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FOSSIL CRINOID STUDIES

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## PART 1

## NOTES ON THE INADUNATE CRINOID GENUS PHANOCRINUS

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## ABSTRACT

The anal sac of *Phanocrinus* is shown to have the form of a tall, slenderly cylindrical tube with upward directed summit spine and outlet near midheight on the anterior side. Also, some flat-based crinoids are judged to belong to this genus, which normally has a basally concave dorsal cup.

## INTRODUCTION

The genus *Phanocrinus* Kirk (1937) is well represented throughout rocks of the Upper Mississippian Chesteran Stage of North America, and is also common in the upper Visean (Lower Carboniferous) of Scotland. Termier & Termier (1950) have illustrated a typical representative of the genus from the upper Visean of North Africa. Considerable variability is exhibited in some large populations (see Wright, 1926, 1939, 1951; Strimple, 1948). The genus needs considerable study before it is fully understood and thus stratigraphically most useful. The main purpose here is to illustrate the nature of the anal sac or tube of *Phanocrinus* and to demonstrate an evolutionary trend hitherto virtually unknown among inadunate crinoids, i.e., the development of cups with a planate base among forms in which the primary lineage has a concave base. Evolution is normally from a convex base to a planate base to a concave base.

All forms ascribed to the Phanocrinidae have a basal concavity save one found in the upper part of the Fraileys Shale or lower part of the Haney Formation (probably Fraileys Shale) east of Anna in Union County, Illinois. The form is described as *Phanocrinus planus* Strimple & Moore, new species.

Attention is drawn to another specialization in *Phanocrinus* which is reflected by the species *P. parviramus* Sutton & Winkler (1940), the

holotype of which is figured herein (Fig. 1,1,2) and *P. alexanderi* Strimple (1948), in which the dorsal cup becomes unusually low and broad, and the arms shorter than common and having well-rounded exteriors. The arms of *Phanocrinus* usually are moderately long to very long and the exteriors are gently convex with sharply delineated, flattened sides.

## ANAL SAC OF PHANOCRINUS

The anal sac of *Phanocrinus* has the form of a long slender tube terminating in a single elongated spine which does not reach to tips of the arms. The anal opening is at about midheight of the sac on the anterior side but the sac is not recurved down to the anal opening. The sac is composed of small hexagonal plates in alternating vertical series. Eight or more such rows of plates appear in all specimens examined. No respiratory slits have been observed in the sac plates.

The anal sac of *Delocrinus* sp. (probably *Delocrinus subhemisphericus* = *D. hemisphericus* fide Moore & Strimple, 1970) has been demonstrated by Moore & Strimple (1941, pl. 1, fig. 4), as well as that of *D. megalobrachiis* (Beede) (Moore & Strimple, 1941, pl. 1, fig. 6). It has the same structure as demonstrated for *Phanocrinus* herein, and supports removal of *Delocrinus* from the family Erisocrinidae by Strimple & Moore (1971). Typical *Erisocrinus* was found



FIG. 1. *Phanocrinus parviramus* Sutton & Winkler, from the Glen Dean Formation, Chesteran, of Kentucky.—1, 2. Holotype crown (Walker Museum 4914) from anterior side,  $\times 3$ , and base,  $\times 3.5$ .

by Strimple & Moore (*ibid.*, pl. 5, fig. 1b) to have a very short, rather broad, recurved anal sac. *Delocrinus* now is assigned to the family Catacrinidae Knapp (1969), which, according to stipulations of the *International Zoological Code*, must be recognized in lieu of another name.

It may very well be found that species identification among representatives of *Phanocrinus* will be ascertained more readily when the anal sacs are known.

*Phanocrinus* sp. cf. *P. bellulus* (Miller & Gurley) is illustrated here (Fig. 2, 1-3) by a well-

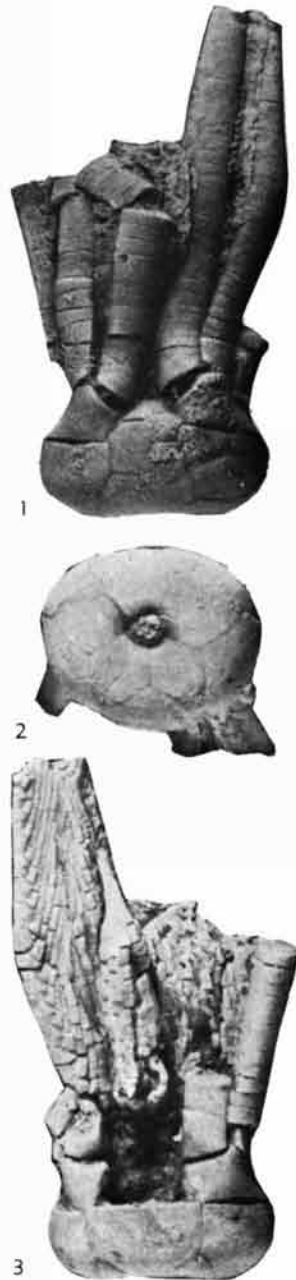


FIG. 2. *Phanocrinus* sp. cf. *P. bellulus* (Miller & Gurley), from the Fraileys Shale Formation, Chesteran, of Illinois.—1-3. Hypotype SUI 34345 crown from posterior, base, and anterior sides with tubelike anal sac, anus, and slender terminating spine exposed,  $\times 2.25$ .

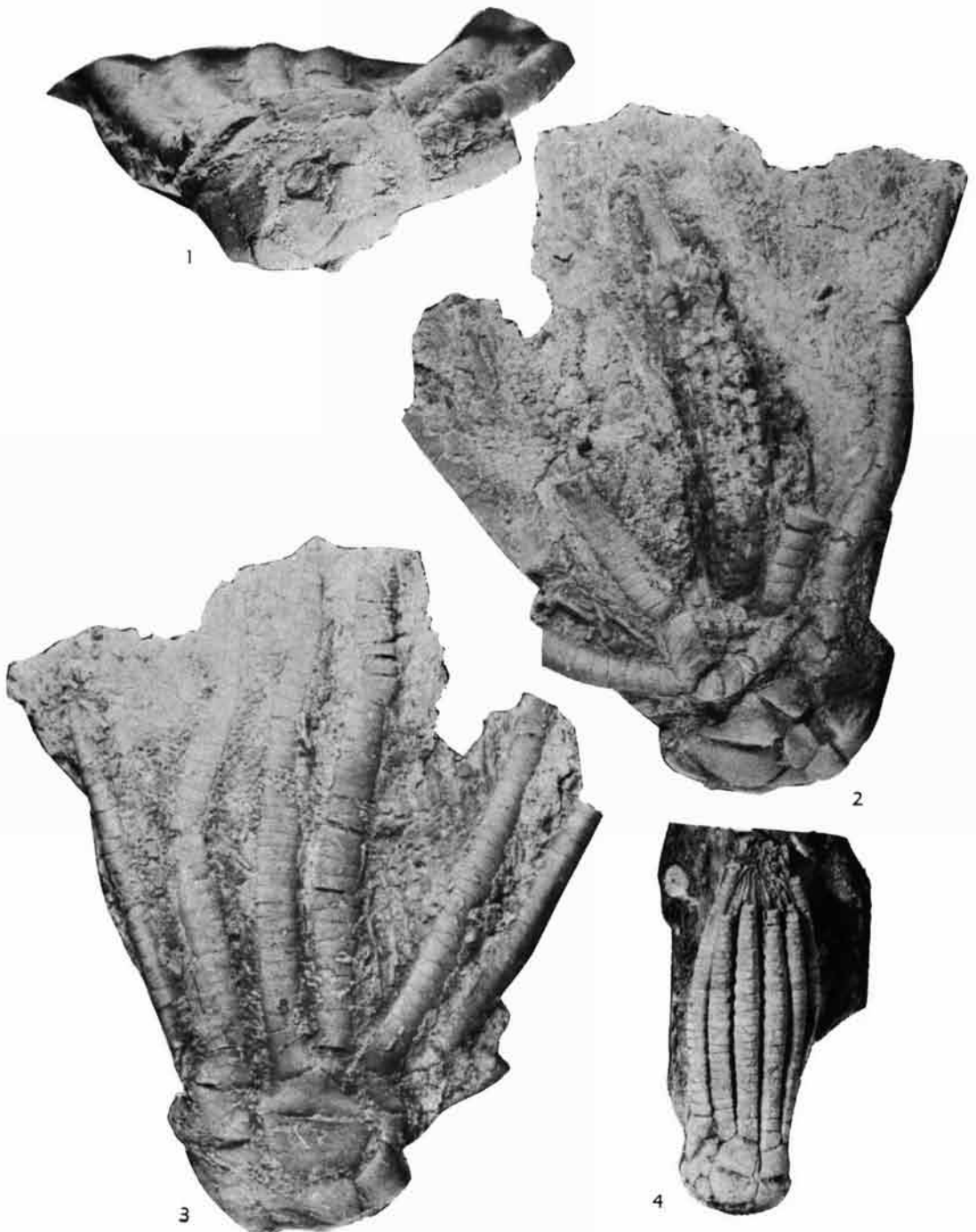


FIG. 3. *Phanocrinus* sp. cf. *P. cylindricus* (Miller & Gurley), from the Fraileys Shale Formation, Chesteran, of Illinois.—1-3. Hypotype SUI 34336 crown from base, posterior side with tubelike anal sac and broad terminating spine exposed, and anterior side,  $\times 2.25$ .—4. *Phanocrinus bellulus* (Miller & Gurley), holotype crown viewed from right posterior (C-ray) side,  $\times 1.6$ .

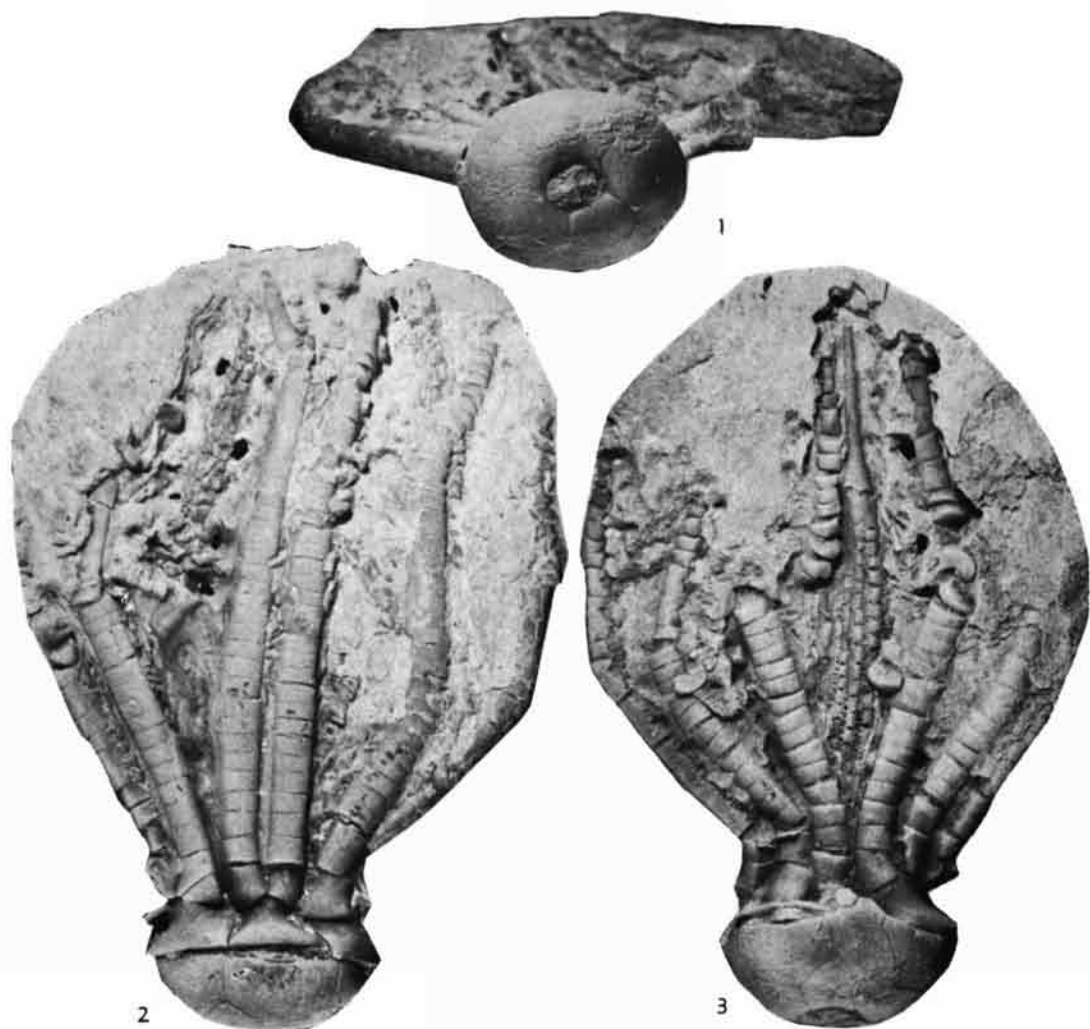


FIG. 4. *Phanocrinus* sp. cf. *P. formosus* (Worthen), from the Fraileys Shale Formation, Chesteran of Illinois.—1-3. Hypotype SUI 34344 crown viewed from base, anterior and posterior sides, with long, tubelike anal sac and slender terminating spine exposed,  $\times 2.25$ .

preserved crown exhibiting a long anal tube which has been broken just below midheight. The terminating spine is very slender and elongate. The cup proportionately wider than in typical *P. bellulus*, the holotype (Field Museum [WM] 6728) of which is illustrated here by Figure 3,4.

Figure 3,1-3, show a large crown with plates of the cup somewhat disarticulated. The specimen is tentatively identified as *Phanocrinus* sp. cf. *P. cylindricus* (Miller & Gurley). The terminating spine is somewhat shorter and broader

than in *Phanocrinus* sp. cf. *P. bellulus*.

Figure 4,1-3, illustrate a common form ascribed to *Phanocrinus* sp. cf. *P. formosus* (Worthen). Its terminating spine is very long and slender.

*Poteriocrinus altonensis* Miller & Gurley (1895) is here ascribed to *Pentaramicrinus altonensis* (Miller & Gurley) Strimple & Moore, new combination. The genus *Pentaramicrinus* has been emended (Burdick & Strimple, 1969, p. 9) to include crinoids with erect sides of the dorsal cup and lack of constriction toward its



FIG. 5. *Pentaramicrinus altonensis* (Miller & Gurley), from the Paint Creek Formation, Chesteran, of Monroe County, Illinois, hypotype SUI 35526 crown from *AB*-interray side with slender anal sac, anus, and minute terminating spines exposed,  $\times 6.5$ .

summit, regardless of number of arms. A specimen (hypotype SUI 35526) from the Downeys Bluff Member, Paint Creek Formation (Gasperan), found near Columbia, Monroe County, Illinois, is illustrated (Fig. 5) by an anterior view to demonstrate the short anal sac, with minute spines at the termination and the anal opening at about midheight of the sac.

## SYSTEMATIC DESCRIPTION

### Subclass INADUNATA

### Wachsmuth & Springer, 1885

### Order CLADIDA Moore & Laudon, 1943

### Family PHANOCRINIDAE Knapp, 1969

**DIAGNOSIS.**—Crown tall cylindrical. Dorsal cup low bowl-shaped, mostly with small basal

concavity; infrabasals not visible from side; radial articular facets occupying full summit of plates; three anals in cup. Arms five to ten, uniserial. Stem round.

**OCCURRENCE.**—Upper Mississippian-Lower Permian.

### Genus PHANOCRINUS Kirk, 1937

#### PHANOCRINUS PLANUS Strimple & Moore, new species

Figure 6, 1-6

**DESCRIPTION.**—Crown long, slender, cylindrical. Dorsal cup low bowl-shaped, with slight distal constriction; base of cup planate or very slightly impressed, infrabasals subhorizontal, extending beyond columnar attachment area; three anal plates in *CD* interrays in normal (primitive) arrangement; anal sac unknown. Arms ten, uniserial, branching on primibrach *1* in all rays. Stem not preserved but columnar cicatrix round and denticulated about perimeter.

**DISCUSSION.**—*Phanocrinus planus* is distinguished from all other species of the genus in having a planate base. Although comparable representatives have not been observed in younger strata, the trend is thought to have produced the Pennsylvanian genus *Contocrinus* Knapp (1969).

**MEASUREMENT OF HOLOTYPE IN MILLIMETERS.**—Height of crown, 33.5; cup height, 4.0, width, 10.4; width of infrabasal circlet, 2.8.

**TYPES.**—Holotype SUI 34163, and paratypes SUI 34165, deposited in Geology Department, The University of Iowa, Iowa City, collected by H. L. Strimple.

**OCCURRENCE.**—Fraileys Shale Formation (upper part) or Haney Formation (lower part), middle Chesteran Stage, Upper Mississippian; roadcut on Illinois State Hwy. 146, 0.3 miles east of intersection of U.S. I-57 (NE  $\frac{1}{4}$ , NW  $\frac{1}{4}$ , sec. 30, T.12S., R.1E.), Union County, Illinois.

## REFERENCES

See composite list following Part 8.

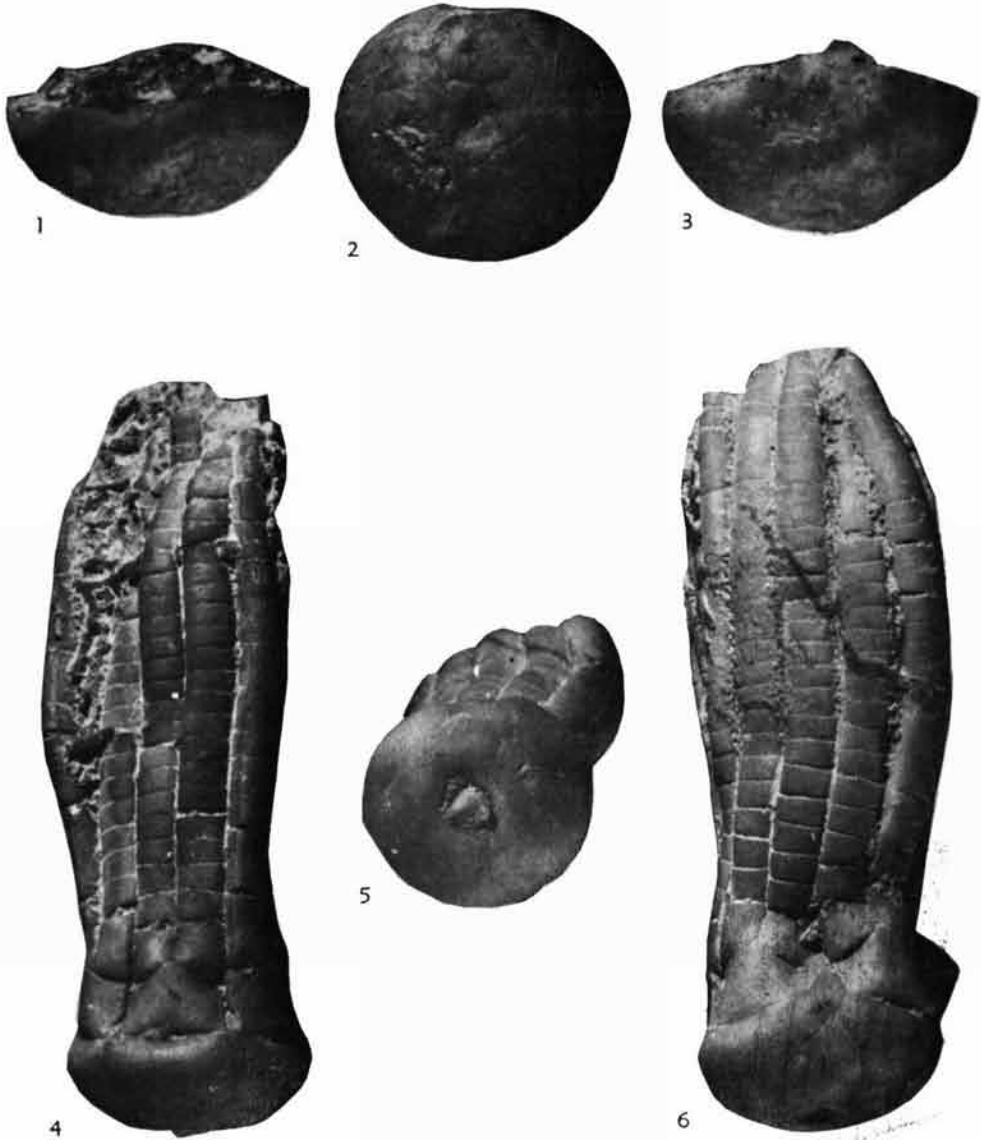


FIG. 6. *Phanocrinus planus* Strimple & Moore, new species, from the Fraileys Shale Formation, Chesteran, Union County, Illinois.—1-3. Paratype SUI 34165 dorsal cup from *D*-ray, base, and posterior, (*CD* interray) sides,  $\times 3$ .  
—4-6. Holotype SUI 34163 crown from anterior, base, and posterior sides,  $\times 3$ .

## PART 2

MIDDLE PENNSYLVANIAN CRINOIDS FROM  
CENTRAL COLORADO

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## ABSTRACT

A crinoid collection from the McCoy Formation, Middle Pennsylvanian, of central Colorado contains representatives of eight species, all but one (flexible) belonging to cladid inadunate genera. Three new species are named *Aglaocrinus keytei*, *Parulocrinus planus* (cromyocrinids), and *Ulocrinus rockymontanus* (ulocrinid). Other forms occur also in Desmoinesian formations of Oklahoma and Texas.

## INTRODUCTION

A collection of crinoids made by the late Dr. I. A. Keyte of Colorado College, Colorado Springs, Colorado, from the McCoy Formation, Middle Pennsylvanian (Desmoinesian) in central Colorado was obtained by one of us (Moore) several years ago. There are 35 identifiable specimens all labeled "McCoy, Colorado," which is in Eagle County, and all but one are cladid inadunates. Specimens are deposited in the Geology Department, Repository, The University of Iowa, Iowa City. The crinoid fauna indicates an early Desmoinesian age, but the possibility of an Atokan age is not entirely ruled out.

Content of the crinoid assemblage is as follows.

*Composition of the McCoy Crinoid Collection*

TAXONOMIC UNITS	NUMBER OF SPECIMENS
Flexibilia (subclass)	
Dactylocrinidae (family)	
<i>Aextrophocrinus formosus</i> (Moore & Plummer)	1
Inadunata (subclass)	
Pirasocrinidae (family)	
<i>Metaffinocrinus tumulosus</i> (Strimple)	1
Protocrinidae (family)	
<i>Neoprotocrinus brachiatus</i> (Moore & Plummer)	1
Cromyocrinidae (family)	
<i>Aglaocrinus keytei</i> Strimple & Moore, n. sp.	6
<i>Paracromyocrinus magnus</i> (Strimple)	22
<i>Parulocrinus planus</i> Strimple & Moore, n. sp.	2

## Ulocrinidae (family)

<i>Ulocrinus extrorsus</i> Strimple & Watkins	1
<i>Ulocrinus rockymontanus</i> Strimple & Moore, n. sp.	3

Roth (in Roth & Skinner, 1930) stated that Keyte had advised him of the fossiliferous collecting localities at McCoy, Eagle County, Colorado, the best of which was very near to the post office of McCoy. There is no way of determining now whether the crinoids were obtained there or in other limestone-shale sequences in the immediate area. Roth & Skinner (*ibid.*) reported 55 genera and 73 species from the McCoy Formation but listed no crinoids. They concluded that the McCoy correlated with the Amsden Formation of Montana, lower portion of the Hartville Formation of Wyoming, Minnelusa Formation of the Black Hills, Cherokee Shale of northern Oklahoma, Wetumka Formation, middle and upper parts of the Atoka Formation of central Oklahoma, part of Glenn Group of southern Oklahoma, portion of Strawn and Bend Groups of central Texas, lower part of the Gaptank Formation of southwestern Texas, Hueco beds of southern New Mexico, and Tradewater Formation of southern Illinois. Their correlations were no doubt based mainly on fusulinids and no attempt has been made here to verify their conclusions. The middle zone is composed of red



conglomerate with cross-bedded sandstone, some interbedded marine shales and thin limestones and is reported to have a thickness of some 1,280 feet. The micaceous shales are red to black and the crinoids are either red or black, with red predominating. Some are free of matrix but most are embedded on one side in limestone and are somewhat distorted.

## SYSTEMATIC DESCRIPTIONS

### Subclass FLEXIBILIA Zittel, 1879 Bather, 1899

#### Family DACTYLOCRINIDAE

[Dactylocrinidae Bather, 1899, p. 923]  
[incl. Calpiocrinidae Jaekel, 1918, p. 79]

DIAGNOSIS.—Crown ovoid, moderately elevated, with virtually no distinction between fixed brachials forming upper part of calyx and dorsal cup composed of radials and lower plate circlets; radial normally lacking but primanal (anal X) commonly distinct and relatively large, followed by other anal plates. Proximal columnal concealing infrabasal circlet in most genera, as well as much or all of basal plates and even portions of radials. Branching of arms strongly heterotomous or isotomous with bifurcations at similar or different levels in various arm branches; interradials and interbrachials few or may be absent.

OCCURRENCE.—Upper Silurian-Upper Permian.

#### Genus AEXITROPHOCRINUS Strimple & Watkins, 1969

[*Aexitrophocrinus* Strimple & Watkins, 1969, p. 229]

TYPE SPECIES.—*Syneroocrinus formosus* Moore & Plummer, 1940, p. 94.

DIAGNOSIS.—Infrabasals are three unequal elements entirely covered by the column, smallest in C-ray position; five basals projecting beyond columnar socket in young specimens but entirely within the depressed area in old specimens except for the CD basal which projects slightly beyond the column even in large forms but does not reach beyond the perimeter of the radial circlet; five radials which penetrate the columnar socket in geologically older specimens; primanal (anal X) large, followed by a double series of subequal plates all of which are united with adjacent radials; four or more interradials between each con-

tiguous pair of rays; two to four brachials in each ray.

OCCURRENCE.—Middle Pennsylvanian-Upper Pennsylvanian, USA (Texas-Oklahoma-Colorado).

#### AEXITROPHOCRINUS FORMOSUS

(Moore & Plummer, 1940)

[=*Syneroocrinus formosus* Moore & Plummer, 1940, p. 94]

Figure 7, I

DESCRIPTION.—A single young specimen considered here is assigned to *Aexitrophocrinus formosus*. The E ray is missing but all other rays are preserved at least through primibrach 1 and in two half rays are preserved through secundi-brach 1. Basals are almost entirely covered by columnar attachment except for CD basal; primanal is followed by two subequal plates; interradials are considerably larger than primanal (which is atypical of the species) and are followed by two plates.

HYPOTYPE.—SUI 36268.

OCCURRENCE.—Oologah Limestone, Tulsa County, Oklahoma; Millsap Lake Formation, Parker County, Texas; McCoy Formation, Eagle County, Colorado; Desmoinesian, Middle Pennsylvanian.

### Subclass INADUNATA Wachsmuth & Springer, 1885

#### Order CLADIDA Moore & Laudon, 1943

[*nom. correct.* Moore, 1952 (*pro* Cladoidea Moore & Laudon, 1943)]

#### Suborder POTERIOCRININA Jaekel, 1918

[*nom. correct.* Moore in Moore, Lalicker, & Fischer, 1952 (*pro* suborder Poteriocrinites Jaekel, 1918)]

#### Family PIRASOCRINIDAE Moore & Laudon, 1943

[Pirasocrinidae Moore & Laudon, 1943, p. 58]

DIAGNOSIS.—Crown tall, pear-shaped. Cup saucer-shaped, with shallow to deep basal concavity, radials reaching basal plane of cup or into concavity, with wide articular facets; two or three anals in cup. Arms numerous, branching isotomously on first primibrach and mostly twice or more at higher levels.

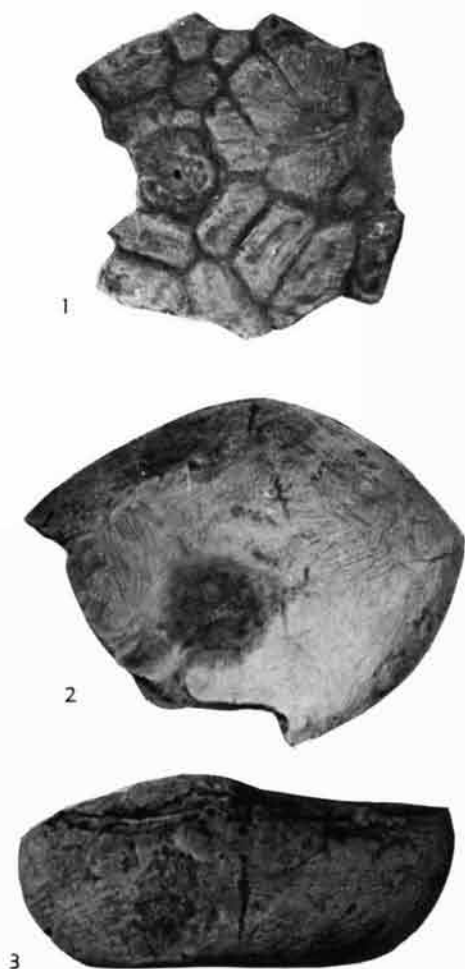


FIG. 7. *Aexitrophocrinus* and *Neoprotencrinus* from the McCoy Formation, McCoy, Colorado.—1. *Aexitrophocrinus formosus* (Moore & Plummer), hypotype SUI 36268 from the base,  $\times 2.5$ .—2,3. *Neoprotencrinus brachiatus* (Moore & Plummer), hypotype SUI 36267, basal and side view of interray,  $\times 2.5$ .

OCCURRENCE.—Middle Pennsylvanian (Atokan)-Permian.

#### Genus METAFFINOCRINUS Knapp, 1969

[*Metaffinocrinus* Knapp, 1969, p. 373]

TYPE SPECIES.—*Plaxocrinus perundatus* Moore & Plummer, 1940, p. 191.

DIAGNOSIS.—Cup low bowl-shaped, broad moderately deep basal concavity; infrabasals slightly downflaring; basal plates broad, with

distal tips visible in side view; posterior interray typically broad; 3 or fewer anal plates in cup.

DISCUSSION.—Differences between *Affinocrinus* Knapp, 1969, and *Metaffinocrinus* are subtle, depending on a slight loss in depth of the basal concavity, decrease in the downflaring attitude of infrabasals, and reduction of tumidity of plates. *Plaxocrinus tumulosus* Strimple has been referred to *Metaffinocrinus* by Knapp (*ibid.*, p. 373).

OCCURRENCE.—Middle Pennsylvanian (Desmoinesian), USA (Oklahoma-Texas-Colorado).

#### METAFFINOCRINUS TUMULOSUS (Strimple), 1949

[=*Plaxocrinus tumulosus* Strimple, 1949, p. 334]

Figure 8, 1, 2

DESCRIPTION.—Dorsal cup broad, low, with large, broad basal concavity. Infrabasals slightly downflared, basals tumid, large, extending well above basal plane to become visible in side view of cup. Radials large, tumid, articular facets large, sloping outward-downward. Posterior interray is atypical in that primanal (radial) has moved to posterior position and is quite large.

MEASUREMENTS.—Dorsal cup is 31.7 mm wide; 9.4 mm high; basal concavity has diameter of 15.0 mm; height, 5.0; infrabasal circlet, 7.7 mm wide; right posterior (*BC*) basal, 10.7 mm wide; 9.9 long; left anterior (*E*) radial, 16.2 mm wide; 9.2 long.

DISCUSSION.—*Plaxocrinus tumulosus* Strimple has been referred to *Metaffinocrinus* by Knapp (1969, p. 373). The holotype is from the Pumpkin Creek Formation of Love County, Oklahoma, and differs from the presently considered hypotype from Colorado only in having three anal plates in normal (primitive) arrangement. As noted above, the Colorado specimen has advanced arrangement in which primanal has migrated to a posterior position and enlarged.

HYPOTYPE.—SUI 35816.

OCCURRENCE.—Pumpkin Creek Limestone, Dornick Hills Formation, Love County, Oklahoma; McCoy Formation, Eagle County, Colorado.

#### Family PROTENCINIDAE Knapp, 1969

[Protencrinidae Knapp, 1969, p. 353]

DIAGNOSIS.—Crown subcylindrical; cup trun-

cate cone- or bowl-shaped, base planate or mildly concave; infrabasals five, subhorizontal or slightly downflared; basals five, small, largely or completely separated from each other by proximal tips of radials, which may rest on infrabasals; radials with wide subhorizontal articular facets; no anal plate other than rudimentary remnant notching articular facets between *C* and *D* radials; primibrach *I* axillary. Arms with almost flattened outer surfaces, usually equibiserial, each brachial bearing a single pinnule.

OCCURRENCE.—Middle Pennsylvanian (Atokan-Desmoinesian).

### Genus NEOPROTENCRINUS Knapp, 1969

[*Neoprotencrinus* Knapp, 1969, p. 354]

TYPE SPECIES.—*Paradelocrinus subplanus* Moore & Plummer, 1940, p. 321.

DIAGNOSIS.—Cup very low; radials forming part of basal concavity; basals very small, tending to be separated laterally by radials and infrabasals. Arms ten, biserial branching isotomously on first primibrach.

OCCURRENCE.—Middle Pennsylvanian (Desmoinesian), USA (Oklahoma-Texas-Colorado).

#### NEOPROTENCRINUS BRACHIATUS (Moore & Plummer, 1940)

[=*Paradelocrinus brachiatus* Moore & Plummer, 1940, p. 318]

Figure 7.2,3

DESCRIPTION.—One rather poorly preserved dorsal cup in the collection is assigned to this species described from beds just below the Kickapoo Falls Limestone Member, Millsap Lake Formation, southwest of Dennis, Hood County, Texas. The hypotype has a width of 21.5 mm, height 8.5 mm.

HYPOTYPE.—SUI 36267.

OCCURRENCE.—Millsap Lake Formation, Hood County, Texas; McCoy Formation, Eagle County, Colorado.

### Family CROMYOCRINIDAE Bather, 1890

[Cromyocrinidae Bather, May, 1890 (*nom. transl.* Jaekel, 1918, *ex series* Cromyocrinites Bather, 1890)]

DIAGNOSIS.—Cup more or less globe-shaped, including forms with upflared or subhorizontal



FIG. 8. *Metaffinocrinus tumulosus* (Strimple) from the McCoy Formation, McCoy, Colorado.—1,2. Hypotype SUI 35816, dorsal cup from *CD* interray and base,  $\times 2$ .

infrabasals; mostly three anal plates in cup but exceptionally only two. Anal sac very short and small. Arms uniserial, unbranched (e.g., *Ureocrinus*, *Cromyocrinus*), or biserial and branched isotomously on primibrachs *I* in all rays, and on secundibrachs *I* in some rays. Column transversely round. *L.Carb.*(*Miss.*)-*L.Perm.*

### Genus AGLAOCRINUS Strimple, 1961

[*Aglaocrinus* Strimple, 1961, p. 86]

TYPE SPECIES.—*Ethelocrinus magnus* Strimple, 1949, p. 12.

DIAGNOSIS.—Cup broad, low, bowl-shaped, surface rugose, sutures typically deeply impressed in V-shaped notches, shallow basal concavity; infrabasals subhorizontal or slightly downflared, forming moderately large disc; anal plates two

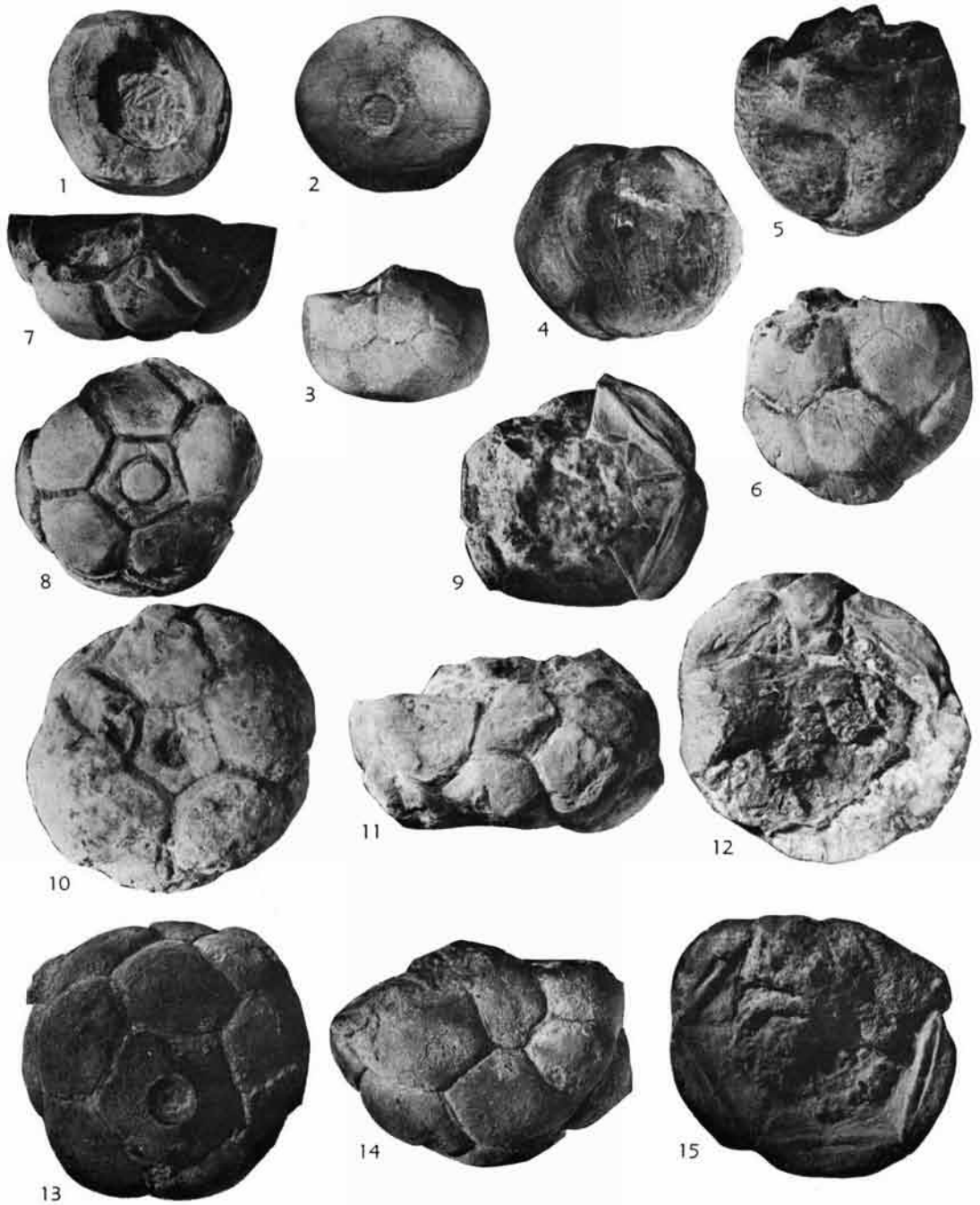


FIG. 9. Cromyocrinids and ulocrinids from the McCoy Formation, McCoy, Colorado.—1-3. *Parulocrinus planus* Strimple & Moore, n. sp., holotype SUI 35811 from summit, base, and posterior side,  $\times 0.7$ .—4-6. *Ulocrinus rockymontanus* Strimple & Moore, n. sp., holotype SUI 35813 from base, anterior, and posterior sides,  $\times 0.7$ .—7-9. *Aglaocrinus keytei* Strimple & Moore, n. sp., holotype SUI 35804 from posterior side, base, and summit,  $\times 0.7$ .—10-12. *Paracromyocrinus magnus* (Strimple), hypotype SUI 35807 from base, posterior side, and summit,  $\times 0.7$ .—13-15. *Ulocrinus extrorsus* Strimple & Watkins, hypotype SUI 35812 from base, posterior side, and summit,  $\times 0.7$ .

or three. Arms biserial, branching on primibrach *I* in all rays and secundibrach *I* in selective rays.

**OCCURRENCE.**—Middle Pennsylvanian-Lower Permian; USA (Oklahoma-Colorado-Kansas-Texas-Nevada).

**AGLAOCRINUS KEYTEI** Strimple & Moore, new species

Figure 9,7-9

**DESCRIPTION.**—Cup low, bowl-shaped, surfaces smooth except for deep V-shaped notches between cup plates. Infrabasal circling subhorizontal, not visible in side view of cup; basals forming portion of basal plane of cup, flexing sharply upward to form much of lateral walls of cup; radials wide, low, proximal tips well above basal plane, with pronounced forefacet at summit of radials appearing as groove backed by outer ligament ridge, outer ligament pit sharply defined, causing pronounced curvature of transverse ridge, inner articular facets large, subhorizontal, with deep intermuscular notches; portion of posterior interray and subjacent areas of the holotype are missing but a large radial is preserved, apparently almost reaching the *D* radial so that primanal (anal *X*) has a short contact with the *CD* basal. A paratype substantiates this.

**DISCUSSION.**—The surface of cup plates is undulating, with ridges formed parallel to the impressed edges of the plates. The V-shaped notches are somewhat more pronounced than is typical for the genus and the base is planate or very slightly impressed.

**MEASUREMENTS OF HOLOTYPE IN MILLIMETERS.**

—Width (*W*) and height (*H*) of *Aglaocrinus keytei* are as follows: dorsal cup, *W*-33.5, *H*-17.0; left anterior (*E*) radial, *W*-17.0, *H*-9.0; anterior (*A*) radial, *W*-18.0, *H*-9.0; right posterior (*BC*) basal, *W*-14.0, *H*-14.0; infrabasal circling, *W*-12.8.

**TYPES.**—Holotype, SUI 35804; paratypes SUI 35805 and SUI 35806.

**OCCURRENCE.**—McCoy Formation, Desmoinesian, Middle Pennsylvanian, Eagle County, Colorado.

**Genus PARULOCRINUS** Moore & Plummer, 1940

[*Paruloerinus* Moore & Plummer, 1940, p. 350]

**TYPE SPECIES.**—*Uloerinus blairi* Miller & Gurler, 1894, p. 57.

**DIAGNOSIS.**—Crown tall, having more than ten long, biserial arms branching on primibrach

*I* and a second time on secundibrach *I* in selective rays. Cup medium-sized, deep bowl-shaped to globose, summit constricted, sutures not appreciably impressed, base typically gently convex but gerontic specimens may be planate; two anal plates in posterior interray but with proximal tip of tertanal (*RX*) entering cup in some. Infrabasal circling relatively large and typically just visible in side view. Arms biserial, more than ten.

**DISCUSSION.**—*Paruloerinus* has not been reported elsewhere from strata older than Missourian. *P. planus* Strimple & Moore, n. sp., is so similar to *P. blairi* that assignment to the genus is made without hesitation.

**OCCURRENCE.**—Middle Pennsylvanian-Lower Permian; USA (Oklahoma-Kansas-Illinois-Missouri-Texas-Colorado).

**PARULOCRINUS PLANUS** Strimple & Moore, n. sp.

Figure 9,1-3

**DESCRIPTION.**—Cup low, subglobose, smooth surface with unimpressed sutures, mildly constricted summit. Infrabasal circling large, gently convex but not visible in side view of cup, columnar cicatrix slightly but sharply impressed and surrounded by low ridge; basals very large; radials almost twice as wide as long, articular facets subhorizontal; anal plates three, although tertanal is small, barely notching cup, and well removed from contact with primanal.

**DISCUSSION.**—This species is very similar to *Paruloerinus blairi*.

**MEASUREMENTS OF HOLOTYPE IN MILLIMETERS.**

—Width (*W*) and height (*H*) as follows: cup, *W*-25.0<sup>av</sup>, *H*-14.6; right posterior (*C*) radial, *W*-13.0, *H*-8.0; right anterior (*B*) radial, *W*-12.1, *H*-7.2; left posterior (*D*) radial, *W*-12.7, *H*-8.0; left anterior (*E*) radial, *W*-12.2, *H*-8.0; anterior (*A*) radial, *W*-14.0, *H*-7.5; right posterior (*BC*) basal, *W*-13.8, *H*-12.0; infrabasal circling, *W*-6.5, *H*-1.2 (<sup>av</sup> average).

**TYPE.**—Holotype SUI 35811.

**OCCURRENCE.**—McCoy Formation, Desmoinesian, Middle Pennsylvanian, Eagle County, Colorado.

**Genus PARACROMYOCRINUS** Strimple, 1966

[*Paracromyocrinus* Strimple, 1966, p. 4]

**TYPE SPECIES.**—*Paruloerinus vetulus* (Lane), 1964, p. 680.

**DIAGNOSIS.**—Crown long cylindrical, arms abutting closely. Cup low, bowl-shaped, sides curving evenly, with slight or decided basal concavity; infrabasal cirlet broad, horizontal or mildly downflared, not visible in side view; basals large, extending to midheight of cup; two or three anal plates in cup, with large primanal. Arms ten, equibiserial.

**OCCURRENCE.**—Lower Pennsylvanian-Upper Pennsylvanian, USA (Oklahoma-Nevada-Texas-Kansas-Arkansas-Colorado).

**PARACROMYOCRINUS MAGNUS (Strimple), 1949**

[=*Ethelocrinus magnus* Strimple, 1949, p. 12; *Agalocrinus magnus* Strimple, 1961, p. 87]

Figure 9,10-12

**DESCRIPTION.**—Cup low bowl-shaped, with ornate surface, impressed sutures, and shallow basal concavity. Infrabasal cirlet relatively small and gently downflared; basals very large, forming basal plane and flexing sharply upward to form large portion of cup walls; radials wide, proximal ends well above basal plane, pronounced forefacets at summit, articular facets subhorizontal; anal plates two, very large, primanal and secundanal (anal X) having broad contact with CD basal, not extending very far above cup summit. Columnar cicatrix circular, slightly impressed, relatively small. Arms and anal sac unknown.

**DISCUSSION.**—Specimens from the McCoy Formation are so similar to dorsal cups from the Pumpkin Creek Limestone, Dornick Hills Formation of Oklahoma that little hesitation is felt in considering them to be conspecific.

**MEASUREMENTS OF HYPOTYPE IN MILLIMETERS.**—Width (W) and height (H), of *Paracromyocrinus magnus* are as follows: cup, W-39.3, H-17.0 (posterior side, 18.0); right posterior (C) radial, W-17.0, H-11.5; right anterior (B) radial, W-19.5, H-18.0; left posterior (D) radial, W-16.6, H-12.0; left anterior (E) radial, W-19.7, H-11.0; anterior (A) radial, W-20.8, H-11.5; right posterior (BC) basal, W-16.1, H-15.7; infrabasal cirlet, W-11.4, H-4.0 (above basal plane).

**TYPES.**—Figured hypotype SUI 35807, other hypotypes SUI 35808, SUI 35809, SUI 35810.

**OCCURRENCE.**—Pumpkin Creek Limestone, Dornick Hills Formation, Atokan, Love County, Oklahoma; McCoy Formation, Desmoinesian, Eagle County, Colorado.

**Family ULOCRINIDAE Moore & Strimple, new family**

**DIAGNOSIS.**—Crown tall, cylindrical, composed mostly of long rounded erect biserial arms. Dorsal cup deep bowl- or vase-shaped with upflared cirlet of infrabasals, large basals and radials, articular facets equal to full width of radials; two anal plates in cup. Arms ten, biserial branching isotomously on first primibrachs, pinulate. Stem round. [Differs from *Cromyocrinidae* in shape of cup, in having two anal plates in cup instead of three, and in biserial structure of its ten arms.]

**OCCURRENCE.**—Middle Pennsylvanian (Atokan)-Permian.

**Genus ULOCRINUS Miller & Gurley, 1890**

[*Ulocrinus* Miller & Gurley, 1890, p. 6]

**TYPE SPECIES.**—*Ulocrinus buttsi* Miller & Gurley, 1890, p. 6.

**DIAGNOSIS.**—Cup globular to pyramidal, infrabasals large, upflared, readily visible in side view; two large anal plates in posterior interray. Arms 10, massive, equibiserial except in proximal portion where some cuneate brachials may be present.

**OCCURRENCE.**—Middle Pennsylvanian (Atokan)-Permian; cosmopolitan.

**ULOCRINUS EXTRORSUS Strimple & Watkins, 1969**

[*Ulocrinus extrorsus* Strimple & Watkins, 1969, p. 165]

Figure 9,13-15

**DIAGNOSIS.**—Cup wide, globular, with infrabasals visible in side view of cup, impressed sutures and smooth surface.

**DISCUSSION.**—The presently considered specimen from the McCoy Formation has an infrabasal cirlet that is typical of the genus, although somewhat lower than found in some species. The forefacet at the summit of the radials is more pronounced than in younger species, and appears to be somewhat more so than in typical *Ulocrinus extrorsus*; the Colorado hypotype is larger than the original type from Texas but the specimen is probably gerontic.

Typical *Ulocrinus extrorsus* has a proportionately shorter cup with more tumid plates than found in *U. rockymontanus*.

**MEASUREMENTS OF HOLOTYPE IN MILLIMETERS.**—Width (W) and height (H) of *Ulocrinus*

*extrorsus* from Colorado are as follows: dorsal cup, W-36.0, H-25.5; right posterior (*C*) radial, W-17.0, H-9.3; right anterior (*B*) radial, W-18.7, H-11.2; left posterior (*D*) radial, W-17.7, H-11.5; left anterior (*E*) radial, W-17.0, H-11.5; anterior (*A*) radial, W-19.2, H-11.0; right posterior (*BC*) basal, W-17.7, H-15.0; infrabasal cirlet, W-17.6, H-5.0.

**HYPOTYPES.**—SUI 35812.

**OCCURRENCE.**—Middle Pennsylvanian (Desmoinesian), Millsap Lake Formation, Parker County, Texas; McCoy Formation, Eagle County, Colorado.

#### ULOCRINUS ROCKYMONTANUS

Strimple & Moore, new species

Figure 9,4-6

**DESCRIPTION.**—Cup slightly compressed laterally, smooth globular, with constricted summit. Infrabasal cirlet low, but readily visible in side view; basals large, mildly tumid; radials moderately large; anal plates two in typical arrangement. Columnar attachment cicatrix round. Arms and anal sac unknown.

**DISCUSSION.**—This species is closely similar to *Ulocrinus percultus* Knapp (1969) from the Burgner Formation (Atokan of Missouri) but

differs in having a proportionately taller calyx. The holotype of *U. percultus* appears to be ornate; however, careful examination of the specimen reveals that the condition is due to differential mineralization. The radiating subsurface canals have been exposed by weathering and are not shown by the four paratypes which have smooth outer surfaces. *U. percultus* has two anal plates in all five type specimens.

**MEASUREMENTS OF HOLOTYPE IN MILLIMETERS.**—Width (W) and height (H) of *Ulocrinus rockymontanus* are as follows: cup, W-27.0 (average), H-28.0; right posterior (*C*) radial, W-13.0, H-9.3; right anterior (*B*) radial, W-11.8, H-9.4; left posterior (*D*) radial, W-13.0, H-11.0; left anterior (*C*) radial, W-13.5, H-10.0; anterior (*A*) radial, W-14.0, H-9.3; right posterior (*BC*) basal, W-14.0, H-15.6; infrabasal cirlet, W-15.0, H-6.0.

**TYPE.**—Holotype, SUI 35813; paratypes SUI 35814, SUI 38815.

**OCCURRENCE.**—Middle Pennsylvanian (Desmoinesian), McCoy Formation, Eagle County, Colorado.

#### REFERENCES

See composite list following Part 8.

### PART 3

## AENIGMOCRINUS, A NEW CHESTERAN INADUNATE CRINOID GENUS

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#### ABSTRACT

A new genus of small inadunate crinoids having nine or ten uniserial arms that branch isotomously on the second primibrachs (except higher in the anterior ray), two anal cup plates, and moderately tall, spine-topped anal sac is named *Aenigmocrinus* and assigned to the Cymbioeriniidae. It is known at present only from Upper Mississippian (Chesteran) rocks of western Illinois.

## INTRODUCTION

All species, save one, *Poteriocrinus anomalus* Wetherby, ascribed to the genus *Cymbiocrinus* Kirk, 1944, have a single anal plate in the posterior interray resting on the truncated distal end of the *CD* basal, and arms that branch on primibrach 2 in all rays. In *C. anomalus* two subequal anal plates occur side by side in the cup and in the anterior ray branching is found on the sixth or seventh primibrach or not at all. As long as the species was confined to a limited geographic and stratigraphic area (Glen Dean F., Pulaski Co., Ky.) it could be considered a localized specialization. Such a premise is no longer supportable since several similar specimens in excellent preservation have been discovered in the upper part of the Fraileys Formation or lower Haney beds in Union County, Illinois. Removal of the species *anomalus* from *Cymbiocrinus* clarifies the diagnostic characters of that genus by eliminating need to incorporate its atypical characters in diagnosis of *Cymbiocrinus*. The species *anomalus* herein is ascribed to a new genus, *Aenigmocrinus*.

## SYSTEMATIC DESCRIPTIONS

Family CYMBOCRINIDAE Strimple  
& Watkins, 1969

[Cymbiocrinidae Strimple & Watkins, 1969, p. 188]

DIAGNOSIS.—Crown tall and slender. Dorsal cup low bowl-shaped with flat or weak narrowly concave base; infrabasals small, not visible from side; radial articular facets occupying full width of plates, sloping outward-upward; single anal (*X*) in cup resting on *CD* basal; anal sac tall, cylindrical, with vertical rows of smooth or strongly rugose plates. Arms uniserial, mostly ten but uncommonly five or more than ten, isotomously branched on primibrach 2. Stem circular, pentagonal or subpentagonal in outline.

OCCURRENCE.—Upper Mississippian (Meramecian)-Upper Pennsylvanian (Missourian).

## Genus AENIGMOCRINUS Strimple, new genus

TYPE SPECIES.—*Poteriocrinus anomalus* Wetherby, 1880, p. 158 [*nom. correct.* Strimple, herein (*pro Poteriocrinus anomalus* Wetherby, 1880, Zool. Code, Art. 32c, 33a,i)].

DESCRIPTION.—Crown rather compact but arms not abutting each other. Cup very shallow, basin-shaped, with broad base containing small invagination; infrabasals small and mostly covered by stem; basals small and confined to basal concavity except *CD* basal which is exceptionally large, its distal apex almost reaching cup summit; radials large, with proximal ends entering basal plane of cup; two subequal plates on *CD* basal extending well above cup (plate at left may be termed secundanal and that at right primanal, although the arrangement is rather unique); cup anal plates followed above by two series of tube plates; anal sac 0.8 or more height of arms, recurved, with large, flattened, stout spines at summit. Arms nine or 10, depending on whether anterior ray branches, stout, with well-rounded exteriors; primibrach 2 axillary in all except *A* ray which may branch on primibrach 6-7 or remain unbranched, brachials other than axillaries outwardly cuneate with constricted midsections, long sides bearing stout pinnules. Column round or subpentagonal.

DISCUSSION.—Wetherby (1880) reported three specimens of the type species, *Aenigmocrinus anomalus* (Wetherby) Strimple, new combination. Kirk (1944, p. 236) reported two specimens in the Springer collection and postulated that one might have been obtained from Wetherby. All five (or four) specimens came from the "Kaskaskia (Chester) Group, Pulaski County, Kentucky" which Kirk correlated with the Glen Dean Formation. The specimen figured by Kirk (*ibid.*, pl. 1, fig. 5) is about 19 mm long and the three largest specimens reported here are about 18 mm long; however, distal portions of the arms are slightly curved in the present specimens. Wetherby's illustrations (*ibid.*, pl. 5, fig. 6a,b) are about twice as large but, as noted by

FIG. 10. *Aenigmocrinus anomalus* (Wetherby) from upper beds of the Fraileys Formation, Union County, Illinois,  $\times 4$ .—1-3. Hypotype crown SUI 35584 showing large, recurved anal sac viewed from anterior, posterior sides, and base.—4,5. Hypotype crown SUI 35585 from anterior side showing atomous anterior arms, and left side with large plates of distal termination of anal sac.—6,7. Hypotype crown SUI 35595 from posterior and anterior sides showing anterior arm bifurcating on primibrach 6.





FIG. 10. (For explanation see facing page.)

Kirk, might have been enlarged by the illustrator. In any event, the genus is comprised of small forms.

Relationship appears to be with the Cymbiocrinidae Strimple & Watkins (1969, p. 188) and Kirk (*ibid.*, p. 236) assigned the type species to *Cymbiocrinus* with the notation "Note comment as to uncertainty of generic assignment." It is doubtful that the genus is intimately related to the Cymbiocrinidae as presently defined and understood.

**OCCURRENCE.**—Upper Mississippian (middle Chesteran); USA (Illinois Basin).

**AENIGMOCRINUS ANOMALUS** (Wetherby, 1880),  
Strimple, new combination

Figure 10, I-7

**DESCRIPTION.**—Characters of genus.

**DISCUSSION.**—Four specimens in collections deposited at the University of Iowa display some variation in structure of the anterior ray. In three specimens the *A* ray remains unbranched to its termination, but in one (SUI 35595) secundi-brach 6 is axillary. In three specimens several large flat spines are visible at the distal termination of the anal tube, are directed subvertically, and in the hypotype (SUI 35584) almost the entire sac is exposed. The large spine plates were

apparently observed by Wetherby who reported "heavy" tube plates but were not observed by Kirk who reported small tube plates. The lower posterior portion of sac has the form of a narrow cylinder which broadens distally in the midportion and forms a broad subplanate surface flanked on each side by outwardly directed broad spines; this surface continues over the large loop of the tube onto its anterior side. The areas below at right and left of the loop are depressed and have moderately large plates. The anus has not been observed but is certain to be low on the anterior side.

**HYPOTYPES.**—SUI 35584, 35585, 35595, 35611, deposited in Geology Department Repository, The University of Iowa, Iowa City, Iowa. Collected by H. L. Strimple.

**OCCURRENCE.**—Upper part of the Fraileys Formation or lower beds of the Hancy Formation, Chesteran, Upper Mississippian; 0.25 mile east of the intersection of Illinois Highway 146 and Interstate 57 (NE  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 30, T.12S., R.1E.), Union County, Illinois.

## REFERENCES

See composite list following Part 8.

## PART 4

# THE INADUNATE CRINOID GENUS HELIOSOCRINUS

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## ABSTRACT

The shallowly concave-based crinoid with outspread biserial arms named *Heliosocrinus* is an Upper Mississippian (Chesteran)-Lower Pennsylvanian (Morrowan) genus included in the Stellarocrinidae. It differs from other stellarocrinids in branching of the arms on primibrach 2, in its strongly pentastellate stem, and some other features.

## INTRODUCTION

The purpose of this study is to illustrate more adequately the species *Heliosocrinus aptonensis* Strimple, type species of *Heliosocrinus*, and to document morphologic features not fully disclosed by the original type material and description. The author is particularly grateful to Hertha Sieverts-Doreck, Stuttgart, West Germany, for her suggestions in these matters.

*Heliosocrinus aptonensis* is known only from natural exposures in the lower part of the Fayetteville Formation along an east-west escarpment in the south half of Sections 10 and 11, T.25N., R.21E., about 7 miles northeast of Vinita, Craig County, Oklahoma.

## SYSTEMATIC DESCRIPTIONS

### Family STELLAROCRINIDAE Strimple, 1961

[Stellarocrinidae Strimple, 1961, p. 108]

**DIAGNOSIS.**—Crown broadly explanate, with well-separated arms spread out laterally. Cup saucerlike with wide, shallow basal concavity, plates smooth or bearing sharp longitudinal ridges; radial articular facets wide but narrower than radial summits, leaving distinct interradian notches, sloping outward-downward; anal plates in cup three, in normal (primitive) arrangement in the older *Heliosocrinus* but advanced in younger genera with large primanal on truncated tip of *CD* basal followed by two small plates which barely reach below cup summit; anal sac tall, cylindrical, commonly with distal spines. Arms biserial, branching isotomously on first primibrachs and at higher levels, pinnulate. Stem pentastellate, pentagonal, or round transversely.

**OCCURRENCE.**—Upper Mississippian (Ches-  
teran)-Lower Permian (Wolfcampian).

### Genus HELIOSOCRINUS Strimple, 1951

[*Heliosocrinus* Strimple, 1951, p. 675]

**TYPE SPECIES.**—*Heliosocrinus aptonensis* Strimple, 1951, p. 676.

**DIAGNOSIS.**—Cup low, bowl-shaped, infra-basals in shallowly impressed base entirely covered by large proximal columnals; basals projected, radials marked by strong axial folds, ar-

ticular facet short and wide but not quite filling distal face of radial; three anal plates in normal (primitive) arrangement. Arms uniserial (cuneate brachials), primibrach 2 axillary in all rays with one additional branching in all rays and third branching observed in some rays; anal sac large, plicate. Stem substellate in outline.

**DISCUSSION.**—Strong axial folds stand in near relation to articulation. Thus radial facets are thickened at axial folds and interradian and radio-basal sutures are slightly excavated there; the periphery of these excavated sutures is crenulated. Facets of anal sac plates are likewise excavated. The cup and anal tube must have possessed a certain amount of mobility.

*Stellarocrinus* Strimple (1940) may have been derived from *Heliosocrinus* through the following modifications: 1) primanal moved to posterior position with equidimensional secundanal and tertanal above but retained in cup; 2) nonaxillary primibrach 1 resorbed or fused with primibrach 2 to form an axillary primibrach 1; 3) arms developed to a biserial arrangement of the brachials and widened; and 4) stem altered to transversely round.

*Brabeocrinus* Strimple & Moore (1971) follows all of the modifications noted above except that the arms remain uniserial (cuneate brachials) and narrow.

*Brychiocrinus* Moore & Plummer (1940) resembles *Brabeocrinus* (and probably is derived from that genus) but brachials have become interlocking (biserial), radials have articular facets as wide as their distal face, and axial folds between plates are eliminated.

*Celonocrinus* Lane & Webster (1966) is apparently derived from *Stellarocrinus*. The arms are moderately to very wide and biserial, the primanal extends above the radial summit, axial folds are eliminated, and the dorsal cup is very low saucer-shaped.

*Rhopocrinus* Kirk (1942) has some characters in common with *Heliosocrinus*, such as spinose axillaries in the arms, first branching on primibrach 2 and a tall anal sac. Differences are in the column, which is circular in outline, and the strong tendency toward biserial structure of the arms in *Rhopocrinus*. Both of these features represent a more advanced state of evolution than the substellate stem and cuneate brachials

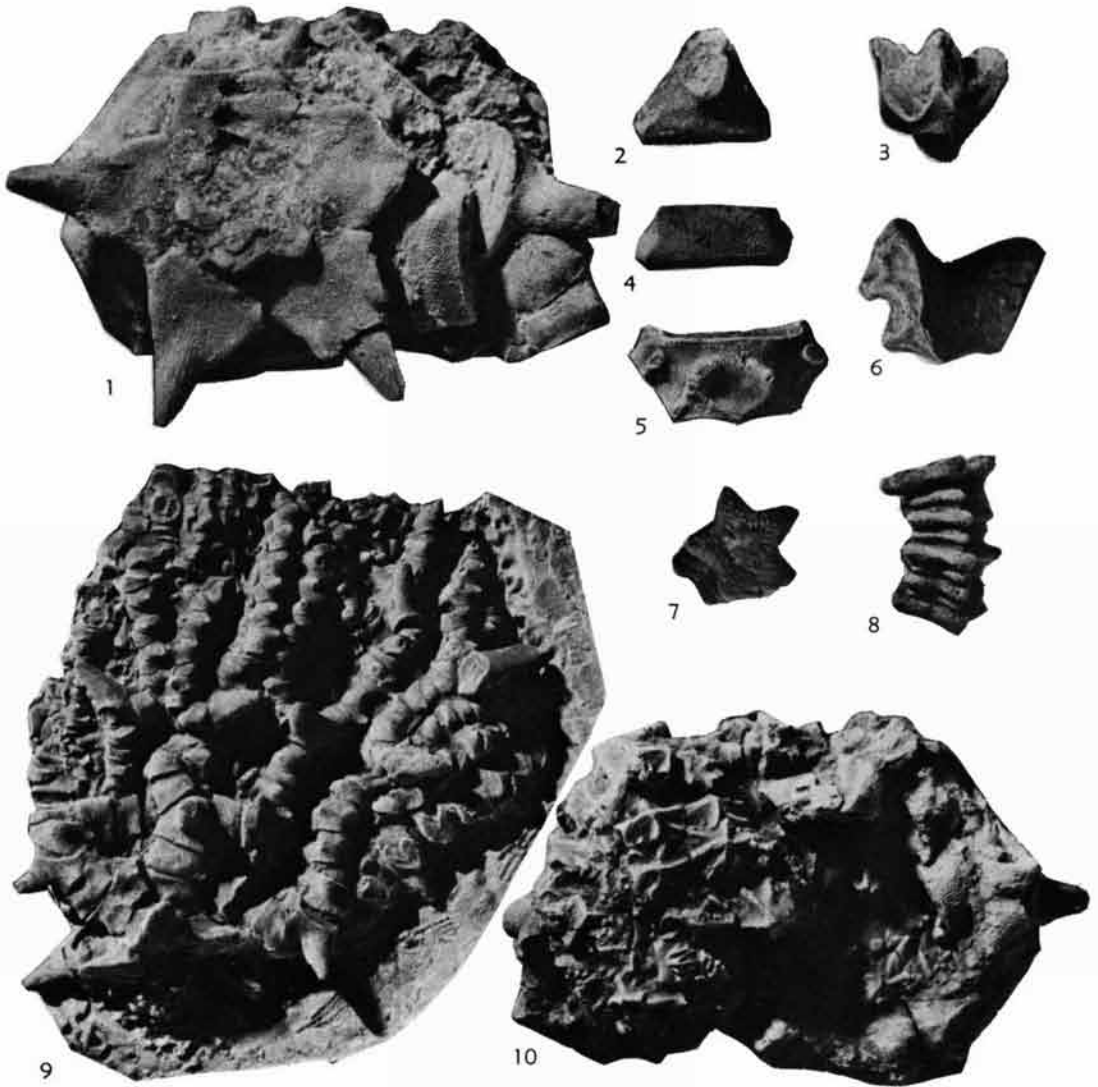


FIG. 11. *Heliosocrinus astonensis* Strimple from the Fayetteville Formation, Craig County, Oklahoma.—1,10. Partial crown SUI 35539 from base showing prominent spinose basals and summit with portion of anal sac,  $\times 2.8$ .—2,3. Primibrach 2 SUI 35543 from exterior and summit,  $\times 2.8$ .—4. Primibrach 1 SUI 35542 from exterior,  $\times 2.8$ .—5,6. Radial SUI 35541 exterior and oblique side views showing fossae on sutural face,  $\times 2.8$ .—7,8. Part of column SUI 35541 showing crenulated sutural surface and side view,  $\times 2.8$ .—9. Slightly distorted crown SUI 32695 from anterior side,  $\times 1.3$ .

of *Heliosocrinus*. Possibly the two genera possessed a common ancestor and possibly some Pennsylvanian stellarocrinids evolved from a *Rhopocrinus*-like stock rather than through *Heliosocrinus*. Yet *Brabeocrinus* retains cuneate brachials (as in *Heliosocrinus*) throughout Penn-

sylvanian time, changing to a biserial structure in distal portions of the arms in the Lower Permian (*B. cuneatus* [Lane & Webster, 1966]).

OCURRENCE.—Upper Mississippian (Chesteran)-Lower Pennsylvanian (Morrowan); USA (Okla.-Ill.).

**HELIOSOCRINUS AFTONENSIS** Strimple, 1951[*Heliosocrinus aftonensis* Strimple, 1951, p. 676]

Figure 11, I-10

DIAGNOSIS.—Characters of genus.

DESCRIPTION.—Entire surface of crown strongly granulose. Basal plates of cup produced as broad, flat spines, parallel to the broad basal plane; axillary brachials protruded as large spines and cuneate nonaxillary brachials bearing small spines on alternate sides; anal sac terminating in spinose plates. Stem with nodals separated by single internodal, sutures depressed, crenulate at periphery; nodals strongly convex, somewhat swollen at interradial corners and surface granulose, surface of internodals smooth; reentrant angles of stem in radial position.

DISCUSSION.—All material used in this study was obtained from the type locality of the species. The broad flat base with stout, subhorizontal spines serves to distinguish *Heliosocrinus aftonensis* from *Abrotocrinus sculptus* (Worthen, 1883) which appears to be related.

TOPOTYPES (Metatypes).—SUI 32695, 33539-35544, deposited in Geology Department Repository, The University of Iowa, Iowa City, Iowa.

OCCURRENCE.—Fayetteville Formation, Chesteran, Craig County, Oklahoma.

## REFERENCES

See composite list following Part 8.

## PART 5

## NOTES ON MISSISSIPPIAN AMPELOCRINIDAE

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## ABSTRACT

Morphologic features of various species of *Armenocrinus* Strimple & Horowitz and of *Ampelocrinus* Kirk are discussed with attention directed toward some evolutionary features. The holotype of *Ampelocrinus kaskaskiensis* (Worthen), which was originally figured only by a drawing, is illustrated here by a photograph. A form from the Fraileys Shale is described as *Ampelocrinus spinosus* Strimple, new species.

## INTRODUCTION

The oldest known representative of the Ampelocrinidae Kirk (1942) is *Armenocrinus neglectus* (Miller & Gurley, 1896) (*vide* Strimple & Horowitz, 1971, p. 23) from the Borden Group (Keokuk) of Montgomery County, Indiana. In *A. neglectus* a single anal plate (primanal) retains a short contact with the BC basal, followed above by two tube plates and in the arms primibrach

4 is axillary. The genus and family have not been recognized in rocks of Meramec age other than in the Ste. Genevieve Formation or equivalent deposits (e.g., lower part of Monteaegle Limestone). *Armenocrinus watersi* Strimple & Horowitz (1971, p. 25) retains the high, cone-shaped cup of *A. neglectus*, has the same type and placement of primanal, and has reduced the number



FIG. 12. *Ampelocrinus mundus* Kirk from the Monteagle Formation, Weatherly Mountain, Huntsville, Alabama,  $\times 2$ .—1,2. Hypotype SUI 35787 crown with *CD* interray to right and opposite side with anal tube showing at summit.—3. Hypotype SUI 35791 crown with *CD* interray to right and long anal tube exposed.

of primibrachs to two except in the anterior ray where primibrach 3 is axillary. *A. watersi* is from lower beds of the Monteagle Limestone (Ste. Genevieve equivalent) south of Huntsville, Alabama, very near the type locality (and almost certainly from essentially the same horizon) as that of *Ampelocrinus mundus* Kirk (1942, p. 27). *A. watersi* differs from *Ampelocrinus* in having very large proximal columnals which lack cirri, a somewhat taller dorsal cup, and one more primibrach in the anterior ray. *Armenocrinus collinsi* Strimple & Horowitz (*ibid.*, p. 25) has only two primibrachs in the anterior ray, as in *Ampelocrinus*, but retains the high cup and very

prominent infrabasals of *A. neglectus*. The single anal plate is more advanced (having completely lost contact with *BC* basal) than found in typical *Armenocrinus*. *A. collinsi* occurs in the Greenbrier Formation (probably Chesteran) of Fayette County, Pennsylvania. The species is here referred to *Ampelocrinus collinsi* Strimple, new combination.

The type specimens of most species of *Ampelocrinus* appear to have rather rapidly expanding dorsal cups which may be due at least partially to lateral compression, since they are impressed in or on limestone or chert matrix. An undistorted specimen (SUI 35787) of *A. mundus* from the same horizon and near the type locality of that species is illustrated herein (Fig. 12,1,2) to demonstrate the cup shape. A portion of the slender anal tube is preserved and may be observed near the distal extremity of the specimen. Another specimen (SUI 35791) from Weatherly Mountain, south of Huntsville, Alabama, also is illustrated (Fig. 12,3) to show a considerable portion of the anal tube which is very long, slender, and composed of four series of plates. An elongated, slender anal sac is characteristic of related *Aesiocrinus*, *Polusocrinus*, and *Moundocrinus* of Pennsylvanian age; however, the sac is formed by six longitudinal rows of plates in Pennsylvanian forms.

The anal plate of *Ampelocrinus bernhardinae* Kirk (*ibid.*, p. 25), the type species, has not been illustrated but is reported to be large and in no specimen to adjoin *BC* basal. A topotype of the species figured herein (Figure 13) exhibits a very small contact between the radial and *BC* basal. Even more convincing is the diagonal slope of the common suture between the primanal and *CD* basal. The specimen is in the Springer Collection, Geology Department Repository, The University of Iowa (SUI 31339), from Pulaski County, Kentucky. It is a white calcite replacement on an almost black fine-grained limestone, just as are type specimens of the species. *Ampelocrinus fimbriatus* Kirk, 1942, from the same locality is very likely a variant of *A. bernhardinae*.

The illustration of *Ampelocrinus kaskaskiensis* (Worthen, 1882) given by him in 1883 (pl. 29, fig. 15) is a drawing which does not show all the described features. A photograph of the holotype is included here (Fig. 14). The species



FIG. 13. *Ampelocrinus bernhardinae* Kirk from Sloans Valley, Pulaski County, Kentucky. Topotype crown SUI 31339 from *CD* interray side,  $\times 1.5$ .

is from Chesteran rocks in bluffs of the Kaskaskia River north of Chester, Illinois, and may be conspecific with *A. bernhardinae*.

### SYSTEMATIC DESCRIPTION

#### Genus AMPELOCRINUS Kirk, 1942

#### AMPELOCRINUS SPINOSUS Strimple, new species

Figures 15,1,2; 16,1,2

DIAGNOSIS.—Cup cone-shaped, with infra-basals low but readily visible in side view; large anal plate (primanal) almost equidimensional with radial plates occupying the entire posterior interray, suture with *CD* basal sloped downward to right but primanal well removed



FIG. 14. *Ampelocrinus kaskaskiensis* (Worthen) from Chesteran rocks, Kaskaskia River bluffs north of Chester, Illinois, holotype crown ISGS [ISM] 2452 from *A*-ray side,  $\times 1.6$ .

from contact with *BC* basal, distal end of primanal with two low-angled facets supporting two elongated sac plates above. Primibrach 1 elongated, tapering, primibrach 2 axillary, expanding from base to upper facets. No further branching observed, although some pinnules are rather large. Secundibrachs keeled in upper portions and extended as small spines on longer sides; evidence of syzygial pairs of brachials obscure other than for primibrachs. Anal sac very tall, straight, slender, composed of four longitudinal series of plates with small slits along their edges.

DISCUSSION.—*Ampelocrinus spinosus* differs from typical *A. mundus* (except one paratype, Kirk, 1942, pl. 2, fig. 3) in having the primanal well removed from contact with the *BC* basal and in possessing minute spines on the secundibrachs. As reported by Kirk, the arms of *A. mundus* may bifurcate more than once in some rays. A specimen (SUI 35786) illustrated herein (Fig. 12,1,2) branches on axillary secundibrach 4 in the left half-ray of *E* ray (right half-ray is partially regenerated) and in the right half-ray of the *C* ray secundibrach 2 is axillary.

*Ampelocrinus bernhardinae* differs from *A. mundus* and *A. spinosus* in having short primibrachs, particularly primibrachs 1, and the arms consistently branch at least twice, the second bifurcation high in the arms.

MEASUREMENTS OF HOLOTYPE IN MILLIMETERS.—Width of dorsal cup 4.5, height 3.0; length of arms (as preserved) 11.0; length of anal tube (as preserved) 13.3.

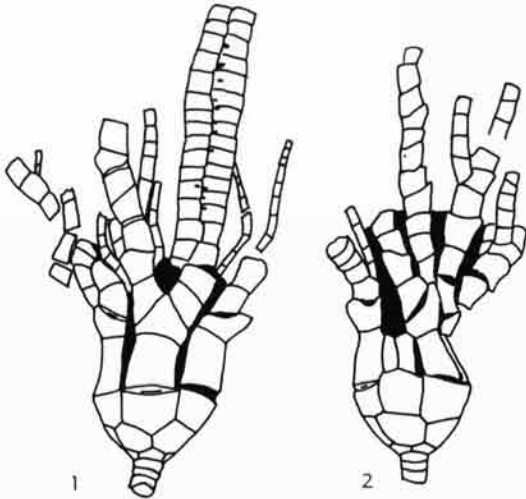


FIG. 15. *Ampelocrinus spinosus* Strimple, n. sp., from upper part of Fraileys Formation, Union County, Illinois.—1, 2. Camera lucida drawings of holotype SUI 35586 from A-ray side showing anal sac, and CD interray,  $\times 3.8$ .

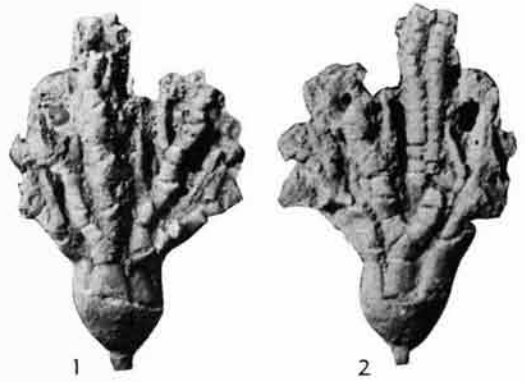


FIG. 16. *Ampelocrinus spinosus* Strimple, n. sp., from Fraileys Formation, Union County, Illinois.—1, 2. Holotype crown SUI 35586 from C-ray and A-ray sides showing elongated anal sac,  $\times 2.4$ .

HOLOTYPE.—SUI 35586, repositied Geology Department Repository, The University of Iowa, Iowa City, Iowa.

OCCURRENCE.—Upper part of Fraileys Formation or lower part of Haney Formation, middle Chesteran Stage, Upper Mississippian; road-cut on Illinois State Hwy. 146, 0.3 mile east of intersection of U.S. Hwy. I-57 (NE  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 30, T.12S., R.1E., Union County, Illinois).

## REFERENCES

See composite list following Part 8.

## PART 6

# ARTICULATE CRINOID (ISOCRINUS) FROM JURASSIC ROCKS OF PRINCE PATRICK ISLAND, CANADA

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## ABSTRACT

Several heteromorphic pluricolumnals (one attached to a partial crown), homeomorphic pluricirrals and columnals preserved on a single block of argillaceous limestone are identified as *Isocrinus patrickensis* Strimple, n. sp. The material is from the Wilkie Point Formation, Jurassic (middle Bajocian), Prince Patrick Island, Canada.





FIG. 17. *Isocrinus patrickensis* Strimple, new species, from Wilkie Point Formation, Prince Patrick Island, Canada. —1. Joint surface of a single columnal,  $\times 3.6$ . —2. Imperfectly preserved holotype crown with attached column,  $\times 3.6$ . —3. Pluricolumnal with attached cirri,  $\times 3.5$ .

## INTRODUCTION

A single block of argillaceous limestone of Jurassic age collected by the Atlantic-Richfield Oil Co., on Prince Patrick Island, bears several portions of crinoid stems (pluricolumnals), many with cirri (pluricirrals) attached, and one pluricolumnal with a fragmentary crown attached.

The specimens are designated *Isocrinus patrickensis* Strimple, n. sp., and appear to represent the first reported specimens of Mesozoic crinoids from the Arctic Islands of Canada. Morphologic terms used here have been proposed by Moore, Jeffords, & Miller, 1968.

## ACKNOWLEDGMENTS

Dr. W. W. Nassichuk, Institute of Sedimentary and Petroleum Geology, Geological Survey of Canada, Calgary, Alberta, recommended that the material be submitted to me for identification. D. L. Koch, Iowa Geological Survey, Iowa City, Iowa, has offered many useful suggestions incorporated in the study.

## SYSTEMATIC DESCRIPTION

Genus *ISOCRINUS* Agassiz, 1835 (1836)*ISOCRINUS PATRICKENSIS* Strimple, new species

DIAGNOSIS.—The largest heteromorphic pluricolumnal has 13 internodals between nodals in the distal portion and 10 internodals between nodals in the proximal portion. Pluricirrials are directed upward toward supranodals. Latera of cirrinodals are moderately impressed by proximal cirri. Distal facets of nodals are essentially smooth but other facets have petaloid crenulae. The transverse outline of columnals is only slightly stellate.

The longest pluricolumnal, which is poorly preserved, has a length of 32.0 mm and is attached to a fragmentary cup. Distally 13 internodals are counted to a point where only one internodal is proximal to the cup. This unusual development is considered to be a specific characteristic.

The best-preserved joint surface of a columnal (Fig. 17,1) shows five petals with nine crenellae on each side and the depressed central area of each petal. A small raised area surrounds the circular lumen. Cirri of one pluricolumnal illustrated (Fig. 17,3) are directed upward at the

point of attachment but rapidly become curved downward.

Although poorly preserved, the cup appears to be low cone-shaped. Primibrach 1 is rather large, and axillary primibrach 2 somewhat larger. The profiles of secundibrachs ?2-3 indicate a syzygial pair.

The crown has a length of 20.5 mm; estimated cup height 3.0 and diameter 8.0 mm; width of the attached column is about 3.4 mm, and length (as preserved) 32.0 mm. An isolated section of columnals (Fig. 17,3) has a length of 22.0 mm and width of 4.5 mm. Unterminated cirri have a length of as much as 37.5 mm.

DISCUSSION.—*Isocrinus wyomingensis* Koch, 1962, from the Sundance Formation, Jurassic, of Wyoming, is most readily distinguished in having more numerous nodals and cirri than found in *I. patrickensis*. The crown of the latter species is poorly preserved but exhibits a proportionately taller primibrach 1 than found in *I. wyomingensis*.

The column of *I. knighti* Springer, from the uppermost Jurassic of Wyoming, has equidimensional nodals and internodals, and the distal portion shows 14 internodals between nodals, as compared with 13 internodals between very thick nodals in *I. patrickensis*.

OCCURRENCE.—Wilkie Point Formation, middle Bajocian, Middle Jurassic, Prince Patrick Island, Canada.

HOLOTYPE.—Geological Survey of Canada catalogue No. C-11494.

## REFERENCES

See composite list following Part 8.

## PART 7

## TEGMINAL STRUCTURE OF SOME INADUNATE CRINOIDS

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## ABSTRACT

The presence of a multipored madreporite and cover of tiny polygonal plates in the gap between radials and primibrachs continuous with similar tegminal plates, as well as anal sac structures is described in three Upper Pennsylvanian inadunate crinoid genera.

## INTRODUCTION

Very little is known about the anal sac or tegmen of most late Paleozoic crinoids. Among several thousand observed specimens of *Delocrinus* Miller & Gurley and *Graffhamicrinus* Strimple only three have been found with the anal sac preserved. Recent discoveries, especially in the crinoid fauna from the LaSalle Limestone (Missourian) near Pontiac, Illinois, found by Christina Strimple and recently described by Strimple & Moore (1971), have provided considerable data relating to the anal sacs and more rarely to the complete tegminal structure of three genera (*Stellarocrinus* Strimple, *Brabeocrinus* Strimple & Moore and *Clathrocrinus* Strimple & Moore). These were known to have plated tegmens as well as cylindrical anal sacs located on the posterior part of the tegmen, but details of their nature are first described and illustrated here. The anal sac usually is composed of six series of plates with pores along their edges and outer sides, and the anus being located at the summit of the sac or on the anterior side just below it. The summit has projecting spines in all three genera. A few specimens of *Clathrocrinus* disclose the presence of ambulacral covering plates extending onto the tegmen and five main oral plates plus a madreporite. The madreporite is a sievelike plate which has been known hitherto only in some Cyathocrinina and Flexibilia among crinoids, as well as in echinoids, ophiuroids, and asteroids, where it serves as an inlet to the water-vascular system. It is suggested

that the posterior oral in forms where it is pierced by a single pore may be a madreporite. Many allagecrinids have such a plate.

## NATURE OF THE MADREPORITE

Among modern echinoderms (other than crinoids) the madreporite is one of five genital plates which is noticeably different in appearance from the other four and which also differs in being perforated. The perforations are numerous. Nichols (1966, p. 222) speculated that "The reason why the madreporite, in many echinoderms at least, is not merely a single pore but a system of tubes of small bore, is probably to obviate the possible blockage of this important passage by foreign objects." He further noted an occurrence recorded by Delage (1902) wherein a sea star regenerated a madreporite with a single pore.

Nichols (1966, p. 222), stated that "In crinoids, there is no direct connection between the exterior and the water-vascular system; instead there are ciliated funnels piercing the tegmen and leading into the inner body coelom, from whence the perforated water ring is presumably replenished."

In that we now know a madreporite does exist in some fossil inadunate crinoids, it might be well to reconsider the small perforated projection often found on the large, posterior oral of the family Allagecrinidae (order Disparida). In this group there are five oral plates which might be considered as homologous to the five "genital plates" of many echinoderms, albeit placed dif-

ferently in the theca. In the past, the pore found in the allagecrinids has usually been referred to questionably as a gonopore. The previously mentioned observation by Delage indicates that a modern starfish is able to function with a madreporite having a single pore.

In some instances the posterior oral of a crinoid has been *assumed* to be a madreporite (e.g., James Wright, 1935, relating to *Edapocrinus rugosus* Wright), but evidence of perforations in this oral plate has not been reported.

### STELLAROCRINUS

*Stellarocrinus* is a specialized inadunate crinoid in which the primanal is located directly

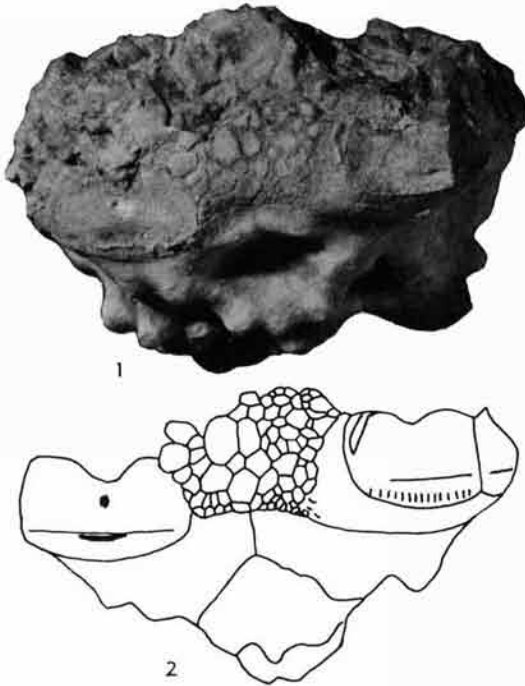


FIG. 18. *Stellarocrinus bilineatus* Strimple & Moore.—1, 2. Metatype dorsal cup (IGS 42P166) viewed from side showing minute plates filling gap between radial articular facets and covering outer ligament fossae,  $\times 3$ ; camera lucida drawing of portion of same specimen showing irregular size of interradial plates,  $\times 3.5$ .

above the distally truncate *CD* basal followed above by equidimensional secundianal and tertianal. Subsequent sac plates are thick, commonly produced as short spines in six longi-

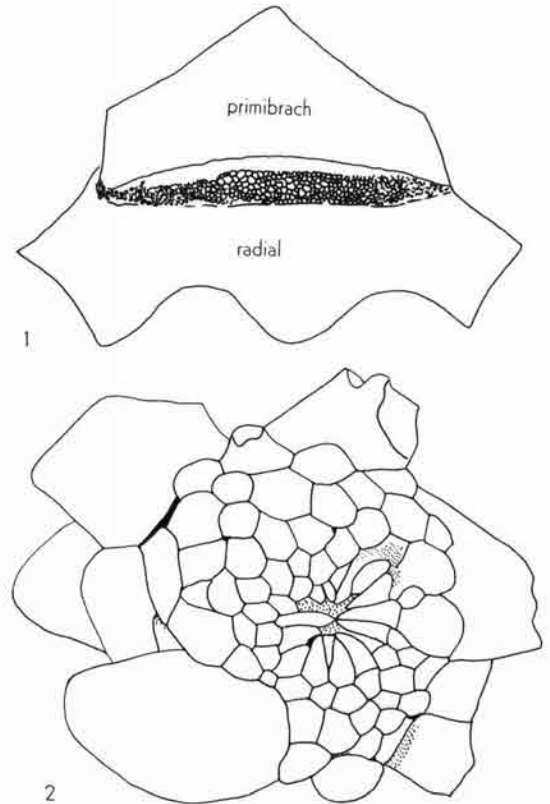


FIG. 19. *Stellarocrinus* spp., camera lucida drawing.—1. *Stellarocrinus bilineatus* Strimple & Moore; same specimen as shown in Figure 18, 1, 2 (IGS 42P166) showing minute covering plates over outer ligament grooves of radial and primibrach 1,  $\times 5.5$ .—2. *Stellarocrinus exsculptus* Strimple (IGS 42P172) summit view of anal tube showing elongate covering plates of anus toward lower right,  $\times 5.5$ .

tudinal rows, with pore slits along both the edges and outer sides. The entire anal sac is usually tilted forward. Several short spines mark the termination of the sac and at maturity the anus is just below the summit on the anterior side. *Platyceras* is found attached to the anus of many specimens.

The arms of *Stellarocrinus* are biserial, rigid to about midlength and in proximal portions are not capable of abutting closely. Prominent adsutural notches divide the radial articular facets leaving a gap between the facets and proximal sections of the arms. One specimen (IGS 42P166) has been found (Fig. 18, 1, 2; 19, 1), with small, irregular-sized, polygonal plates which cover the

gap and extend also over the outer ligament slit. The small plates are seen also to reach over the body cavity, although the tegmen collapsed before fossilization. Several other specimens have been observed with collapsed tegmens composed of minute plates. A light ridge passes across the gap between radial articular facets and the proximal edges of the minute plates rest on the almost imperceptible distal surface of the ridges.

A juvenile specimen of *Stellarocrinus* (IGS 45P171) has been found in which five principal oral plates and a madreporite are perfectly preserved (Fig. 20,2; 21,1). The tegmen is collapsed into the cup but preservation is excellent. The madreporite is large (about 1.66 mm wide by 1.25 mm long), has a subpentagonal outline, and displays an undulating surface.

### BRABEOCRINUS

One crown (IGS 42P173) of *Brabeocrinus christinae* Strimple & Moore (1971) has been found in which the gap between radial articular facets has been covered by a wall of variable-sized (minute to relatively large) small plates, extending onto proximal portions of the first primibrachs (Fig. 20,3,4). The arrangement is identical to that found in *Stellarocrinus*, which is not surprising since the genera are closely related.

### CLATHROCRINUS

A single specimen (IGS 42P12C) of *Clathrocrinus clathratus* Strimple & Moore (1971) has been observed (Fig. 22,4) in which the entire nature of the tegmen is preserved, including ambulacral covering plates extending into the tegmen. Unfortunately, the orals are somewhat obscure in this fossil but orals have been discovered in a large cup (IGS 42P170) of *C. clinatus* Strimple & Moore (1971). A large madreporite is in posterior position flanked by two elongate oral plates toward the front (Fig. 22,3; 21,2). Other orals are arranged in a semi-circle toward the anterior side and do not touch the madreporite.

The madreporite of *Clathrocrinus clinatus* has a subquadrangular outline and small projected horseshoe-shaped arc in its midportion pierced by a large pore (?genital pore). A

groovelike depression occurs at the base of the ridge, opposite the open side. It is about 1.5 mm wide 1.4 mm long. A madreporite also has been found slightly displaced in the body cavity of another topotype of *C. clinatus*; on being broken in preparation, it revealed minute pores penetrating the thickness of the plate.

*Clathrocrinus* has a long, slender anal sac composed of six vertical series of thin plates with irregularly placed pores along their edges and at its summit are two to four long slender spines. The rather large circular anal opening of *C. clinatus* (IGS 42P174) is placed slightly below the summit of the sac on its anterior side. A covered anus is illustrated in Figures 22,2, and 21,3.

The arms of *Clathrocrinus* are described by Strimple & Moore (1971, p. 35) as: "Arms ten, composed of elongate slender brachials which are transversely semicylindrical on outer (dorsal) side, without pinnules but on inner (ventral) side biserially arranged ambulacrals which are not normal cover plates because they bear a circular pore at mid-distance between margin and midline of brachials, with 10 or 20 or more such plates on each side of midline of brachials; pattern of arm branching highly distinctive in that each primaxil is followed by two secundi-axils directed laterally straight outward or obliquely outward and upward, each brachial above primaxils bearing single free armlet and another axillary plate, free armlets being given off in regular alternation from opposite sides of arms." The most interesting point noted here is preservation of the biserially arranged ambulacrals continuing onto the tegmen (Fig. 22,4).

### RELATIONSHIPS

Among inadunate crinoids, the genus *Cyathocrinites* Miller is known to have narrow radial articular facets which lack a transverse ridge, nonpinnulate arms, a strong tegmen with covered ambulacral grooves extending onto its surface, and a short stout anal sac situated on the posterior side of the tegmen. The anal sac is composed of imperforate plates and its opening is at the summit. The oral plates are not distinct enough to be identified readily. *Clathrocrinus* has wider radial articular facets with more muscular and ligament fossae, arms are nonpinnulate, distinct

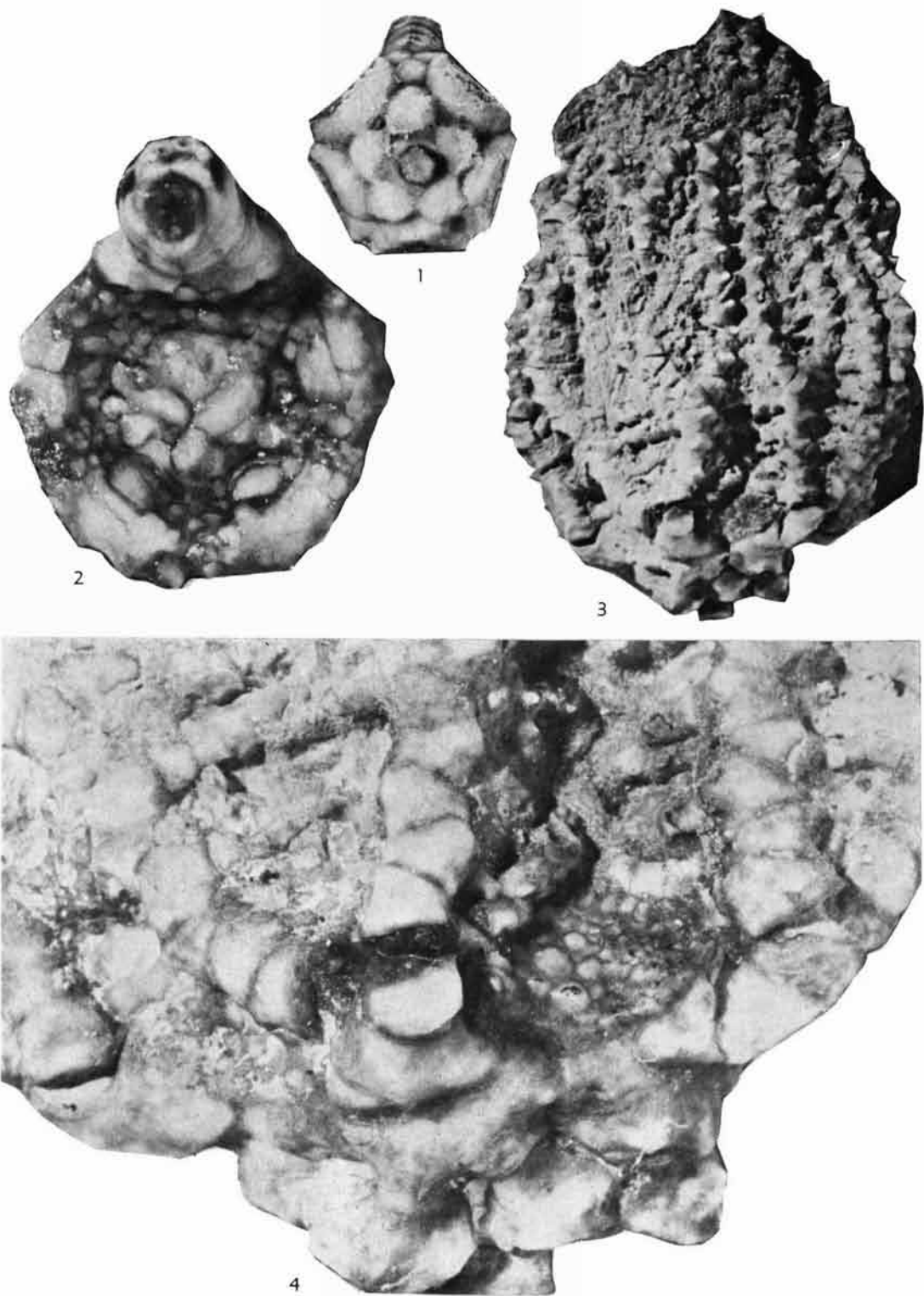


FIG. 20. (For explanation see facing page.)

orals include a madreporite, some plates of the anal sac are perforate, and the anus is situated slightly below the anal sac termination. Some characters (e.g., nonpinnulate arms) are common to both *Cyathocrinites* and *Clathrocrinus*, but the nature of plates of the posterior interray precludes any direct relationship. *Cyathocrinites* (Upper Silurian-Lower Mississippian, ?Upper Pennsylvanian) has only one anal plate, which is in line with the radials, whereas *Clathrocrinus* (Upper Pennsylvanian) has three anal plates in the cup. To attain three anal plates, especially with the primanal in subradial position, from a one-anal-plate ancestor is not thinkable, for this would require a reversal of normal evolution. Secundibrach and tertibrach are generally conceded to be derived from anal sac plates, but the primanal is judged to have originated as a subradial and thus an original integral part of the cup. *Clathrocrinus* is interpreted to belong among crinoids of the Poteriocrinina unrelated directly to *Cyathocrinites* and other Cyathocrinina.

*Stellarocrinus* is now known to have minute covering plates above the body cavity but the tegmen seems less well organized than in *Clathrocrinus*. Anal plates of the posterior interray are in a more advanced position; also, the arms of *Stellarocrinus* are biserial and pinnule-bearing, which is more advanced than the uniserial non-pinnulate arms of *Clathrocrinus*. *Brabeocrinus* is very closely related to *Stellarocrinus*. Arrangement of the madreporite and two adjacent oral plates is almost identical in *Clathrocrinus* and *Stellarocrinus*.

## OCCURRENCE OF MATERIAL STUDIED

All specimens used in this study were collected by Christina Strimple from the LaSalle Limestone Member, Bond Formation, Missourian Stage, Upper Pennsylvanian, at the Wagner

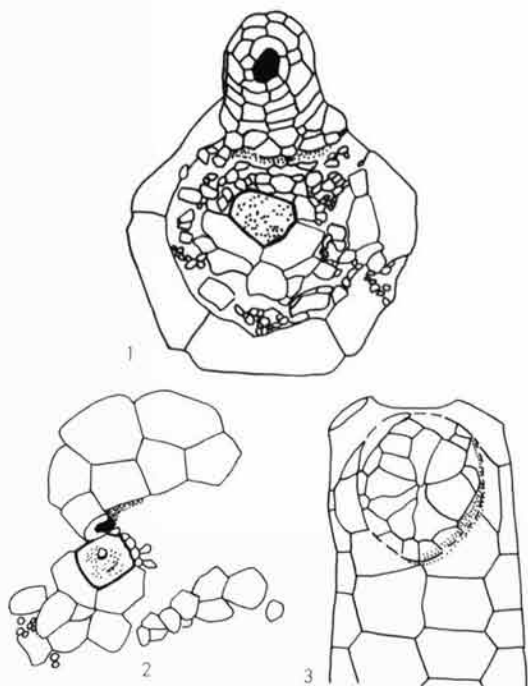


FIG. 21. *Stellarocrinus* and *Clathrocrinus* camera lucida drawings.—1. *Stellarocrinus* sp., young specimen (IGS 42P171) ventral view showing anal tube with anus just below summit on anterior side and tegmen plates collapsed into cup, including five primary oral plates and large madreporite (see also Fig. 20.2),  $\times 5.5$ .—2,3. *Clathrocrinus clinatus* Strimple & Moore, metatype (IGS 42P170) ventral view showing proximal anal tube plates and five primary orals and a madreporite,  $\times 5.5$ ; metatype (IGS 42P174) anterior side of anal tube at summit showing anus and covering plates (see also Fig. 22.2),  $\times 5.5$ .

Stone Company quarry in NW  $\frac{1}{4}$  of sec. 19, T.24N., R.5E., Livingston County, Illinois. The specimens are reposit in collections of the Illinois Geological Survey, Urbana, Illinois.

## REFERENCES

See composite list following Part 8.

FIG. 20. *Stellarocrinus* and *Brabeocrinus*.

1,2. *Stellarocrinus* sp., basal view of young specimen (IGS 42P171) coated with sublimate of ammonium chloride,  $\times 3.5$ , and summit view of same coated with glycerin, showing anal tube and opening at top with tegmen plates collapsed into body cavity including in midportion five orals and a large madreporite,  $\times 7$ .

3,4. *Brabeocrinus christinae* Strimple & Moore, metatype crown (IGS 42P173) coated with sublimate of ammonium chloride from AB interray showing minute plates filling gap between radial articular facets and lowermost arm brachials,  $\times 2.1$ , and enlargement of lower portion of same specimen coated with glycerin,  $\times 7$ .



FIG. 22. *Clathrocrinus* spp. coated with glycerin.

- 1-3. *Clathrocrinus clinatus* Strimple & Moore.—1, 2. Metatype (IGS 42P174) anal tube from posterior side showing large pore slits along edges of plates and anal tube from front showing smaller pore slits than on posterior side and position of anus with covering plates,  $\times 4$ .—3. Metatype (IGS 42P170) from summit showing proximal anal tube plates at top and tegmen plates collapsed into cup including five primary orals and a large madreporite,  $\times 8.2$ .
4. *Clathrocrinus clathratus* Strimple & Moore; metatype (IGS 42P12C) summit view showing minute tegmen plates including ambulacral covering plates and slightly obscured oral plates in midportion,  $\times 8.2$ .



## PART 8

## TEGMEN OF CAMPTOCRINUS

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## ABSTRACT

A diminutive crinoid theca from Upper Mississippian (Chesteran) deposits of northern Alabama has special interest in that it is the first discovered individual of the coiled-stem camerate genus *Camptocrinus* showing a well-preserved tegmen. Chiefly important are five relatively large, upwardly projecting orals, among which the posterior one with small corrugations and multiple pores is interpreted as a madreporite. Its rear side is troughlike and embraces a flattened spinose secundanal.

## INTRODUCTION

The holotype (SUI 37236) of *Camptocrinus alabamensis* Strimple & Moore, new species, was discovered in a shale sample collected by D. W. Burdick in September, 1972, from a roadcut through a low hill about 2 miles southeast of Littleville, Colbert County, northern Alabama (Fig. 23, 24). The crinoid-bearing stratum belongs to lower Bangor Limestone in the lower part of upper Chesteran deposits, Upper Mississippian.

On a collecting trip in April, 1973, Harrell and Christina Strimple found a second specimen of *Camptocrinus alabamensis* at the locality which yielded the holotype described and illustrated in this paper. This is now designated as paratype (SUI 37239). It differs from the holotype only in almost imperceptibly larger size and insignificant tiny blemishes produced in cleaning from adherent matrix. Illustrations of the paratype are given in Figure 25.

By current definition the only difference between *Dichocrinus* Münster (1839) and *Camptocrinus* Wachsmuth & Springer (1897) is found in the stem which in the former is round and straight but in the latter crescentric or lozenge-shaped distally with concave center and coiled arrangement around the crown. The cup of *Dichocrinus* is bullet-shaped with prominent basals as observed also in older (Osagian) species of *Camptocrinus*. *C. cirrifer* Wachsmuth &

Springer (1897), from Meramecian (Ste. Genevieve Ls.) and Lower Chesteran (Renault-Paint Creek) strata has a widened cup base and basals proportionately short in side view, giving the cup a bowl-shaped form. *C. multicirrus* Springer (1926) from the basal upper Chesteran (Glen Dean Ls.) has a very broad base with erect sides producing a box shape. This species is closely related to *C. alabamensis*. The primary type locality of *C. multicirrus*, designated by Springer, is Sloans Valley, Pulaski County, Kentucky, where the Glen Dean is a massive limestone. Most of the crinoids from this locality were recovered from the overlying shale and limestone lentils now called the Tar Springs Formation.

*Talarocrinus* Wachsmuth & Springer (1881), another genus closely related to *Camptocrinus*, first appears in lower Chesteran rocks of North America. The height of the tegmen of *Talarocrinus* usually equals the cup height, the anus is a lateral opening near the summit of the tegmen, and primibrachs 1 are axillary. In *Camptocrinus* and *Dichocrinus* primibrachs 2 are axillary and the tegmens are different.

## TEGMINAL STRUCTURES

Attached to all of the radials are short arm stumps consisting of a pair of low wide primibrachs and a varying small number of secundi-

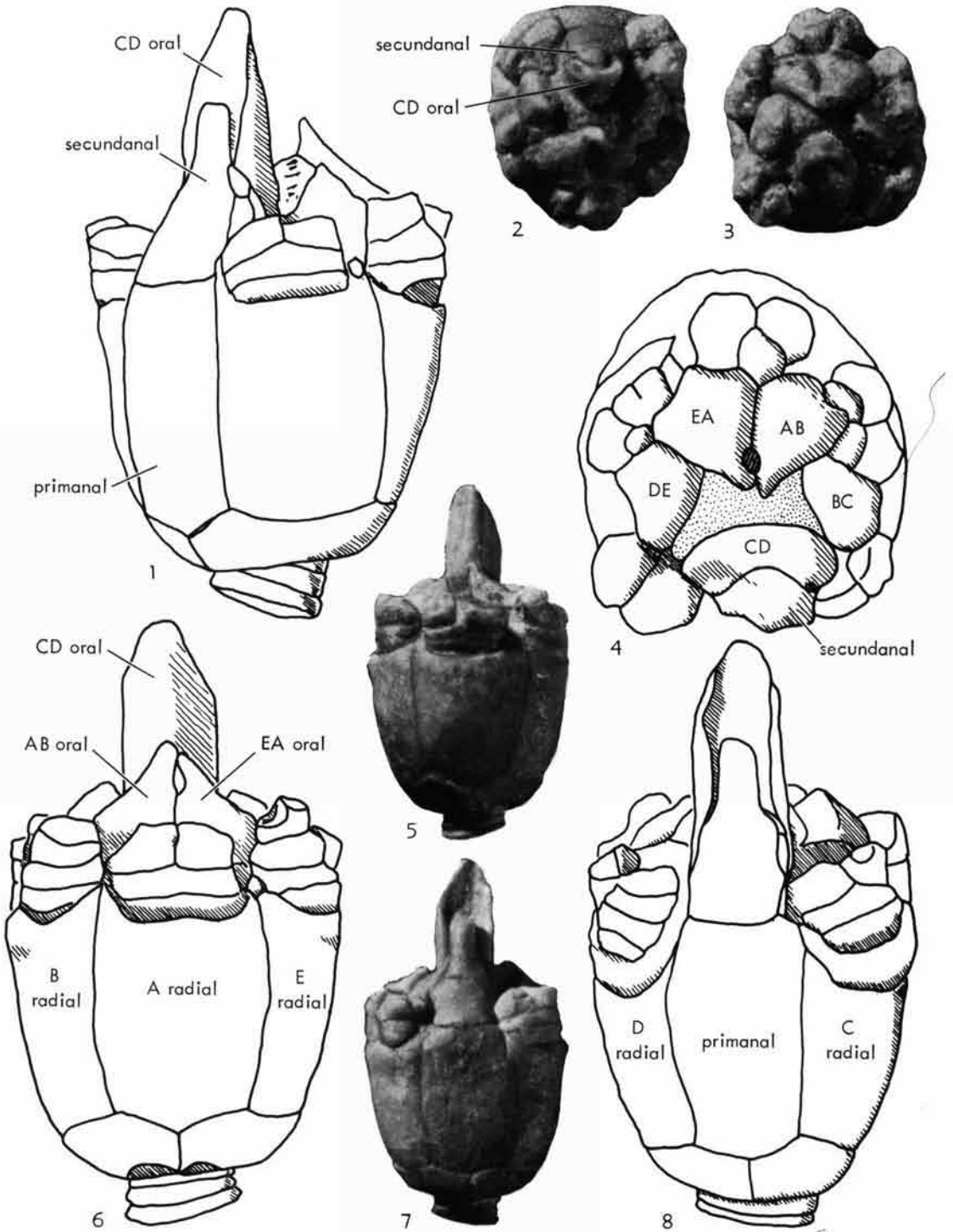


FIG. 23. (For explanation see facing page.)

brachs. These arm plates appear to be free above the gaping radial articular facets and no interradials are observed. The tegmen consists of all plates of the thecal summit girdled by the ring of arm bases; on the posterior side it includes the single secundanal which rests on the elongate primanal interposed between the *C* and *D* radials downward to the two basals. The occurrence of this plate and the rigid tegmen show that *Camptocrinus* and other members of the Dichocrinidae are camerates instead of inadunates which they resemble.

*Orals*.—The five largest plates of the tegmen of *Camptocrinus* are orals, all located interradially. The two anterior orals (*AB* and *EA*) are distally pointed plates which slope rather strongly upward toward the tegminal center (Fig. 23,4,6). The *BC* and *DE* orals are subtriangular in outline, smaller than the anterior orals, and do not meet one another centrally. The posterior oral is a large erect plate, convex on the anterior side and distinctly concave on the opposite, posterior side, which forms a troughlike hollow embracing the anus and in its lower two-thirds a secundanal (Fig. 23,1,4,8). This prominent posterior oral, when examined under a microscope, is seen to contain many small pores and its surface is finely corrugated. Seemingly it is a madreporite. Next to it toward the center of the tegmen is an irregular open space containing a few tiny plates. The mouth probably is located here.

## SYSTEMATIC DESCRIPTION

### Family DICHOCHRINIDAE

S. A. Miller, 1889

[Dichocrinidae S. A. Miller, 1889, p. 214]

TYPE GENUS.—*Dichocrinus* Münster, 1839, p. 31.

DIAGNOSIS.—Calyx convex-based cup-shaped, composed of two basals with suture between them in plane of midline of *A* radial and *CD* interray, five large subquadrangular radials sepa-

rated on posterior side by radial-like primanal extending from basals to tegmen containing orals and possibly ambulacrals, interambulacrals, and anals, some genera bearing prominent wing plates. Arms long, typically biserial, branching isotomously near calyx, pinnulate. Stem transversely round or ovate, cirriferous.

OCCURRENCE.—Lower Pennsylvanian-Upper Permian.

### Genus CAMPTOCRINUS Wachsmuth & Springer 1897

TYPE SPECIES.—*Camptocrinus myelodactylus* Wachsmuth & Springer, 1897, p. 779; original designation.

DIAGNOSIS.—Characters of family supplemented by features of coiled stem which contains somewhat close-spaced pairs of united nodals which together bear long cirri, mostly in pairs directed toward inner side of stem coil so as partly or completely to cover crown but in *Camptocrinus pleniccirrus* Springer (1926) with whorls of five cirri.

DISCUSSION.—The tegmen of *Dichocrinus* is reported to be formed of numerous small interambulacrals and ambulacrals with five central orals, *CD* oral enlarged; anal opening in *CD* interray of tegmen on small protuberance or at end of short, conical anal tube. The tegmen of *Camptocrinus*, as represented by *C. alabamensis*, does not possess plates which can be recognized as ambulacrals and is mainly composed of five orals, two of which (*AB* and *EA*) are distally pointed, and the large posterior oral which is strongly projected upward.

OCCURRENCE.—Lower Mississippian (Osagian)-Upper Mississippian (Chesteran), USA (Indiana-Kentucky); Lower Carboniferous (Viséan), Europe (Scotland); Upper Permian (Basleoan), Indonesia (Timor).

### CAMPTOCRINUS ALABAMENSIS

Strimple & Moore, new species

Figures 23,1-8; 24,1-4; 25,1-6

DESCRIPTION.—Theca budlike with calyx and

FIG. 23. Theca of *Camptocrinus alabamensis* Strimple & Moore, new species, holotype with attached lowermost parts of arms and proximal columnals.

1,4,6,8. *C*-ray, ventral, *A*-ray, and posterior views,  $\times 9$  (camera lucida drawings).

2,3,5,7. Ventral (posterior side up), same (posterior side

down), *A*-ray and *CD*-interray views of theca,  $\times 3$ .

tegmen nearly equal in height, distinguished by 5 large orals, among which tall troughlike posterior oral has numerous minute pores and finely wrinkled surface and is judged to be a madreporite with concave posterior side occupied by

a secundanal. The secundanal is shaped like a bell clapper with the shaft placed distally. It is flanked on the left by two thin elongate plates which taper rapidly and on the right by comparable plates which, however, are followed by a small triangular plate, all terminating near the point where the secundanal appears. Only proximal uniserial parts of arms which divide isotomously on 2nd primibrachs, and 3 ovate columnals attached to calyx known; cirri not observed.

**DIMENSIONS.**—The holotype, which is the only yet known specimen, has the following measurements in millimeters: height of theca, 11.3;—calyx, 5.6;—tegmen, 5.7;—posterior oral, 5.5;—basal, 1.3;—radial, 4.6;—primanal, 4.7;—secundanal, 4.0;—anterior oral, 3.5;—and primibrach, 0.45;—width of theca, 6.9;—radial, 3.8;—primanal, 2.9;—primibrach, 2.9;—columnal, 2.5.

**DISCUSSION.**—The cup of *Camptocrinus alabamensis* is readily distinguished from other species of the genus, except *C. multicirrus* Springer (1926) and *C. indoaustralicus* Wanner (1924), by its broad base, low infrabasals, and straight sides. It differs from *C. multicirrus* also in having a liplike projected area below the radial articular facets. *C. indoaustralicus*, from the Permian of Timor, Indonesia, has a rugose surface, at least on one side, with elongate, subhorizontal ridges on the radial plates. If the ridges were impressions of the cirri produced by compression they would be disposed longitudinally (Wanner, 1924, pl. 3, fig. 9).

The tegmen of *Camptocrinus alabamensis* is equal in height to the cup height owing to the strongly projected posterior oral; otherwise, the height of the tegmen is half that of the cup.

Proximal columnals of *Camptocrinus alabamensis* are oval transversely, whereas these elements are reported to be round in other species of the genus.

**TYPES.**—Holotype SUI 37326, paratype SUI 37329, Department of Geology Repository, The University of Iowa, Iowa City; collected by H. L. Strimple.

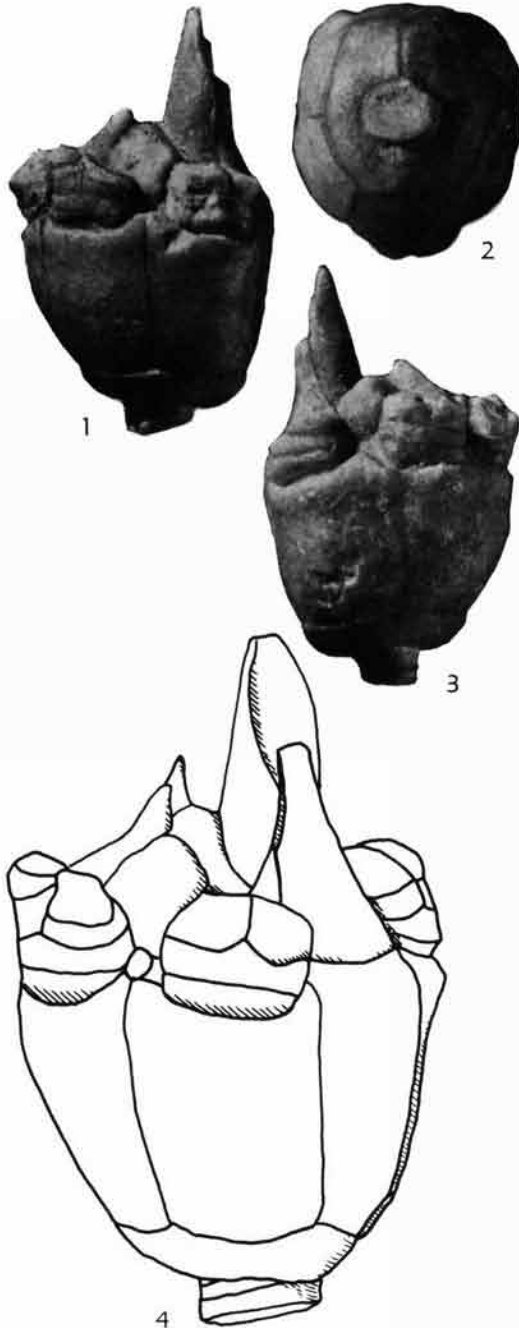


FIG. 24. Theca of *Camptocrinus alabamensis* Strimple & Moore, new species, holotype with attached lowermost parts of arms and proximal columnals.—1-3. DE-interray, dorsal, and AE-interray views of theca,  $\times 3$ . —4. D-ray view of theca (camera lucida drawing),  $\times 9$ .



FIG. 25. Theca of *Camptocrinus alabamensis* Strimple & Moore, new species, paratype with attached lowermost parts of arms and proximal columnals.—1-6. A-ray, BC-interray, CD-interray, DE-interray, dorsal, and ventral views,  $\times 5.3$ .

OCCURRENCE.—Lower part of Bangor Limestone, Upper Mississippian (upper Chesteran), about 2 miles southeast of Littleville, in SW  $\frac{1}{4}$ ,

SW  $\frac{1}{4}$ , sec. 36, T.5S., R.11W., Colbert County, Alabama.

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