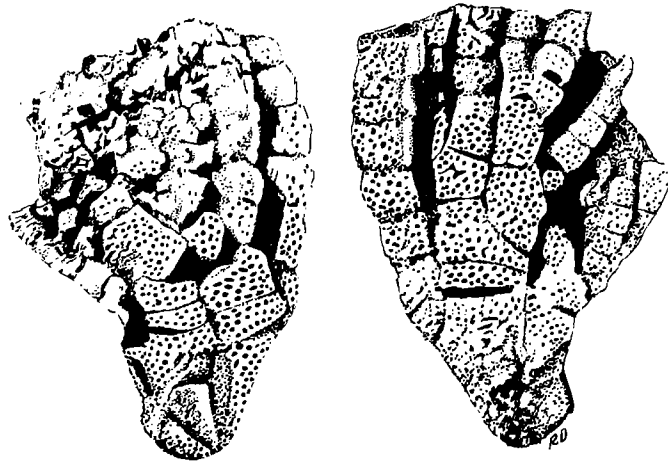




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**CALCEOCCRINIDS FROM THE BROMIDE  
FORMATION (MIDDLE ORDOVICIAN)  
OF SOUTHERN OKLAHOMA**

JAMES C. BROWER



The University of Oklahoma  
Norman  
1977

**Title Page Illustration**

Ink drawing by Roy D. Davis of *Anulocrinus ramifer*, new species, showing A- and B-ray and D-ray views. This stout young specimen, also illustrated on plate 3, was collected from the Culley (Spring) Creek locality, Criner Hills, Carter County, Oklahoma.

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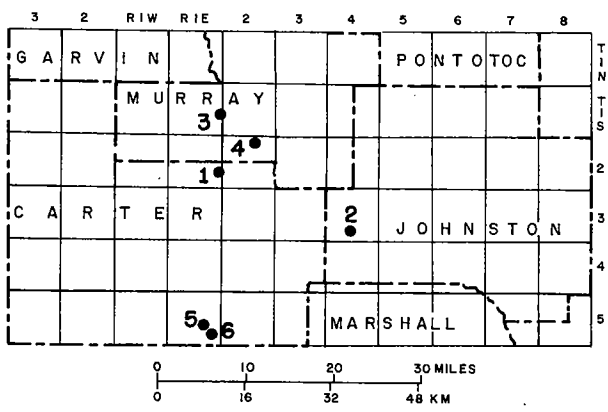
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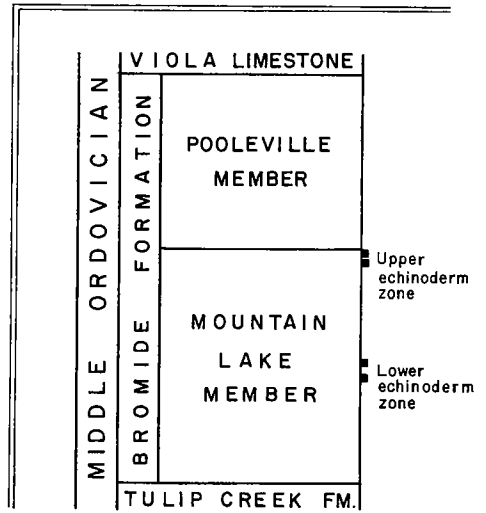
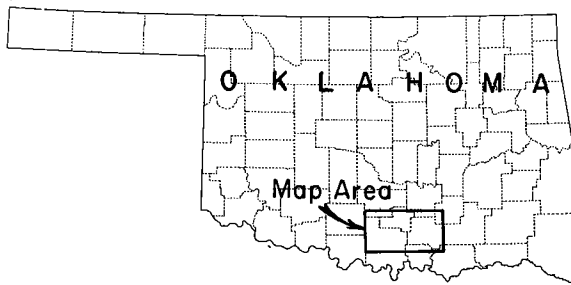
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Text-figure 1. Index map showing localities referred to in text (left), and stratigraphic chart showing position of Bromide Formation (right).

# CALCEOCCRINIDS FROM THE BROMIDE FORMATION (MIDDLE ORDOVICIAN) OF SOUTHERN OKLAHOMA

JAMES C. BROWER<sup>1</sup>

**Abstract**—Three calceocrinids are known from the Bromide Formation, *Paracremacrinus laticardinalis*, new genus and new species, *Anulocrinus ramifer*, new species, and *Calceocrinus longifrons*, new species. The Bromide calceocrinids indicate that these animals exploited a "runner" mode of life. Several specimens of *C. longifrons*, new species, and *Paracremacrinus laticardinalis*, new genus and species, have complete stems that are shorter than the crowns. These crinoids must have lived so that the stem ran along the sea floor with its distal end rooted into the sediment. The crown lay along the stem, roughly parallel to the substrate, with the hinge in the closed position. The crown was raised and the arms expanded for food gathering upon opening the hinge. During the ontogeny of *Anulocrinus ramifer*, new species, the number of brachials (presumably also the number of food-catching tube-feet) and the length of the arms developed more rapidly relative to crown size than one would predict, based on the geometry of the dimensions involved. Two of the Bromide forms are represented by numerous specimens that allow the examination of variability. The arm-branching pattern of *Paracremacrinus laticardinalis*, new genus and species, is largely stabilized as in *Cremacrinus*, but *Anulocrinus ramifer*, new species, exhibits greater variability of the arm structure. The Bromide species constitute some of the oldest known calceocrinids, and they should eventually provide useful data on the early evolution of the family. The 4 most primitive calceocrinid genera, *Anulocrinus*, *Calceocrinus*, *Cremacrinus*, and *Paracremacrinus*, new genus, 3 of which occur in the Bromide, first appear in Middle Ordovician rocks of Black River age; and the radiation of the family must have been well under way at this time.

## INTRODUCTION

Although echinoderms have been known from Middle Ordovician rocks of the Bromide Formation for over four decades (Decker and Merritt, 1931, p. 40-50), calceocrinids were first reported by Brower (1966, p. 619-623). The Bromide calceocrinid fauna consists of *Paracremacrinus laticardinalis*, new genus and species, from the Mountain Lake Member; and *Anulocrinus ramifer*, new species, and *Calceocrinus longifrons*, new species, from the Pooleville Member (see text-fig. 1).

The Bromide calceocrinids are of interest for several reasons. First, they provide information about living habits and functional morphology (e.g., Jaekel, 1918, p. 86-88; Springer, 1926, p. 98, 99; Moore, 1962, p. 4, 5; Brower, 1966, p. 613-618; Kesling and Sigler, 1969, p. 355-360; Breimer and Webster, 1975, p. 162, 163).

Several living habits have been suggested for calceocrinids. In the "drooper" habit, the stem was upright and rooted into the sea floor. When the hinge was closed, the crown was recumbent along the stem. This constituted the resting or nonfeeding orientation, during which the crinoid resembled a wilting or drooping flower. With the hinge open, the crown would have faced away from the stem at about a right angle for feeding. Specimens of Mississippian calceocrinids with open and closed hinges are pictured in Springer (1926, pl. 30, figs. 4-21). The "runner" mode of life was first proposed by Jaekel (1918, p. 86-88). Here, the stem functioned as a runner along the substrate with its distal end attached by a holdfast. With the hinge and the arms closed, the crown was recumbent along the stem and parallel to the substrate. Opening the hinge elevated the crown and spread the arms for feeding while the stem remained on the substrate (see Moore, 1962, text-fig. 2; Jaekel, 1918, fig. 83).

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Two complete specimens from the Bromide indicate that most calceocrinids probably exploited a "runner" habit. In these crinoids the stem is shorter than the crown (pl. 2, fig. 10). If these individuals were "droopers," the arms would have dragged on the sea floor when the crown was closed, which would have injured or fouled the food grooves. Obviously, these two animals must have been "runners," living with the stem recumbent on the substrate. Springer (1926, p. 99) noted similar short-stemmed specimens from the Silurian of England in which the roots were attached to foreign objects. However, in most calceocrinids with well-preserved stems, the column is longer than the crown. Regardless of stem length, most calceocrinids were probably "runners" during part or all of their lives. Breimer and Webster (1975, p. 162, 163) suggested a compromise life style for some calceocrinids. With the arms in the closed position, the stem lay along the substrate as in the "runner" existence. Many calceocrinids lived in environments that were agitated at least some of the time by gentle or stronger bottom currents (Brower, 1966, p. 615). Opening the hinge raised the arms into the current. According to Breimer and Webster, this could have created lift that would have carried or aided in carrying the crown up above the sea floor so that the stem was oriented at about a 45° angle with respect to the substrate. In this case, the crown would have been maintained in this position by the lift generated by the expanded arms and possibly by locking the ligaments of the stem into place. Not all calceocrinids could have functioned in this fashion. Only forms with light crowns, complexly branched arms with many ramules, and long stems could have exploited this life style. Calceocrinids with dense and heavy crowns, short arms with few ramules, and short stems would have been restricted to the "runner" habit at all times. Of the Bromide calceocrinids, the short stems of *Paracremacrinus laticardinalis*, new genus and species, and *Calceocrinus longifrons*, new species, indicate a "runner" mode of existence throughout life. Although definitive evidence is lacking, the short arms with few ramules of *Anulocrinus ramifer*, new species, suggest the same life habits.

As an interesting aside, Arendt (1974,

p. 45-51, figs. 5, 8) believes that several Mesozoic species of *Hemicrinus* and *Cyrtoocrinus* were modified "droopers." According to his restoration, the crown was permanently fixed at a right angle to the column. Scrutiny of the shape of the massive holdfast shows that the stem was oriented at approximately a 70° to 90° angle to the sea bed. The stem is short and massive and only consists of two(?) columnals, one fixed to the calyx and the other joined to the holdfast. The suture between the two(?) columnals occurs roughly in the middle of the stem, and this joint may have been somewhat flexible. The crown is short, stout, and heavy. The overall configuration probably represents an adaptation to rough water. Several lines of evidence demonstrate that calceocrinids were not "droopers" like *Hemicrinus* and *Cyrtoocrinus*. The holdfast in calceocrinids is too small compared to the size and weight of the crown and stem. Calceocrinids are characterized by numerous columnals, which result in a flexible stem; this is in contrast to the massive and rigid column of *Hemicrinus* and *Cyrtoocrinus*, which consists only of a few plates.

Second, the earliest known calceocrinids occur in Middle Ordovician rocks of Black River age in the Midcontinent and southern Appalachians. Thus the Bromide calceocrinids are critical in understanding the origin and evolution of the family. In addition, the Bromide species are relatively abundant, which allows detailed study of growth and variation. This, in turn, yields valuable insight into conservative and variable features during the early stages of calceocrinid evolution.

The purpose of this paper is to describe briefly the Bromide calceocrinids. Full details of growth and evolution will be incorporated into a planned monograph on all Bromide echinoderms.

#### Acknowledgments

I cordially thank the following for loan of specimens: R. O. Fay of the Oklahoma Geological Survey and P. K. Sutherland of The University of Oklahoma (OU), James Sprinkle of The University of Texas at Austin (UT), and Porter M. Kier and Mary Lawson of the National Museum of Natural History (NMNH). Mary Lawson

kindly provided some literature and useful information about many specimens. My research associate, Julia Veinus, processed the photographs and aided in taxonomic determinations, while Denise Jud of Syracuse University typed the manuscript. H. C. Strimple of The University of Iowa expedited the development of this paper. Thanks are due R. O. Fay and James Sprinkle, and Alan Horowitz and N. G. Lane (both of Indiana University), for review of the manuscript.

### SYSTEMATIC PALEONTOLOGY

Subclass INADUNATA Wachsmuth  
and Springer, 1885

Order DISPARIDA Moore and Laudon, 1943

Family CALCEOCRINIDAE Meek  
and Worthen, 1869

Genus *Paracremacrinus*, new genus

*Type species.*—*Paracremacrinus latiscardinalis*, new species, by monotypy and designation herein.

*Diagnosis.*—A calceocrinid genus like *Cremacrinus*, except that single radials are found in the *B* and *C* rays; unlike most cremacrinids, the *E*-ray arm bifurcates once proximally, thereafter branching heterotomously.

*Description.*—Calceocrinidae with four arm-bearing rays. *E*-ray arm bifurcates near the dorsal cup; higher parts of *E* ray branch heterotomously. *A*, *B*, and *D* rays branch as in *Cremacrinus*; 2 main axil series present, each consisting of about 2 plates; axil arms branch repeatedly, usually on every 2d plate according to usual calceocrinid pattern; *B*-ray arm slightly smaller than those of *A* and *D* rays. Basals 4, in which the column facet is shared by all 4 plates; proximal plates of *C* and *B* rays bear a groove for reception of the stem where the crown is in the recumbent position. Inferradials and superradials of *C* and *B* rays represented by one plate in each ray; *B*- and *C*-ray inferradials either have been lost or are fused with superradials to form a single plate.

*Remarks.*—*Paracremacrinus* is most closely allied to *Cremacrinus* (Ulrich, 1886, p. 107; see detailed discussion in Moore, 1962, p. 8-14, 20, 21) and *Anulocrinus*

(Ramsbottom, 1961, p. 8; see Moore, 1962, p. 8-14, 21-24), both of which have four rays with arms. The unique feature of *Paracremacrinus* is the nature of the *B*- and *C*-ray radials. In *Cremacrinus* and *Anulocrinus*, the *B* and *C* rays are characterized by divided radials consisting of inferradials and superradials. The inferradials are typically small and roughly triangular elements that lie between the basal circlet and the associated *B*- and *C*-ray superradials; the *B*- and *C*-ray inferradials do not touch each other (see Moore, 1962, p. 8-14, 20-24, text-figs. 3a, 5-1, 6, 10, 14, pl. 1, figs. 1, 3-5). In *Paracremacrinus*, the *B*- and *C*-ray radials are each represented by a single large plate, and there is no trace of inferradials. The two large plates rest on the basals and are in lateral contact with each other (see pls. 1, 2). The distal margins of the two plates are situated roughly at the same level as the primaxils of the adjacent *A* and *D* rays, although the *B*-ray plate reaches slightly higher. The distal margins of the superradials in *Cremacrinus* (e.g., see *C. punctatus* Ulrich as illustrated by Springer, 1926, p. 110, pl. 28, figs. 16-20; *C. articulatus* [Billings] in Springer, 1926, p. 108, pl. 28, figs. 9-14; *C. kentuckiensis* [Miller and Gurley] in Springer, 1926, p. 109, pl. 28, figs. 14, 15; *C. tubuliferus* Springer, 1926, p. 106, pl. 28, figs. 3-6) and in *Anulocrinus* (see *A. ramifer* of this paper; Brower, 1966, p. 619, pl. 75, figs. 10-12, 25, text-figs. 1a-g) are found at approximately the same level. Thus, it appears that *Paracremacrinus* has lost the inferradials of the *B* and *C* rays.

Several mechanisms are possible to explain this change. The first two possibilities assume that the Calceocrinidae were derived from an ancestor with divided radials in the *B*, *C*, and *E* rays, such as homocrinids. This parallels the ideas of most workers on the phylogeny of primitive calceocrinids (e.g., Moore, 1962, p. 37-38; Brower, 1966, p. 613-618). First, the inferradials simply may have failed to develop during ontogeny—a change that would have affected the sequence of plate formation. Second, the embryonic *B* and *C* rays might have possessed both inferradials and superradials that fused sometime later in ontogeny. Which mechanism applies cannot be determined from the

available material, in which the youngest growth stages are lacking. The smallest known crinoids have cups about 4.0 mm high, and these show no traces of infer-radial sutures. The fact that the large plates in the *B* and *C* rays of *Paracremacrinus* are about the same size as the combined inferradials and superradials of the same rays in roughly contemporary species of *Cremacrinus* and *Anulocrinus* suggests that fusion is the more likely origin. At any rate, I consider the two large plates in the *B* and *C* rays as undivided radials regardless of their origin. It might be suggested that the two large plates interpreted as *B*- and *C*-ray radials are inferradials, and that super-radials are present in the form of the first primaxil of the *B* ray of the anal *X* of the *C* ray. Such is probably not the case. All cremacrinoids and anulocrinoids known to me have the same number of primaxils in the *A* and *B* rays. Two primaxils almost always occur in the *A* ray, and two primaxils should also be found in the *B* ray. For this to hold true, all the radial elements of the *B* ray in *Paracremacrinus* must be contained in the single large plate that is believed to be an undivided radial. Presumably, the same situation applies to the anals in the *C* ray.

The third possibility involves a change in the postulated phylogeny. Perhaps *Paracremacrinus* could have descended from an ancestor with single or undivided radials in all rays except for the *E* ray. If so, the large undivided radials would have been inherited from the ancestral stock. According to this hypothesis, the similarities between *Cremacrinus* and *Anulocrinus*, on the one hand, and *Paracremacrinus*, on the other, would have been acquired by convergent evolution. This possibility is tentatively rejected on several grounds. A plausible ancestor is conspicuously lacking in that there is no known monocyclic inadunate crinoid with undivided radials in the *A*, *B*, *C*, and *D* rays in conjunction with a divided radial in the *E* ray. Total morphological comparison indicates that *Paracremacrinus* is a typical calceocrinid in most features. This, in combination with the lack of a plausible ancestor other than a homocrinid or primitive calceocrinid, rules out convergent evolution. Consequently, I believe that

*Paracremacrinus* represents a bona fide calceocrinid that shares common ancestry with the rest of the family (see later discussion).

*Paracremacrinus* also differs from *Anulocrinus* and *Cremacrinus* in various aspects of the arms. The *E* ray of *Paracremacrinus* divides into 2 equal branches, invariably, on the 2d primibrach; above this level, heterotomous branching takes place. Most species of *Cremacrinus* (e.g., *C. punctatus* Ulrich; *C. ulrichi* Springer, 1926, p. 105, pl. 28, figs. 1, 2; *C. tubuliferus*; *C. decatur* Springer, 1926, p. 107, pl. 28, fig. 7; *C. arctus* Sardeson, 1928, p. 36, text-figs. 1-5; Kolata, 1975, p. 20, pl. 3, figs. 3-9, 11-13; *C. guttenbergensis* Kolata, 1975, p. 23, pl. 3, figs. 10, 14, text-fig. 6; and *C. inaequalis* [E. Billings] as pictured in Wilson, 1946, p. 35, pl. 5, figs. 4a, b) and *Anulocrinus* (e.g., *A. ramifer* of this paper; *A. drummuckensis* Ramsbottom, 1961, p. 9, pl. 2, figs. 9, 10; Moore, 1962, p. 24, pl. 1, figs. 5a, b, text-figs. 14-1, 2; *A. simplex* [Springer], 1926, p. 107, pl. 28, figs. 8, 8a; Moore, 1962, p. 24, pl. 3, fig. 5, text-figs. 14-1, 2; and *A. forrestonensis* Kolata, 1975, p. 25, pl. 3, fig. 1, text-fig. 7) are characterized by unbranched *E*-ray arms. The *E*-ray arm of *A. thraivensis* Ramsbottom (1961, p. 8, pl. 2, figs. 1-8, text-fig. 7; see Moore, 1962, p. 22, pl. 1, figs. 4a-d, text-figs. 12, 13) and *A. latus* Brower and Veinus (1974, p. 24, pl. 3, fig. 1) bifurcates several times. *E* rays that branch isotomously are also known in several species of *Cremacrinus*, including *C. articulatus* and *C. kentuckiensis* in which the distal parts of the arms branch once. The Trenton species *C. furcillatus* (Billings) (1887, p. 51, unnumbered fig.; see Ringueberg, 1889, p. 393, pl. 10, figs. 1a, b) exhibits an *E*-ray arm similar to that of *Paracremacrinus*. However, the branches are more widely spaced in the Trenton crinoid in which ramules are observed on every 3d plate rather than on every 2d plate as in *Paracremacrinus*. *Cremacrinus furcillatus* is easily separated from *Paracremacrinus* by the nature of the radials in the *B* and *C* rays according to the original description.

The arm-branching patterns of the *A*, *B*, and *D* rays of *Paracremacrinus* and *Cremacrinus* are essentially the same, but a different plan is present in *Anulocrinus*.



*Paracremacrinus* has two series of main axils and axil arms that branch heterotomously on every other plate. This results in extensively branched *A*, *B*, and *D* rays in mature crinoids. The axil arms of *Anulocrinus* branch less commonly, and generally three or fewer branches can be counted in a single axil arm (see *A. thraivensis* as illustrated by Moore, 1962, p. 22, pl. 1, figs. 4a-d, text-figs. 12, 13; *A. drummuckensis* in Moore, 1962, p. 22, pl. 1, figs. 5a, b, text-figs. 14-1, 2; *A. simplex* in Moore, 1962, p. 22, text-figs. 14-3, 4; *A. ramifer* of this paper; and *A. forrestonensis*). The number of main axils ranges from 1 to 4 in *Anulocrinus* in contrast to the invariable 2 of *Paracremacrinus*.

*Paracremacrinus* is most similar to *Cremacrinus*, and in particular to the Trenton species *C. furcillatus*, which is morphologically intermediate between the Black River species of *Cremacrinus* and *Paracremacrinus*, having the dorsal-cup structure of the former and the type of *E*-ray arm found in the latter. However, stratigraphic position clearly indicates that *C. furcillatus* is not the ancestor of either Black River species of *Cremacrinus* or the contemporary *Paracremacrinus*, although it may reflect the ancestral stock or stocks. A mixture of primitive and advanced characters is found in *Paracremacrinus*. Primitive features include the four arm-bearing rays, the nature of the basals, and the type of branching seen in the *A*, *B*, and *D* rays. The branching pattern of the *E* ray is characteristic of homocrinids such as *Ectenocrinus* and *Drymocrinus* (see Ulrich, 1924, for diagnoses of these genera). Calceocrinids were probably descended from the Homocrinidae (Moore, 1962, p. 37). Thus, the *E*-ray arm of *Paracremacrinus* could have been inherited from a homocrinid ancestor, or it may have been a secondarily derived character acquired after origination of the Calceocrinidae. The presence of undivided radials in the *B* and *C* rays is definitely an advanced feature. At present, the exact evolutionary position of *Paracremacrinus* is uncertain, and this will be the subject of later multivariate statistical studies. Species of all three primitive calceocrinid genera are known from Middle Ordovician rocks of Black River age.

*Derivation of name.*—*Paracremacrinus*,

in allusion to the close similarity and presumable relationship with *Cremacrinus*.

*Occurrence.*—Middle Ordovician, Black River; Bromide Formation, Lower echinoderm zone of Mountain Lake Member; Oklahoma.

#### **Paracremacrinus laticardinalis**

new species

Pls. 1, 2

Text-figs. 2a-e

*Diagnosis.*—For genus, inasmuch as there is only one species known.

*Description of adult.*—Crown large with heavy arms. Calyx plates either smooth or faintly rugose. Dorsal cup much wider than high, hinge greatly extended; in *E*-ray view, the cup appears constricted above the hinge; hinge bears supplementary plates where completely preserved. Axillary brachs larger and more nodose than nonaxillary plates; axillaries twisted so that the ramules are hidden inside the arms where the crown is in the closed position. Ramules long, slender, much more narrow than associated parts of the axil arms.

Basal series triangular, consisting of 4 plates; stem facet shared by all 4 basals; basals partly fused in some specimens.

*E*-ray inferradial roughly rectangular with central constriction, wider than high, joining *E*-ray superradial and basals. Superradial trapezoidal, expanding distally. Facet of *E*-ray superradial with transverse ridge and narrow dorsal fossa for ligaments; two broad and poorly defined ligament and (or) muscle fossae present, which are separated by an elongate ridge (text-fig. 2a). *E*-ray arm branches isotomously on primibrach 2. Higher parts of *E* ray show heterotomous branching; usually branching takes place on every 2d plate, but in some cases the 1st or 3d is axillary; some specimens exhibit over 16 branches, and the arms are not complete; proximal heterotomous branch is invariably on outside of *E* ray.

*A*- and *D*-ray radials undivided, largest plates in dorsal cup. Two main axil series present; each usually consists of 2 plates with the 2d axillary; rarely the 1st or 3d plate is axillary; nonaxillary plates rectangular, axillaries pentagonal. Primaxil and secundaxil arms branch commonly according to typical calceocrinid heterotomous pattern; generally every other brach of the axil

arms is axillary, but some branching is on the 1st or 3d plate; at least 20 ramules are present in the arms of 1 large crinoid; proximal ramules of primaxil and secundaxil arms on *E*-ray side of radial; omega ramule is on posterior side of secundaxil.

*B* and *C* rays have only one large radial plate each, these roughly rhomboidal, in contact with basal circlet. *B*- and *C*-ray inferradials are either absent or fused with the superradials to form undivided radials; the latter possibility is more likely in view of the large size of the plates. *B*-ray radial reaches level of primaxils in *A* ray; *C*-ray radial terminates slightly lower than that of the *B* ray. *B*- and *C*-ray radials grooved for reception of stem when crown was closed.

Only proximal portion of anal tube known; anal *X* roughly rectangular, strongly convex; 1st and 2d anal-tube plates similar to anal *X*; higher parts of anal tube are enveloped by the arms.

*B*-ray arms slightly smaller than those of the *A* and *D* rays; *B*-ray arms composed of smaller brachials that are higher relative to width than in the *A* and *D* rays; branching formula of *B* ray like that of *A* and *D* rays.

Facet for omega ramule with two deep ligament pits, which are separated by a sharp median ridge; lateral margins of ligament pits also may be bounded by sharp ridges; food grooves V-shaped, sharp but not deep; food grooves slightly offset toward outermost ligament pit (text-fig. 2d). Facets for other ramules are similar, although the ligament pits are less deep. Facets of non-axillary brachials quite variable; some brachials have rims around the outer margins of the plate, but other plates lack these rims; the articular surfaces of brachials more or less concave, not differentiated into transverse ridge, dorsal-ligament fossa, etc.; food grooves small, sharp, not deep, with rounded or V-shaped base (text-figs. 2b, c). Covering plates known from several brachials, irregular, about six sets per brachial (text-fig. 2e).

Complete column known in one specimen, short, only about two-thirds as long as the crown is high, consisting of one order of columnals; columnals become higher toward rooting device; distal columnals round; proximal columnals round in some specimens. In other crinoids, the side of the columnals that fits into the groove between the *C*- and *D*-ray radials may be slightly flattened to

provide a better fit when the crown was closed. Rooting device consists of massive lump or disc of calcite that bears at least four heavy rootlets.

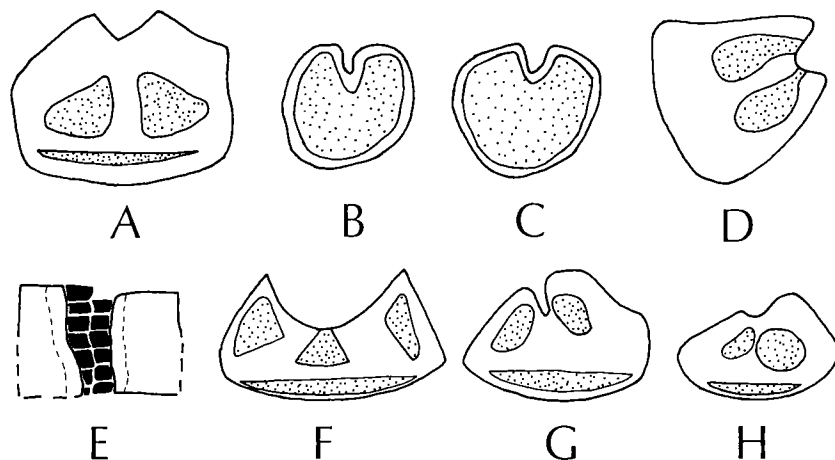
*Remarks.*—*P. laticardinalis* is a common species, being known from about 95 specimens consisting of partial crowns, parts of arms, and dorsal cups, all of which have been collected from the Mountain Lake Member. The abundant material is suitable for study of growth and variation. Only a few brief comments about ontogeny will be given here; full details will be presented in a later study. Table 1 lists the statistics for the arm-branching pattern. The data comprise the number of plates in the different series of brachials. Several generalizations are drawn from the statistics:

1. Only low variation is observed compared to most other calceocrinids. This is reflected by the fact that the coefficients of variation range from nil to 36 percent, although most are less than 20 percent. This denotes that the arm-branching structure of *P. laticardinalis* is largely stabilized as in *Cremaecrinus* (Brower, 1966, p. 622, 623, table 2). As discussed later, anulocrinids exhibit a much less stable pattern of arm branching.

2. The average number of plates in each brachial series of *Paracremacrinus laticardinalis* is roughly 2.0 regardless of where the plate series is situated, and, similarly, the variation in number of plates in the different brachial series as shown by the standard deviations is independent of the position of the plates. This pattern contrasts greatly with that of *Anulocrinus ramifer*, new species, as indicated later. This doubtless is due to differences in paleogenetics and evolutionary roles among the cremaecrinid, paracremaecrinid, and anulocrinid genera.

3. The variation in number of plates is asymmetrical. Normal plate series exhibit two plates. Most variants have 1 plate, and specimens with 3 or more brachials are relatively rare. Where a single plate is present, it is generally as high as the two plates in normal series of brachials. This suggests that series with 1 plate are produced by fusion of 2 plates in a normal series. This is corroborated by the presence of a complete spectrum of plate series ranging from two separate to a single fused brachial.

The cups range from about 4.0 to 10.0



Text-figure 2. Radial facets and brachials of Bromide calceocrinids. Fossae are stippled in **A-D** and **F-H**; covering plates are shown in black in **E**.

**A-E:** *Paracremacrinus laticardinalis*, new genus and species.

**A**, paratype, OU 8467; radial facet of *E* ray,  $\times 6.9$ . Daube Ranch locality.

**B, C**, paratype, UT 1121TX 25; facets of nonaxillary brachials of small crinoid,  $\times 9.2$ . Daube Ranch locality.

**D**, paratype, OU 8468; facet for omega ramule, food groove at right,  $\times 9.2$ . Lick Creek locality.

**E**, paratype, OU 8466; view of nonaxillary brachial with covering plates,  $\times 9.2$ . Lick Creek locality.

**F-H:** *Anulocrinus ramifer*, new species. Paratype, NMNH 156263; views of radial facets,  $\times 6.0$ . Culley Creek (Spring Creek) locality.

**F**, *E* ray.

**G**, *D* ray.

**H**, *B* ray.

mm high. Unfortunately, complete crowns are unknown, and ontogeny of the arms cannot be studied *in toto*. There are two striking changes in ontogeny. Seen in *E*-ray view, the cups of young specimens are trapezoidal with maximum width at the hinge (pl. 2, figs. 1, 2). During later ontogeny, the width of the hinge is augmented more rapidly than the rest of the cup so that the hinge is extended into "ear"-like projections (pl. 1, fig. 6). The relationship was quantified by a reduced major axis for the height of the cup (measured parallel to *E* ray from the base of the hinge to distal margin of the superradial) and the width of the hinge (measured along the base of the cup running from the *A* ray to the *D* ray). The equation is

$$(\text{Hinge width}) = 0.58(\text{cup height})^{1.56}$$

If the two variables increased isometrically so that the shape remained constant throughout ontogeny, the ideal exponent would be 1.0. The observed exponent of 1.56 is much larger than the ideal value, which indicates that the width of the hinge developed much faster relative to cup height than one would expect, based on ideal geometrical considerations. This more rapid development had several advantages. The ligaments or muscles attached to the hinge served to elevate the crown from the closed or recumbent position, with the crown roughly parallel to the substrate and the stem, into the erect or feeding orientation (for more details on morphology and function of the hinge in calceocrinids, see Brower, 1966, p. 613-618; Kesling and Sigler, 1969, p. 355-360). Maximizing the

TABLE 1.—STATISTICS FOR DIFFERENT SERIES OF BRACHIALS IN *Paracremacrinus laticardinalis*

Ray	Plate series	Average number of plates	Maximum number of plates	Minimum number of plates	Standard deviation	Coefficient of variation [(std. dev.)/(mean)] X 100	Number of rays counted
A&D	Primaxils	2.01	3	2	0.0921	4.58	118
A&D	Alphabrachs in primaxil arm	2.00	2	2	0	0	82
A&D	Betrabrachs in primaxil arm	1.98	2	1	0.146	7.37	47
A&D	Gammabrachs in primaxil arm	2.00	2	2	0	0	28
A&D	Deltabrachs in primaxil arm	2.00	2	2	0	0	22
A&D	Epsilon-brachs in primaxil arm	1.93	2	1	0.267	13.9	14
A&D	Zetrabrachs in primaxil arm	1.89	2	1	0.333	17.6	9
A&D	Secundaxils	2.00	2	2	0	0	54
A&D	Alphabrachs in secundaxil arm	2.00	2	2	0	0	37
A&D	Betrabrachs in secundaxil arm	2.00	2	2	0	0	23
A&D	Gammabrachs in secundaxil arm	1.93	2	1	0.258	13.4	15
A&D	Deltabrachs in secundaxil arm	2.00	2	2	0	0	8
A&D	Epsilon-brachs in secundaxil arm	2.00	2	2	0	0	6
A&D	Zetrabrachs in secundaxil arm	1.80	2	1	0.447	24.8	5
B	Primaxils	1.87	2	0	0.404	21.7	45
B	Alphabrachs in primaxil arm	2.04	3	2	0.189	9.28	28
B	Betrabrachs in primaxil arm	2.06	3	2	0.236	10.5	18
B	Gammabrachs in primaxil arm	2.00	2	2	0	0	8
B	Deltabrachs in primaxil arm	2.00	2	2	0	0	5
B	Epsilon-brachs in primaxil arm	2.00	2	2	0	0	5
B	Zetrabrachs in primaxil arm	2.00	2	2	0	0	5
B	Secundaxils	2.00	2	2	0	0	25
B	Alphabrachs in secundaxil arm	2.00	2	2	0	0	17
B	Betrabrachs in secundaxil arm	2.00	2	2	0	0	10
B	Gammabrachs in secundaxil arm	2.00	2	2	0	0	8
B	Deltabrachs in secundaxil arm	2.00	2	2	0	0	6
B	Epsilon-brachs in secundaxil arm	2.00	2	2	0	0	5
B	Zetrabrachs in secundaxil arm	2.00	2	2	0	0	3
E	Primibrachs	2.00	2	2	0	0	62
E	Secundibrachs	2.02	3	2	0.149	7.37	45
E	Tertibrachs	1.97	2	1	0.180	9.13	31
E	Quartibrachs	2.00	2	2	0	0	25
E	Quintibrachs	1.94	2	1	0.236	12.1	18
E	Sexibrachs	1.77	2	1	0.438	24.8	13
E	Septibrachs	1.50	2	1	0.534	35.6	8

width of the hinge maximizes the strength of the ligaments within the basic geometrical limits of the structure. Assuming that all calceocrinids have the same type of ligaments along the hinge, the strength should have been proportional to the cross-sectional area of the ligaments. This should have aided in elevating and maintaining the crown in the open or feeding position (see Brower, 1974, p. 44-46, for outline of some similar problems in camerate crinoids). During life, the stem probably lay along or close to the substrate, possibly covered with a thin film of sediment and algae (for living positions of calceocrinids, see Brower, 1966, p. 613-618; Kesling and Sigler, 1969, p. 355-360; Moore, 1962, text-fig. 2). In this case, the hinge most likely rested on the sea floor, and the acquisition of "ears" on the side of the hinge would have increased the stability of the crown on the substrate, especially with the crown in the erect position. Such would also provide maximum mechanical leverage, because the crown could have been flexed open and closed against the stem and basals and the sea bed. In this context, it is notable that in any one size range the shapes of the hinge are extremely variable. Some individuals exhibit large symmetrical "ears," and these are believed to have lived on flat substrates. Other animals are asymmetrical so that one side of the hinge is longer than the other; still others have warped and bent hinges. Plates 1 and 2 illustrate some of the observed variations. Perhaps these crinoids dwelt in cracks, nooks, crannies, and depressions, or with part of the hinge buried in the sediment or abutting against some rigid object such as a bryozoan colony that caused the asymmetrical or warped development of the hinge. This type of variation is definitely nongenetic.

The second major growth trend affected the brachials at all levels. In young specimens, the brachials were relatively high compared to their width. In subsequent growth, the width of the brachials was augmented more rapidly than height so that the height/width ratios of the plates decreased as the crinoids became older. In addition, the axillaries of older crinoids appear more knobby than in immature specimens (see pl. 1, figs. 4-6; pl. 2, figs. 1, 2).

*Specific name.*—*Laticardinalis*, in allusion to the relatively wide hinge with "ears" seen in most adult crinoids.

*Holotype.*—OU 8458.

*Paratypes.*—OU 8459-8473; UT 1121TX 24-33.

*Occurrence.*—Lower echinoderm zone, Mountain Lake Member of Bromide Formation; Daube Ranch locality on West Branch of Sycamore Creek, 152-154.5 feet below top of member, NE SW SE NW $\frac{1}{4}$  sec. 27, T. 3 S., R. 4 E., Johnston County; Lick Creek locality, 159-160 feet below top of member, SE NE NE $\frac{1}{4}$  sec. 23, T. 1 S., R. 1 E., Murray County; Amis Ranch locality, 122-125 feet below top of member, SE NW SE SW $\frac{1}{4}$  sec. 3, T. 2 S., R. 2 E., Murray County; Cornell Ranch locality, east of old Highway 77, 169-172 feet below top of member, NE NW SE NE $\frac{1}{4}$  sec. 25, T. 2 S., R. 1 E., Carter County; all from the Arbuckle Mountains of southern Oklahoma.

Genus *Anulocrinus* Ramsbottom, 1961

*Anulocrinus ramifer*, new species

Pl. 3, figs. 1, 4-9; pl. 4, figs. 9-11

Text-figs. 2f-h

*Anulocrinus* sp. aff. *A. drummuckensis* Ramsbottom; BROWER, 1966, p. 619, pl. 75, figs. 10-12, text-figs. 1a-g.

*Diagnosis.*—A species of *Anulocrinus* with pits on all calyx plates; crown stout with large dorsal cup compared to the most closely related species. Arm-branching formula simple: axil arms branch 2 or 3 times; 2 axil arms per ray; *E*-ray arm usually unbranched, but some branch once on primibrachs 8 to 15.

*Description.*—Crown moderately stout with large dorsal cup relative to size of arms; some dorsal-cup plates commonly partially fused. Crown has numerous small pits. Brachials uniserial; nonaxillaries have variable shapes; proximal plates typically equidimensional; distal plates higher than wide; axillaries pentagonal, not nodose.

Basal series triangular, consisting of 1 to 4 plates.

*E*-ray inferradial rectangular, with central constriction, higher than wide. *E*-ray superradial pentagonal; superradial facet with dorsal ligament fossa and transverse ridge; intermuscular notch on ventral margin; two ventral ligament or muscle fossae situated near sides of facet; small triangular fossa between transverse ridge

and intermuscular notch (text-fig. 2f). *E*-ray arm generally unbranched, consisting of large plates, some bifurcating on primibrachs 8 to 12 or 15.

*A*- and *D*-ray radials undivided, largest plates in dorsal cup, bearing 2 series of main axils; radial facets with intermuscular notch, dorsal-ligament fossa and 2 ventral fossae for ligaments or muscles (text-fig. 2g). From 1 to 3 primaxils and usually from 1 to 4 secundaxils present. Primaxil arm generally with 3 or 4 alphabrachs; betabrachs vary from 2 to 9 plates; primaxil arm generally only branches twice; if 3 branches are present, about 4 gammabrachs are present. Secundaxil arm usually branches once or twice; alphabrachs range from 2 to 5 plates; if the arms branch again, about 4 betabrachs are present.

*B* and *C* rays have inferradials and superradials; inferradials are relatively large triangular plates between basal circlet and overlying superradials; inferradials not in lateral contact. *B*-ray superradial of moderate size, smaller than *A*- and *D*-ray radials, reaching level of first primaxil in *A* and *D* rays; radial facet like that of *A* and *D* rays (text-fig. 2h). *C*-ray superradial roughly rectangular, strongly convex, bearing anal-*X* plate and anal tube; anal *X* similar to superradial; anal tube unknown, enveloped by arms.

*B*-ray arm poorly known, smaller than arms of *A* and *D* rays, generally with two primaxils and secundaxils. Primaxil arm branches once or twice with 1 to 3 alphabrachs; 4 betabrachs present where arm branches twice. Secundaxil arm not fully preserved, branching on alphabrach 3 or 4.

Articular surfaces of brachials smooth; food grooves moderately deep with rounded or V-shaped base; covering plates small, irregular; those of nonaxillary brachials generally arranged in pairs but some have 3 rows of plates; nonaxillary brachials generally have about 4 sets of covering plates.

Column round, composed of wide, smooth columnals.

*Remarks.*—Brower (1966, p. 619, pl. 75, figs. 10-12, 25, text-figs. 1a-g) originally described this crinoid as *A. sp. aff. A. drummuckensis*. At that time, it was realized that the form constituted a new species, but formal description was post-

poned until more material could be assembled. *A. ramifer* is a common crinoid in the Pooleville Member, and about 65 specimens have been examined. The crown heights of the crinoids range from about 9 to 26 mm. Although most individuals are concentrated in the small sizes, the size distribution is continuous enough to demonstrate that all crinoids are conspecific. Most examples of *A. ramifer* are known from two zones at the Culley Creek locality, one 29 to 32 feet and the other 37 to 44 feet below the base of the Viola. The two suites of crinoids differ to some extent, and animals from the lower zone have longer arms and non-nodose brachials in the *E* ray in contrast to the shorter arms and somewhat nodose or smooth brachials in the *E* ray of specimens from the upper zone. Preliminary statistical texts indicate that there is no significant statistical difference between the two groups of crinoids, and all individuals are considered as a single species. About four specimens and numerous fragments were collected from the Rudd Quarry. Two of these animals represent typical smaller individuals like those from the Culley Creek locality, and there is no doubt that these are all conspecific (see pl. 3; compare fig. 4 with figs. 5-9). The two largest crowns were also obtained from the Rudd Quarry (pl. 3, fig. 1; pl. 4, figs. 9-11). A moderate gap in size is observed between these two large specimens and the smaller individuals in which the crown heights equal 26 mm for the largest crinoids and 9.0 to 19 mm for the smaller animals. Despite the discontinuity in size, the larger animals are definitely considered conspecific. Extrapolation of the growth patterns in the smaller specimens would produce the larger ones; in other words, the largest crinoids are simply scaled-up versions of the smaller crowns. Detailed studies of ontogeny will be presented in a subsequent paper.

The most striking characteristics of *A. ramifer* consist of the coarsely pitted surface and simple arm structure. The Bromide species most closely resembles *A. drummuckensis* Ramsbottom (1961, p. 9, pl. 2, figs. 9, 10; see Moore, 1962, p. 24, pl. 1, figs. 5a, b, text-figs. 14-1, 2) and *A. forrestonensis* Kolata (1975, p. 25, pl. 3, fig. 1, text-fig. 7). Both of these taxa possess more slender cups and crowns than *A. ramifer*.

In addition, the pits of *A. drummuckensis* are finer than in this species. Unbranched *E*-ray arms are found in *A. drummuckensis* and *A. forrestonensis*. This is also true for most complete crowns of *A. ramifer*, but some specimens of the Bromide species have *E*-ray arms that branch isotomously on primibrach 8 to 12 or 15. *A. simplex* (Springer) (1926, p. 107, pl. 28, figs. 8, 8a) also exhibits a simple pattern of arm branching. However, the smooth plates and very high brachials contrast with the pitted surfaces and shorter brachials of *A. ramifer*.

*A. latus* Brower and Veinus (1974, p. 25, pl. 3, fig. 1) is characterized by a much more massive crown in conjunction with brachials that are much wider relative to height. The *E*-ray arm of *A. latus* shows at least two isotomous branches near the dorsal cup. *A. thraivensis* Ramsbottom (1961, p. 8, pl. 2, figs. 1-8, text-fig. 7; Moore, 1962, p. 22, pl. 1, figs. 4a-d, text-figs. 12, 13) bears an *E*-ray arm that bifurcates several times. Also the crown of *A. thraivensis* is more slender than in *A. ramifer*.

Brower (1966, p. 621-623, table 1) enumerated variation of arm-branching pattern in about 40 specimens. Table 2 presents means, standard deviations, and other data, based on 65 individuals. Not all series of brachials can be counted in most individuals, which causes considerable changes in the numbers of specimens for the different parts of the arms. Table 3 lists the matrix of correlation coefficients between the means, standard deviations, and positions of the brachial series. The brachial positions are in sequence so that the numbers increase from proximal to distal; for example, the brachial series containing the primaxils and secundaxils are assigned values of 1.0 and 2.0, respectively. The main themes follow.

1. *A. ramifer* constitutes a protean form in which the coefficients of variation range from 12.7 to 61.8 percent. This form is much more variable than *Cremaerinus* and *Paracremaerinus*, in which the arm structure is largely stabilized.

2. The correlation matrix demonstrates that the average number of plates in a brachial series, and variation as shown by the standard deviations, increase from proximal to distal parts of the arms. All corre-

lations are positive, and all are significantly greater than nil at the 5.0-percent risk level. Thus the average number of brachials and the variation thereof are greater than in the primaxils, and so on. This pattern of distally increasing number of plates and variation in number of plates characterizes the arms of many Paleozoic crinoids, and this may be important in the genetic programming of arm branching (e.g., systematic descriptions in Brower, 1973). Although not clearly displayed in table 2, the *B* ray is more variable than the *A* and *D* rays in most specimens.

Some of the cup plates may be wholly or partially fused in *A. ramifer* and *A. thraivensis*. This process most commonly affects the basals, and in some cases no sutures can be found. Some *B*- and *C*-ray inferradials are partly fused with the overlying superradials; this could indicate some connection between *Anulocrinus* and *Paracremaerinus*. The *E*-ray inferradial may be partially joined to the adjacent *A*- and *D*-ray radials. Incipient fusion of plates is unknown in the arms of anulocrinids.

A reasonable range of sizes allows some study of ontogeny. The crowns span a height interval of about 9.0 to 26 mm. The total number of plates in, and length of, the arms can be estimated approximately. The most striking growth change is increase in number of brachials and length of the arms. Young crowns bear about 80 brachials, but about 300 plates are present in the largest. All new plates form at the distal tips of the arms, and new plates are not intercalated between previously developed ones. The length of the arms ranges from about 40 to almost 300 mm. Augmentation of length is due to the interaction between two processes: first, the addition of new plates (i.e., the plate-development sequence), and second, calcite accretion onto old plates.

*Specific name.*—*Ramifer*, referring to the ramules present in this species and many other calceocrinids.

*Holotype.*—NMNH 156261 (see Brower, 1966, pl. 75, fig. 12, text-fig. 1c for illustrations).

*Paratypes.*—OU 8450-8454; NMNH 156259, 156260, 156262, 156263, 221563-221565.

*Occurrence.*—Upper part of Pooleville

*Anulocrinus ramifer*TABLE 2.—STATISTICS FOR DIFFERENT SERIES OF BRACHIALS IN *Anulocrinus ramifer*

Ray	Plate series	Average number of plates	Maximum number of plates	Minimum number of plates	Standard deviation	Coefficient of variation [(std. dev.)/(mean)]	Number of Specimens
A	Primaxils	2.02	3	1	0.280	13.8	39
A	Secundaxils	2.47	4	2	0.612	24.7	19
A	Alphabrachs in primaxil arm	3.16	4	2	0.554	17.5	25
A	Betabrachs in primaxil arm	5.60	9	3	2.41	43.0	5
A	Alphabrachs in secundaxil arm	4.00	5	2	1.16	28.9	7
D	Primaxils	2.00	3	1	0.254	12.7	32
D	Secundaxils	2.17	7	1	1.34	61.8	18
D	Alphabrachs in primaxil arm	2.42	6	1	0.974	40.3	24
D	Betabrachs in primaxil arm	3.46	5	2	0.820	23.7	11
D	Alphabrachs in secundaxil arm	2.40	3	2	0.516	21.5	10
B	Primaxils	2.17	4	2	0.577	26.6	12
B	Secundaxils	2.14	3	2	0.378	17.6	7
B	Alphabrachs in primaxil arm	2.11	3	1	0.601	28.5	9
B	Alphabrachs in secundaxil arm	3.5	4	3	0.701	20.2	2



TABLE 3.—MATRIX OF CORRELATION COEFFICIENTS FOR BRACHIALS IN *Anulocrinus ramifer*

	Position of brachial series	Average number of plates in brachial series	Standard deviation for number of plates in brachial series
Position of brachial series	1.0	0.76	0.60
Average number of plates in brachial series	0.76	1.0	0.82
Standard deviation for number of plates in brachial series	0.60	0.82	1.0

Member of Bromide Formation; Rudd Quarry locality (lower quarry or south quarry), 8 feet below Viola Limestone, NW $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$  sec. 22, T. 5 S., R. 1 E., Carter County; Culley Creek locality (formerly called Spring Creek locality), 29 to 32 feet and 37 to 44 feet below Viola Limestone, near center of NW $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 26, T. 5 S., R. 1 E., Carter County; all from the Criner Hills of southern Oklahoma.

Genus *Calceocrinus* Hall, 1852

*Calceocrinus longifrons*, new species

Pl. 3, figs. 2, 3; pl. 4, figs. 1-8

*Calceocrinus?* n. sp. BROWER, 1966, p. 620, pl. 75, fig. 24, text-figs. 1j, k.

*Diagnosis.*—A species of *Calceocrinus* with pitted plates. Dorsal cup slender and elongate, much higher than wide. Arms slender with two series of main axils. *E*-ray arm appears unbranched.

*Description.*—Crown small with slender arms and elongate cup. Calyx plates have numerous small pits. Proximal brachials roughly equidimensional; distal plates higher than wide; axillaries pentagonal, not strongly nodose.

Basal series triangular, consisting of four plates in most specimens; basals wholly or partially fused in some individuals. Stem facet round, only shared by *AB* and *BC* interray basals in most specimens.

*E*-ray inferradial very elongate, much higher than wide, becoming wider proximally; inferradial joins superradial in all but 1 or possibly 2 specimens. Superradial trapezoidal, expanding distally. *E*-ray arm appears unbranched, consisting of large primibrachs; four primibrachs present in largest specimen definitely assigned to this species.

*A*- and *D*-ray radials undivided, largest plates in dorsal cup, much higher than wide, curving sharply around on *E*-ray side of cup. Two main axil series present, each consisting of two plates. Axil arms not fully known. Primaxil arm branches once on alphabrach 4 or 5. Secundaxil arm and omega ramule only represented by about 4 or 5 unbranched plates.

Articular surfaces of brachials smooth; food grooves rounded, only moderately deep; covering plates not known.

*B*- and *C*-ray inferradials generally small triangular plates located between basals and single plate representing fused

*B-* and *C*-ray superradials; inferradials not in lateral contact in most specimens but may be joined in one crinoid. *B-* and *C*-ray superradial plate generally pentagonal, much wider than high. Anal-*X* plate large, quadrangular, wider than high, not strongly convex. Anal tube probably short, only represented by several roughly quadrangular plates that taper distally.

Complete column known in one specimen tentatively referred to this form; column short, much shorter than crown. Columnals round, much wider than high, smooth or faintly nodose. Rooting device consists of small lump of calcite with distally radiating rootlets; rootlets slender and unbranched; short zone of small irregular plates where stem joins holdfast.

*Remarks.*—Several crinoids of this species were figured by Brower (1966, p. 620, pl. 75, fig. 24, text-figs. 1j, k) as *Calceocrinus?* n. sp. Since then, more material has been found and developed, and at present this form is represented by about 15 specimens. Most individuals comprise small and slender cups or partial crowns in which the cup heights range from about 3.0 to 6.0 mm (pl. 3, figs. 2, 3; pl. 4, figs. 1-8). One larger specimen with a cup height of 8.0 mm is tentatively assigned here (figured by Brower, 1966, pl. 75, fig. 24, text-fig. 1k). This crinoid is more robust than typical specimens of *C. longifrons*, and the arms are not well preserved, which makes the identification questionable. This individual is mainly of interest because a complete stem and root are present.

*C. longifrons* is easily distinguished from most species of *Calceocrinus* by the presence of a long, slender cup that is high relative to width, slender arms, and pitted plate surfaces. The following calceocrinids are characterized by more massive crowns and cups with smooth or pustulose plates: the Silurian forms *C. pustulosus* Johnson (Brower, 1966, p. 627, pl. 75, fig. 13, text-fig. 2c), *C. humilis* Strimple (1963, p. 58, pl. 1, figs. 12-14, text-figs. 14a-d, 15d-f), *C. anglicus* (Springer) (1926, p. 113, pl. 29, figs. 6, 6a, text-fig. 3c), *C. ontario* (Springer) (1919, p. 127, fig. 6; see 1926, p. 113, text-fig. 3b), *C. minor* (Springer) (1926, p. 112, pl. 29, figs. 5, 5a, b), *C. indianensis* S. A. Miller (see Springer, 1926, p. 114, pl. 29, figs. 4, 4a, b), and *C. chrysalis* Hall (see

Springer, 1926, p. 112, pl. 29, figs. 1-3); and the Ordovician crinoid *C. constrictus* Brower (1966, p. 623, pl. 75, figs. 21, 26, 27, text-figs. 2a, e; 1973, p. 451, pl. 78, figs. 2, 3).

Like the Bromide form, the Trenton *C. multibifurcatus* Brower (1966, p. 624, pl. 75, figs. 17, 18, text-figs. 2d, h) possesses a pitted calyx, but the pits are finer than those of *C. longifrons*. Also, a much heavier cup and an extensively branched *E*-ray arm are found in the Trenton form.

*C. longifrons* is most closely allied to *C. barrandei* Walcott (1883, p. 212, pl. 17, figs. 1, 2) of the Trenton, and similar slender cups are seen in both taxa. However *C. barrandei* differs in having granulose plates and 4 series of main axils in contrast to the pitted plates and 2 main-axil series of the Bromide form.

*Specific name.*—*Longifrons*, in allusion to the long and slender dorsal cup.

*Holotype.*—NMNH 221567.

*Paratypes.*—NMNH 156267, 221568-221570; OU 8455-8457.

*Figured specimen.*—NMNH 156266.

*Occurrence.*—Pooleville Member of Bromide Formation; Culley Creek locality (formerly called Spring Creek locality), 29 to 32 feet below Viola Limestone, near center of NW $\frac{1}{4}$ NW $\frac{1}{4}$  sec. 26, T. 5 S., R. 1 E., Carter County, Criner Hills, southern Oklahoma.

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**PLATES**

**Plate 1**

*Paracremacrinus laticardinalis*, new genus and species.

- Fig. 1. Paratype, OU 8460; A-ray view of rather poorly preserved crown; note ramules of *E* ray, which are not generally visible; ×2. Amis Ranch locality.
- Figs. 2, 3. Paratype, OU 8459; *D*-ray and *A*- and *B*-ray views of crown; observe ramules, which are not fully hidden inside of arms; ×2. Daube Ranch locality.
- Figs. 4-6. Holotype, OU 8458; *B*- and *C*-ray, *A*-ray, and *E*-ray views of largest known crown; note widely expanded hinge; ×2. Daube Ranch locality.



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**Plate 2**

*Paracremacrinus laticardinalis*, new genus and species.

- Fig. 1. Paratype, UT 1121TX 24; *E*-ray view of one of smallest specimens;  $\times 4$ . Daube Ranch locality.
- Fig. 2. Paratype, UT 1121TX 25; *E*-ray view of small specimen; note relatively narrow hinge;  $\times 3$ . Daube Ranch locality.
- Fig. 3. Paratype, UT 1121TX 26; *A*- and *E*-ray view of small crinoid;  $\times 2.5$ . Daube Ranch locality.
- Fig. 4. Paratype, OU 8465; *E*-ray view of small partial crown;  $\times 3$ . Lick Creek locality.
- Fig. 5. Paratype, OU 8464; *E*-ray view of intermediate-sized individual;  $\times 2$ . Daube Ranch locality.
- Fig. 6. Paratype, OU 8463; *E*-ray view of mature specimen with widely expanded hinge;  $\times 2$ . Lick Creek locality.
- Figs. 7-9. Paratype, OU 8462; *B*- and *C*-ray, *A*-ray, and *E*-ray views of partial crown; *B* ray is abnormal in that only 1 primaxil is present rather than the 2 plates of normal crinoids;  $\times 2$ . Lick Creek locality.
- Fig. 10. Paratype, OU 8461; *D*-ray view of crown with complete stem and root; observe that stem is shorter than crown; bend in stem near attachment device suggests that distal part of stem and root was buried in sediment while proximal portion of stem ran along substrate; crown is in closed position;  $\times 2$ . Daube Ranch locality.



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**Plate 3**

Figs. 1, 4-9. *Anulocrinus ramifer*, new species.

- Fig. 1. Paratype, OU 8454; *D*- and *E*-ray view of large adult;  $\times 3$ . Rudd Quarry locality.  
Fig. 4. Paratype, OU 8451; *B*- and *C*-ray view of small crown; hinge is open, and arms are spread with closed covering plates;  $\times 5$ . Rudd Quarry locality.  
Fig. 5. Paratype, NMNH 221564; *D*- and *E*-ray view of smallest crown; note short arms consisting of few plates;  $\times 6$ . Culley Creek locality.  
Fig. 6. Paratype, OU 8452; *D*- and *E*-ray view of small crown;  $\times 4$ . Culley Creek locality.  
Fig. 7. Paratype, NMNH 221563; *A*-ray view of slender juvenile;  $\times 4$ . Culley Creek locality.  
Figs. 8, 9. Paratype, OU 8453; *A*- and *B*-ray and *D*-ray views of relatively stout young specimen;  $\times 5$ . Culley Creek locality.

Figs. 2, 3. *Calceocrinus longifrons*, new species. Paratype, NMNH 221570; *E*-ray and *C*-ray views of small crown;  $\times 7$ . Culley Creek locality.



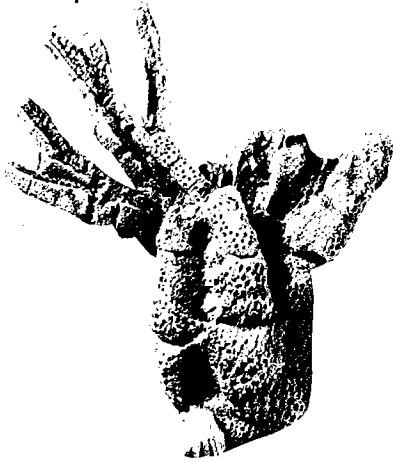
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**Plate 4**

Figs. 1-8. *Calceocrinus longifrons*, new species.

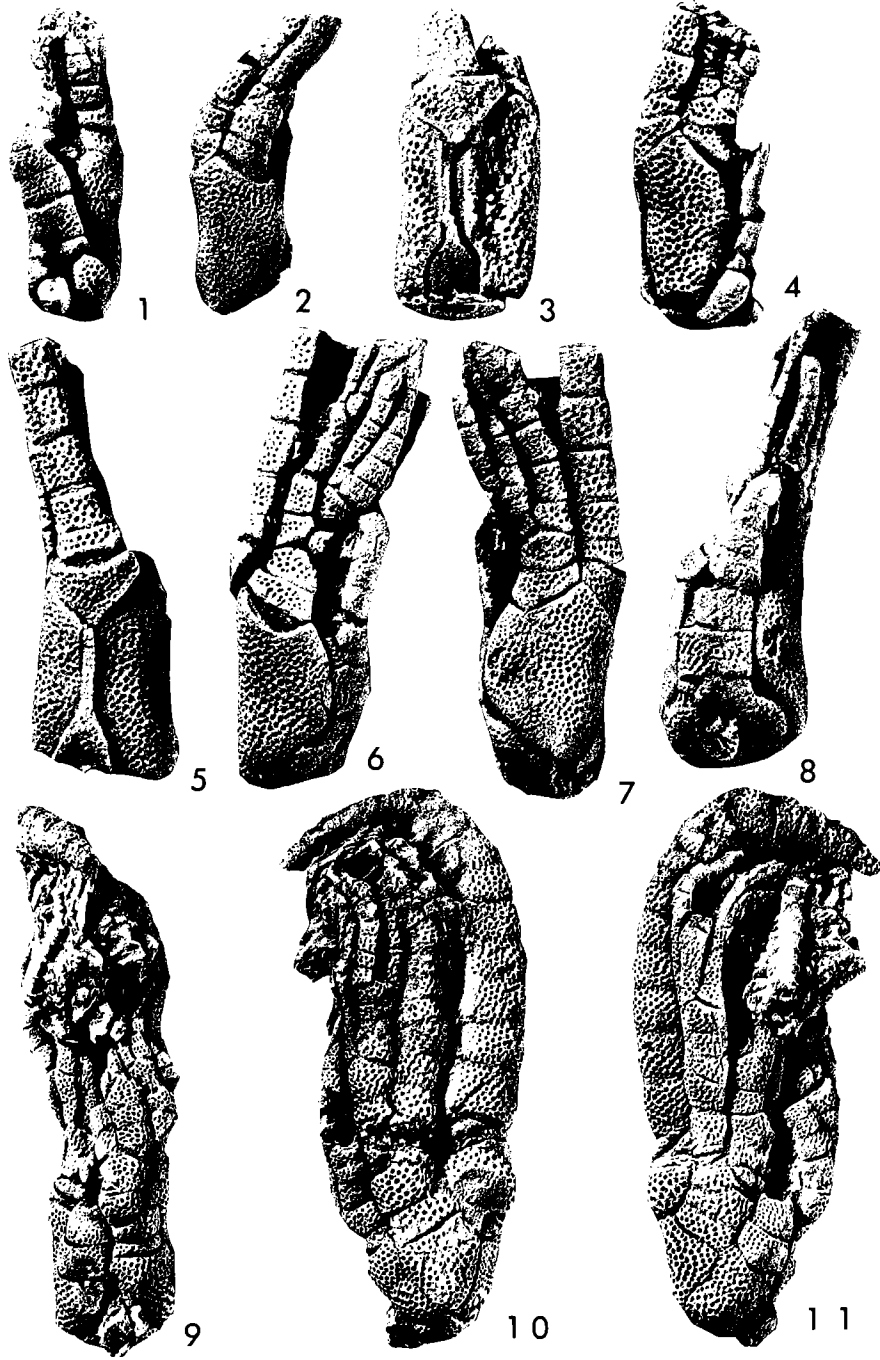
Figs. 1, 4. Paratype, NMNH 21568; *C*-ray and *D*-ray views of small crinoid with well-preserved posterior; ×6. Culley Creek locality.

Fig. 2. Paratype, NMNH 221570; *D*-ray view of small crown; ×6. Spring Creek (Culley Creek) locality.

Fig. 3. Paratype, OU 8455; *E*-ray view of small specimen; note nature of *E*-ray inferradial; ×7. Culley Creek locality.

Figs. 5-8. Holotype, NMNH 221567; *E*-ray, *D*-ray, *A*-ray, and *C*-ray views of small crown; observe narrow contact between basals and *C*-ray superradial; ×6. Culley Creek locality.

Figs. 9-11. *Anulocrinus ramifer*, new species. Paratype, OU 8450; *B*- and *C*-ray, *A*-ray, and *D*-ray views of largest known crown; observe long arms, composed of many brachials; ×3. Rudd Quarry locality.



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