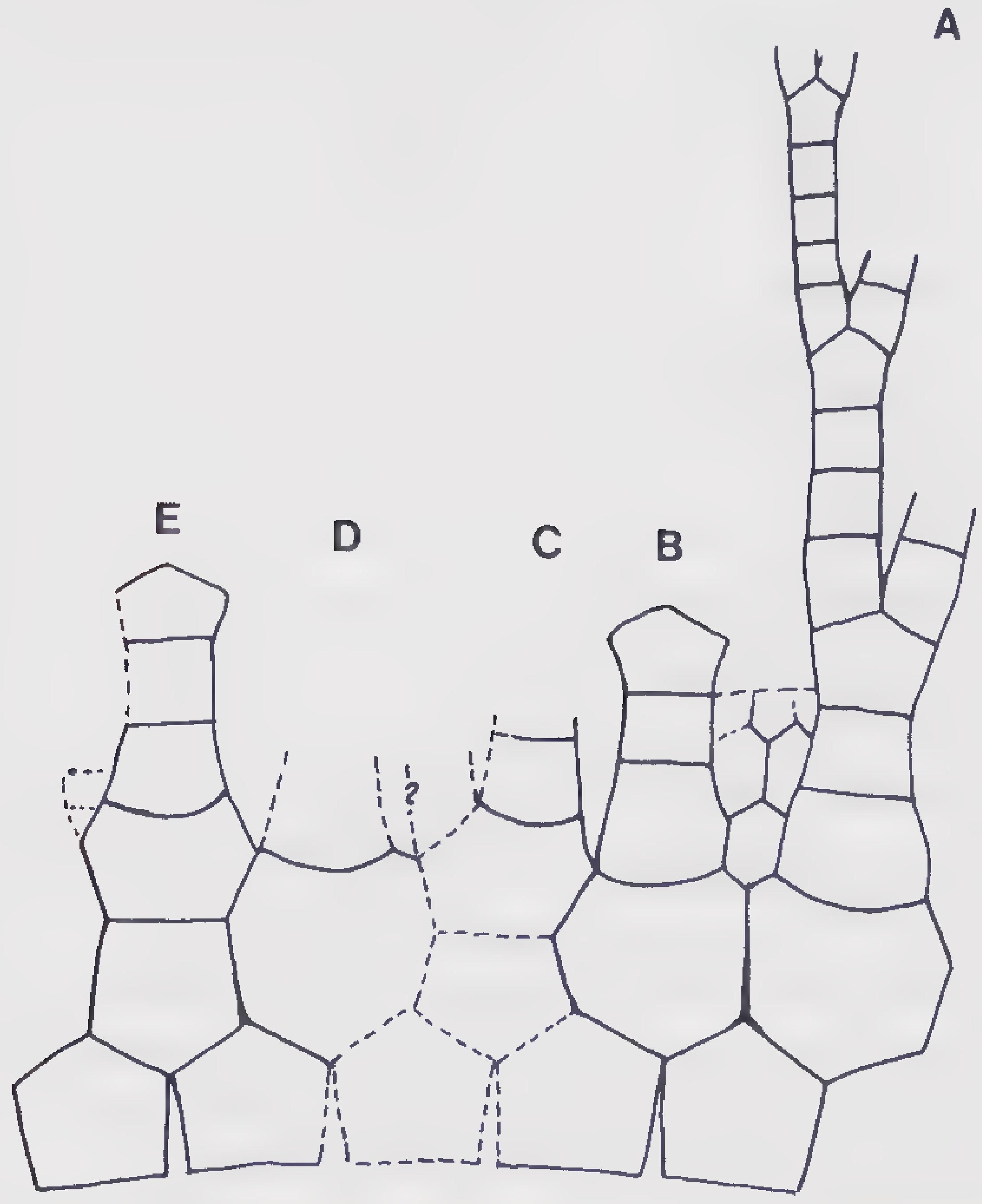
Diagnosis.—A species of *Doliocrinus* characterized by a moderate-sized crown with smooth, flush cup plates; round proximal column with smooth columnals.

Description.—Crown moderate-sized (see Measurements); cup steeply conical but with rapidly diverging nearly straight sides, about as high as wide, widest distally. Cup plates smooth, slightly convex, sutures flush.

BB five, subequal-sized, pentagonal, about as high as wide to slightly higher than wide; AB interray **B** symmetrical, other **BB** slightly asymmetrical because of slightly larger facets where abutting biradials. **RR**

five, two biradials (C, E rays), three simple (A, B, D rays). Radial facets deeply arcuate, not as wide as **RR**. Biradials much taller than simple **RR**, extend nearly to top of $\mathbf{IBr}_1$ in rays with simple **RR**, sides notched for insertion of vertices from simple **RR**. Simple **RR** large, about as tall as wide, asymmetrical heptagons; A, B ray **RR** mutually abut across straight suture. E ray **iR** inverted symmetrical pentagon, slightly taller than E ray **sR**; E ray **sR** obscure hexagon, slightly wider than E ray **iR**. C ray biradial only partly exposed, slightly shorter than E ray biradial; **iR** shorter than **sR**, also shorter than E ray **iR**. Small polygonal **iBrr** fill V-shaped gaps between $\mathbf{IBrr}_1$, **sRR**; extend farthest proximally in AB interray where hexagonal **iBr** fills notch between distal A, B ray **RR**, then followed by two irregular polygonal plates (Pl. 7, fig. 9). Tegmen obscured, apparently highly vaulted. Anal series unknown; anal tube apparently of irregular, small polygonal plates.

Arms long, approximately four times as long as cup height, slender, non-pinnulate, branching isotomously four to five times. **Brr** with evenly rounded dorsal surfaces; **Brr** beyond **IBrr** can be ornamented with faint, irregular, sublongitudinal ridges; $\mathbf{IIBrr}_1$ and $\mathbf{IIBrr}_2$ pairs appressed; some **IBrr**, **IIBrr** with narrow ventrolateral shelves, shelves can abut across **Brr**. **IBrr** widest at proximal $\mathbf{IBrr}_1$, tapering to $\mathbf{IBrr}_2$, then expand again at axillary $\mathbf{IBrr}_3$; $\mathbf{IBr}_1$ fixed, A, E ray **IBrr**, wider than high, B ray $\mathbf{IBr}_1$ about as high as wide; $\mathbf{IBrr}_3$ typically slightly wider than high, variable. $\mathbf{IIBr}_{3\text{ to }4}$ axillary; **IIBrr** approximately as tall as wide, variable. $\mathbf{IIIBrr}_{3\text{ to }5}$ axillary; **IIIBrr** taller than wide, variable. **IVBrr**, **VBrr** typically taller than wide; **IVBrr** numerous along each arm branch.



Text-figure 6.—*Doliocrinus monilicaulis* n. sp., plate diagram of cup, showing arm branching pattern. Dashed lines indicate not exposed; from holotype UI X-5716, ×2.5.

Proximal 4.5 cm of column known; round; distally expanding. Columnals smooth; single nodals alternate with single much thinner, narrower internodals; external expression of point of abutment between nodals and internodals smooth curve (without distinct topographic break) (Pl. 7, fig. 8). Nodals thick, distally enlarged; proximally with low, rounded, evenly curved latera; distally becoming bulbous, bead-like, with wide evenly curved latera. Distalmost two nodals with faint longitudinal indentations indicating ?fused pentameres. Internodals thin, straight to slightly concave-sided, nearly as wide as nodals proximally, becoming much narrower than nodals distally, forming narrow necks between bulbous nodals. Lumen small, possibly pentagonal. Distal column, holdfast unknown.

Remarks.—*Doliocrinus monilicaulis* n. sp. has a similar cup plate arrangement to *D. pustulatus* Warn, 1982, from the Lower Echinoderm Zone, Mountain Lake Member, Bromide Formation, Oklahoma. The Oklahoma species is easily distinguished, however, by its coarse pustulose plate ornament, impressed cup sutures, and non-bulbous pustular columnals, and relatively shorter simple **RR**.

Types and occurrence.—The figured and measured holotype and only specimen, UI X-5716 is from the lower member of the Lebanon Limestone at locality Z-654a.

Measurements (in mm).—Height is first, width second for each pair of plate measurements. Crown length = 23.8*; cup height = 4.5; cup width = 5.2*. **BB**: AB = 1.7, 1.7; BC = 1.7, –; EA = 1.7, 1.5. **RR**: A = 2.1, 2.1; B = 1.9, 2.1; C **sR** = 1.4, –; E **iR** = 1.6, 1.4; E **sR** = 1.5, 1.8. Column diameter at base of cup = 2.3 [* = estimated].

Genus COLUMBICRINUS Ulrich, 1925

Type species.—*Columbicrinus crassus* Ulrich, 1925, p. 91, fig. 8.

Emended diagnosis.—Cincinnaticrininae with ten long pinnulate arms, **Brr** beyond bifurcation uniserial, cuneate. **BB** nearly as tall as or taller than undivided **RR**, obscurely hexagonal in side view. **IBrr** much shorter than **RR**.

Remarks.—Ulrich (1925, p. 91, fig. 8) described *Columbicrinus* from a single cup and proximal arms through **IBrr** and parts of **IIBrr** in A and B rays (Pl. 7, figs. 3, 4). The only locality and horizon data available for Ulrich's specimen is "lower half of the Leb-

Table 9.—Measurements of ten specimens of *Columbicrinus crassus* Ulrich (in mm).

	USNM 89826 (holotype)	UI X-5704	UI X-5705	UI X-5706	UI X-5707	UI X-5708	UI X-5709	UI X-5711	UI X-5712	UI X-5713
Cup height	9.5	12.0	11.0	8.0	10*	9.0	—	6.7	6.5*	6.6
Cup width	9.3	11.2	10.8	8.5	10*	8.3	8.3	8.0	7.0	7.3
AB **B** height	5.2*	6.8	6.3	4.5	—	—	—	4.0*	—	—
AB **B** width	4.7	6.0	5.7	4.2	—	—	4.2	4.0	—	3.4
A **R** height	5.3	6.3	6.3	4.7	—	5.0	4.1*	4.0	—	3.2
A **R** width	5.0	5.8	5.8	4.9	—	5.5	4.7*	4.7	—	4.0
B **R** height	5.5	6.7	6.3	4.7	—	—	4.0*	4.4	—	3.9
B **R** width	5.0	6.3	6.2	4.8	—	—	4.7*	4.3	—	4.0
C **iR** height	3.4	5.0	4.7	3.5	4.0	—	3.5	3.5	2.5	2.8
C iR width	5.9	6.0	6.1	4.5	5.4	—	4.3	4.5	3.2*	3.5
C **sR** height	3.5	3.7	3.5	2.5	3.1	—	2.5	2.5	—	2.3
C **sR** width	4.8	6.5	5.5	4.7	5.5	—	4.6	4.4	3.5*	4.0
D **R** height	5.5	6.8	6.3	4.3	5.3	—	4.8	4.3	3.4*	4.0
D **R** width	5.7	7.5	7.3	5.7	6.5	—	6.0	5.1	4.1	4.3
E **iR** height	3.7	5.0	4.5	3.3	—	4.1	3.7	3.2	2.7*	3.0
E **iR** width	4.8	6.3	5.7	4.7	—	5.5	4.4	4.3	3.2*	3.5*
E **sR** height	2.6	3.0	3.0	2.3	—	2.1	2.0	1.9	2.2*	1.9
E **sR** width	5.0	5.8	5.3	4.5	—	5.0	4.5	3.8	3.0*	3.1
Width of column at base of cup	5.3*	6.0	6.3	4.5	—	4.3	—	5.2	3.8	—
Crown height	—	—	73	60*	85	75	40*	55*	—	48

* = estimated.
** = mean value.

anon Limestone, Columbia, Tennessee." Warn and Strimple (1977, p. 31) considered *Columbicrinus* unrecognizable because the type lacks distal arms and column. Frest, Strimple, and McGinnis (1979, p. 408) followed this view and named a new genus, *Praecursoricinus,* based on more complete material from the upper Mountain Lake Member, Bromide Formation, of Oklahoma. The authors noted that *Praecursoricrinus* has the same basic cup and proximal arm plating arrangement as *Columbicrinus.* (See remarks under *C. crassus* for a comparison of the two forms.) Their criteria for taxon recognition are not clear, however; in the same paper (p. 413), these authors base a new genus, *Difficilicrinus,* on the cup alone, material less complete than the holotype of *Columbicrinus.* I have collected 15 additional specimens that I believe to be conspecific with Ulrich's type. Twelve of these specimens were found in the lower member and one in the upper member of the Lebanon, within 10 km of Columbia (loc. Z-654); two specimens are from the lower member and one is from the upper member near Nashville, Tennessee (loc. Z-651). Several of the new specimens are complete crowns with proximal column. All specimens with cup and proximal arms have plate arrangements essentially identical to those of the holotype of *Columbicrinus.* Further, there are no significant arm structure variations among the more complete new specimens. The holotype of *Columbicrinus crassus* is in the mid-size range of the new specimens. No other known crinoid in the Lebanon could be easily confused with *Columbicrinus.* I therefore consider *Columbicrinus* to be readily recognizable and *Praecursoricrinus* Frest, Strimple, and McGinnis, 1979, is a junior synonym; it is therefore suppressed. *Praecursoricrinus sulphurensis* Frest, Strimple, and McGinnis, 1979, is herein reassigned to *Columbicrinus sulphurensis.*

Columbicrinus crassus Ulrich, 1925
Plate 7, figures 3–5, 10–13, 16;
Plate 8, figures 1, 2, 4, 6–10, 17; Text-figure 7

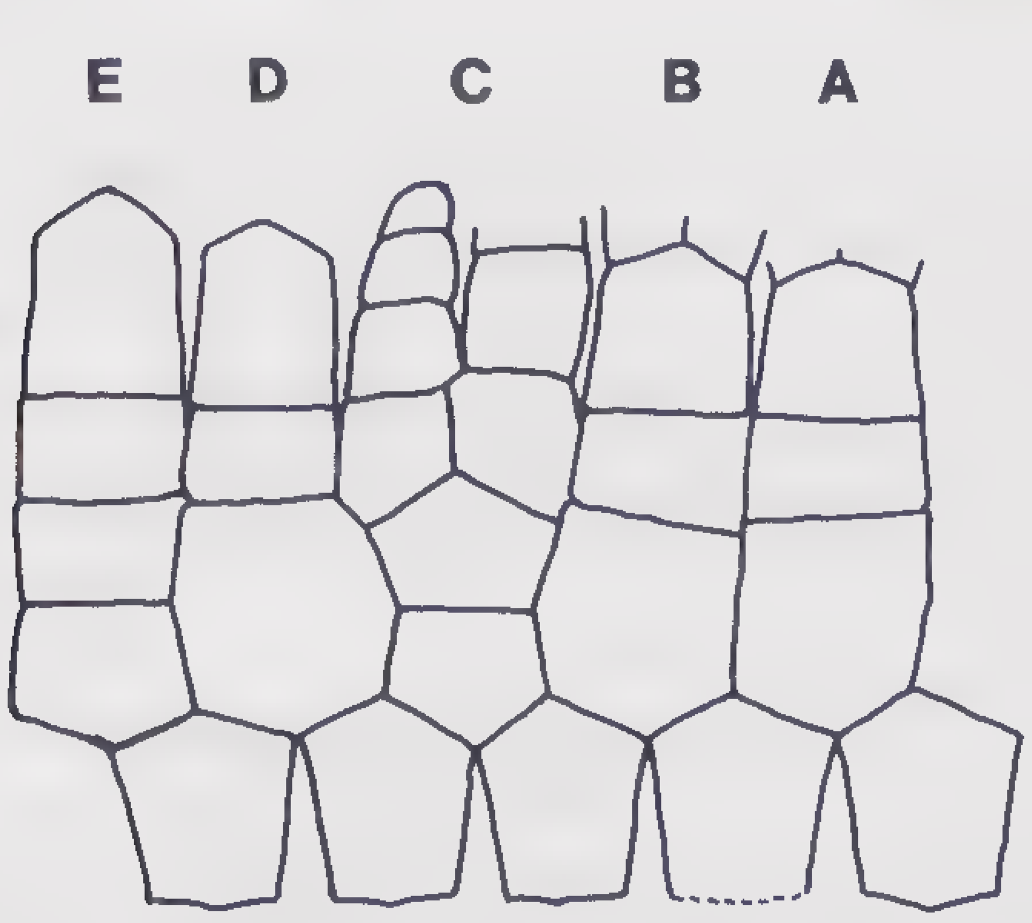
Columbicrinus crassus Ulrich, 1925, p. 91, fig. 8.
Columbicrinus crassus Ulrich. Moore, 1962b, p. 13, fig. 5, no. 5.
Unrecognizable crinoid. Warn and Strimple, 1977, p. 31, pl. 2. figs. 6–7.
Columbicrinus crassus Ulrich. Moore *et al.,* 1978, p. T549, fig. 342, nos. 4a, b.
Unrecognizable crinoid. Frest, Strimple, and McGinnis, 1979, p. 408.

Diagnosis.—*Columbicrinus* with moderate to large crown, up to 85 mm in height; **BB** about as tall as simple **RR**; simple **RR** nearly as wide as high to wider than high; **sRR** much wider than high, shorter than **iRR**; $\mathbf{IBrr}_{2,3}$ axillary; proximal column round to obscurely pentagonal.

Emended description.—Crown moderate to large (Table 9). Cup higher than wide, maximum cup width at **RR** tops approximately 2.2 times as broad as proximalmost column; steeply obconical with sides distinctly to slightly convex; slightly oval in transverse section, variable, with major axis from C ray or BC interray through EA interray, minor axis from AB interray through D ray. A, B ray side of cup typically indented at level of **RR**, **IBrr**$_1$. Sutures deeply to slightly impressed, plates smooth, thick.

BB five, subequal, higher than wide to approximately as high as wide, symmetrical to slightly asymmetrical hexagons with one vertex each pointing up and down, lower vertex obscure; sides diverge slightly distally; upper shoulders typically slightly unequal, with shoulders bordering **iRR** largest. **RR** five, biradials in C, E rays, simple in A, B, D rays; biradials extend slightly beyond simple **RR** in both aboral and adoral directions; **R** facets fully as wide as **RR**. A ray **R** symmetrically pentagonal to obscurely hexagonal (obscure vertex along side to accommodate E ray biradial), typically slightly higher than wide, can be approximately as high as wide. B ray **R** asymmetrically hexagonal, approximately as high as wide, **R** facet tilted slightly away from C ray (to accommodate anal series). C ray **iR** symmetrical inverted pentagon, wider than high; higher than, typically slightly narrower than C ray **sR**. C ray **sR** upright asymmetrical pentagon, much wider than high; **R** facet wider than facet for **X**$_1$, slightly narrower than other **R** facets. D ray **R** very large, widest plate in cup, wider than high, asymmetrical, obscurely octagonal to heptagonal; vertices on plate sides form wide angles; abuts **X**$_1$. E ray **iR** inverted symmetrical pentagon, wider than high; higher, slightly wider than E ray **sR**. E ray **sR** quadrangular, much wider than high, nearly straight-sided, or sides expanding slightly distally.

Anal series short, incurved; slightly narrower than adjacent arms proximally, tapering rapidly distally; of six or (?)seven plates in some specimens, apparently as few as four in others. **X**$_1$ inverted subpentagon, lower, lateral margins curved, inserted in notch formed by upper left shoulder of C ray **sR**, upper right shoulder of D ray **R**. **X**$_{2\text{ to }5}$ quadrangular, wider than high to about as wide as high.



Text-figure 7.—*Columbicrinus crassus* Ulrich, plate diagram of cup. Holotype USNM 89826, ×2.5.

Arms ten, uniserial cuneate, pinnulate; long, approximately six to ten times longer than cup height; slender, tapering slightly, gradually over most of length, rapidly near distal tips. **IBr**$_{2\text{ or }3}$ axillary; **IBrr** distally tapering (primaxil can expand slightly), stout, thick. **IBrr**$_1$ wider than high, **IBrr**$_2$ much higher than wide when axillary, approximately as high as wide when non-axillary; primaxil slightly constricted laterally, distally. **IIBrr** subquadrangular proximally, becoming wedge-shaped, cuneate beyond **IIBr**$_{2\text{ to }10}$; up to 90 per arm. Pinnules given off alternately from **IIBr**$_{3\text{ or }4}$ and beyond, inserted into notches on lateral sides of **Brr**. Pinnules large, long, laterally compressed, each with as many as 12 subrectangular pinnulars.

Column heteromorphic, long, greater than 30 cm long in UI X-5710 (distal portion illustrated on Pl. 8, fig. 17); narrow, from one-half to five-eighths as wide as cup near cup; round to obscurely pentagonal over proximal, medial column; distally becoming subpentalobate and finally pentagonal by distal column. Column typically expands for 4 to 8 cm, then tapers slightly toward holdfast, finally expands slightly for approximately last 0.5 cm before holdfast. Proximal, medial column of solid columnals, medial distal column (3 to 7 cm of column length) of pentameres, distalmost column of longitudinal plate rows. Column length, columnal size, shape variable among specimens (compare Pl. 7, figs. 5, 11, 12 and Pl. 8, fig. 9). Nodals large, thick; only slightly wider than adjacent internodals with slight convex latera near crown, becoming wider than adjacent internodals with prominent convex rounded latera distally. Distal nodals subpentalobate in outline, pentamere articulations in vertical notches between lobes; can have one or two faint striations on either side of distal lateral pentamere articulations. Internodes low, straight or slightly convex-sided, typically not as thick to rarely slightly thicker than adjacent nodals; typically one columnal per internode, occasionally up to three internodals with middle priminternodal intermediate between typical nodals and internodals in size. Nodals and internodals become compressed distally with internodes eventually being concealed between abutting nodals; grade transitionally into distalmost column. Distalmost column of distally thinning, greatly compressed pentameres, with low convex latera, abut adjacent rows along irregular to zigzag sutures. Proximal, medial column lumen small, quinquestellate, vertices correspond to pentamere articulations distally.

Holdfast discoidal, dorsally multiplated; plates small subpolygonal, tightly abutting along flush sutures; column facet 3 to 4 mm in diameter among three specimens.

Remarks.—*Columbicrinus crassus* resembles *C. sulphurensis* (Frest, Strimple, and McGinnis, 1979) from the upper (*Oklahomacystis* Zone) Mountain Lake Member, Bromide Formation, Oklahoma, but the latter can be distinguished most readily by its smaller crown, typically narrower cup, relatively taller **BB**, which are taller than simple **RR**, relatively narrow simple **RR**, which are taller than wide, and by its more angular pentagonal proximalmost column.

The relatively large number of specimens of *Columbicrinus crassus* display intraspecific variation, particularly in the column and less so in the cup. Two specimens from the upper Lebanon, UI X-5711 and UI X-5712, differ slightly from those in the lower Lebanon; UI X-5711 (Pl. 8, fig. 1) possesses a relatively wider proximal column and UI X-5712 (Pl. 7, fig. 16) possesses **BB** in which lower margins project laterally slightly from the proximal column. All specimens are considered to be within the possible range of intraspecific variation.

The column in this species was reconstructed using composite information from several incomplete columns. Approximate equivalent positions along the column were determined using overlap among the various specimens. UI X-5710 is a nearly complete column and probably is the same specimen as partial crown UI X-5715. The holdfast in this species is similar to those described as "Podolithus" by Sardeson (1908), and type 1C of Lewis (1982).

Types and occurrence.—The holotype (USNM 89826; here refigured and measured) is from the lower Lebanon Limestone, near Columbia, Tennessee. Fifteen other hypotypes are referred to this species. Three hypotypes are from locality Z-651: UI X-5704, and 5714 are from the lower member, Lebanon Limestone, and UI X-5711 is from the upper member approximately 3 m below the top of the Lebanon Limestone. UI X-5712 is from the *Sowerbyella - Diplograptus* Zone of the upper member, Lebanon Limestone, at locality Z-654. The remaining hypotypes are from the lower member, Lebanon Limestone at locality Z-654a, and are UI X-5705 through 5710, 5713, 5693, 5715, 5768, and 5815. USNM 89826, UI X-5704, 5705, 5707, 5708, and 5711 through 5713 are figured and measured; UI X-5693, 5714, and 5768 are figured; UI X-5706 and 5709 are measured.

Subfamily **TRYSSOCRININAE** new subfamily

Diagnosis.—Cincinnaticrinidae with steeply conical dorsal cup. Unequal-sized compound **RR** taller than fused **RR**. $\mathbf{X_1}$ large, deeply set in dorsal cup, resting on C ray **iR**; anal series long, armlike.

Remarks.—The new subfamily agrees with other cincinnaticrinaceans in having compound **RR** in C, E rays, a conical dorsal cup, and initial isotomous arm bifurcations. Differences include the deeply inserted $\mathbf{X_1}$ resting directly on the C ray **iR**, endotomous arm branching beyond the initial bifurcation, and wide, often asymmetrical, pentagonal, hexagonal, or heptagonal **RR**. Other subfamilies within the superfamily Cincinnaticrinacea are the Cincinnaticrininae and Othneiocrininae (Atopocrininae). In cincinnaticrinines $\mathbf{X_1}$ abuts C ray **sR**, arm branching is isotomous or alternating heterotomous, and **RR** are generally inverted pentagons. Othneiocrinines differ principally in having $\mathbf{X_1}$ branch from $\mathbf{IBr_1}$, a less steeply conical cup, and alternating heterotomous branching beyond the initial bifurcation.

The Tryssocrininae is similar in several ways to the Daedalocrininae of the superfamily Homocrinacea. Arm branching, cup shape, proximal anal series and stem morphologies are all similar. Under the scheme of classifications of Moore *et al.* (1978), and Warn and Strimple (1977), these similarities are subordinate to cup plate arrangement, particularly the number and position of compound **RR** (= bilateral symmetry planes of Ubaghs, 1953). Cup plate differences include the facts that $\mathbf{X_1}$ rests on C ray **sR**, **BB** are proportionately much lower, and, most importantly, the B ray **R** is compound in *Daedalocrinus* Ulrich, 1925.

Genus **TRYSSOCRINUS** new genus

Etymology of name.—*tryssus* (Gr.) = delicate, dainty (refers to the crown) + *crinum* (L.) = lily (the standard crinoid suffix).

Diagnosis.—Tryssocrininae with wide, pentagonal **BB**, sutures flush, plates smooth; endotomously branched armlets after the initial isotomous bifurcation.

Tryssocrinus endotomitus new species
Plate 8, figures 3, 5, 11–16, 18–20;
Plate 9, figures 1, 2, 6, 7, 14, 15; Text-figure 8

Etymology of name.—*endo* (Gr.) = within, inside + *tomos* (L.) = part (refers to the armlet branching in this species).

Diagnosis.—As for genus.

Description.—Dorsal cup small (see Table 10), approximately twice as wide as high, widest at level of $\mathbf{IBrr_1}$, steeply conical, nearly straight to slightly convex-sided, cup height from base of **BB** to top of E ray **sR** varies from 4.1 to 5.5 mm. Plates smooth or with slightly irregular surfaces, sutures flush.

Table 10.—Measurements of six specimens of *Tryssocrinus endotomitus* n. gen. and sp. (in mm).

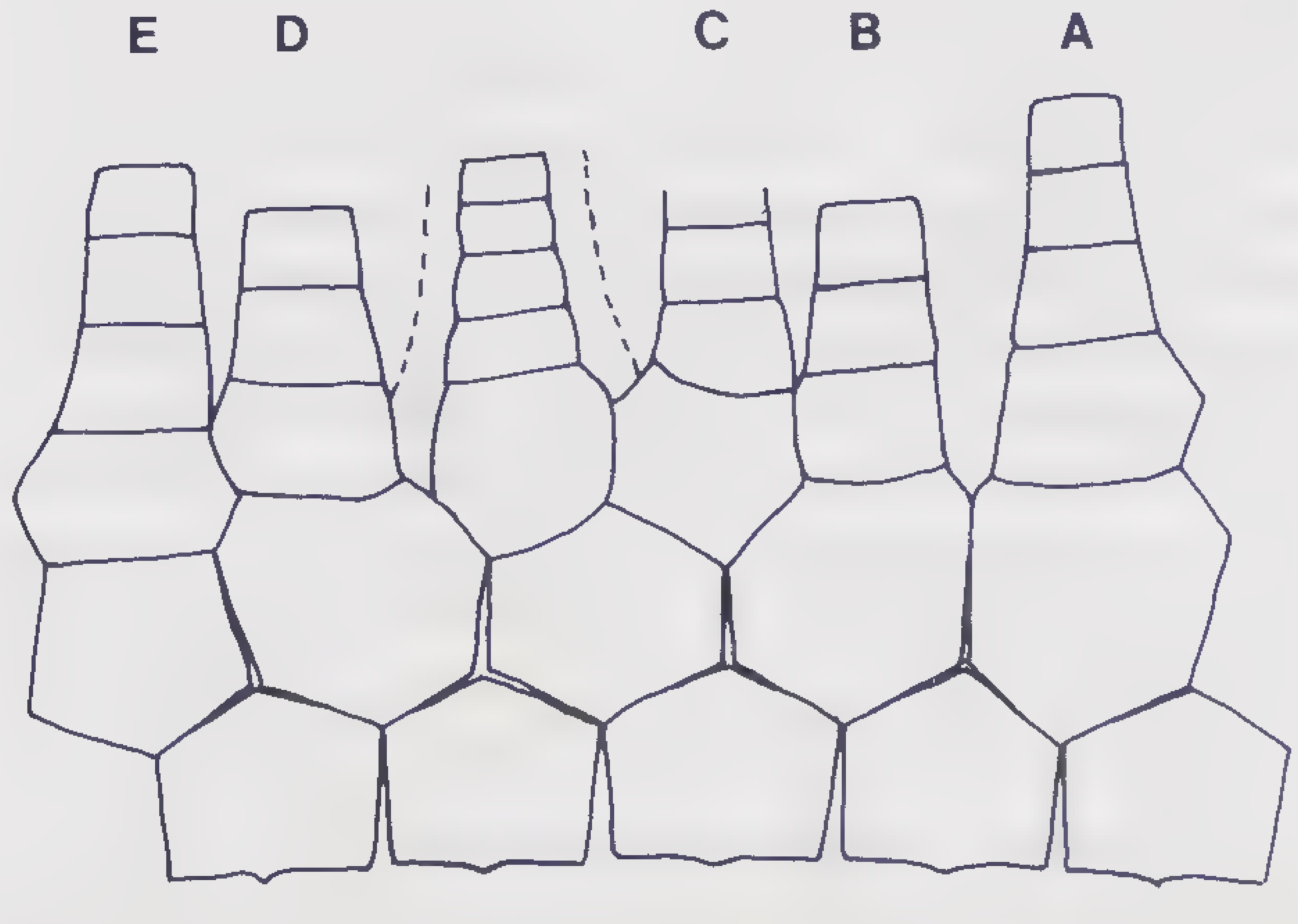
	UI X-5810	UI X-5816	UI X-5820	UI X-5824 (holotype)	UI X-5828	UI X-5831
Cup height[1]	—	4.1	4.6	4.5	4.8	4.7*
Cup width[2]	5.1	4.3	4.8	4.5	5.1	4.9*
AB **B** height	—	1.6	2.1	1.8	—	1.9
AB **B** width	—	1.9	1.9	1.9	2.2	1.8
A **R** height	—	2.1	2.3	2.1	2.5	2.3
A **R** width	—	2.2	2.8	2.3	2.6	2.3
B **R** height	—	2.1	2.3	2.1	2.4	2.3
B **R** width	—	2.3	2.3	2.3	2.7	2.2
C **iR** height	2.6	2.1	2.3	2.4	2.5	2.2
C **iR** width	2.8	2.3	2.5	2.5	2.9	2.5
C **sR** height	1.7	1.5	1.3	1.4	1.6	1.5
C **sR** width	2.7	1.9	1.9	1.9	2.2	2.0
D **R** height	—	2.1	2.2	2.5	2.4	2.1*
D **R** width	—	2.5	2.5*	2.5	3.1	3.0
E **iR** height	—	1.8	1.8	1.9	1.9	1.8
E **iR** width	—	1.9	1.9	2.0	2.0	1.9
E **sR** height	—	1.1	1.2	1.3	1.6	1.4
E **sR** width	—	1.9	2.1	2.2	2.3	2.1
Width of column at base of cup	3.0	2.6	2.3	2.2	3.3	2.6*

[1] = measured from base to top at E ray **sR**.
[2] = measured at level of top at E ray **sR**.
* = estimated.

Basals five, symmetrically pentagonal, vertical margins usually diverging slightly upward, can be nearly straight-sided; central lower margin can have small downward projecting vertex, CD basal averaging slightly wider than other subequal-sized basals. **RR** five, three simple (A, B, D rays), two compound (C, E rays); compound **RR** slightly taller than simple **RR**. Radial facets slightly concave. A ray **R** about as tall as wide, asymmetrically hexagonal, side adjacent to E ray with vertice to accommodate compound **R**. B ray **R** about as high as wide, asymmetrically hexagonal, posterior (towards C ray) side with vertice to accommodate compound **R**. C ray **iR** symmetrically hexagonal, wider than tall; C ray **sR** much smaller than C ray **iR**, displaced away from CD interray to accommodate deeply set large $\mathbf{X}_1$, pentagonal to obscurely hexagonal; **R** facet displaced away from CD interray. D ray **R** asymmetrically heptagonal, wider than high with one vertice on either side to accommodate compound **RR**. E ray **iR** about as high as wide, symmetrical inverted pentagon; E ray **sR** symmetrically hexagonal, much wider than tall.

Anal tube tall, narrow, non-tapering as far as known, approximately two-thirds arm length in one specimen; consists of dorsal anal series, lateral and ventral thin small polygonal plates apparently higher than wide laterally, wider than high ventrally. $\mathbf{X}_1$ large, approximately equal to C ray **sR**, set deep in cup; resting below on C ray **iR**, abuts D ray **R** on lower left, C ray **iR** on right side; upper margin extends slightly to far beyond upper margin of C ray **sR**. Anals beyond $\mathbf{X}_1$ narrower, much smaller than $\mathbf{X}_1$, narrow slightly distally; subquadrangular to obscurely hexagonal, first four to six wider than high, gradually becoming higher than wide more distally.

Arms ten, long, thin, as much as nine or ten times longer than cup height (Pl. 8, fig. 3). Initial bifurcation



Text-figure 8.—*Tryssocrinus endotomitus* n. gen. and sp., plate diagram of cup. Drawn primarily from paratype UI X-5824; dashed lines indicate approximate position of anal tube, approximately ×6.

isotomous followed by numerous endotomous armlet bifurcations. **IBr**$_{4 \text{ or } 5}$ axillary; **IBrr**$_1$ fixed in rays with fused **RR**, enlarged, laterally abut compound **RR**. **IBrr** taper distally. Armlet bifurcations every fourth or fifth **Br** proximally, increased to every other **Br** distally; axillary **Brr** wider than intervening non-axillary **Brr**. Armlets long, slender, pinnule-like, becoming shorter distally; unbranched to rarely bifurcating once isotomously (only one example observed); as many as 34 armlets per arm.

Column heteromorphic, gradually changing, of alternating nodals, internodes for most of column length (Pl. 9, figs. 1, 6, 7, 14, 15); long, 3.5 to 5 times as long as crown height, greater than 14.5 cm long in UI X-5808; narrow, approximately one-third cup width at base of cup, tapers slightly for approximately 1 to 2 cm below crown, then expands slightly for most of column length, then tapers slightly again for one-third to one-fifth column length, finally expands slightly again for approximately the last 1 cm before holdfast; round proximally, gradually changing to pentalobate, then to pentagonal by distalmost column. Columnals solid for approximately first half of column, of pentameres for last half of column. Nodals thick near crown, about as wide as internodals, straight or slightly convex-sided; gradually becoming much wider than internodals with wide rounded pentalobate latera along distomedial column regions. Notches between lobes mark lateral pentamere articulation facets. Internodes straight or nearly straight-sided; of single thin columnal near crown, much thinner than adjacent nodals; increasing to typically three (maximum five) internodals at approximately two-thirds distance to holdfast; internode up to twice as thick as adjacent nodals. Internodes of medial/distal column can have fine faint longitudinal ridges (Pl. 9, figs. 6, 14). Nodals, internodals become compressed, nodals become relatively smaller merging with internodals, pentameres become wedge-shaped toward distalmost column region. Distalmost column of five longitudinal plate rows; plates alternate laterally with plates of adjacent longitudinal rows, form zigzag suture patterns (Pl. 9, fig. 15) between plate rows. Plates of distalmost column thin, wedge-shaped, straight-sided, subequal in size. Lumen quinquestellate, small proximally, moderate in size distally; vertices correspond with sutures of pentameres. Articulae cryptosymplectial.

Holdfast small, 6 mm in diameter in paratype UI X-5826; column articular facet large, approximately 4.5 mm in diameter in same specimen; dorsally polyplated, discoidal, encrusting. Dorsal plates small, subpolygonal, tightly interlocking along flush sutures; ventral surface with thick (?)single plate.

Types and occurrence.—Holotype: UI X-5808; Paratypes: UI X-5759 through 5766, 5797, 5798, 5804, 5806, 5809, 5810, 5812, 5813, 5816 through 5831, 5941, 6047, 6050, 6052. All are from the lower member of the Lebanon Limestone at locality Z-654a. UI X-5816, 5824, and 5831 and measured and figured; UI X-5810 and 5820 are measured; UI X-5764, 5804, 5808, 5809, 5819, 5823, and 5826 are figured.

Superfamily **ANOMALOCRINACEA**
Wachsmuth and Springer, 1886

Family **ANOMALOCRINIDAE**
Wachsmuth and Springer, 1886

Genus **ANOMALOCRINUS**
Meek and Worthen, 1865

Type species.—*Anomalocrinus incurvus* Meek and Worthen, 1865.

?**Anomalocrinus antiquus** new species
Plate 9, figure 17; Text-figure 9

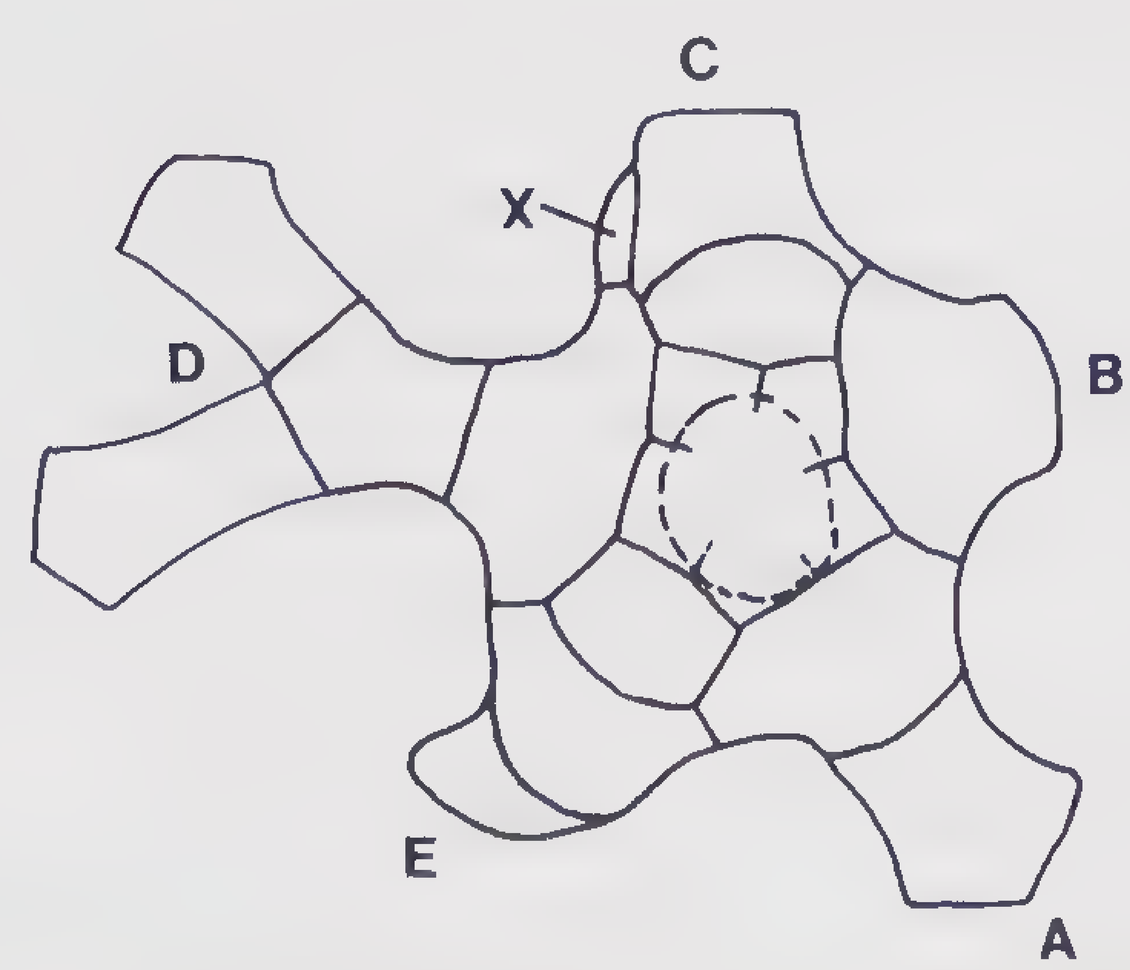
Etymology of name.—*antiquus* (L.) = ancient, old (refers to the early occurrence of this species).

Diagnosis.—A species of *Anomalocrinus* characterized by a small, low bowl-shaped cup with small slightly unequal-sized, slightly upflared **BB**; relatively long, thin arms with tall thin **Brr**; and **IBrr**$_1$, **IIBrr**$_1$ axillary.

Description.—Crown small, dorsal cup low, bowl-shaped, widest at tops of **RR**, pentagonal in outline, approximately 2.5 times as broad as column articular facet. Cup plates smooth, sutures flush.

BB five, small, unequal in size, pentagonal, wider to much wider than tall, sides rapidly diverging, upflared only slightly; BC, CD, DE **BB** subequal-sized, apparently larger than AB, EA **BB**.

RR five, two compound (C, E rays), three simple (A,



Text-figure 9.—?*Anomalocrinus antiquus* n. sp., camera lucida drawing of cup and parts of arms (as seen from below, based on holotype, UI X-5852). Dashed line marks position of partial column as preserved, approximately ×4.

B, D rays). Compound **RR** taller, narrower than simple **RR**. **R** facets at ends of short distolaterally projecting necks; necks much narrower than **RR**, round in transverse section (Pl. 9, fig. 17). Simple **RR** largest plates in cup, wider than tall; D ray **R** obscurely octagonal (counting distal margin as one side); A, B ray **RR** subhexagonal. **iRR** narrower, shorter than **sRR**, symmetrical inverted pentagons, wider than tall, wide-angled lower vertice. **sRR** wider than, and abutting adjacent **iR**, simple **RR** along straight sutures; C ray **sR** abuts $\mathbf{X_1}$.

$\mathbf{X_1}$ probably wider than tall, inserted into broad, shallow, notch in CD interray; notch formed by upper left shoulder of C ray **sR**, upper right shoulder of D ray **R**; distal margin apparently gently curved.

Arms poorly known, distal arm described from D ray only. Arms thin, at least three times longer than cup height, initial branching isotomous, succeeding branchings heterotomous, ramules in one known ray branch beyond **IIBrr** at irregular intervals. **Brr** round in cross section; **Br** pair immediately above axillaries well separated, rapidly diverging (Pl. 9, fig. 17). $\mathbf{IBrr_1}$ axillary, higher than wide, widest distally. $\mathbf{IIBrr_1}$ axillary, higher than wide. **IIIBrr** as much as five times taller than wide. Two apparent ramules visible on different arm branches, branch from $\mathbf{IIIBr_2}$, $\mathbf{IIIBr_3}$; consist of few **Brr** (two or three), **Brr** much higher than wide.

Column unknown; small fragment attached to crown suggests proximal columnals were thin.

Remarks.—?*Anomalocrinus antiquus* n. sp. is broadly similar to the type species, *A. incurvatus* Meek and Worthen, 1865, from the Maysvillian Fairview Formation at Cincinnati, Ohio. The latter species can be distinguished primarily by its thicker, shorter arms, and relatively shorter primibrachs. Some specimens of *A. incurvatus* possess an extra quadrangular plate in the basal circlet and a vertically divided D ray radial; neither of these features are present in the type and only known specimen of *A. antiquus*. The new species could be generically distinct, but is retained in *Anomalocrinus* until better preserved material is found.

Type and occurrence.—The figured holotype, UI X-5852, is from the upper member of the Lebanon Limestone at locality Z-653.

Superfamily **MYELODACTYLACEA** Miller, 1883

Family **TORNATILICRINIDAE** new family

Type genus.—*Tornatilicrinus* n. gen.

Diagnosis.—Myelodactylacea with slender, elongate crown; cup of moderate height, biradials probably in all five rays (B ray **R** unknown), anal series resting on, extending directly above left shoulder of C ray **sR**; A, D, E ray **iRR** of different heights, all projecting above upper margin of C ray **iR**, below C ray **sR**; **R** facets fully as wide as **RR**; rays five, arms 10, equal-sized; column of pentameres.

Remarks.—The new family is monogeneric. It is assigned to the Myelodactylacea because it possesses biradials in all five rays or possibly a single biradial in the C ray only, depending on terminology used (see discussion below). Difficulties concerning this classification arise from the nature of present disparid classification which, as previously discussed under remarks for the order Disparida, is based primarily on position and number of biradials and the difficulty of recognition of biradials in *Tornatilicrinus.* Recognition of biradials in all but the C ray is uncertain because 1) cup and arms merge without distinctive break, and 2) plates herein designated as **sRR** in the A, D, E rays appear almost the same as succeeding **IBrr** and extend for about half their heights to slightly different heights beyond the top of the C ray **sR**. This last feature is due primarily to **iR** heights in these rays that are distinctly unequal, with A > D > E.

The only known specimen of *Tornatilicrinus* is slightly disarticulated with **BB** and **RR** circlets separated and rays slightly ajar. The first two plates in each ray (here designated **iRR**, **sRR**) remain tightly appressed, however, thus suggesting a strong connection. Lateral facets of the first two plates (**iR**, **sR**) of the A ray are visible with the zygosynostosial articular facet of the first plate (**iR**) continuing across to the second (**sR**), then narrowing and disappearing distally. The second plate (**sR**) thus appears to have been a rigid part of the cup structure. The upper margins of the second ray plates (**sRR**) in the A, D, E rays of *Tornatilicrinus* are at only slightly different levels. Morphologic evidence, therefore, supports the designations of **sRR** and **iRR** (and classification) adopted here. However, the designation of these second ray plates as **sRR** rather than fixed **Brr** remains uncertain and arbitrary due to their intermediate position between free arms and cup. (See Ubaghs, 1978b, p. T119 for a discussion concerning this difficulty.) Further, no consistency exists for resolving similar problems in other disparids. Plates with similar positions to the second ray plates (**sRR**) in the Tornatilicrinidae are termed **sRR** in *Eustenocrinus* Ulrich, 1925 (Eustenocrinidae) whereas they are fixed **Brr** in *Herpetocrinus* Salter, 1873 (Myelodactylidae).

Three other families are presently included in the Myelodactylacea; the Myelodactylidae, Iocrinidea, and Eustenocrinidae. The Myelodactylidae differs from the new family in having specialized bilateral columnals arranged in a doubly recurved coil, with elongate cirri that protect the crown. The crown has five unequal-sized rays or only four rays, compound **R** in the C ray only. Crown similarities include $\mathbf{X}_1$ resting on, extending upward from left shoulder of C ray **sR**, and initial arm bifurcation well above the cup. The Iocrinidae differs in having a relatively wider cup, five undivided equal-sized **RR** with prominent distal articular facets, and an anibrachial (not a biradial) plate above the C ray **R** from which the anal series and the C ray branch (Ubaghs, 1978b, p. T118). Eustenocrinids are similar in having compound **RR** in all five rays, but differ significantly in having $\mathbf{X}_1$ supported directly by C ray **sR** (no arm in C ray) or by the left side of $\mathbf{IBr}_1$.

Beyond the Myelodactylacea, *Tornatilicrinus* n. gen. is most similar to *Ibexocrinus* Lane, 1970, of the Homocrinacea. Dorsal cups are similar in shape and broadly similar in plate arrangement; both have $\mathbf{X}_1$ resting on the left shoulder of C ray **sR** only. Proximal columns are similarly of thin pentamere circlets, and both have 10 arms. *Ibexocrinus,* however, does not have compound **RR** in A, D rays (this difference from *Tornatilicrinus* is not great, however, as it is the result of only minor proportional differences in **R**, **IBr** plate heights). Arm branching occurs much closer to the cup in *Ibexocrinus* than in *Tornatilicrinus*; armlets are alternating heterotomous in *Ibexocrinus,* endotomous in *Tornatilicrinus.*

That *Tornatilicrinus* is a primitive disparid inadunate is supported by its simple, generalized cup plate arrangement and column of pentameres. In order to fit present disparid classification it is placed in the Myelodactylacea although it is similar in many ways to *Ibexocrinus* of the Homocrinacea. *Tornatilicrinus* might indicate a close relationship between at least some of the disparid superfamilies [Anomalocrinacea, Cincinnaticrinacea, Homocrinacea, Myelodactylacea in part] than has previously been believed, but its phylogenetic relationships are obscure.

Genus **TORNATILICRINUS** new genus

Etymology of name.—tornatilis (L.) = beautifully rounded, turned (refers to the elegant crown) + *crinum* (L.) = lily.

Type species.—Tornatilicrinus longicaudis n. sp.

Diagnosis.—Tornatilicrinidae with a small crown having a slightly wider than tall cup, no distinct break between arms and cup, initial isotomous arm bifurcation well above dorsal cup at $\mathbf{IBr}_{7\,\mathrm{or}\,8}$, in single known example, few (approximately three) armlets branched endotomously on **IIBrr**; proximal column pentagonal.

Tornatilicrinus longicaudis new species

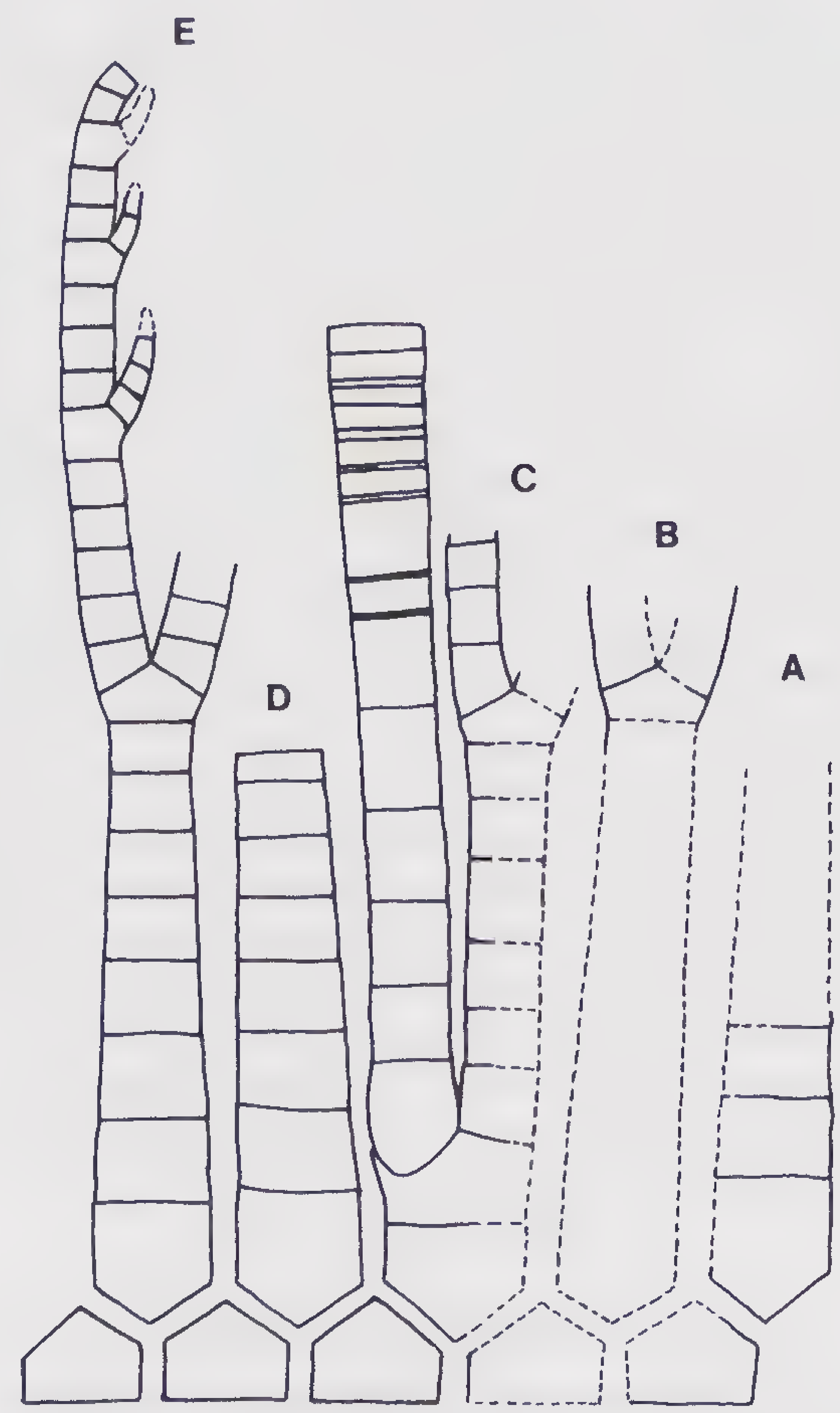
Plate 9, figures 3–5, 9, 12, 13, 20;
Text-figure 10

Etymology of name.—longis (L.) = long + *caudis* (L.) = stem (refers to the long column in this species).

Diagnosis.—As for the genus.

Description.—Crown small, narrow; cup steeply conical, sides slightly convex, slightly wider than tall, widest at top of cup, approximately 1.6 times as wide as proximalmost column, subpentagonal in transverse outline at level of **BB**, round at level of **RR**. Cup plates smooth, slightly convex to flat, sutures flush.

BB five, symmetrical to nearly symmetrical pentagons, slightly wider than high, sides subvertical to slightly diverging; facets bordering C ray **iR** slightly longer than other distal facets. **RR** five, probably all compound, B ray **R** unknown; straight or nearly straight-sided, C ray **R** apparently widest. **R** facets fully as wide as **RR** in all but C ray. **IRR** symmetrical inverted pentagons, of differing heights; heights range



Text-figure 10.—*Tornatilicrinus longicaudis* n. gen. and sp., plate diagram of partial crown (based on holotype UI X-5755). Distal parts of some arms not shown, dashed lines indicate not exposed or missing. Magnification approximately ×5.5.

from A, D, E, C in order from tallest to shortest; A, D, E ray **iRR** higher than wide, C ray **iR** approximately as tall as wide, much lower than other **iRR**. A, D, E ray **sRR** quadrangular, wider than high; C ray **sR** subpentagonal, about as tall as other **sRR**, not extending as far distally as other **sRR**, with divergent left side and deep asymmetrical concavity in upper left shoulder for insertion of $\mathbf{X}_1$.

Anal tube tall, narrow, widens distally to near tops of arms, termination unknown; of dorsal armlike anal series, lateral plates small, thin, ventral plates much wider than high. Anals rectangular, varying greatly in height along series, becoming wider distally, narrower than adjacent **Brr** proximally; becoming wider than adjacent **Brr** distally, distal anals approximately one-quarter to one-third wider than proximal anals. $\mathbf{X}_1$ higher than wide, left side slightly convex, lower margin asymmetrical, highly convex. $\mathbf{X}_2$ about as high as wide, $\mathbf{X}_{3 \text{ to } 6}$ taller than wide. Beginning with $\mathbf{X}_7$, short much wider than tall plates intercalated into and typically alternating with taller plates (Pl. 9, fig. 5).

Arms long, approximately four times longer than cup height, tapering gradually away from cup; arm bundle approximately as wide as cup when folded together. **Brr** dorsally flattened; **Brr** other than **Axx** rectangular, sides subparallel. **IBrr** wider than tall; $\mathbf{IBrr}_8$, at least, axillary, much wider than high, about as wide as $\mathbf{IBrr}_1$; $\mathbf{IBrr}_7$ approximately two-thirds width of $\mathbf{IBrr}_1$. Initial arm bifurcation isotomous. **IIBrr** about as high as wide to slightly wider than high, variable. Two or three short armlets branch endotomously from **IIBrr**; branching begins on $\mathbf{IIBrr}_6$, at least, occurs every third or fourth **IIBrr** thereafter.

Column incompletely known, long, narrow, >20 cm in holotype (Pl. 9, figs. 3, 4, 20); tapers slightly for approximately 4 mm away from crown, then gradually expands distally; pentagonal over most of known length, apparently rounded distally. Columnals of straight-sided thin to moderately thick pentameres, thicknesses variable, generally thicken distally; thick and thin columnals can alternate along length; some columnals 6 to 8 cm below crown incomplete in holotype, pentameres lens-shaped, not abutting laterally. Exteriors of pentameres typically with rounded upper and lower margins, form thin discontinuous notches between columnals. Apparent far distal column segment (Pl. 9, fig. 9) of five vertical series of subhexagonal plates; plates much wider than high, correspond in position to pentameres of proximal column. Each plate series alternates with adjacent series forming zigzag suture between series. Proximal, medial column lumen pentagonal, vertices correspond with vertical pentamere sutures and are midway between angles of column. Articulae symplectial; crenularium petaloidal (Pl. 9, fig. 12), each "petal" corresponds with pentamere.

Remarks.—"*Dendrocrinus modestus*" Safford, 1869 (*nom. nud.*), is tentatively referred to this species. Safford's only known specimen is apparently lost; however, two casts of the specimen (Pl. 9, fig. 12) are preserved as USNM S2273. The casts do not show great detail, but do show similar cup shape, arm branching, and size to the holotype of *Tornatilicrinus.* The casts also indicate a B ray **R** similar to other **RR**.

Types and occurrence.—The figured and measured holotype, UI X-5755, is from the lower member of the Lebanon Limestone at locality Z-655. Two column fragments, UI X-5756 and UI X-5757, were associated with the holotype. UI X-5757 is figured. The referred casts, USNM S2273, are from an unspecified horizon in the Lebanon Limestone at Lebanon, Tennessee.

Measurements of UI X-5755 (in mm).—Crown height = 21*; cup height = 3.1; cup width = 3.5*; CD **B** height = 1.4; CD **B** width = 1.7; A **iR** height = 1.8; A **sR** height = 1.1; C **iR** height = 1.5; C **sR** height = 1.4; D **iR** height = 1.8; D **iR** width = 1.6; D **sR** height = 1.0; D **sR** width = 1.6; E **iR** height = 1.4; E **iR** width = 1.6; E **sR** height = 1.0; E **sR** width = 1.6; column diameter at base of cup = 2.2 [* = estimated].

Order **HYBOCRINIDA** Jaekel, 1918

Family **HYBOCRINIDAE** Zittel, 1879

Genus **HYBOCRINUS** Billings, 1857

Type species.—*Hybocrinus conicus* Billings, 1857, p. 275; 1859, p. 29, pl. 2, figs. 2a, b.

Hybocrinus bilateralis new species

Plate 9, figures 8, 10, 11, 16, 18, 19;
Plate 10, figures 1–11, 13–16, 18, 21, 22

Etymology of name.—*bi* (L.) = two, *lateralis* (L.) = at the side (refers to the crown, which is nearly bilaterally symmetrical through the A/CD plane).

Diagnosis.—A species of *Hybocrinus* characterized by a large subglobular calyx with tumid plates; subpentagonal as viewed from oral surface; plate surfaces pitted; A ray markedly thicker than others; anal **X** projects slightly above level of adjacent **RR**, upper margin with faint to distinct grooves.

Description.—Calyx relatively large in largest specimens, maximum height measured from posterior over 20 mm; subglobular, distinctly asymmetrical with posterior protuberant in large specimens, calyx more conical in small specimens (Pl. 9, fig. 16); posterior margin slightly higher than anterior margin; subpentagonal as viewed from oral surface. Major calyx, arm plate surfaces finely to coarsely pitted (Pl. 10, figs. 9, 10); pits irregular, from three to six per mm; pits sometimes weathered, obscure. Some specimens with fine alternating grooves or striations along and perpendicular to calyx plate margins; grooves and striations abut across sutures (Pl. 10, fig. 10). Grooves, striations 1 mm long, rapidly disappear toward plate centers. Sutures slightly impressed, dorsal cup plates slightly tumid. Upper margins of anal **X** with weak to strong grooves; commonly pass confluently to upper lateral margins of **RR**, lateral surfaces of **BB** (Pl. 10, figs. 3, 18).

BB five, asymmetrical pentagons subequal in size; shape variable, nearly always taller than wide, or about as tall as wide. **BB** of CD, DE interray largest, other **BB** slightly smaller, shorter. Radial circlet plates largest in cup, plate size increases from A ray **R** toward **RA**, D ray **R**. A, B, D, E ray **RR** subpentagonal (assuming upper margins as one side), **RA** hexagonal; height-to-width ratio of **RR** variable. Small, subpentagonal C ray **R** rests on right shoulder of **RA**. **R** facets large, about one-third **R** width in B, C, D, E rays, one-half **R** width in A ray, nearly round; mounted on low protuberant necks in B, C, D, E rays, on high prominent protuberant neck on A ray **R** (Pl. 10, fig. 5). Radial facets directed slightly laterally in B through E rays; markedly laterally in A ray. Ambulacral furrows deep, narrow. Anal **X** rests on upper left shoulder of **RA**, taller than wide to about as tall as wide, widest distally; upper margin convex, elevated slightly above level of adjacent **RR**, with faint to distinct grooves.

Tegmen nearly flat, ambulacral furrows radially disposed about central oral opening; CD interray area slightly larger than others. Four anterior **OO** similar-sized, subquadrate, cover AB, BC, DE, AE interrays; distolateral margins notched, form elongate slits confluent with ambulacral furrows, extend to within 1 mm of oral opening where **OO** abut. Slits in C, D rays bordered posteriorly by small plates. CD interray oral moderate-sized, suboval to hemicircular, forms bridge between oral opening, CD interray area; with small circular hydropore located atop conical mound. Ambulacral furrows extend from arms along slits, then above proximally abutting **OO**, converge above circular oral opening. Ambulacral cover plates of DE and BC ray pairs merge lateral to oral opening, form keeled triradiate medial suture pattern above oral opening, proximal **OO**. Proximal ambulacrals keeled, of larger transversely elongate plates, smaller wedge-shaped plates intercalated medially. CD interray area apparently with valvular anal pyramid surrounded by small loosely connected ossicles. Anal pyramid plates apparently elongate, triangular (Pl. 10, fig. 11).

Arms short, narrow (except A ray arm), uniserial, non-branching, with gradual distal taper; averaging 1.3 times longer than calyx height in two specimens. A ray arm stout, much wider and deeper than C and D arms which are slightly wider and deeper than B and E arms. **Brr** variable, usually taller than wide, can be about as tall as wide. Ambulacral cover plates on arms slightly wider than tall, subtrapezoidal to subrectangular, meet medially along keeled nearly straight to slightly zigzag suture; approximately seven ambulacral plate pairs per **Br**.

Column heteromorphic, short, length about equal to crown height, narrow, usually tapering slightly away from crown, then expanding near holdfast (Pl. 9, fig. 8; Pl. 10, fig. 22). Columnal morphologies change gradually along column length. Approximately proximal third of column of thin columnals having low, rounded nodose latera; nodes can abut with those of proximal-distal columnals forming faint longitudinal ridges (Pl. 9, fig. 10). Medial column columnals irregularly multipartite, thinner than proximal columnals, latera similar to proximal column. Distal column of small irregular subequidimensional subpolygonal plates tightly abutting to form irregular mosaic; plates with central nodes (Pl. 9, fig. 10). Holdfast small, low, encrusting, discoidal, apparently of a single solid ossicle.

Remarks.—The new species resembles *Hybocrinus tumidus* Billings, 1859 from the "Trenton Limestone", Ottawa, Ontario, Canada. Both have a similar subglobular calyx, tumid calyx plates, and $\mathbf{X}_1$ with grooved upper margin elevated above adjacent radials. *H. bilateralis* n. sp. can be differentiated, however, by its larger size, in having the A ray much thicker than the other rays, and in having a relatively smaller, narrower anal **X**. *Hybocrinus nitidus* Sinclair, 1945, from the Mountain Lake Member, Bromide Formation, Oklahoma resembles the new species in having an enlarged A ray. The Oklahoma species can be distinguished by its subcircular calyx outline as seen from above, less protuberant arm articular facets on **RR**, and pustular plate ornament (Sprinkle, 1982d, p. 121). *Hybocrinus bilateralis* also resembles *H. pristinus* Billings, 1858, from the "Chazy Limestone," Montreal, Canada, is smaller, has coarse granulate ornament, and apparently has equisized arms.

Coarseness of ornamental pitting is highly variable among specimens of *H. bilateralis* (Pl. 10, figs. 9, 10). This variation is believed to be intraspecific because no other correlative variable morphological features were seen, and pitting coarseness is gradational among specimens.

Types and occurrence.—Holotype: UI X-5807; paratypes UI X-5799, 5858 through 5869 (all from the lower member of the Lebanon Limestone at locality Z-654a). UI X-5799, 5807, 5861–5864, and 5867–5869 are figured.

Order **CLADIDA** Moore and Laudon, 1943

Suborder **CYATHOCRININA** Bather, 1899

Superfamily **GASTEROCOMACEA** Roemer, 1854

Family **CARABOCRINIDAE** Bather, 1899

Genus **CARABOCRINUS** Billings, 1857

Type species.—*Carabocrinus radiatus* Billings, 1857, p. 275; 1859, p. 31, pl. 2, figs. 3a–e.

Carabocrinus species
Plate 10, figures 12, 17, 20, 24, 25

Description.—Crown large, cup shape unknown; plates thin. Fine, sharp, radiating ridges extend from, perpendicular to, cup plate margins toward plate centers where many meet. Ridge intersections form chevrons (Pl. 10, fig. 17), ridges abut across adjacent plate faces; ridge frequency averages approximately 0.63 mm. Respiration "rhombs" (see Sprinkle, 1982c, p. 145) large, involving **RR**, **OO** (Pl. 10, figs. 20, 25), of many thin folds, elevated above general plate surfaces. **RR** with at least 20 folds per "rhomb".

IBB poorly known, sides rapidly diverging. **BB** taller than wide, widest distally. C ray **B** heptagonal. **RR** large, subhexagonal, approximately 20 mm wide, 18 mm tall in one specimen; sides subparallel. **R** facets horseshoe-shaped, much taller than wide; ambulacral groove deeply cleft with narrow sides.

Arms of moderate length, branching isotomously initially, heterotomously thereafter, up to seven branchings per arm (Pl. 10, fig. 20). **Brr** uniserial; first one or two **Br** pairs beyond axillaries tightly abutting; typically subcuneiform. Proximal **Brr** elongate dorsoventrally (transversely), becoming subround by approximately mid-arm-length. Each **Br** lateral margin with pair of sharp ridges; each ridge borders an impressed suture between **Brr**; similar structures of adjacent **Brr** form series of wedge-shaped grooves (between lateral sides of **Brr**) bordered by sharp ridges (Pl. 10, fig. 20); grooves appear to be covered by small plates. These covered grooves appear to be contiguous with respiratory "rhombs". **IBrr**$_3$ axillary; **IIBrr**$_{4\ or\ 5}$ axillary.

Column poorly known; long, narrowing slightly distally, round. Proximally of thin, straight-sided radially (externally) undulating columnals (Pl. 10, fig. 12). Distally, much wider than tall, of thicker, approximately equisized columnals; divided into pentameres (Pl. 10, fig. 24). Laterally adjacent pentameres slightly offset, sutures canted, form discontinuous in-echelon series extending along column length. Lumen pentalobate proximally, pentastellate distally, Articulae symplectial; fine crenulae disposed radially about outer margin of articular surfaces.

Remarks.—Lebanon carabocrinids are represented by several mostly fragmentary and corroded specimens. UI X-5857 (Pl. 10, fig. 25) differs from other specimens in having faint thecal plate ridges. The frequency, distribution and size of the ridges, where observable, however, is the same as in other specimens; respiratory "rhomb" morphology is also similar. This specimen has possibly undergone localized dissolution along surfaces of the thecal plates (associated specimens of *Hybocrinus* Billings, 1857, and *Cleiocrinus* Billings, 1857, also from locality Z-654a, show such partial obliteration of fine surface detail). Column fragments assigned to this species were found in a single stratum associated with thecal plates belonging to *Carabocrinus* sp. No other crinoids were discovered in this stratum. The size of the fragments seem reasonable for the associated thecal plates. Final confirmation, however, must await discovery of attached cup and column. All Lebanon carabocrinid specimens are tentatively assigned to this species.

Carabocrinus sp. apparently most closely resembles *Carabocrinus* sp. from the Blackriveran part of the Chickamauga Limestone, Alabama (Butts, 1926, pl. 31, figs. 2, 3) and *Carabocrinus* sp. from the Blackriveran Grand Detour Formation, northern Illinois (Kolata, 1975, pp. 30, 31, figs. 1, 2). All three agree in having taller than wide **BB** and large goniospires that are elevated above general plate surfaces. The Lebanon species differs in having fewer, more widely-spaced ridges. This species also resembles *Carabocrinus treadwelli* Sinclair, 1945 (see Sprinkle, 1982c, for redescription of this species) from the Mountain Lake Member, Bromide Formation, Oklahoma, but this species differs in having fewer thecal plate ridges. Known Lebanon specimens of *Carabocrinus* are too poorly preserved to allow specific assignment. Overall poor preservation of this species probably results from large size and relatively fragile construction.

Types and occurrence.—UI X-5856, 5857 are from the lower member of the Lebanon Limestone at locality Z-654a; UI X-5855 is from the lower member, Lebanon Limestone, at locality Z-651; UI X-5978, 5980, 5991 through 5993 are from the lower member, Lebanon Limestone, at locality Z-652. UI X-5855 through 5857, 5981, and 5991 are figured.

Family **POROCRINIDAE** Miller and Gurley, 1894

Genus **POROCRINUS** Billings, 1857

Type species.—*Porocrinus conicus* Billings, 1857, p. 279; 1859, p. 34, pl. 2, figs. 5a–d.

Porocrinus lebanonensis new species
Plate 10, figures 19, 23; Plate 11, figures 3–5

Etymology of name.—Lebanon (Limestone) + *ensis* (L.) = at the place of (refers to the source of the type material).

Diagnosis.—A species of *Porocrinus* characterized by a relatively large obovate dorsal cup, **IBB** about as tall as wide, column articular facet small; moderate to prominent calyx ridges with superimposed secondary ridges; well-developed goniospires, decrease in size from bottom to top of calyx, those of **R-R-O** corners small; **R** facets small; zone of proximal columnals narrow, short.

Description.—Dorsal cup obovate; large for genus, height approximately 19 mm in largest specimen. Calyx ridges moderate to prominently developed for genus, abut across plate boundaries; with zero to four, usually three superimposed secondary ridges that disappear at plate centers (Pl. 11, fig. 3). Plate surfaces, particularly between calyx ridges, with fine punctae; no punctae on goniospires; plate sutures flush. Goniospires moderately inset, at corners of adjacent cup plates, of moderate size, decreasing in size distally; those of **R-R-O** corners small; **IB-IB-B** goniospires with approximately 12 folds. **IBB** about as high as wide (Pl. 10, fig. 23), widest distally, much smaller than **BB**. Lower lateral vertices of **IBB** can be rounded, form notches into which attenuated proximal columnals fit; column articular facet small for genus, averaging about as wide as each **IBB**. **BB** large, as large to slightly larger than **RR**, as tall as wide to slightly taller than wide; CD and probably BC interray **BB** heptagonal, other **BB** hexagonal. **RR** large, approximately as tall as wide, **R** facets horeshoe-shaped, slightly elevated, laterally constricted, one-third to one-fourth as wide as **R** widths, **RA** small, quadrate, slightly wider than high, upper left shoulder articulates with anal **X**. Anal **X** small, only slightly larger than **RA**, slightly higher than wide, subpentagonal. **OO** poorly known, apparently large. Anal area large, covered with small, irregular, polygonal plates. Arms narrow, long unbranched, uniserial, at least two-and-one-half times longer than calyx height. **Brr** much wider than tall proximally, becoming nearly as tall as wide distally, lateral margins rounded, form notches between adjacent **Brr** along lateral margins of arms. Ambulacrals apparently of single alternating biseries, much wider than high proximally; articulate medially along distinct zigzag suture.

Column heteromorphic; proximal column region short, narrow, averaging about 3 mm long for three specimens, subpentagonal proximally, becoming round distally; of thin, expanding columnals with finely crenulate or possibly smooth outer surfaces. One specimen (UI X-5796) with approximately five faint longitudinal radially-disposed striae that continue for 1 to 2 cm onto distal column (Pl. 11, fig. 3). Proximal column tapers rapidly, passes transitionally to narrower medial/distal column. Medial/distal column known for approximately 3 cm in two specimens; transversely round to subround, slightly tapering distally; of thin straight to slightly convex-sided much wider than tall columnals, height to width ratio becoming somewhat smaller distally. Alternating thin and thick variable columnals proximally; distally of thicker, variable columnals, intermittent thicker columnals with slightly convex sides. Medial column articulae cryptosymplectial; lumen small, pentagonal.

Remarks.—The relatively small, slightly depressed goniospires, the usually prominent calyx ridges, narrow short proximal column and **IBB** that are as tall as wide together separate *P. lebanonensis* n. sp. from other species of *Porocrinus. P. lebanonensis* n. sp. closely resembles *P. elegans* Kesling and Paul, 1968, from the early Trentonian (Rocklandian) Decorah Shale of Minnesota but the latter species differs in having **IBB** averaging approximately 1.5 times wider than tall, a relatively larger column attachment facet and slightly wider proximal column region, and a smaller known crown size. *Porocrinus plattinensis* Shourd and Winter, 1976, from the Blackriveran Plattin Limestone, Missouri, is also similar to the new species but can be most easily distinguished by its low wide infrabasals averaging 1.7 times wider than tall and lack of secondary calyx ridges. *Porocrinus fayettensis* Slocum, 1924, from the Upper Ordovician Maquoketa Formation, Iowa, is only broadly similar to the new species and can be readily distinguished by its much larger goniospires.

UI X-5796 differs slightly from other specimens assigned to *P. lebanonensis* n. sp. in having low, wide calyx ridges with more prominent widely-separated secondary ridges.

Types and occurrence.—The holotype UI X-5803 and three paratypes, UI X-5796, 5800, 5889, are from the lower member, Lebanon Limestone, at locality Z-654a. All type specimens are figured. One isolated thecal plate tentatively referred to this species, UI X-5890, is from the upper member, Lebanon Limestone, at locality Z-653.

Superfamily **DENDROCRINACEA**
Wachsmuth and Springer, 1886

Family **DENDROCRINIDAE**
Wachsmuth and Springer, 1886

Genus **QUINQUECAUDEX**
Brower and Veinus, 1982

Type species.—*Quinquecaudex glabellus* Brower and Veinus, 1982, p. 134, pl. 10, figs. 1–11.

Quinquecaudex species A
Plate 11, figures 1, 2, 11

Description.—Crown large, more than 50 mm tall; narrow. Dorsal cup conical, steep-sided; plates smooth, sutures slightly depressed, small depressions at triple juncture points. **IBB** hexagonal, wider than high. **BB** probably hexagonal, slightly higher than wide, largest plates in cup; **B** below anal **X** truncated, heptagonal, higher than wide. **RR** wider than high; facets nearly as wide as (B ray) or as wide as (C ray) **R** plates. **RA** below C ray **R**, probably subpentagonal, much wider posteriorly; facet articulating with C ray **R** tilted strongly away from anal series. Arrangement of anals within cup not discernable. Proximal anals above dorsal cup smooth, small, generally slightly wider than high; distally becoming much wider than high, plicate. Arms long, slender, non-pinnulate, isotomously branching proximally; dorsal margins flattened proximally, rounded distally. $\mathbf{IBr}_7$ axillary, **IBrr** much wider than high. Distal **Brr** nearly as high as wide.

Column heteromorphic, gradually changing; long, much longer than crown length; wide, apparently nearly as wide as cup proximally, distally tapering; pentalobate. Columnals thin, of pentameres. Large and small columnals typically alternate proximally; even smaller, exceedingly thin columnals intercalated over short column segments. Distal columnals become thicker, equisized. Concave constricted ridges abut across laterally adjacent pentameres, expand to form pentamere midsections; single pore in depressions between ridges at vertical sutures, best developed distally. Protruding midsections of pentameres flat or slightly convex-sided; articulations between pentamere circlets can be slightly depressed. Lumen pentagonal, large. Articulae symplectial at least distally; crenulae faint, arranged in semicircles adjacent to external margin of each pentamere.

Remarks.—This species is assigned to *Quinquecaudex* Brower and Veinus, 1982, on the basis of 1) dendrocrinine crown features such as the steeply conical cup, upflared **BB**, **RA** below C ray **R**, elongate anal sac of plicate plates, and elongate narrow non-pinnulate arms and 2) a pentalobate column of pentameres (see Brower and Veinus, 1982, p. 134). **R** facets are unusually wide compared with most other dendrocrinids.

The exact shape of dorsal cup, branching pattern of the arms, and shape and arrangement of some of the cup plates, including the anal series, are unknown. Therefore this material cannot be assigned to species. The Lebanon species appears to be most similar to *Q. glabellus* Brower and Veinus, 1982, from the Pooleville Member, Bromide Formation of Oklahoma, but the latter species is considerably smaller and probably has fewer **IBrr**. *Quinquecaudex* [*Dendrocrinus*] *springeri* (Kolata, 1975) from Blackriveran and early Trentonian beds of Illinois and Canada, respectively, has a non-tapering pentagonal column. *Quinquecaudex cincinnatiensis* (Meek, 1873), from the Upper Ordovician of Ohio, has a more angular column and possibly a wider, more rapidly expanding dorsal cup. *Quinquecaudex* [*Dendrocrinus*] sp. A of Kolata (1975) from Blackriveran strata, northern Illinois, is smaller, and appears to have a less angular column, without prominent sutural pores.

Types and occurrence.—Two specimens, UI X-5700 and UI X-5699, are assigned to this species; the former specimen is from approximately 3 m below the top of the upper member of the Lebanon Limestone at locality Z-651, and the latter is from within 8 m of the base of the Lebanon Limestone, lower member, at locality Z-658. UI X-5700 is figured.

Family **CUPULOCRINIDAE**
Moore and Laudon, 1943

Genus **CUPULOCRINUS** d'Orbigny, 1849b

Type species.—*Scyphocrinus heterocostalis* Hall, 1847, p. 85, pl. 28, figs. 3a–f.

Cupulocrinus species cf. **C. gracilis** (Hall)
Plate 11, figures 6, 7

Poteriocrinus gracilis Hall, 1847, p. 84, pl. 28, figs. 2a–f.
Dendrocrinus gracilis (Hall). Wachsmuth and Springer, 1879, p. 299.
Non *Cupulocrinus gracilis* Ramsbottom, 1961, p. 13, pl. 5, figs. 6, 7.
Cupulocrinus gracilis (Hall). Kolata, 1975, pp. 37, 38, pl. 7, figs. 6–8.
Cupulocrinus gracilis (Hall). Brower and Veinus, 1978, p. 429, pl. 13, figs. 5, 7.

Remarks.—*Cupulocrinus gracilis* (Hall) was originally described from the Trenton Limestone, New York. It has since been redescribed based principally on specimens from the Blackriveran Platteville Group, northern Illinois (Kolata, 1975, pp. 37, 38) and approximately equivalent-aged Platteville Limestone, St. Paul, Minnesota (Brower and Veinus, 1978, pp. 426–430).

Two Lebanon specimens, UI X-5701 and UI X-5703, are tentatively referred to this species. UI X-5701 is a nearly complete crown with proximal column and UI X-5703 is a crown and proximal column with a largely disarticulated dorsal cup; neither specimen has the CD interray exposed. The Lebanon specimens are very

Table 11.—Measurements of three specimens of *Cupulocrinus* (in mm).

	Cupulocrinus sp. cf. *C. gracilis*		*Cupulo-crinus* sp.
	UI X-5701	UI X-5703	UI X-5702
Crown height	33	—	—
Cup height	6.5	—	—
Cup width	6.0	—	—
IB height	2.2	—	—
IB width	1.8	—	—
B height	3.1	—	4.7
B width	2.5	—	3.8
R height	2.2	2.1	2.8
R width	2.8	2.8	3.8
Column diameter at base of cup	2.0	2.0	—

similar to other specimens of *Cupulocrinus gracilis* but differ slightly in possessing relatively wider **RR** and tightly appressed rather than well-separated $\mathbf{IIBrr_1}$ pairs. The Lebanon specimens also differ from those from northern Illinois but agree with the Minnesota specimens in possessing a slightly tapering rather than non-tapering column near the crown. These differences are considered minor and within possible intraspecific variation range.

Types and occurrence.—UI X-5701 is from the *Sowerbyella - Diplograptus* Zone of the upper member, Lebanon Limestone, at locality Z-652 and UI X-5703 is from the upper Lebanon Limestone at locality Z-651. Both specimens are figured.

Cupulocrinus species
Plate 11, figures 8, 9

Remarks.—One crown fragment, UI X-5702, is referable to *Cupulocrinus,* but cannot be assigned to species. The specimen is larger than specimens assigned to *Cupulocrinus gracilis.* It is similar in size and plate configuration to specimens of *Cupulocrinus plattevillensis* Kolata, 1975, from the Blackriveran Platteville Group, northern Illinois.

Types and occurrence.—The single figured and measured specimen, UI X-5702, is from the lower member, Lebanon Limestone, at locality Z-651.

Class **PARACRINOIDEA** Regnell, 1945

Order **COMAROCYSTITIDA**
Parsley and Mintz, 1975

Family **AMYGDALOCYSTITIDAE** Jaekel, 1900
[*nom. corr.* Kesling, 1968,
pro **AMYGDALOCYSTIDAE** Jaekel, 1900]

Genus **OKLAHOMACYSTIS**
Parsley and Mintz, 1975

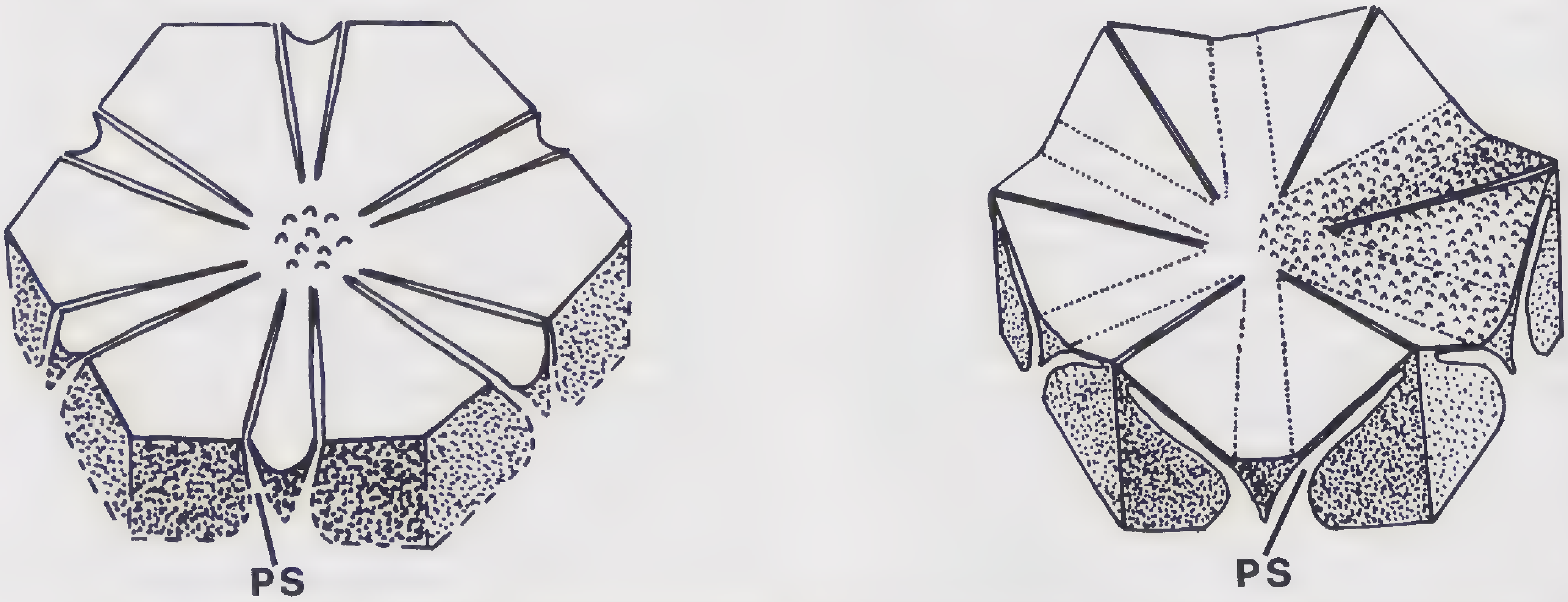
Type species.—*Amygdalocystites tribrachiatus* Bassler, 1943.

Remarks.—The emended generic diagnosis given by Parsley (1982, p. 215) is applicable to *O. trigonis* n. sp., except that thecal ornament ridge morphology includes raised flat-topped trigons as well as raised pyramid ridges.

Oklahomacystis trigonis new species
Plate 11, figures 10, 12, 14–18;
Plate 12, figures 1–8; Text-figure 11

Etymology of name.—*trigonis* (L.) = triangle (refers to the thecal plate ornament).

Diagnosis.—*Oklahomacystis* with two unbranched



Text-figure 11.—Oblique view restorations of typical thecal plates in *Oklahomacystis trigonis* n. sp. (left) and *Oklahomacystis bibrachiatus* Parsley, 1982 (right); *Oklahomacystis trigonis* plate has partial flat-topped trigons; *Oklahomacystis bibrachiatus* has partial raised trigons; pore slits (PS) are demarcated in both illustrations. Much enlarged.

recumbent ambulacra; periproct situated to right of thecal apex on slightly elevated rim, adjacent to right ambulacra; hydropore and gonopore subapical, aligned with, continuing toward apex from left ambulacra; gonopore elevated atop moundlike plate; thecal ornament ridge morphology varies from low to raised, nearly flat-topped trigons to raised pyramids; pore slits extend onto pyramid faces, border margins of trigons; raised pyramids concentrated near arms, apical region; stem articular facet ventralmost point of theca.

Description.—Theca small- to moderate-sized, ranging from 14.0 through 22.5 mm high among known specimens; suboval to amygdaloid in profile; cross-sectional outline oval in small individuals, broadly oval in larger individuals, largest diameter toward dorsal end of theca; of approximately 50 to 60 plates; right side protuberant. Areas about peristome, periproct, centers of thecal plates, ambulacra, brachioles with pustulose ornament; thecal plate centers can have single, large pustule.

Three basals offset with stem articular facet to left, apparently without mutual pore slits. Stem articular facet ventralmost point on theca (theca does not extend below level of facet), suboval (?), with small central pore for lumen. Thecal plates typically hexagonal, plate centers depressed; major ornamental rays radiate from near plate centers toward plate corners (triple juncture points), expand away from plate centers. Ray morphology variable, gradational among, within specimens. Rays meet similar rays at plate corners, together form moderately-raised nearly flat-topped trigons (Pl. 11, figs. 10, 16; Text-fig. 11) to triangular pyramids (or triacts); pyramids concentrated near arm, peristome regions (Pl. 11, fig. 15; Pl. 12, fig. 2). Pyramid faces, trigon sides bisected by plate sutures so that each triact/trigon formed equally of parts from three plates. Pyramids and trigons arranged in rosettes about plate centers on thecal surface. Thin skeletal sheets extend outward along sides of trigons, above and along pyramid faces. Pore slits in gaps between trigons/pyramids and adjacent skeletal sheets; slits from opposing pyramid faces, trigon sides form slit pairs in low areas between adjacent pyramid/trigon faces. Pore slits open to exterior through slits between trigons, skeletal sheets and gaps in sheets above distal faces of pyramids (Pl. 11, figs. 10, 14, 15; Pl. 12, fig. 3); openings possibly due to weathering of available material; therefore, slits possibly completely enclosed in skeletal material.

Ambulacra two, unbranched, recumbent, nearly straight, transversely arranged on theca; taper gradually, distally away from peristome. Food groove anterior in left ambulacra; posterior in right ambulacra. Right ambulacra with 13 to 15 segments, extends about two-thirds or three-fourths distance to stem facet. Left ambulacra with 13 to 16 segments, extends along anterolateral side of theca to anterior side of stem articular facet. Left ambulacra of UI X-5920 appears to touch proximal stem. Covering plates small, apparently of alternating biseries meeting submedially along zigzag suture. Brachials thin, shorter than thecal height in UI X-5920 (Pl. 12, fig. 3), gradually tapering, increase in size toward peristome. Brachiolars taller than wide, transversely evenly rounded away from food grooves; food grooves covered by tiny transversely elongate plates.

Gonopore, hydropore subapically positioned, aligned with left ambulacra. Gonopore adjacent to peristome, elevated atop rounded moundlike plate. Hydropore V- or S-shaped, surrounded by elevated rim, rim apparently comprised of three plates. Peristome subapical, offset slightly to left. Periproct opening circular, offset to right of apex on anterior face, adjacent to left arm; bordered by four plates forming low rim, slightly to (rarely) moderately raised above theca. Periproct covered by anal pyramid of seven wedge-shaped plates in UI X-5974; each plate with single prominent pustule.

Stem round, homeomorphic, apparently shorter than thecal height, proximally flexed, slightly expanding distally in UI X-5932 (Pl. 12, figs. 1, 2); of thin columnals. Columnals with nearly smooth, irregularly rounded, or nodose sides (Pl. 12, fig. 4). Stem in UI X-5932 articulates distally with possible low, digitate, encrusting holdfast.

Remarks.—This species is assigned to *Oklahomacystis* because it has 1) a broadly elliptical transverse outline, and 2) thecal plate structure similar to though slightly different from previously described species of *Oklahomacystis*. Previously known species of *Oklahomacystis* are *O. tribrachiatus* (Bassler, 1943) and *O. bibrachiatus* Parsley, 1982, both from the Upper Echinoderm Zone, Mountain Lake Member, Bromide Formation, Oklahoma.

Thecal plates of *Oklahomacystis* are characterized by pore slits that extend from the interior toward the thecal exterior. Plates have sharp, raised ridges radiating from plate centers, expanding toward corners (triple juncture points). Ridges from adjacent plates in *O. bibrachiatus* and *O. tribrachiatus* abut forming triangular pyramids (triacts) (Parsley and Mintz, 1975, p. 53; Parsley, 1982, p. 215). In well-preserved specimens of these species, thin skeletal sheets extend outward above and along pyramid faces; these sheets coalesce with pyramids along pyramid ridges. Pore slits occupy the gaps between skeletal sheets above and pyramids below and are closed to the exterior by skeletal material (Parsley and Mintz, 1975, p. 53) (Text-fig.

11). Weathered specimens of these species have the thin outer skeletal sheets partly removed, exposing the pore slits and pyramids below. Raised pyramids and accompanying skeletal sheets are arranged in rosettes on the thecal surface similarly to pyramids/trigons in *Oklahomacystis trigonis* n. sp.

The thecal plates of *Oklahomacystis trigonis* n. sp. differ from those in the two previously described species in having plate rays that form pyramids to raised flat to nearly flat-topped trigons (triangles). As noted in the description, skeletal sheets covering pore slits in available specimens of *O. trigonis* are incomplete, leaving openings (to the exterior) contiguous with pore slits. These openings result from corrosion (dissolution) or were incompletely calcified in life. Pyramids on *O. trigonis* greatly resemble weathered examples of *O. bibrachiatus* and *O. tribrachiatus* (compare Pl. 11, fig. 16; Pl. 12, fig. 3 with Parsley and Mintz, 1975, pl. 6, fig. 1) suggesting the former possibility is correct. However, some specimens with openings display good preservation including delicate pustules on thecal plates and brachiolars and tiny ambulacral coverplates. If skeletal sheets did completely enclose pore slits in *O. trigonis,* they must have been very thin.

Of the two previously described species, *Oklahomacystis trigonis* is most similar to *O. bibrachiatus.* Both species have two transversely arranged ambulacra. In addition to the above thecal plate differences, *O. bibrachiatus* can be distinguished from *O. trigonis* in having 1) an apically positioned periproct mounted atop a prominent low chimney, 2) the peristome below the level of the thecal apex and canted to the left, 3) relatively thinner ambulacra, 4) the right side of the theca extending well below the level of the stem articular facet in larger specimens, 5) the gonopore situated atop a small tubercle and positioned ventrally from the hydropore and ambulacra, 6) a more straight-sided, relatively less bulbous dorsal region of the theca, and 7) a right ambulacra typically moderately to strongly deflected around the anal chimney. *O. tribrachiatus* can be easily distinguished from the new species by its three ambulacra.

UI X-5931 consists of an incomplete theca and partial stem buried in hard matrix. The thecal size is small and pore slits are relatively short and do not reach as far toward plate centers as they do in larger specimens (Pl. 12, fig. 8); both are features that Parsley and Mintz (1975, p. 54, pl. 6, figs. 2, 3) attributed to immaturity in *Oklahomacystis tribrachiatus.* Thecal shape, thecal plate shapes, distribution and position of the periproct and stratigraphic occurrence within the lower Lebanon Limestone indicate that this specimen belongs to *O. trigonis* n. sp. and is immature.

UI X-5932 is a poorly preserved, crushed, but nearly complete individual. Thecal plate and arm morphology is identical, insofar as can be determined, to other, better preserved specimens assigned to *Oklahomacystis trigonis.* The specimen is of considerable interest because it possesses a nearly complete column, which is attached to an apparent low solid irregular holdfast (Pl. 12, fig. 2). The surface of the holdfast is obscured, as it was appressed against or encrusted by a bryozoan; a broken edge, however, shows characteristic echinoderm cleavage. The holdfast encrusts a trepostome bryozoan. The column is shorter than the thecal height and expands slightly toward the holdfast.

Amygdalocystitid life modes have long been enigmatic. This problem is due to their unique thecal nature and lack of preserved columns with associated attachment devices. There is general agreement that thecal symmetry and arm distribution indicate that most if not all amygdalocystitids were rheophyllic organisms with the theca canted into prevailing currents, but it was not known how this was accomplished. The holdfast and short column in *Oklahomacystis trigonis* (specimen UI X-5932) indicates this species was an attached low level suspension feeder. The proximal column flexure, shown best in other specimens of *O. trigonis* (Pl. 12, fig. 4), could have helped orient the theca upright from irregular, inclined, firm attachment sites as well as into prevailing currents. This life mode resembles that shown in a restoration by Parsley and Mintz (1975, text-fig. 6) for *Amygdalocystites florealis* Billings, 1854 (though their interpretation lacks an encrusting holdfast). The occurrence of UI X-5932 in an associated thick mat of trepostome bryozoans is similar to *O. tribrachiatus,* which occurs along the edges of bryozoan bioherms (Fay and Graffham, 1969, p. 39) and might indicate *Oklahomacystis* utilized the current baffling effects of other organisms (or irregular substrates) to maintain stability.

Types and Occurrence.—Twenty specimens are assigned to *Oklahomacystis trigonis* n. sp. The holotype UI X-5922 and paratypes UI X-5801, 5921, 5923 through 5930, 5933 through 5937, and 5974 are from the lower member of the Lebanon Limestone at locality Z-654a. Paratypes UI X-5920, 5931, and 5932 are from the lower member of the Lebanon Limestone at locality Z-651. Isolated thecal plates probably belonging to this species were observed at many exposures of the Lebanon Limestone. Figured specimens are UI X-5920, 5922, 5931, 5932, 5934, and 5936.

Oklahomacystis species aff. **O. trigonis**
new species
Plate 11, figures 13, 19, 20

Remarks.—One damaged but uncrushed partial theca from the upper member of the Lebanon Limestone resembles specimens of *Oklahomacystis trigonis* n. sp. from the lower member of that unit in the nature of the thecal plate ray and pore slit morphology, the length and disposition of the arms and pustulose ornament, and position and shape of the periproct, hydropore, gonopore and stem facet. The specimen differs, however, in being about one-third larger, having a more amygdaloid profile, a more compressed transverse outline, and greater number of thecal plates. The differences may be within the range of variation for *O. trigonis,* or the specimen may represent a new, closely related species. The single incomplete specimen is considered insufficient to warrant erection of a new taxon.

Types and occurrence.—The single figured specimen, UI X-5938 is from the upper member of the Lebanon Limestone at locality Z-653.

Class **RHOMBIFERA** Zittel, 1879
(emended Paul, 1968)

Order **DICHOPORATA** Jaekel, 1899

Superfamily **GLYPTOCYSTIDA** Bather, 1899

Family **GLYPTOCYSTIDAE** Bather, 1899
(emend. Paul, 1972; Sprinkle, 1982b)

Genus **TANAOCYSTIS** Sprinkle, 1982b

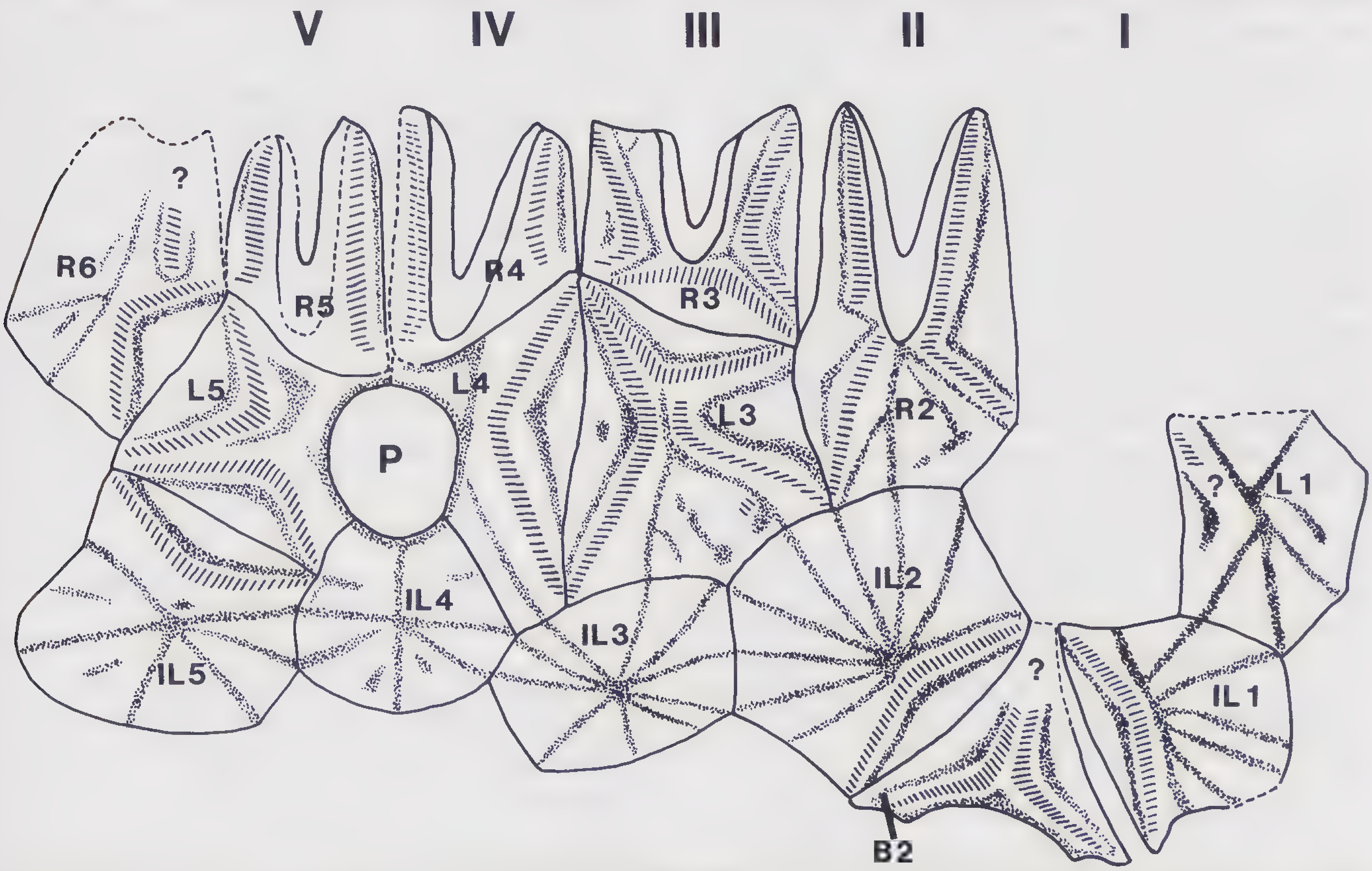
Type species.—*Tanaocystis watkinsi* Sprinkle, 1982b.

Remarks.—The generic diagnosis of Sprinkle (1982b) encompasses the Lebanon species except that the new form possesses 13 rhombs and demirhombs instead of 10 to 12 and apparently rounded rather than skirted outer proximal stem columnals. These differences are considered specific taxobases and are incorporated into the generic diagnosis.

Tanaocystis sprinklei new species
Plate 12, figures 9–14, 16, 17; Text-figure 12

Etymology of name.—The specific name honors James Sprinkle.

Diagnosis.—A species of *Tanaocystis* characterized by an elongate theca; **B1-B2**, **B2-B3** sutures curved; rhombs greatly elongate, medium length dichopores with approximately 0.14 mm average spacing, **IL5-L5** rhomb present; thecal plates ornamented with numerous prominent, wide, subcentral, radiating, discontinuous ridges, nodes common between ridges; periproct



Text-figure 12.—*Tanaocystis sprinklei* n. sp., composite partial plate diagram; based primarily on holotype UI X-5880, also on paratype plates UI X-5877 through UI X-5879, UI X-5881 through 5885. Thecal ridges are stippled, inferred areas are dashed; areas where pore slits or thecal ridges cannot be inferred accurately are marked by question marks. Much enlarged.

subround; outer columnals of distal portion of proximal stem region rounded with faint nodes.

Description.—Theca moderate to large for the genus, approximate height of holotype 28 mm; apparently tapering, subcylindrical, with rounded summit; maximum width just above base of **ILL** circlet.

Thecal plates thin. Prominent, thick, irregular slightly curved ridges radiate from thecal plate centers, abut across adjacent plates; can be discontinuous, especially at plate edges. Major ridges typically radiate to midpoints of plate faces, in some to plate corners; secondary, commonly discontinuous ridges radiate to plate edges between major ridges, many do not reach edges of plates; major chevron-shaped ridges can be along rhombs, between rhomb and adjacent plate face. Plate surfaces of **ILL**, **LL**, some **BB** series typically with faint to moderately prominent closely-spaced tiny pustules between ridges; nodes can be arranged in subconcentric bands perpendicular to radiating ridges (Pl. 12, fig. 13).

Partial **B2** only **B** known; distal, proximal tips missing, probably hexagonal, **B1-B2** and **B2-B3** sutures curved. All **ILL** known, medium to large. **IL1** and **IL2** share rhombs with **B2**; **IL1** subpentagonal, **IL2** through **IL5** all subhexagonal, **IL4** forms lower margin of periproct opening; **IL3** and **IL4** without rhombs or demirhombs; **IL5-L5** share rhomb. **L1** and **L3** through **L5** known, large to very large; **LL** circlet interrupted by **R2**; **L1** hexagonal; **L3** subpentagonal, oral margin steeply inclined; **L4** and **L5** subpentagonal, form sides, upper margin of periproct opening; **L5** with two rhombs, **L1** and **L4** with one rhomb, **L3** with two rhombs and one demirhomb (UI X-5899 has a very small second ?irregular demirhomb [Pl. 12, fig. 12]). **RR2** through **6** known, **RR** apparently form a closed circlet; **R2** very large, elongate, other **RR** medium to large. **R3** through **R5** modified rectangular (assumes radial sinuses as one side), **R2** modified hexagonal; **R2** and **R3** with one rhomb and two demirhombs or two rhombs and one demirhomb each, **R4** and **R5** apparently with two demirhombs each, **R6** with at least one rhomb and one demirhomb. Ambulacral sinuses of medium length extending nearly to aboral edges of **R3** through **R5**. **R6** shares ambulacrum 1 with **R1**. **OO** poorly known, apparently medium-sized, elongate.

Periproct round or nearly so, medium-sized (for cylindrical rhombiferans), not more than 5 mm in diameter in holotype, surrounded by three thecal plates (**IL4**, **L4**, **L5**).

Rhombs, demirhombs 13, greatly elongated, of closely-spaced medium length dichopores each surrounded by faint, low, narrow rim. Dichopores spaced moderately closely, from 0.12 to 0.18 mm, averaging 0.14 mm apart.

Ambulacra extend about one-third distance down theca as indicated by **RR** sinuses. Ambulacrum **II**, probably ambulacrum **I**, longer than other ambulacra. Ambulacral floorplates, covering plates, brachioles unknown.

Only medial to distal region of proximal stem known; gradually tapering, of medium width (Pl. 12, fig. 9); stem apparently mounted in basal concavity as indicated by shape of **B2** thecal plate. Outer columnals evenly rounded, some, at least, with faint nodes; inner columnals subpentagonal.

Remarks.—*Tanaocystis sprinklei* n. sp. is incompletely known (Text-fig. 12). The holotype is a partial theca with associated partial proximal column (Pl. 12, fig. 9). Isolated thecal plates were used to determine shapes and arrangement of some plates not present in the holotype.

Tanaocystis sprinklei n. sp. resembles *Tanaocystis watkinsi* Sprinkle, 1982b, from the upper part of the Pooleville Member, Bromide Formation, Oklahoma, but the latter species differs most conspicuously in possessing fewer, thinner, thecal plate ornamenting ridges, slightly more widely spaced dichopores, no **IL5-L5** rhomb and a relatively larger **L1** plate. *Coronocystis durandensis* Kolata, 1975 is provisionally assigned to ?*Tanaocystis* by Sprinkle (1982b). This species differs from *T. sprinklei* n. sp. in apparently possessing four plates around the periproct, fewer, high, thecal plate ridges, and fewer (10 vs. 13) rhombs and demirhombs.

Types and occurrence.—The holotype, UI X-5880 and all paratype isolated thecal plates UI X-5874 through 5879, 5881 through 5887 are from the lower member, Lebanon Limestone, about 14 m below the massive member at locality Z-651. UI X-5877 through 5884 are figured.

Family **PLEUROCYSTIDAE** Neumayr, 1889

Genus **PRAEPLEUROCYSTIS** Paul, 1967a

Type species.—*Pleurocystites watkinsi* Strimple, 1948.

Praepleurocystis ranaformis new species
Plate 12, figures 15, 18–20, 22–27;
Text-figures 13, 14

Etymology of name.—*rana* (L.) = frog + *formis* (L.) = resembles (refers to the holotype theca which was mistaken for a frog by a quarry worker).

Diagnosis.—A species of *Praepleurocystis* characterized by a strongly-arched dorsal surface; thecal outline rounded subtriangular; large to rarely moderate-sized pectinirhombs; dorsal thecal plates ornamented with prominent, radiating, rounded ridges; **B2**, **B3** typically contacting or nearly contacting **L2**, **L3**, respectively;

B1, **B4**, attaining periproctal margin; **L1**, **L4** contact along narrow suture.

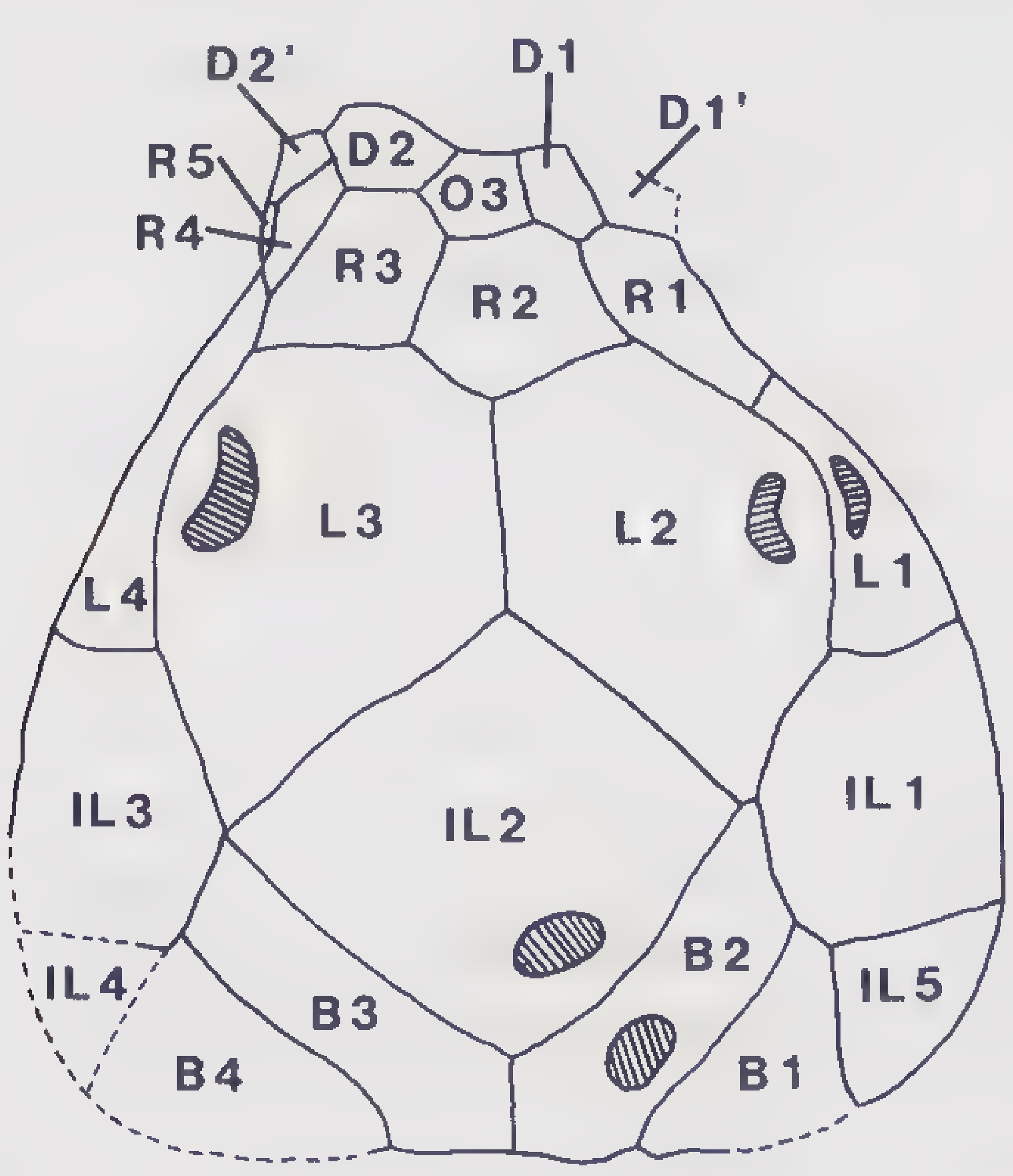
Description.—Theca moderate-sized, 26 mm long and 21 mm wide in holotype; rounded symmetrical triangular outline as seen in dorsal or ventral views; dorsal surface strongly arched (moderate for genus); ventral surface subplanar, sides (**LL**, **ILL** area) incurved gently with slight keel along each margin (Pl. 12, fig. 24); thecal margins surrounding periproct moderately wide; stem embayment shallow.

Plates of dorsal surface thick, ornamented with broad, low, discontinuous, sometimes faint ridges; ridges typically extend to, abut across plate corners of plate face centers; ridges can disappear toward plate centers; prominent ridges form cross at juncture of **B2**, **IL1**, **IL2**, **L2** plates; rarely with a few faint concentric ridges on **IL1** or **IL3** (Pl. 12, fig. 19).

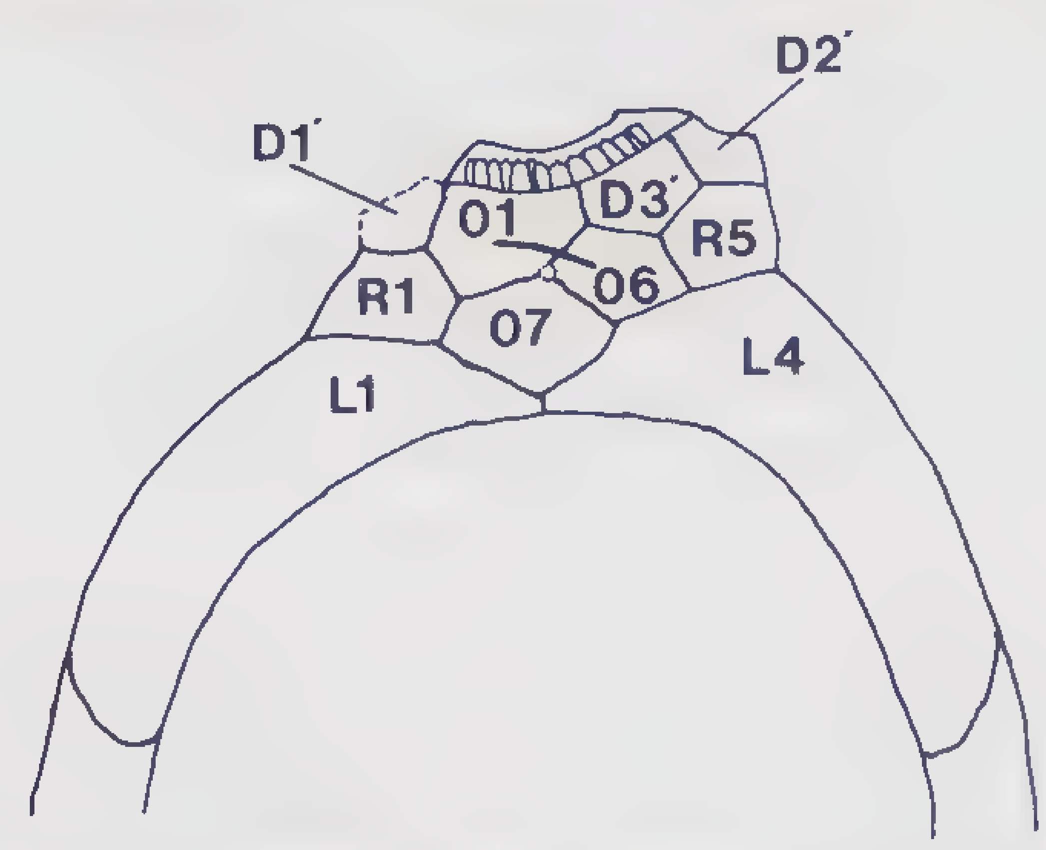
B2, **B3** basals pentagonal, together with V-shaped outline (as in *P. watkinsi*), distally contact or nearly contact **L2**, **L3**, respectively. **B1**, **B4** lateral to, below **B2**, **B3** on dorsal face, subtriangular in dorsal outline, articulating with **B2**, **B4**, **IL1**, **IL5**, and **B1**, **B3**, **IL3**, **IL4**, respectively; articulate sagittally on ventral surface to form lateral, ventral margins of stem articular facet; form proximal periproct margin. **IL1** large, subpentagonal, borders **B1**, **B2**, **L1**, **L2**, **IL5**; attains periproctal margin along short distance because of inclined ventral sutures with **IL5** (extending distally) and **L1** (extending proximally). **IL2** large, quadrangular, borders **B2**, **B3**, **L2**, **L3**. **IL3** subhexagonal, large, borders **IL4**, **B3**, **B4**, **L3**, **L4**; with short periproctal border as in **IL1** because of inclined sutures with **IL4**, **L4**. **IL4**, **IL5** small, rounded subtriangular in dorsal view, form rounded proximal thecal angles. **L2**, **L3** very large, as large as **IL2**, subhexagonal, to subheptagonal depending on whether very short **B2** or **B3** facet present; **L2** borders **B2** (barely), **IL1**, **IL2**, **L3**, **R1**, **R2**, **L1**; **L3** borders **B3** (barely), **IL2**, **IL3**, **L2**, **L4**, **R2**, **R3**. **L1**, **L4** laterally directed on dorsal face, both subquadrangular, meet distally along short suture, form entire proximal periproct border. **R1** relatively large, heptagonal; articulates dorsally with **L1**, **L2**, **R2**, **D1**, and **D1′**; articulates ventrally with **L1**, **O7**, **O1**, **D1′**. **R2** hexagonal, articulates with **L2**, **L3**, **R1**, **R3**, **O3**, and **D1**; **R3** hexagonal, articulating with **L3**, **L4**, **R2**, **R4**, **O3**, **D2**; **R4** small, confined to dorsal surface, pentagonal, articulating with **L4**, **R3**, **R5**, **D2**, **D2′**; **R5** pentagonal, primarily confined to ventral surface but forms small part of lateral thecal margin, articulates with **L4**, **R4**, **O6**, **D3′**, **D2′**. Distodorsal thecal border between brachioles formed by **D2**, **O3**, **D1**, and **D1′** (from left to right as seen from dorsal). Ventral distal somatic series of three plates, **O7**, **O6**, **O1**; **O7** pentagonal, fits proximally into notch formed by **L1**, **L4**; **O6** pentagonal, articulates along right distal **O7** margin; **O1** hexagonal, articulates along left distal **O7** margin, separated from **L1** by **O7**, **R1**.

Narrow hydropore slit shared by **O1**, **O6** plates; abuts across their common suture. Gonopore round, approximately at triple juncture between **O1**, **O6**, **O7** plates. Pectinirhombs three, distributed on, shared across **B2/IL2**, **L1/L2**, and **L3/L4** plates; disjunct, elevated, with prominent wide rims particularly on dorsal halves (**IL2**, **L2**, **L3**), low rims on ventral halves. Corridor between pectinirhomb halves raised ridge bisected by plate sutures, plate sutures at these points convex toward dorsal. Form 11 to 16 slits per half rhomb, average is 13.

Periproct incompletely known, of many (approx. 200–300) thin, small, subpolygonal plates; plates typically hexagonal or pentagonal subequant away from



Text-figure 13.—*Praepleurocystis ranaformis* n. sp., plate diagram of dorsal face, based mainly on holotype UI X-5697. Dashed lines drawn from paratypes UI X-5698 and 5850. Plate abbreviations after Parsley, 1970, approx. ×2.



Text-figure 14.—*Praepleurocystis ranaformis* n. sp. Plate diagram of distal part of ventral face (also based mainly on holotype). Dashed lines from paratype UI X-5850. Plate abbreviations after Parsley, 1970. Approx. ×2.

periproct margin, elongate subquadrate near periproct margin. Anal pyramid unknown.

Brachioles long, apparently somewhat longer than theca, thin, gradually tapering, subround in cross-section; brachiolars biserially arranged, wider than long; coverplates biserial, wider than long, some with small intercalated wedge-shaped plates (Pl. 12, fig. 26).

Stem typical for pleurocystids; long, approximately 4 cm known in UI X-5850, of proximal, distal regions; the two regions rapidly merge. Proximal region of alternating wide outer columnals, narrow inner columnals; outer columnals evenly rounded, smooth, occasionally with faint longitudinal ridges (Pl. 12, fig. 27); lumen large, round. Distal stem of barrel-shaped, wider-than-tall columnals near proximal column region, much taller than wide cylindrical columnals far distally; articular surfaces with slightly depressed ring between lumen and outer edge (Pl. 12, fig. 20).

Remarks.—*Praepleurocystis ranaformis* n. sp. closely resembles *P. watkinsi* (Strimple, 1948) from the upper Pooleville Member, Bromide Formation, Oklahoma, particularly in plate arrangements; the latter species can be distinguished primarily by its angular thecal outline in dorsal or ventral views, relatively larger, more protruding distal ventral region, prominent sharp concentric ornamental ridges on the dorsal thecal plates; **L1** and **L4** plates that in ventral view are relatively wider and that mutually articulate along a relatively long suture, generally smaller pectinirhombs, and **B2**, **B3** plates that usually do not articulate with **IL1** and **IL3**, respectively.

Praepleurocystis nodosus Westphal, 1974a, from the Blackriveran Platteville Group, southwest Wisconsin, is poorly known but can be differentiated from the Lebanon species by its highly arched dorsal surface, nodose radiating dorsal thecal plate ridges, and the wide separation of **B2** and **B3** from **IL1** and **IL3**, respectively, in the single known specimen.

Types and occurrence.—This species is represented by 19 specimens, most of which are fragmentary or buried in hard matrices. The holotype, UI X-5697, and paratypes UI X-5698, 5977 through 5979, and 5981 through 5990 are from the lower member, Lebanon Limestone, approximately 3 m below the massive member at locality Z-652. Paratype UI X-5691 is from the *Sowerbyella - Diplograptus* Zone of the upper member, Lebanon Limestone, at locality Z-654 and paratype UI X-5692 is from the same horizon at locality Z-666. One isolated thecal plate UI X-5851 is from the lower member of the Lebanon Limestone at locality Z-656. Paratype UI X-5850 is from the lower member of the Lebanon Limestone at locality Z-655. Figured specimens are UI X-5697, 5698, 5850, 5983, and 5985. *Praepleurocystis ranaformis* n. sp. is one of the more common and widespread echinoderms in the Lebanon Limestone at or below the *Sowerbyella - Diplograptus* Zone of the upper member. No specimens have been found above the *Sowerbyella - Diplograptus* Zone.

Praepleurocystis species cf. **P. watkinsi**
(Strimple, 1948)
Plate 12, figure 21

Pleurocystites watkinsi Strimple, 1948, pp. 761–764, pl. 1, figs. 1–3.
Praepleurocystis watkinsi (Strimple). Paul, 1967a, p. 120.
Pleurocystites watkinsi Strimple. Parsley, 1970, pp. 171–177, pl. 24, fig. 2, pl. 28, figs. 3–8.
Praepleurocystis watkinsi (Strimple). Parsley, 1982, pp. 275–279, pl. 34, figs. 1, 5, 7, 9–11, 13–19.

Remarks.—This species is represented by three thecal plates; probable **L2**, **L3** plates, and a fragment of uncertain derivation (its position was isolated). The (?)**L2**, (?)**L3** plates each possess a relatively small disjunct pectinirhomb encircled by an upraised rim. All plates are ornamented with flattened to rounded concentric discontinuous ridges broken by prominent radiating ridges. The plates closely resemble those of *P. watkinsi* from the Pooleville Member, Bromide Formation, Oklahoma, but plates of the latter species possess somewhat sharper, more numerous concentric ridges. Incomplete material precludes definite specific assignment.

Types and occurrence.—Two associated thecal plates, UI X-5893, are from the upper member, Lebanon Limestone, at locality Z-663, and one of these is figured. A single thecal plate, UI X-5870, is from the upper member, Lebanon Limestone, at locality Z-653.

Genus **AMECYSTIS** Ulrich and Kirk, 1921

Type species.—*Pleurocystites laevus* Raymond, 1921.

Amecystis nanus new species
Plate 13, figures 1–5; Text-figure 15

Etymology of name.—*nanus* (L.) = dwarf (refers to the small size of this species).

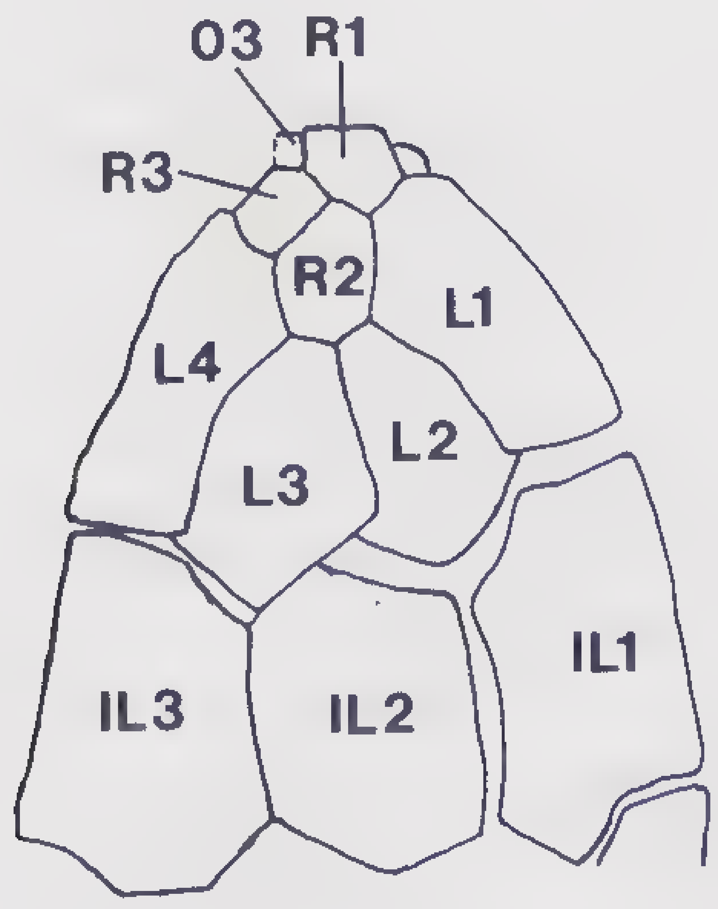
Diagnosis.—A species of *Amecystis* Ulrich and Kirk, 1921, characterized by a small, flattened, evenly sagittate theca; proximal lobes evenly rounded, formed principally by **B1**, **B4**; thecal plates thin, smooth; dorsal **RR**, **OO** small, compressed distally with **L2** not articulating with **R3**; **R1** and **R3** small, in contact, **R2** not contacting **O3**; outer proximal stem columnals with short spinose projections.

Description.—Theca small, 9 mm long, 6 mm wide in holotype, approximately 15 mm long and 10.5 mm wide in largest paratype, evenly sagittate in outline;

proximal lobes rounded equidimensional, slightly expanded; thecal margins along **LL** slightly curved to nearly straight; thecal margin about periproct narrow. Dorsal surface slightly convex with shallow depression running adjacent to thecal margin (Pl. 13, fig. 1); ventral surface nearly flat. Dorsal thecal plates thin, though thickened along thecal, periproct margin; smooth, flat or nearly so.

B2, **B3** mediodorsal to **B1**, **B4**; both subpentagonal, moderate-sized; articulate with thecal plates **B1**, **B3**, **IL1**, **IL2**, possibly **IL5**, and **B2**, **B4**, **IL2**, **IL3**, respectively. **B1**, **B4** subtriangular in dorsal view, moderate-sized; form proximal lobe angles; mutually articulate medioventrally, form proximalmost periproct margin; also articulate with **B2**, possibly **IL1**, **IL5** and **B3**, **IL3**, **IL4**, respectively. **IL1**, **IL3** large, elongate proximodistally; **IL1** borders dorsal thecal plates possibly **B1**, **B2**, **IL2**, **IL5**, **L1** and **L2**; **IL3** borders dorsal plates **B3**, **B4**, **IL2**, **IL4**, **L3**, **L4**. **IL2** large, hexagonal, central on dorsal surface. **L1**, **L4** moderately large, proximodistally elongate; **L1** articulates with dorsal plates **IL1**, **L2**, possibly **R1**, **R2**; **L4** articulates with dorsal plates **IL3**, **L3**, **R3**, **R2**. **L2**, **L3** moderate-sized, smaller than **L1**, **L4** in holotype (UI X-5871); **L2** articulates with **IL1**, **IL2**, **L1**, **L3**, **R2**; **L3** articulates with **IL2**, **IL3**, **L2**, **L4**, **R2**. **RR** small, restricted to far distal thecal surface in dorsal view, designations uncertain. **R1** small, bordered dorsally by **L1**, **R2**, **R3**, and **O3**. **R2** small, hexagonal, lying between **L1**, **L4**; borders **L1**, **L2**, **L3**, **L4**, **R1**, **R3**. **R3** small, articulates with **L4**, **R1**, **R2**, and **O3**. **R1**, **R3** meet **R2** proximally. **R2** does not contact **O3**. **O3** very small. Distoventral thecal region unknown.

Periproct large, covered by many (200+) small, thin plates; plates typically hexagonal, arranged in poorly defined longitudinal rows (Pl. 13, fig. 3). Anal pyramid small, subcircular, of seven wedge-shaped plates in UI X-5872.



Text-figure 15.—*Amecystis nanus* n. sp., plate tracing of adoral part of dorsal face (from photo of holotype UI X-5872). Some plates overlap others slightly, approx. ×6.

Single brachiole known in holotype (UI X-5871); it is gradually tapering, 6.2 mm in length (slightly longer than thecal length), biserial (Pl. 13, fig. 1). Brachiolars much wider than tall proximally, becoming slightly wider than tall distally; smooth or nearly smooth.

Stem longer than thecal length, typical for family, of proximal, distal regions. Proximal region of alternating outer (wider), inner columnals; outer columnals with short spinose projections. Distal region of subcylindrical columnals, gradually become much taller than wide distally.

Remarks.—*Amecystis nanus* n. sp. most closely resembles the type species, *A. laevus* (Raymond, 1921), from the Trentonian "Lower Trenton Limestone," northern Michigan, and the Kirkfield Limestone, Kirkfield, Ontario, but the latter species is most readily distinguished by its much larger known size, different ventral plate arrangement with **L3** articulating with **R3**, **L4** not articulating with **R2**, and smooth or grooved (instead of spinose) outer proximal columnals. *A. woodi* Broadhead and Strimple, 1975, differs in having pustulose dorsal thecal plate ornament as well as all the differences listed for *A. laevus*. *A. raymondi* Parsley, 1970, from the Blackriveran Shippensburg Limestone, Pennsylvania, and (?) the Benbolt Formation, Tennessee, differs in having angular proximal lobes, fine radiating ridges on dorsal thecal plates, and **L3** contacting **R3**.

Types and occurrence.—The holotype, UI X-5871, is from the lower member of the Lebanon Limestone approximately 15 m below the middle massive member at locality Z-651; paratype UI X-5873 is from the lower member, Lebanon Limestone, also at locality Z-651. Paratype UI X-5872 is from the lower member, Lebanon Limestone, about 3 m below the massive member at locality Z-652. All specimens are figured.

Class **ASTEROIDEA** de Blainville, 1830

Remarks.—Students of fossil sea stars have traditionally assigned Paleozoic taxa to modern orders, however, affinities between the groups are not clearly established (Kesling, 1969; McKnight, 1975). None of the Lebanon asteroids, therefore, are assigned to an order at this time.

Order Uncertain

Suborder **PUSTULOSINA** Spencer, 1951

Family **HUDSONASTERIDAE** Schuchert, 1915

Genus **HUDSONASTER** Stürtz, 1900

Type species.—*Palasterina rugosus* Billings, 1857, p. 291; *Palasterina rugosa* Billings, 1858, p. 77, pl. 9, figs. 2a–c.

Remarks.—Schuchert (1915, pp. 53–56) suppressed *Protopaleaster* Hudson, 1912, and reassigned the type species, *P. narrawayi,* to *Hudsonaster.* Schuchert argued that Hudson (1912, p. 24) had misinterpreted the morphology of his specimen and that the specimen was morphologically similar to others assigned to *Hudsonaster.* Subsequently, Spencer and Wright (1966, p. U50) and Branstrator (1982) resurrected *Protopaleaster.* Spencer and Wright (1966) separated the two on the basis of ray shape: those in *Hudsonaster* are "clearly not fused" whereas rays "tend to fuse" in *Protopaleaster* (Spencer and Wright, 1966, p. U50). The meaning of these characterizations does not appear clear, but might refer to the outline of the interbrachial angles. Branstrator (1982) separated the two genera on the basis of a single criterion: in adult specimens, the rays of *Hudsonaster* taper more rapidly than do those of *Protopaleaster.* Insofar as I have been able to ascertain, other characters, including ossicle shape and arrangement, are the same for both. Degree of ray taper alone is here considered insufficient for generic differentiation; therefore Schuchert's view that *Protopaleaster* be suppressed is followed.

Hudsonaster species cf. **H. narrawayi** (Hudson)
Plate 13, figure 12

Protopaleaster narrawayi Hudson, 1912, p. 25, pls. 1–3; Hudson, 1913, pp. 77–84; Spencer, 1914, p. 21, fig. 19.
Hudsonaster narrawayi (Hudson). Schuchert, 1915, p. 59, pl. 1, fig. 1; pl. 2, fig. 1; pl. 4, fig. 1.
Protopaleaster narrawayi Hudson. Spencer and Wright, 1966, p. U50, fig. 43a–d.
Protopaleaster narrawayi Hudson. Branstrator, 1982, p. 320, pl. 42, figs. 4, 5.

Remarks.—A single, small, well-preserved individual, USNM 60619, was studied. The entire actinal side and parts of at least two abactinal rays are exposed. Primary measurements in mm of the specimen as preserved are as follows: R (major radius: center of disc to tips of normal arms) = 5.2, r (mean shortest distance between disc center and thecal margin) = 2.7, Rw (arm width at the base) = 2.8. The specimen agrees well with the illustrations and drawings of the type specimen from the "Black River" Formation at Ottawa, Ontario, except that the latter is about twice as large, has proportionately slightly longer, less rapidly tapering rays, and slightly more ossicles in ossicle rows. These differences are here attributed to an earlier ontogenetic stage of the Lebanon specimen. Branstrator (1982) states that many juvenile pustulosinids, such as members of the Promopaleasteridae and Mesopaleasteridae, could go through an early postlarval *Hudsonaster*-like stage. If true, this would cast doubt as to the identity of the Lebanon Limestone specimen; the specimen might be a juvenile pustulosinid. Until Branstrator's view is tested by adequate growth series, however, the assignment of the Lebanon Limestone specimen to *Hudsonaster* must be retained.

Types and occurrence.—The single specimen, USNM 60619, is here figured; it is from an unknown horizon in the Lebanon Limestone at Shelbyville, Tennessee. The surrounding matrix suggests the specimen is from the upper member.

Order Uncertain

Family **SCHUCHERTIIDAE** Schuchert, 1915

Genus **SCHUCHERTIA** Gregory, 1899

Type species.—*Palasterina stellata* Billings, 1857, p. 290; Billings, 1858, p. 76, pl. 9, figs. 1a, 1b.

Schuchertia darwini new species
Plate 14, figures 1–3

Etymology of name.—The specific name honors Charles Darwin (1809–1882).

Diagnosis.—A species of *Schuchertia* characterized by relatively large proximal marginals and tiny accessory axillaries along adradiodistal margins of axillary marginals; otherwise resembles *S. stellata* as far as can be compared.

Description.—Size small, primary measurements of holotype in mm as preserved are: R = approximately 9.9, r = 3.9, Rw = 3.8 (see Remarks under *Hudsonaster* sp. cf. *H. narrawayi* for definitions of measurements). Disc moderately large with small interbrachial arcs; rays taper rapidly, more rapidly nearer disc so that arms appear slightly concave in abactinal view.

Ambulacral grooves narrow as preserved. **MAPP**, **Adambb**, marginals, abactinals all (?) with pustules bearing short, tiny spines; spines dense, slightly larger in ambulacral grooves, oral area. **Adambb**, marginals, abactinals with convex rounded external surfaces; marginals can have identations along sides.

Ambb hidden. **MAPP** proximodistally elongate, with arcuate keels along adradioactinal margins. **Adambb** wider than long, with well-developed furrow prominences; equisized nearly to ray tips, then rapidly diminishing in size. Apparent tiny accessory axillary ossicles at junctures of **Adambb**, axillary marginal, and succeeding marginal (Pl. 14, fig. 3). Single row of marginals border **Adambb** throughout ray length except where interrupted by accessory axillaries; proximally confined to actinal surface, becoming lateral medially, extending to ray tips. Marginals decrease in size gradually but significantly distally; subequant in outline proximally, becoming proximodistally elongate along distal rays. Axillary marginals large; each abuts two

MAPP, four **Adambb**, two marginals, two accessory axillaries, and abactinal; abuts abactinal along narrow surface. Abactinal ossicles arranged in quincunx rows; of similar-sized and -shaped ossicles as far as can be observed. Ossicle rows terminate against marginals, extend interbrachially onto actinal surface (Pl. 14, fig. 1); overlap adjacent rows abradially. Abactinals small, outlines suboval to subrectangular, closely abutting, not separated by significant gaps. Ratio of ossicle length to width increases, and size decreases distally along rows.

Remarks.—*Schuchertia darwini* n. sp. is based on a single, well-preserved, slightly compressed specimen. The actinal surface is exposed showing two nearly complete rays, two partial rays, the disc, and the lateral parts of the abactinal surface of two rays. It is assigned to *Schuchertia* based on the relatively large disc and short rays, abactinal surface of small non-differentiated ossicles arranged in quincunx, interbrachial arcs formed by abactinal ossicles, a single row of marginals abutting **Adambb**, and large axillary marginals bordering the **MAPP**: all are features listed in Schuchert's emended description of the genus (1915, p. 195). The new species differs from all other species assigned to *Schuchertia* in apparently possessing a few small accessory axillaries between the **Adambb** and marginals. These accessory axillaries are considered to be part of the specific diagnosis only because they are small, and do not form distinct rows that separate marginals and **Adambb** rows, but rather fill gaps caused by indentations along the sides of the proximalmost marginals.

S. darwini n. sp. is similar to the type species *S. stellata* (Billings, 1857) from the Trentonian at Ottawa, Ontario, Canada, but the latter species possesses relatively smaller proximal **InfMM**, and lacks accessory interbrachials. *S. laxata* Schuchert, 1915, from the Richmondian Waynesville Formation at Waynesville, Ohio, and *S. ordinaria* Schuchert, 1915, from the Upper Ordovician Girardeau Limestone, Alexander County, Illinois, differ in having smaller more numerous abactinals.

Types and occurrence.—The single specimen, UI X-5844, is figured; it is from the lower member, Lebanon Limestone, at locality Z-656.

Order Uncertain

Suborder **URACTININA**
Spencer and Wright, 1966

Family **URASTERELLIDAE** Schuchert, 1914

Genus **SALTERASTER** Stürtz, 1893

Type species.—*Palaeaster coronella* Salter, 1857, p. 326 [no illustr.].

Remarks.—*Salteraster* is distinguished from the closely-related genus *Urasterella* McCoy, 1851, by its more highly convex (*i.e.,* "swollen" of Spencer and Wright, 1966, p. U71) abactinal ray surfaces and the presence of abactinals of similar size and shape between the carinals and marginals (Spencer, 1950, p. 406). Abactinal ray convexity is often difficult to assess in fossil asteroids because of distortion and disarticulation; it is therefore here considered not as useful a generic criterion as are the nature and arrangement of the abactinals.

Salteraster species cf. **S. grandis** (Meek)
Plate 13, figures 7, 10, 13

Stenaster grandis Meek, 1872, p. 258; 1873, p. 66, pl. 3, figs. 7a–c.
Urasterella grandis Meek, 1873, p. 67.
Palaeaster harrisi Miller, 1879, p. 117, pl. 10, figs. 2, 2a.
Urasterella grandis (Meek). Schuchert, 1915, pp. 180, 181, pl. 27, figs. 6–8; pl. 28, figs. 1–2; pl. 30, fig. 104.
Salteraster grandis (Meek). Spencer, 1950, p. 406.
Salteraster grandis (Meek). Spencer and Wright, 1966, p. U71, fig. 64, 4c.

Remarks.—Two Lebanon specimens are assigned to this species. UI X-5776 is a large, slightly flattened and distorted specimen preserving the central disc, three rays nearly complete and two partial rays (Pl. 13, fig. 13). UI X-6035 is a partial ray of a large specimen. Measurements of UI X-5775 in mm as preserved are: $R = 68$ (1 ray only), $r = 4.5$, $Rw = 6.5$ (see Remarks under *Hudsonaster* sp. cf. *H. narrawayi* for definitions of measurements). The Lebanon specimens are similar to the holotype of *S.* (*Urasterella*) *grandis* from the upper Ordovician Richmondian stage at Richmond, Indiana, except the type specimen differs in possessing somewhat thicker paxillary shafts and less proximodistally elongate marginals.

The new occurrence significantly extends the stratigraphic range of *Salteraster.*

Types and occurrence.—The two specimens, UI X-5775 and UI X-6035 are from the lower member of the Lebanon Limestone at locality Z-654a. UI X-5775 is figured.

juvenile **Salteraster** species
Plate 13, figure 9

Remarks.—This form is represented by two specimens. UI X-5845 is a somewhat corroded complete specimen with the disc, two complete and two partial rays of the abactinal surface exposed. UI X-5854 is an extensively disarticulated individual exposing the abactinal surface. Measurements in mm of UI X-5845 as preserved are: $R = 7.0$, $r = 2.0$, $Rw = 1.9$ (see Remarks under *Hudsonaster* sp. cf. *H. narrawayi* for definitions of measurements). The disc is relatively large with rounded, convex rays that taper uniformly and rapidly. Abactinals typically are small; each carries a single large paxillary shaft. They are arranged in quincunx rows and are differentiated into carinals and lateral abactinals. Carinals are proximodistally elongate, slightly larger than lateral abactinals. Lateral abactinals are subequal in size. They extend along the sides of abactinal surfaces and are Y-shaped when well preserved with pores through gaps created by excavated ossicle sides. The abactinal disc has a small non-paxillate centrale surrounded by two circles of six, then 15 paxillate ossicles. The outer circlet contains the five proximalmost carinals. The madreporite is small, crenulostriate, and positioned laterally on the disc between two rays.

Generic assignment of these specimens to *Salteraster* is based on similar shape and arrangement of abactinal ossicles, particularly the slightly enlarged carinals, which are abradially flanked by rows of abactinals having similar size and shape. The madreporite size and position, and the convex arms also resemble *Salteraster.* The specimens described here differ principally from larger specimens of *Salteraster* in possessing a relatively larger disc, more rapidly tapering rays, and fewer rows of lateral abactinals. These differences, and the small size of the specimens, reflect ontogenetic stages. Modern asteroids show similar changes during early postlarval ontogeny. In addition, a closely-related immature form attributed to *Ulrichaster* (*Urasterella*) *ulrichi* (Schuchert, 1915) from the Blackriveran, Minnesota, by Schuchert (1915, pl. 30, figs. 6, 7; Spencer and Wright, 1966, fig. 64, 2a, 2b) has a similar large disc, rapidly tapering rays, and reduced number of lateral abactinal ossicle rows. The Lebanon specimens could belong to *Salteraster* sp. cf. *S. grandis* (Meek, 1873) which also occurs in the Lebanon but incompletely exposed material and lack of intermediate-sized individuals precludes specific assignment.

Types and occurrence.—UI X-5845 and 5854 are from the lower member, Lebanon Limestone, at locality Z-651. UI X-5845 is figured.

Class **EDRIOASTEROIDEA** Billings, 1858

Order **ISOROPHIDA** Bell, 1976

Isorophida species indeterminate
Plate 13, figure 11

Remarks.—A single fragment consisting of a weathered partial peripheral rim only can be assigned to the Isorophida but no further. The rim consists of approximately six circlets of plates; the plates overlap proximally and diminish rapidly in size distally. The proximalmost circlet of plates are concentrically elongate; the distal circlet plates are radially elongate.

Types and occurrence.—The single specimen, UI X-5848, is figured; it is from the lower member of the Lebanon Limestone at locality Z-655.

Suborder **CYATHOCYSTINA** Bell, 1975

Family **CYATHOCYSTIDAE** Bather, 1899

Genus **CYATHOCYSTIS** Schmidt, 1879

?**Cyathocystis** species
Plate 13, figure 6

Remarks.—A single specimen showing the distinctive solid canister-shaped sides and bottom of the theca is tentatively assigned to *Cyathocystis.* The oral surface is buried in very hard matrix and may be missing, so more definite assignment is impractical at this time. No sutures are evident and the sides and bottom of the specimen appear to behave optically as a single crystal.

Type and occurrence.—The single specimen, UI X-5846, is from the lower member of the Lebanon Limestone at locality Z-651. It is figured.

Order **EDRIOASTERIDA** Bell, 1976

Family **EDRIOASTERIDAE** Bather, 1899 (1898)

Genus **EDRIOASTER** Billings, 1858

Type species.—*Edrioaster bigsbyi* (Billings, 1858), pp. 82, 83, pl. 8, figs. 1, 1a, 2, 2a.

?**Edrioaster** species A
Plate 13, figures 8, 14

Remarks.—Two incomplete specimens are referred to ?*Edrioaster* sp. UI X-5847 is an extensively damaged theca with only distal parts of ambulacra and interambulacra preserved; UI X-5849 is a well-preserved thecal fragment with a short ambulacral segment and a few adjacent interambulacral plates. The clavate thecal shape, thick tessellate interambulacrals, and characteristic ambulacral coverplates and floorplates easily allow assignment of the Lebanon specimens to the Edrioasteridae. Further subdivision within this family to the closely related *Edrioaster* or *Edriophus* Bell, 1976, is based on the nature of the oral frame and hydropore structure, ambulacral curvature, and details of ambulacral coverplate and floorplate morphology (Bell, 1976). Only coverplate morphology was available and well-preserved in the Lebanon specimens (Pl. 13, fig. 8); these resemble *Edrioaster* in being evenly curved along the exterior surface and pointed perradially, yielding a zigzag perradial suture line (see Bell, 1976, p. 296). *Edriophus* differs in having coverplates upraised along perradial margins; coverplates further have sinuous perradial margins (Bell, 1976, p. 306). The Lebanon Limestone specimens, therefore, are provisionally assigned to *Edrioaster*; they differ slightly from the type species *Edrioaster bigsbyi* in possessing fine to medium reticulate plate ornament and interambulacral plates with slightly impressed sutures (Pl. 13, fig. 14). Incomplete material precludes specific assignment. The Lebanon Limestone specimens have very similar plate ornament to fragmentary edrioasteroids from the Mountain Lake Member, Bromide Formation, Oklahoma, and referred to *Edriophus* sp. cf. *E. laevus* (Bather, 1914) by Bell (1982, p. 297). Bell based his assignment on ambulacral curvature. The Oklahoma and Tennessee specimens extend the range of the Edrioasteridae downward to the Blackriveran.

Types and occurrence.—The two specimens, UI X-5847 and UI X-5849, are both figured. They are from the lower member of the Lebanon Limestone at locality Z-655.

Class **ECHINOIDEA** Leske, 1778

Order **BOTHRIOCIDARIDA** Zittel, 1879

Family **BOTHRIOCIDARIDAE** Klem, 1904

Genus **BOTHRIOCIDARIS** Eichwald, 1859

Type species.—*Bothriocidaris globulus* Eichwald, 1859, p. 654.

Bothriocidaris vulcani new species
Plate 14, figures 4–10

Etymology of name.—The specific name honors the Vulcan Materials Company, Nashville, Tennessee, whose cooperation in this study is greatly appreciated.

Diagnosis.—A species of *Bothriocidaris* characterized by ambulacral plates averaging twice as wide as tall near ambitus; two perforate primary tubercles on peripodia; ambulacrals without secondary perforate tubercles; largest interambulacral plates with one perforate primary tubercle and up to 12 secondary perforate tubercles.

Description.—Test apparently spherical, approximately 16 mm in diameter in holotype, UI X-5842, approximately twice as wide as paratype UI X-5841.

Apical system as shown in paratype dominated by five large radials. Radials wider than tall, ornamented with two to four primary tubercles, several smaller secondary tubercles; radials barely contiguous along narrow sutures; largest radial is the madreporite; madreporite externally with crenulostriate openings. Five small quadrate plates intercalated interradially, apically in notches between radials (Pl. 14, figs. 6, 7). At least one additional circlet of small plates fills periproct.

Ambulacra of two columns of alternating plates; approximately 60 plates per ambulacrum in holotype; perradial suture a pronounced zigzag, adradial sutures with interambulacra slightly zigzag to straight. Plates much wider than tall, averaging twice as wide as tall for plates near ambitus; with two primary tubercles, one on each side of the peripodia; typically no secondary tubercles, rarely can have up to four secondary tubercles (Pl. 14, fig. 9); plate surfaces with slight irregularities. Primary tubercles average 0.5 mm in diameter, separated by about 0.6 or 0.7 mm. Peripodia elliptical, low, highest apically between primary tubercles. Pore pairs arranged obliquely at approximately 30° to long axis of plate with perradialmost pore positioned apically.

Interambulacra without distinct plate rows, from one to three plates across interambulacra. Interambulacrals vary greatly in size, largest plates near ambitus, larger than adjacent ambulacrals, smallest plates much smaller than adjacent ambulacrals; shapes variable, typically subequant, quadrangular to hexagonal in outline; larger plates with subcentral primary tubercle, up to 14 secondary tubercles; smaller plates typically with secondary tubercles only.

Primary spines conical, short, with longitudinal striations; secondary spines similar to primary spines but shorter, slightly narrower. Three small apparent tube feet extending from podial pores in UI X-5841 (Pl. 14, fig. 7); conical with concentric thin ossicles aligned perpendicular to tube foot axis; no indication of suctorial disc.

Remarks.—*Bothriocidaris vulcani* n. sp. most closely resembles *B. solemi* Kolata, 1975, from the Blackriveran Grand Detour Formation, northern Illinois, but the latter species differs in having ambulacrals with a width-to-height ratio less than 2.0, and five to six secondary tubercles. *Bothriocidaris kolatai* Kier, 1982, is easily distinguishable from the new species by its up to four large primary ambulacral plate tubercles and lack of peripodial rims. *B. maquoketensis* Kolata, Strimple, and Levorson, 1977, from the Cincinnatian Fort Atkinson Formation is also similar to the new species but differs most conspicuously in having no secondary tubercles on the interambulacra, and radials that articulate along broader sutures. *Bothriocidaris eichwaldi* Männil, 1962, from the Upper Ordovician Pirgu Stage (F_{1c}), Estonia, and *B. pahleni* Schmidt, 1864, from the Middle Ordovician *Johvi* D_1 strata, Estonia, are the only other species with two primary tubercles on the peripodial rim. These species differ in possessing ambulacrals with a much greater height-to-width ratio and a more prominent round peripodial rim; both species also differ in having no primary tubercles on the interambulacrals.

Types and occurrence.—The holotype, UI X-5842, is from the lower member, Lebanon Limestone, at locality Z-656. Two paratypes, UI X-5841 and UI X-5839, are from the lower member of the Lebanon Limestone at locality Z-651. The holotype, and paratype UI X-5841, are partial tests; paratype UI X-5843 is an ambulacral plate. All specimens are figured.

Genus **UNIBOTHRIOCIDARIS** Kier, 1982

Type species.—*Unibothriocidaris bromidensis* Kier, 1982, p. 310.

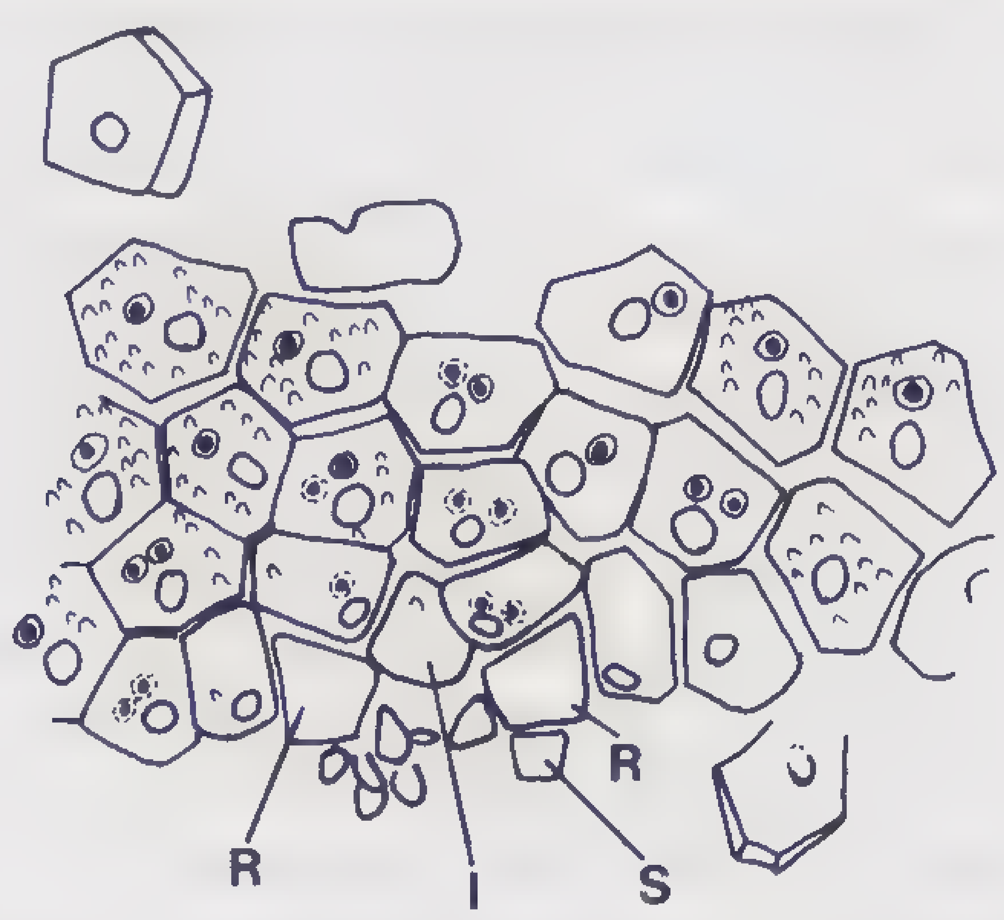
Unibothriocidaris kieri new species
Plate 14, figures 12–15; Text-figure 16

Etymology of name.—The specific name honors Porter M. Kier.

Diagnosis.—A species of *Unibothriocidaris* characterized by up to eight columns per ambulacrum; ambulacral plates with peripodia absent or low, faint; a single perforate tubercle perradially adjacent to single plate pore (on peripodia, if present), up to 16 pustules (12 average); interambulacrals without tubercles for spine attachment, with up to 14 pustules.

Description.—Test shape, diameter unknown. Coronal plates thick, tightly abut along vertical to nearly vertical sutures.

Ambulacra dominate corona, with eight columns of plates at ambitus; plates increase in size perradially, ambitally, lateralmost columns of plates mutually articulate along narrow sutures. Plates of each ambulacra arranged in offset rows, rows form chevron patterns (Pl. 14, fig. 13); hexagonal to pentagonal, quadrate in outermost column; largest are wider than high, smaller plates about as high as wide but variable. Large plate is 1.7 mm wide, 1.3 mm high. Each plate possesses a single large elliptical pore (correspond with pore pairs) that passes vertically through the test, can be constricted medially along major axis of ellipse; pores situated toward adradial margins of plates. Peripodia absent or low, faint; a single large perforate tubercle situated perradially, adjacent to pore near plate center, on peripodia (if present); plates near peristome with two closely-spaced tubercles, also near plate centers (Pl. 14, fig. 12). Pustules widely distributed on plate surfaces; larger plates with as many as 16 pustules, averaging 12.



Text-figure 16.—*Unibothriocidaris kieri* n. sp., tracing of partial peristome region in paratype, UI X-5835, ×6. Radial plates (R) alternate with interradial plates (I); subinterradial plates (S) are also present.

Interambulacra of a single column of hexagonal plates at least; columns originate at or close to apical region, do not reach peristome (Pl. 14, fig. 12). Plates without tubercles or spines, possess up to 14 pustules. Large interambulacral plate in holotype is 1.5 mm wide, 1.3 mm high.

Peristome partly known in holotype; apparently of five small subquadrate radial plates alternating with five subequally-sized interradial plates. Radials without pores, articulating with two ambulacrals adapically, two small (?)subinterradials actinally; small nondifferentiated plates present actinally (Pl. 14, fig. 12).

Remarks.—The type material of *Unibothriocidaris kieri* n. sp. consists of several articulated patches of plates and a few single plates that are scattered over approximately one-third square meter of a single bedding plane. No preserved parts are duplicated, and the sizes of the plates are comparable, strongly suggesting a single individual is present. The patches and isolated plates are each assigned a separate number, however, because it is possible that more than one individual is present.

The new species closely resembles isolated plates assigned by Kolata (1975, p. 68, pl. 14, figs. 3–8) to Bothriocidaridae, genus and species unknown. The plate morphologies are remarkably similar in the two, but the latter specimens possess slightly more prominent peripodia. *U. bromidensis* Kier, 1982, differs from the Lebanon species in possessing ambulacral plates with more prominent peripodia and fewer pustules.

U. kieri n. sp. is the only species of *Unibothriocidaris* in which the peristome is known. The peristome in this species greatly resembles the one illustrated by Männil for *Bothriocidaris eichwaldi,* Männil, 1962, and reinforces the opinion of Kier (1982) that the two genera are closely related.

Types and occurrence.—The holotype, UI X-5832 and paratypes UI X-5833 through 5838, and 6036 through 6044 are from the lower member of the Lebanon Limestone at locality Z-651. UI X-5832, 5835, 5837, and 5838 are figured.

?**Unibothriocidaris** species
Plate 13, figure 15

Remarks.—A single patch of plates, UI X-5840, exposed from the inside only is tentatively referred to *Unibothriocidaris* Kier, 1982, because it possesses a single pore passing through each plate. The specimen differs slightly from others referred to this genus in possessing podial pores with distinct medial constrictions nearly producing pore pairs, in having moderately inclined plate sutures, and in being larger than any other specimen referred to this genus. Without external plate surfaces exposed, the specimen cannot be assigned further.

Types and occurrence.—The single specimen, UI X-5840, is from the lower member of the Lebanon Limestone at locality Z-655. It is figured.

Genus **NEOBOTHRIOCIDARIS** Paul, 1967b

?**Neobothriocidaris** species
Plate 14, figure 11

Remarks.—A single ambulacral plate, UI X-5839, is provisionally referred to *Neobothriocidaris.* The plate has a subcentral pore and one sutural pore and therefore bordered an interambulacrum. (Ambulacrals not bordering interambulacra in this genus have one subcentral pore and two sutural pores.) A large perforate tubercle is positioned subcentrally on the peripodium. The peripodium is low but distinct. The plate is 1.1 mm high, and 1.5 mm wide.

Types and occurrence.—The single plate, UI X-5839, is figured; it is from the *Sowerbyella - Diplograptus* Zone of the upper member, Lebanon Limestone, at locality Z-652.

Class Unknown
Holdfasts

Remarks.—At least three kinds of holdfasts, a basal attachment plate, and a cirrus-bearing column segment were collected, which could not be definitely assigned to any Lebanon echinoderm. Most holdfasts, including types B, C, and some type A specimens probably belong to crinoids because associated distal columnals, when present, are divided into pentameres, and the columnal lumena are stellate (Lewis, 1982, pp. 58–60). The basal attachment plate and cirrus-bearing column segment probably also belong to crinoids because their morphologies are similar to specimens known or thought to be crinoids.

holdfast type A
Plate 14, figures 17–19, 23, 24

Remarks.—This holdfast is small- to moderate-sized (approximately 4 to 12 mm in diameter) and appears to consist dorsally of a single piece of calcite. It is low to medium height and subconical with short, irregular, lobate radicles. Deeply weathered (Pl. 14, fig. 24) specimens showing holdfast interiors are penetrated by small tubular canals; the canals may extend beyond the holdfast into the distal column. The column articular facet is large, averaging approximately half as wide as the holdfast; it is dish-shaped with faint, radially disposed crenulations. The axial canal as seen from the column articular facet is typically irregularly lobate; in UI X-6030, it is irregularly pentalobate.

A small attached column segment in UI X-6005 is composed of thin columnals divided into pentameres with small platelets between the columnals; the axial canal is large and pentastellate. Specimens show a wide range of weathering states ranging from essentially unweathered (UI X-6005) to nearly completely obliterated (UI X-6004). Identification of many holdfasts was accomplished using specimens in intermediate stages of weathering.

Several small specimens tentatively assigned to this holdfast type could belong to a different echinoderm from the other specimens. These small specimens are unweathered, lack attached columns, and show only gross external morphology. They are similar to other specimens as far as can be compared. The specimens show no diagnostic features (Pl. 14, fig. 19).

Holdfasts of this type, particularly larger specimens, closely match type 1A of Lewis (1982, p. 58) and may be congeneric with it. Lewis (1982, p. 59) suggests this type of holdfast was formed by *Carabocrinus* Billings, 1857, or *Paleocrinus* Billings, 1857. *Paleocrinus* is as yet unknown from the Lebanon. *Carabocrinus* thecal plates, however, are not uncommon in the Lebanon and occur at the same horizons as the holdfasts, though they have not yet been found directly associated with them. *Carabocrinus,* therefore, seems to be a likely candidate for the origin of at least some of these Lebanon holdfasts.

Types and occurrence.—Thirteen specimens are referred to this holdfast type. UI X-6004, 6005, 6010, 6020, and 6029 are from the lower member, Lebanon Limestone, at locality Z-652; UI X-6002 through 6027, 6030, and 6031 are from the lower member of the Lebanon Limestone at locality Z-654. UI X-6009 is from the lower member of the Lebanon Limestone at locality Z-651. Figured specimens are UI X-6010, and 6029 through 6031.

holdfast type B
Plate 14, figures 21, 25

Remarks.—This is a moderate-sized holdfast with

(?) five, large, long, branching radicles that extend into the substrate. Radicles are comprised of typically wider-than-tall plates that form distally alternating biseries; opposing plates of the biseries articulated along zigzag sutures. The distal column is subpentagonal, 7 mm in diameter, and it is composed of thin straight-sided columnals divided into pentamere circlets. The lumen is pentastellate, points of the pentastellate lumen correspond with lateral pentamere articulations. Columnal articular surfaces are symplectial with radially disposed crenulae.

This type of holdfast closely resembles type 1B of Lewis (1982) from the Bromide Formation, Oklahoma, who tentatively assigned his specimens to *Cleiocrinus* Billings, 1857. *Cleiocrinus tessellatus* (Troost, *in* Wood, 1909) from the Lebanon Limestone probably possessed a large conical holdfast and different columnal articulation surfaces with flat-bottomed triangular notches at lateral pentamere articulation points (see ?*Cleiocrinus* column and holdfast descriptions). Therefore, assignment to this species appears highly unlikely. It could be that the Lebanon Limestone species *Cleiocrinus laevus* Springer, 1911, which has a crown more like the common Bromide species (*Cleiocrinus bromidensis* Kolata, 1982), is the source of this holdfast. Both this type of holdfast and *C. laevus* crown fragments are rare in the Lebanon Limestone (two specimens and one specimen, respectively). However, I feel assignment to *C. laevus* is also unlikely. *Quinquecaudex springeri* (Kolata, 1975), from the Trenton (Ottawa) Limestone, Ottawa, Ontario, has holdfast morphology similar to these Lebanon specimens (see Kolata, 1975, pl. 6, fig. 5 for comparison). The resemblance is particularly striking in radicle morphology. *Quinquecaudex* or some other dendrocrinid, is, in my opinion, the most likely choice for this holdfast, given available information.

Types and occurrence.—UI X-6034 is figured and is from the upper member, Lebanon Limestone, at locality Z-653. It is a largely complete distal column and holdfast though much broken. Possible radicles of this type, UI X-6035, are from the lower member, Lebanon Limestone, at locality Z-651.

holdfast type C (*Lichenocrinus*)
Plate 14, figures 20, 23, 26, 27

Remarks.—These are small, discoidal, encrusting holdfasts, approximately 3 to 5 mm in diameter. The upper surface has a central depression and is polyplated with small, subpolygonal, tightly-interlocking plates. Attached column fragments are narrow, approximately 0.8 mm in diameter, and composed of pentagonal columnals. The columnals are composed of pentameres; the lumen is pentastellate. The holdfasts are attached to bioclasts such as brachiopods, and arthropod fragments, or to firm substrates.

These holdfasts are the same as those previously described as *Lichenocrinus* Sardeson, 1908, and type IC of Lewis (1982). Various authors (Sardeson, 1908; Warn and Strimple, 1977; Lewis, 1982; etc.) have ascribed these holdfasts to juvenile cincinnaticrinids or homocrinids. Four known cincinnaticrinid and homocrinid genera occur in the Lebanon: *Columbicrinus* Ulrich, 1925, *Doliocrinus* Warn, 1982, *Tryssocrinus* n. gen., and *Apodasmocrinus* Warn and Strimple, 1977. None of the specimens of these genera were found associated with the holdfasts described here. Adults of *Columbicrinus* and *Tryssocrinus* have larger holdfasts with relatively wider column articular facets than specimens assigned to this holdfast type but are otherwise similar (see Modes of Life under superfamily Cincinnaticrinacea). Holdfasts of *Doliocrinus* and *Apodasmocrinus* are unknown.

Types and occurrence.—UI X-6008 and 6021 are from the lower member, Lebanon Limestone, at locality Z-651. UI X-6013 through 6019 are from the lower member, Lebanon Limestone, at locality Z-652, and UI X-6028 is from the lower member of the Lebanon Limestone at locality Z-656. UI X-6014, 6015, and 6028 are figured.

basal attachment plate
Plate 14, figure 22

Remarks.—A single small subcircular basal attachment disc has numerous radially-disposed low septa; five enlarged septa are arranged in rough pentagonal symmetry. The specimen resembles attachment plates referred to "*Podolithus*" and "*Disconia*" (see Brower and Veinus, 1978; Westphal, 1974a, 1974b) and attachment plates of holdfast type 1c of Lewis (1982, p. 60, pl. 3, figs. 12, 33).

Types and occurrence.—The single specimen UI X-6032 is from the lower member, Lebanon Limestone, at locality Z-654 and is associated with a type A crinoid holdfast. The specimen is figured.

column segment with cirrus attachment facets
Plate 14, figure 16

Remarks.—A single column fragment has numerous variously-sized facets for attachment of cirri. The columnals are nearly straight-sided and thick.

Types and occurrence.—The single specimen UI X-6033 is figured, and is from the *Sowerbyella* - *Diplograptus* Zone of the upper member, Lebanon Limestone, at locality Z-652.

APPENDIX
LOCALITY REGISTER

The following 12 localities yielded the echinoderms found during this study. Approximate positions of the localities are shown on Text-figure 1. Tennessee Grid Coordinate System (T.G.C.S.)* numbers are in feet. All references made to members are to subunits of the Lebanon Limestone.

Z-651: Upper 28 m of Lebanon Limestone including most of the lower member and all of the massive and upper members, and all of the Carters Limestone; Vulcan Materials Company Quarry at Una on southeast side of Nashville, Davidson County, Tennessee; T.G.C.S. 617,500 N, 1,801,900 E, Antioch 7.5′ Quad.

Z-652: Ridley Limestone, and the lower 27 m of the Lebanon Limestone including all of lower and massive members, lower part of upper member; M. C. West Lime Company Quarry at Turney, 6 km south of Pulaski, Giles County, Tennessee; T.G.C.S. 275,400 N, 1,684,400 E, Pulaski 7.5′ Quad.

Z-653: Upper 16 m of the Lebanon Limestone including nearly all of the upper member, and all of the Carters Limestone; Stone Man Company Quarry on south side of U.S. Highway 41 about 1.2 km east of Duck River bridge and approximately 7 km southeast of Shelbyville, Bedford County, Tennessee; T.G.C.S. 389,000 N, 1,890,000 E, Normandy 7.5′ Quad.

Z-654: Upper 27 m of the Lebanon Limestone including most of the lower member and all of the massive and upper members, and the lower Carters Limestone. Highway cut, mile 43 on Interstate 65 approximately 12 km east-southeast of Columbia, Maury County, Tennessee; T.G.C.S. 440,400 N, 1,732,000 E, Glendale 7.5′ Quad. Locality Z-654a is a gray shale interbed in the lower member, approximately 3.8 m below the lower contact of the *Sowerbyella - Diplograptus* Zone of the upper member and approximately 3.5 m below the massive member.

Z-655: Approximately 10 m of the lower member of the Lebanon Limestone; roadcut on Interstate 24 approximately 2.8 km north of Hoovers Gap exit (approx. 15 km southeast of Murphreesboro), Rutherford County, Tennessee; T.G.C.S. 474,000 N, 1,911,450 E, Webbs Jungle 7.5′ Quad.

Z-656: Approximately 8 m of the lower member of the Lebanon Limestone; roadcut on Interstate 65 approximately 0.3 km south of bridge over Duck River, Maury County, Tennessee; T.G.C.S. 426,400 N, 1,730,500 E, Glendale 7.5′ Quad.

Z-658: The upper part of the Ridley Limestone, and the lower 14 m of the lower member of the Lebanon Limestone; Rutherford County Quarry, approximately 6 km south of Murphreesboro on east side of Highway 231, Rutherford County, Tennessee; T.G.C.S. 499,000 N, 1,881,200 E, Murphreesboro 7.5′ Quad.

Z-659: Approximately 6 m of the lower member of the Lebanon Limestone; small quarry on northeast corner of intersection of Sam Ridley Parkway and U.S. 70 (= Highway 41), Rutherford County, Tennessee; T.G.C.S. 584,000 N, 1,842,000 E, Smyrna 7.5′ Quad.

Z-661: Approximately 3 m of the upper member of the Lebanon Limestone; roadcut on highway 64 2.2 km east-southeast of Shelbyville, Bedford County, Tennessee; T.G.C.S. 394,500 N, 1,877,000 E, Shelbyville 7.5′ Quad.

Z-662: Upper 6 m of the upper member of the Lebanon Limestone; most of the Carters Limestone; abandoned quarry of Marquette Cement Manufacturing Company at Martha, Wilson County, Tennessee; T.G.C.S. 666,050 N, 1,870,700 E, Martha 7.5′ Quad.

Z-663: Approximately 4 m of the upper member of the Lebanon Limestone; roadcut at mile 54 on Interstate 65 approximately 1.6 km north of county line, Williamson County, Tennessee; T.G.C.S. 497,000 N, 1,742,250 E, Bethesda 7.5′ Quad.

Z-666: Upper 2.5 m of the lower member, all of the massive member, and the upper 2 m of the upper member of the Lebanon Limestone; roadcut on highway 231, approximately 3.0 km north of Rutherford County line, Wilson County, Tennessee; T.G.C.S. 601,050 N, 1,895,500 E, Vine 7.5′ Quad.

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* The Tennessee Grid Coordinate System is a surveying system used on published U.S.G.S. 7.5 minute quadrangle maps in Tennessee. It is based on footage distances from an arbitrary point near the southwest corner of Tennessee (actually in Mississippi). Locations are read in feet north and east of this point [oral commun., Ray Gilbert (Tennessee Geological Survey), 1984].

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PLATES

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1, 2.	Figured specimen, UI X-5915, wide column: 1. Lateral view, showing thin pentamere circlets, and lens-shaped plates between pentameres (arrows), ×1.5; 2. Articular surface, showing wide crenularium-areola, and flat triangular notches at pentamere articulations (arrow), ×2.	
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22–24.	Figured specimen, UI X-5919: 22. Entire specimen, ×1.5; 23. Detail of small area, ×4; 24. Detail of apex region, showing ?anal structure (arrow). Specimen photographed under xylene, ×4.	


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1–3, 6, 7.	***Cleiocrinus laevus*** Springer	22
	Holotype, USNM 50045, partial cup: 1. Basal view, ×2; 2. Oblique view, ×1.5; 3. Cup plate detail, showing fine concentric ridges, pores along sutures, ×4; 6. CD interray view, ×2; 7. A ray view, ×2.	
4, 8, 9.	***Cleiocrinus springeri*** new species	22
	Holotype, UI X-5918, partial cup: 4. Cup plate detail, unweathered, ×4; 8. E ray view, specimen badly corroded, ×1.5; 9. B ray view, ×1.5.	
5, 17.	***Reteocrinus polki*** new species	31
	5. Paratype, UI X-5413, partial cup, showing interinfrabasal depressions (arrow), ×2.	
	17. Paratype, UI X-5417, small crown and proximal column, anterior view, showing incipient spine-like lateral projections (arrow), small plates in interbasal gaps, ×2.	
10–13, 18.	***Reteocrinus fenestratus*** new species	30
	10. Paratype, UI X-5696, partial cup, proximal column, posterior view, ×2.	
	11. Paratype, UI X-5695, partial crown, posterior view, showing **Brr** and **RR** with lateral projections (arrow), **iBrr** with stellate ridges, ×1.5.	
	12, 13, 18. Holotype UI X-5690: 12. Partial cup, column, ×1; 13. Detail of cup, proximal column in posterior view, ×2; 18. Detail of medial column segment, ×2.	
14–16, 20.	***Reteocrinus variabilicaulis*** new species	32
	14. Paratype, UI X-5409, DE interray view of small crown, ×3.	
	15. Paratype, UI X-5408, partial cup, proximal column, showing thin nodals-internodals, ×2.	
	16. Figured specimen, UI X-5415, crown, proximal column, in D ray view, ×2.	
	20. Paratype, UI X-5412, CD interray view of crown, proximal column, showing supernumerary cup plates, ×2.	
19.	***Reteocrinus*** species	33
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1, 3.	***Gustabilicrinus plektanikaulos*** new genus and species, and ***Reteocrinus polki*** new species	33, 31
	1. Paratype, UI X-5791, *Gustabilicrinus plektanikaulos* partial crown (lower left), anterior view; and holotype, UI X-5790, *Reteocrinus polki,* flattened, nearly complete crown (right), DE interray view, showing distal anal series (arrow), ×2.	
	3. Paratype, UI X-5791, *Gustabilicrinus plektanikaulos,* partial crown (above left); paratype, UI X-5792, *Gustabilicrinus plektanikaulos,* coiled distal column (below); and holotype, UI X-5790, *Reteocrinus polki,* nearly complete individual (except for distalmost column and holdfast), ×1.	
2, 4, 11.	***Reteocrinus polki*** new species	31
	2. Paratype, UI X-5410, partial crown, anterior view, showing distended cup plates, ×1.	
	4, 11. Holotype, UI X-5790: 4. Detail of interbasal gap area showing small plates in gap, ×4; 11. Distal column showing pentameres changing rapidly to mosaic of tiny plates, ×2.	
5–10, 13.	***Reteocrinus variabilicaulis*** new species	32
	5–8, 13. Paratype, UI X-5805: 5. Nearly complete individual, ×1; 6. Detail of medial column showing widely-spaced nodals and ornate ornament, ×2; 7. Distal column of pentameres with holdfast, ×4; 8. CD interray view of crown and proximal column, ×2; 13. Interbasal gap with small plates, ×4.	
	9, 10. Holotype, UI X-5411: 9. Nearly complete specimen (except for holdfast), A ray view, showing wide nodals, internodals compressed and not visible, ×1; 10. Detail of crown, showing interinfrabasal depressions open below, ×2.	
12.	***Reteocrinus*** species cf. ***R. variabilicaulis*** new species	33
	Figured specimen, UI X-5414, C ray view of partial crown and column, showing **iBrr** with stellate ornament, ×2.	


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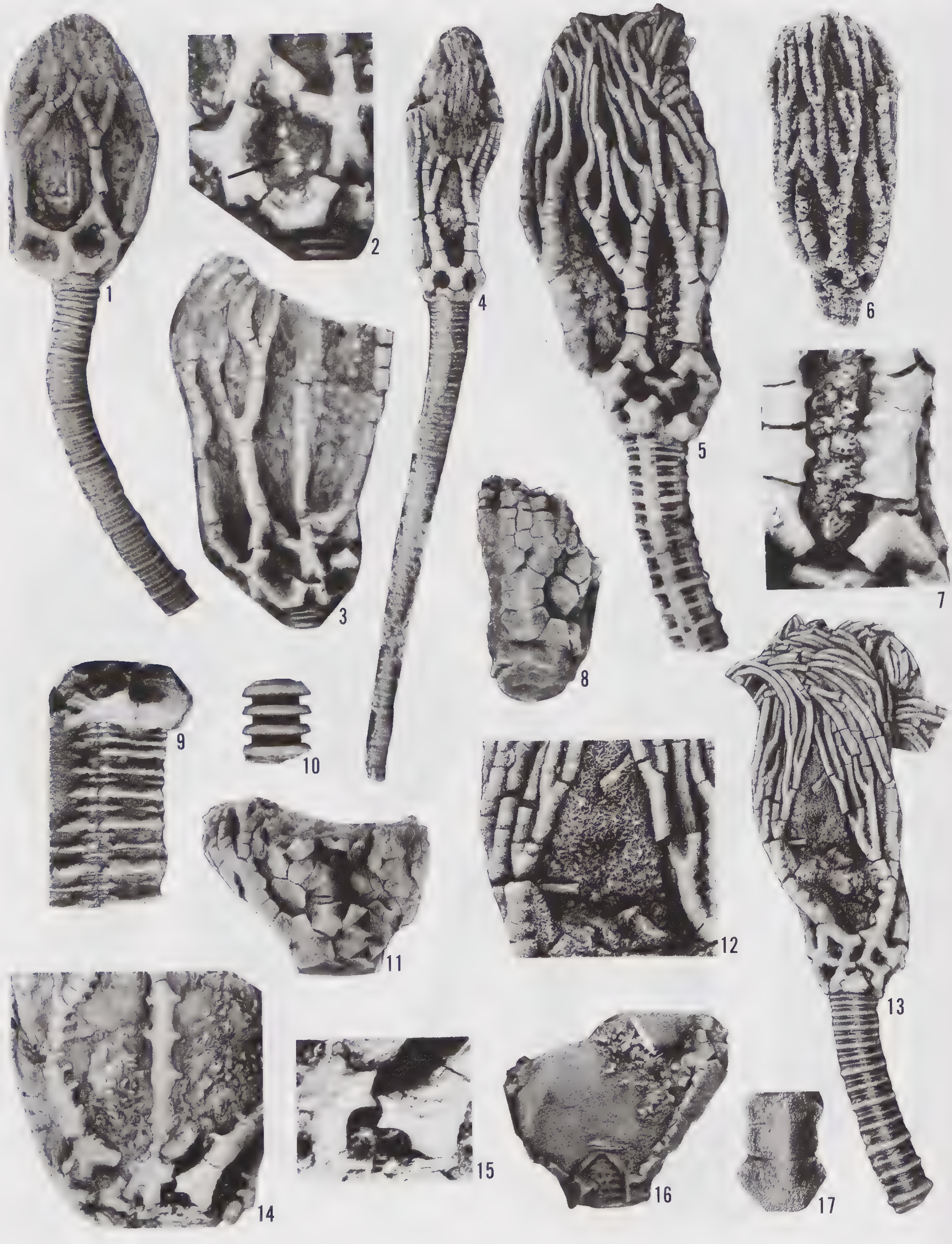
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EXPLANATION OF PLATE 4

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1–3. ***Reteocrinus stellaris*** Billings 28
1. Lectotype, GSC-1525, anterior view of partial crown, showing proximal column, interbasal areas, ×2.
2, 3. Paralectotype, GSC-1525b: 2. Detail of interbasal gap (photographed in water), showing small stellate plates in gap (arrow), ×4; 3. Posterior view of partial crown, ×2.

4. ***Reteocrinus elongatus*** Raymond 30
Holotype, MCZ-3370, crown and proximal column, slightly corroded, showing small lateral projections, ×2.

5–7, 9, 14, 15. ***Reteocrinus alveolatus*** Miller and Gurley 29
5, 7. Hypotype, UC-35991 (Kopf Collection): 5. Crown, anterior view, showing proximal column, ×2; 7. Detail of interbrachial area, showing pores in **iBrr**, ×4.
6. Holotype, FM(UC)-6045, coarsely silicified crown, ×2.
9. Hypotype, UC-34514 (Kopf Collection), proximal column with **IBB**, showing weathered, very thin columnals, cryptosymplectial articulations, ×4.
14, 15. Hypotype, UC-36006 (Kopf Collection): 14. Partial crown, ×2; 15. Detail of partial interbasal gap, showing plates in gap, ×4.

8, 10, 11, 16, 17. ***Gustabilicrinus latomium*** new species 35
Holotype, UI X-5961: 8. Well-preserved ray of partial cup, showing wide, short **RR** and **IBrr**, ×3; 10. Proximal column fragment with attenuated serrate latera, ×3; 11. ?Anterior view of cup fragment, ×3; 16. Lateral view weathered side of cup, showing spinose projections on tegmen plates (arrow), ×3; 17. Detail of **R**, **IBrr**, showing very fine ornamenting ridges, ×5.

12, 13. ***Reteocrinus variabilicaulis*** new species 32
Paratype, UI X-5694: 12. Detail of **iBr** plates, tegmen, ×4; 13. Crown and proximal column, showing supernumerary cup plates, ×2.

EXPLANATION OF PLATE 5

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1, 6. ***Gustabilicrinus latomium*** new species 35

Paratype, UI X-5962, ×3: 1. C ray view, showing probable CD interray (arrow); 6. EA interray view.

2–5, 12, 13, 18, 20–22. ***Gustabilicrinus plektanikaulos*** new genus and species 33

2, 3. Holotype, UI X-5952, ×1.5: 2. View of flattened crown, position of CD interray unknown; 3. Reverse side of specimen.

4. Paratype, UI X-5951, damaged cup fragment showing broken **BB**, **IBB**, proximalmost column, ×2.

5. Paratype, UI X-5758, partial crown, flattened, broken, lowermost cup missing, showing slightly impressed sutures, slight depressions at plate centers, ×1.5.

12, 18, 20. Paratype, UI X-5943, partial cup: 12. Cup, lateral view, showing large **iR** (lower left), ×3; 18. Anterior view, ×3; 20. Detail of cup plates, showing slightly impressed sutures, faint median ray ridges, fine pitting, ×6.

13. Paratype, UI X-5773, fragmentary crown with attached column segment, ×1.

21, 22. Paratype, UI X-5959, coiled distal column: 21. Column wrapped around distal column of ?*Trysso-crinus endotomitus* n. gen. et sp., ×1; 22. Detail showing nodals with radially-arranged ridges on epifacets, internodes of many thin columnals, ×4.

7–11, 14–17, 19. ***Archaeocrinus snyderi*** new species 36

7. Paratype, UI X-5745, medial column segment, ×1.

8. Paratype UI X-5744, proximal column segment, ×1.5.

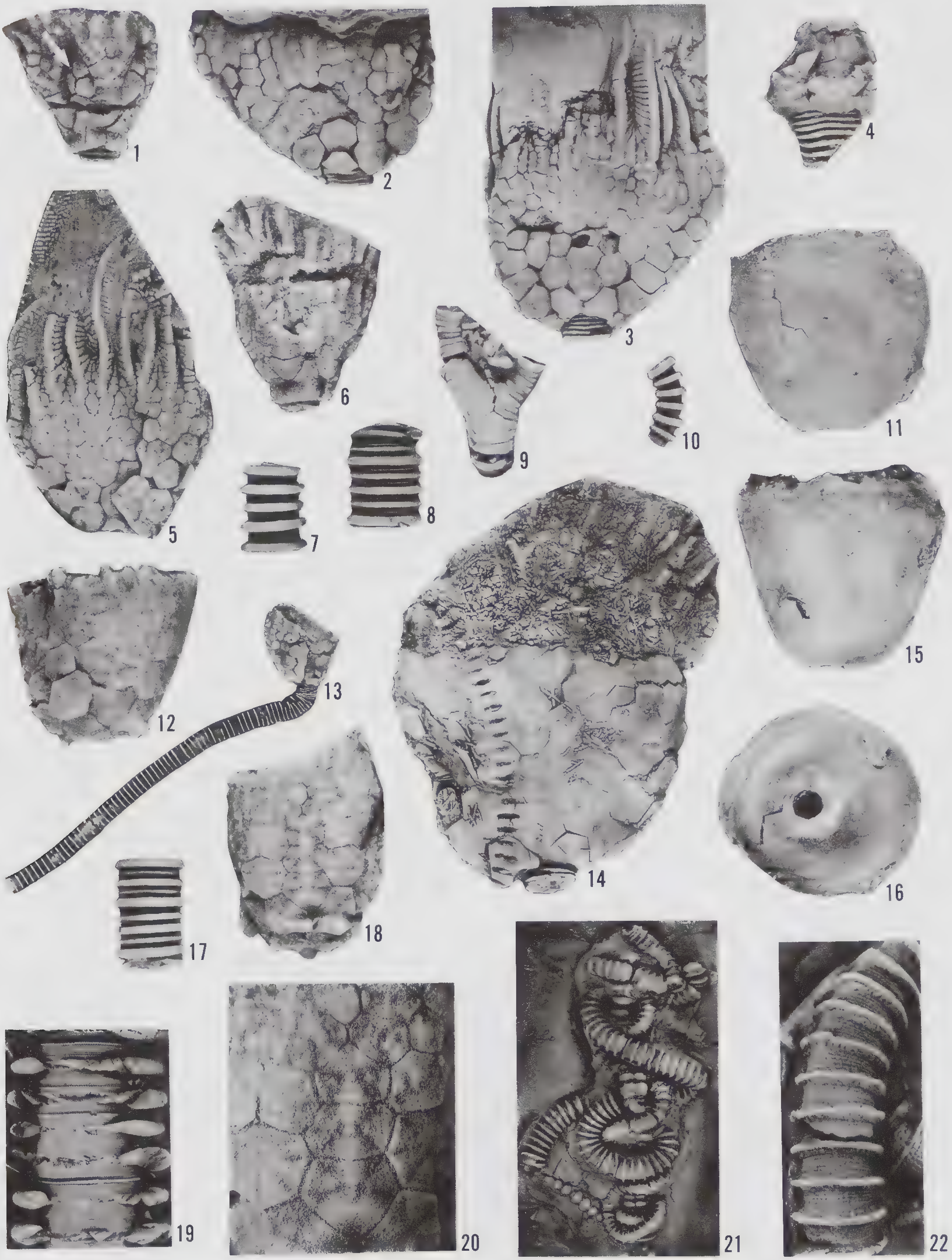
9, 14. Paratype, UI X-5742, partial crown: 9. Detail of free **IIBrr**, **IIIBrr**, showing ray bifurcation, ×3; 14. ?Anterior view, specimen partially flattened, showing faint median ray ridges, ×1.

10. Paratype, UI X-5737, distal column segment, showing faint, low, node-like projections on nodals, ×1.5.

11, 15, 16. Holotype, UI X-5740, cup, ×1: 11. A ray view; 15. CD interray view, showing two plates in primanal position; 16. Basal view, showing large basal concavity.

17. Paratype, UI X-5743, proximomedial column segment, ×1.5.

19. Paratype, UI X-5739, medial column segment, nodals partly broken away, showing symplectial articulations, ×3.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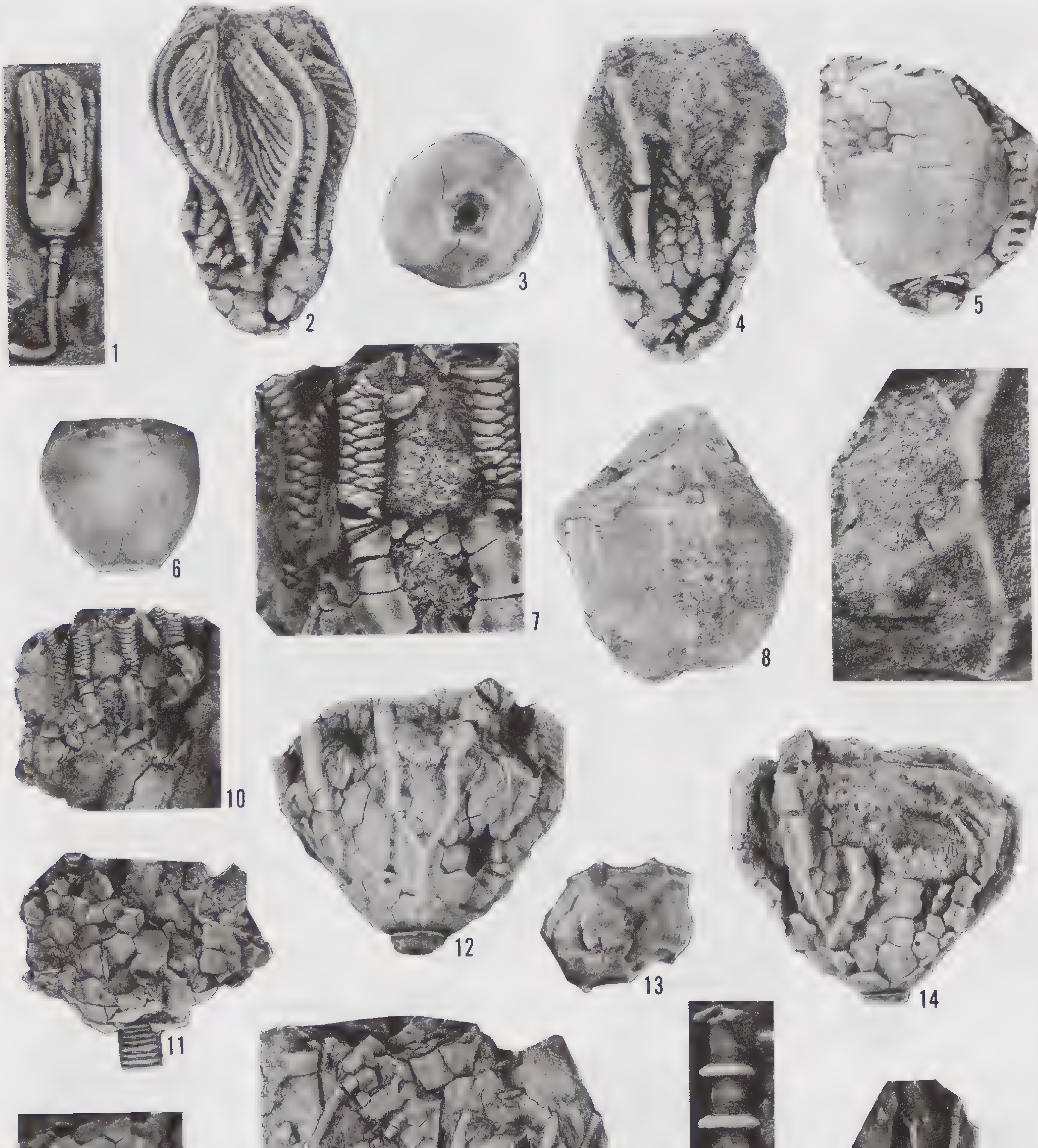
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EXPLANATION OF PLATE 6

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1, 2, 4.	?***Diabolocrinus*** species A	37
	1. Figured specimen, UI X-5767, anterior view of small crown, proximal column, ×4.	
	2, 4. Figured specimen, UI X-5853, flattened crown, ×4: 2. A ray view; 4. CD interray view.	
3, 5, 6.	***Archaeocrinus snyderi*** new species	36
	3, 6. Paratype, UI X-5750, small cup, ×1: 3. Basal view, showing large basal concavity; 6. Anterior view.	
	5. Paratype, UI X-5741, partial cup showing CD interray of primanal followed by row of three **iIBrr**, ×1.	
7, 10, 11.	Rhodocrinitid species A	37
	Figured specimen, UI X-5752, fragmentary crown, proximal column: 7. Detail of biserial free **IIBrr**, ×4; 10. Partial cup, arms, ×1.5; 11. Partial cup, column, ×1.5.	
8, 9.	Rhodocrinitacid species A	38
	Figured specimen, UI X-5753, much-weathered calyx: 8. Lateral view, ×1; 9. Detail of well-preserved plates, showing fine ridges and pustules, ×4.	
12–18.	***Abludoglyptocrinus gregatus*** new species	39
	12, 14. Holotype, UI X-5964, slightly flattened calyx and proximal arms, ×2: 12. A ray view; 14. CD interray view.	
	13, 18. Paratype, UI X-5969, calyx, ×1.5: 13. Basal view; 18. A ray view.	
	15. Paratype, UI X-5998, partial cup and proximalmost column, ×2.	
	16. Paratypes UI X-5996 (upper left) and UI X-5995 (lower right), partial crowns embedded in matrix, ×1.5.	
	17. Paratype, UI X-5997, distal column segment, showing low projections (nodes) on nodals, ×2.	

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1, 2, 7. ***Cremacrinus*** species cf. ***C. punctatus*** Ulrich	41

1, 2. Figured specimen, UI X-5892, partial crown, ×3: 1. E ray view, showing small E ray; 2. CD interray view.
7. Figured specimen, UI X-5891, A ray view of crown, proximal column, in matrix, showing large E ray, ×2.

3–5, 10–13, 16. ***Columbicrinus crassus*** Ulrich ... 44

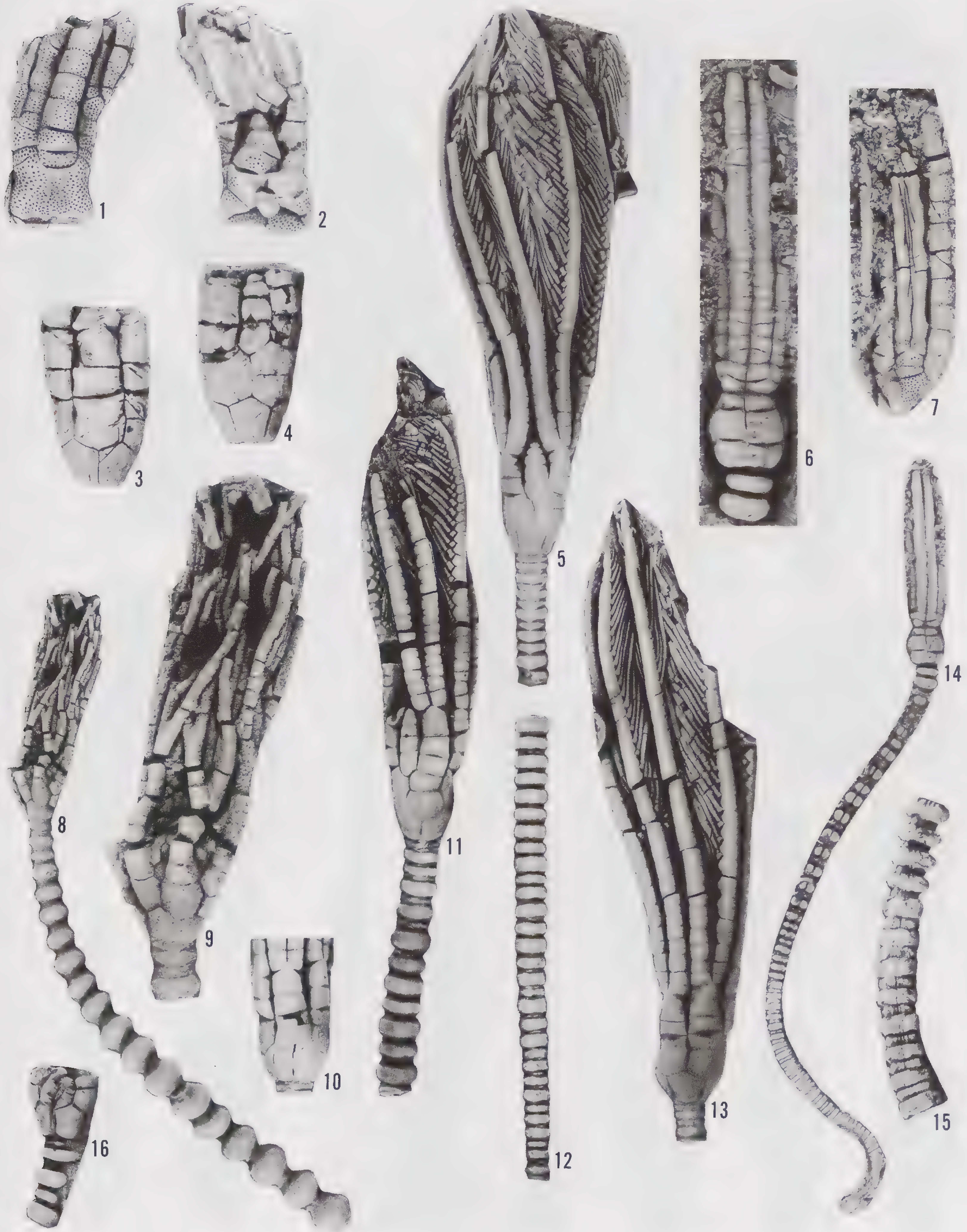
3, 4. Holotype, USNM 89826, weathered cup and proximal arms. ×2: 3. A ray view; 4. CD interray view.
5, 12. Hypotype, UI X-5707, crown with proximal and medial column, approximately 1 cm column segment between figures is missing, ×1.25: 5. Crown, CD interray view, showing pinnulation, proximal column; 12. Proximal to medial column, showing atypical distal taper.
10, 11. Hypotype, UI X-5705, crown and proximal column, ×1.25: 10. A ray view of cup and proximal arms; 11. C ray view of crown and proximal column.
13. Hypotype, UI X-5708, EA interray view of crown and proximalmost column, showing atypical wide-flaring **BB**, ×1.5.
16. Hypotype, UI X-5712, partial cup and proximal column, aboral margins of **BB** project slightly beyond column articular facet, cup plates with impressed sutures, ×2.

6, 14, 15. ***Apodasmocrinus*** species cf. ***A. daubei*** Warn and Strimple ... 40

Figured specimen, UI X-5716, crown and most of column, in hard matrix: 6. Detail of crown, proximal column, DE interray view, ×3; 14. Entire specimen, ×1; 15. Detail of medial column, showing striations adjacent to lateral pentamere articulations, transition in column morphology, ×3.

8, 9. ***Doliocrinus monilicaulis*** new species ... 42

Holotype, UI X-5716: 8. Crown and partial column, showing beadlike columnals, ×2; 9. Detail of crown, A ray view, showing that **iBr** touches **RR** in AB interray, ×4.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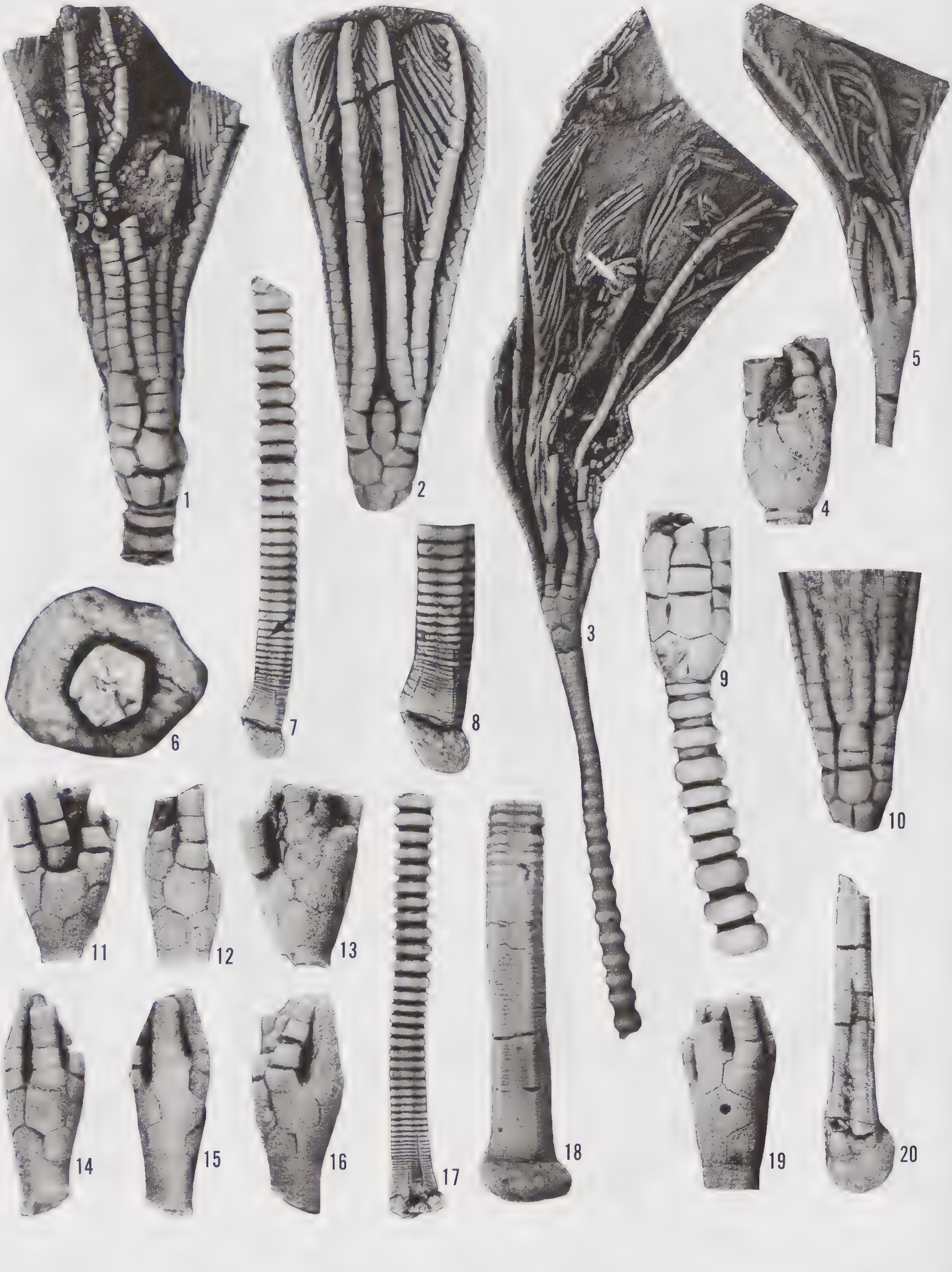
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1, 2, 4, 6–10, 17. ***Columbicrinus crassus*** Ulrich 44

1. Hypotype, UI X-5711, A ray view of crown, proximal column, showing narrow, steep-sided cup, impressed sutures, ×2.

2, 10. Hypotype, UI X-5713, ×2: 2. Crown, CD interray view, showing narrow cup, impressed sutures; 10. A ray view of cup, proximal arms.

4, 9. Hypotype, UI X-5704, ?gerontic individual, ×1.5: 4. D ray view of large robust cup; 9. A ray view of cup, proximal arms, and proximal column with thick and wide nodals.

6. Hypotype, UI X-5714, holdfast and distalmost column, ×4.

7, 8. Hypotype, UI X-5693: 7. Distal column and attached partial holdfast, distal columnals of pentameres with faint striations (arrow), ×1.25; 8. Detail of distalmost column, holdfast, ×2.

17. Hypotype, UI X-5768, distal column with attached partial holdfast, ×1.25.

3, 5, 11–16, 18–20. ***Tryssocrinus endotomitus*** new genus and species 46

3. Paratype, UI X-5809, crown and proximal column, showing multiplated anal tube (arrow), supernumerary cup plates in this specimen, ×2.

5. Paratype, UI X-5804, CD interray view of crown, including proximal anal tube, ×2.

11–13. Paratype, UI X-5831, cup and proximal arms, ×4: 11. A ray view; 12. B ray view; 13. CD interray view.

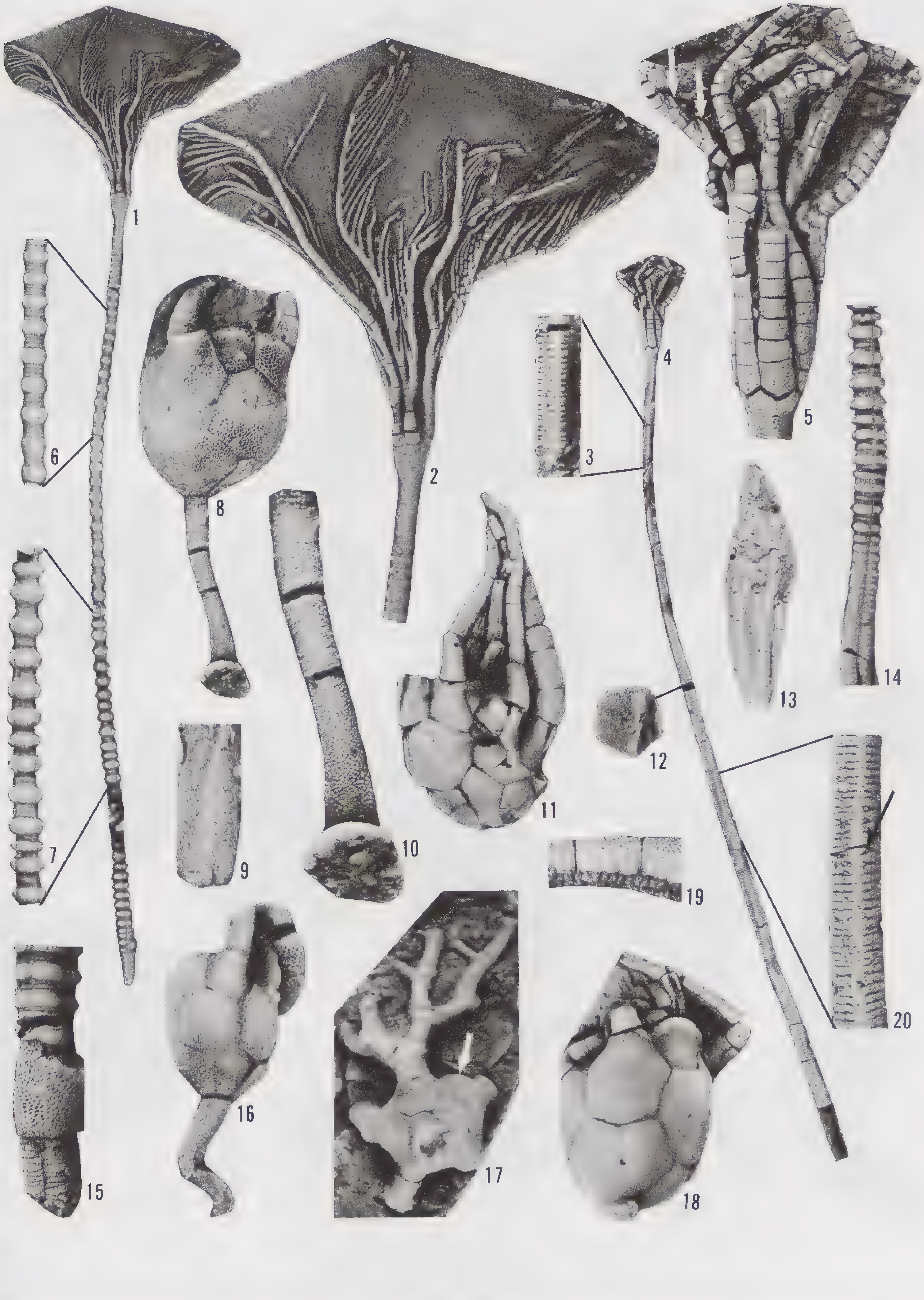
14–16. Paratype, UI X-5816, proximal column, cup, and proximal arms, ×4: 14. A ray view; 15. CD interray view; 16. D ray view.

18. Paratype, UI X-5826, pentagonal distalmost column and multiplated discoidal holdfast, ×3.

19. Paratype, UI X-5824, C ray view of cup, showing pit on C ray **iR** caused by parasite, ×4.

20. Paratype, UI X-5823, distalmost column and holdfast, ×2.

EXPLANATION OF PLATE 9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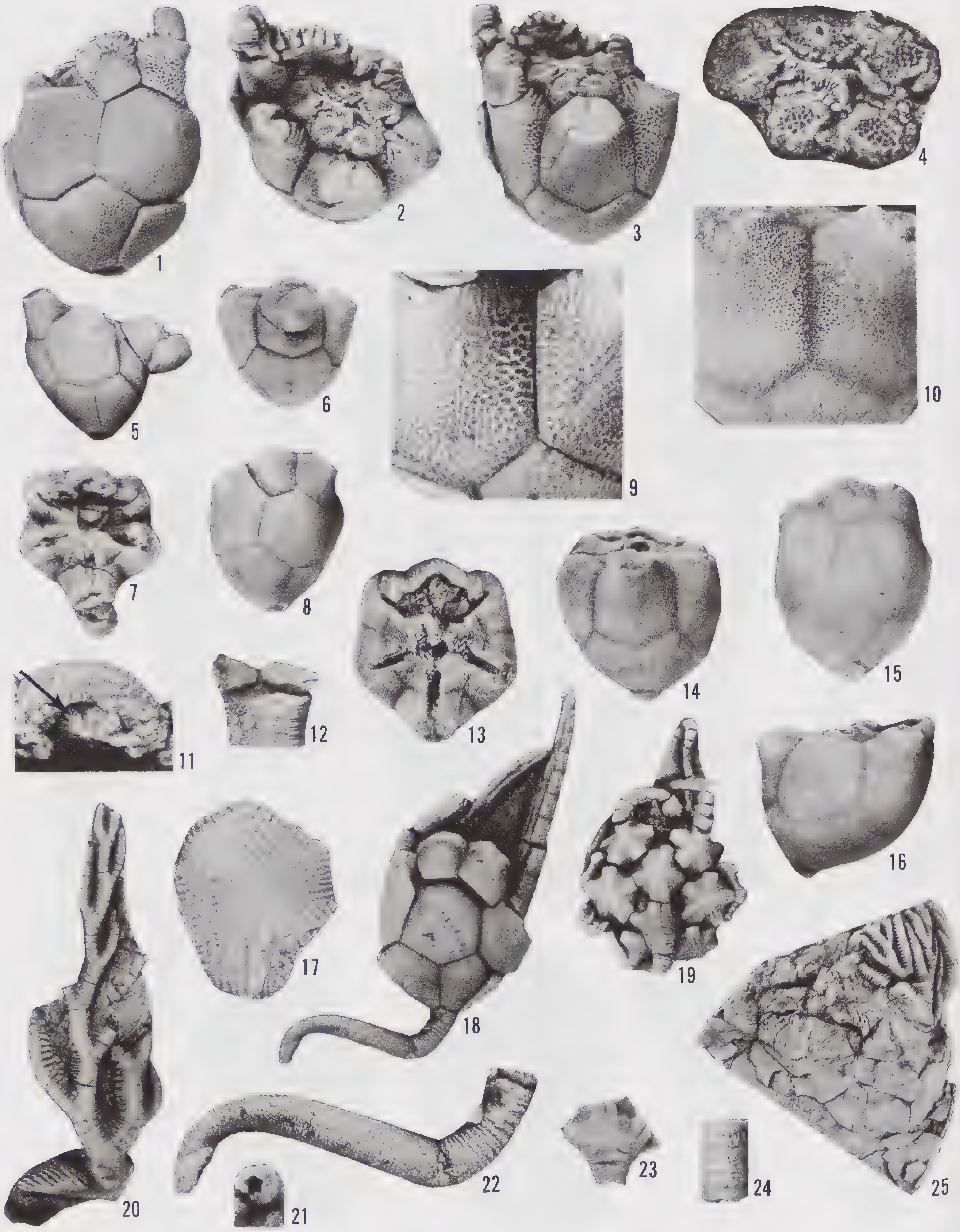
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EXPLANATION OF PLATE 10

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1–11, 13–16, 18, 21, 22. ***Hybocrinus bilateralis*** new species 51

1–4, 9. Paratype, UI X-5868, large calyx: 1. CD ray view, ×2; 2. Oral view, ×2; 3. A ray view, ×2; 4. Detail of oral area, showing coverplates, hydropore (upper center), ×4; 9. Detail of cup plates showing coarse pitting, ×4.

5–8, 11. Paratype, UI X-5869, calyx: 5. D ray view, ×2; 6. A ray view, ×2; 7. Oral view, ×2; 8. CD interray view, showing fine pitting, ×2; 11. Detail of ?valvular anal structure (arrow), ×6.

10, 13–16. Paratype, UI X-5867, globular calyx: 10. Detail of cup plates, showing fine pitting (compare with fig. 9), ×4; 13. Oral view, ×2; 14. A ray view, ×2; 15. CD interray view, ×2; 16. DE interray view, ×2.

18, 22. Paratype, UI X-5864: 18. Nearly complete partly flattened specimen, showing cup plates with fine pitting, ×2; 22. Detail of column and small holdfast, ×4.

21. Paratype, UI X-5861, detail of proximal columnal articular surface, showing pentalobate lumen, ×4.

12, 17, 20, 24, 25. ***Carabocrinus*** species 53

12. Figured specimen, UI X-5991, proximalmost column, and fragments of broken **IBB**, with thin undulatory columnals, ×2.

17. Figured specimen, UI X-5855, C ray **B**, showing radiating ridges, ×2.

20. Figured specimen, UI X-5856, partial **R**, arm, ×2.

24. Figured specimen, UI X-5980, column fragment of pentameres, associated with other fragments of this species, ×2.

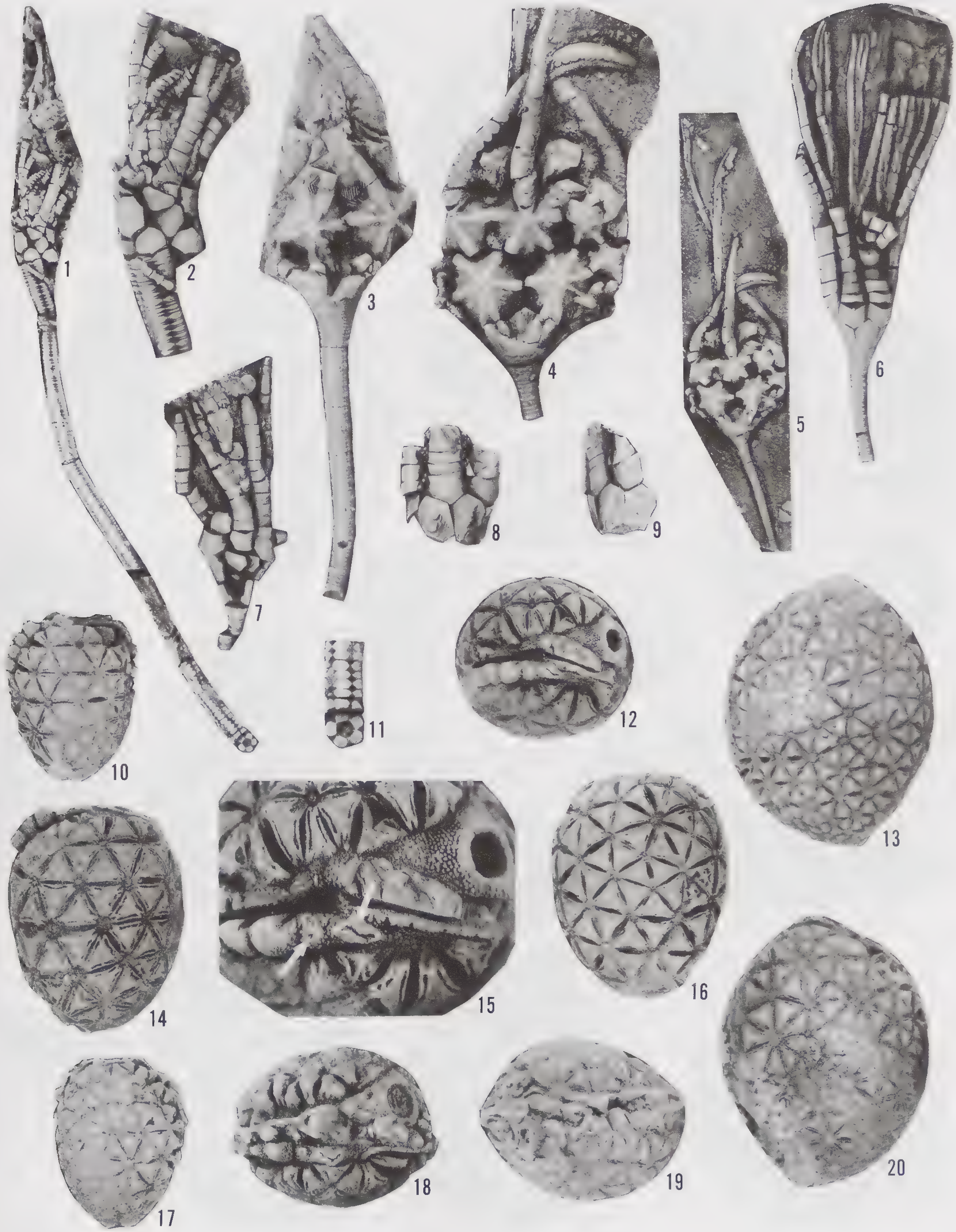
25. Figured specimen, UI X-5857, crown fragment, showing distorted, broken, and corroded cup plates, ×1.

19, 23. ***Porocrinus lebanonensis*** new species 54

19. Paratype, UI X-5796, anterior view of flattened crown, showing secondary ridges superimposed on primary calyx ridges, ×2.

23. Paratype, UI X-5889, **IBB** and proximal column, showing relatively tall **IBB** (for genus), ×3.

EXPLANATION OF PLATE 11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1–8. ***Oklahomacystis trigonis*** new species 56

1, 2. Paratype, UI X-5932: 1. Crushed, locally corroded, but nearly complete individual, ×2; 2. Detail of column attached to probable holdfast, ×4.

3, 4. Paratype, UI X-5920: 3. Theca with brachioles, partial column, ?posterior view, ×2; 4. Closeup of column, ×4.

5, 6. Paratype, UI X-5934: 5. Crushed theca, anterior view, ×2; 6. Detail of periproct area, showing covering plates, ×6.

7, 8. Paratype, UI X-5931: 7. Juvenile partial theca, column, anterior view, ×2; 8. Detail of thecal plates, ×4.

9–14, 16, 17. ***Tanaocystis sprinklei*** new species 59

9, 10. Holotype, UI X-5880, ×2: 9. Side view of partly disarticulated theca, showing the three plates that surround the periproct; 10. Another side view, with **L1** (right center).

11. Paratype, UI X-5877, **L3**, lower left margin broken, ×2.

12. Paratype, UI X-5879, **L3**, ?irregular demirhomb (arrow), showing broken lower left margin, ×2.

13. Paratype, UI X-5881 (left), probable **IL3**, paratype UI X-5882 (right), **IL2**, ×2.

14. Paratype, UI X-5884, **R3**, ×2.

16. Paratype, UI X-5883, **R2**, ×2.

17. Paratype, UI X-5878, **B2**, upper corner broken, ×2.

15, 18–20, 22–27. ***Praepleurocystis ranaformis*** new species 60

15. Paratype, UI X-5983, patch of periproctal plates, ×4.

18–20, 24, 25. Holotype, UI X-5697, well-preserved theca, ×2: 18. Right lateral view; 19. Left lateral view; 20. Proximal transverse view; 24. Periproctal view; 25. Rhomb view.

22. Paratype, UI X-5698, rhomb (dorsal) view, theca distorted, partly disarticulated, ×2.

23, 26. Paratype, UI X-5850: 23. Partial specimen, showing nearly complete stem, ×1; 26. Detail of distal periproctal face, showing gonopore and hydropore slit, ×3.

27. Paratype, UI X-5985, partial theca, proximal column, showing longitudinal grooves and ridges on columnals, ×2.

21. ***Praepleurocystis*** species cf. ***P. watkinsi*** (Strimple) 62

Figured specimen, UI X-5893, possible **L3** thecal plate, ×2.

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1–5. ***Amecystis nanus*** new species 62

1, 5. Holotype, UI X-5871, nearly complete small specimen: 1. Dorsal face, one arm preserved, ×3; 5. Detail of posterior theca (for plate designations, see Text-fig. 15), ×6.

2. Paratype, UI X-5873, periproctal view: Proximal column showing nodose outer columnals, and proximal portion of theca; most of theca preserved as mold, ×4.

3, 4. Paratype, UI X-5872, partial theca, stem: 3. Periproctal face, distal stem reflexed toward theca, ×3; 4. Detail, showing valvular anal structure, nodose proximal stem, ×6.

6. ?***Cyathocystis*** species 66

Figured specimen, UI X-5846, lateral view of canister-shaped theca, ×2.

7, 10, 13. ***Salteraster*** species cf. ***S. grandis*** (Meek) 65

Figured specimen, UI X-5775: 7. Lateral ray detail, showing abactinals with long paxillary shafts, ×4; 10. Detail of actinal surface, dismembered ray showing ambulacrals and adambulacrals in transverse view (arrow), ×4; 13. Entire specimen, showing primarily actinal view, ×1.

8, 14. ?***Edrioaster*** species A 66

8. Figured specimen, UI X-5849, thecal fragment, showing ambulacral coverplates in place, ×3.

14. Figured specimen, UI X-5847, extensively damaged theca, showing coarse reticulate ornament, ×2.

9. juvenile ***Salteraster*** species 65

Figured specimen, UI X-5845, abactinal view, ×4.

11. Isorophida species indeterminate 66

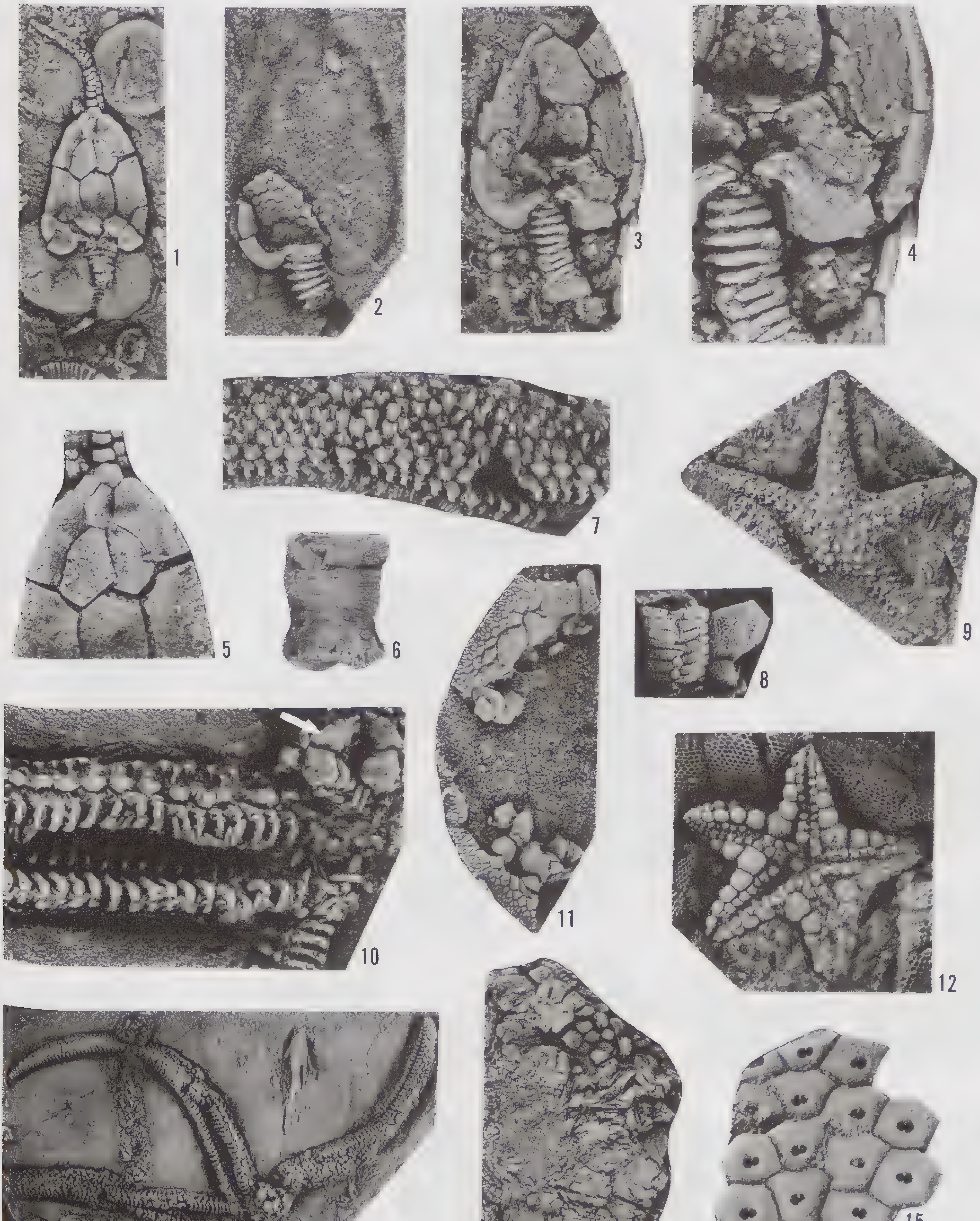
Figured specimen, UI X-5848, partial peripheral rim, ×3.

12. ***Hudsonaster*** species cf. ***H. narrawayi*** (Hudson) 64

Figured specimen, USNM 60619, actinal surface, ×4.

15. ?***Unibothriocidaris*** species 69

Figured specimen, UI X-5840, inner surface of ambulacral plate patch, pores constricted, almost forming pore pairs, ×4.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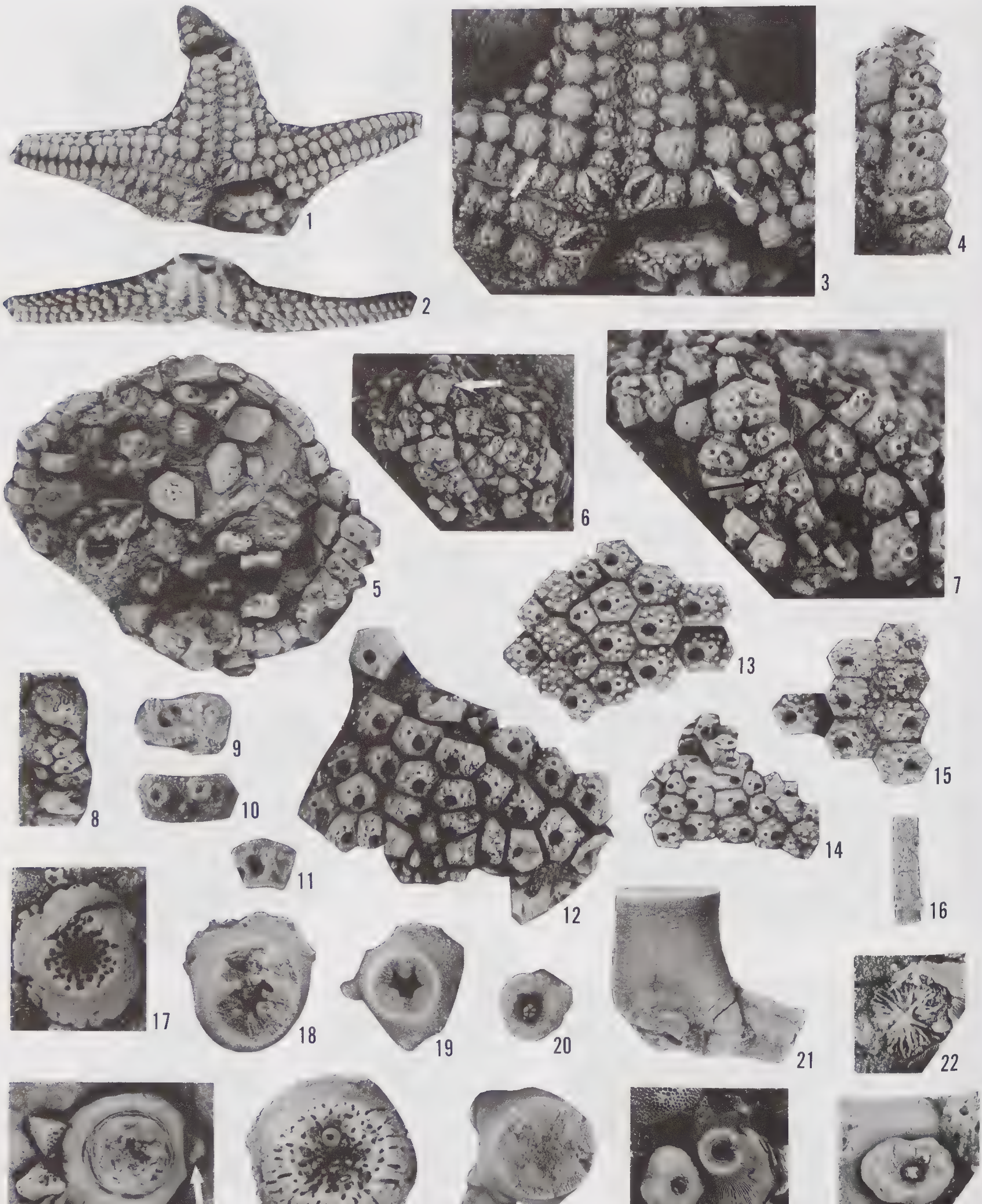
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EXPLANATION OF PLATE 14

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1–3. ***Schuchertia darwini*** new species 64
Holotype, UI X-5844: 1. Actinal view, ×4; 2. Lateral view, ×4; 3. Detail of oral area, showing tiny accessory axillaries (arrows), ×6.

4–10. ***Bothriocidaris vulcani*** new species 67
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11. ?***Neobothriocidaris*** species 69
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16. column segment with cirrus attachment facets 70
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17–19, 24. holdfast type A 69
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EXPLANATION OF PLATE 15

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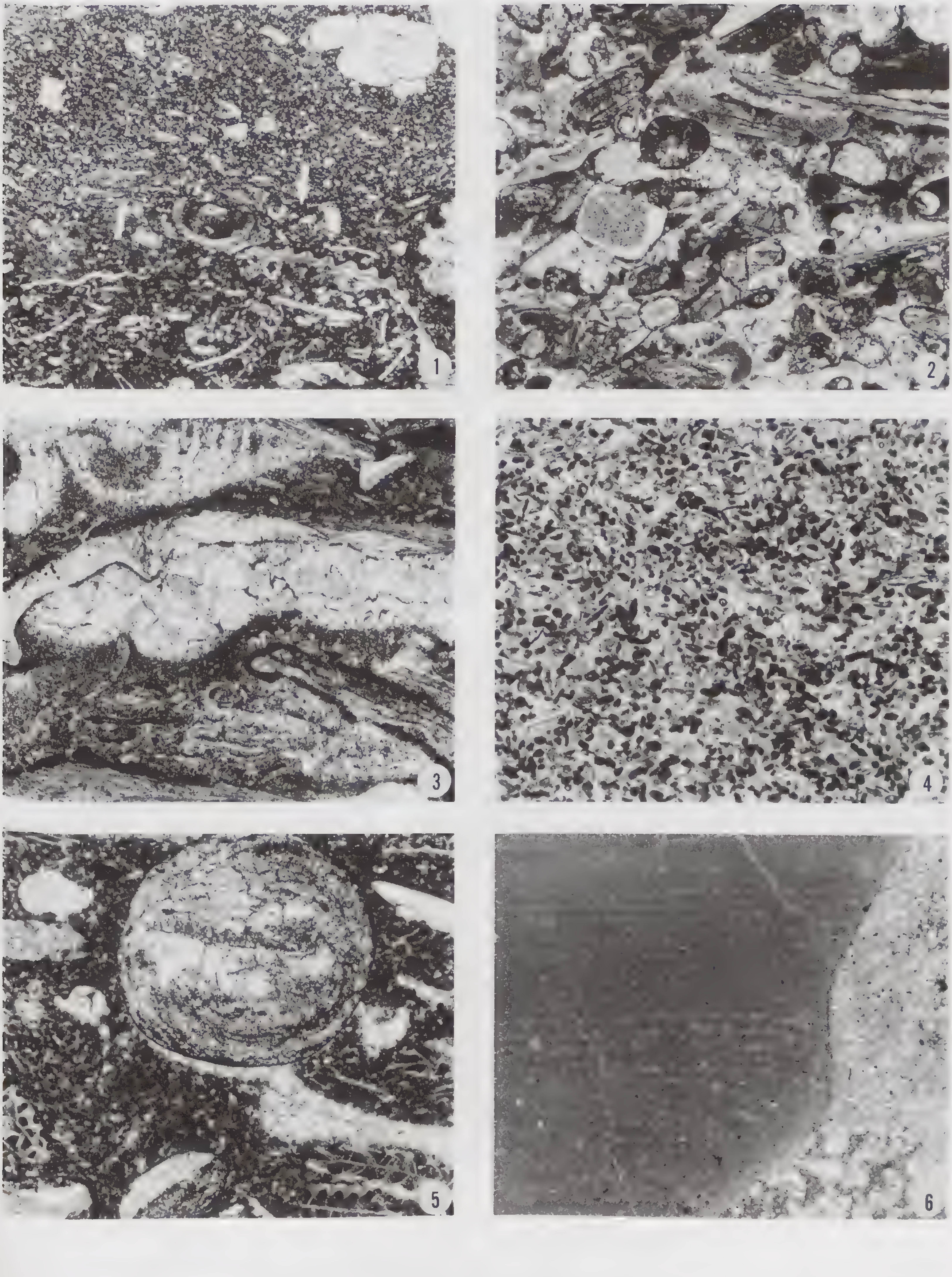
3. Poorly-sorted brachiopod biocalcirudite (lithofacies 4) with lutite matrix, spar-filled umbrella structure across center of photograph, *Sowerbyella-Diplograptus* Zone, upper member at locality Z-653.
4. Moderately well-sorted pellet biocalcarenite (lithofacies 1), massive member at locality Z-660.
5. Oncolite in poorly-sorted pellet biocalcirudite (mixed lithofacies 1 and 4), upper member at locality Z-651.
6. Laminated biocalcisilite-calcilutite (lithofacies 2). *Sowerbyella-Diplograptus* Zone, upper member at locality Z-654.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EXPLANATION OF PLATE 16

Figure Page

1–4. Lebanon Limestone exposures 7, 8, 10

1. Lower member, thinly-developed massive member (arrow), locality Z-654.
2. Quarry floor exposing single bedding plane of megaripples (small scale dunes) just above massive member, crane (for scale) approximately 14 m long, locality Z-653. Prominent megaripples occur at an approximately equivalent horizon at locality Z-654.
3. Calcirudite-calcarenite lenses in nodular weathering calcilutite: note abrupt lateral margin of lens (arrow), lens cap for scale is approximately 7 cm long, locality Z-652.
4. Approximate level of Lebanon Limestone–Carters Limestone contact marked by head of hammer (arrow).

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Note: Page numbers are in lightface, plate numbers are in **boldface** type.

Table 12.—Explanation of acronyms used in the taxonomy section. Parentheses denote the plural usage.

Crinoids	
IB(B) = infrabasal	
B(B) = basal	
R(R) = radial	
iR(R) = interradial	
sR(R) = superradial	
Br(r) = brachial	
IBr(r) = primibrachial	Numerical subscripts following these acronyms indicate the specific plate(s) of the series in question.
IIBr(r) = secundibrachial	
IIIBr(r) = tertibrachial	
IVBr(r) = quartibrachial	
iIBr(r) = interprimibrachial	
iIIBr(r) = intersecundibrachial	
iIIIBr(r) = intertertibrachial	
O(O) = oral	
X(X) = anal plates (disparid inadunates)	Numerical subscripts following this term indicate the specific plate(s) of the series in question.
RA = radianal (in *Hybocrinus, Porocrinus, Quinquecaudex*)	
Rhombiferans	
Numbers following abbreviations refer to specific plates of the series in question.	
B(B) = basal	
IL(L) = infralateral	
L(L) = lateral	
R(R) = radial	
O(O) = oral	
D,D′ = distal plates (pleurocystitids only, superscript (′) indicates plates found on ventral surface.)	
Asteroids	
Amb(b) = ambulacral	
Adamb(b) = adambulacral	
MAP(P) = mouth angle plate	
InfMM = inferomarginals	

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