UNUSUAL FORMS OF FOSSIL CRINOIDS

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INTRODUCTION

It was originally my intention when preparing the monograph on the Crinoidea Flexibilia to follow it up with a similar systematic treatise on the Inadunata. But the time and labor consumed in bringing out such works proved to be too great, and I have been compelled to relinquish the project for the last-mentioned treatise. Many preparatory studies were made, however, with such a work in view, some of which are embraced in the present paper, containing the results of researches extending over many years, which I have long desired to publish, but which have been delayed by the pressure of other matters. The material used is chiefly from my own collection, now in the United States National Museum, much of it accumulated with special reference to these researches. Most of the drawings have been made by Mr. Kenneth M. Chapman, of Santa Fe, New Mexico, and some by Miss Francesca Wieser, of the National Museum. I am much indebted to Dr. R. S. Bassler and Dr. C. E. Resser, of the National Museum, for their assistance in making the photographs upon which the drawings are based.

THE USUAL STRUCTURE OF CRINOIDS

The generalized picture of a crinoid, as seen in the forms by which the class is most commonly known, is that of a marine organism having a calyx, cup, or theca composed of calcareous plates definitely arranged, inclosing a cavity which contains the visceral organs; attached to the sea bottom or other objects, temporarily or permanently, by a columnar stem formed by a series of centrally perforated segments; and fringed at the opposite end by a ring of movable, food-gathering appendages called arms; these are likewise built up of calcareous segments, but instead of being pierced by a central opening for a tubular canal, as in the stem, they are notched at one side, forming a groove along which the microscopic food is carried by means of currents produced by minute cilia to the oral center, or mouth. The arms when gathering food are stretched upward or outward, but may be folded together when not so employed in such a manner that the vital organs and soft parts are protected by an outer envelope of hard calcareous material. The excrement is discharged through an orifice, either directly piercing the tegmen, or roof, or at the end or side of a projecting tube, or exceptionally through the side wall of the cup.

The plates of which the calyx is composed are arranged usually according to a quinqueradiate plan, most plainly developed on the lower side to which the stem is attached, from which the radiation extends upward and continues into the arms. This is called the dorsal side, in contradistinction to that next to which the arms are located, which is the ventral side or tegmen; and the part of the calyx below the origin of the arms is called the dorsal cup, or simply the cup, which incloses or supports the visceral organs.

This cup in the usual crinoid is made up of a base, consisting either of a single ring of five, four, three, or two plates (or some of these coalesced into a single undivided disk), called basals; or of this and another alternating ring below it of five or three plates (also sometimes fused into one), called infrabasals; and following the basal ring another set of five alternating plates, called radials, with sometimes a ring of interradials in line with them.

The two rings of cup plates—basals and radials—are the fundamental elements of the adult crinoid structure. They are found throughout all the major divisions of the class, and of the blastoids also. In the typical crinoid these two elements are symmetrically arranged in alternating contact with each other, and the radials are symmetric among themselves. This is the plan in the great majority of fossil, and practically all the existing, crinoids. But to this generalized type there are numerous exceptions.

The general tendency of the crinoids as a class, starting in the earliest Paleozoic with the asymmetric form which they inherited from cystidean ancestors, was toward that of complete pentamerous symmetry. This was attained in the Mesozoic and Recent crinoids generally, and in a few genera of the Paleozoic. In most of the Paleozoic crinoids an incomplete pentamerous symmetry was reached, modified by the bilaterial symmetry due to the presence of anal structures. The course of this development was by no means one of continual progress. It was marked by numerous recessions and sudden changes.

Two of the major divisions of the crinoids, Camerata and Flexibilia, and for the most part the third, Inadunata, culminated and were extinguished before the end of the Paleozoic. During this vast stretch of time many peculiar modifications of the type as we chiefly know it occurred, the causes of which are unknown, but which serve as examples of the infinite variety with which the processes of nature go on. Many of these are already well known, and some others it is the purpose of this paper to illustrate. No general discussion of crinoid morphology is here attempted. For that reference should be had to the works of Bather in part 3 of the Lankester Zoology; of Austin H. Clark on the Existing Crinoids; of Wachsmuth and Springer on the Crinoidea Camerata; of myself on the Crinoidea Flexibilia; and to various papers by Jaekel.

I am simply presenting a number of facts, more or less unrelated, bearing upon some of the unusual features and changes above alluded to, by which the general progress of the crinoids in geological time was characterized; together with discussion of some remarkable parallel modifications which I am now able to illustrate more completely than was possible heretofore.

THE COILED BILATERAL STEM

While the possession of a stem is one of the characters by which the crinoids as a class are best known—so much so that a large part of the early literature treating of them was devoted mainly to discussion of the isolated segments of which it is composed—there was in some instances a remarkable tendency to get rid of it. This appendage probably existed in the larval stage of all crinoids, but in by far the greater part of the existing forms, the comatulids, it is cast off at approaching maturity, and the adult crinoid becomes a free floater. In some, the pentacrinites, it attained a great length; and in some (thought to be due to living on reefs in shallow water) the stem is very short, or even disappears, fixation being accomplished through direct attachment by the fused base.

In most of the Paleozoic genera the stem was present, sometimes attached or anchored by remarkable specialized structures (*Scyphocrinus*, *Ancyrocrinus*, etc.)[1]; in many cases only resting in the soft ooze of the sea bottom by finely pointed terminals, and often not permanently fixed.[2]

The great Paleozoic divisions, Camerata and Flexibilia, and the chiefly Paleozoic Inadunata, had stems with but few exceptions, such as *Edriocrinus* in which the base was fused and attached directly to other objects or became rounded and free from attachment, and *Agassizocrinus* in which a free floating stage in some of its species was also attained. The same thing is true of the Mesozoic crinoids.

[1] Springer, On the crinoid genus Scyphocrinus, Smiths. Misc. Coll. Publication 2440, 1917, pp. 9–12.

[2] Dr. Edwin Kirk's instructive paper on Eleutherozoic Pelmatozoa, Proc. U. S. Nat. Mus., vol. 41, 1911, pp. 1–137.

A special form of stem development which I wish to illustrate is that in which the usually cylindrical or pentagonal straight stem loses its characteristic shape, becomes coiled, and takes on a bilateral symmetry, by which for the greater part of its length it is flattened or concave at the inner side, with the columnals elliptic or crescentic in cross section; and the cirri, instead of occurring in whorls around the column, are borne only in two rows at or near the margins of the flattened or concave side, or sometimes at the back. This structure is correlated—either as a cause or an effect—with a tendency of the crown to bend back upon the stem, and of the stem to coil around it in the opposite direction in such a way that the crown may be tightly enclosed within the coil and completely enveloped by the cirri. The part of the stem proximal to the calyx is circular in section, much reduced in diameter, relatively short as a rule, but variable in length; and it bears no cirri. The reversed curve is similar to that of a swan's neck, and for convenience the term "neck" may be used for it in the discussions.

This character was evidently protective in origin, as the crown is often very small in comparison with the stem; and in some forms, where the cirri are short and closely packed, the crown is so surrounded by the stem structures that it can rarely be seen in the fossils; while in others, in which the cirri are more scattered but strong and branching, the neck upon which the crown was borne is long, slender, and exceedingly brittle, not tightly rolled, but evidently loosely enveloped in a fringe formed by the strong cirri. Here it must have been very sensitive to disturbance, for in the fossil the stem is almost invariably broken off at the slender neck. In those forms in which the stem was tightly coiled it could be uncoiled and the crown exposed.

This type of stem is found in otherwise unrelated forms from the Silurian to the latest member of the Lower Carboniferous. It occurs irregularly, and so far as yet known, without continuity, and without any definite or exclusive correlation with other characters. After appearing in several Inadunate species in the Niagaran of America, and the Wenlockian of England and Sweden, closely followed by three in the Lower Devonian and one of uncertain relations in the Middle Devonian, the coiled stem structure reappears after a considerable interval in the Burlington limestone of the Lower Carboniferous, but in a different suborder of the crinoids, the Camerata, in one family of which it continues to the end in the upper part of the Chester. Generic names have been given based upon these occurrences; but in the Silurian forms, owing to the closely inrolled condition in which the stems are usually found, the crown is very seldom seen in a state from which the elements of the calyx can be ascertained sufficiently for a proper diagnosis. While there are some well marked differences in the details of the columnals and cirri, which furnish excellent specific characters, it is not practicable to correlate them with other characters to form larger groups; and as to the stem itself, its superficial aspect in some of the Silurian forms closely approximates that in some from the Lower Carboniferous.

So far as can be ascertained, the crown in the Silurian and Lower Devonian forms is of irregular composition, more or less deformed—induced perhaps by the restricted mode of life of the crinoid—and of Heterocrinid type. In some of the Carboniferous species the crown, while otherwise regular, is somewhat deformed by pressure.

It would appear probable, therefore, that this peculiar modification of stem structure is a secondary character, arising from some special condition of life, which may be repeated independently without materially influencing the primary characters upon which genera and families are founded, and therefore of minor taxonomic importance as compared with the great alteration in the superficial appearance of the organism which results from it.

The Silurian form of the crinoid with coiled stem was first described by Hall in 1852 [3] under the name *Myelodactylus*, based upon fragmentary specimens from the Rochester shale which he took to be parts of arms. In 1873 Salter [4] described a British species showing the true relation of the crown to the stem, for which he proposed the name *Herpetocrinus*. Angelin in the Iconographia, 1878, described three species from Gotland under Hall's name; and in 1893 Bather, in the Crinoidea of Gotland (p. 36 and following), revised the whole subject, redescribing Salter's species, rejecting all of Angelin's, and adding three new ones of his own. He gave a full summary of all the literature, together with a minute account of the morphology of the stem, with elaborate illustrations which for beauty of execution and fulness of detail leave nothing to be desired. He adopted Salter's name *Herpetocrinus*, rejecting Hall's *Myelodactylus* because he thought it misleading and based upon incorrect interpretation of the structure. In 1895, in an article in the American Geologist (vol. 16, p. 213) Doctor Bather again discussed *Herpetocrinus* in connection with *Brachiocrinus*, another genus of Hall, which he rightly considered to be of the same type, but which he also rejected because, as in his first genus, Hall had mistaken his specimens for arm fragments instead of stem.

Hall's description of *Myelodactylus*, however erroneously conceived as to the nature of the specimens, was accompanied by good figures, by which not only the generic type, but also the two species

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[3] Paleontology of New York, vol. 2, p. 191.

[4] Catalog fossils in the Geological Museum, Cambridge, p. 118.

which he described under it, may be readily recognized. Therefore his name will have to stand, under the rules of nomenclature as now interpreted. Inasmuch as in the type species of *Herpetocrinus*, *H. fletcheri*, as redescribed by Bather, the composition of the calyx has been definitely shown to be essentially that of the Heterocrinidae, but with only four rays, while in at least one of the American species it is now known to be somewhat different, it might be suggested that Salter's name should be retained, at least for that species. But from the little we know of the crown it is probable that the Silurian species in America are similarly deformed, and so the separation of genera on this ground is problematic. Therefore I think it the safe course, with our present knowledge, to treat all the species under the name first published.

Six American species have been described: *M. convolutus* Hall and *M. brachiatus* Hall, from the Rochester shale; *M. gorbyi* S. A. Miller, perhaps from the Waldron; *M. bridgeportensis* S. A. Miller, from the Racine dolomite; *M.* (*Eomyelodactylus*) *rotundatus* Foerste, from the Brassfield; *M.* (*Brachiocrinus*) *nodosarius* Hall, from the Helderbergian. To these will be added two new species from the Niagaran; also one from the Keyser, and one from the Linden beds of the Lower Devonian. Furthermore, I have recognized from the American rocks of Niagaran age one of Doctor Bather's Gotland species of the equivalent Wenlockian, which also occurs in England. From data now available as to the occurrence of these several species, it may be said that the Silurian type ranges from the early Niagaran through most of its principal formations, and continues into the Lower Devonian. It has not thus far been recognized from the Middle or Upper Devonian, although a remarkable modification of it is now known from the former horizon and will be herein described, which is perhaps more nearly related to the Lower Carboniferous phase of the coiled stem type.

Genus MYELODACTYLUS Hall

Plates 1–5

Myelodactylus Hall, Pal. New York, vol. 2, 1852, p. 191.
Herpetrocrinus Bather, Crinoidea of Gotland, 1893, p. 36.
Silurian to Devonian.

Hall's generic diagnosis, based on the idea that the coiled stem was an arm, is of no service, but the form can be recognized from the two species which he figured and described. With our present knowledge its characters may be stated as follows:

An Inadunate crinoid with coiled stem, which more or less completely envelops the crown. Stem in proximal region evolute, circular in section, composed of very thin uniform ossicles; in middle and distal regions involute, enlarging, sometimes diminishing again, bilaterally symmetric, elliptic or subcrescentric in section; with two rows of jointed cirri along the margins or the back of the bilateral part varying in arrangement, which may converge over the closely coiled noncirriferous proximal portion like spokes of a wheel. Crown of the type of the Heterocrinidae; without compound radials, and rather resembling *Iocrinus* than *Heterocrinus;* rays irregular, more or less unequal in size, four or five in number; arms dichotomous or slightly heterotomous. (Partly adapted from Bather under *Herpetocrinus.*)

As observed by Bather,[5] the chief diagnostic characters within the genus are furnished by the stem and its appendages. The crown is rarely seen, and owing to pressure resulting from its inrolled habitus the calyx did not have the freedom to develop in the usual way, and is therefore more or less deformed.

Except in the Devonian species, the crown is usually very slender and elongate, so that it can lie along the grooved side of the stem, between the two rows of cirri, without producing any swelling or bulging to indicate its presence. In that condition it is impossible to see anything beyond the general outline of the crown, and we are therefore unable to analyze its composition. In the two cases in which the full contour of the calyx has been seen, one a Silurian and the other a Devonian species, the former has four rays and the latter five. If this difference were known to be constant, it might furnish ground for a subdivision of the genus. But in the presence of so remarkable a specialization the crown was doubtless in a plastic condition, and with the evidence we have, or are likely to obtain, there seems to be no other course than to treat these variations as secondary occurrences, incident to the cramped condition in which the crown habitually grew, which necessarily produced more or less suppression or deformation of the parts subject to pressure.

On the other hand, the stem was a seat of activity unusual in the stalked crinoids, and the cirri took on special functions analogous to those of the comatulids—that is to say, they became active, perhaps prehensile, organs, free to develop according to their conditions; and their modifications, as in the comatulids, furnish important characters for the discrimination of species. Bather suggests[5] (p. 46) that these probably broke off any rooted attachment they may have formed, and that they clung to corals or other objects by their cirri—a mode of life that would furnish the stimulus for numerous variations. This suggestion is reinforced by my observations, showing positively that in some species the stem was free from any attachment whatever.

[5] Crinoidea of Gotland, p. 45.

Eight or ten different plans of structure and arrangement of the cirri and columnals, some of them widely different, are seen in the material thus far discovered, and in those cases where we are able to test them in considerable numbers of specimens it is found that they hold good with remarkable constancy.

The Silurian species of Europe and American fall into two groups which are somewhat parallel; one in which the cirri, with many variations, are borne upon the margins formed by the two ends of the crescentic or elliptic columnals, which is the most frequent condition, and the other in which they spring more or less from the back of the stem.

As usually found, we have for comparison only the coiled proximal or middle portion of the stem, the longer uncoiled or broadly curved portion being only exceptionally recovered.

If we trace the course of the stem from the point where the slender circular portion proximal to the calyx enlarges and changes to a bilateral form with elliptic section, and the reverse curve begins (regions 1 and 2 of Bather's description), we find that the involute curve usually proceeds for about one to one and a half coils, and then the stem does one of two things; either 1, tapers off rapidly to a narrow pointed end which clings rather closely to the preceding coil; or 2, deviates from this course and goes off in an increasingly wide curve (which sometimes becomes almost straight) for a considerable distance, without any marked diminution in width, probably to a terminal of attachment. The first we call a "close coil," which in some species is all there is; and the second a "loose coil": and when in the discussion of species measurement is given of the diameter of coil, it means the same thing in both types, namely, the primary coil before the deviation into a broader curve. We can not fix a very accurate limit for this distinction, but it serves a convenient purpose in description. The "close coil" represents the unattached form; the "loose coil" the form which may have been temporarily or permanently attached by the stem to the sea bottom or to other objects.

Genotype.—Myelodactylus convolutus Hall.

Distribution.—Silurian to Lower Devonian; North America, England, Sweden.

MYELODACTYLUS CONVOLUTUS Hall

Plate 1, figs. 1–8

Myelodactylus convolutus HALL, Pal. New York, vol. 2, 1852, p. 192, pl. 45, figs. 5*a*, 6, 6*a–h*.

Herpetocrinus convolutus, BATHER, Crinoidea of Gotland, 1893, p. 48, pl. 2, figs. 50–53.

Coil close in proximal region; open and broadly convolute distalwards. Columnals very short, quadrangular and uniform. Cirri numerous, flat, and closely apposed; regularly paired, one at each side of successive columnals along greater part of stem.

This is one of two thoroughly distinct and well marked forms, both described by Hall when proposing the genus, and illustrated by good figures. It is the most widely distributed species, and the farthest ranging. Bather has described a specimen of it from the Wenlockian of Gotland; and in America specimens which can not be distinguished from it in the condition as found occur in nearly all the formations from the later Clinton through the greater part of the Niagaran. Its range may thus be said to be almost coextensive with the principal Silurian formations of Europe and America.

Hall's type of the species was from the Rochester shale at Lockport, New York. It is rather rare at that locality, only four specimens having been recognized in the abundant material I have from the shales, and one from the underlying limestone of late Clinton age. It has since been found to occur (or two forms indistinguishable from it with our present knowledge) in the Brassfield formation of the upper Clinton in Ohio; the Laurel limestone of Indiana; the Racine dolomite of the Chicago area; and in a closely allied species in the Brownsport limestone of the later Niagaran.

I am now able to illustrate the species more fully than was done originally, showing the extent of the column distally, the distribution of the cirri along the greater part of its length, and some of the slender, circular part leading to the calyx, of which we have the crown partly visible in one specimen, but not enough to determine its structure. As shown by these specimens, the stem beyond the close coil is quite long, and the cirri very narrow, flat and closely packed, so that as seen from either side each columnal bears a cirrus. In the large specimen (pl. 1, fig. 1) the stem extends for 12 cm. beyond the close coil, in which it is 4 mm. wide, maintaining this width to the incomplete distal end. In the St. Paul specimen (pl. 1, fig. 7) the stem is broken off where it was beginning to open a short distance beyond the close coil, and it is of the full width of 4 mm., which is probably maintained for a distance of at least 7 cm. more. There are five other specimens from the St. Paul locality, more or less fragmentary, and in all but one of them the *convolutus* plan of cirri is constant.

The occurrence of this species in the Laurel limestone at St. Paul, Indiana, is an excellent illustration of Foerste's observation[6] that "students of the crinoidea are aware of the frequency with which species occurring at St. Paul find their nearest relatives in the Waldron, Brownsport, and Racine, many of them showing Gotlandian affinities."

[6] Ohio Journ. Sci., vol. 21, Dec. 1920, p. 64.

I also give for comparison (pl. 1) some figures of the type species of *Herpetocrinus*, *H. fletcheri*, from the Wenlock limestone at Dudley, England, including my own specimen which shows the crown to consist of 4 rays[7]; also Salter's type specimen in the Geological Museum at Cambridge, England, with the crown exposed on one side. In these, and in two other specimens in my collection, the bead-like form of the slender cirri, which is the chief distinctive character separating it from the closely related American species, is thoroughly shown. There is some irregularity in their distribution, as is said by Bather[8]; and I find more alternation in successive columnals than his description indicates. *H. fletcheri* occurs both in England and Gotland, and for a complete revised description see Bather's work previously cited, especially his beautiful figures on plate 2, and details of the stem structure on page 41.

Horizon and locality.—Silurian, Rochester shale, and also the later Clinton; Lockport, New York; Brassfield limestone, Xenia, Ohio; Racine dolomite, Chicago; also the Wenlock limestone; Dudley, England, and Gotland, Sweden.

MYELODACTYLUS BREVIS, new species

Plate 1, figs. 9, 9*a*

I figure under this name a solitary specimen from the Brownsport formation of the late Niagaran, which agrees with *M. convolutus* in all the diagnostic characters of the columnals and cirri, but differs in the extreme shortness of the stem, and the close coil. It has no distal extension whatever beyond the tightly rolled coil, as is shown by the rapid taper, which is evidently very near the end. While the specimen may be sporadic amid the great abundance of the prevalent species of that horizon, yet the agreement with the form from the Rochester shale in the essentials of cirri structure is so complete that it can hardly be ignored, while at the same time the close coil, terminating in a point, is shown by abundant material in another form to be a good specific character.

Horizon and locality.—Silurian, Brownsport formation; Decatur county, Tennessee.

MYELODACTYLUS AMMONIS (Bather)

Plate 2, figs. 1–9

Herpetocrinus ammonis Bather, Crinoidea of Gotland, 1893, p. 49, pl. 2, figs. 54–63.

Coil very close, stem short, extending but little beyond the proximal part of the involute coil; wide in the middle region and tapering to a point at the distal end. Cirri numerous, short, flat and

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[7] Mentioned by Bather in Crinoidea of Gotland, p. 182, under fig. 38.

[8] Crinoidea of Gotland, p. 46.

closely apposed; either regularly paired on alternate columnals, or regularly alternating, one from the broad end of successive columnals. Crown usually concealed by the coil; its detailed structure unknown.

Among the collections made for me by Professor Pate in the Brownsport formation of Decatur county, Tennessee, are upwards of fifty specimens belonging to this genus. With a solitary exception they all have alternating columnals according to one of two plans: either 1, long, hourglass-shaped ossicles as seen from the inner side, with a cirrus at each end and a shorter, lenticular, non-cirriferous ossicle interposed; or 2, uniform wedge-shaped ossicles, with a cirrus springing only from the broad end of each. The cirri are in close contact, short, tapering rapidly, when intact meeting at the center of the coil, or slightly overlapping at the smaller ends—thus filling the entire visible space with a conspicuous convergent structure. Seen from either side, there is one cirrus for every two columnals. The difference between this form and *M. convolutus* is readily apparent. The latter has twice as many cirri, which are relatively only half as wide, as the former. In the exception above mentioned the specimen differs so decisively in structure that I have separated it as *M. brevis*.

These specimens fall into two categories: 1, with a short stem, closely coiled, the distal end tapering while still in contact with the coil, thus indicating that it did not extend much farther, and in fact, when not broken off, narrowing to a point; 2, with stem much elongated, extending by broad curves beyond the small proximal coil, without noticeable dimunition in width to near the distal end—sometimes becoming almost straight. This difference is not due to age, for both large and small individuals have an open coil, while those that are closely coiled are sometimes quite robust, although generally smaller than the former.

These forms constitute two well marked subdivisions of the type under consideration, each numerously represented among the material from the Decatur County area. In a few specimens where the stem is broken off close to the proximal region of the coil the identification is uncertain, but in most cases one can determine from the condition at the point of fracture whether the stem is beginning to taper distalward or not; and the two structures impart a certain superficial aspect by which, when once understood, the forms are readily recognized. In specimens which are nearly complete the difference is apparent at a glance.

Each of these divisions includes specimens with both types of columnals as above described, which I have been unable to correlate with any other character for a further and desirable subdivision. Bather, when describing his *H. ammonis*, recognized two varieties based upon these characters, which he called *bijugicirrus*, with the hourglass-shaped, and *alternicirrus*, with the wedge-shaped, ossicles. He did not think it advisable to separate them as species, because he found the structures somewhat intermingled in his principal type specimen, and also in view of the practical difficulty of distinguishing them owing to the fact that the stem in both varieties, as seen from the outer curve, and also from the side, presents the same appearance, it being usually only on the inner curve that any difference is apparent. I have found the same difficulty, and among the numerous specimens now in hand there are several, otherwise well preserved, which I should be unable to identify upon this character alone. The intermingling of the two varieties is well shown on plates 2 and 3, and in one fragment from St. Paul (pl. 3, fig. 12) both are seen to exist in the same specimen.

Out of 22 specimens of this species in which the form of the columnals can be readily observed, 13 are of the variety *bijugicirrus* and 9 of variety *alternicirrus.* And among 21 specimens of the species with the loose coil, *M. extensus*, 7 are of variety *bijugicirrus*, and 14 of variety *alternicirrus.* Thus while the two characters are so intermingled as to preclude the basing of species upon them, yet on the strength of preponderance in numbers the evidence of these varieties may be considered as confirmatory of the separation of the two species which we have made upon other grounds.

I have referred the close coiled form to *M.* (*H.*) *ammonis*, on the strength not only of Bather's statement in the specific diagnosis, but of the measurements which he gives on page 50, showing the diminution in width of the stem in a distal direction, and of his figure 56 on plate 2, which bears a striking resemblance to many of my specimens. For the form with the loose, extended coil I am proposing the new species, *M. extensus.* From the evidence of specimens which I have from Dudley, I judge that the two types with the close and open coil exist among the English forms also.

The recognition of this Swedish and English species in the American rocks of equivalent age adds another fact to the evidence of the close relationship between the Silurian faunas of the two regions.

As a rule the specimens are tightly inrolled, so that the cirri are usually better preserved than in the open coiled form. They have a very compact, robust, and well-rounded appearance. The stem swells from the proximal region to a considerable width (often wider than in open coiled specimens of much greater length) at about midway of the exposed part, and from there diminishes to a narrow point at the distal end, which is just beyond the last contact with the preceeding coil (pl. 2, fig. 3*a*). Usually this narrow terminal is broken off, but it is present in several specimens (pl. 2, various figures);

even when detached the taper in width of the stem for some distance back is plain to the eye. The diminution is decisively shown by measurements. In six specimens having the stem complete to the narrow distal end, with diameters of coil from 20 mm. down to 12 mm., the diminution from the widest median part to the distal end is from 5—5—4—4—3—2.5 mm. down to 1 mm. or less; whereas in the five largest specimens of the open-coiled form, with diameters in the corresponding part of the coil of from 24 to 14 mm., the average maximum width is 3 mm., only reaching 4 mm. in one case; and this width is in most cases maintained with but little diminution so far as the stem is preserved. In the largest specimen, with stem extending about 8 cm. beyond the coil, the width is still 3 mm. at the incomplete distal end. In one of the six close-coiled specimens above mentioned, having diameters of 12 and 14 mm., the distal portion diminishes in width from 4 mm. to a point in a distance of only two and a half times its maximum width.

In the present species the involute, or bilateral, portion of the stem is limited to about one and a half convolutions with diameters ranging from 9 mm. to a maximum of 24 mm., while in the open-coiled form there may be one or two more loose coils, with the stem extending still farther in a broad curve, or nearly straight.

In many of the specimens the two outer longitudinal sutures, remnants of the primitive five by which the stem was originally divided, are very prominent (pl. 2, fig. 2*a*), and the stem between them is often raised into a rounded ridge, as mentioned by Bather under *H. ammonis*.[9]

There is no doubt that this form, with its abbreviated and rootless stem, led a free life; whereas it is probable that the other form, with elongate stem, was sessile, temporarily or permanently.

In addition to the specimens from the Decatur County area, I have about an equal number from the Waldron shale at Newsom, Tenn., which I am unable to distinguish from them by any characters disclosed in the fossils, and which have a remarkable uniformity in the characters above desscribed. Hence notwithstanding the difference in horizon, they will with our present knowledge have to be referred to the same species. So far as observed, the form with the open coil does not occur at the Waldron locality.

This description is based upon about forty specimens, almost equally divided between the two localities.

Horizon and locality.—Silurian, Brownsport formation; Decatur County, Tennessee; and Waldron shale, at Newsom, Tennessee. A small fragment from St. Paul, Indiana, shows that this or the fol-

[9] Crinoidea of Gotland, p. 51.

lowing species exists also in the Laurel formation; it has the cirri paired on alternate columnals, the cirriferous ossicles having an hour-glass shape as seen from the inner side of the curve, with a shorter, lenticular one between them (pl. 2, fig. 5). Also Wenlockian Gotland, Sweden, and probably Dudley, England.

MYELODACTYLUS EXTENSUS, new species

Plate 3, figs. 1–13*a*

Like *M. ammonis*, except that the coil is open beyond the proximal region; stem elongate and extended for a considerable distance in a broad curve toward the distal end.

This species, differing from the preceding only in the extent and mode of termination of the stem, is represented by a series of about 30 specimens, which for the most part are considerably the largest of the two. In diameter of the corresponding coil they range from 12 mm. to 30 mm., to which must be added the extension of the stem after deviating from the coil. In one specimen with the close coil about 25 mm. in diameter the total length of the bilateral part of the stem is about 16 cm., of which more than half lies beyond the region of the coil, without reaching the distal end, and with but little diminution; and it is almost straight (pl. 3, fig. 1). In another, in which the coil is loosely maintained in large curves, the stem is preserved to near the distal end, where it seems to terminate in some small radicular cirri (pl. 3, fig. 3). Another specimen has a close coil of 12 mm., from which it opens in a broad coil for one and a half whorls more for about 12 cm., maintaining a width of about 3.5 mm. to near the distal end, where it diminishes to 2.5 mm. (pl. 3, fig. 5). Another, not figured, has the stem extended beyond the point of deviation for a distance of 12 cm. and is still large, having diminished in width from 5 mm. in the median part to 4 mm. Besides the other specimens with long extension shown on the plate, there are three more with incomplete extended part from 4 to 6 cm. long, with little or no diminution, thus giving ten specimens in which this character is strongly emphasized, in contrast to the still greater number belonging to *M. ammonis* in which the stem is restricted to the close coil with its pointed distal end. The small size in which this form also occurs is shown by figures 10 and 11 of plate 3.

The open coiled form would seem to be favorable for the discovery of the crown; and in view of the fine preservation of many of the specimens from the Decatur county locality I fully expected to find it. But after diligent search I was only able to uncover it, in imperfect condition, in a few specimens, not well enough preserved to show the composition of the calyx. I then tried grinding, and after several failures succeeded in getting a polished section giving the outline of the crown. All that it shows is that the arms are long and extremely slender, with calyx evidently of the heterocrinid type (pl. 3, fig. 7). To judge by the space it occupies this crown may have only four rays.

On plate 9, figure 10, there is a picture of a round stem spirally coiled and tightly wound about another crinoid stem, without any trace of bilateralism. It is shown here in order to caution observers against being misled by a superficial resemblance, in view of the fact that coiled stem fragments like this, attached to other objects, are not uncommon in the same Silurian formation of Tennessee which contains species of *Myelodactylus* herein described. Such a piece was figured by Roemer in Silurian Fauna des Westlichen Tennessee, 1860 (pl. 4, figs. 11*a*, *b*, *c*) and discussed on page 57. These spiral stems have not been found in connection with the corresponding crown or calyx. But this form has nothing whatever to do with the bilateral stem of *Myelodactylus*, and belongs to some entirely different group.

These two kinds of stem have formed the subject of an elaborate paper by Dr. K. Ehrenberg upon Coiled Stems in the Pelmatozoa and their relation to Sessility,[10] which only came to my attention after the present memoir was nearly completed. In it he refers to another paper devoted especially to *Herpetocrinus* soon to appear, but which I have not seen.

Doctor Ehrenberg divides the crinoids with coiled stem into two general types, the first with nonbilateral stem in which the coiling is more or less limited to the distal part—which would be like the specimens above mentioned; and the second in which the stem is bilateral, and coiled throughout its entire length, such as *Myelodactylus* (*Herpetocrinus* as he prefers to call it) and similar forms. The first type, being capable of attachment by its coiled distal end to other objects, he considers to be adapted to a sessile mode of life. In the second, where the coiling involves the entire stem, and the crown is enveloped within it, there is no indication of sessility, but it had a vagrant, pelagic habitus, somewhat like that of the Ammonites. In each type the coiling must be viewed as an adaptation to its particular mode of life.

I do not here attempt to follow the author's discussion of the origin of the coiled stem, and its bearing upon the phylogeny of the Pelmatozoa, but I hope the new facts now being brought out may throw further light upon that phase of the subject.

Horizon and locality.—Silurian, Brownsport formation of the late Niagaran; Decatur County, Tennessee.

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[10] Acta Zoologica, Vienna, 1922, vol. 3, p. 271, and following.

MYELODACTYLUS BRIDGEPORTENSIS S. A. Miller

Myelodactylus bridgeportensis, S. A. Miller, Journ. Cin. Soc. Nat. Hist., sec. 2, vol. 3, 1880, p. 141, pl. 4, figs. 2*a*—*e*.

MYELODACTYLUS GORBYI S. A. Miller

Myelodactylus gorbyi, S. A. Miller, 17th Rep. Geol. Surv. Indiana, 1891, p. 72, pl. 2, figs. 6, 7.

When describing these species Mr. Miller still clung to the idea that they represented the arms of a crinoid, and his statements therefore throw no light upon their specific characters. Both were described from rather poor material, but under the first one, from the Racine dolomite of the Chicago area, there is enough detail in the figures to show that it is of the type of *M. convolutus*, having paired cirri on every columnal; and, so far as appears from the specimens, it should be referred to that species. As to the second species, *M. gorbyi*, said to be from the Niagara limestone near Nashville, Tennessee, the single small type specimen as figured shows no diagnostic character whatever. Nor is there any information to indicate its exact horizon—there being more than one Niagara formation in the vicinity of Nashville. It possibly was from Newsom, which is in that vicinity, but whether it belongs to the same species as the specimens from that locality mentioned under *M. ammonis*, can not be ascertained from the figure or description, and the location of the type is unknown.

MYELODACTYLUS ROTUNDATUS (Foerste)

Eomyelodactylus rotundatus Foerste, Bull. 19, Sci. Lab. Denison Univ., p. 19, pl. 1, fig. 8; pl. 2, fig. 3.

Under the name *Eomyelodactylus* Foerste has described a specimen from the Brassfield formation of Ohio, equivalent to the late Clinton, which has all the characters of *M. convolutus*. As already stated, this species occurs both in its typical horizon, the Rochester shale, and the underlying Clinton limestone at Lockport, and therefore may well be expected in the Brassfield.

MYELODACTYLUS BRACHIATUS Hall

Plate 4, figs. 1–10

Myelodactylus brachiatus Hall, Pal. New York, vol. 2, 1852, p. 232, pl. 45, figs. 7*a*–*e*.
Herpetocrinus brachiatus, Bather, Crinoidea of Gotland, 1893, p. 46.

Coil open; circular part of stem very long and slender. Cirri few, round, limited to the distal region, and branching; springing alternately from the back of the stem at intervals of several columnals. Crown small, superficially resembling *Iocrinus*, but calyx elements not fully known.

Hall's description has scarcely anything of diagnostic value, being based, like that of *convolutus*, upon the idea that the fossils before him were the arms of a crinoid. But his figures clearly show the important fact that the cirri are few, originating at alternate intervals from the back of the stem. These characters enable us readily to identify the prevalent form of the genus occurring in the Rochester shale at Lockport, New York. I have upwards of seventy specimens, assembled from the extensive collection of Doctor Ringueberg, and the fruits of three seasons' work in the shales at Lockport by Frederick Braun. This material brings out the further remarkable fact, unknown to Hall, that the cirri are branching—a character which I believe to be hitherto unknown in any crinoid, fossil or recent, except in cases where the cirri belong strictly to the root.[11]

This fact emphasizes the broad distinction between the two original species from the type locality, the characters of *M. convolutus* being in strong contrast to those of *M. brachiatus* in almost every particular. Instead of the cirri being short, flat, numerous, and extending well toward the proximal region, as in the former species, here there are but few of them, at intervals of several columnals, springing from the back instead of the lateral margins, and restricted to the distal region of the stem. But what they lack in number they make up in size. Notwithstanding the fine preservation of many of the specimens, in which the strong, round cirri are present to the extent of several branches, it is doubtful if we have the cirri preserved to their full length in any of them. But it is evident that in many cases—perhaps always—they exceeded in length the entire elliptic or crescentic portion of the stem, so that with their numerous branches they formed a complete fringe, by which when retracted by its slender neck the crown was surrounded without being closely infolded as in *convolutus* and species of similar type We have the stem preserved to the distal end, where it becomes round and tapers rapidly to a point.

Among the material obtained by Braun during his campaigns at Lockport in the years 1910, 1911, and 1914, were a number of specimens in which the thick distal and median portion of the stem was seen imbedded in a fine-grained matrix favorable for preparation. Upon carefully following this up, I came first to the slender

[11] A figure in Goldfuss (Petrof. Germ., vol. 1, 1829, p. 190, pl. 58, T. fig. 7, Z), under the heading of *Cyathocrinus pinnatus* Goldfuss, of a fragment from the Devonian of the Rheinland, seems to show a coiled bilateral stem, with two marginal rows of cirri, which fork at a distance of several ossicles from the stem. There is nothing to indicate its relation to other forms, not even to the other fragments figured under the same name; and it may be an arm trunk of some Melocrinid.

neck forming the round part, which proved to be unexpectedly long, and after executing a doubly reversed curve passed out of the coil and finally terminated at the crown, which thus assumed an erect position. It is small and fragile, and while the arms are preserved to nearly their full length the structure of the calyx can not be fully made out, so that beyond its *Iocrinus*-like appearance not much can be said about it. Encouraged by this favorable beginning in the new material, expectation was aroused that we should soon have the desired information as to its exact structure. The second specimen investigated followed the same course as the first until the slender neck of the stem turned outward from the coil, and then it suddenly came to an end, broken squarely off, with the crown absent And although I worked every specimen, thirty-four in number, in which the favorable condition appeared, the same result followed. In every one of them the crown was gone—snapped off at time of death. This form must have been peculiarly sensitive to disturbance or change of conditions, causing it to cast off the crown, as certain existing crinoids cast off their arms on being brought to the surface.

Conformably to the habitus thus described, I do not find in this species the close coiling of the stem in the proximal region as in the other species. The contrast in thickness between this part of the stem and that lower down is very great. The broad curve in the latter part is always conspicuous, terminating when sufficiently preserved to show it in a pointed end.

In a maximum specimen the diameter of the coil is 15 mm.; length of stem from coil to distal end is 30 mm.; and of the part included in the coil about 35 mm., to which must be added that of the circular part, 20 mm., making the total length of stem 10 cm. Width of stem in middle region 4 mm., in circular proximal part 1 mm. Length of an upper cirrus, branching four times, 2.5 cm.; lower cirri, not fully preserved, undoubtedly much longer. Maximum number of cirri about 12 or 13, at intervals of about 6 or 7 columnals between the cirri at each side. The columnals are quadrangular, very short, and of uniform length, about .5 to .8 mm. The diameter of an average cirrus at its base is 1.5 mm., so that its socket may abut upon 2 or 3 columnals. Minimum specimens may have a diameter of coil of 7 mm. or less, with other dimensions in proportion.

This species is comparable to *Herpetocrinus flabellicirrus* Bather, from Gotland, in the fact that the cirri spring from the back of the stem and are confined to the distal region, but in no other important character. In the Gotland species, instead of single cirri at intervals, there are large cirri separated by several columnals bearing successively diminishing cirri, arranged so as to form a fan-like cluster. Compare Bather's figure 68 of plate 2, with figure 5 of plate 4 herein.

Horizon and locality.—Silurian, Rochester shale; Lockport, New York, where it is one of the leading crinoid species. No trace of it has been seen in other horizons in which the genus occurs.

MYELODACTYLUS KEYSERENSIS, new species

Plate 6, figs. 1–3

Coil open, with stem diminishing but little distalwards. Cirri numerous, long, slender, closely apposed, slightly rounded but not moniliform; mostly paired on successive columnals. Crown large, with long arms branching repeatedly; its bulk producing a noticeable swelling of the two rows of closely packed cirri inclosing it. Rays 5, irregular, of the *Iocrinus* type, the anal tube borne on the left shoulder of r. post. Rs.

This species differs from all Silurian forms in the conspicuous bulging caused by the large size of the crown. I have nine specimens from the Keyser beds, in all of which the presence of the crown is indicated by this feature. In size, shape, and distribution of the cirri this form does not differ essentially from *M. convolutus*, but the bulkiness of the crown differentiates the two readily.

In two of the specimens the crown is well exposed, so that its composition may be studied. The swelling is not due to the calyx, but appears in the arm region, leading to the inference that it is caused by an inflated anal tube or sac, such as occurs in *Ohiocrinus*, and, though rarely seen, in *Anomalocrinus*. The rays differ greatly in size in the one specimen in which they can be fully observed (pl. 6 figs. 1–1*c*) ; *r. post.* and *r. ant.* being narrow, the other three much wider; *l. ant.* the widest of all, and branching higher up than the others. The difference in the development of the rays is connected with their relative position in the curvature of the crown. The largest one, *l. ant.*, being at the outside of the curve, was freest to develop and filled the greatest space; whereas *r. post.* and *r. ant.* were much cramped at the inner side of the curve, compressed, and dwarfed in their growth, especially *r. ant.*, which does not branch at all. The first bifurcation in the others is at different heights, and beyond that the arms branch five or six times to very fine finials.

In the two largest specimens, having diameters at the close coil of about 30 mm., the stems extend for 5 and 6 cm. beyond that, and are 4.5 and 5.5 mm. in width, without noticeable diminution; in these the thickness of the swollen part is 6 and 12.5 mm. respectively, being thus about double the width of the stems. In another large incomplete specimen the swelling is 15 mm. thick (pl. 6. fig. 3) ; and a smaller specimen, with a coil 18 mm. in diameter, has the swelling enlarged to 15 mm.

Horizon and locality.—Lower Devonian, Helderbergian, Keyser formation; Keyser, West Virginia.

MYELODACTYLUS NODOSARIUS (Hall)

Plate 5, figs. 1–8.

Brachiocrinus nodosarius Hall, Pal. New York, vol. 3, 1859, p. 118, pl. 5, figs. 5, 6, 7; pl. 6, figs. 1, 2, 3.

Herpetocrinus nodosarius, Bather, Amer. Geol., vol. 16, 1895, pp. 213, 217.—*Brachiocrinus* (*Herpetocrinus*) *nodosarius*, Talbot, Amer. Journ. Sci., 20, 1905, p. 32.—*Brachiocrinus nodosarius*, Kirk, Proc. U. S. Nat. Mus., vol. 41, 1911, p. 48.—*Brachiocrinus nodosarius*, Goldring, Devonian Crinoids of New York, 1924, p. 332, pl. 41, figs. 1–4.

Coil open. Stem elongate, extending without sensible diminution considerably beyond the coil, terminating in a bulbous enlargement; columnals short, uniform. Cirri few, short and thick, composed of a few rounded cirrals; moniliform, thickest about the middle, where their diameter often exceeds that of the stem from which they spring; alternating, at intervals of usually 1 to 5 columnals.

The most remarkable thing about this Lower Devonian form is the ponderous character of its rounded, bead-like, doubly tapering cirri. In this respect it evolved an unparalleled modification, for in no other known crinoid are the cirri thicker than the stem on which they are borne. Here they are often very much thicker. In three specimens with stems 3 mm. wide many of the cirri are 4 mm. in width; and in all the ten specimens in hand the cirri are nearly all as thick as, or thicker than, the stem. There is considerable irregularity in the size of the cirri, and one gets the impression of hypertrophy due to some unusual stimulus.

Some are decidedly swollen in the middle, increasing in size for a few ossicles, and then diminish to sharp extremities. Some are about equal throughout, and often both kinds are seen in the same specimen; usually the first cirral is shorter than those directly following it. The cirri originate along the curved outer margins of the modified stem, alternately at the longer face of successive cuneate columnals, giving them often the appearance of being opposite, and in pairs. Beginning at the distal end of the stem, the first few cirri are in close contact, but higher up they are separated by increasing intervals of one to five columnals, which are short and equal. Occasionally the two cirrus-bearing columnals are fused.

The cirri are few in number, not exceeding eight to ten pairs in the longest stems observed, which are 5 to 10 cm. in length, without being complete. One of these is almost straight for its entire length. The proximal part of the stem, and also the crown, are unknown.

Another character wherein this form is unique among its congeners is that the distal end of the stem terminates in a rounded condyle having the appearance of a secondary growth after fracture of the stem from its original attachment. This is not a mere casual occurrence; in seven specimens, with the distal end preserved, six have a bulbous termination, and the seventh is irregularly enlarged, followed by a short tapering appendix.

The only other known species possessing medially swollen cirri is *H. flabellicirrus* Bather, from Gotland, in which they are thickly crowded, in fan-like clusters, and originate at the back side of the stem.

The material available for this investigation consists of eight specimens in the New York Museum at Albany, most obligingly loaned me by Dr. John M. Clarke, in which are included two of Hall's types.[12] In addition to these I have had the use of some fragments from a different locality showing the full rotundity of the bulbous distal end, for which I am indebted to the courtesy of Prof. Charles Schuchert of the Yale University Museum. The other specimens figured by Hall I have not been able to locate. One of them [13] has about 10 cm. of the stem, with the curvature toward the proximal coil well shown, but not, however, either the proximal or distal end.

I see no reason to doubt the conclusion reached by Bather in his discussion of 1895 that this species is congeneric with those which he referred to *Herpetocrinus*. The difference from the typical forms in the character of the cirri is of course very great, but not relatively more than that of some of the other species, such as *flabellicirrus* or *brachiatus*, while the general type of stem construction remains the same.

Horizon and locality.—Lower Devonian, Helderbergian, New Scotland formation; Schoharie, and Helderberg Mountains in Albany County, New York.

MYELODACTYLUS SCHUCHERTI, new species

Plate 5, figs. 9–9c.

Coil apparently of the close variety; circular part of stem long, and relatively thick. Cirri round, short, tapering, somewhat irregular in size, paired on successive columnals, which in the cirrus-bearing part are uniformly quadrangular, with straight sides. Crown unknown.

Diameter of coil as preserved about 15 mm. Length of main or crescentic portion of stem remaining about 40 mm.; length of columnals in that part average 0.5 mm.; width at place of fracture 4 mm., diminishing to 3 mm. in the curve next to the neck, and then to 2 mm. in the proximal neck, which, as far as preserved, is

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[12] Paleontology of New York, vol. 3, pl. 5, fig. 5; pl. 6, fig. 1.

[13] Idem, pl. 5, fig. 7.

20 mm. long. Columnals in circular neck average .17 mm. long, except where increased by coalescing to twice that length.

This species is of interest as giving us an additional Devonian representative. It is founded upon a single specimen, in excellent preservation as to some details, but unfortunately broken so that both the distal and proximal portions are wanting. The arrangement of cirri is upon the plan of *M. convolutus*, but they are relatively shorter and coarser. The most striking characters are the robustness of the proximal neck, which is about half the diameter of the main stem in the next adjoining coil, and the peculiar distribution of the columnals of which it is composed. These are extremely thin throughout, about .17 mm. on the outer side of the curve, but in the portion of the neck which is proximal to the calyx, they seem to become coalesced at either side so as to form for every two ossicles a single one of double their length. Thus in a side view the columnals here are about .35 mm. in length at the bottom, and when seen from the top one of the ossicles takes on a lenticular form. At some point between this part, which is that freely exposed in the figures, and that where the reversed curve begins, this doubling in length of columnals seems to disappear, so that it is not continuous for the whole of the neck. The ends of the enlarged columnals, and the form of the lenticular ossicle between them, have nearly the appearance of those in the variety *bijugicirrus*, but in fact they have no facets and bear no relation whatever to cirri. I am unable to give any explanation of this singular structure, which is a very definite one, as shown by the detailed drawings.

The species is named in honor of Prof. Charles Schuchert, by whom the unique type was collected many years ago in the course of researches upon the Helderbergian formations of Tennessee.

Horizon and locality.—Helderbergian, Linden formation; Benton county, Tennessee.

AMMONICRINUS, new genus

Plate 6

Of the type of *Myelodactylus* in having the crown enveloped by a coiled bilateral stem; but without jointed cirri, their place being taken by unarticulated solid processes projecting from the two horns of the crescentic columnals; and with calyx of Camerate type.

Genotype.—*Ammonicrinus wanneri*, new species.

Distribution.—Middle Devonian; Eifel, Germany.

AMMONICRINUS WANNERI, new species

Plate 6, figs. 4–6

I have proposed this genus and species upon the evidence of two very perfect specimens and some fragments from the Middle Devonian of the Eifel, which have been in my possession for many years, but hitherto undescribed because I was uncertain of their affinities. With the present study of this group it seemed probable that these curious fossils belonged here, although they resemble nothing in the crinoid line that has ever been seen before. Their superficial appearance is that of a coiled shell; but that idea was excluded by the fact that they have a jointed structure, and are built up of movable segments, coordinated by an axial nerve cord lodged in a canal which perforates the coil longitudinally, thus enabling it to open and close. Their systematic relation with the group now under consideration was definitely established when upon removing the projecting processes from the segments on one side there was disclosed the calyx of a crinoid tightly enveloped within the coil.

The extreme width of the segments forming the enclosing structure, in proportion to the diameter of the coil, seemed to preclude any analogy with the stem of a crinoid; but the facts as brought forth by the investigation show conclusively that it can not be anything else. They disclose a specialization which amounts almost to a freak, furnishing a fresh exemplification of the truth that in nature any modification of an organism may be expected which is not a mechanical impossibility.

A few measurements will show to what an extreme the modification in this form has gone. The coil is tightly closed in both specimens, with the distal end closely adherent and tapering rapidly to a point. It is more or less elliptic in both, with long and short diameters, respectively, of 18–22 and 15–16 mm. It is composed of relatively few segments, or columnals, which are of great width and thickness, and project on the perimeter of the curve in strong ridges, like cogs upon a wheel. In the smaller specimen there are 20 columnals on the exposed surface, a distance of about 50 mm., and in the larger one 24 columnals in a distance of 62 mm. Thus the columnals are about 2.5 mm. in thickness, or length longitudinal to the curve, at the exterior. In coils of *Myelodactylus ammonis* of like diameter there would be about 70 and 85 columnals for corresponding lengths of curve.

The width of the columnals is still more extraordinary as compared with those of any similar form. In the region of greatest width in the two specimens they are respectively 10 and 12 mm. wide. That is to say, this over-developed or hypertrophied coiled stem has a width exceeding half the diameter of the coil. We are accustomed to think of the stem of a crinoid as a much elongated structure, but here we have a stem of which the width is about one sixth of its possible length.

The most remarkable thing about the organism, however, is the marginal appendages, which occupy at either end of the segments the same position as the cirri in *Myelodactylus*. They are relatively of fair length, 5 to 11 mm., and somewhat irregular in shape, although mostly tapering to a point. Upon the most careful examination I am unable to find any sign of articulation, sutural division into cirrals, or of any organic structure; yet from the manner in which they overlap toward the center, these appendages must have had a certain amount of flexibility, to adapt themselves to the movements of the segments when inrolling. That there was ample facility for movement of this kind among the segments is clearly shown by their crenellated edges and strong beveling at the back in the two principal specimens, and by the presence of a fulcral ridge and fossae for muscles and ligaments as shown in the isolated ossicles. The axial nerve canal by which they are perforated extends to the last of the rapidly narrowing columnals, which are preserved in one specimen almost to the very end, and is also seen in the fragments.

It does not seem possible that articulations and intercirral sutures existing in life could have been completely obliterated in these fossils, which are unusually perfect and well preserved; but of course if the appendages should prove to be jointed structures the generic position might depend upon the calyx, as there would be no essential character discoverable to separate it by the stem alone from *Myelodactylus* or from *Camptocrinus*.

As to the crown, which has been partially exposed by cutting away the appendages at one side, I am unable to ascertain the details of its construction. The calyx is strong and thick, and probably belongs to the Camerata—perhaps to some form of the Hexacrinidae, which take on many strange modifications. There is a suggestion of *Arthracantha* in the remnants of calyx and arms which are seen.

In general form this species is to be compared with *Myelodactylus ammonis*, which has a similarly short coil, wide, and narrowly terminated, and in some specimens of which the maximum width of the stem is equal to one-third the diameter of the coil. Both were undoubtedly free, this one completely so, as it is hard to see how the apparently functionless appendages could have served for clinging to other objects.

From the little we can see of the crown, which bears no resemblance to that of the Heterocrinidae, there seems to be no reason to regard this strangely modified form as the end of the *Myelodactylus* series. My guess would be that it belongs to the Camerata, and might be regarded as the beginning of the *Camptocrinus* series. From the singular way in which the Carboniferous genus *Dichocrinus* adapts itself to some very broad modifications in the structure of stem, arms, and other appendages, it might reasonably be supposed that the prolific genus *Hexacrinus* among Devonian crinoids would do something of the same kind.[14]

This remarkable species is named in honor of Prof. Johannes Wanner, of the University of Bonn, an ardent student of the crinoids, whose works upon the Echinoderms of the island of Timor have brought to light one of the most extraordinary crinoidal faunas ever discovered.

Horizon and locality.—Middle Devonian, Eifel limestone; Prüm, Eifel, Germany.

CAMPTOCRINUS Wachsmuth and Springer

Plates 7, 8

Camptocrinus WACHSMUTH and SPRINGER, North American Crinoidea Camerata, 1897, p. 779. Mississippian; Burlington to Chester.

Camptocrinus is simply a *Dichocrinus* with a coiled bilateral stem; or it might be called a *Myelodactylus* with a Camerate crown. It is the Carboniferous representative of the type under consideration. Whatever may have been the origin of this extreme stem modification, it developed independently in the two orders of the Crinoidea, without the slightest evidence of any evolutionary connection between the two genera in which it appeared, and then reappeared after the long time interval from the Lower Devonian to the Lower Carboniferous.

The genus *Dichocrinus* was peculiarly susceptible to secondary modifications upon a primitive type, and underwent a number of striking changes involving the stem and arms. The stem especially was in a plastic condition, yielding a variety of modifications in addition to that of the bilateral, coiled feature, which were not correlated with any material changes in the structure of the crown. Usually the stem is without cirri (pl. 11, fig. 4), but in some of the later forms ordinary cirri are present, in whorls along the greater part of the stem. I have some excellent specimens showing this. In one species the cirri are developed in numerous crowded whorls, limited to the upper part of the stem, and rising far beyond the height of the calyx and arms (pl. 11, fig. 7).

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[14] There is even some ground for suspecting that the mysterious *Edriocrinus* might be an offshoot from the Hexacrinidae. The calyx is fundamentally similar—five strong radials, with a large anal plate of similar form interposed in line with them. As it is now known to be a monocyclic crinoid with four basals (Springer, Crinoidea Flexibilia, 1920, p. 443), the analogy in this respect also is not so very remote. The Hexacrinidae include forms with two and with three basals, why not four? The secondary modification of the base by way of fused basals, often directly fixed without a stem, thought to be a result of reef life in shallow waters, reappears in different geological epochs down to the present time, in wholly unrelated forms; and there is no reason *a priori* why it may not have occurred independently in the Hexacrinidae.

The arrangement of columnals varies from uniformly short throughout to alternation with longer ones on different plans. The arms vary from 10, the usual number, to 20, 30, and 40; from uniserial to biserial; and from dichotomous to a heterotomous arrangement. They also in some species take on a recumbent habitus—a modification which occurs independently among the Rhodocrinidae, Melocrinidae, Batocrinidae and Platycrinidae. A reduction of primibrachs to a single small axillary plate forms the genus *Talarocrinus*, with the calyx elements otherwise similar to *Dichocrinus*, but with incipient changes in the tegmen by the enlargement of the axillary ambulacral, or radial dome plate, which when developed into huge wing-like processes produces the remarkable specialization of *Pterotocrinus*.

Finally the calyx itself begins to add a new element, in the form of additional rings of plates between basals and radials, leading to the extraordinary multiplication of such plates which we find in *Acrocrinus*, the latest survivor of the Camerata.

In the present form, owing to the more solid construction of the calyx and the simple character of the arms, there is no such irregularity or deformity as has been observed in *Myelodactylus*, only a slight distortion at the base due to pressure; and for the same reason the crown is more prominent and better exposed. Therefore it is found in perfect condition in several of the species, so that it may be fully inspected. Throughout the long geological range in which the genus persisted—from the Burlington to the later Chester—we find that the calyx has undergone little material change, and from that alone it will be difficult to differentiate some of the species. In all where the arms are known they are ten in number, and usualy uniserial, the brachials often passing into cuneate form, and perhaps interlocking toward the extremities.

But as in the Silurian type, the specialized stem offers good specific characters resulting from modifications upon a new plan. In all species, as before, the columnals in the proximal, rounded and noncirriferous region of the stem are very short and uniform; but beyond this, where the stem becomes elliptic, the columnals are of different lengths, parallel, and have marginal cirri at each end forming two rows along the inner or concave side of the stem. These usually spring from the suture between paired or doubled nodals, with one, two or three internodals interposed, each about the size of the combined nodal pair. No wedge-formed columnals have been observed. By far the most frequent plan is that of duplicate or triplicate cirri, of which the outer ones are borne upon facets at the junction of the nodal segments, forming clusters which diminish in size inwards. The cirrus-facet seems to lie directly above the suture.

The peculiar modification in stem structure which is manifested in the genus *Camptocrinus* is itself subject to some singular variations, of which one of the most striking seems to be connected with an effort toward resumption of the usual arrangement of cirri in whorls upon a rounded stem. This tendency is evidenced by the presence of incipient, immature, or rudimentary cirri, supplemental to those in the marginal rows, usually much dwarfed in size; they consist of a few small cirrals, often of only a single ossicle breaking through at the suture between the paired nodal segments, rounded off distally and without any axial canal through which further growth could be innervated. Rarely also it results in fully developed, fairly equal cirri in whorls of five, upon a stem which retains in part the elliptic section.

In this genus the form of the coiled stem differs considerably in transverse section from that of *Myelodactylus;* instead of being crescentic, with a decided concavity at the inner side as in the latter (pl. 1, fig. 6), it is here simply elliptic, with the curvature at the inner and outer sides almost alike, sometimes but little flattened and tending to become circular (pl. 8, various outline figures).

In this genus also the rounded proximal part of the stem, or neck, is usually materially shorter than in *Myelodactylus.*

Distribution.—Mississippian, Burlington to latest Chester; limited, so far as hitherto known, to North America, but now found to occur in the East Indies, in a formation claimed to be Permian.

CAMPTOCRINUS PRAENUNTIUS, new species

Plate 7, fig. 1

Of large size; stem with broad open coil; round, slender, with reversed curvature in the proximal region, much enlarged in the middle region, and tapering to the distal end, where it begins to assume a bilateral form, with a few short cirri. Crown not closely enveloped by the stem; it is of the type of *Dichocrinus angustus,* with ten uniserial arms; apparently only a single primibrach, as long as the usual two.

This species from the Burlington limestone may be considered as the beginning of the modification leading to the fully developed *Camptocrinus.* It is the largest of the known species, the stem having a total length of 19 cm. In the great diminution of the otherwise thick stem in the proximal region, its reversed curvature, and the position of the crown in relation to it, the habitus of the species is thoroughly characteristic of the type; but it lacks the close envelopment of the crown by the stem and cirri, the stem being round for the greater part of its length. The cirri occur at the inner side of the curve only in the last 5 cm., where the columnals, which are of about equal length throughout, become slightly elliptic; they are small, not very regularly placed, but mostly on alternate columnals. The alternation of paired nodals with one or more large internodals, which is so marked a character in the later species, has not appeared in this one.

This form is exceedingly rare, not having been observed by any of the early collectors at Burlington—the fine specimen here illustrated and another imperfect one being the only examples among the numerous collections covering a period of over fifty years at that prolific locality.

Horizon and locality.—Mississippian, Upper Burlington limestone; Burlington, Iowa.

CAMPTOCRINUS MYELODACTYLUS Wachsmuth and Springer

Plate 7, figs. 2–5*b*

Camptocrinus myelodactylus WACHSMUTH and SPRINGER, North American Crinoidea Camerata, 1897, p. 779, pl. 75, figs. 2*a* and 2*b* (not fig. 1).

Coil close in proximal region. Stem long, extending in the middle and distal portions into a broad curve, tapering to near the end; below the proximal neck, which is relatively short, it is composed of pairs of short columnals (nodals) bearing the cirri in marginal rows at each end, with a longer one (internodal) interposed between them equal in length to the two combined nodals. Cirri strong, rounded, rather long; composed of 15 to 20 diminishing cirrals, and tapering rapidly from their origin; they are doubled (or trebled) from each side of the paired nodals, springing from a large facet midway of the pair, with an additional facet or bifurcation following behind it. Thus there are along each margin at the concave side of the stem what appear to be duplicate cirri, separated by the interval of the longer internodal columnal. This is the way they usually appear in well preserved specimens; but actually there is frequently a third cirrus, and perhaps a fourth, each smaller than the one preceding, forming a cluster diminishing in size inward. The innermost cirri beyond the second are only to be seen after most careful preparation under a strong magnifier, being crowded inward and covered by the outer ones overlapping owing to the curvature of the stem. It was only after patient work, under exceptionally favorable conditions of preservation, that the facts were ascertained from which the sketches were composed by Mr. Chapman, showing the details of these structures in this and other species.

The exact mode of succession of these diminishing cirri is rather difficult to ascertain; the outer one rests in a good sized facet upon the suture between the two short nodals, and each succeeding one seems to be articulated upon the first cirral of its predecessor, somewhat as shown by the sketches on plate 7.

The occurrence of the cirri in diminishing clusters recalls the more elaborate arrangement seen in Bather's *Herpetocrinus flabellicirrus.* There is no sign of rudimentary cirri, outside of the marginal rows, in any of the specimens of this species. The crown is imperfectly known, being usually closely enveloped by the cirri, as is most of the species of *Myelodactylus*, but enough is exposed in one specimen to show that it belongs to the usual *Dichocrinus* type: it was evidently smaller than in the other Keokuk species. Total length of stem in maximum specimen 10.5 cm. with probably 1.5 cm. missing at the distal end; length of circular neck about 1 cm.; diameter of proximal coil in two specimens having the most complete stem about one-fourth the total length of stem.

In connection with the original description three specimens were figured, two of which are of the type above described; and it was from these two that the description relative to the details of stem and cirri was made, it being stated that the cirri were slender, composed of about sixteen to eighteen joints ending in a sharp point, and that they arose from alternate columnals—overlooking the fact that in the two specimens above mentioned the "alternate joint" is a pair of short columnals equaling in length the single one interposed.

The type locality is given as Indian Creek, Montgomery County, Indiana, and it is from there that the two specimens, together with three others subsequently acquired, were derived. In one of the latter the stem is preserved to nearly its full length, showing its broad and open curve (pl. 7, fig. 5). The original of Wachsmuth and Springer's figure 1 is from another locality and a somewhat higher horizon; it has a different arrangement of columnals and cirri—a form for which I have proposed the species *C. crawfordsvillensis.* While it is true that the description of the crown was made from this specimen, there is nothing substantially distinctive about it, and as in our present view the decisive specific characters in these forms are to be looked for in the stem, that fact may be disregarded.

In the character of multiple cirri springing from a pair of short columnals, this species takes on a plan which became the leading character in the later Carboniferous forms.

Horizon and locality.—Mississippian, Keokuk limestone, lower horizon; Indian Creek, Montgomery County, Indiana.

CAMPTOCRINUS CRAWFORDSVILLENSIS, new species

Plate 8, figs. 1–3*e*

Camptocrinus myelodactylus WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, pl. 75, fig. 1 (not 2*a*, *b*).

Coil open, not closely enveloping the crown. Cirri doubled, or rarely trebled, as in the preceding species, or exceptionally single, and springing from a pair of short nodal columnals; but instead of these alternating with a single longer one, there are 2, 3, or exceptionally 4 internodals interposed between them, each about the size of the combined pair. The marginal cirri on either side are long and fairly stout, composed of 20 to 25 cirrals; and in addition to them there are, especially toward the distal end, remnants of smaller secondary cirri at the back of the same columnals, as if forming rudimentary whorls; where these appear the stem tends to lose its bilateral form and become round. This structure, occurring in a different horizon of the Keokuk from that of the last species, is constant in three specimens. The stem is not preserved to its full length in any of them, but extends well beyond the proximal coil. The calyx is that of the typical *Dichocrinus*, elongate with base one third the height of the cup. Arms two to the ray, composed of rather long, quadrangular ossicles. The crown is relatively larger than in the succeeding species.

Horizon and localtiy.—Mississippian, Keokuk limestone, upper horizon; Crawfordsville, Montgomery County, Indiana.

CAMPTOCRINUS PLENICIRRUS, new species

Plate 7, figs. 6, 6*a*

This species is proposed for a small specimen associated with the preceding which, while of the typical *Camptocrinus* type in the curvature, form and proportions of the stem and its elliptic section, has the cirri developed into complete whorls of five, nearly equal in size. In the arrangement of columnals, with paired short nodals and a single long internodal, it is like *C. myelodactylus*, but the cirri are distributed on a different plan; also it comes from a different horizon. From the other Crawfordsville species, last described, it differs in the single internodal, instead of two or more, and in the short, strongly tapering cirri not arranged in marginal rows. Unfortunately less than half the stem is preserved; if we had the whole of it, I have no doubt we should find it circular toward the distal end. The species represents a stage in the modifications of the type under consideration in which the cirri have resumed almost the distribution of those in a normal crinoid.

Horizon and locality.—Mississippian, Keokuk limestone, upper horizon; Crawfordsville, Indiana.

CAMPTOCRINUS MULTICIRRUS, new species

Plate 8, figs. 4–9

Camptocrinus cirrifer WACHSMUTH and SPRINGER North Amer. Crin. Cam., 1897, pl. 76, fig. 13*c* (not 13*a*, *b*.).

Stem long, tapering almost to a point, becoming round and very slender at the distal end, but throughout the middle region strongly elliptic, and maintaining a nearly uniform width. Cirri doubled or in clusters of 3, diminishing inward; exceptionally single, springing from each end of pairs of short nodal columnals alternating with a long internodal as in *C. myelodactylus;* they are rounded, long and slender, composed when complete of upwards of 30 cirrals, mostly longer than wide. Besides the prominent marginal cirri in two rows at the concave side of the stem, additional cirri occur at the back in many places tending to form whorls; these secondary cirri are much smaller than the others and appear in a variety of rudimentary stages. Some have two, three or four cirrals; many have only the first cirral remaining, but pierced by the axial canal, indicating that one or more others followed; still others, rather numerous, have the first cirral imperfect with no axial canal, but rounded off like a terminal ossicle, as if it had just broken through without being able to grow farther. These details are fully shown by the instructive sketches made from the two remarkably perfect specimens figured on plate 8 (figs. 4, 4*a*, 6, 6*a*). The proximal circular neck is relatively short, and the crown is not closely enveloped by the cirri. The calyx is shorter than in *C. crawfordsvillensis*, especially the basal plates, which are not over one-fourth the height of the cup; they are frequently deformed owing to compression by the curved stem, so that they are shorter at one side than the other, as shown in figure 4 of plate 8. Arms two to the ray, uniserial with more or less cuneate ossicles; rather longer than is usual in *Dichocrinus.*

Dimensions of a maximum specimen: Total length of stem, 12.5 cm.; of circular neck 10 mm.; long diameter of columnal in middle portion 2.5 mm.; short diameter 1.5 mm.; diameter at circular neck 1 mm.; at distal end, rounded almost to a point, .5 mm.

This is the most abundant and widely distributed species of the genus, being represented in the collection by upwards of thirty specimens from two well separated areas, namely, that of Huntsville, Alabama, and of Monroe county, Illinois. It occurs in the lower part of the Chester, in the Ohara formation at Huntsville, and in what is regarded as its equivalent formation at the Illinois locality. Many of the specimens from both localities are beautifully preserved, having the stem to its full length, with the crown plainly showing through the thin fringe of delicate cirri, and sometimes completely isolated. The multiple arrangement of the cirri on alternating pairs of columnals is constant throughout all this material, except that in some specimens near the distal end the columnals tend to become more nearly equal in length, and the intervals between the cirri somewhat longer. I am figuring characteristic specimens from each of the localities. In none of them is there such a close, compact coil in the proximal region as occurs in *C. myelodactylus.*[15]

Horizon and locality.—Mississippian, lower part of Chester, Ohara and Renault formations; Huntsville, Alabama and Burksville, Monroe County, Illinois.

CAMPTOCRINUS CIRRIFER Wachsmuth and Springer

Plate 8, figs. 10, 10*a*

Camptocrinus cirrifer WACHSMUTH AND SPRINGER, North American Crinoidea, Camerata, 1897, p. 780, pl. 76, figs. 13*a*, *b* (not 13*c*).

Like *C. multicirrus*, except that the cirri are more attenuate, and there is a tendency of the pairs of short columnals bearing the multiple cirri to coalesce so as to resemble a single ossicle; also in some specimens the rudimentary cirri toward the distal end tend to form rather well defined whorls associated with a more rounded stem, which may well mark the end of the specialization by which this whole type is characterized.

This species occurs in the upper part of the Chester, the Glen Dean formation, the fauna of which is sharply distinguished from that of the preceding species. The differences from that species are very slight, and if the two occurred in the same formation might well be disregarded. But in view of the changes which took place in other genera of the echinoderms during the considerable time interval between the respective formations, it seems best to recognize

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[15] *Camptocrinus indoaustralicus* Wanner.

Die Permischen Krinoiden von Timor, vol. 2, 1924, p. 81, pl. 3, figs. 9–11. This species, the description of which appeared subsequent to the preparation of the text hereof, adds another to the strictly Lower Carboniferous types which have been found associated with the remarkable Permian fauna of the East Indies. The author notes its great similarity to *C. cirrifer*, from which he says a separation is scarcely possible by the characters of the calyx and arms, but he thinks the structure of the stem offers sufficient differences to justify a new species. But the similarity is even greater than he thought, when comparison is made with the form of *C. cirrifer* now separated under *C. multicirrus*. For the stem character upon which he mainly relies, namely, two short ossicles alternating with one longer, is most conspicuous in our species; and the "small knots" which he mentions as occurring along the suture line between the short pair are the remains of budding cirri as above described.

the modifications, however slight they may appear in the fossils, as indicating a definite specific change.

Wachsmuth and Springer's figure 13*c*, although not very characteristic, must go with *C. multicirrus* in conformity with the horizon from which the specimen is derived.

The extreme tenuity of the cirri in this species is constant in several specimens, in which they often contain as many as forty narrow cirrals, which are longer than wide.

Horizon and locality.—Mississippian, upper part of the Chester, Glen Dean formation; chiefly at Sloan's Valley, Pulaski County, Kentucky, but also at Newman's Ridge, Bland County, Virginia.

THE RECUMBENT ARMS

Among existing crinoids those taken by the dredge or otherwise captured have been found with their arms, when preserved, either outstretched or folded together. On the sea bottom, in the case of stalked crinoids, both positions may be assumed, depending upon whether the crinoid 1, was seeking food, in which case the arms would be spread so as to bring the maximum of surface on the ventral side into contact with the water containing the organisms upon which the crinoid feeds, or 2, was in a state of rest, in which case the arms would probably be folded as a matter of protection to the vital organs. Which attitude was most frequent, or longest continued, we have no means of knowing, but among the specimens as taken out of the water both conditions are found. When disturbed by the dredge or tangles, many individuals respond to the contact by opening the arms widely, while others seem to bring them close together, and still others cast them off.

Among fossil crinoids the second was undoubtedly the most frequent occurrence, for practically nine out of every ten well preserved specimens, deposited so as to become imbedded in soft material, have the arms folded. And in certain large groups, such as the Flexibilia, they are scarcely ever found in any other condition. Therefore it is to be assumed that such was the usual position of the fossil crinoids at death. Any other disposition of the arms by which they become so firmly retracted as to remain fixed in that position after death, and to become fossilized in it, must therefore be associated with some structural modification in the articulation of the arms by which their motion in an upward direction would be restricted. Many instances have been observed in which this is apparently the case, and in which the facts are not explained by supposing that the recumbent arms were due merely to casual movements by the animal, voluntary or involuntary. It is evident that the mechanics of the arm structure was such that the motion of the arms upon their hinges was downward rather than upward, and that the pendent position, with the dorsal side of the arms pressing backward upon the calyx and stem, was the position of rest, or of greatest fixity. Then the arms, instead of opening out from the top in order to extend themselves and their pinnules for the maximum of contact with the water, would be extended from the bottom, the ventral side containing the food grooves being already in position for complete connection with the currents by means of the pinnules and their softer appendages.

The proof of this is found in the fact that in numerous instances the marks of long continued pressure by the arms in habitual positions are found upon the outer wall of the calyx and the stem, producing permanent indentations which could not have occurred unless the arms had become fixed in that position (pls. 9, fig. 9; 18, fig. 4).

In the most conspicuous cases of this kind I have observed that the recumbent arms are always profusely provided with long and thickly studded pinnules, and these, standing out from the curving surface of the reversed arms, have all the food-gathering exposure that they could obtain in any other way.

It is also worth noting that the entire group Flexiblia, in which the arms are almost invariably found folded together in the fossil state, and in which recumbent arms are unknown, are destitute of pinnules.

Neither are the recumbent arms, of the type which I am about to describe, found among the Inadunata, whether with pinnules or without; and regardless of the matter of pinnules it is probable that the mechanics of the arm joint, both in the Flexibilia and the Inadunata, precluded the possibility of any such backward and downward motion as would be required for the arms to become settled in that position.

While it is true that among the Recent crinoids specimens brought up by the dredge frequently have the arms curved backwards upon the stem, leaving the oral surface open except for its forest of pinnules, this is merely one phase of arm movement in the natural and usual condition, due to their enormous flexibility. There is not that complete reversal in the habitus of the arm which makes it hang downward as if suspended from the roof of the calyx. For that the solid dome of the Camerata is needed to afford a firm anchorage for the suspended arms, often projecting as it does at the edge of the tegmen out over the dorsal wall below it, and at all events furnishing a rigid means of support. In typical examples to be mentioned the covering plates of adjacent arms are for quite a distance suturally connected, thus preventing the usual motion of the arms.

It is only among the Camerata that such a well supported hinge is found; and here the structure occurs in several of its families, occasionally, as an independent modification, and in otherwise unrelated forms; specifically distinct, and sufficiently rare to fall within our category of "unusual forms." It is not even a generic character.

Hitherto the recumbent type of arms has been observed among the following families and genera of the Camerata:

Family Rhodocrinidae, genus *Gilbertsocrinus.*
Family Batocrinidae, genus *Barrandeocrinus.*
Family Platycrinidae, genus *Eucladocrinus.*
Family Hexacrinidae, genus *Dichocrinus.*
Family Hexacrinidae, genus *Acrocrinus.*

I have now to add a remarkable new species of *Macrostylocrinus* among the Melocrinidae, and another of the typical *Platycrinus.*

The oldest example now known, and one of the most characteristic, of this type of arms is *Barrandeocrinus* from the Silurian of the island of Gotland—a form with the calyx of the Batocrinidae. It exhibits the extreme compactness of the curtain of arms as they press firmly against the calyx and stem, leaving distinct impressions due to the protracted pressure, as is shown by the beautiful figure drawn by Mr. Liljevall from one of the specimens in the Stockholm Museum, published by Wachsmuth and Springer in the North American Crinoidea Camerata (pl. 8, fig. 1), and reproduced herein, as plate 9, figure 6, and by another from a specimen of my own, figure 7, showing the calyx completely enveloped by the arms.

The next in order was a holdover from the Silurian, which did not take on the recumbent arm structure until it reappeared under a new species in the Devonian, which will now be described.

Genus MACROSTYLOCRINUS Hall

Macrostylocrinus HALL, Pal. New York, vol. 2, 1852, p. 203.
Silurian to Devonian.

MACROSTYLOCRINUS RECUMBENS, new species

Plate 9, figs. 1–4

The genus *Macrostylocrinus* Hall, of the family Melocrinidae, is diagnosed by Wachsmuth and Springer[16] substantially as follows:

Monocyclic. Lower brachials, with well defined interbrachials between them, forming a part of the dorsal cup. Radials in contact all around. Basals three, unequal. Interbrachials few. Anal area much the widest, and quite distinct; three plates in the first range, the middle one large, supported by the sloping shoulders of the two posterior radials, and flanked by a smaller one at either side which, together with the first primibrach, rests upon the upper face of the radial; the middle or anal plate is usually followed by one or two other anals, longitudinally arranged. Radials very large, their upper

[16] North American Crinoidea Camerata, 1897, p. 285.

corners but slightly truncated by the interbrachials. Arms usually ten, long, biserial, simple throughout. Tegmen low, composed of numerous irregular plates.

The genus stands out distinctly from all the other Melocrinidae by having three basals, and in the anal interradius three plates in the first range above the closed radial ring, instead of only one. The form is typically Silurian, six species having thus far been recognized, of which two are from the Rochester shale, three from the Waldron, and one from the Louisville limestone. The specimens of these species are rather small. The arms, so far as known, are two to the ray, rather heavy, and of the normal type.

When the remarkable Devonian material upon which the present species is described was first seen, its generic affinities were not apparent, because the calyx was completely enveloped in the downward hanging arms, and its composition was thereby hidden; there was no thought of its belonging to a form of which the superficial appearance was so widely different. It was only after removing part of the arms from two specimens that I was able to determine the essential elements which fixed its position as now recognized. Comparison of the two figures on plate 9 with the foregoing statement of generic characters leaves not the slighest doubt that we have here a well marked representative of *Macrostylocrinus*, which on passing over from the Silurian to the Devonian has undergone some striking changes.

The outstanding difference from all previously described species lies in the number of arms, and their recumbent habitus. Instead of being limited to 10, the arms occur in clusters of 5 to the ray, perhaps 4 in two of them, given a total of 23 to 25 arms, the bifurcations being indicated in the tegmen by nodose axillary ambulacrals. The mode of articulation is such that their facets are directed downwards from underneath a projection, or overhang, from the edge of the tegmen, which is thus broader by at least a fourth than the calyx at the arm bases. Accordingly the tegmen is left free and clear as a smooth roof, and the arms, heavy and closely apposed, form a closed fringe or curtain about the calyx, meeting by their distal ends around the stem, and having their outer sides thickly studded with strong pinnules. They do not, however, in this species press closely against the calyx wall so as to leave indentations, as in some other forms, but there is an open space between the calyx and the dorsal side of the arms, so that in case of fracture in the region of the arm bases the calyx may come loose and separate freely from the curtain of arms which surrounds it, as actually happened with the two largest specimens.

In the series of specimens obtained there are 14 individuals, and in all of them, without a single exception, the arms are firmly and regularly fixed in the position above described—a fact which seems to warrant the conclusion that this habitus is associated with a definite structure, and is not a temporary condition due to casual movements of highly flexible appendages.

As to minor details: The anal series is strongly developed in this species, forming a more prominent ridge than usual in the Silurian species, being especially conspicuous when seen from the tegmen. The stem is constructed of very short columnals, one of which projects at intervals of five or six, with a beaded perimeter.

In point of size, this species presents a wide difference from all the others, which, as stated, are usually small, the largest, and latest in age, *M. meeki* Lyon, of the later Niagaran, having the calyx 20 mm. high and 22 mm. wide at the arm bases; whereas our two specimens with the calyx exposed are about 25 mm. high and 25 mm. wide at the arm bases. Measured from the surface of the tegmen to the distal end of the pendent arms where they close around the stem, and in width over all at the outside of the pinnules, these dimensions are about 35 mm. and 32 mm. respectively. In figure 1, and in two other specimens not figured, the same measurements give 40 mm. in height and 37 mm. in width.

But this by no means represents the maximum dimensions of the species, for among the 14 specimens, all from the same layer and locality, are two from which the calyx, including tegmen and arm bases, is broken away, that were more than three times as large. Only the hollow shell remains, containing the closely apposed arms from an irregular fractured edge below the arm bases to the distal end. That much of the crown is 12.5 cm. high and 7.5 cm. wide. Inasmuch as one-seventh of the individuals attain this great size, it is clear that the optimum for this species is far beyond that for any of the Silurian forms.

Horizon and locality.—Lower Devonian, Oriskany; Cumberland, Maryland. The specimens occur in a friable calcareous sandstone, associated with *Edriocrinus*, *Technocrinus*, and numerous other forms peculiar to that horizon. The fossils as found have been leached by the percolation of water, carrying away the calcareous material, and partially replacing it by silica. By this leaching the finer surface markings have been obliterated. The series of specimens under consideration are part of a large collection made by Frank Hartley and acquired by me many years ago; but they have remained undescribed until now for want of time.

Some other occurrences of this nature, not all new species, which should be further illustrated, will be here discussed.

Genus GILBERTSOCRINUS Phillips

Devonian to Keokuk.

GILBERTSOCRINUS DISPANSUS Wachsmuth and Springer

Plate 10, fig. 1

Gilbertsocrinus dispansus WACHSMUTH and SPRINGER, North Amer. Crin-Cam., 1897, p. 233.

In most of the species of this genus in which the arms are known they tend to hang downward over the cup, emerging beneath an overhang at the edge of the tegmen. One of the species in which the arms are not pendent, *G. tuberculatus* of the Burlington limestone, is so closely similar to one of the same formation in which they are that the two can scarcely be differentiated by other characters. In a species from the Keokuk limestone of Indiana, *G. dispansus*[17] it now appears from specimens obtained since the description was made that sometimes the arms, which are extremely long and slender, after extending downward for a part of their length bend backward upon themselves and are directed upward toward the tegmen, with the result that the ambulacral furrows and pinnules in one part of the arm appear to be upon the outside, and in another upon the inside (pl. 10, fig. 1). It is rare to find these two conditions completely shown in one specimen, as is fortunately the case in the one I have figured; and their presence separately in different specimens has led to some curious theories touching the properties of arms peculiar to this crinoid. This was probably the occasion of the erroneous figure by Meek and Worthen in the second volume of the Geological Survey of Illinois (p. 220), in which the arms are pictured as recumbent over the dorsal cup, but with the ventral side underneath, and as to which the authors say, on page 221:

> In the above cut the minute true arms of the typical species of *Goniasteroidocrinus* are seen to branch so as to form nine to each ray. The cut shows only their outside, on which we have seen no indications of ambulacral furrows; these may have been obliterated in cleaning the specimen, or possibly they may present the anomalous character of being on the *under side* and thus differ from those of all other known crinoids.

Horizon and locality.—Mississippian, Keokuk limestone, lower horizon; Indian Creek, Indiana.

Genus PLATYCRINUS Miller

Devonian through Lower Carboniferous.

PLATYCRINUS PENDENS Wachsmuth and Springer

Plate 9, figs. 5, 5*a*

Platycrinus pendens WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, p. 647.

Among the vast number of species of *Platycrinus* which were treated by Wachsmuth and Springer in the Camerata Monograph,

[17] Wachsmuth and Springer, N. A. Crin. Cam., p. 240, pl. 15, figs. 2*a*–*d*.

there were none which showed any indication of recumbent arms. In the closely related *Eucladocrinus* the long radial extensions, or tubular appendages, frequently show a tendency to bend backward over the calyx, but always the true arms are folded over the ventral side; even in cases like that of *E. tuberosus*[18], where the tegmen is strongly hemispherical, and the arm bases are directed far below the horizontal, the arms fold in the normal way. The same thing may be said of other genera with hemispheric calyx, like *Megistocrinus*, *Agaricocrinus*, etc.

In recent years, however, I have obtained two specimens of *Platycrinus* from the well known locality of Le Grand, Iowa, but at a different horizon from that of the numerous species heretofore described, in which the arms are compactly folded backward upon the calyx and stem, and apparently fixed in that position, after the manner of *Barrandeocrinus* and *Acrocrinus*. The calyx in both is completely enveloped, and can only be partially exposed, considerably distorted, in one of them. We know that the species belongs to *Platycrinus*, because both specimens have the twisted, elliptic stem. Of other characters little can be said, and the position of the arms must distinguish the species. I am giving two views of one specimen; the other is slightly larger, and equally characteristic as to the arms.

Horizon and locality.—Mississippian, Kinderhook group, lower horizon; Le Grand, Iowa.

Genus DICHOCRINUS Münster

Plate 11

Dichocrinus Wachsmuth and Springer, North Amer. Crin. Cam., 1897, p. 753.

Lower Carboniferous, Kinderhook to Chester.

Among the changes to which this highly variable genus and its allies were subject, the recumbent arm took a strong hold. This was illustrated by Wachsmuth and Springer under their species *Dichocrinus pendens* from the Burlington limestone[19], and I am now giving some additional figures of it, including one of a specimen with the complete stem and crown, partly to show the persistence of this character, several specimens having now been found, and partly to exhibit the *Dichocrinus* stem as usually seen, in comparison with one of its remarkable variations (pl. 11, figs. 4, 7). The first is without cirri, except in the form of distal root branches, while the latter has cirri in regular whorls, beginning in the upper region of the stem, of such an extraordinary length that they completely envelop the

[18] North Amer. Crin. Cam., pl. 72, figs. 4*a*, 6*c*.

[19] Idem, p. 774, pl. 78, fig. 15.

calyx, and probably the arms, which are broken off. While there is no trace either of coiling or bilateralism, yet the peculiar behavior of the cirri in this specimen should be considered in connection with what was later developed under *Camptocrinus*.

Wachsmuth and Springer at the same time described from the Warsaw group another species, *Dichocrinus oblongus*[20], founded upon a unique specimen having only the calyx preserved. Specimens subsequently obtained with the arms attached show that these are of the recumbent variety, and I am accordingly illustrating the species anew (pl. 11, figs. 5, 6).

In these two species, however, as I see them now, there does not seem to be quite the same structural type, or mode of attachment of the arms, that we have in the preceding examples. The arms are not so compactly placed, nor connected in the tegmen by their covering plates, and their appearance seems more like that of ordinary bending backward as the result of great flexibility.

Genus ACROCRINUS Yandell

Plates 9, 12, and 18

Acrocrinus YANDELL, Amer. Journ. Sci. and Arts, vol. 20, 1855, p. 135.—WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, p. 805.—BATHER, Lankester Zoology, pt. 3, 1900, p. 159.

Carboniferous, Burlington to Pennsylvanian.

Of a very different character from those last mentioned are the arms of *Acrocrinus*, the last successor in the family Hexacrinidae, which is thoroughly illustrated in the Camerata monograph (pl. 80). In this form we have in one species a perfect example of the recumbent arm structure as I have described it, in which not only are the arms compactly placed, in close contact, connected in the tegmen so as to restrict motion, directed downward from the edge of the tegmen and closing around the stem, but the calyx is marked by numerous longitudinal impressions following the course of the arms and formed by the continued pressure of the arms from their dorsal side. I think there is no doubt that they grew in that way, and that the mode of life of this species was to have the arms completely recurved with the pinnules on the outside.

The species in which the recumbent arm occurs, *Acrocrinus amphora* Wachsmuth and Springer, came from a single colony at Huntsville, Alabama, in the Ohara formation of the lower Chester (formerly referred to the St. Louis), in which it was fairly abundant. Upwards of sixty specimens were collected by Wachsmuth, and with one or two imperfect exceptions the structure as above set

[20] North Amer. Crin. Cam., p. 759, pl. 78, fig. 9.

forth is constant throughout. But this does not apply to the type species, *A. shumardi*, which is from a higher horizon, the Glen Dean formation of the upper Chester; of this five specimens are known, and in every one of them the arms are erect, and there is no sign of indentations upon the calyx, while the species is well characterized otherwise by the less height and greater width of the radial plates.

Therefore it must be conceded that while this specialization has nothing to do with the genus as a controlling character, since in five of the genera in which it occurs both types of arms are found, it does hold good for the species.

While reference should be had to the ample illustrations given by Wachsmuth and Springer on plate 80 of the Camerata monograph, some of which I reproduce, I am for convenience giving some additional figures, especially a new one of the rarer species, *A. shumardi.*

ADDITIONAL ELEMENTS IN THE CALYX

In connection with the genera last above discussed, another singular modification is to be considered.

As before stated, the dorsal cup of a crinoid consists primarily of a circlet of radials supporting the arms, and one or two rings of basals below them, plus interradial structures if present. While the latter may or may not be present, and when present are regarded as secondary elements which exhibit a wide range of variation in form and number, any departure from the normal two, or three, rings of primary plates has been considered as extremely exceptional. Therefore the occurrence of numerous additional sets or series of plates between the radial and basal circlets in *Acrocrinus*, the last survivor of the Camerata, has been regarded as a structure *sui generis*, appearing suddenly at the end of the series, as a reversion to their cystid ancestry.

While such a multiplication of plates is not uncommon among the irregular, many-plated cystid types, the definite insertion of an extra ring of primary plates in a form of otherwise regular construction is to be noted in the Ordovician genus *Macrocystella*, thus producing a dorsal cup of 4 rings of plates. This modification was not followed up in either of the orders of the crinoids. But it is now of interest to note that the extensive development of such additional plates in *Acrocrinus* is not the sudden occurrence that we have hitherto supposed, but is the culmination of one of the several remarkable modifications that took place in the generic types represented by *Dichocrinus* and its derivitives. As evidence of this fact I am able to offer well-marked specimens of two species from widely different horizons.

ACROCRINUS PRAECURSOR, new species

Plate 12, fig. 1

I have given this name to an isolated specimen from the Burlington limestone consisting of the calyx and part of the cuneate arms, somewhat displaced, at first supposed to be merely an abnormal *Dichocrinus.* The bisected base and the radials with the interposed anal plate are distinct, and in good condition. Between these two primitive rings of plates is interpolated a wide band of supplementary pieces occupying more than half the total height of the dorsal cup. Those next to the radials are more than half their size, and form a ring alternating with them; from there down to the basals the plates diminish rapidly in size, and the alternation becomes irregular, but represents the equivalent of at least three additional rings of plates. The smaller size of the lower plates would indicate that they were the latest formed. The anal plate, which is fully as large as the radials, is succeeded downward by a diminishing vertical series of three plates in line with the interbasal suture.

As compared with species of *Dichocrinus* in the same formation the radials are very much shorter, the space which they ordinarily occupy being in part taken by the anomalous additional plates. As the relative height of the radials becomes important, the following measurements of the type specimen may be noted: total height of calyx 9 mm.; of radials 2.5 mm.; of basals 1.5 mm.; of band of supplementary plates 5 mm. Thus the radials occupy 27 per cent of the height of the cup; whereas in four of the principal species of *Dichocrinus* of the Upper Burlington limestone the radials constitute from 60 to 66 per cent of the height of the cup; and in no other species from any formation do they occupy less than 50 per cent. In other words, these are not the radials of *Dichocrinus.* The arms, ten in number, and relatively slender, are somewhat displaced in the fossil, and those which appear directly above the anal series do not belong there.

From the fact that no such a specimen has ever been seen before in all the numerous collections made at Burlington during more than half a century, it might be suggested that this is a mere sporadic occurrence. And perhaps it is. Nevertheless it is a definite structure, foreshadowing one of the most remarkable derivatives of *Dichocrinus*, and containing all its essential characters; therefore a place for it must be found. The question is whether to call it a delayed *Dichocrinus* or a premature *Acrocrinus?* This question has in fact been answered in advance; for just such a contingency as is here presented was provided for by Wachsmuth and Springer in the Camerata Monograph, when in discussing these genera we said on page 804:

The introduction of a narrow belt of supplementary pieces between the basals and radials would be sufficient to transform any *Dichocrinus* into an *Acrocrinus*.

When along with this is correlated the further fact that the radials in this form, by reason of their extreme relative shortness, are not the radials of *Dichocrinus* but of *Acrocrinus*, the conclusion logically follows that it is best placed under the latter genus.

This means that the tendency to this new specialization by way of multiplication of calyx plates began earlier than has been supposed; and it will be shown by the next following species that its development to the extreme stage attained by the typical *Acrocrinus* was by a further gradual process.

It may be here observed that along with all these various derivatives of *Dichocrinus* the strong parent genus continued to carry on to the end of the lower Carboniferous, where it is represented by a well defined species, *D. superstes*, occurring in the latest formation of the Chester. The only one that survived it was *Acrocrinus*, which held over into the Coal Measures with a degenerate species having only six bands of supplementary plates, actually less like the typical form than is the species just described.

Horizon and locality.—Mississippian, Upper Burlington limestone; Burlington, Iowa.

ACROCRINUS INTERMEDIUS, new species

Plate 12, figs. 2–5

In this species, presenting a further immature or rudimentary stage of the genus, we are not obliged to rely upon an isolated individual, but are fortunate in the possession of a series of excellent specimens from a single colony, by which all the characters of this type are thoroughly illustrated. They were found by Frederick Braun while collecting for me in the season of 1913 [21] in Monroe County, Illinois, as a part of a considerable colony of well preserved crinoids from a formation in the lower part of the Chester now designated by the Geological Survey of Illinois as the Renault formation.

The material consists of two nearly complete specimens, with arms and stem well preserved, and two calices which contribute important information. All agree in having a band of supplementary plates, of either two or of three rings, which diminish downwards, intercalated between the bisected base and the radials: the plates of the successive rings above the basals alternate regularly except at the posterior side, where there is a vertical series below the anal. Above

[21] Explorations and Fieldwork of the Smithsonian Institution in 1913. Smithson. Misc. Coll., vol. 63, no. 8, pp. 14–16.

the anal plate, and back from the edge, is a pyramid of small plates marking an opening through the tegmen. As in the preceding species, the radials are relatively short, their average height in the four specimens being 32 per cent out of a total of 6 to 7 mm. The calyx is well elongated and conical, with curved sides; height to width at the top being as 1.5 to 1, and at the base as 1.5 to .27. The species is small, the four specimens varying but little from 6 mm. in height of cup.

The arms are relatively strong, biserial, erect, and closely fringed with long pinnules. The stem is composed of rounded, nearly equal columnals, about half as long as wide, increasing somewhat in width distally; this is not so evident in one of the figures because not well exposed in the matrix.

The striking feature of this series of specimens is the extreme regularity of their construction, with the single exception of the number of ranges of the supplementary plates; two of the specimens having two ranges, one three, and the fourth, which is considerably crushed, apparently has partly both. Thus the addition of the inserted plates is a definite structure, somewhat plastic, heralding their great development to the twenty circlets of the typical *Acrocrinus*. Presumably the new species preceded the latter in time, but our knowledge of the stratigraphy of their occurrence is not sufficiently minute to furnish the proof of it. *A. shumardi*, from the Glen Dean formation of the Upper Chester, is, of course, later than the present species. *A. amphora*, from the Ohara formation, may be of approximately equivalent age; both of these species being from a different region. But there is a third very rare species, *A. urnaeformis*, in the same mature stage, described by Hall from the same region in Illinois as our species,[22] of which there can be no doubt, as I found a well marked specimen of it in the same layer which produced the types herein described; so that while the matured form continued into the later formations, with our present knowledge it must be considered that both forms existed together at one period.

As a result of the facts brought out under the last two heads, we have in the concurrent development in the genus *Dichocrinus* and its derivatives of two such striking characters as the recumbent arms and an added calyx element, a remarkable example of long preparation for an eventual culmination which is to mark the extinction of the order to which it belongs.

Horizon and locality.—Mississippian, lower Chester, Renault formation; Burksville. Monroe County. Illinois.

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[22] Geol. Iowa, pt. 2, 1858, p. 690, pl. 25, figs. 11*a*, *b*.

The following species are also illustrated for comparison:

ACROCRINUS SHUMARDI Yandell

Plate 12, figs 6, 7

Acrocrinus shumardi YANDELL, Amer. Journ. Sci., vol. 20, 1855, p. 135.—WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, p. 806, pl. 80, figs. 1–3.

Upper Chester, Glen Dean formation; Grayson County, Kentucky.

ACROCRINUS AMPHORA Wachsmuth and Springer

Plates 9, figs. 8, 9; plate 12, figs. 8, 9; plate 18, fig. 4

Acrocrinus amphora WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, p. 808, pl. 80, figs. 4–9.

Lower Chester, Ohara formation; Huntsville, Alabama.

ACROCRINUS WORTHENI Wachsmuth

Plate 12, fig. 10

Acrocrinus wortheni WACHSMUTH, Geol. Surv. Illinois, vol. 7, 1882, p. 343, pl. 30, fig. 13.—WACHSMUTH and SPRINGER, N. A. Crin. Cam., 1897, p. 807, pl. 80, figs. 10*a*, *b*.

Coal Measures; Peoria County, Illinois.

THE WING-LIKE RADIAL PROCESSES

There still remains to point out another line of productive modification furnished by this fertile genus *Dichocrinus*, leading to a specialization of an entirely different type. In this the major development takes place in the tegmen, at the expense of the arms and the dorsal cup. The arms become short and relatively inconspicuous; the radials small and no longer dominating the cup; the two fair-sized primibrachs of the parent genus have been reduced to a single minute triangular piece, which is often invisible; the large anal plate, which was of similar form and size to the radials, is now a pentangular or more or less wedge-formed piece, narrowing upward, sometimes to an apex below the level of the radials. The chief developmental activity of the skeleton is concentrated in the ambulacral region of the tegmen, where the axillary plate, or radial dome plate, is hypertrophied into a variety of forms, some thin and knife-like; some thick, rounded, club-shaped, or spatulate; and still others bifurcating, until there is produced the wing-like processes of *Pterotocrinus*, structures unlike those seen in any other crinoid. They are analogous to the spines of *Dorycrinus*, but far more specialized and complex; their different forms are shown upon plate 79 of the Camerata monograph.

The essential calyx elements of *Pterotocrinus* are the same as those of *Dichocrinus*, namely, two basals, a ring of radials, and an anal plate in line with them. The line of succession between them through the genus *Talarocrinus*, as was stated by Wachsmuth and Springer when proposing it, is plain and evident. It is intermediate in structure, and partly so in time. While *Dichocrinus* carries its strong and simple calyx through from the Kinderhook to the end of the Lower Carboniferous, *Talarocrinus* as one of its off-shoots begins with an isolated species in the Warsaw, and develops mainly in the lower Chester; and *Pterotocrinus*, although first occurring in one of the lower formations of the Chester, is characteristically a genus of the upper Chester. *Talarocrinus* was short lived, sharply limited in time, and is found by the geologists to be an excellent horizon marker. (See pls. 13, 14.)

Talarocrinus has the same basals, radials, and anal plate as *Dichocrinus*, but drops one primibrach, retaining a small triangular axillary. In *Pterotocrinus* the minute primibrach, sometimes invisible, is followed by single secundibrachs, also axillary, which often together with the outer tertibrachs rest almost horizontally within the radial facet and are suturally connected with it, so that the ray to that extent is not free, but is incorporated in the dorsal cup. The *Talarocrinus* tegmen enlarges with a variety of more or less tumid plates, among which the axillary ambulacral especially begins to develop into prominence, from low convex to sharp, nodose or spiniferous (pl. 13, figs. 1–15; pl. 14, fig. 6). Not all of these plates are so modified; among several hundred well preserved specimens in which the general tendency can be observed, it appears that about half of them are distinctly enlarged. Some of these are shown by figures on plate 78 of the Camerata mongraph, and the genus has also been extensively illustrated by Ulrich[23] and by Weller,[24] from whose figures the many variations can be studied in detail.

The modified ambulacral in *Pterotocrinus* is seated in a distinct facet, from which it sometimes falls out (pl. 13, fig. 20), and the same thing occurs in *Talarocrinus* (pl. 13, fig. 13). Along with these tendencies, it is now further instructive to see that occasionally in *Talarocrinus* the anal plate is reduced to the acuminate piece of *Pterotocrinus* (pl. 13, fig. 5).

[23] Mississippian formations of western Kentucky, 1917, pls. 8, 9, 10.

[24] Illinois State Geol. Surv. Bulletin 41, 1920, pl. 6.

Genus PTEROTOCRINUS Lyon and Casseday

Plates 13, 14

Asterocrinus LYON, Geol. Rep. Kentucky, vol. 3, 1857, p. 472.—*Pterotocrinus* LYON and CASSEDAY, Amer. Journ. Sci. and Arts, vol. 29, 1860, p. 68.—WACHSMUTH and SPRINGER, Rev. Pal., pt. 2, 1881, p. 87; North Amer. Crin. Cam., 1897, p. 791.
Mississippian, Upper Chester.

This genus was proposed by Lyon under the name *Asterocrinus* with two species, *A. capitalis* and *A. coronarius*, which being preoccupied was afterwards changed by Lyon and Casseday to *Pterotocrinus*, and three new species described. The several species are illustrated by Wachsmuth and Springer;[25] but I am adding some new figures, 1, to illustrate a species of Lyon and Casseday that was never figured; 2, to clarify the account of the most remarkable of all the species, not hitherto understood for lack of proper illustration; and 3, to give along with them a good representation of the other leading species.

PTEROTOCRINUS RUGOSUS Lyon and Casseday

Plate 13, figs. 17–20

Pterotocrinus rugosus LYON and CASSEDAY, Amer. Journ. Sci. and Arts, vol. 29, 1860, p. 71.

The description, unaccompanied by any figure, is as follows:

> The condition of our specimen is such that a particular description can not be made; the arrangement of the parts, however, is evidently quite similar to that of *P. depressus*. The basals, first, second, and third radials are present, together with parts of the wings and a portion of one of the arms. This species differs remarkably from *P. depressus* in the greater thickness of the pieces, prominence of the base, the knobby protuberances upon it and upon the first radials, the depth of the columnar pit, as well as by its roughness and more robust appearance.

This species was founded upon a "single crushed and imperfect specimen," which I am now figuring after being developed by further preparation, together with three other calices which confirm the description very clearly. This new material shows that instead of being conspecific with *Pt. acutus*, as Wachsmuth and Springer[26] thought it might be, this form is a very well marked variation of the type of *Pt. depressus*, from which it is distinguishable, as the authors pointed out, by the characters of the base.

Horizon and locality.—Mississippian, Upper Chester, Glen Dean formation; Falls of Rough Creek, Breckinridge County, Kentucky.

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[25] North Amer. Crin. Cam., 1897, p. 79.
[26] Idem, p. 801.

PTEROTOCRINUS CORONARIUS Lyon

Plate 14, figs. 1–3*a*

Asterocrinus (?) *coronarius* Lyon, Geol. Surv. Kentucky, vol. 3, 1857, p. 476, pl. 1, figs. 1, 1*a*.

Pterotocrinus coronarius Lyon and Casseday, Proc. Amer. Acad. Arts and Sci., vol. 4, 1859, p. 302.—Wachsmuth and Springer, Rev. Pal., pt. 2, 1881, p. 91; North Amer. Crin. Cam., 1897, p. 795, pl. 79, figs. 7*a*, *b*.—H. E. Wilson, Journ. Geol., vol. 34, 1916, pl. 3, fig. 11; note by F. S. on p. 492.

This species has a singular history. As originally described by Lyon, the type consisted of the tegmen only, being as stated by him a "unique crinoidal fragment," having "neither basal, radial nor arm plates." When Wachsmuth and Springer borrowed the type for description in the Camerata monograph we received the same specimen, and thus figured only the tegmen with the ponderous wing plates. While that work was going through the press I discovered in the Museum of Comparative Zoology at Harvard a lead cast of what was apparently the same specimen, but with the complete dorsal cup attached. No explanation of this fact was to be found, but I made a record of it in a footnote to page 795 of the monograph. When in 1903 I acquired the collection of the deceased Col. Sydney S. Lyon, I found associated with the tegmen constituting the published type the dorsal cup reproduced in the cast; the two parts were separated, but I have again united them in the position shown by the cast.

I was informed by Colonel Lyon's son, Victor W. Lyon, himself an experienced collector, that the two pieces were found together but detached; and from their color, size and lithological appearance there is every reason to believe that they pertained to the same individual. Mr. Lyon was of the opinion that subsequent to the description in the Kentucky Report his father became convinced that the fragments belonged together and accordingly united them, made and distributed the casts among his correspondents with the intention of amending the description when opportunity offered. This was prevented by the intervention of the Civil War through which he was an officer in the Federal army; the specimens were afterwards separated during one of the periodic inundations of the Ohio River by which the collection was submerged. The fact that they belong to the same species is proved beyond question by another specimen found associated with them having the same dorsal cup with one of the wing plates attached (pl. 14, fig. 2). Along with these, all from the same locality, is a third good cup and two other fragments—so that there is now in hand abundant material for the elucidation of the species. As now understood, the structure of the dorsal cup is fully as anomalous as that of the tegmen, presenting a wide departure from all other species of the genus.

In this species the basal plates are very small and flat, while the radials are of enormous size, larger than all the other plates of the cup combined; this being the reverse of the structure in *P. capitalis* and all other known species. In fact, the relative smallness of the radials is one of the striking differences between this genus in its usual form and its predecessors, *Dichocrinus* and *Talarocrinus*, while here the radials completely dominate the dorsal side; but instead of having a cylindrical exterior they form large gibbous protuberances, which occupy the greater part of the surface of the cup. The single primibrach and the secundibrachs are relatively large, and, as usual in the genus, the latter are articulated directly with the radial facet.

I am giving figures of the three important specimens upon which the foregoing statements are based. The species is exceedingly rare, no others having been found since Lyon's time among all the extensive collections made from the Chester group, except some isolated plates now thought to belong to it.

Horizon and locality.—Mississippian, lower part of the upper Chester, Golconda formation; Crittenden County, Kentucky. Lyon stated that the species was associated with *Pt.* (*Asterocrinus*) *capitalis*, another unusual form described by him at the same time. Extensive investigations of the Chester formations in recent years by Doctor Weller have shown that the latter species is an exceedingly characteristic fossil of the Golconda formation of Southern Illinois and Kentucky, which he correlates with the lower Okaw division of the Upper Chester, and that it is limited to that horizon. He has found the plates of *capitalis* in Johnson and Pope counties, Illinois.[27] And in a letter of December 29, 1921, he informed me that he had since found fragments of *Pt. coronarius* in the same beds. A species described by Hall in 1858[28] as *Dichocrinus protuberans*, from a fragmentary base, probably is identical with this. It was said to be from Chester, Illinois, which, as collections were made at that time, might mean anywhere in that region.

PTEROTOCRINUS CAPITALIS (Lyon)

Plate 13, fig. 23

Asterocrinus capitalis LYON, Geol. Rep. Kentucky, vol. 3, 1857, p. 472, pl. 3, figs. 1*a–h*.

Pterotocrinus capitalis, LYON and CASSEDAY, Proc. Amer. Acad. Arts and Sci., 1859, p. 301.—WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, p. 794, pl. 79, figs. 6*a*, *b*.

Lower part of upper Chester, Golconda formation; Crittenden County, Kentucky. Johnson and Pope Counties, Illinois.

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[27] Illinois State Geol. Surv. Bull. 41, 1920, p. 184.

[28] Geol. Rep. Iowa, pt. 2, p. 689, pl. 25, fig. 7.

PTEROTOCRINUS PYRAMIDALIS Lyon and Casseday

Plate 13, figs. 21, 22

Pterotocrinus pyramidalis LYON and CASSEDAY, Amer. Journ. Sci., vol. 29, 1860, p. 69.—WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, p. 798, figs. 4*a*, *b*.

Upper Chester, Glen Dean formation; Grayson Springs, Kentucky.

PTEROTOCRINUS DEPRESSUS Lyon and Casseday

Plate 14, figs. 4, 4*a*

Pterotocrinus depressus LYON and CASSEDAY, Amer. Journ. Sci., vol. 29, 1860, p. 68.—WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, p. 796, pl. 79, figs. 2*a–e*.

Upper Chester, Glen Dean formation; Grayson, Pulaski, and Breckinridge Counties, Kentucky.

PTEROTOCRINUS ACUTUS Wetherby

Plate 13, fig. 16

Pterocrinus acutus WETHERBY, Journ. Cincinnati Soc. Nat. Hist., vol. 2, 1879, pl. 11, figs. 2*a–c*.—WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, p. 799, pl. 79, figs. 3*a–g*.

Upper Chester, Glen Dean formation; Pulaski and Breckinridge Counties, Kentucky.

PTEROTOCRINUS BIFURCATUS Wetherby

Plate 14, fig. 5

Pterotocrinus bifurcatus WETHERBY, Journ. Cincinnati Soc. Nat. Hist., vol. 2, 1879, p. 136, pl. 11, figs. 1*a–e*.—WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, p. 801, pl. 79, figs. 9*a*, *b*.

Upper Chester, Glen Dean formation; Sloan's Valley, Pulaski County, Kentucky.

HETEROTOMOUS BRANCHING OF THE ARMS

In order to complete the story of the ramifications of *Dichocrinus*, attention should be called to the species *D. polydactylus* Casseday and Lyon,[29] from the Keokuk limestone, which has gone off upon a new line in regard to arm structure. All other species have dichotomous arms, branching by approximately equal bifurcations. In this one, however, the ray divides into two main branches, from which usually three subordinate branches are given off to the outer side of the dichotom, thus producing one form of unilateral heterotomy—a difference which in other groups has been regarded as sufficient for generic separation. This is not an isolated or sporadic occurrence, for it is one of the strongest species of the genus, from the great

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[29] Proc. Amer. Acad. Arts and Sci., vol. 5, 1860, p. 18. WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, p. 756, pl. 77, figs. 1*a*, *b*.

crinoid colony at Crawfordsville, Indiana, as is evidenced by upwards of fifty good specimens in my own collection, all thoroughly constant in this character.

Furthermore, I have in recent years acquired some specimens of this type from the lower horizon at Indian Creek, which persistently differ from the Crawfordsville form in characters sufficient for specific definition. Both species attain a large size, far larger than any others that have been referred to *Dichocrinus*, the crown in mature specimens being upwards of 10 cm. in height; and in both the posterior interradius in the tegmen is raised into a pyramid as high as the cup, the summit of which lodges the anus.

In view of this pronounced differentiation in arm structure represented by two species, one of which has to be described as new, it seems advisable to place them in a separate genus based on the foregoing characters, for which I propose the name *Paradichocrinus*, with *P. polydactylus* as genotype.

PARADICHOCRINUS, new genus

Mississippian, Keokuk.

PARADICHOCRINUS PLANUS, new species

Plate 10, figs. 2, 3, 4

Similar to *P. polydactylus*, except that the dorsal cup plates are smooth, without nodes or tubercles with which that species is profusely ornamented, and the arms usually give off four subordinate branches to the outer side of the dichotom, making ten arms to the ray; also the specimens average rather larger than those of that species, a maximum crown being 10.5 cm. in height. Five specimens have appeared, all from the Indian Creek colony, in which these characters are well maintained. Three have the arms complete, showing with but a single exception the number constant at ten to the ray, whereas in *P. polydactylus* 36 out of 44 specimens with arms, or 80 per cent of the whole, have 8 arms to the ray, five of the others having 9, and one or two 10. All the specimens agree in lacking the pustulose ornament so conspicuous in *P. polydactylus*, of which for comparison I give a figure showing the base, and another a posterior view of the calyx (pl. 10, figs. 5, 6).

Horizon and locality.—The genus and both species are restricted to the Keokuk limestone of the Mississippian, *P. planus* occurring at Indian Creek, and *P. polydactylus* at Crawfordsville, Indiana.

UNEQUAL RADIALS

Usually the radial plates of a crinoid, as well as the arm structures which they support, are symmetrically arranged, and substantially alike in size and form. Exceptions to this rule must be noted in the cases of compound radials, of a primitive radianal, and of many genera in which there is a regular difference among the rays in the number of arm openings or of arm branches;[30] also some slight irregularities in the size of radials and other plates, as in *Dolatocrinus*.[31] A conspicuous example of complete departure from equality among the radials is furnished by the family Catillocrinidae, in which certain radials regularly exceed the others greatly in size, and bear a greater number of arms, which I have already discussed in a separate paper;[32] and another equally striking by the family Cremacrinidae, in which, in conjunction with the bending of the crown, one or mostly two arms have disappeared, and of those that remain two are peculiarly modified; the group has been elaborately treated by Bather[33] under the name Calceocrinidae. Other isolated instances of defective radiation arising from the loss or atrophy of certain rays may be cited, such as *Atelestocrinus*, *Tribrachiacrinus*, *Trigonocrinus*, *Tetracrinus*, *Lageniocrinus*, *Monobrachiacrinus*, *Embryocrinus*, and other new genera described by Wanner from Timor.

Another remarkable case of this kind is to be seen in the Silurian genus *Cholocrinus* of the Flexibilia, which I have described when treating of that group.[34] In that genus, while the radials themselves are not so very different in size, the arms in the two antero-lateral rays are dwarfed almost to the extent of atrophy. In the discussion I alluded to a species described by Whitfield from the Chester in which an opposite irregularity appears, the antero-lateral rays being disproportionately enlarged. The inequality of the rays in Whitfield's species goes one step farther than that seen in other species, in that while in them it occurs among the different rays of the same specimen, in this it lies also between the two branches of the same ray, taking the form of a distinct and constant hypertrophy of certain arms. I wish here to consider it in somewhat greater detail partly for that reason, and partly because it proves to be related to a genus which is closely associated geologically with some of those just discussed, and which, although one of the most numerous and widely distributed forms of the Chester group, and the subject of frequent mention in crinoid literature upon morphological grounds, has hitherto not been understood, namely:

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[30] Springer, Crinoidea Flexibilia, 1920, p. 171–2.

[31] Springer, Bull. 115, U. S. Nat. Mus., 1921, p. 18.

[32] On the Fossil crinoid family Catillocrinidae, Smithsonian Misc. Coll., vol. 76, 1923, No 3.

[33] Crinoidea of Gotland, 1893, p. 54. Also Jaekel, Philogenie und System, 1918, pp. 86, 88.

[34] Crinoidea Flexibilia, 1920, p. 170.

Genus AGASSIZOCRINUS Owen and Shumard

Plate 15

Agassizocrinus TROOST, Ms., Proc. Amer. Assn. Adv. Sci., 1850, p. 60. Not defined, *nomen nudum*.—OWEN and SHUMARD, Journ. Acad. Nat. Sci. Phila., ser. 2, 1852, p. 93.—SHUMARD, Marcy's Red River Exped., 1854, p. 173.

Astylocrinus ROEMER, Lethaea Geognost., 1855, vol. 1, pl. 2, p. 229.

Agassizocrinus, WACHSMUTH and SPRINGER, Rev. Pal., pt. 3, 1886. p. 262.—S. A. MILLER, N. A. Geol. and Pal., 1889, p. 221.—BATHER, Lankester Zoology, pt. 3, 1900, p. 103.—ZITTEL-EASTMAN, Textb. Pal., 1913, p. 224.[35]

Mississippian, Upper Chester.

The following species, in chronological order, have been described under this genus, or referred to it; all upper Chester unless otherwise stated:

1852. *Agassizocrinus conicus* OWEN and SHUMARD, Journ. Acad. Nat. Sci. Phila., ser. 2, vol. 2, p. 93, pl. 11, fig. 6; Geol. Sur. Iowa, Wis. and Minn., 1852, p. 597, pl. 5B, fig. 6.—MEEK and WORTHEN, Geol. Surv. Ill., vol. 5, 1873, pl. 21, fig. 8.

Elongate conical; no marks for insertion of column; base (IBB) composed of 5 pieces closely adhering, usually anchylosed; IBB cone extremely high, higher than in any species subsequently described; height to width to height of IBB, in mm., 25/17/15. Chester, Illinois.

1852. Also described in the same publication as *Poteriocrinus*, and referred by subsequent authors to this genus: *A tumidus* (Owen and Shumard), p. 90, pl. 11; figs. 3*a*, *b*. *A. occidentalis* (Owen and Shumard), p. 92, pl. 11, figs. 5*a*, *b*. Both Chester, Illinois.

1854. *A dactyliformis* SHUMARD, Marcy's Red River Exped., p. 173, pl. 1, fig. 7. Washington county, Arkansas.

1855. *A. laevis* (ROEMER), Lethaea Geogn., vol. 1, pl. 2, p. 229, pl. 4, figs. 13*a–d* (as *Astylocrinus*). Figs. *b*, *c*, *d* are from the small basal cones found in great abundance on Prairie du Long creek in Randolph county, Illinois; fig. *a* from a nearly complete specimen said by the author to be from Indiana, but the authentic type is from Chester, Illinois.—PICTET, Traité d. Pal., 1857, vol. 4, p. 291, pl. 99, fig. 8; copied from Roemer with some changes, among them inserting a circlet of divided plates above the basal cone, making 4 ranges of plates.—(As *A. dactyliformis* Troost), MEEK and WORTHEN, Ill., vol. 5, 1873, pl. 21, figs. 7*a*, *b*.—S. A. MILLER, North Amer. Geol. and Pal., 1889, p. 221, fig. 240.—TROOST, Ms., *nomen nudum*. Proc. Amer. Assn. Adv. Sci., 1850, p. 60; Bull. 64, U. S. Nat. Mus., 1909, p. 96, pl. 12, fig. 1.

Large, broadly rounded ovate; base fused, with traces of sutures in upper part; IBB more than ⅓ total height of calyx; H to W to IBB 21/19/9. Chester, Illinois.

1858. *A. gibbosus* HALL, Geol. Iowa, pt. 2, p. 686, pl. 25, fig. 6.—WORTHEN, Ill., vol. 5, p. 556, pl. 21, fig. 11.

Small, broadly conical; base fused, IBB not over ⅓ total height of calyx: 12/11/4. Chester, Illinois.

[35] I am not attempting to give complete synonymy under any of the genera, but only such references as will indicate the chief sources of information and facilitate the consideration of the forms under discussion.

1858. *A constrictus* HALL, Iowa, p. 687, pl. 25, fig. 10.
Small, narrow conical; IBB divided, high, constricted, more than ⅓ total height; 14/9/6. Chester, Illinois.

1867. *A. papillatus* WORTHEN, Bull. 1, Illinois State Mus., p. 36; Ill., vol. 7, 1882, p. 315, pl. 29, fig. 17.
Small, subovate, wider than high; IBB divided, with 2 or 3 joints of column attached, very low; 8/11/2. Probably lower Chester, Monroe County, Illinois.

1867. *A. hemisphericus* WORTHEN, Bull. 1, Illinois State Mus., p. 37; Ill., vol. 7, 1882, p. 316, pl. 29, fig. 7.
Small, low, globose, much wider than high; figures show column facet and divided IBB, but description says no column facet; IBB very low; 6/9/1.5. Randolph County, Illinois.

1873. *A. pentagonus* WORTHEN, Ill., vol. 5, p. 556, pl. 21, figs. 10*a*, *b*.
Small, wider than high, pentagonal outline; BB concave; IBB divided, with distinct column facet, low; 13/15/4. Chester, Illinois.

1873. *A. globosus* WORTHEN Ill., vol. 5, p. 557, pl. 21, figs. 12*a*, *b*, *c*.
Small, globose, wider than high; IBB divided, with small, round column facet, very low; 12/14/2. Chester, Illinois.

1873. *A. chesterensis* WORTHEN, Ill., vol. 5, p. 558, pl. 21, fig. 9.
Medium size, ovoid, higher than wide; faint trace of column attachment, but no suture lines visible; IBB low. Chester, Illinois.

1873. *A. carbonarius* WORTHEN, Ill., vol. 5, p. 566, pl. 24, fig. 4.
Fused basal cone only. Coal Measures; Shelby County, Illinois.

1896. *A. ovalis* MILLER and GURLEY, Bull. 9, Illinois State Mus., p. 36, pl. 2, figs. 13, 14.
Medium size, globose; no evidence of a column; IBB very low; 14/15/3. Randolph County, Illinois.

1920. *A. dissimilis* WELLER, Bull. 41, Geol. Surv. Illinois, p. 544, pl. 5, figs. 29, 30.
Small, globose, sutures deeply incised; IBB fused. Lower Chester, Paint Creek formation; St. Clair County, Illinois.

Although the name *Agassizocrinus*, and what was formerly held by some authors to be the type species, *A. dactyliformis*, was given by Troost in 1850, yet it was Owen and Shumard who first published, crediting Troost with the genus, a description and figure of a species of their own, by which the generic characters may be readily recognized; therefore under the law of priority the genus must be credited to them, and their species, *A. conicus*, must be accepted as the genotype. The fact that Shumard two years later, in connection with the description and figure of a species which he called *A. dactyliformis*, published a short account of the genus, crediting both to Troost, does not affect the record with regard to the genus.

Even as to the species the record is peculiarly complicated. The genus is most widely known by the form described by Roemer in the Lethaea Geognostica, 1855, as *Astylocrinus laevis*, with a beautiful figure of what was said to be a "nearly perfect specimen," made from a cast furnished by Shumard, but having the arms considerably restored. This figure, somewhat amended, was copied by Pictet;

and afterwards by Meek and Worthen,[36] but under the name "*Agassizocrinus dactyliformis* Troost," as of a "specimen perfect in all its parts," along with another figure (7*b*) said to be "from a specimen in the State collection"; their figure was in turn copied under the same name by S. A. Miller,[37] and under Roemer's name by Zittel in the Grundzüge (1895, p. 137), and Zittel-Eastman in Text-book of Paleontology, editions of 1896 and 1913 (pp. 162 and 224); thus it was given a wide circulation both in this country and in Europe.

Shumard's description and figure of *A. dactyliformis* in 1854 were made from an imperfect calyx, consisting only of the fused infrabasals and part of the basals, and for any close comparison of species may be disregarded. But none of these publications, although all using Troost's name, brought out the authentic type specimen on which Troost proposed the species, which was not done until 1909, when his monograph was published by the U. S. National Museum, edited by Miss Wood. Hence all the figures based on the Roemer type, either the original or copies, must be called *A. laevis;* and Troost's species, *A. dactyliformis*, must fall under it as a synonym.

The original specimen from which Roemer's figure was made is now in my possession, formerly in the collection of B. F. Shumard, and I am giving photographs of it after some additional preparation (pl. 15, figs. 5, 5*a*). From this it will be seen that while restoring the lacking parts of the arms, Roemer missed the important element of the anal plates, which were not shown in his cast because concealed by the matrix.

In order to have an authentic starting point, I am also figuring the type specimen of Owen and Shumard's genotype, *A. conicus*, now in the United States National Museum (pl. 15, fig. 1). In addition to these, I have prepared a number of figures from complete calices as found in several localities throughout the region in which the genus abounds, among which may be identified some of the numerous species which have been described, based upon the more or less conical or globose form of the calyx (pl. 15). These specimens are also important in connection with the newly discovered leading character of the genus, to be presently explained.

Agassizocrinus is typically a late Chester form. Its earliest observed occurrence is in the upper Ohara, or Renault formation of the lower Chester; but it becomes common in the lower Okaw division of the upper Chester under its local appellations of Golconda, Gasper, etc., and what is known as the *Pentremites godoni* bed. It continues in great abundance in the upper Okaw, Glen Dean, etc.,

[36] Ill., vol. 5, pl. 21, fig. 7*a*.

[37] North Amer. Geol. and Pal. p. 221.

division to the end of the Chester, with which it becomes practically extinct—a single species, *A. carbonarius*, having been recognized by Worthen from an isolated fragment in the Coal Measures of Illinois. As showing the broad distribution of this crinoid, I may add that I found a specimen of the common infrabasal cup at Santa Fe, New Mexico, in a formation on the flank of the Rocky Mountains strongly resembling the upper Chester, but now correlated as Pennsylvanian.

Fragmentary specimens consisting of the detached bases occur throughout the upper Chester by the hundreds at all the principal localities in southern Illinois, Kentucky, Tennessee, Alabama, Virginia, Ohio, and Arkansas. Complete calices are rare, and very few have been seen with any part of the arms attached; but I have been fortunate in obtaining several of these in condition available for the comparison about to be made.

One of the generally accepted traditions about *Agassizocrinus*, and the character by which it is chiefly known and most frequently referred to in morphological discussions, is that it was a stemless crinoid, at least in the adult stage. Shumard describes it thus in the Marcy Report:

> In young individuals the division of the pelvis into 5 pieces is well marked, but in adult age they are usually firmly anchylosed and often all traces of sutures obliterated.

This has been adopted as a settled conclusion by Wachsmuth and Springer and authors generally. Nevertheless the known facts do not bear out this dictum without qualification.

Among 250 specimens of detached bases from the Gasper formation at Huntsville, Alabama, mostly of medium size, from 7 to 15 mm. in diameter, about 200 have the infrabasals anchylosed, while about 35 below medium size and 15 of medium size or larger have traces of infrabasal sutures and column facet; among these one of the largest in all the collections, 20 mm. in width, has the infrabasals well divided on the inside (compare figures 21 and 23 on plate 15 for the two extremes). From the same formation in Breckinridge County, Kentucky, there are about 70 specimens, of which 23 show the infrabasals divided at the inside, 18 at the outside with the column facet traceable, and the remainder have the infrabasals completely anchylosed; these differences are not strictly related to size, some of those with column facet present being among the larger.

Specimens are numerous in the collections from the Glen Dean formation in Grayson and Pulaski counties, Kentucky. Out of upwards of 200, about one-fourth (mostly the smaller ones but also some of above medium size) show infrabasal sutures on the inside; some of fairly average size have the infrabasals distinctly divided, and the column facet present (pl. 15, figs. 10, 11); and also a few have portions of arms. In the remainder the infrabasals are fused.

From the Chester region, upper Okaw, equivalent to the Glen Dean formation of Kentucky, in Randolph and adjoining counties in southern Illinois, from which most of the described species have been derived, there are about 70 specimens; in about 60 of these all traces of infrabasal sutures are absent, while in 10 these plates are divided, and traces of column facet visible. The specimens range from 8 to 20 mm. in diameter. Roemer's type is 19 mm. wide, and shows a sutural division at the upper part of the infrabasals, but no trace of a column facet.

Among the 15 described species, as shown by the descriptions and figures, the following have the infrabasals completely fused, and all trace of column absent: *A. conicus*, *A. dactyliformis*, *A. laevis*, *A. gibbosus*, *A. chesterensis*, *A. dissimilis*, and *A. carbonarius*,=7. These have the infrabasals divided, and a column facet present: *A. occidentalis*, *A. tumidus*, *A. constrictus*, *A. papillatus*, *A. pentagonus*, and *A. globosus*,=6. Of the remaining two, *A. hemisphericus* and *A. ovalis*, the figures show the infrabasals divided, but the descriptions say there is no evidence of a column. Thus at least 40 per cent of the described species had a column, and there is nothing in either figures or descriptions to indicate that these were based upon immature individuals.

On examining the specimens with reference to the fusion of the base several conditions will be found: some have the infrabasals completely anchylosed—usually a good sized cone; some have them well divided, with a facet suitable for the attachment of the column; in some they appear divided only at the inside of the cup; still others have a more or less imperfect division, with suture lines ragged or curving (pl. 15, figs. 18, 19), as if in a transition state, or one in which the sharp definition of the suture is hindered by a restricted mode of growth, accompanied by the formation of zigzag radiating nerve canals, passing out into the wall of the cup instead of down into a stem (pl. 15, fig. 24).

In 1882 Whitfield described a species from the upper zone of the Maxville formation of Ohio, equivalent to the Glen Dean of Kentucky, under the name *Cyathocrinus inequidactylus*.[38] Some years afterwards, finding the name preoccupied, he republished the description, changing the specific name to *C. maxvillensis*.[39] He had three specimens, of which he gave good figures, the arms being partly preserved in two of them. The distinctive character of the

[38] Ann. New York Acad. Sci., vol. 2, p. 219, pl. 9, figs. 5–8.

[39] Idem. vol. 3, Feb. 1891, p. 577, pl. 13, figs. 5–8; Geol. Surv. Ohio, vol. 8, 1893, p. 465, pl. 9, figs. 5–8.

species as defined was the inequality of the arms, the structure of which was described as follows:

Second radials, or first arm plates, smaller than the first radials and narrowing upward; wedge formed above, and each supporting two arms. On the postero-lateral, with the arms slender. On the anterior ray it is short and supports two slender arms; while on the antero-lateral rays they support a slender arm similar to those of the other rays on the anterior side, and on the outer side an arm several times larger and stronger than the others, and composed of longer and stronger plates.

That is to say, there are 10 arms, but those on the axillary faces of the antero-lateral primibrachs are unequal, the branch on each outer face (toward the posterior side) being hypertrophied, thus giving two disproportionately large arms, and eight, much smaller, about equal among themselves.

In one of the specimens the strong antero-lateral arm is preserved to more than an inch. In all three the infrabasals are distinctly divided, forming a rather low conical cup, to which a well developed stem is attached.

Now the radial facets occupy the full width of the radials, and are equipped with a complete muscular articulation, while the anal side is that of the later Poteriocrinidae; so it was long ago evident that this species does not belong to the genus *Cyathocrinus*. Casting about to find a place for it, having meantime acquired an excellent specimen clearly belonging to the species, I was struck with the resemblance of the calyx in all essential characters to that of those species of *Agassizocrinus* having divided infrabasals and a column facet. Upon reviewing my material which has been referred to that genus, I found two specimens with the arms transversely fractured which plainly disclosed in cross section the two hypertrophied arms, precisely as in Whitfield's specimens. In both of these also the infrabasals are divided, and a distinct column facet is present.

Upon making careful measurements I found that the difference in the size of arms was reflected in the width of the radials at the distal facet, which was nearly the same in the two specimens, the mean of the two, in millimeters, being:

ant.	l. ant.	l. post.	r. post.	r. ant.
6.5	7	5.2	5.2	6.7

This suggested the probability that similar measurements might furnish a clue to the existence of unequal arms in specimens in which only the calyx was intact. I thereupon assembled all such specimens supposed to belong to *Agassizocrinus*, from five of the principal regions, and tabulated the data for the width of the radial facets, measured at the outside in 15 of these, of which 6 have the infrabassals divided and the column facet or distinct traces of it present, and 9 have the infrabasals fused. Taking the means for the two sets, I obtained a composite for each, and for the whole, as follows:

	ant.	l. a.	l. p.	r. p.	r. a.
IBB divided	6.1	7	5.6	5.4	7
IBB undivided	6.3	7.3	6.1	5.9	7.1
General average	6.2	7.15	5.8	5.6	7.05

Four specimens not included in the table, while having the same relative widths otherwise, have the anterior radial as wide as, or wider than, the two lateral radials; which indicates that in some specimens the enlargement extended to the anterior ray while the two posterior remained small, which might not be unexpected with an abnormal character like this.

Thus it appears that throughout the entire assemblage of specimens, which includes representatives of the best known species, including some types, the radials differ in width with a certain regularity which is expressed by the mean of all the measurements; and that taking this mean as conclusive evidence of the facts, the two lateral radials exceed the two posterior radials in width by about 1.3 mm., and the anterior radial by about two thirds of that amount—this excess being enough in most cases to accommodate the greater width of arm on one face of the axillary primibrach, the faces of which differ in the proposition of about 3 to 2, or 5 to 3. Also that this difference is not confined to those forms having divided infrabasals and a stem, but is equally pronounced in those having the infrabasals anchylosed and all traces of stem obliterated.

Among the material under consideration are the type specimens of two of the earliest described species of *Agassizocrinus:* 1. That of the genotype, *A. conicus* of Owen and Shumard, U. S. National Museum, Catalogue No. 17937, sent in 1887 from the University of Indiana, where it had been deposited by David Dale Owen, along with other types of species described by him and Shumard in the second of their papers in the Philadelphia Academy of 1852 (those of the first paper being now in the University of Chicago); one radial is not visible (pl. 15, fig. 1). 2. That of Roemer's *A. laevis*, already mentioned. Corresponding measurements of these give the following widths:

	ant.	l. a.	l. p.	r. p.	r. a.
A. conicus	9	10	--------	7	10.5
A. laevis	9	9	8	8	9

Thus we find the same relative excess in width of the lateral radials over the posterior radials. Hence the inequality of radials shown to exist in the specimens generally is now found to be a character in the types of those species which have been considered typical of *Agassizocrinus*, including the genotype itself. Although in these two specimens the anterior radial is also more or less enlarged, as in some others before mentioned, it does not follow that the same inequality of arms extends to that ray. For in the *A. laevis* type I was able, by additional preparation, to expose the distal faces of the axillary primibrachs all around, with the interesting result that while in the antero-lateral rays the faces of the axillary are 6 and 4 mm. respectively, in the anterior ray the faces are equal at 5 mm.—those in the posterior rays being 4.5 mm.; so that while in some specimens the anterior arms may be a little larger than the posterior, there is probably no such hypertrophy or inequality as exists in the latter in Whitfield's species. Not only so, but this specimen as now prepared affords a comparative view of the posterior arms and the antero-lateral arm next to them, by which the greater size of the latter can be plainly seen (pl. 15, fig. 5*a*).

By way of a check upon these observations, and in order to see whether analogous differences might not exist among the rays of other closely related genera, I tabulated the widths of the radial facets in 26 specimens from the same formations and localities, belonging to three species of *Eupachycrinus*, which has the anal side identical with that of *Agassizocrinus*, with the result that the mean width of the five radials differs not exceeding 0.5 mm. between any two of them, and not according to any definite plan. The composite of the 26 is as follows:

ant.	l. a.	l. p.	r. p.	r. a.
8.9	9	8.6	8.5	8.7

The obvious conclusion from these facts is that the anomalous arm structure exhibited in Whitfield's species pertains more or less to the species of *Agassizocrinus* generally, and that the dominant character of the latter genus is not the absence of a stem but the hypertrophy of certain arms in two (perhaps occasionally three) of the rays, producing an asymmetry within the ray itself; that the fusion of infrabasals is not entirely a matter of adult growth (although the elimination of the stem is undoubtedly an adult character in the ontogeny of the crinoids) but that the instability of the base follows a tendency to change directly associated with the abnormal modification of the arms. It may thus be a character which became fixed in certain species, or it may have occurred sporadically or at different stages of growth in different species. Thus F. B. Meek commenting in 1874 on the figures of *Agassizocrinus* on plate 21 of volume 5 of the Illinois Reports says:

Some species, such as those represented by figs. 10 and 12, may even have remained attached by a slender column during their whole life.[40]

The further obvious conclusion follows that Whitfield's species must be referred to *Agassizocrinus* with a modified diagnosis, and that inasmuch as his original specific name was not preoccupied under the genus to which it now proves to belong, it must under the rules of nomenclature be now restored, and the species written *Agassizocrinus inequidactylus* (Whitfield).

I have reserved for special mention the particular specimen which led me to the present investigation, and which by reason of its excellent preservation gives us the most striking picture of the remarkable specialization which has developed in this genus. It was acquired with the collection of the late Col. S. S. Lyon, who had recognized its anomalous structure, and, as I have elsewhere stated, proposed to describe it under one of his favorite hyphenated names as *Poteriocrinus brachialis-irregularis.* The two ponderous antero-lateral arms are almost complete, and they show better than the measurements of radials what an enormous difference in size there is between them and the other arms (pl. 15, fig. 13). The specimen has the infrabasals divided, and a column facet with axial opening; and it belongs beyond question to the species described by Whitfield.

In the structure of the anal interradius there is no appreciable difference between the species referred to *Agassizocrinus* and those of *Cromyocrinus* and *Eupachycrinus*, which are all closely associated in geological position. Bather in the Lankester Zoology (pt. 3, p. 103), defined *Agassizocrinus* as "a *Cromyocrinus* that loses its column in adult life, while IBB fuse to a solid mass." With the knowledge furnished by the present investigation we are able to place the definition of *Agassizocrinus* upon a surer basis, distinguishing it from the other two genera by the inequality of the radii due to the greater size of the two lateral rays, and of one of the arms of which they are composed, and perhaps exceptionally of the anterior ray also. This will be irrespective of the presence or absence of a stem, although the strong tendency to fusion of the base and elimination of the stem is recognized:

Genus AGASSIZOCRINUS Owen and Shumard

Poteriorcrininae with calyx elongate to pyriform. Infrabasals five, with facet for round column often present, but more frequently fused into a rounded conical base, on which all trace of column is wanting. Radials unequal, those of the two lateral rays (and some-

[40] Amer. Journ. Sci., vol. 7, p. 484.

times the anterior) larger than the others; primibrachs usually one, that of the lateral rays unsymmetric, and supporting on the longer articular face a greatly hypertrophied arm. Arms ten, unequal, uniserial, brachials mostly quadrangular; pinnules small and closely packed. Ventral sac unknown, probably inconspicuous or wanting.

Distribution.—Carboniferous, Chester to Pennsylvanian.

There must now be added to the list of species given above:

AGASSIZOCRINUS INEQUIDACTYLUS (Whitfield)

Cyathocrinus inequidactylus, Ann. New York Acad. Sci., vol. 2, 1882, p. 219, pl. 9, figs. 5–8.

Cyathocrinus maxvillensis WHITFIELD, Ann. New York Acad. Sci., vol. 5, 1891, p. 557, pl. 13, figs. 5–8; Geol. Surv. Ohio, vol. 7, 1893, p. 465, pl. 9, figs. 5–8.—MORSE, Proc. Ohio State Acad. Sci., vol. 5, 1911, p. 361, 362, figs. 3*a–d*.

Belongs to the subconical type, of medium size, and well characterized by a low cone of perfectly divided infrabasals and a strong stem. Highest part of the Chester, Maxville limestone (upper zone) and Glen Dean formations. Type locality near Newtonville, Clermont County, Ohio; also occurs at Sloan's Valley, Pulaski County, Grayson Springs, Grayson County, and Stephensport, Breckenridge County, all in Kentucky, but has not been reported from the equivalent Okaw of the southern Illinois area.

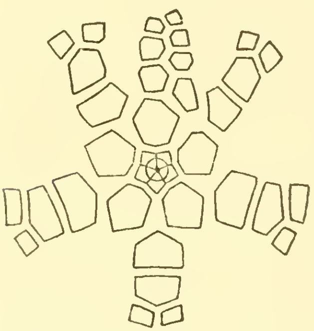

FIG. 1. ANALYSIS OF CALYX OF AGASSIZOCRINUS

Like many other species of the Glen Dean formation this is a wide ranging form. In addition to Whitfield's types from Ohio, four specimens have been found at three widely separated localities in Kentucky, all from the uppermost beds of the Chester; they are figured on plate 15. The nearly conical contour of the calyx and low infrabasal cone are constant in all.

While I am not essaying a critical review of the species of *Agassizocrinus*, yet in view of its profuse occurrence and wide distribution, and the desirability of having the status of the species fixed as far as possible, I will attempt briefly to summarize our information regarding them:

Of the seventeen described species (including Whitfield's and a new species), two-thirds of which are based upon specimens from the vicinity of Chester, Illinois, three may be excluded from consideration because not sufficiently defined to show more than generic characters, namely: *A. dactyliformis* Shumard, *A. tumidus* Owen and Shumard, and *A. carbonarius* Worthen.

Five may be accepted distinguished by well defined special characters, some of which may be only individual variations, namely:

1. *A. conicus* Owen and Shumard, by its strictly conical and very elongate form, large size, and great relative height of the infrabasal cone, which is more than half the height of the calyx (pl. 15, fig. 1).

2. *A. laevis* Roemer, by its broadly rounded, ovoid calyx, of which the base is more than one-third its height (pl. 15, fig. 5); this includes Troost's Ms. species, *A dactyliformis*, and the specimen figured by Meek and Worthen in Illinois (vol. 5, pl. 21, fig. 7).

3. *A. constrictus* Hall, by its very elongate, narrow calyx, and constricted base.

4. *A. pentagonus* Worthen, by its pentagonal outline, and concave basal plates.

5. *A. dissimilis* Weller, by its deeply incised sutures.

Nos. 1, 2, and 5 have the infrabasals fused.

Of the remaining species, which include three synonyms, six might be arranged, for want of any better criterion, according to the general form of the calyx as used in many of the descriptions, whether subconical, ovoid, or globose; to which may be usefully added the relative height of the infrabasal cone or disk:

6. *A. gibbosus* Hall, syn. *A. chesterensis* Worthen; subconical, but much more rounded and less elongate than *conicus*, both as to the entire calyx and the infrabasal cone, the height being slightly more than the greatest width, and the infrabasals one-fourth to one-third the height of calyx; infrabasals fused (pl. 15, fig. 8).

Widely distributed, found in all the principal Chester areas.

7. *A. inequidactylus* (Whitfield); similar to last, only having infrabasals divided and a column; and being more elongate and more distinctly conical in form (pl. 15, figs. 10–13).

8. *A. papillatus* Worthen, syn. *A. hemisphericus* Worthen; and (?) *A. occidentalis* Owen and Shumard; calyx globose, wider than high; infrabasals forming a low disk, less than one-fourth the height of calyx, divided, with a column facet. *A. occidentalis* is included here with a (?); if the characters were certain it would have to head the group, being earliest in date. Probably from the Paint Creek formation, a lower horizon than all the others except No. 5.

9. *A. globosus* Worthen; characters not materially different from the last, but it is slightly larger, and from a higher horizon, being characteristic of the Gasper formation, especially in Breckrenridge County, Kentucky (pl. 15, fig. 14).

10. *A. ovalis* Miller and Gurley; same as last, except that while the figures show divided infrabasals, the descriptions say there is no evidence of a column (pl. 15, figs. 15, 16, 17).

11. *Agassizocrinus lobatus*, new species. A thoroughly distinct species, from the Gasper formation at Huntsville, Alabama, represented by 12 specimens that only came to light in the collection after the foregoing discussion was prepared. It is remarkable for having the infrabasal cup (which is the only part known) strongly lobed next to the top, and more or less divided, while it is rounded and fused at the bottom. I have figured a set of six of the cups in which these characters are fully shown (pl. 26, figs. 13–18).

As a fairly general rule, it seems that those forms with a well rounded ovoid or globose calyx, combined with very short infrabasals, have mostly a divided base; but the subconical No. 7 has it also.

Thus the recognizable species are reduced to eleven, and it is probable that there are still more synonyms, but the material is not at hand for close comparison of some species.

THE INFLATED VENTRAL SAC

The leading character of the Fistulate division of the Crinoidea Inadunata is the great development of the posterior interradius, which in some genera takes the form of an elongate anal tube with the opening at the distal end, while in others almost the entire tegmen is extended into a closed sac, in which the anal opening, instead of being at the distal end, or at the posterior side, is located at the anterior side of the tube, either at the base, or part way up, sometimes at the end of a lateral spout.

This organ exhibits various forms and modifications, some of which are illustrated by Wachsmuth and Springer on plate 7 of the North American Crinoidea Camerata. It is not my purpose to discuss these structures in detail, further than is desirable to clarify our knowledge in regard to one of them that has hitherto been obscure, and to supply some needed information regarding certain species which for lack of adequate illustration have not hitherto been clearly understood, several of the important ones never having been figured at all. The modification which I wish especially to consider is the one which is characterized by a peculiar reversal in the position of the anal opening, by which in certain forms it emerges at the anterior side instead of the posterior, where it is usually expected. This has been a perplexing fact in the morphology of the group, giving rise to some rather far-fetched theories for its explanation. Later investigations, as I have hitherto stated in the Flexibilia monograph, indicate that there is no essential difference between the "anal tube," such as is found in *Cyathocrinus*, and the "ventral sac," as in *Aulocrinus;* and that all forms of tube in which the anus is not at the distal end may be explained by the recurving of the gut with its enveloping tube in its upward or distal extension, from the vertical toward the anterior side, folding or doubling back upon itself more or less completely, so that the opening may emerge through the wall of the tube at any point between the distal end and the base.

The tendency of the tube, perhaps primarily owing to some obstruction in the early stages, is to expand at or near the point where it is bent, either producing a rounded or nodose enlargement, or developing a variety of peculiar inflated or spiniferous structures, which have been called balloon-shaped or mushroom-shaped. Some of these extend beyond the limits of the arms, surmounting the crown with a conspicuous expanded appendage; others are wholly enclosed by the arms. All are enlarged extensions of a narrow neck by which they are connected with the cup.

This form of sac was especially developed in the Lower Carboniferous, where it is characteristic of a considerable group of genera, beginning in the earliest members, the Kinderhook and Lower Burlington, with the genus *Coeliocrinus*, a variable form, which continued with modifications into some of the later formations, and was succeeded toward the close by *Hydreionocrinus*, which combines one of its forms of sac with a different type of calyx and arm structure, and as thus modified passed on to the Upper Carboniferous. The sac with the infradistal position of the anus is subject to considerable modification in details of structure, and in one form or another occurs as a conspicuous feature in several genera besides the two above named. It is also found associated with different plans of arm arrangement and forms of calyx. As to these characters there is no very stable correlation, and the lack of fixity in this respect is often confusing.

For example: *Pachylocrinus arboreus* (Worthen) and *P. florealis* (Yandell and Shumard) with more or less dichotomous arms, have the opening toward the top, the former somewhat below the bulbous enlargement, and the latter almost at the very top, next to the terminal cluster of a few spiniferous plates (pl. 16, figs. 3–9). *Abrotocrinus unicus* (Hall), with the arms of *Pachylocrinus* somewhat modified but having a pentagonal stem, has the anus about midway (pl. 17, figs. 1–3); as have also *Scytalocrinus* and *Decadocrinus*, with their ten unbranched arms, the former with slender pinnules and the latter with strong armlets or ramules.[41] In *Aulocrinus*, with arms and pinnules of the *Decadocrinus* type, the opening is at about the same height, but projected from a lateral tube (pl. 19).

Zeacrinus, with heterotomous arms and short brachials, exhibits great variation in tube structure: *Z. elegans* of the Burlington has a rounded sac expanding upwards (pl. 21, fig. 2*a*); *Z. commaticus* of the Keokuk has the opening at the base of an elongated sac (pl. 22, fig. 3*a*); while the typical species, *Z. wortheni* of the Chester, has an altogether different form of sac, being a pyramid narrowing upwards to an apex, but having the opening about midway (pl. 23, fig. 2*a*).

Hydreionocrinus, with a highly distinctive spiniferous sac, and the opening in at least one species about midway, has no less than three

[41] North Amer. Crin. Cam., pl. 7, and herein, pl. 17.

different types of arms: *H. wetherbyi* nearly dichotomous, an intermediate stage; *H. depressus* strongly heterotomous, with the branching toward the inner side of the dichotom (pls. 25 and 26); and the British species, *H. woodianus*, with the branching toward the outer side of the dichotom. As if this were not a sufficient confusion of characters, it may be added that the two American species have respectively round and pentagonal stems.

In view of such lack of constancy in the characters of a single genus of this type, it is not certain that the position of the anal opening, as shown in the species above mentioned, will hold good for other species of the respective genera. This unusual development of the sac represents a hypertrophied condition of the organ, and structures modified by that sort of growth are apt to be more or less unstable. In fact the acquisition of large additions to the collection of the later Inadunate genera, since I discussed the Poteriocrinidae in 1911, has disclosed such an intermingling of characters which in other groups are regarded as distinctive, especially in the arrangement of anal structures, as to render the definition of some of these genera, containing a great number of species, perplexing and subject to exceptions.

Returning now to the consideration of the process by which the anal opening came to be upon the anterior side of the sac, it is not necessary to assume any extraordinary change in the organic development of the crinoid to produce this result. It depends merely upon the movements of the gut, which, as I have elsewhere shown,[42] are the cause of great morphological changes, and have produced many modifications in the external form of the calyx. Beginning in its primitive position in the ontogeny of the growing crinoid at one of the corners between the larval basals and orals, it migrates through a great variety of positions, so that the anal opening may issue and be finally fixed in the calyx of the adult crinoid at any point between the level of the radials and the middle of the tegmen. Its general tendency is towards the latter, that is, an upward growth, which finds expression in a greatly elongated central tube, such as that of the Batocrinidae. But this tendency may be diverted by unknown causes, and the course of the gut completely changed. This occurs for example in the Camerate genus *Siphonocrinus*, where in some species, instead of growing upward from its original posterior position, the gut is bent over and continued underneath the plates of the tegmen, passing completely over the oral portion to the anterior side of the calyx, where it opens out at or below the arm regions.[43] This is precisely what has happened in the Inadunate forms under consideration, except that the deflection and recurving occur at a

[42] Crinoidea Flexibilia, pp. 67, 81, 86.

[43] North Amer. Crin. Cam., p. 210, pl. 19, figs. 3*a*, *b*, *c*; and herein, pl. 18, fig. 5.

later stage, involving not only the gut but also its tubular sheath of calcareous plates, and that instead of following a simple curvature continuing along a convex surface, the direction of the tube is more or less suddenly or abruptly reversed. With its upward growth thus arrested, the activity of the organ finds an outlet in different forms of expansion, or abnormal structures, at or near the point where the reversal occurs. As the tube in forms of this group is usually built up of plates arranged in longitudinal columns, it is not difficult to trace the course of these changes.

The simplest case is seen in species of *Pachylocrinus*, such as *P. arboreus* or *P. scoparius* (pl. 16, figs. 3–7; 2), where the tube is greatly curved downward toward the anterior to an opening near or above midway; the walls along the line of contact are coalesced and the curved portion considerably swollen, but not rising beyond the limit of the arms. The longitudinal lines of plates forming the sac are distinctly seen in the swollen part.

In *P. florealis* (pl. 16, figs. 8, 9) the opening lies just below the distal end, and the tube is terminated by four spiniferous plates barely surmounting the arms.

In *Coeliocrinus ventricosus*, where the inflation of the sac is at the distal end and takes the form of a narrow-necked balloon, the longitudinal columns of plates which appear in several of the specimens testify that this is only the hypertrophied part of the tube incident to its reversal of direction (pl. 24, figs. 1–8). The anus has not been observed in this genus, but we know it must have been somewhere in the narrow neck below the inflated part.

Aulocrinus, which with its lateral spout appears to be the most aberrant form of all, really tells the story the best. This may be understood from the figures upon plate 19, made from a remarkable series of specimens in which the spout-like tube is shown in various positions. Here the longitudinal columns of plates are very conspicuous, being marked by sharp ridges, and it will be observed that the number of these columns when seen in a lateral view is considerably greater above the level of the spout than it is below. This results from the doubling of the tube upon itself, and the fusion of the apposed walls of the parts thus brought into contact; the process is completely shown by the two specimens in which the tube is exposed laterally (figs. 2 and 3). In figure 2 the ridged rows of plates can be traced continuously from the original tube into the reversed part.

From these it will be seen that the tube of *Aulocrinus*, instead of being curved and inflated as in the preceding examples, is abruptly reversed, as if it might have been bent, almost to the point of fracture, and the pieces bound together so that the distal end could continue to grow in the opposite direction from before. At the line where the reversal occurred incipient spines were developed, instead of a swollen sac—a modification which became dominant in *Hydreionocrinus*.

Thus the position of the anus on the anterior side depends upon the extent to which the tube grows downward after reversal, and if this is continued far enough the opening will be at the base of the tube, as in "*Scaphiocrinus*" *elegans;* and with the evidence afforded by the above mentioned examples it is clear that its position in all forms where located below the distal end may be accounted for.

The genera characterized by the Inflated Sac fall into a fairly well limited group forming a section of the subfamily Poteriocrininae as defined in the Zittel-Eastman textbook, edition of 1913. It has an extreme range from the earliest Lower Carboniferous through the principal subdivisions and into the Upper Carboniferous, and according to Wanner into the Permian. It reached its acme in variety and abundance in the Burlington and Keokuk, and in extravagance of form in the later formations. Coincident with the establishment of the mushroom form in the Chester, the group began to decline, and to be replaced by a series of genera in which the strong anal tube as a solid structure disappeared, and the anal plates were lifted out of the calyx until they no longer occupied a place within the ring of radials, and ceased to form an integral part of the calyx wall.

This series started with the long-lived *Eupachycrinus*, which began, as I now know, in the Keokuk with a rare and isolated species, and lasted through the Upper Carboniferous; and which, while retaining the strong radianal and anal plates of its predecessors, had only a remnant of the tube. The change progressed through *Cromyocrinus*, *Agassizocrinus*, *Ulocrinus*, *Erisocrinus*, and finally to *Encrinus* in the Trias, when all trace of anal structures in the calyx was lost.

The section with a tube, therefore, all having strong anal plates in the calyx to support it, includes the genera from *Poteriocrinus* to *Scytalocrinus* of the subfamily Poteriocrininae above mentioned, with some additions. In view of the close interrelationships of the genera comprising this group, the need of better description and illustration of some of them, and the presence of some new forms, it is desirable to give, along with the new matter, a general summary of their characters.

In this group, specialized as it is in regard to the ventral sac, there must be recognized, as already intimated, a considerable complexity and intermingling of characters, and the definition of genera is complicated by the occurrence of exceptions in regard to characters which in some other groups are considered to be of generic value. We simply have to select some character that appears to be dominant, and hold to it in spite of exceptions and uncertain correlations.

In the mode of arm branching, for instance, between a ray with two or more subordinate branches always borne on the same side of a main arm, as in *Hydreionocrinus depressus*—heterotomous—and one in which the arms divide by successive nearly equal bifurcations, as in *Pachylocrinus aequalis*—dichotomous— there is a clear distinction. The latter, with two or more full bifurcations, would give 8 or more arms to the ray. But if only 1 arm of the second bifurcation branches, that would give but 6 arms to the ray, making an intermediate condition which may occur under either category, and has to be dealt with according to circumstances, as for example in the heterotomous *Zeacrinus elegans*, or the dichotomous *Pachylocrinus arboreus*. So also the stem varies from circular to pentagonal, occasionally both in one species, and sometimes both in forms not otherwise separable generically. In the case of *Abrotocrinus* I have utilized Miller and Gurley's genus, separated only by this character, because it offers a convenient means of subdividing the unwieldy genus *Pachylocrinus*. It is not a very reliable character in this group. *Pachylocrinus aequalis*, with usually a round stem, has it sometimes pentagonal next to the calyx, and *Abrotocrinus unicus* has the stem both ways, but mostly pentagonal. Again, in *Zeacrinus*, the character most relied on is the very short brachials, which we call quadrangular, notwithstanding the fact that in various specimens some of the lower brachials are clearly cuneiform. Such exceptions, being part of the infinite variety in nature, must not disturb us.

The following table shows the relations of the genera as they appear in the light of present information:

ANALYSIS OF THE GENERA

Subfamily Poteriocrininae.

Section A. Poteriocrininae with elongated ventral sac, in which the anal opening is below the distal end, and at the anterior side. Anal plates, including radianal, strongly developed within the cup.

IBB 5: 2–3 anals in the calyx.
Radial facet round, not filling distal face of R.
  Sac tapering distally to an apex beyond the arms_________ Poteriocrinus.
Radial facet straight, filling distal face of R.
  Sac enlarging distally to a more or less rounded,
    nodose or spiniferous terminal.
  Arms branching on or beyond IIBr.
    Branching usually more than once.
   Dichotomous, uniserial, brachials cuneiform.
    Sac strong, club-shaped, occasionally spinose.

Arms rounded and not abutting.
IBr not more than 2.
Column round ---------- **Pachylocrinus.**
(**Olim Scaphiocrinus**).
Column pentagonal ---------- **Abrotocrinus.**
IBr more than 2. Arms branching unequally beyond them ---------- **Culmicrinus.**
Sac with strong median row of plates ---------- **Liparocrinus.**
Heterotomous.
Brachials cuneiform or biserial, arms not abutting.
Sac balloon-shaped, exceptionally spiniferous.
Cup turbinate ---------- **Coeliocrinus.**
Sac mushroom-shaped, spiniferous.
Cup low, cup-shaped ---------- **Hydreionocrinus.**
Brachials quadrangular, uniserial.
Sac club-shaped or pyramidal.
Arms closely abutting ---------- **Zeacrinus.**
Arms branching once on IIBr.
Arms not abutting; 4 to the ray, exceptionally 3 or 2.
Dichotomous: brachials cuneiform, fairly long ---------- **Ulrichicrinus.**
brachials quadrangular, very short, arms heavy ---------- **Woodocrinus.**
Arms not branching beyond IIBr.
10 main rami, unbranched.
Brachials cuneiform.
Bearing strong ramules.
Cup usually depressed, with flat or concave base.
Anal opening directly through side of sac ---------- **Decadocrinus.**
Anal opening at end of lateral spout ---------- **Aulocrinus.**
Bearing ordinary pinnules.
Cup usually elongate, sometimes obconical to low bowl-shaped, rounded base.
Anal opening directly through sac ---------- **Scytalocrinus.**

Genus PACHYLOCRINUS Wachsmuth and Springer

Plate 16

Scaphiocrinus Hall, Geol. Iowa, pt. 2, 1858, p. 550.—Wachsmuth and Springer, Rev. Pal., pt. 1, 1879, p. 112; pt. 3, 1886, p. 235.

Pachylocrinus Wachsmuth and Springer, Rev. Pal., pt. 1, 1879, p. 115; pt. 3, p. 242.—Springer, New Amer. Foss. Crin., 1911, p. 145.—Zittel-Eastman, Textb. Pal., 1913, p. 222.

Mississippian; Kinderhook to Upper Carboniferous.

The reason for adopting this name for a majority of the great number of species described under *Scaphiocrinus* (*nomen nudum* because its type species belonged to the previously established *Graphiocrinus*) were set forth in my paper of 1911, above cited. It is one of the most prolific and long lived of Carboniferous types, containing, before removal of those with pentagonal stem under *Abrotocrinus*, upwards of 100 described species, ranging from the Kinderhook to the Upper Carboniferous. Although having typically dichotomous arms, it will include some intermediate forms in which there are one or two arms branching unequally to the inner side of the ray, provided these are rounded arms, not abutting as in *Zeacrinus.* Observance of this distinction will help to remedy some of the confusion in the descriptions. The type species, *P. aequalis* (Hall) of the Keokuk,[44] is shown by good figures in Geological Survey of Illinois (vol. 5, pl. 15, fig. 6), in Zittel-Eastman (1913, p. 222, fig. 323), and herein (pl. 16, fig. 1). It is a very abundant species, and specimens are to be seen in almost all collections. Sac and opening are similar to those of *P. arboreus*, but rarely seen.

Other good examples of this type are:

Pachylocrinus (*Poteriocrinus*) *concinnus* Meek and Worthen, Geol. Surv. Illinois, vol. 5, 1873, pl. 14, fig. 3.

Pachylocr. (*Poteriocr.*) *jesupi* Whitfield, Bull. 1, Amer. Mus. Nat. Hist., 1881, pls. 1, 2. Syn. of *P. swallovi*, Meek and Worthen, Geol. Surv. Ill., vol. 2, pl. 16, figs. 4*a*, *b*.

Pachylocr. (*Poteriocr.*) *coxanus* Worthen, Geol. Surv. Illinois, vol. 7, 1883, pl. 27, fig. 1. 12 arms to the ray.

Pachylocr. (*poteriocr.*) *spartarius* Miller and Gurley, Journ. Cin. Soc. Nat. Hist., 1890, pl. 7, figs. 1, 2, 3. 8 arms to the ray.

Notwithstanding the abundance of species belong to this genus, specimens showing the position of the anal opening are rare. To illustrate it I have used two species from the later formations, in one of which the opening is the nearest to the distal end of any I have seen.

PACHYLOCRINUS AQUALIS (Hall)

Plate 16, fig. 10

Scaphiocrinus aqualis Hall, Supp. Geol. Iowa, 1860, p. 83.

Lower Burlington limestone; Burlington, Iowa.

I am figuring a characteristic specimen of this species, which is one of the most conspicuous of its formation, but has not before been illustrated. It attains a large size, some specimens being considerably larger than the one here figured, which I have selected for its excellent showing of the sac. I am glad of the opportunity to furnish an authentic figure of the species, to help clarify the confusion heretofore existing between the name and that of *P. aequalis* of the Keokuk.

PACHYLOCRINUS ARBOREUS (Worthen)

Plate 16, figs. 3–7

Zeacrinus arboreus Worthen, Geol. Surv. Ill., vol. 5, p. 534, pl. 20, fig. 5.—Springer, Amer. Geol., vol. 26, 1900, pl. 16, figs. 18–23.

Chester group, Ohara formation (formerly called St. Louis); Huntsville, Alabama.

This is a prolific species, found in good preservation, and represented in the collection by upwards of one hundred specimens. The

[44] Boston Journ. Nat. Hist., 1861, p. 316.

rounded end of the sac as shown in the figures is constant in form and position in many specimens, and the opening just below it in several. The species belongs to the intermediate type of arm branching, which has caused it sometimes to be labeled *Zeacrinus*, while the resemblance in form of the inflated sac has also led to a reference to *Coeliocrinus.*

PACHYLOCRINUS FLOREALIS (Yandell and Shumard)

Plate 16, figs. 8, 9

Cyathocrinus florealis YANDELL and SHUMARD, Cont. Geol. Kentucky, 1847, p. 24, pl. 1, fig. 1.

Zeacrinus florealis, SHUMARD, Cat. Pal. Foss., 1866, pt. 1 p. 399.

Chester group, Glen Dean formation; Grayson Springs, Kentucky.

Three specimens of this rare species show the same peculiar small spiniferous termination of the sac above the ends of the arms, with the anal opening near the distal end. The wide difference in the structure of the sac between this and the preceding species emphasizes the extreme variability of this character.

Genus ABROTOCRINUS Miller and Gurley

Plates 16, 17

Abrotocrinus MILLER and GURLEY, Journ. Cin. Soc. Nat. Hist., vol. 13, 1890, p. 30; 16th Rep. Geol. Surv. Indiana, 1891, p. 350.

Mississippian; Lower Burlington to Keokuk.

As already mentioned, I have utilized this genus, heretofore ranked as a synonym, to include those species of *Pachylocrinus* which have a pentagonal stem. It offers the medium of a convenient and much needed subdivision of that genus. The character is not a very reliable one, some intermediate forms having the stem pentagonal near the calyx and round lower down. The type species, *Abrotocrinus cymosus* Miller and Gurley,[45] from the Keokuk limestone of Canton, Indiana, is in its arm structure a beautiful example of the *Pachylocrinus* type. I am illustrating two species, one from the Upper Burlington which has never been figured, and one from the Keokuk, showing the median position of the anal opening.

ABROTOCRINUS RUSTICELLUS (White)

Plate 16, fig. 11

Poteriocrinus rusticellus WHITE, Boston Journ. Nat. Hist., vol. 7, 1863, p. 505.

Upper Burlington limestone; Burlington, Iowa.

Another prominent Burlington species, not hitherto understood. There are several specimens even more conspicuous than the one

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[45] Journ. Cin. Soc. Nat. Hist. 1890, pl. 5, fig. 2.

here shown, but I am figuring it because enough of the sac can be seen on the opposite side, although too much shattered for drawing, to show that it was substantially like that of the other species figured, with the opening about midway.

ABROTOCRINUS UNICUS (Hall)

Plate 17, figs. 1–3

Poteriocrinus (*Scaphiocrinus*) *unicus* HALL, Boston Journ. Nat. Hist., 1861, p. 313.—MEEK and WORTHEN, Geol. Surv. Ill., vol. 5, pl. 15, fig. 5.—WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, pl. 7, fig. 6.

Keokuk limestone; Crawfordsville, Indiana.

One of the very prominent species of its celebrated locality, in which the sac with its midway opening is shown by numerous specimens, quite constant throughout. The pentagonal stem, at least next to the calyx, is distinct in more than fifty specimens.

Genus CULMICRINUS Jaekel

Plate 18

Culmicrinus JAEKEL, Philogenie und System der Polmatozen, Pal. Deutschl., Berlin, vol. 3, 1918, p. 62. Untercarb. (Kulm). Pro *Poteriocrinus regularis* H. von Meyer, Herborn. To include *Poteriocr. missouriensis* Shumard.

Devonian to upper Chester.

Under this name Professor Jaekel has included a form which I have had set apart in my collection for many years as a new genus, containing species from at least four different formations. The dominant character is that it has more than two primibrachs, the number actually ranging from five to ten before the first bifurcation, after which the arms branch a few times at long intervals, with rather sparse pinnules borne on cuneiform brachials. The calyx is elongate, turbinate, with round stem. The remarkable thing about this form is its extremely large sac, rising to the full height of the arms, with the anal opening at the very base.

The form with extra primibrachs, varying considerably in other characters, ranges in America from the Chemung through the Waverly or its equivalent into the St. Louis, ending in the upper formation of the Chester. Several Chemung and Portage species have been described by Miss Winifred Goldring under *Liparocrinus* and three other new genera in the Monograph of the Devonian Crinoids just published by the State Museum of New York, and received too late for detailed consideration here. The species from the Waverly equivalent, or basal Mississippian, as yet undescribed, occurs in the form of imperfect impressions in western Pennsylvania. The other two are figured herewith.

CULMICRINUS MISSOURIENSIS (Shumard)

Plate 18, fig. 3

Poteriocrinus missouriensis SHUMARD, Geol. Rep. Missouri, 1857, p. 188, pl. B, figs. *a–c*.
St. Louis limestone; St. Louis, Missouri.

One of the best known fossils in the St. Louis limestone, of which many good specimens have been found with the elongate ventral sac preserved, but it is only in the one herewith figured that the position of the anal opening is definitely fixed at the anterior side close down to the base. The species is notable for the slender, graceful contour of the crown.

In the Revision of Palaeocrinoidea (pt. 1, 1879, p. 114), Wachsmuth and Springer called attention to the fact that this species "differs from all others in this group in having a single arm to each ray, the first bifurcation taking place at the tenth or twelfth plate."

CULMICRINUS ELEGANS (Wachsmuth and Springer)

Plate 18, figs. 1, 1*a*

"*Scaphiocrinus*" *elegans*, WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, pl. 7, figs. 1, 2.
Chester group, Glen Dean formation; Sloan's Valley, Kentucky.

I have figured at full length the type specimen, of which only a partial figure was given in 1897, in order to show the great size of the sac, this being the best known example of the lowest position of the opening. The tube is actually a little longer than is here shown, as it appears in a second specimen from the same locality otherwise not so perfect, which has some nodose plates to mark the change of direction. As in many of the genera of this group, the anterior ray differs from the others, in this case being unbranched.

Genus AULOCRINUS Wachsmuth and Springer

Plate 19.

AULOCRINUS AGASSIZI Wachsmuth and Springer

Aulocrinus agassizi WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, pl. 7, fig. 9.—SPRINGER, Amer. Geol., vol. 26, 1900, pl. 16, figs. 11, 12.
Mississippian; Keokuk group, Indian creek, Montgomery County, Indiana.

A monotypic genus founded on the species *A. agassizi*, figured as above without definition, or description, but based solely upon the extraordinary form of the ventral sac, which with its lateral spout exhibits a specialization without precedent among the crinoids. Aside from this the form is essentially that of *Decadocrinus* as to calyx and arms, but differs in the stem and cirri.

The species *Aulocrinus agassizi* is strongly characterized by sharp and prominent wrinkles upon the calyx plates; the angular and keeled brachials; the well defined pores at the sides of the hexagonal tube plates; and the sharp longitudinal columns in which these plates are arranged. The stem is sharply pentagonal, and is provided with strong cirri, which are not shown upon the plate for want of space. The species is represented by ten specimens, six of which show the lateral spout. I am figuring a series of these to show all aspects of the remarkable structures, including a posterior view of the tube to its full length, and three views of the spout in such positions as enable us to trace the longitudinal ridges along the tube past the point where it doubles upon itself and branches backward into the spout. Especially instructive in this respect is the broken specimen (fig. 3), in which the ridges may be followed without interruption.

ULRICHICRINUS, new genus

Plate 20

Upper Carboniferous; Pennsylvanian.

Between *Pachylocrinus*, *Scytalocrinus*, and *Woodocrinus*. Of a facies somewhat similar to that of *Scytalocrinus*, but has more than 10 long, slender, unbranched arms, bifurcating on the IIBr, both or only one, giving 4 or 3 arms to the ray. Brachials cuneiform, which distinguishes it from *Woodocrinus*, as also does the great relative difference in size of the arms. It has too many bifurcations for *Scytalocrinus* and not enough for *Pachylocrinus*. Calyx conical, spreading from the base about the same as in the turbinate Poteriocrininae generally. The tube has not been exposed, but from the elongate series of strong anal plates it is undoubtedly of the type of the related genera.

This genus is proposed for the reception of a species from the Morrow formation of Oklahoma, based upon specimens collected many years ago by Dr. E. O. Ulrich, while engaged in field work for the U. S. Geological Survey, and now placed in my hands for description by Dr. George T. Girty, in charge of Carboniferous researches for the Survey, which I have been unable to place under any of the described genera. It was, however, found to be congeneric with a well marked species from the Keokuk of Indiana described by S. A. Miller as *Poteriocrinus coryphaeus*, which while represented by numerous good specimens has always made trouble in the collections because it would not fit exactly under any known genus. With this addition the new genus is well distributed. I have pleasure in associating with this interesting form the name of the discoverer, my neighbor and colleague, Dr. E. O. Ulrich, of the United States National Museum, and United States Geological Survey.

ULRICHICRINUS OKLAHOMA, new species

Plate 20, figs. 1, 2

Specimens large, crown about 10 cm. high. Calyx rather low, turbinate; IBr filling distal face of RR. Anal side with strong plates of Poteriocrinid type, with RA; post. B wide, narrowing to a very small apex, barely truncate, followed by a narrow anal plate *x*, with a large RA at the right. IBB rather tall and erect. BB almost as large as RR.

Arms long and deeply rounded, unbranched, pinnulate, of about uniform thickness to near the extremities, where they taper rapidly; they are uniserial, composed of extremely short, cuneate brachials, which in the median portion of the arm interlock to the stage of incipient biseriality, but become uniserial again towards the ends. Hence the pinnules springing from the long faces of the brachials are seen on successive ossicles in the middle portion and on alternate ossicles towards the distal ends. Stem strong, round, composed of alternate long and short columnals, contrasting greatly in length, the shorter ones being almost linear.

The species is to be compared with *Poteriocrinus coryphaeus* S. A. Miller, of the Keokuk limestone, which has flatter and broader arms, with longer brachials in the lower part, but nowhere tending to interlock. Post. B is not quite so narrow at the top, and is of smaller size, but the general type, number and mode of branching of the arms, are substantially the same.

There are two specimens of the new species, showing all the characters very clearly, except that the most complete one is damaged at the anal side. They were found in the same locality and horizon with the type of *Zeacrinus girtyi*, hereinafter described.

Horizon and Locality.—Upper Carboniferous. Morrow formation of the basal Pennsylvanian; near Crittenden, northeastern Oklahoma.

ULRICHICRINUS CORYPHAEUS (S. A. Miller)

Plate 20, fig. 3

Poteriocrinus coryphaeus S. A. MILLER, 17th Rep. Geol. Surv. Indiana, 1891, p. 44, pl. 9, fig. 1.

Keokuk limestone; Canton, Indiana.

Abundant at Indian creek, Montgomery county, Indiana. *P. brittsi S. A. Miller*,[46] from Boonville, Missouri, may be identical with this, and if so would take the species. *P. amoenus* S. A. Miller,[47] is only a small specimen of *P. coryphaeus*.

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[46] Bull. 4, Geol. Surv. Missouri, p. 30.

[47] 17th Rep. Indiana, p. 45, pl. 9, fig. 6.

Genus WOODOCRINUS De Koninck

Plate 26

Woodocrinus De Koninck, Rech. Crin. Carb. Belg., Supp. 1854, p. 4.—Wachsmuth and Springer, Rev. Pal., pt. 1, 1879, p. 124; pt. 3, 1886, p. 239.—Zittel-Eastman, Textb. Pal., 1913, p. 223.—Wright, Trans. Geol. Soc. Glasgow, vol. 16, 1917–18, pp. 364–391; Geol. Mag., vol. 61, 1924, pp. 270–9.

Mountain limestone to Hurlet formation; England and Scotland.

Much confusion in the literature was caused by the action of Wachsmuth and Springer in 1886, in referring to this genus a large number of American species previously ranged under *Pachylocrinus*, *Zeacrinus*, etc. Subsequent consideration has shown that the arrangmeent was not well founded, and it should be disregarded.

The genus, with a calyx substantially similar to that of other turbinate forms of the group, is strongly characterized by its few ponderous, rounded arms, composed of extremely short brachials with parallel sutures; they branch into mostly equal divisions somewhat irregularly, giving 4, 3, and occasionally only 2, arms to the ray. The plates of the anal side are unusually conspicuous and numerous, passing in a strong series up between the rays, which with the spreading arms indicates a large ventral sac of the expanding type—not yet observed, however.

The range of this genus as originally described from the mountain limestone of Yorkshire has been materially increased by the researches of James Wright in the Hurlet Limestone of Inverteil, and of Penton Linns, Scotland, where he finds it occurring abundantly, in probably two species different from the type. As the Hurlet formation represents in part the American Chester, passing up into the Coal Measures, this gives a stratigraphic range comparable to that of *Zeacrinus* and other genera of this group. For comparison I am figuring a characteristic specimen of the type species, *W. macrodactylus* De Koninck, from Richmond, England (pl. 26, fig. 19). There is also a good figure of it in Zittel-Eastman, 1913 (p. 223, fig. 324.)

Genus ZEACRINUS (Troost) Hall

Plates 21, 22, 23

Zeacrinus Hall, Geol. Iowa, pt. 2, 1858, p. 144.—Meek and Worthen, Geol. Surv. Ill. vol. 2, 1860, p. 186.—Wachsmuth and Springer, Rev. Pal., pt. 1, 1879, p. 125; pt. 3, 1886, p. 243.—Bather, Edinb. Geol. Soc., vol. 10, 1911, p. 61.—Wright, Trans. Geol. Soc. Glasgow, vol. 16, pt. 3, 1917–18, 380.

Mississippian; Kinderhook to Upper Carboniferous; and Hurlet limestone, Scotland.

The characters of this genus as fully set forth by Wachsmuth and Springer in 1879 (Rev. Pal., pt. 1, p. 125) hold good in the main for the typical species, and my chief object in introducing it now is to illustrate more fully the form and structure of the ventral sac, which is especially notable for its variability. Later acquired specimens confirm the description of the sac given on page 127 of the work above cited as to some of the species, but exhibit great modification of it in others. They also enable me to show, what was not before known, the position of the anal opening, which notwithstanding the acuminate form of the sac as described, hinting somewhat at the possibility of a distal opening, proves to be strictly in accordance with the type characteristic of the other genera, namely, at the anterior side, about midway.

The differences in form of the sac bear some relation to the different geological positions of the species in which they occur, and the great stratigraphic range of the genus, from the Kinderhook to the Coal Measures, offers an excellent field for modification of such a special structure.

The dominant characters of the genus are the rather flat, closely abutting, infolding arms, meeting by linear margins, branching repeatedly but only from the outer arms of the ray toward the inner side of the dichotom; and the uniserial brachials, usually short, wide, and quadrangular, but with exceptions in the last respect in the lower part. This excludes nearly all species with rounded, divergent arms, and with wedge-shaped brachials, the inclusion of which by authors has been the cause of considerable confusion; but nevertheless allowance must be made for intermediate forms, some of which have to be included. It was formerly supposed that the genus required also a depressed cup, basin-shaped, with more or less concave base; but we are compelled to admit an exception in a well marked, otherwise characteristic species with an elongate, turbinate calyx, as was recognized in the diagnosis made by Wachsmuth and Springer. In fact, it seems after a final review of the material now available that the only stable character is the heterotomous arm-branching, with mostly uniserial, short and distally quadrangular brachials. Within this may occur: depressed or turbinate calyx; wide or narrow anal area; long or short RA; flat or rounded arms; club or balloon-shaped or pyramidal sac; round or pentagonal stem.

Variations in the structure of the anal side have caused some confusion in the attempt to formulate a generic diagnosis which would reconcile the differences between the earlier and later species. In the typical Chester species, *Z. wortheni*, the radianal is a long and narrow plate, often passing down between two basals almost to a contact with the infrabasals—a form and position so unusual that it has attracted special attention. But all species from the earlier formations are now known to have a short and broad radianal;

and it appears that in the very latest species of all, from the Pennsylvanian, the earlier form of radianal was resumed. Therefore such a range of variation in this character must be accepted for the genus.

So in regard to the arms. The typical species have the arms flat and closely apposed, touching all around by linear margins and forming a more or less smooth, rotund or ellipsoidal crown. But we are obliged to admit as exceptions others in which the arms are rounded and not in close contact, with axillaries prominent or nodose, as for instance, *Z. asper* Meek and Worthen.

Again, the sac typically is enclosed by the arms; but in some species, as *Z. commaticus* and *Z. girtyi*, it rises distinctly above them, and among the various species appears in the three different forms already mentioned.

As a general rule there is only the single axillary primibrach in the four rays other than the anterior, which regularly adds one or more brachials between that and the radial; but to this also there are a few exceptions.

Zeacrinus ranges through the entire Lower Carboniferous, beginning in the Kinderhook, culminating in the Chester, and passing up into the Pennsylvanian. It has hitherto been regarded as strictly an American genus, but it now appears prominently as a part of the remarkable crinoidal fauna brought to light in recent years by Mr. Wright from formations in Scotland equivalent to our Chester.

A few representative species will now be considered in detail:

ZEACRINUS BURSAEFORMIS White

Plate 21, fig. 1

Zeacrinus bursaeformis WHITE, Proc. Boston Soc. Nat. Hist., vol. 9, 1862, p. 10.

Lower Burlington limestone; Burlington, Iowa.

A well-defined species, not before figured; represented by four good specimens, besides the type in the Museum of Comparative Zoology; differing from typical species by having the calyx in the form of an inverted, truncated cone, spreading directly to the arm bases, with turbinate base, instead of concave. Arms flat on the back, rather closely apposed, about 8 to the ray except the anterior which usually has 6. To the foregoing abstract from the original description may be added the following remark by the author:

> This species not only resembles *Zeacrinus* above the base, but possesses those characters which have been regarded as peculiar to that genus of having but two radials (R+IBr) to four of the rays, and a greater number in the anterior one; yet the body has the true form and development of *Poteriocrinus*.

That is, it is one of the striking exceptions to the type which upon a preponderance of characters must be held within the genus. It has a wide anal area, with posterior basal broadly truncate and a short and broad radianal, as is the case with all Burlington and Keokuk species. Form of the sac is unknown, but from the shape of the crown is probably similar to that of *Z. elegans*, which the species also strongly resembles in the short, quadrangular brachials, and mode of branching of the arms.

There is an undescribed species from the Keokuk limestone at Indian Creek, Indiana, represented by several specimens, with a turbinate calyx like *bursaeformis*, but otherwise a good *Zeacrinus*.

ZEACRINUS ELEGANS Hall

Plate 21, figs. 2–4

Zeacrinus elegans Hall, Geol. Iowa, pt. 2, 1858, p. 547, pl. 9, figs. 1, 2.
Upper Burlington limestone; Burlington, Iowa.

The true *Zeacrinus* of the earlier type, with depressed calyx, post. B broadly truncate, RA short and wide, not passing down between BB. This structure is uniform in 28 specimens showing the anal side; and in a total of 43 specimens all have a single IBr, axillary, in four rays, and 3 or 4 in the anterior. There are 6 to 11 arms to the ray, usually 8 or 10. In this species we have the expanded, club-shaped sac, lying well within the arms, in marked contrast to that of the Chester species. I am figuring a good example of this, also another to show the range of variation in number of arms, and another of smaller size. The opening has not been observed. The other Burlington and most of the Keokuk species are true to this type, with variations as to minor details.

ZEACRINUS COMMATICUS S. A. Miller

Plate 22, figs. 1–3*a*

Zeacrinus commaticus S. A. Miller, Geol. Surv. Missouri, Bull. 4, 1891, p. 36, pl. 5. figs. 10, 11.
Upper part Keokuk limestone; Boonville, Missouri.

A species remarkable for the introduction within the genus of a new type of sac, which rises above the limits of the arms, and has the anal opening at the base. The term "club-shaped" is especially well adapted to this sac, as it is in form a veritable war club, with a strong handle and knotted end. The species is abundant and strongly marked. It has the broadly truncate post. B, with short RA, of the earlier type, 49 specimens being all in that condition with little variation; and of these 37 have one IBr in four rays, and 12 have two IBr all around—an exceptional occurrence for the genus, but one which is repeated in the latest species. The projecting part of the sac with its rounded nodes is shown in many specimens, and its full length with the anal opening in two.

ZEACRINUS WORTHENI Hall

Plate 23, figs. 1–8

Zeacrinus wortheni HALL, Geol. Iowa, pt. 2, 1858, p. 683, also p. 545.
Chester group, Okaw and Glen Dean formations; Randolph County, Illinois, Pulaski, Grayson, Todd and Breckinridge counties, Kentucky.

ZEACRINUS MAGNOLIAEFORMIS (Troost) Hall

Plate 22, figs. 4–11

Zeacrinus magnoliaeformis, HALL, Geol. Iowa, pt. 2, 1858, p. 684, also p. 545.
Chester group, Gasper formation; Huntsville, Alabama.

The two typical species of the genus, in which is introduced the pyramidal form of sac, acuminate instead of rounded distally, which is most commonly associated with the genus, and which was the basis of the description of the sac in Revision of Paleocrinoidea, (1, p. 126). It is best shown in *Z. wortheni*, which is the more widely distributed and in better preservation. From this we now know the location of the anal opening, about midway, clearly shown in several specimens, from which the instructive illustrations are selected. In these species, especially *Z. wortheni*, is introduced the long, slender radianal, producing the narrow anal side which is so different from that of the earlier species.

As the two species are among the important fossils of their formations, and their names have been used rather indiscriminately by geologists in listing the fossils collected in various localities of the Chester area, it is very desirable to ascertain which is which.

There is nothing in Hall's formal description of the species to separate them. The principal discussion is on page 545, where it is said that *Z. wortheni* "has a narrow and less rotund base, with the cavity much less deep, and the subradial and first radial plates (BB and RR) proportionately shorter and the latter narrower, while the anterior ray has two intermediate radial plates." This might be true as between two individual specimens, but will not hold good for the numbers that are now in hand. In a note he says that *Z. wortheni* is distinct from *Z. magnoliaeformis*, "with shorter first radials, extending a little above the plane of the base, and arms much shorter and less robust." He gives a diagram of each, that of *Z. magnoliaeformis* from Troost's type; it does not show the anal side.

The diagram of *Z. wortheni* shows the anal side with post. B acuminate like the other BB, not connecting with *x* (next anal above), and RA narrow, passing low down between BB—that is, a narrow anal area.

The *Z. magnoliaeformis* type specimen is from Huntsville, Alabama, in what is now known as the Gasper formation of the upper Chester, where the species occurs numerously; while *Z. wortheni*, as found in several localities in Illinois and Kentucky, is from the next higher formation of the Chester, Glen Dean of Kentucky and Okaw of Illinois. Numerous specimens of both forms enable me to make a close comparison as to the corresponding characters.

From the Huntsville locality, Gasper formation, there are about 100 specimens, including 7 complete crowns. Measurement of these for height of crown and diameter of calyx at top of radials gives an average of 57 mm. height (ranging from 45 to 68), and 19 mm. diameter (17 to 21). Out of the total, 79 specimens have post. B broadly truncate, RA large and broad, producing a more or less wide anal area; 12 have post. B acuminate as in the type of *Z. wortheni*—a narrow anal area; and 9 are in an intermediate stage. Thus with 80 per cent of the specimens having post. B broadly truncate, it may be said in general that the earlier, Gasper, form has a wide anal area.

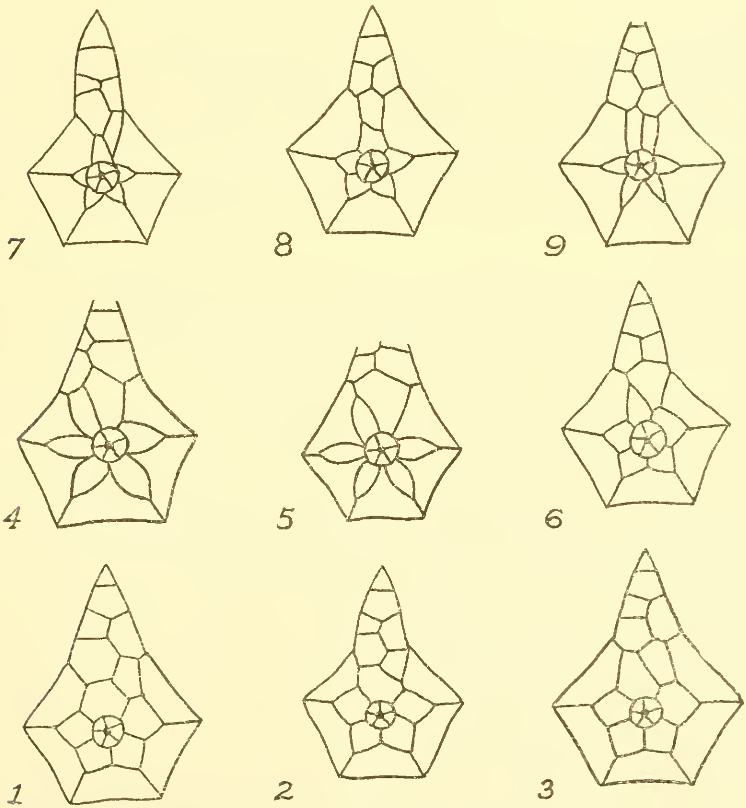
From the later formation, Glen Dean, at the most prolific locality, Sloan's Valley, Pulaski County, Kentucky, there are 65 specimens, among which are 22 complete crowns. Measurement of these yields an average of 30 mm. height (16 to 40) and 13 mm. diameter of calyx (7 to 17). Thus while on an average the absolute height of crown is about twice as great in *Z. magnoliaeformis* as in *Z. wortheni*, its relative height to the width of calyx is also much greater, being as 3 by 1 to 2.3 by 1. Of the Sloan's Valley specimens 37 have the post. B acuminate, with a narrow RA passing down alongside post. B almost to a connection with IBB. In the remainder the post. B is truncate to a varying extent, from 18 having a very narrow connection with the succeeding anal, being practically acuminate, to 10 in which the truncation is as broad as in the Huntsville specimens, with some intermediate stages; but in most of them the RA is an elongate plate, and the anal area in 85 per cent of the specimens should be classed as narrow.

These data seemed to furnish two good characters for distinguishing the species, until I was tempted to inspect the anal side of Troost's type by removing the hard matrix by which it was enclosed, and found that it has a pointed post. B, and thus falls under the exception instead of the general rule. Nevertheless, we are warranted by the great preponderance of the evidence in claiming the wide anal area as one of the characters for *Z. magnoliaeformis*, when correlated with the larger crown.

From the foregoing facts it results that the decisive difference between the two species as stated by Hall holds good in the greater length of crown in *Z. magnoliaeformis;* to which may be added that along with this it has usually larger basals, deeper basal cavity, and fewer bifurcations, these rarely exceeding two from the IIBr, giving 6 arms to the ray, while in *Z. wortheni* they usually run from 8 to 10. Each species is limited to its respective formation, and thus they are good horizon markers.

As in the earlier type, this one has uniformly an extra plate below the axillary in the anterior ray, but only the axillary IBr in the other four.

For comparison of the structures of the anal side in these species, and in those of the earlier type, I am giving a series of drawings showing the typical forms and the most notable variations observed in the course of this investigation (text-figures 1 to 9).



Figs. 1–9.—Zeacrinus; variations in anal area. 1. Z. elegans; 2. Z. commaticus; 3. Z. girtyi; 4, 5. Z. magnoliaeformis (see also pl. 22, figs. 7–10); 6, 7, 8, 9. Z. wortheni (see also pl. 22, fig. 12, and pl. 23, figs. 6, 7, 8)

Dr. Bather[48] has described from the Scotch Carboniferous of Fife some cups belonging to this genus under the name *Zeacrinus konincki.*

[48] Trans. Edinb. Geol. Soc., vol. 10, 1911, p. 61.

Mr. Wright[49] has given further particulars of the occurrence of the genus in that region, which he finds to be quite abundant in two localities. He has noted variations in the anal area analogous to those which I have recorded for the two Chester species, and it is interesting to observe that out of 45 specimens examined by him 41 have the post. B acuminate with RA more or less elongate, all from one locality, and 3 have post. B truncate, with shorter RA, and are from a different locality. The similarity in this respect to the American species adds another significant fact toward the correlation of the two horizons, and we shall await with interest the description of the crowns to see what further resemblance is disclosed.

ZEACRINUS GIRTYI, new species

Plate 23, figs. 9, 9*a*

This is the latest known occurrence of the genus, having a low cup, long truncate posterior basal, strongly heterotomous arms, partly uniserial; but to some extent with cuneiform brachials, and balloon-shaped ventral sac. The species is founded on a single very well preserved specimen from the basal Pennsylvanian of Oklahoma, of larger size than is usual in the genus, the length of crown being 6.5 cm.

Specifically it is exceedingly well marked by the fact that the heterotomy and the inflated sac are developed to an extent unknown in any other species. The rays divide on the second plate above the radial into two main and equal branches; each of these bifurcates further, but unequally—the outer branch of the ray continuing strong and dividing several times, giving off to the inner side of the dichotom successive branches, the lowest about one-third the thickness of the main branch at the point of bifurcation, and continuing simple to the full height of the ray. The differences in size between the outer arm and the inner ramules become less and less until the last division is about equal. This type of heterotomy is the same as that of *Z. wortheni* of the Chester, but it is more marked in this specimen than in any of that species, the taper of the main arms is more pronounced, and the bifurcations more numerous—there being seven here, whereas I have never seen more than five in the largest Chester specimen.

This species has also two primibrachs, so that the ray bifurcates on the second plate above the radial, instead of the first as is the rule in the genus except in the anterior ray, which usually has one or more additional brachials. In *Scytalocrinus* and similar genera closely allied to *Pachylocrinus* both structures are found, with many species of each; but in *Zeacrinus* and the closely related *Coeliocrinus*

[49] Trans. Geol. Soc. Glasgow, vol. 16, pt. 3, 1917–18, p. 380.

and *Hydreionocrinus* I do not remember to have seen before, except in a few specimens of *Z. commaticus*, an exception to the rule of a single primibrach to all the rays other than the anterior.

The ventral sac, which in other species except *commaticus* is only about half the height of the arms, is here of extraordinary size for the genus, approaching rather the structure of *Coeliocrinus* in this respect; it rises entirely above the ends of the arms, which are themselves unusually long and slender.

While the arm structure, as above stated, is like that of the Chester species, *Z. wortheni*, it is curious that the calyx of this species is more like that of the earlier forms of the Burlington limestone, such as *Z. elegans*, in having quite large and prominent basals instead of small ones almost concealed in the basal cavity, and also a short radianal.

On the whole, this may be termed an acmic species, recapitulating to some extent the characters found in the genus in earlier periods; and it doubtless represents the culmination of the genus, which has not hitherto been recognized later than the Chester.

The specific name of this remarkable species is given in honor of Dr. George T. Girty, in charge of Carboniferous researches for the U. S. Geological Survey, to whom I am indebted for the use of the material.

Horizon and *Locality*.—Morrow formation of the basal Pennsylvanian; near Crittenden in northeastern Oklahoma. Found by Dr. E. O. Ulrich associated with *Ulrichicrinus oklahoma*.

Genus COELIOCRINUS White

Plates 24, 25

Coeliocrinus WHITE, Boston Journ. Nat. Hist., vol. 7, 1863, p. 499.

Coeliocrinus, subgenus of *Poteriocrinus*, MEEK and WORTHEN, Proc, Acad. Nat. Sci. Phila., 1869, p. 138.

Coeliocrinus, subgenus of *Hydreionocrinus*, WACHSMUTH and SPRINGER, Rev. Pal., pt. 1, 1879, p. 131.

Mississippian; Lower Burlington to Keokuk.

The prominent features of this genus are stated by the author as folows:

First, the large inflated ventral sack, varying in size in different species, from four or five times the capacity of the calyx to ten or twenty times that capacity. It is widest at the top, in some cases extending above the tips of the arms—the lower part being contracted between the arms like the neck of a balloon—and joins by this the anal series.

Second, the proportionally small calyx formed by the basal, subradial, radial, and first anal plates, which is so small as to render it certain that could not contain the necessary internal organs for the support of the other parts. These organs must have been located in the plated sack, which I have denominated the ventral sack; thus reversing their usual order of operation, as the mouth was doubtless at the side of the neck, near the base of the arms. This aperture, however, has not been observed, although a separated sack of *C. dilatatus* has been carefully examined, together with more than half its neck, without the discovery of any aperture whatever, and four plates of the anal series seen, with no better result.

The genus was founded upon three species, *Poteriocrinus dilatatus* and *P. ventricosus*, previously described by Hall, and *Coeliocrinus subspinosus* of White, then described, all from the Burlington limestone. *P. dilatatus* was designated as the genotype. The descriptions of these species were unaccompanied by any figures, and none of them has since been illustrated, save by an incidental figure of the inflated sac of *C. ventricosus* given by Wachsmuth and Springer on plate 7 of the Camerata Monograph, and one of *C. dilatatus* by Whitfield (not of the type) in 1893. The arm branching is of the heterotomous type in principle, but not very well defined, there being usually seen only a single bifurcation beyond the IIBr, on the outer arm of the ray, the inner arm of equal size usually remaining unbranched. It is a sort of intermediate stage between dichotomy and heterotomy, which might fall under either term in some cases.

COELIOCRINUS DILATATUS (Hall)

Plate 24, figs. 9–13

Poteriocrinus dilatatus Hall, Journ. Boston Soc. Nat. Hist., vol. 7, 1861, p. 300.

Coeliocrinus dilatatus, White, Boston Journ. Nat. Hist., vol. 7, 1863, p. 501.—Wachsmuth and Springer, Rev. Pal., pt. 1, 1879., p. 133.—Whitfield, Mem. Amer. Mus. Nat. Hist., vol. 1, 1893, pl. 3, fig. 18.

Lower Burlington limestone; Burlington, Iowa.

COELIOCRINUS VENTRICOSUS (Hall)

Plate 24, figs. 1–8; plate 25, fig. 1

Poteriocrinus ventricosus Hall, Journ. Boston Soc. Nat. Hist., vol. 7, 1861, p. 301.

Coeliocrinus ventricosus, White, Boston Journ. Nat. Hist., vol. 7, 1863, p. 501.—Wachsmuth and Springer, Rev. Pal., pt. 1, 1879, p. 133; North Amer. Crin. Cam., 1897, pl. 7, figs. 10*a*, *b*.

Lower Burlington limestone; Burlington, Iowa.

COELIOCRINUS SUBSPINOSUS White

Plate 25, figs. 2, 3

Coeliocrinus subspinosus White, Boston Journ. Nat. Hist., vol. 7, 1863, p. 501.—Wachsmuth and Springer, Rev. Pal., pl. 1, 1879, p. 133.

Upper Burlington limestone; Burlington, Iowa.

The three foregoing species agree in having a cup-shaped, expanding calyx, with a narrow conical base, as distinguished from typical *Hydreionocrinus* with a more or less broadly rounded cup and concave base; in all, the arms are composed of wedge-form brachials, and the branching is more or less of the heterotomous type, not always very distinct.

The first two, both from the lower Burlington limestone, have a true balloon-shaped ventral sac, with a narrow neck supporting a widely expanding bag above it, composed of numerous plates sharply sculptured or rising into angular nodes; whereas the third, from the Upper Burlington formation, having likewise a narrow neck, takes on the mushroom form, spreading out into a flattened disk, composed of rather numerous plates, some of which are produced into spines of variable length, like those of the later appearing *Hydreionocrinus*.

The differences between the first two as claimed by their author are rather slight, but between them and the third the distinction is very great, the spiniferous flattened top being constant in 15 specimens from the upper Burlington bed, as against about 25 from the lower in which the sac is always rounded and non-spiniferous; only two or three somewhat intermediate specimens have been seen. As between the lower bed species, the author notes that in *C. ventricosus* the second radials (IBr) are smaller than the first, and the arms more distinctly wedge-form, while in *C. dilatatus* the second radials are larger than the first and united at their lateral margins; and that in the former the sac is composed of large plates in the lower part and smaller in the upper, which is the reverse of the latter. Taking the specimens as they come these differences seem not to be very constant, but on the whole the plates of the sac at the distal part appear generally larger in *C. dilatatus* than in *C. ventricosus*.

As all three of these species were described without illustrations, paleontologists will welcome the publication of adequate figures now. I am giving photographs of the types of *C. dilatatus* and *C. ventricosus* now in my possession, formerly in the collection of Dr. C. A. White, together with some other specimens showing the characters of the species more completely; also of characteristic specimens of *C. subspinosus* as well known to the Burlington collectors. In none of the 40 specimens of the three species is the position of the anal opening disclosed, but it must be at some point below the inflated portion of the sac.

I am also figuring two specimens of the inflated sac of one or both the lower Burlington species from the equivalent horizon in southern New Mexico discovered by me in 1883,[50] showing the great geographical range of this highly specialized form.

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[50] Sprigner. On the Occurrence of the lower Burlington limestone in New Mexico, Amer. Journ. Sci., vol. 25, 1884, pp. 97–103.

Horizon and locality.—Mississippian, lower and upper Burlington limestone as above stated; Burlington, Iowa, and Lake Valley, New Mexico.

COELIOCRINUS LYRA (Meek and Worthen)

Zeacrinus lyra MEEK and WORTHEN, Geol. Surv. Illinois, vol. 5, 1873, p. 432, pl. 1, figs. 11*a*, *b*.

Lower Burlington limestone; Burlington, Iowa.

This species has been referred to *Coeliocrinus*. The figures do not show the sac, but the description says that one specimen shows "a ventral prolongation nearly as long as the arms, somewhat expanded and covered with spines at the upper extremity." It has the strictly heterotomous arms of *Zeacrinus*, with numerous branches from the outer arm to the inner side of the dichotom; but the wedge-shaped brachials exclude it from that genus.

Another species, *Zeacrinus dubius* of Miller and Gurley,[51] from the Keokuk at Bono, Indiana, is almost a duplicate of *Coeliocrinus subspinosus*.

Genus HYDREIONOCRINUS De Koninck

Plates 25, 26

Hydreionocrinus DE KONINCK, Bull. Acad. Royale Belgique, vol. 8, 1858, pt. 2, p. 13.—WACHSMUTH and SPRINGER, Rev. Pal., pt. 1, 1879, p. 129; pt. 3, 1886, p. 245.—BATHER, Trans. Edinb. Geol. Soc., vol. 10, pt. 1, 1911–12, pp. 61–76.—WRIGHT, Trans. Geol. Soc. Glasgow, vol. 16, 1917–18, pp. 364–383.—WANNER, Permischen Echinod. von Timor, 1916, pp. 150–166.

Lower Carboniferous to Upper Carboniferous.

The distinctive character of this genus, having the form of calyx and arrangement of anal plates substantially as in *Zeacrinus*, is the ventral sac, which at the distal end is transversely flattened like a mushroom, abruptly spreading beyond the tips of the arms and forming a low canopy composed of 5 to 35 or more plates; these are either a few, spiniferous and meeting towards the middle, or more frequently many nodose or flattened plates in the middle part, irregularly arranged, and bordered at the margin by a connected ring of spiniferous plates. This wide spreading sac is supported by a narrow tube, in which the anal opening is at the anterior side about midway, as now shown by three specimens. The cup is depressed, rounded, bowl-shaped, with the infrabasals, and sometimes basals also, sunken in a more or less deep cavity. This form of cup, and the constant presence of spines on the sac and on many of the brachial axillaries, distinguish the genus from *Coeliocrinus*, of

[51] Journ. Cincinnati Soc. Nat. Hist., 1890, p. 44, pl. 7, figs. 7, 8.

which it may be the successor. The genus belongs typically to the later Lower Carboniferous, Hurlet in Britain and Chester in America, and ranges up into the Upper Carboniferous.

The British species of the genus have been extensively discussed in recent years by Doctor Bather and Mr. Wright, with the benefit of fine newly discovered material obtained by the latter gentleman in the Hurlet limestone of Scotland, especially of the species *H. woodianus*, in which the structures of the ventral sac and arms are well shown. Along with a careful account of the generic characters, Bather,[52] with his usual lucid diagrams and figures, gives the most particular description yet published of the ventral sac and arms. Of the latter he says:

> Only one ramus, after each bifurcation, bifurcates again, and that is the one next to the middle line of the ray; all branches on the outer side continue single to the end.

This excellent description of the mode of arm branching has a special interest in relation to the American species. As to the ventral sac he says:

> No anal opening is yet known, but it probably lay at the base of the ventral sac on the anterior side, where Wachsmuth and Springer have found it in other fistulate crinoids.

Professor Wanner, in his work of 1916 on Permischen Echinodermen von Timor (pp. 150–166), has described and figured several species under this genus,[53] some of which seem to me to have more the habitus of *Coeliocrinus*, with the rounded inflated ventral sac.

HYDREIONOCRINUS DEPRESSUS (Hall from Troost)

Plate 26, figs. 1–2

Zeacrinus depressus HALL, Geol. Iowa, pt. 2, 1858, p. 546.

Hydreionocrinus armiger, WACHSMUTH and SPRINGER, Rev. Pal., pt. 1, 1879, p. 31; pt. 3, p. 245.—WETHERBY, Journ. Cincinnati Soc. Nat. Hist., 1881, p. 325, pl. 9, figs. 1–4, 6.

Upper Chester; Pulaski and Grayson Counties, Kentucky.

HYDREIONOCRINUS WETHERBYI Wachsmuth and Springer

Plate 25, figs. 4–12

Hydreionocrinus armiger, WACHSMUTH and SPRINGER, Rev. Pal., pt. 1, 1879, p. 131.—WETHERBY, Journ. Cincinnati Soc. Nat. Hist., 1881, p. 328, pl. 9, figs. 4–11.

Hydreionocrinus wetherbyi WACHSMUTH and SPRINGER, Rev. Pal., pt. 3, 1886, p. 245.

Upper Chester; Pulaski and Grayson Counties, Kentucky.

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[52] Notes on *Hydreionocrinus*, Trans. Edinb. Geol. Soc., vol. 10, pt. 1, 1911–12, pp. 61–76, with one plate.

[53] Now, in the second volume of his work, 1924, p. 250, referred to a new genus, *Cadocrinus*, which, for lack of radianal, does not strictly fall within this subfamily.

The characters of these two species must be sought chiefly in the work of Wetherby, above cited, where the descriptions are accompanied by excellent illustrations made from a series of finely preserved specimens of both, which exhibit the structure of the arms and ventral sac. Although himself in doubt as to their identity with the species previously described from imperfect material, he redescribed and figured them under the original names. This course as to the second species was not accepted by Wachsmuth and Springer, who changed it to *H. wetherbyi.* A large quantity of excellent material derived from Wetherby's locality enables me to confirm his observations in several particulars, and to add some newly discovered facts. These forms are of interest because they represent the culmination of the inflated sac in the later American Lower Carboniferous, and because the two species, although occuring closely associated in the same localities, are so completely distinct:

H. depressus. Basal cavity large, deep, rather pentagonal, involving most of BB, the IBB being buried at the bottom; stem pentagonal. IBr single, axillary and spiniferous except in the anterior ray, where one or two additional biserial pairs of brachials are interposed, and the bifurcation and spine are on the second or third brachial. Arms biserial, dividing on the third IIBr, followed by three or four divisions at intervals of about 4 brachials, always from the outer arm of the dichotom, the inner branch remaining single (the reverse of the British species), giving 34–42 ultimate branches, the number in the anterior ray being diminished. Summit of sac composed of a central area of numerous irregular plates surrounded by a peripheral band of plates terminated by spines projecting horizontally or a little downward, 20–35 plates in all.

H. wethebyi. Basal cavity small, shallow, almost restricted to the infrabasals; stem round; BB mostly visible. IBr single all around, axillary and spiniferous. Arms dividing on the sixth or seventh brachial above IAx, with not over two divisions at intervals of 7 or 8 brachials; usually only the outer branch bifurcating, giving about 26 final branches; all axillaries nodose or spiniferous; brachials cuneate, interlocking to biserial. Summit of sac without any inner set of plates, but composed entirely of spiniferous plates meeting in the middle, from 5 to 7 or 8 in number.

Thus the two species can be recognized from fragments only by either: (1) The base, with or without a section of the stem; (2) the calyx, if the anterior ray can be seen to the bifurcation; (3) the arms; or (4) the summit of the sac. *H. depressus* is the more abundant species, being represented in the collection by 170 specimens, and *H. wetherbyi*, much rarer, by 30. The characters above specified are constant throughout them all.

Horizon and locality.—Mississippian; Glen Dean formation of the upper Chester; Sloan's Valley, Pulaski County, and Grayson Springs, Kentucky. Most of the specimens of both species came from the same locality at Sloan's Valley, within a distance of a few hundred feet; but as the collection was made from the débris of a tunnel excavation, they may not have been derived from the same layer, although the matrix and lithological appearance are identical. Both species also occur at Grayson Springs in the same formation, but whether in the same layer is not known. They have not been recognized in other Chester localities.

For completion of the series under this group I am figuring some representative species of *Decadocrinus* and *Scytalocrinus*. The two genera exhibit variations of a well defined arm structure of two to the ray, unbranched; and while typical forms of the two are readily distinguished, there has been some uncertainty in the placing of certain species. As a general rule *Decadocrinus* has a depressed cup, with pentagonal stem, while that of *Scytalocrinus* is more or less elongate and turbinate, with rounded stem. But as to these there are exceptions; and the most reliable character in practice is found in the structure of the pinnules, those of *Decadocrinus* being large and well separated, resembling ramules, while those of *Scytalocrinus* are closely packed like regular pinnules. Both show good examples of the inflated sac. Those of the specimens which I figure are materially different in form, although both species have the anal opening about midway. But whether this difference is constant is not known, as the sac is too rarely found exposed to furnish a general rule. In both genera the anterior ray occasionally has but a single arm, making only 9 in all; and in both there may be either one or two primibrachs.

Genus DECADOCRINUS Wachsmuth and Springer

Decadocrinus WACHSMUTH and SPRINGER, Rev. Pal., pt. 1, 1879, p. 119.
Devonian to Lower Carboniferous.

DECADOCRINUS HALLI (Hall)

Plate 17, figs. 4, 5.

Scaphiocrinus halli HALL, Boston Journ. Nat. Hist., 1861, p. 308.
Decadocrinus halli WACHSMUTH and SPRINGER, Rev. Pal., pt. 1, p. 119.
Upper Burlington limestone; Burlington, Iowa.

An excellent example of the delicate Burlington forms of the genus. It only differs from *D. scalaris*,[54] from the same bed, which was designated by Wachsmuth and Springer [55] as type of the genus, by having a single primibrach instead of two.

[54] Meek and Worthen, Geol. Surv. Ill., vol. 5, 1869, p. 421, pl. 2, fig. 10.
[55] Rev. Pal., pt. 1, p. 120.

DECADOCRINUS TUMIDULUS (Miller and Gurley)

Plate 17, fig. 6.

Cyathocrinus tumidulus MILLER and GURLEY, Bull. 3, Ill. State Mus., p. 31, pl. 3, fig. 7.

Decadocrinus grandis WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, pl. 7, figs. 4, 5.—SPRINGER, Amer. Geol., vol. 26, 1900, pl. 16, figs. 5, 6.

Keokuk limestone; Indian creek and Canton, Indiana.

A very striking species, numerously represented at its principal locality, and illustrating the development of the genus through the later formations. A specimen showing the anal opening about midway was figured in the Camerata monograph, erroneously designated as *D. grandis*.

Genus SCYTALOCRINUS Wachsmuth and Springer

Scytalocrinus WACHSMUTH and SPRINGER, Rev. Pal., pt. 1, 1879, p. 116. Devonian to Upper Carboniferous.

SCYTALOCRINUS VALIDUS Wachsmuth and Springer

Plate 17, figs. 7, 8

Scytalocrinus validus WACHSMUTH and SPRINGER, North Amer. Crin. Cam., 1897, pl. 7, figs. 2*a*, *b*, 3.—SPRINGER, Amer. Geol., vol. 26, 1900, pl. 16, figs. 9, 10.

Keokuk limestone; Indian Creek Indiana.

A characteristic example of the genus, except in the rather depressed calyx; selected to show the anal opening in the sac midway, and the single arm as sometimes found in the anterior ray.

Genus TIMOROCRINUS Wanner, 1912, 1916, 1924

Timorocrinus WANNER, Perm. Krin. Timor, vol. 2, 1924, pp. 54, 63, 181, 269.—JAEKEL, Phylogenie und System der Pelmatozoen, 1916, p. 64.

The relation of this, the most abundant and heretofore the most mysterious of all the Timor crinoids, was satisfactorily settled by Professor Wanner in his latest discussion in 1924. He now recedes from his former view referring it to the Flexibilia, and concludes, following the opinion of Jaekel, that this remarkable genus, superficially unlike any other known crinoid, belongs to the Inadunate family Poteriocrinidae. It has a strongly inflated ventral sac, strengthened by numerous projecting longitudinal ridges of different grades, separated by corresponding furrows, in which the delicate arms and their branches were lodged, probably for protection. The sac is connected with the dorsal cup by means of a single strong anal, or proximal, plate meeting the greatly enlarged posterior basal. Basals are unequal, infrabasals fused and buried under the column. Anal opening is near the top of the sac, but on the posterior side instead of the anterior, which together with the absence of a radianal, differentiates it from the other genera in the group under consideration.

Timorocrinus is by far the most prominent crinoid of the Timor fauna, specimens being found by thousands, from which Wanner has described 11 species and 5 varieties.

THE CRINOID FAUNA OF TIMOR

Professor Wanner's second volume (and also his work on the blastoids) has been published,[56] bringing that wonderful assemblage of unfamiliar forms up to a total of 41 new crinoid genera named, 18 hitherto known, all but one from other regions, 42 indicated by imperfect material but not named; and 189 species named plus about 50 only indicated. The 59 named genera are distributed as follows: Camerata, 6; Flexibilia, 10; Cyathocrinidae, 14; Poteriocrinidae, 25; Larviformia, 2; Insertae sedis, 2. Of the Camerata, the Rhodocrinidae and Batocrinidae are unrepresented, and the Actinocrinidae, Platycrinidae and Hexacrinidae are present with a few species. All the Flexibilia belong to the small and compact Lecanocrinidae except a single species, evidenced by one specimen, which falls under the Ichthyocrinidae. Including those forms not named, but which are all figured and described as far as possible, we have a probable aggregate of about 100 genera and 239 species. Besides these, there are 13 genera and 32 species of blastoids, all but 2 genera and 2 species new, and all belonging to families of distinctively Lower Carboniferous age.

A considerable part of the Timor crinoids might be classed among the "Unusual Forms," for 10 of the genera and 138 species are founded upon a single specimen, and many of those which are abundant are of types elsewhere wholly unknown. But I am only mentioning a few which bear some relation to the forms herein discussed. There are some general characteristics of the fauna, however, to which a brief allusion may be made.

The predominant element consists of types which point to a life in strongly moving water, essentially a reef life, resulting in a number of striking modifications and departures from the normal structures, shown by the great prevalence of variations, malformations, and special adaptions to the environment, such as the slanting position of the calyx upon the stem; compact, rounded forms with thick calyx plates; short, simple, infolding arms, many of them fitting snugly into furrows as a means of protection. The highly organized, complex forms with long, pliant stems and delicately

[56] Die Permischen Krinoiden von Timor, pt. 2, 1924, 348 pp., 22 plates. The Hague. Die Permischen Blastoiden von Timor, 1924. The Hague.

constructed arms and pinnules, so characteristic of the great Silurian and Carboniferous crinoid deposits of Europe and America, are but little represented in Timor; although there were evidently some areas of quiet water protected from wave action, as on the lee side of reefs, which accommodated species with thin stems, especially the multitudes of blastoids, of which there have been collected, belonging to a single genus, upwards of 60,000 specimens. The crinoids, now largely imbedded in marls and volcanic tufas, have been much broken up by action of rough water, transportation from their original habitat, and by subsequent geological movements, so that complete specimens are rare; and many strong isolated stem fragments are present, indicating the existence of forms of which the other parts have disappeared.

The most remarkable modification caused by the life conditions was the reduction and loss of arms, thought to be due to the action of currents bringing the food directly to the stationary crinoids without the aid of moving arms, which through atrophy from disuse were reduced in number, even finally to complete suppression. There are 9 genera of such forms occurring here, two of them before described from other areas, while 7 are new and restricted to Timor. Two of these have 3 arm-bearing rays, three have only one, and in the remaining four all the arms have disappeared. The latter must represent a persistent larval condition, being composed of the primative elements of the crinoid skeleton, namely, basals and orals, with the addition of well developed infrabasals, and in one case of rudimentary radials. Some of the specimens bear a striking resemblance to the larval *Comactinia*, as illustrated on plate B of my work on the Crinoidea Flexibilia.

While the absence of arms is the predominating character, the four genera are separated by differences readily recognized, which emphasize the extreme modifications produced by the conditions under which they existed. For example, one of the genera, appropriately named *Embryocrinus*, has radials upon which the arms might potentially have grown, but did not; they are very small, rudimentary, and not in contact—substantially as in the early stage of the *Comactinia* larva. But in the other three there is no trace or vestige of radials, the interval between basals and orals, where the radials normally originate, being shut off by the close contact of those plates. In one of these, *Lageniocrinus*, the orals are interradial in position, in line with the basals—being the normal location in crinoids generally—which theoretically would leave a place at the corners for arms to develop; but in the other two, *Coenocystis* and *Acariaiocrinus*, they are radial, alternating with the basals—an unprecedented arrangement which would exclude every possibility, actual or theoretical, of the development of arms. Two of the most striking of these forms, *Monobrachiacrinus* with one arm, and *Embryocrinus* armless, are very abundant, indicating a wide extent of the conditions and their effects; while the others are rare. One of the two genera with aberrant orals, *Coenocystis* Girty, already known in America, is represented by a single specimen, which might be attributed to malformation; but of the other there are two well defined specimens in which the exceptional character is clearly shown, leaving no doubt of its being a definite structure.

Evidently this extreme specialization marked the end of the line, for these armless crinoids left no successors to our knowledge, either in the prolific deposits of the Mesozoic, or among the numerous species which inhabit the present oceans. But there are certain other forms which seem in a remarkable way to anticipate Mesozoic types; for example, the genera *Prophyllocrinus* and *Proapsidocrinus*, which may well be taken as the ancestors of the Jurassic genera from which their names are adapted. Equally remarkable as a survival, or a prophetic type, or more probably as an independent example of adaptation to a reef life, is *Palaeholopus*, which like *Edriocrinus* of the Devonian, *Cyathidium* of the Chalk, and *Holopus* of the present seas, had no stem, but was attached directly by the greatly modified base to rocks or corals at shallow depths.

The age of the Timor crinoids and blastoids, held by the author to be Permian, remains a perplexing question, owing to the presence of such a large element of distinctly Lower Carboniferous affinities. This was briefly discussed by me,[57] and somewhat further since.[58] While it is admitted that much remains to be learned concerning the geology of Timor, yet in view of the concurrent opinion to the same effect of the other authors who have studied the associated invertebrate fossils, it would seem that the Permian age of the formation as now determined should be accepted.

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[57] Smithson. Misc. Coll., vol. 76, 1923, p. 30.
[58] Amer. Journ. Science, vol. 8, October, 1924, p. 325

EXPLANATION OF PLATES

Enlargement, if any, of the drawings is indicated by the sign at the end of the paragraph. Unless so noted the figure is of natural size. All the specimems figured, except as otherwise stated, are in the author's collection, now in the United States National Museum.

PLATE 1

All figures not otherwise noted natural size

Page

MYELODACTYLUS CONVOLUTUS Hall 8

FIG. 1. A very large specimen, with broadly curved stem beyond the proximal coil, showing the closely packed cirri paired on successive parallel columnals in the bilateral part, some of the noncirriferous proximal coil with circular neck leading to the crown, which is imperfectly exposed from beneath the enveloping cirri.

2. Another specimen, with stem broken off beyond the close coil, and a few cirrals and part of the neck exposed. × $\frac{3}{2}$.

3. Another typical, but smaller specimen, with much of the broad curve intact, and cirri converging at center of close coil completely enveloping the crown.

4. Fragment of bilateral part of stem seen from the outer side of curve, showing the longitudinal sutures. × $\frac{3}{2}$.

5. Another fragment from inner side of curve, showing the cirrus-facets at each end of successive columnals. × $\frac{3}{2}$.

6. Joint-face of a columnal from median bilateral part of stem. × $\frac{3}{2}$.

7. Specimem from Laurel limestone, St. Paul, Ind.; showing close coil and beginning of broad curve of stem. Cirri not preserved, but their facets are to be seen like those in the fragment following.

8. Fragment from same locality, seen from inner side of curve, with cirrus-facets on each columnal. × $\frac{3}{2}$.

All except 7 and 8 are from the Rochester shale, Niagaran; Lockport, New York.

MYELODACTYLUS BREVIS, new species........ 10

FIG. 9. The only specimen; a nearly complete coil tapering to the distal end, with cirri paired on each columnal and converging to the center. × $\frac{3}{2}$.

9*a*. Distal outer view of same, showing taper almost to the end. × $\frac{3}{2}$.

Niagaran, Brownsport limestone: Decatur County, Tennessee.

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MYELODACTYLUS FLETCHERI (Salter) 10

FIG. 10. Salter's type, in the museum of Cambridge University, England, by which the true nature of the fossil was first shown. Drawn from a cast in which the details of calyx and arms are indistinct, but the composition of stem and cirri is evident.

11. A specimen in the British Museum, showing the form, proportions and mutual relations of stem, cirri and crown. By permission of the Keeper of Geology.

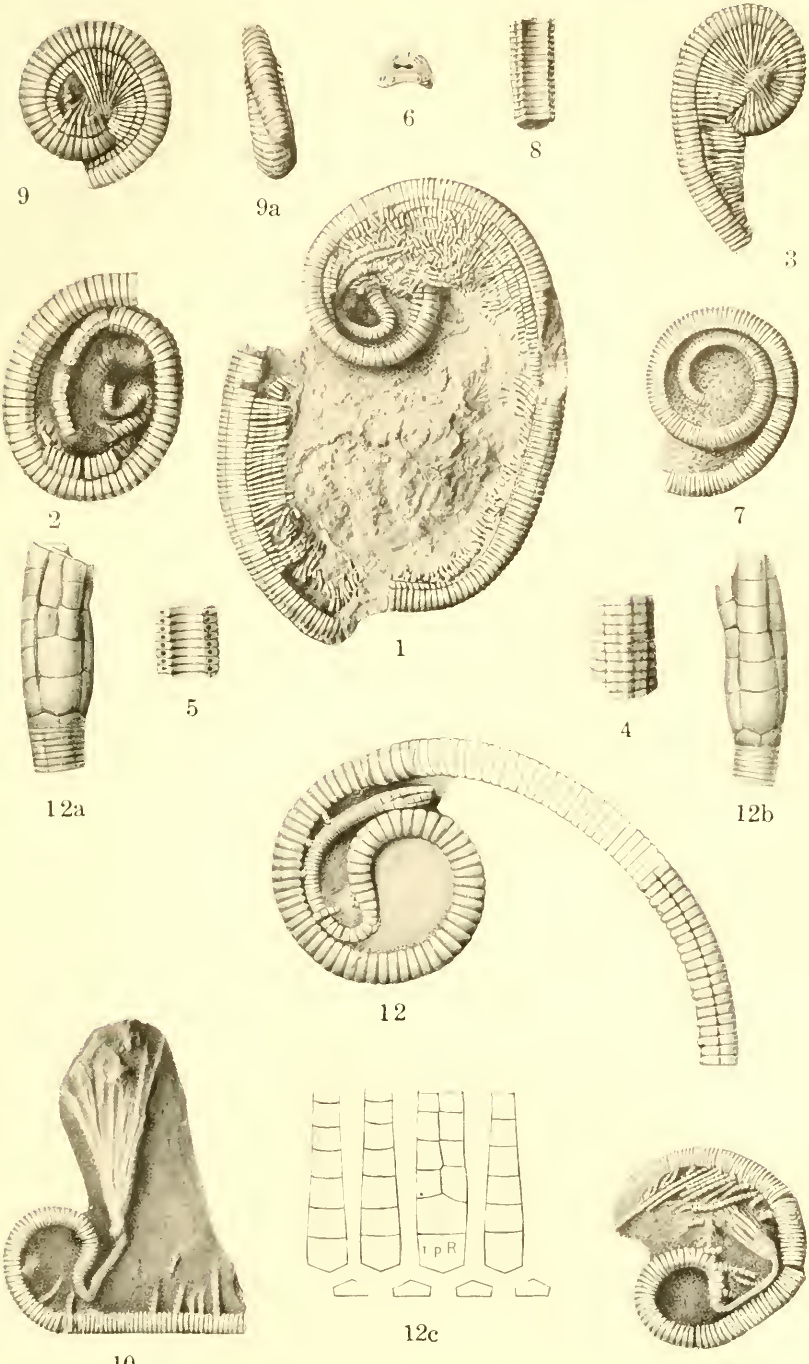
12. A specimen in the author's collection, of which the crown is detachable for inspection at all sides, showing that it has only 4 radii. × 2.

12*a*. Calyx of same from posterior side, with anal tube resting upon the left shoulder of r. post. Rs. × 6

12*b*. Calyx from anterior side. × 6.

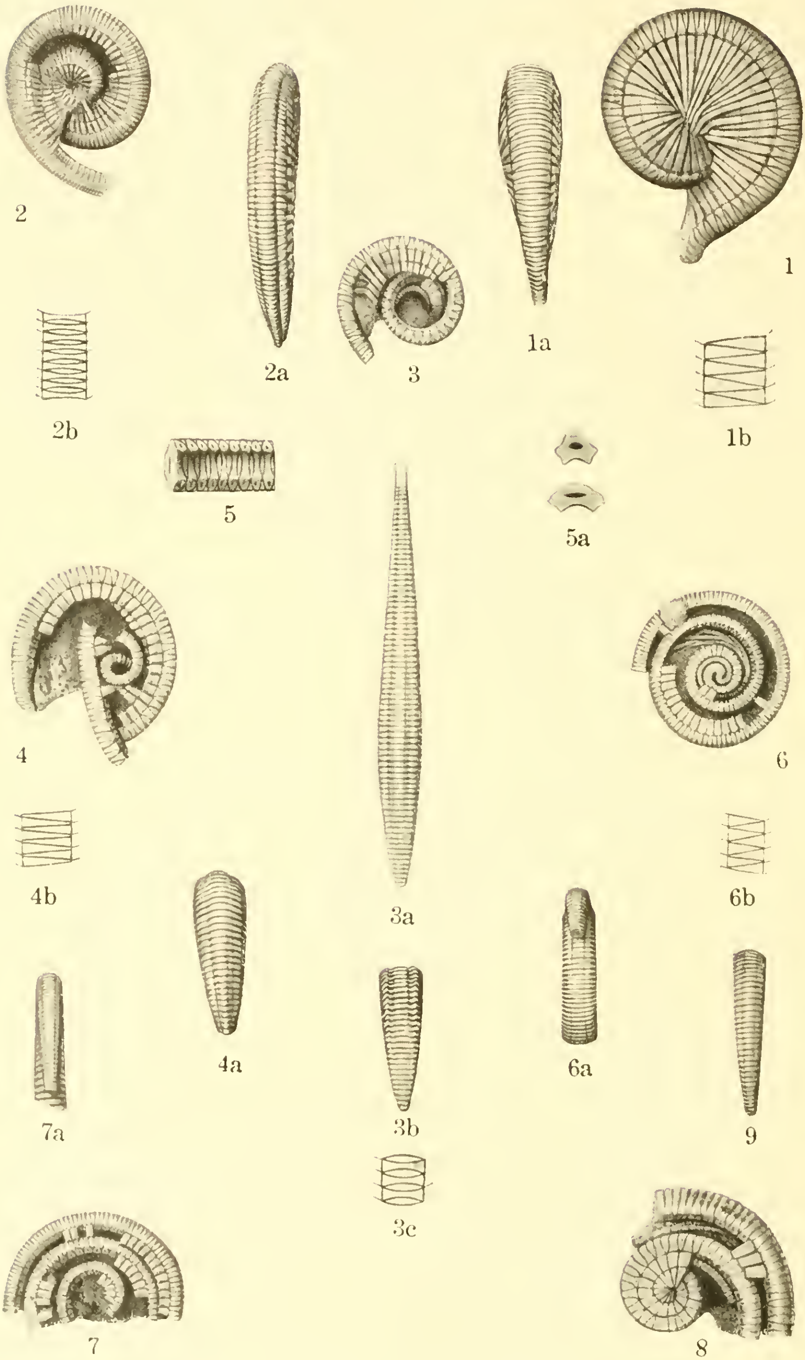
12*c*. Diagram of calyx and arms.

Silurian, Wenlockian: Dudley, England.



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGES 97, 98



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGES 99, 100

PLATE 2

All figures not otherwise noted natural size

	Page.
MYELODACTYLUS AMMONIS (Bather)	10

FIG. 1. A close coil, with stem tapering to a point; cuneate interlocking columnals with a cirrus from the broad end of each; cirri converging to center, completely enveloping the crown. × $\frac{3}{2}$.

1*a*. The same specimen, seen from outer curve, showing the rapid taper of stem to a narrow distal end; longitudinal sutures not visible in this specimen. × $\frac{3}{2}$.

1*b*. The alternate succession of columnals in outline—var. *alternicirrus*.

2. A similar specimen (figure not enlarged), with hour-glass shaped columnals bearing a cirrus at each end, and lenticular, non cirriferous ossicles interposed.

2*a*. The same seen from the outer curve, tapering to a point, and with longitudinal sutures strongly developed. × $\frac{3}{2}$.

2*b*. The paired succession of cirri in outline—var. *bijugicirrus*.

3. A small specimen of similar type to last, with strong distal taper. × $\frac{3}{2}$.

3*a*. The outer side of same specimen as it would appear if stretched out straight; to show the great relative breadth in the middle region, narrowing both ways, and ending distally in a point; outer longitudinal sutures strong. × $\frac{3}{2}$.

3*b*. The distal end of same. × $\frac{3}{2}$.

3*c*. The succession of columnals in outline, with paired arrangement of cirri—var. *bijugicirrus*.

4. A similar specimen, with alternate cuneate columnals; small part of proximal coil is shown. × $\frac{3}{2}$.

4*a*, *b*. The tapering distal end, and the succession of columnals in outline—var. *alternicirrus*.

5. Part of a remnant of two coils, from the inner side of the innermost coil, showing the form and arrangement of columnals for the paired cirri—var. *bijugicirrus*. × $\frac{3}{2}$.

5*a*. Transverse view of the fractured section of the two coils, the upper one being near the distal end, therefore thicker and narrower than the lower. × $\frac{3}{2}$.

All the foregoing are from the Brownsport limestone, Niagaran; Decatur County, Tennessee.

6. Specimen with three involute coils, tapering to a narrow distal end. The cirri have mostly fallen away, exposing the proximal evolute coil with the slender, circular neck leading to the faintly outlined crown lying along the concave side of the middle coil.

6*a*. Outer curve of same, showing distal end and longitudinal sutures.

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FIG. 6*b*. The succession of columnals—var. *alternicirrus*. 10

7, 7*a*. Similar views of a fractured specimen of same type, showing form and proportions of first cirrals on three successive coils—var. *alternicirrus*.

8. Remnant of a fractured specimen associated with the two preceding in the same layer, having paired cirri—var. *bijugicirrus*; a portion of the circular neck and of the crown are visible. × $\frac{3}{2}$.

9. The tapering distal end only of a stem with extremely slender termination. × $\frac{3}{2}$.

The last four specimens (6–9) are from the Waldron shale, Niagaran: Newsom, Tennessee.

Plate 3

All figures not otherwise noted natural size

	Page
MYELODACTYLUS EXTENSUS, new species	14

Fig. 1. A large specimen with stem extended about 8 cm. beyond the close coil, nearly straight, not terminating in a point. Has cirri on alternating, cuneate columnals.

1*a*. The succession of columnals—var. *alternicirrus*.

2. Another large specimen with stem extended about 5 cm. beyond the deviation from the close coil, and beginning to diminish at point of fracture; the proximal reverse curve is seen. Has paired cirri on hour-glass shaped columnals.

2*a*. The succession of columnals—var. *bijugicirrus*.

3. Another specimen with stem extended about 6.5 cm. beyond the close coil, tapering near the end where it seems to terminate in small roots of radicular cirri. Has paired cirri.

3*a*. The succession of columnals—var. *bijugicirrus*.

4, 4*a*. A small specimen with some alternating cirri in place, and outline showing succession of columnals—var. *alternicirrus*. $\times \frac{3}{2}$.

5. A large specimen with very small close coil, and the loose coil, partly restored, extended for about 12 cm. beyond the place of deviation, and not yet terminated. Parts of a few cirri are in place. Columnals of var. *bijugicirrus*.

6. Smaller specimen with much of extended stem broken off. Proximal coil is seen, with reversed curve of the circular neck, followed by the crown, of which the calyx is indistinct. Columnals of var. *alternicirrus*. $\times \frac{3}{2}$.

7. Large specimen with incomplete stem for about 7 cm. beyond close coil. Polished section obtained by grinding down to the axial canal, showing the proximal coil, neck, and crown in outline, with scattered cirrals in some places. Columnals of var. *bijugicirrus*.

8, 8*a*. Reverse sides of a specimen with only the close coil remaining, having the cirri complete, converging at the center. Columnals of var. *bijugicirrus*.

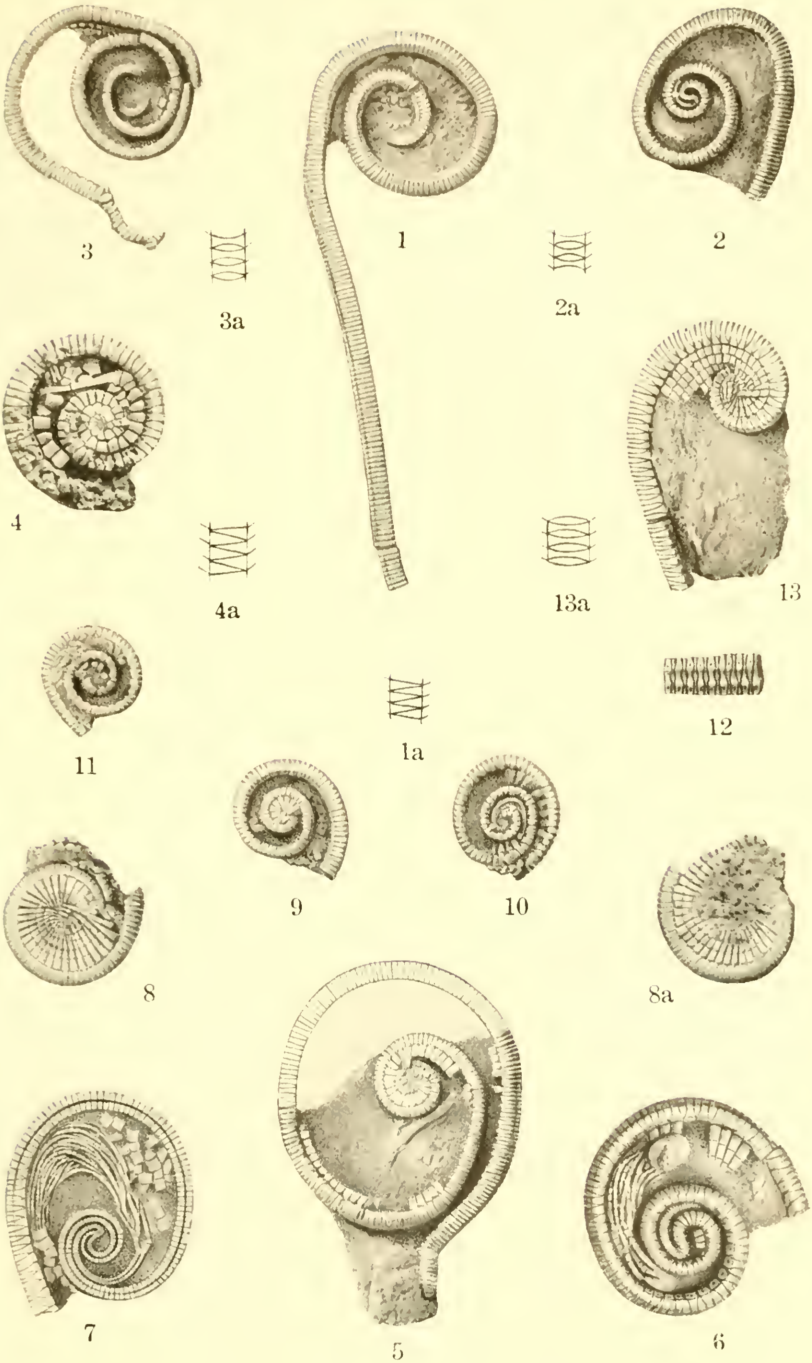
9, 10, 11. Three small specimens with stems broken off, not far beyond the close coil. All of var. *alternicirrus*.

12. Fragment of stem from St. Paul, Indiana, showing both paired and alternate cirri in the same specimen. $\times \frac{3}{2}$

13. A specimen from the Wenlockian at Dudley, England, with paired cirri in place at the closed coil, and stem extended far beyond that region, not yet diminishing distalwards.

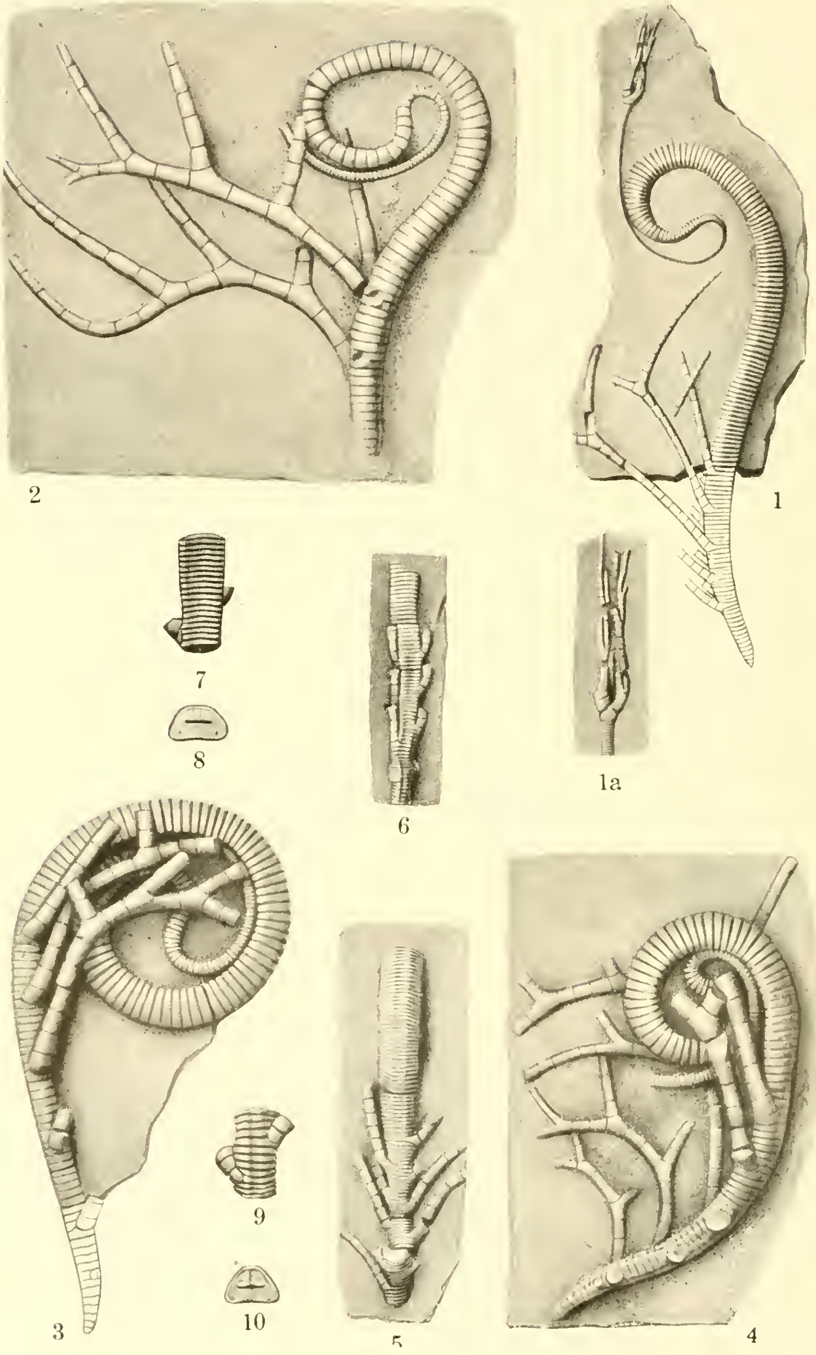
13*a*. The succession of columnals—var. *bijugicirrus*.

All except 12 and 13 are from the Brownsport limestone, Niagaran; Decatur County, Tennessee.



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 102



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 103

Plate 4

Figures not otherwise noted natural size

Page

MYELODACTYLUS BRACHIATUS Hall 16

Fig. 1. Specimen with the crown preserved, showing the extreme length and slenderness of the proximal neck leading to it at the end of the reversed curve, and outside of the main coil of the stem. Some of the branching cirri are shown, limited to the distal region. × $\frac{3}{2}$.

1*a*. The crown of same, further enlarged. × 3.

2. A small specimen, with nearly complete stem extending to near the calyx, where the slender neck is broken off outside the main coil, as in all specimens except the preceding. It shows the great relative size and repeated branching of the cirri, which are almost as long as the thickened part of the stem. × 3.

3, 4. Two specimens with neck similarly broken off, showing the numerous branching cirri in various positions rising from the distal region, enveloping the proximal coil like a fringe. Fig. 3 shows the complete stem, tapering to a point at the distal end. × 2.

5. A very large specimen seen from outside of curve, showing the longitudinal sutures, and alternate arrangement of the rounded cirri arising from back of stem, and limited to the distal region. Columnals of this specimen are 6 mm. wide at the back.

6. Distal portion of a broken specimen seen from the inner side of the curve.

7. Fragment from above the upper limit of cirri, seen from inner side of curve. × $\frac{3}{2}$.

8. Transection of stem at about same position as last, showing form of axial canal. × $\frac{3}{2}$.

9. Fragment toward the distal end, seen from outer side of curve, showing origin of cirri at back of stem. × $\frac{3}{2}$.

10. Transverse view of joint-face at about same level, showing the relative narrowing and thickening of the stem approaching a circular form at the termination. × $\frac{3}{2}$.

Niagaran, Rochester shale; Lockport, New York.

Plate 5

Figures not otherwise noted natural size

	Page
MYELODACTYLUS NODOSARIUS Hall	20

Fig. 1. One of Hall's types (Pal. N. Y., vol. 3, pl. 5, fig. 5), showing the great size of the ponderous cirri compared with the smaller stem, and the bulbous terminal at distal end, seen from outer side of curve.

2. A similar specimen in which the terminal bulb ends in a point.

3. Another type (idem, pl. 6, fig. 1), seen from inner side of curve, showing the full length of cirri swollen in the middle.

4. Specimen showing still greater swelling of the cirri.

5. Specimen showing considerable length of the cirrus-bearing part of the stem.

6. Distal end of stem, showing relative size of terminal bulb, and first cirrals. Author's collection.

7. The same structures with addition of several cirri, showing small size of first cirrals.

8. Inner side at distal end, showing terminal bulb, small size of stem and mode of attachment of cirri. Collection Yale University.

Helderbergian, New Scotland formation; Schoharie County, New York. All the specimens not otherwise noted are in the New York State Museum, Albany.

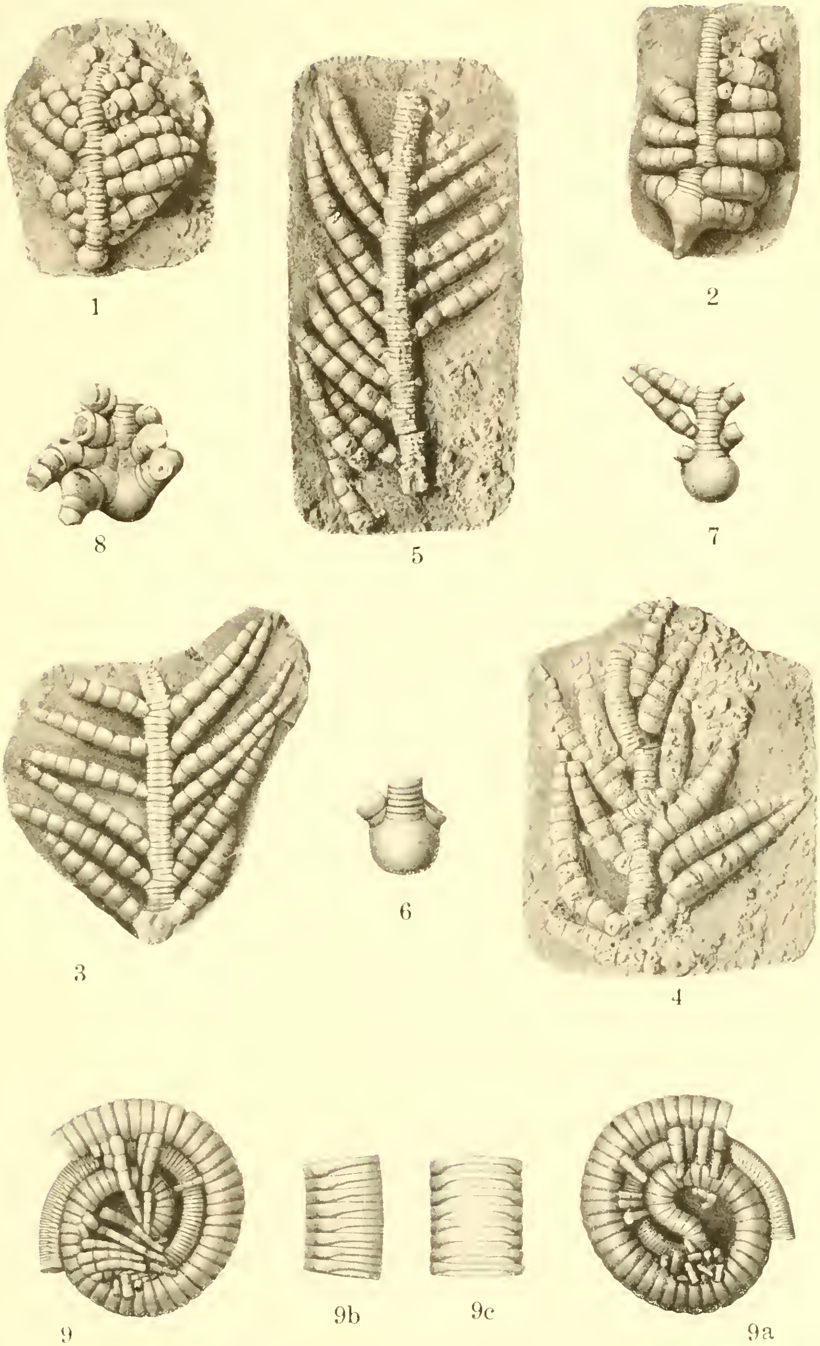
MYELODACTYLUS SCHUCHERTI, new species	21

Fig. 9. The only specimen, with both distal and proximal portions broken off, leaving one coil of the main, crescentic region of the stem, followed by the reverse curve, and the very robust proximal neck; several cirri are in place, paired on successive columnals. × 2.

9*a*. Reverse side of same, showing the same structures. Note the peculiar arrangement of columnals in the exposed part of the proximal neck. × 2.

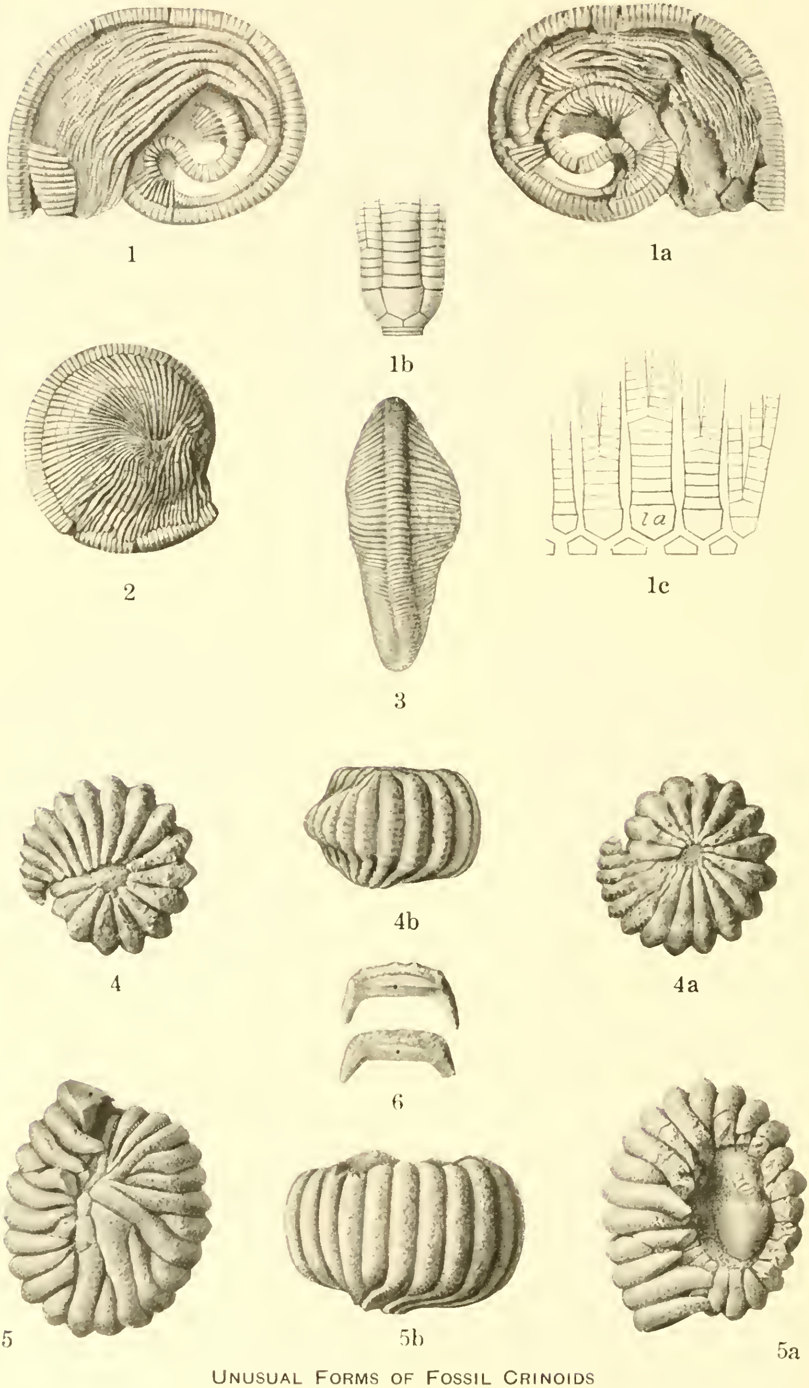
9*b*, 9*c*. Details of columnals in the part of the neck towards the calyx; side and top views, further enlarged. × 6.

Helderbergian, Linden formation; Benton County, Tennessee. Coll. U. S. National Museum.



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 104



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGES 105, 106

Plate 6

All figures not otherwise noted natural size

Fig. 1. A nearly complete specimen, lacking only the distal part of the stem; crown fully exposed on both sides by removal of cirri. Seen from the many branched anterior radius, with the unbranched right anterior radius to the left of it. The proximal neck and reverse curve are in full view, and a few cirri are in place distalwards, one to each columnal.

1*a*. Reverse side of same, left posterior view, showing the same structures; cirri exposed opposite some of those seen in the preceding figure, proving their paired arrangement on succeeding columnals. The crescentic stem toward the ends of the arms is 4.5 mm. wide, while the mass of arms is swollen beyond it at either side until it is 12 mm. thick, measured vertical to the plane of these figures.

1*b*. Calyx and lower part of arms of same specimen, from left anterior radius. × 2.

1*c*. Analysis of the crown, showing the presence of five radii, no two alike; r. post. radius at the right with anal tube resting on the left sloping face of the superior half of the radial; r. ant. radius at the left, unbranched; the others branching at different heights. General arrangement similar to that of *Iocrinus*.

2. Another specimen closely inrolled, with crown completely enveloped by the long, slender, cirri converging at the center; swollen to a thickness of 8.5 mm.

3. A specimen showing the great swelling of the crown at the distal region, as it lies enveloped in the cirri; it is here 15 mm. in thickness. Seen from outer curve of stem.

Lower Devonian, Keyser formation; Keyser, West Virginia.

Fig. 4. A small specimen, tightly inrolled, seen from the side, showing the large columnals, tapering to a point at the distal end, with strong, apparently non-articulated processes converging toward the center, in the position of cirri. × $\frac{3}{2}$.

4*a*. The same, seen from the reverse side. × $\frac{3}{2}$.

4*b*. The same, seen from outer side of curve, showing the deep beveling of the columnals, their great width and rapid taper to distal end. × $\frac{3}{2}$.

5. The larger specimen; lateral view showing the cirrus-like, but unarticulated, processes converging at the center in irregular forms. Note perforation at the fractured distal end for the axial canal. × $\frac{3}{2}$.

Page

FIG. 5*a*. Reverse side of same, with the processes partially removed by preparation, exposing calyx of a Camerate crinoid with trace of arms. × $\frac{3}{2}$. 22

5*b*. Outer curve of same, showing great width of columnals and their rapid diminution distalwards. × $\frac{3}{2}$.

6. Two detached columnals from some other specimen, showing the articulating joint faces, fulcral ridge, perforation for axial canal, and non-articulated processes at the side solidly attached where cirri would be in other forms. × $\frac{3}{2}$.

Middle Devonian; Eifel, Germany.

Plate 7

All figures not otherwise noted natural size

Fig. 1. A nearly complete specimen, with scattered cirri at irregular intervals, limited to the distal portion. Natural size.
Mississippian, Burlington limestone; Burlington, Iowa.

Figs. 2, 3. Two of the types of Wachsmuth and Springer (North Amer. Crin. Cam., pl. 75, figs. *2a, b*,) after additional cleaning; they show the doubled nodal columnals, each bearing a cluster of two, three, or rarely four, rather short tapering cirri diminishing in size inwards; alternating with these is a single internodal, nearly the length of the pair; occasionally the internodal is wanting, or the cirri limited to one. The cirrus clusters form two marginal rows at the inner side of the curve, the outermost cirrus being so much larger than the others of its cluster that the latter often cannot be seen except by very close observation after careful preparation. × $\frac{3}{2}$.

It should be noted in regard to these and all the figures showing the marginal cirri, especially the detailed sketches, that we only see one row, that upon the opposite margin being omitted in the sketches.

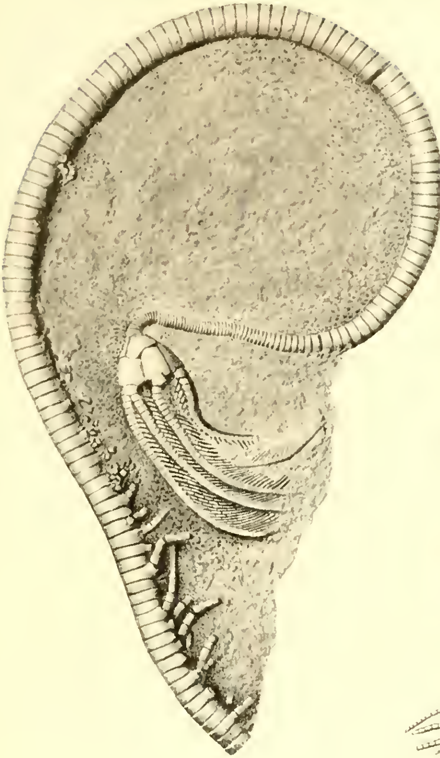
3a, 3b. Detail from the original of figure 3, including 16 cirri counting from the second cirrus next to the broken off distal end. This drawing is made in two parts for convenience in mounting. The elliptic outlines in this and similar figures give the cross sections from measurements at the part of the stem next to them. Distal is to the right. × 3.

3c. Detail from the same specimen, further enlarged, to show the position of the first cirrus-facet directly over the suture between the nodal pair. × 6.

3d. Another view showing the mode of succession of the cirri following the first cirrus in the cluster. × 6.

4. A specimen with the stem tapering nearly to the distal end, showing the crowded condition of the cirri as seen unenlarged; in this and the next figure they appear as if chiefly two to the nodal, but the smaller, inner cirri are mostly crowded inward out of sight.

5. The largest specimen, the only one showing the proximal circular part of the stem; it also shows a portion of the calyx, so distorted and cracked that the plates can not be definitely shown. The stem is nearly complete, about 9 cm. long from the proximal part distalwards.



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5b

5a

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3c

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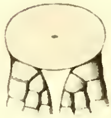

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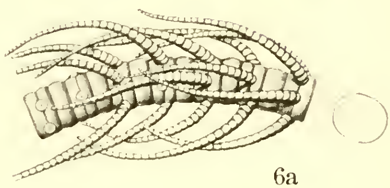
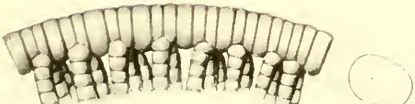


6a



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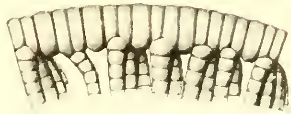
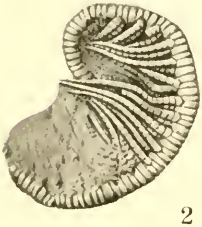


3b



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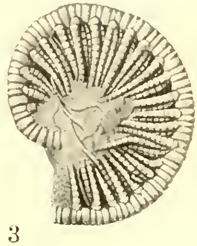

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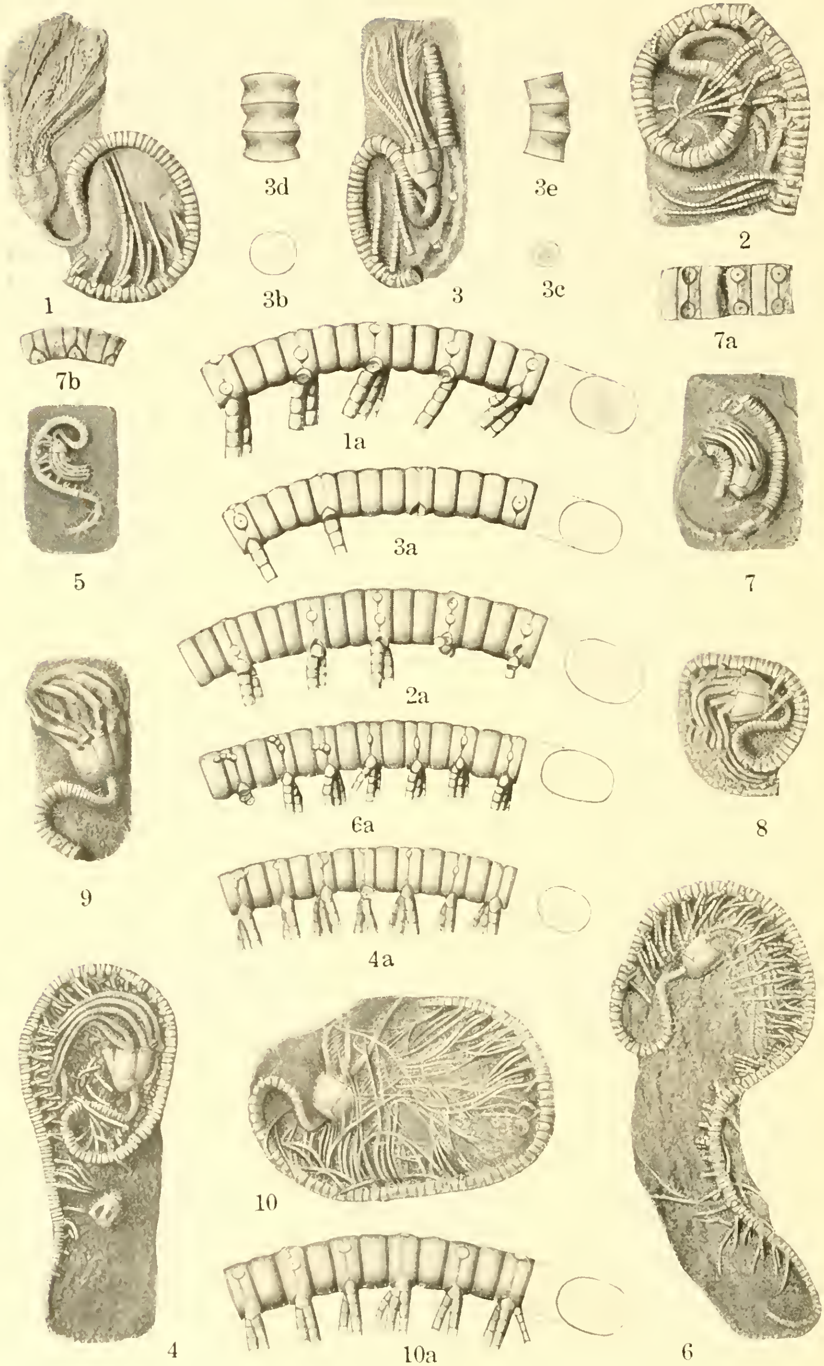
UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGES 107, 108



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGES 109, 110

PLATE 8

All figures not otherwise noted natural size

Page

CAMPTOCRINUS CRAWFORDSVILLENSIS, new species 30

FIG. 1. Specimen showing full size and proportions of the crown, with probably less than half the stem preserved; clusters of two and three elongate cirri spring from each nodal pair in marginal rows along the inner side of the curve, together with traces of much smaller rudimentary cirri rather irregularly distributed around the periphery of the nodals at the convex outer side; and two, rarely three, internodals interposed.

1*a*. Detail from same next to broken end of stem, with elliptic cross section at right. Distal is toward the left. × 3.

2. A similar specimen, with whorl of dwarfed cirri somewhat better defined; two, or three, internodals.

2*a*. Detail from same next to broken end of stem; with elliptic section at right. Distal toward the right. × 3.

3. Original of Wachsmuth and Springer's plate 75, figure 1, with stem preserved well toward the distal end where it loses its elliptic form; marginal cirri apparently limited to a single one for each nodal pair at either side, and whorls of rudimentary cirri, less prominent than in the last specimen, are also seen; internodals mostly three, also two or four.

3*a*. Detail from same near the fracture at bottom in the figure, with elliptic section measured at the widest part of stem to the left. Distal is toward the left. × 3.

3*b*, 3*c*. Section at the lower fracture, where the stem is nearly round, and at the uppermost fracture where it is entirely so. × 3.

3*d*, 3*e*. Top and side views of part of same stem at the curve to the left of the calyx, where the columnals have become transversely hollowed. × 3.

Mississippian, Keokuk limestone; Crawfordsville, Indiana.

CAMPTOCRINUS MULTICIRRUS, new species 31

FIG. 4. Specimen from Huntsville, Alabama, with crown and stem complete; shows the clusters of two and three marginal cirri to the nodal pair, and a very large internodal interposed; basal plates unequal, deformed by pressure of curve. A minute specimen of *Taxocrinus huntsvillae* lies alongside. × 3.

4*a*. Detail from stem of same, with section at right from the median portion; it shows the secondary or incipient cirri disproportionately small, with two or three cirrals developed in some places, and in others only single rudimentary ossicles just broken through on the suture line, without any axial canal to innervate further growth. Distal is toward the left.

Page

FIG. 5. A very young specimen from the same locality, showing form and proportions of complete crown and stem. 31

6. A complete specimen from Monroe county, Illinois, with stem preserved to the extreme distal extremity, showing that it terminated in a point, and had no means of attachment to any solid object except by clinging with the cirri.

6*a*. Detail from same, with elliptic section, showing arrangement of the marginal clusters and the rudimentary cirri, and the undeveloped cirrals lacking the axial canal. Distal is to the right. × 3.

It should be noted that in the two principal specimens, figs. 4 and 6, both sides are well exposed in some places, showing the presence of the two rows of cirrus clusters in conformity with the bilateral, elliptic form of the stem.

7, 8, 9. Three specimens from same locality as last, showing various details of crown and stem.

7*a*, *b*. Inner and side views of columnals from stem of specimen 7, showing position of cirrus-facets with and without remnants of cirri adhering. × 3.

Mississippian, lower part of Chester; Alabama and Illinois.

CAMPTOCRINUS CIRRIFER Wachsmuth and Springer______ 32

FIG. 10. Type of Wachsmuth and Springer (pl. 76, fig. 13*a*). A complete specimen, showing the extremely long and slender cirrus clusters.

10*a*. Detail from same, showing the almost undivided nodals, single large internodals, and first cirrals of small secondary cirri. × 3.

Mississippian, upper part of Chester; Pulaski county, Kentucky.

Plate 9

All figures natural size unless otherwise stated

Page

MACROSTYLOCRINUS RECUMBENS, new species — 35

Fig. 1. Side view of a specimen with arms curved backward over the dorsal cup and around the stem; pinnules directed outward.

2. The tegmen of a large specimen in similar condition, showing general outline, origin of arms, and projecting anal plates between the posterior rays.

3. Lateral view of specimen with the arms partly removed; showing relation of calyx, arms, stem and cirri, the plates of two radii, and the first iBr between them.

4. Posterior view of a similar specimen, showing calyx from the anal side, with the anal series complete up to the tegmen.

Lower Devonian, Oriskany; Cumberland, Maryland.

PLATYCRINUS PENDENS, new species — 38

Fig. 5. Dorsal view, showing calyx as enveloped by the closely recumbent arms; much distorted by pressure.

5a. Ventral view of same; showing food grooves, and pinnules directed to the exterior.

Mississippian, Kinderhook; Le Grand, Iowa.

BARRANDEOCRINUS SCEPTRUM Angelin — 35

Fig. 6. A complete specimen showing the relative position of the recumbent arms and stem, and the depressions caused by the contact of arms with the surface of the calyx. For comparison with preceding species. From a drawing by G. Liljevall made for Wachsmuth and Springer. Riks Museum, Stockholm.

7. A specimen in the author's collection, in which the calyx is completely enveloped by the recumbent arms.

Silurian, Wenlock limestone; Gotland, Sweden.

ACROCRINUS AMPHORA Wachsmuth and Springer — 40, 41, 45

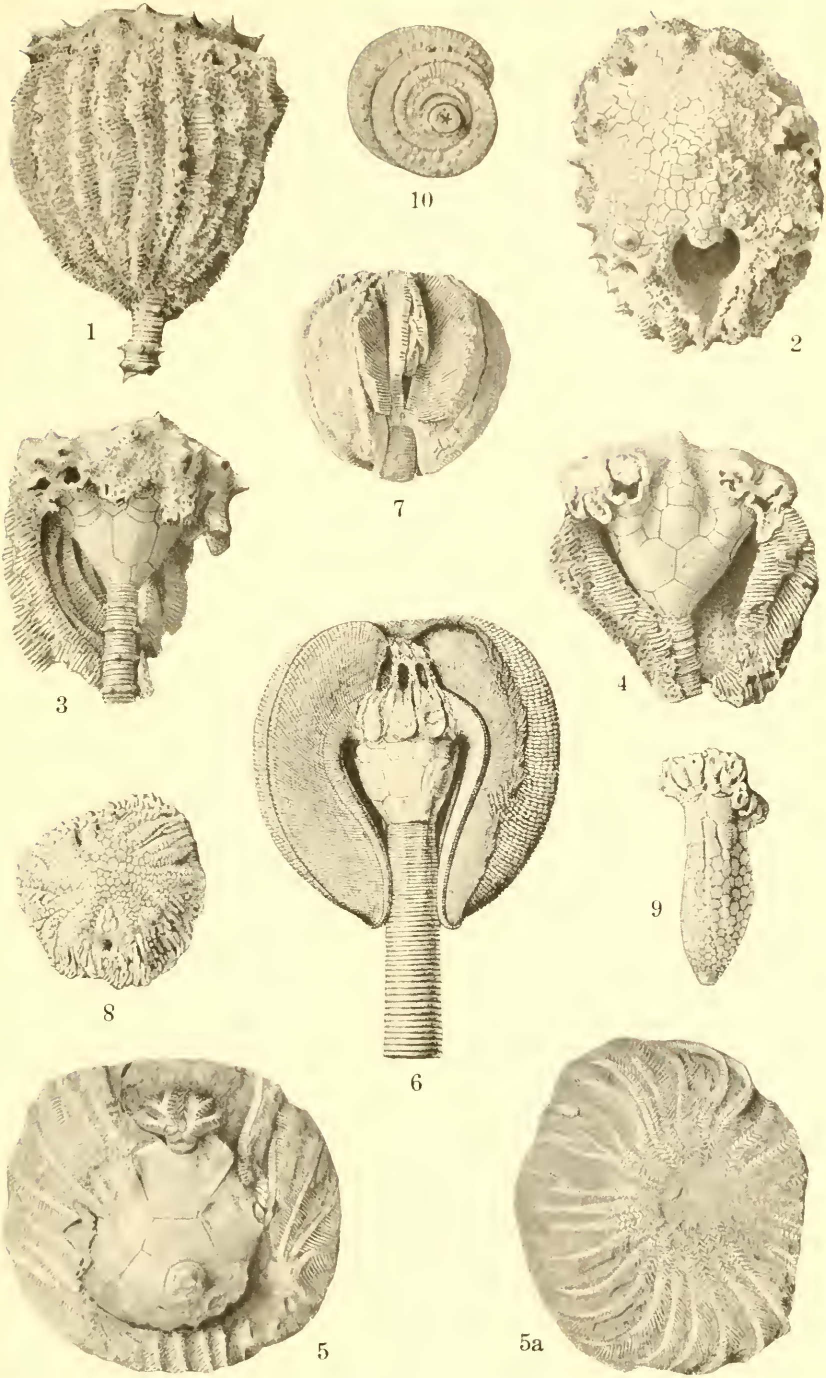
Figs. 8, 9. Specimens showing the tegmen, composition of the calyx, position of the arm bases, and the marks of pressure by arms upon the outer surface.

Lower Chester, Ohara formation; Huntsville, Alabama.

A coiled stem; not **MYELODACTYLUS** — 15

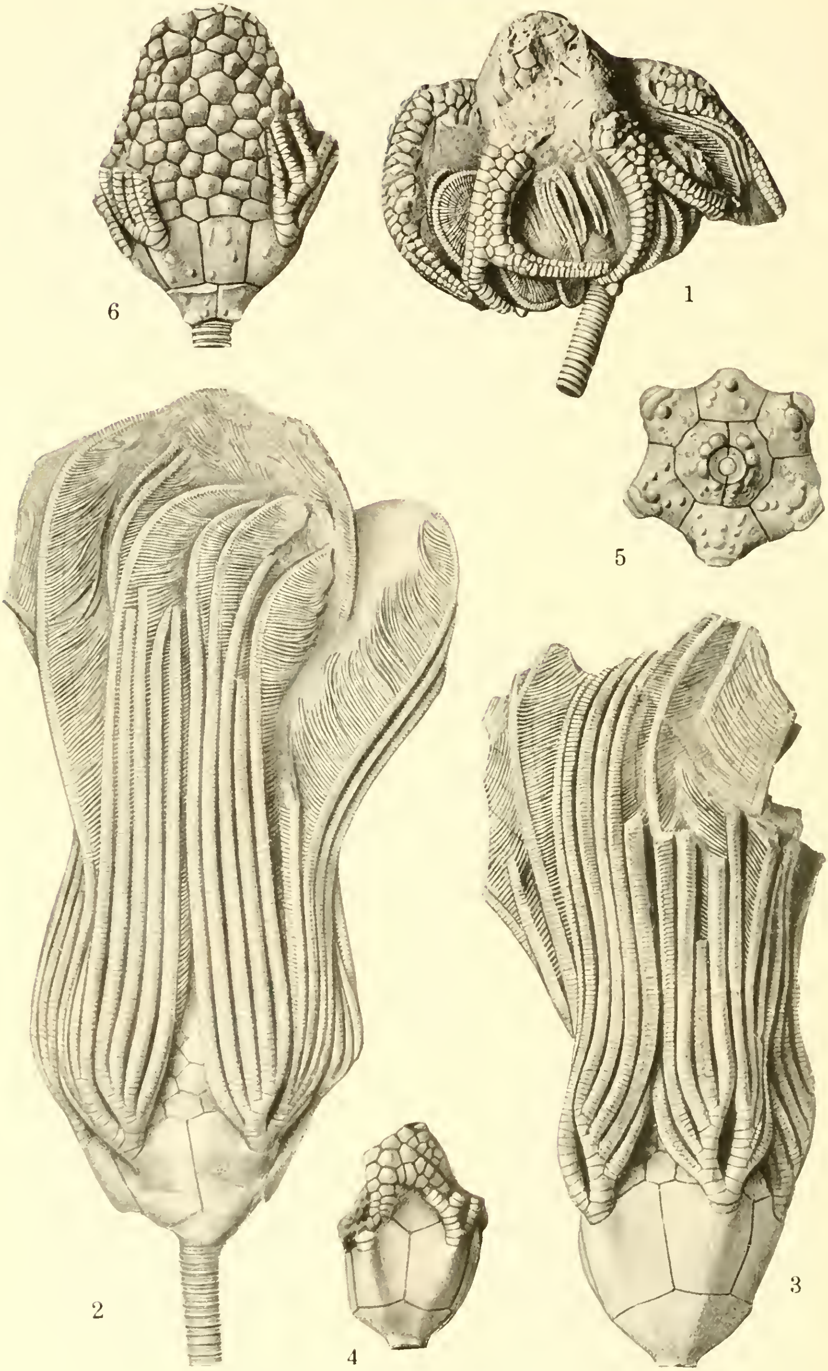
Fig. 10. A normal stem of unknown species, spirally coiled around a fragment of another stem. For comparison with figures on preceding plates.

Niagaran, Waldron shale; Newsom, Tennessee.



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 112



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 113

PLATE 10

All figures natural size

	Page
GILBERTSOCRINUS DISPANSUS Wachsmuth and Springer	38

FIG. 1. Specimen with the true arms in place; to show the arms partially recumbent, with the position of the arms and pinnules apparently opposite in the same individual. In the middle part the arms bend downward, and the pinnules are outermost, away from the calyx; at either side the arms make a reverse curve, bending upwards, so that the pinnules point inwards toward the calyx. The hump at the top is a *Platyceras*, fastened over the anal opening to feed upon the excrement of the crinoid.

Keokuk limestone; Indian Creek, Indiana.

PARADICHOCRINUS PLANUS, new species	51

FIG. 2. An extremely large specimen, with 5 or 4 arms to the cluster in each half ray, formed by successive unilateral branching to the outer side of the dichotom. The very thin and smooth calyx plates are much broken by pressure, and their arrangement has been restored from other specimens. Interradial view.

3. A smaller specimen in which the arrangement of the calyx plates and their perfectly smooth surface are well shown; it has 5 arms to each outer side of the dichotom. Interradial view.

4. A calyx, to show structure of the tegmen.

Keokuk limestone, lower horizon; Indian Creek, Indiana.

PARADICHOCRINUS POLYDACTYLUS Casseday and Lyon	50

FIG. 5. Dorsal view of a vertically flattened calyx, to show the strong, pustular or nodose ornamentation, in contrast to the smooth surface of the last species.

6. Posterior view of a calyx with nodose ornament, and showing the great elevation of the tegmen. For the arm structure of this species see Wachsmuth and Springer (North Amer. Crin. Cam., pl. 77, fig. 1*a*).

Keokuk limestone, higher horizon; Crawfordsville, Indiana.

Plate 11

All figures natural size

Fig. 1. The holotype, figured in North American Crinoidea Camerata, pl. 78, fig. 15, showing the relation of calyx, pendent arms, pinnules, and stem.

2. Another specimen, showing form of calyx, with the arms mostly removed.

3. A specimen with calyx completely enveloped by arms bent backward upon the stem; pinnules at the outside.

4. Specimen with complete stem and branching root; no cirri.

Upper Burlington limestone; Burlington, Iowa.

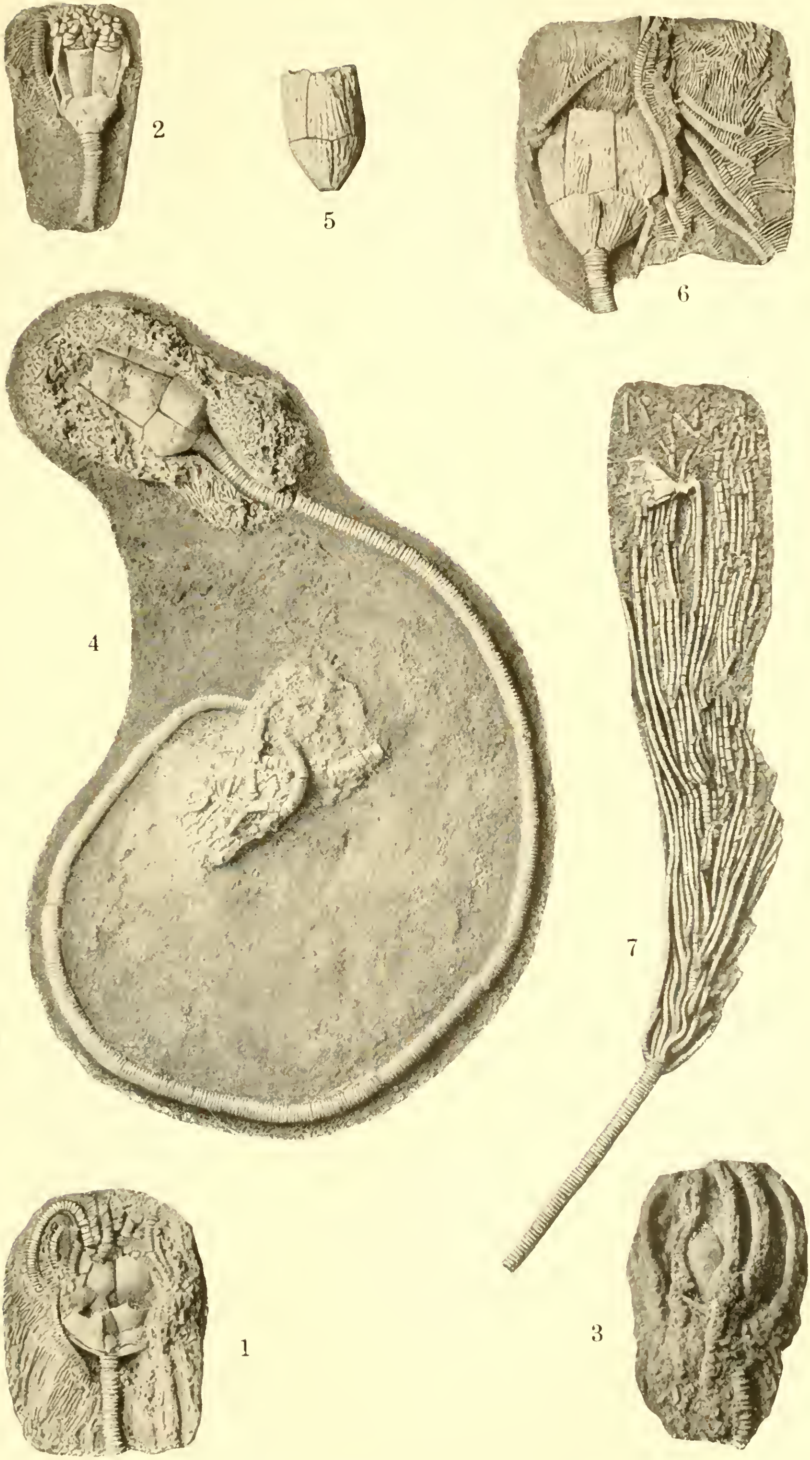
Fig. 5. The holotype, calyx only, figured in North American Crinoidea Camerata, pl. 78, fig. 9.

6. A specimen discovered since the original description, showing the pendent arms.

Warsaw limestone; Spergen Hill, Indiana.

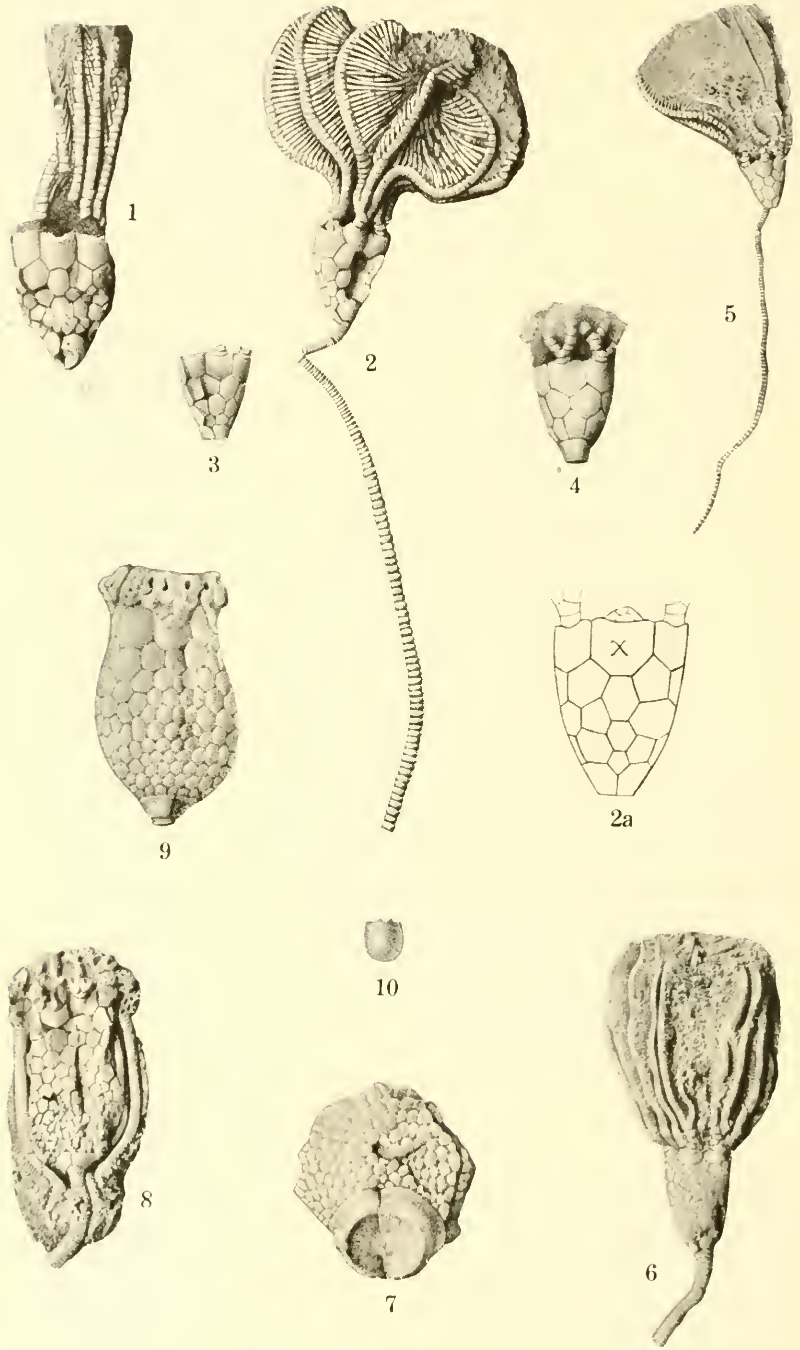
Fig. 7. A specimen with long stem but lacking the arms; having extremely long curri, enveloping the small calyx in an upward direction.

Upper Burlington limestone; Burlington, Iowa.



Unusual Forms of Fossil Crinoids

For explanation of plate see page 114



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 115

PLATE 12

All figures natural size unless otherwise stated

	Page
ACROCRINUS PRAECURSOR, new species	42

FIG. 1. Posterior view of calyx and part of arms, both somewhat displaced by pressure, showing numerous ranges of irregular plates between BB and RR.
Upper Burlington limestone; Burlington, Iowa.

ACROCRINUS INTERMEDIUS, new species 43

FIG. 2. A complete crown with long stem; r. post. view, showing erect, biserial arms and pinnules, and the anal series with pyramid of small plates surmounting it. Has 3 ranges of plates between BB and RR. × 2.
2a. Diagram of calyx of same; drawn from the posterior side, giving the complete succession of anal plates.
3. Similar view of a detached calyx having 2 and 3 ranges of supplemental plates interposed. × 2.
4. Right anterior view of calyx of another specimen with 2 ranges of plates interposed. × 2.
5. Anterior view of a nearly complete crown and stem, with 2 ranges of plates interposed; natural size.
Lower Chester; Monroe County, Illinois.

ACROCRINUS SHUMARDI Yandell 11, 44, 45

FIG. 6. A complete crown, with arms erect. Grayson Springs.
7. Lower part of calyx. After Wachsmuth and Springer. Sloan's Valley, Pulaski County. × 2.
Upper Chester, Glen Dean formation; Kentucky.

ACROCRINUS AMPHORA Wachsmuth and Springer 40, 44, 45

FIG. 8. A specimen from Huntsville, to show relation of base, calyx with supplementary plates, and recumbent arms.
9. A complete calyx without the arms, to show the arrangement of plates Same locality. After Wachsmuth and Springer. × $\frac{3}{2}$.
Lower Chester, Ohara formation; Huntsville, Alabama.

ACROCRINUS WORTHENI Wachsmuth 45

FIG. 10. Outline of the calyx, to show relative size After Wachsmuth and Springer.
Lower Coal Measures; Peoria County, Illinois.

PLATE 13.

All figures natural size unless otherwise noted

FIGS. 1, 2, 3, 4. A series of complete crowns, part of a colony of several hundred specimens from one locality; showing variation in number of arms from 4, 3, and rarely 2 to the ray. Fig. 3 shows a normal anal plate, completely separating the adjacent radials.

5. A specimen with abnormal anal plate, wedge shaped, with the two radials meeting above it—a variation toward *Pterotocrinus.*

6–12. A series of calices from the same colony showing different forms of tegmen, in which the axillary ambulacral is but slightly developed, or not at all. Fig. 12 is enlarged × 2.

13. Lateral view of a calyx in which the axillary ambulacrals are developed into strong nodes, two of which have been displaced, affording a view of the facets in which they were seated. 13*a* is the nodose ambulacral which came out of the facet seen directly at the front. × 2.

14. Basal view of calyx.

Lower Chester, Ohara formation, formerly called St. Louis, and afterwards Ste. Genevieve; near Sample, Breckinridge County, Kentucky.

FIG. 15. Specimen with very strong spines, closely resembling the form of these plates in some species of *Pterotocrinus.* × 2.

Upper Chester, Gasper formation; Flagpoint, Virginia.

FIG. 16. The axillary ambulacrals hypertrophied into large, club-shaped appendages, tapering to a point. The remainder of the tegmen is covered by a *Platyceras* permanently attached over the anus for feeding commensally upon the excrement of the crinoid.

Upper Chester, Glen Dean formation; Sloan's Valley, Pulaski County, Kentucky.

FIGS. 17, 18, 19, 20. Lyon's type (17) with thin wing-like processes; and other specimens showing basal, lateral, and tegminal views—the latter especially showing the facets in which the processes are seated.

Upper Chester, Gasper formation; Breckinridge County, Kentucky.

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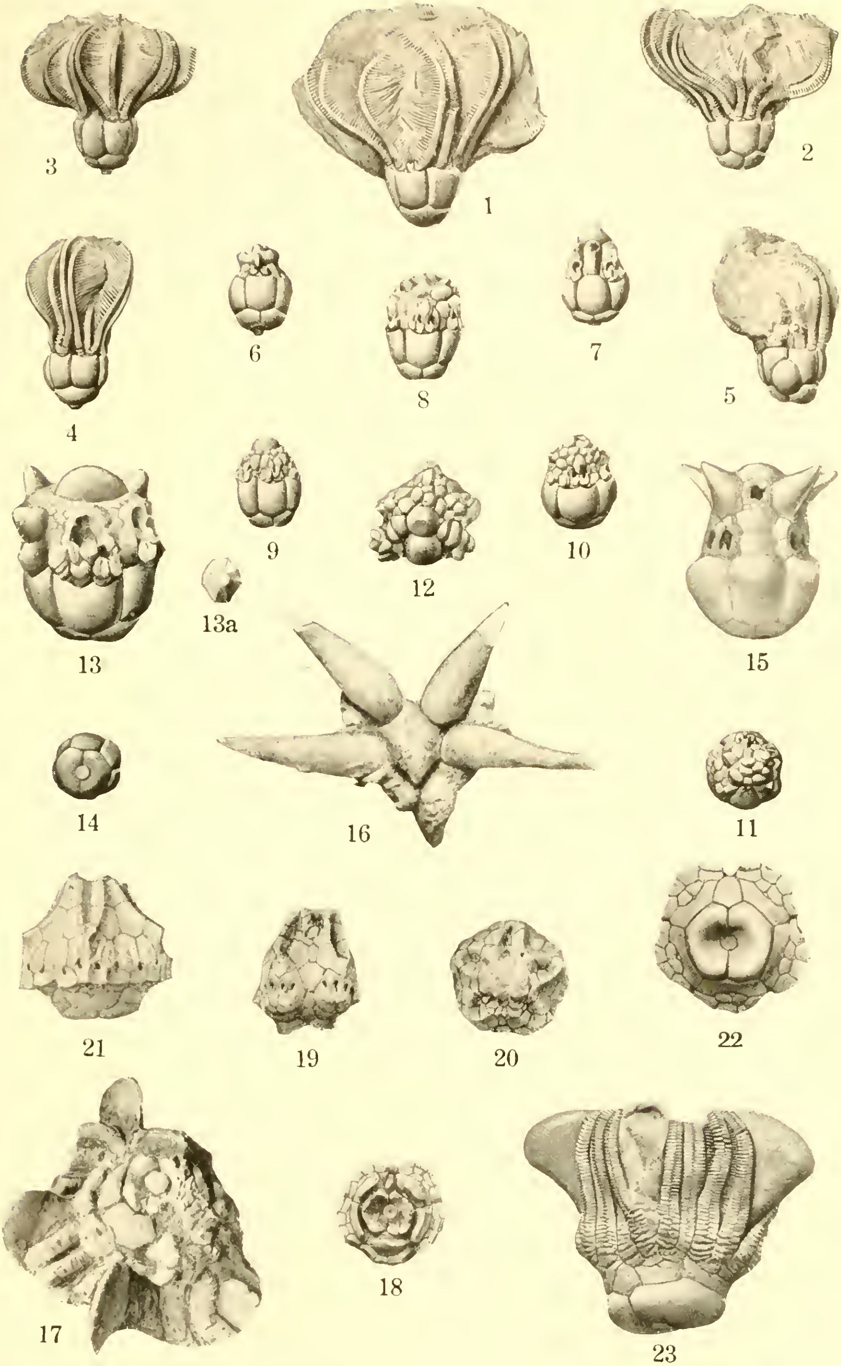
PTEROTOCRINUS PYRAMIDALIS Lyon and Casseday 50

Figs. 21, 22. Lateral and basal views of the type.
Horizon and locality same as last.

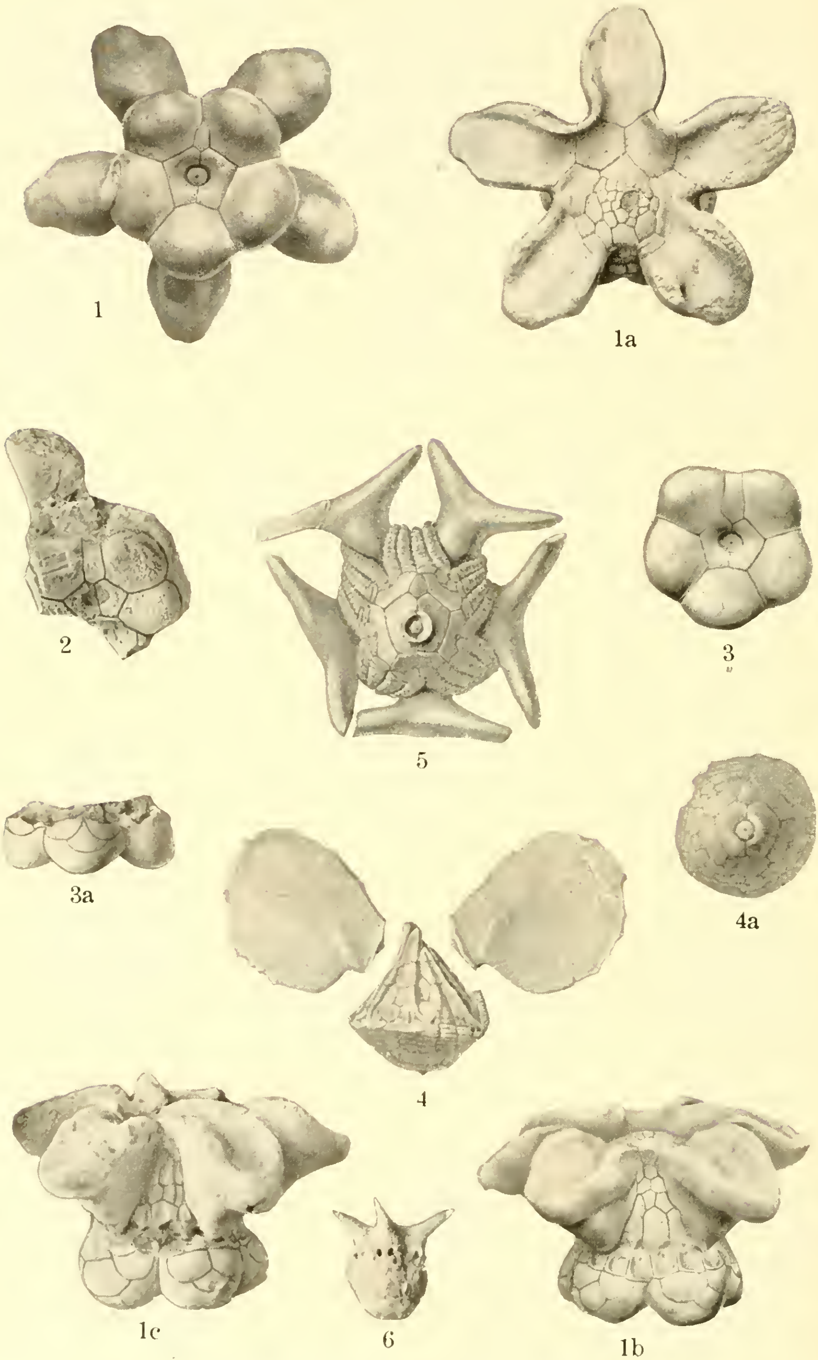
PTEROTOCRINUS CAPITALIS Lyon and Casseday 49

Fig. 23. The type, with extremely large and gibbous basals, and heavy processes, thickening outward to large blunt extremities.
Upper Chester, Golconda formation; Crittenden County, Kentucky.



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGES 117, 118



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 119

Plate 14

All figures natural size

Page.

PTEROTOCRINUS CORONARIUS Lyon 48

Figs. 1, 1*a*, 1*b*, 1*c*. The holotype, with the dorsal cup added to the tegminal part originally figured by Lyon, and afterwards by Wachsmuth and Springer: dorsal, ventral, antero- and postero-lateral views; showing the great size of the gibbous radial plates, contrasted with those of all other known species and the huge, massive spatulate processes into which the axillary ambulacrals have developed.

2. A fractured specimen found associated with the preceding, having one of the spatulate "wing processes" attached to the dorsal cup, both of the same type as those of figure 1, proving beyond question that the two belong toegther.

3, 3*a*. Basal and lateral views of another specimen from the same locality, with only the dorsal cup preserved.

Upper Chester, Golconda formation; Crittenden County, Kentucky.

PTEROTOCRINUS DEPRESSUS Lyon and Casseday 50

Figs. 4, 4*a*. The species with the "wing processes" laterally compressed into thin, knife-like "blades," in contrast to the ponderous appendages of most of the other species. Lateral view of calyx, with two detached "blades" in proper position; and a dorsal view for comparison of form and proportions of basal and radial plates with those of fig. 1.

Upper Chester, Glen Dean formation; Sloan's Valley, Pulaski County, Kentucky.

PTEROTOCRINUS BIFURCATUS Wetherby 50

Fig. 5. In this species the processes of the heavy rounded type have developed in a still different manner by forking almost at right angles. After Wetherby. The original is in the collection of the University of Chicago.

Upper Chester, Glen Dean formation; Sloan's Valley, Pulaski County, Kentucky.

TALAROCRINUS CORNIGERUS (Shumard) 46

Fig. 6. A specimen with the axillary ambulacral developed into prominent spines—precursor of the winged processes of *Pterotocrinus*.

Lower Chester, Ohara format on; Tateville, Pulaski County, Kentucky.

All figures natural size unless otherwise noted

FIG. 1. The holotype, from Chester, Illinois. Note the great length of the fused infrabasal cone, over half the total height of the calyx. The sharply conical contour is not an inflexible character for the species, as there is upon the same matrix with the type another specimen with a more rounded ovoid outline; but the high IBB cone seems to hold good. Coll. U. S. National Museum, No. 17937.

2. A very large specimen also from Chester, more broadly rounded than the type, with IBB half the height of calyx.

3, 4. Two very elongate fused IBB cones, perhaps of this species, but much smaller than that of the type; part of a series of 10 or more similar elongate bases found at the same locality in Union County, Illinois, varying in contour from conical to ovoid, but agreeing in the extremely high IBB. Fig. 4 is from a specimen longitudinally bisected, showing the axial canal extending almost to the end of the fused cone.

Upper part of Chester, Okaw formation.

FIG. 5. The holotype, original of Roemer's figure, formerly in the collection of B. F. Shumard. A direct photograph, showing the arms as they actually are in the specimen (partly restored in the type figure), and the anal plates (not shown in the original figure). The r. post. ray is well shown nearly to the end of the arms. IBB, though solidly fused at the bottom, have sutures for a short distance from the upper margin. Chester, Illinois.

5*a*. L. ant. view of same, showing the great width of the radial, the axillary IBr with its unequal faces, and the increased size of the left arm as compared with those of the adjoining r. post. ray.

6, 7. Anterior and posterior views of two calices from Clear Creek, Hardin County, Kentucky.

Upper Chester, Okaw, and Glen Dean formations.

FIGS. 8, 9. Posterior and anterior views of two characteristic specimens, that of fig. 8 being perfectly typical.

Upper Chester, Okaw formation; Chester, Illinois.

FIGS. 10, 10*a*. Posterior and anterior views of specimen from Sloan's Valley, Pulaski County, Kentucky, with arms broken off slightly above the primibrachs; showing the unequal radials, small size of anterior arm, and unequal faces of the antero-lateral primibrach.

11, 11*a*. Similar views of another specimen from the same locality, having part of the hypertrophied left lateral arm preserved, showing its great size as compared with those adjacent.

Page

FIGS. 10*b*. 11*b*. Cross sectional views of the fractured arms of the two preceding specimens, in which the inequality of the arms in both is still more apparent. 63

12. A calyx from Stephensport, Breckenridge County, Kentucky, in the upper series of the Chester, showing the unequal faces of a lateral primibrach.

13. The original of Lyon's proposed description. A nearly complete crown, with the two pairs of posterior arms and the enormously hypertrophied antero-lateral arms in full view: giving a complete exposition of the dominant character of the genus. Grayson Springs, Grayson County, Kentucky. × $\frac{3}{2}$.

Upper Chester, Glen Dean formation.

AGASSIZOCRINUS GLOBOSUS Worthen________________________ 54, 63

FIG. 14. Posterior view of calyx, slightly less broadly rounded than the type; one of a number of specimens of this and the following species varying slightly in contour from strictly globose to subovate. Near Hardinsburg, Breckenridge County, Kentucky.

Upper Chester, Gasper formation.

AGASSIZOCRINUS OVALIS Miller and Gurley________________ 54, 63

FIGS. 15, 16, 17. Posterior, anterior, and distal views of three calices from same locality as the last: that of fig. 17 to show by direct view the relative width of the radials. There is practically no difference between the specimens referred to this and the preceding species except the divided and fused infrabasal cone, and as to this there are apparently intermediate stages, as well as variation in contour from ovoid to globose.

Horizon and locality same as last.

AGASSIZOCRINUS, species________________________________ 57

FIGS. 18, 19, 20. Dorsal views and a lateral view of three bases, from same locality as last, in different stages of division of infrabasals; the sutures being more or less obscure, in some deviating from a straight line, and in some passing only part way down. A number of other specimens exhibit similar unstable features; and the condition of the Breckenridge County forms as here shown leads to the inference that in this formation at least the IBB may be divided or fused in the adult stage within the same species.

Upper Chester, Gasper formation; Breckenridge County, Kentucky.

AGASSIZOCRINUS, species________________________________ 56

FIGS. 21, 22, 23. Three infrabasal cones from Huntsville, Alabama, perhaps of the same species, of minimum, medium, and maximum size; the first two being solidly fused, and the last, fig. 23, being divided by distinct sutures at the distal face which extend almost to the lower end.

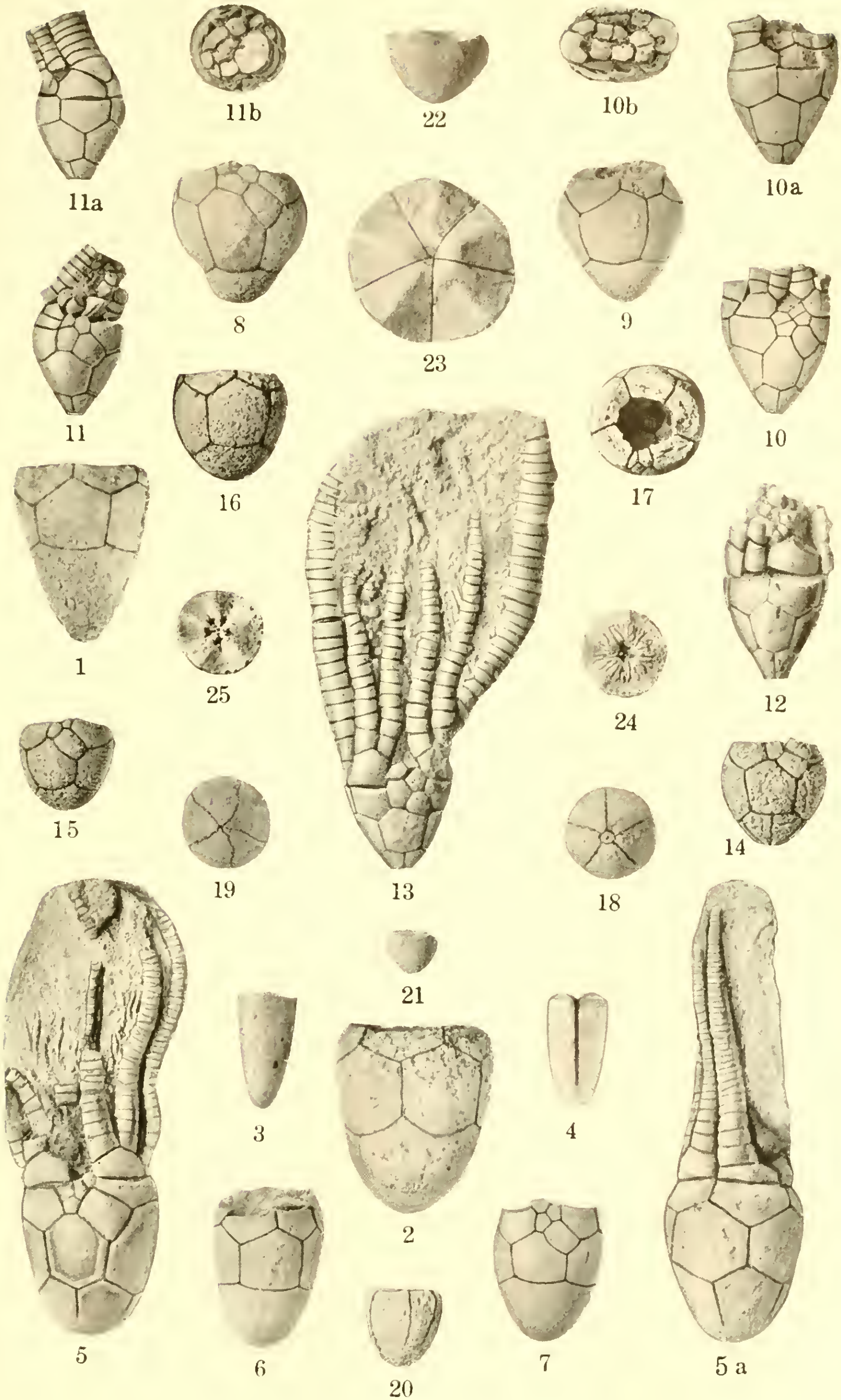
Upper Chester, Gasper formation.

AGASSIZOCRINUS, species________________________________ 57

FIG. 24. Distal face of a fused cone in which the axial nerve canals, being restricted in their downward course, are split into radiating branches passing outward into the wall of the cup.

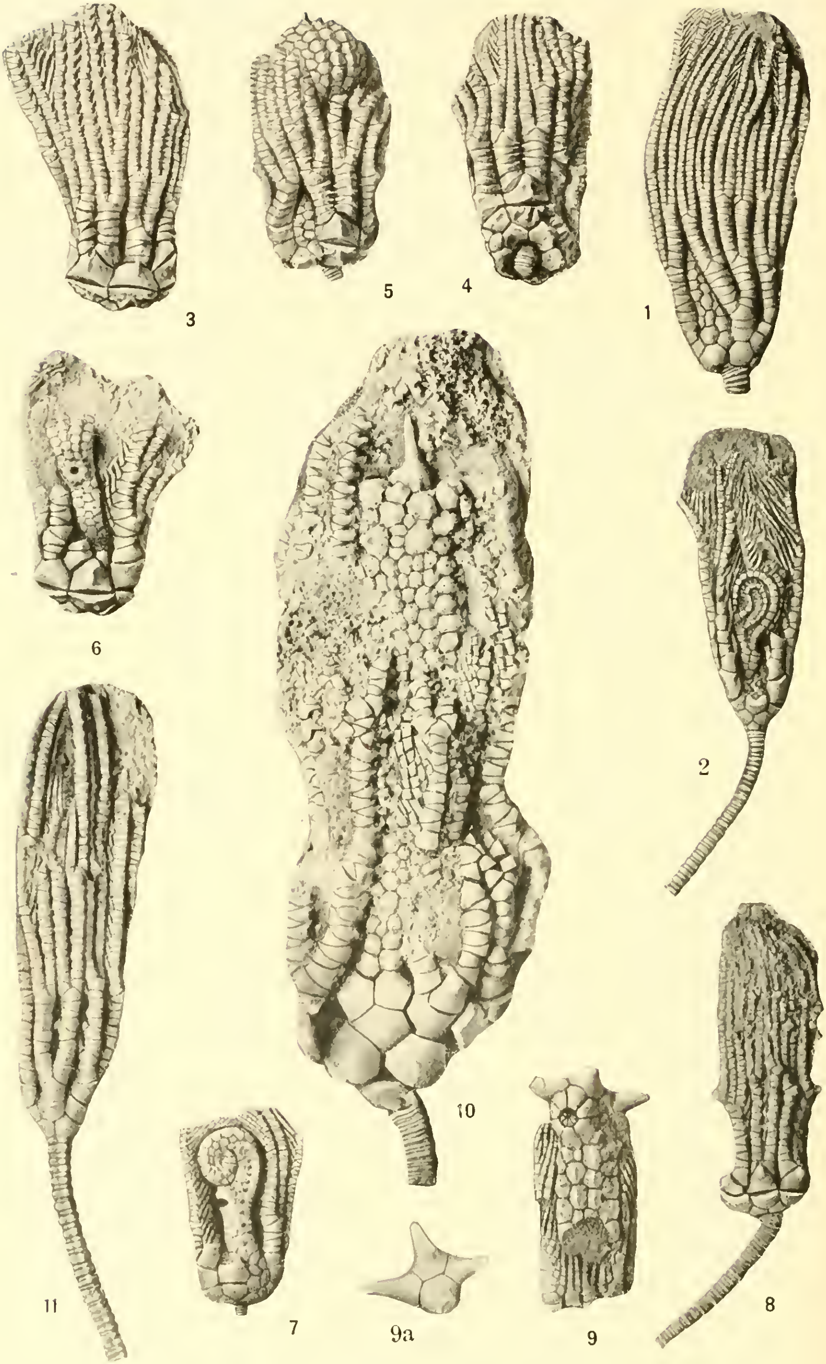
25. Similar cone in which the nerve canals penetrate the fused infrabasals undivided for part of their length.

Upper Chester, Gasper formation; Huntsville.



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGES 121, 122



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 123

PLATE 16

Natural size unless otherwise stated

FIG. 1. Posterior view, to show anal side passing into ventral sac, and mode of arm branching.

Keokuk limestone; Crawfordsville, Indiana.

2. Lateral view, l. ant., showing the sac curving upon itself toward the anterior.

Upper Chester; Grayson Springs, Kentucky.

3. Anterior view, showing structure of arms and pinnules. × $\frac{3}{2}$.
4. Another specimen, l. post. view, giving also a basal view of the calyx. × $\frac{3}{2}$.
5. R. post. radial view of another specimen, showing anal side and curvature of inflated sac. × $\frac{3}{2}$
6. R. ant. radial view, showing nearly full length of sac, doubling on itself toward the anterior, with opening about midway. × $\frac{3}{2}$.
7. L. post. view of similar specimen, showing full length of sac, with curvature in side view, and anal opening at the left. × $\frac{3}{2}$.

Lower Chester; Huntsville, Alabama.

FIG. 8. A complete crown, showing the distal end of the sac projecting beyond the arms.

9. Distal portion of sac from another specimen with spiniferous projection, and the anal opening next to it. × $\frac{3}{2}$.

9*a*. The spiny projection of same seen from the upper side, consisting of four plates. × $\frac{3}{2}$.

Upper Chester; Grayson Springs, Kentucky.

10. Posterior view of large specimen showing full length of sac with terminal spine, and arms extending beyond it.

Lower Burlington limestone; Burlington, Iowa.

11. Complete crown with pentagonal stem attached; l. ant. view; the opposite side shows the sac much fractured, not extending beyond the arms, and with opening about midway.

Upper Burlington limestone; Burlington, Iowa.

Plate 17

All figures natural size

Page

ABROTOCRINUS UNICUS (Hall) 65, 73

Fig. 1. Anterior view of complete crown, to show general arrangement of arms, and pentagonal stem.

2. Posterior view of calyx, with sac completely exposed.

3. Anterior view of crown with sac exposed, showing anal opening midway, and spines at distal end.

Keokuk limestone; Crawfordsville, Indiana.

DECADOCRINUS HALLI (Hall) 65, 91

Fig. 4. Anterior view of complete crown, showing delicate structure of species in the earlier formations.

5. Posterior view of a similar specimen.

Upper Burlington limestone; Burlington, Iowa.

DECADOCRINUS TUMIDULUS (Miller and Gurley) 65, 92

Fig. 6. Posterior view of crown, with tumid basal and anal plates, and inflated distal end of sac. For anal opening in sac, see North American Crinoidea Camerata, pl. 7, figs. 4, 5.

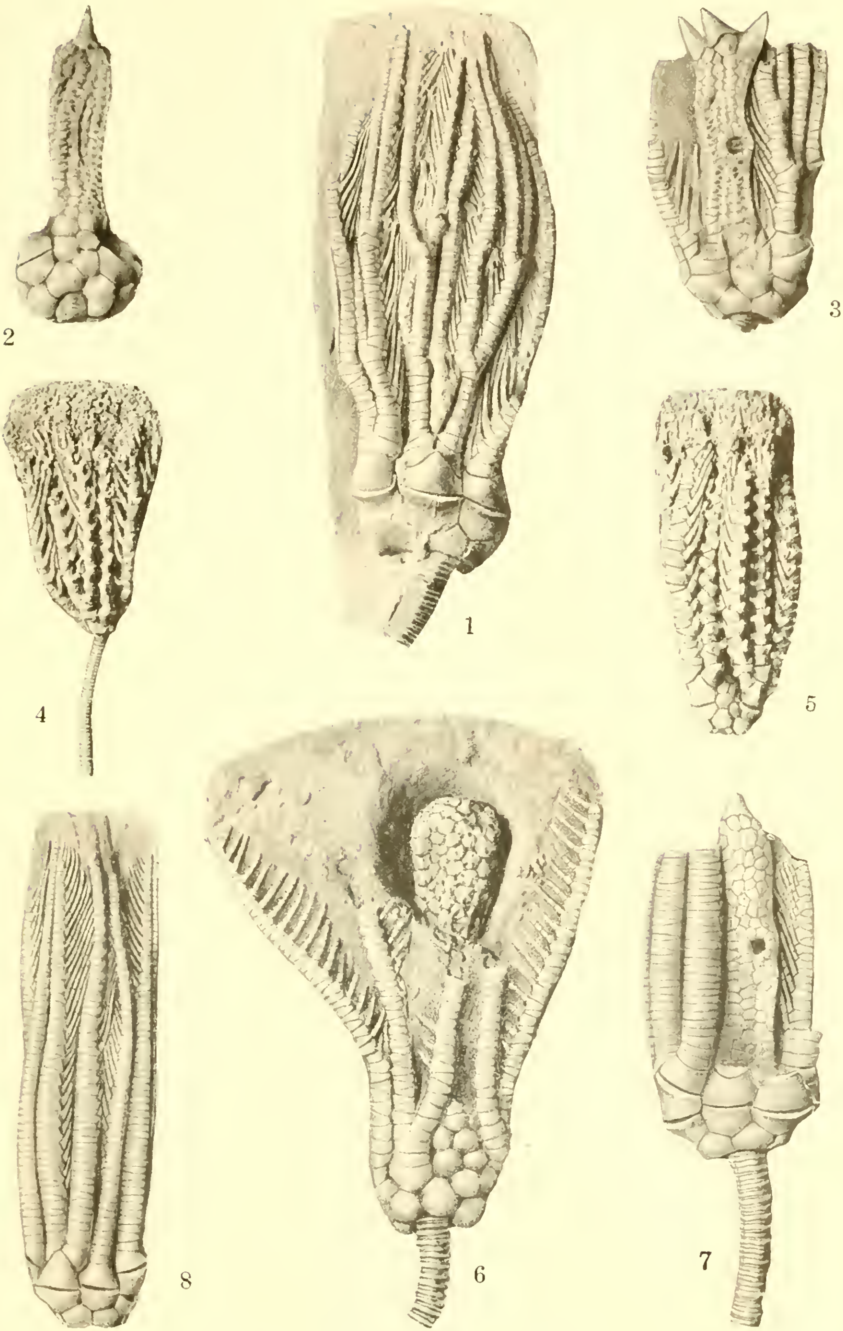
Keokuk limestone; Indian Creek, Indiana.

SCYTALOCRINUS VALIDUS Wachsmuth and Springer 65, 92

Fig. 7. Anterior view of specimen with sac completely exposed, and anal opening midway; arms broken off about half way up.

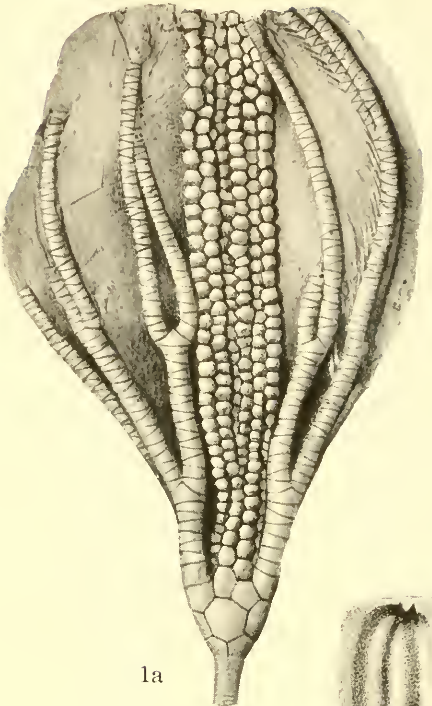
8. Another specimen showing full length of arms, and single arm in anterior ray.

Keokuk limestone; Indian Creek, Indiana.



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 124



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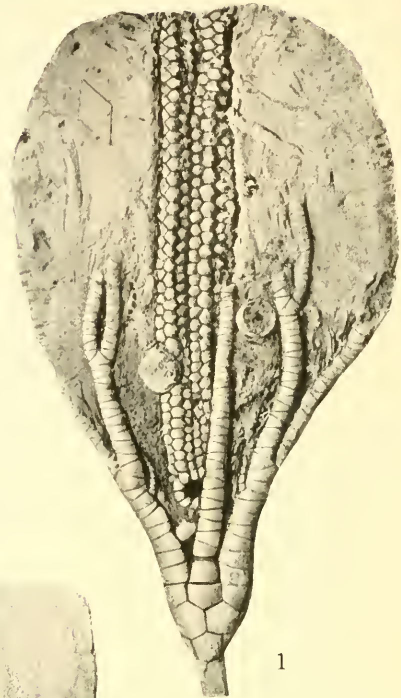

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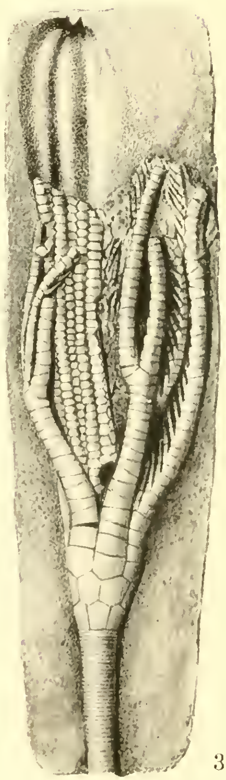

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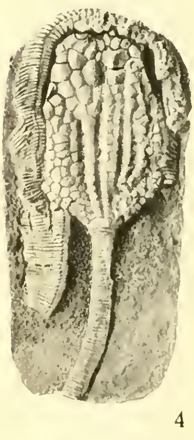

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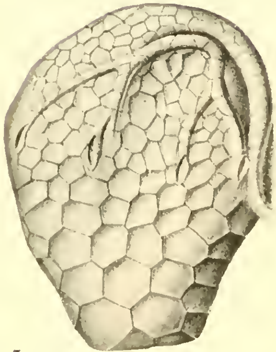

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UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 125

PLATE 18

All figures natural size

CULMICRINUS ELEGANS (Wachsmuth and Springer)

FIG. 1. Anterior view of crown, with ventral sac to nearly its full length, and anal opening at the base; arms with about 10 IBr.

1*a*. Posterior view of same, showing arms probably extending beyond the sac.

Upper Chester; Sloan's Valley, Kentucky.

FIG. 2. (Omitted.)

CULMICRINUS MISSOURIENSIS (Shumard)

FIG. 3. Anterior view of crown, showing full length of sac, with anal opening at base.

St. Louis limestone; St. Louis, Missouri.

ACROCRINUS AMPHORA Wachsmuth and Springer

FIG. 4. Lateral view of crown, with calyx exposed by removal of part of recumbent arms; to show longitudinal grooves made by pressure of arms in their recumbent position. (See also plates 9 and 12.)

Lower Chester; Huntsville, Alabama.

SIPHONOCRINUS ARMOSUS (McChesney)

FIG. 5. Internal cast, with plates of test exfoliated or removed by chemical action; showing the anal tube bent completely over the oral portions of the viscera, so as to emerge at the anterior side below the level of the arm bases. After Wachsmuth and Springer, North Amer. Crin. Cam., pl. 19.

Niagaran, Racine formation; Milwaukee, Wisconsin.

Plate 19.

All figures natural size

Page

AULOCRINUS AGASSIZI Wachsmuth and Springer................ 67

Fig. 1. Anterior view of specimen with sac complete, doubled upon itself and projecting downward in form of a spout, at the end of which is the anal opening; the place of bending marked by spinous nodes.

2. Lateral view of another specimen with sac complete, showing its full curvature leading to the spout. Note the longitudinal ridges, which can be traced the full length of the sac upward and following the curve down again into the spout, the number of ridges being correspondingly increased in the doubled part.

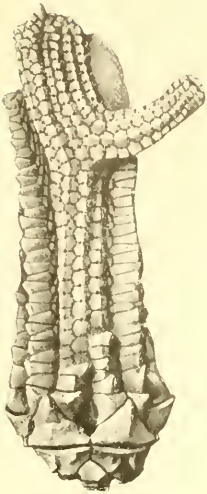
2a. Posterior view of same specimen, showing the anal plates, and the sharp angular sculpture of the calyx.

3. Distal portion of another specimen, showing in greater detail the same structures as the last.

4. Posterior view of another specimen, showing the sac complete to the point of bending, marked by spinous nodes, and the distal end of the spout which projects from the opposite side; the sharp sculpture of the anal and other calyx plates; and the pores with which the hexagonal tube plates are profusely perforated at the middle of their sides.

5. Anterior view of specimen with arms in place to their full length, showing their proportions and the character of the pinnules.

Keokuk limestone; Indian Creek, Indiana.



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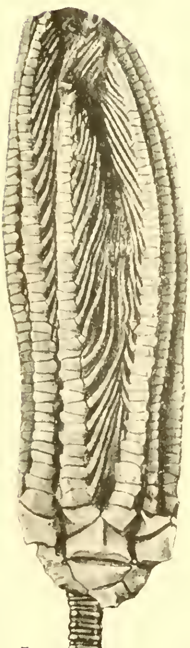

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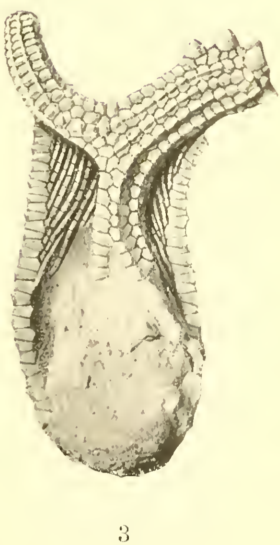

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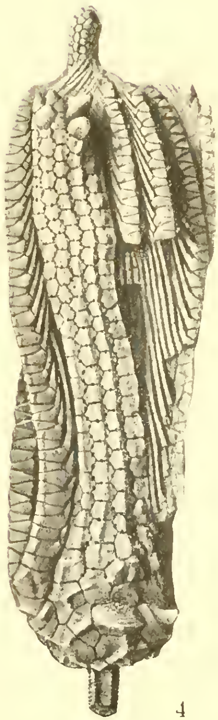

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UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 128

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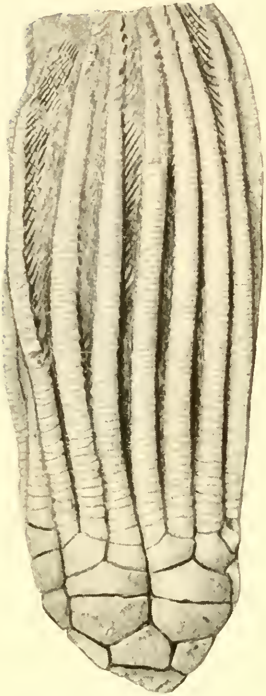

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UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 127

PLATE 20

All figures except 3 natural size

Page

ULRICHICRINUS OKLAHOMA, new species 76

FIG. 1. Posterior view of principal type, showing distribution of arms and pinnules, form of brachials, structure of stem, and relative size of anal area.

2. Anterior view of another complete crown, showing structure of arms and pinnules, and form and proportions of calyx plates.

2a. Posterior side of same, showing more clearly the structure of the anal area, and the narrowly truncated posterior basal.

Pennsylvanian, Morrow formation; Crittendon, Oklahoma.

ULRICHICRINUS CORYPHAEUS (S. A. Miller) 76

FIG. 3. Posterior view of crown, for comparison with preceding species. $\times \frac{3}{2}$.

Mississippian, Keokuk limestone; Indian creek, Indiana.

Plate 21

All figures natural size

Fig. 1. Posterior view of complete crown, showing anal area with broadly truncate post. B, short RA, short quadrangular brachials and heterotomous arms, but having elongate instead of depressed calyx, and turbinate base instead of concave.

Lower Burlington limestone; Burlington, Iowa.

Fig. 2. Anterior view of a typical specimen, with complete crown, showing depressed broadly rounded calyx, and maximum number of bifurcations all on the outer arm of the ray toward the inner side; anterior ray branches on second brachial above primibrach.

2*a*. R. post. view of same, showing form of club-shaped sac with rounded and expanding distal end.

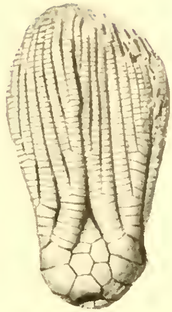
3. Posterior view of another large specimen having only six arms to the ray.

3*a*. Anterior view of same, with anterior ray bifurcating on third brachial, and having only 4 arms.

4. Posterior view of small specimen, with typical form of anal area for the earlier species—broadly truncate post. B. and short RA.

Upper Burlington limestone; Burlington, Iowa.

3



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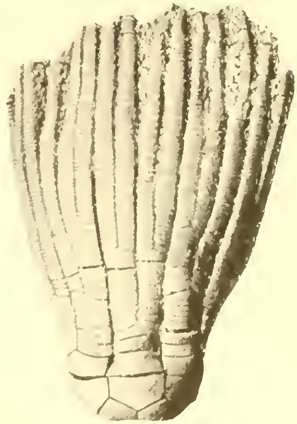
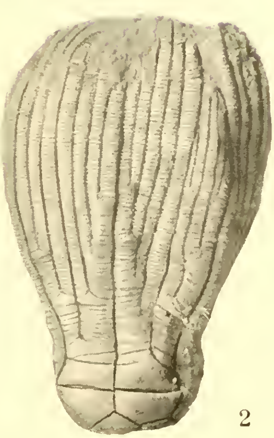


3a

1



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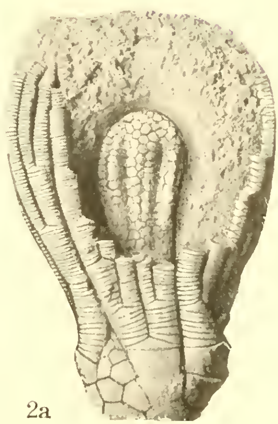

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UNUSUAL FORMS OF FOSSIL CRINOIDS

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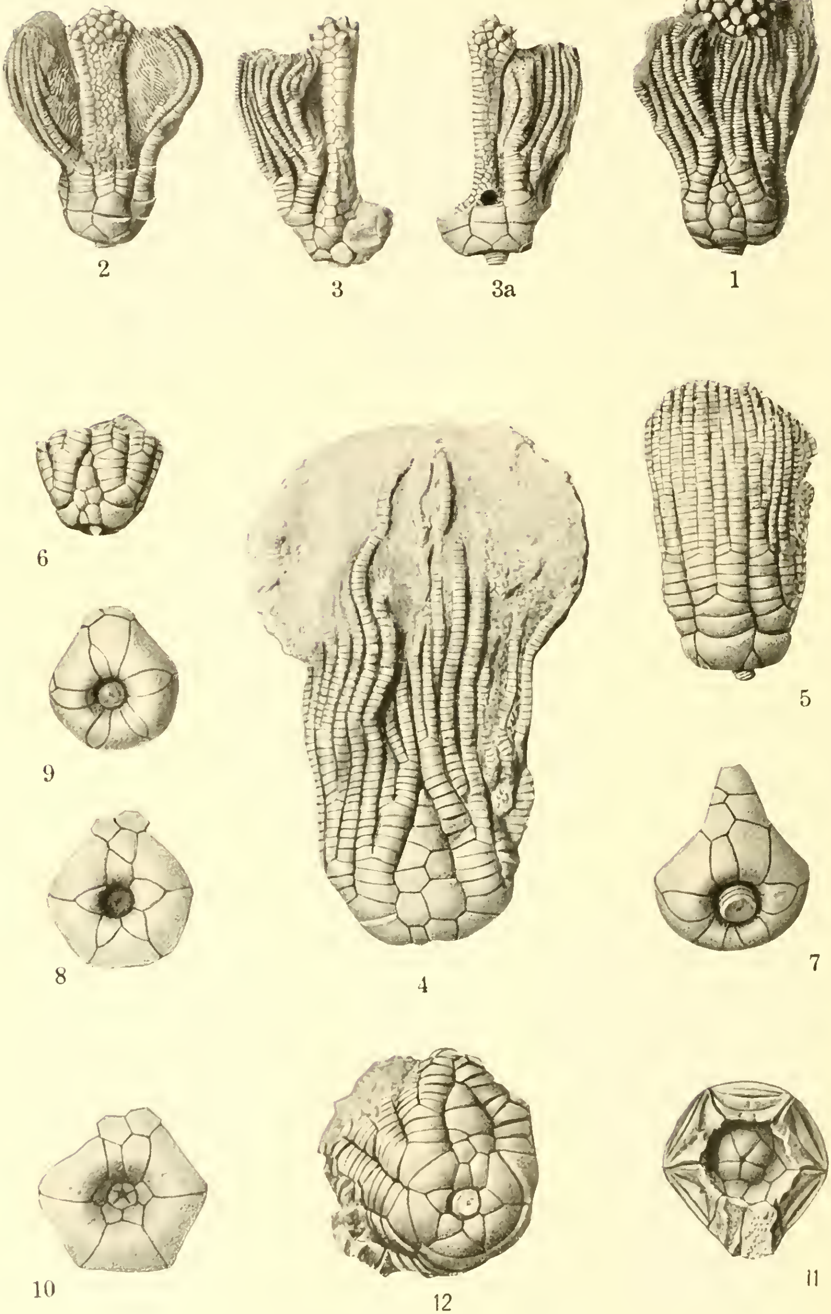


UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 129

Plate 22

All figures natural size

	Page
ZEACRINUS COMMATICUS S. A. Miller	65, 80

Fig. 1. Posterior view of complete crown, showing mode of arm branching, nodose distal end of sac projecting beyond arms, and arrangement of anal plates as usually seen.

2. Left anterior view of another specimen with sac partially exposed, showing the increased number of IBr in anterior ray.

3. Specimen exposing full length of club-shaped sac, from the posterior side, showing complete succession of plates from the anal area up.

3*a*. Anterior view of same, showing anal opening at base of sac.

Keokuk limestone, upper part; Boonville, Missouri.

ZEACRINUS MAGNOLIAEFORMIS (Troost) Hall 81

Fig. 4. A maximum specimen, seen from the posterior side, showing form and proportions of crown, and arrangement of anal plates as usually found.

5. A medium sized specimen; anterior view of complete crown, showing the usual arrangement of arms.

6. Lower part of crown of smaller specimen, from the posterior side, showing anal plates.

7. Basal view of detached calyx, with typical arrangement of broad anal area, as seen in about 80 per cent of the specimens; RA elongate and passing down into the basal ring, and post. B truncate; BB large.

8. Similar view of calyx with narrow anal area, as found in about 12 per cent of the specimens; RA short, and post. B acuminate, not connecting with succeeding plate.

9. Another variation of the narrow anal area. BB elongate, petal shaped, as in most of the specimens.

10. Basal view of calyx with broad anal side, showing IBB, and BB entirely within the cavity, exceptionally small.

11. Interior view of calyx, showing the cone of greatly enlarged infrabasals.

Upper Chester, Gasper formation; Huntsville, Alabama.

ZEACRINUS WORTHENI Hall 65, 81

Fig. 12. Basal view of specimen with broad anal area, for comparison with *Z. magnoliaeformis*.

Upper Chester, Glen Dean formation; Sloan's Valley, Kentucky.

Plate 23

All figures natural size

Fig. 1. Typical specimen, posterior view, showing the usual contour of crown with arms closely folded; narrow anal area with small basals, posterior basal acuminate, and RA occupying entire width of area above it, as occurs in 55 per cent of the specimens.

2. Posterior view of a similar specimen, with like narrow anal area and small basals.

2*a*. Anterior view of same with three rays removed, exposing three sides of the pyramidal ventral sac, with anal opening midway.

3. L. ant. view of specimen with sac completely exposed, showing opening midway at anterior side; apex of pyramid broken off.

4. Posterior view of another specimen with sac intact; narrow anal area with sharp ridge-like succession of plates following it.

5. Distal view of sac of another specimen vertically compressed, with apex broken.

6. Basal view of a typical specimen with the usual form of anal area.

7. Posterior view of specimen with another form of narrow anal area.

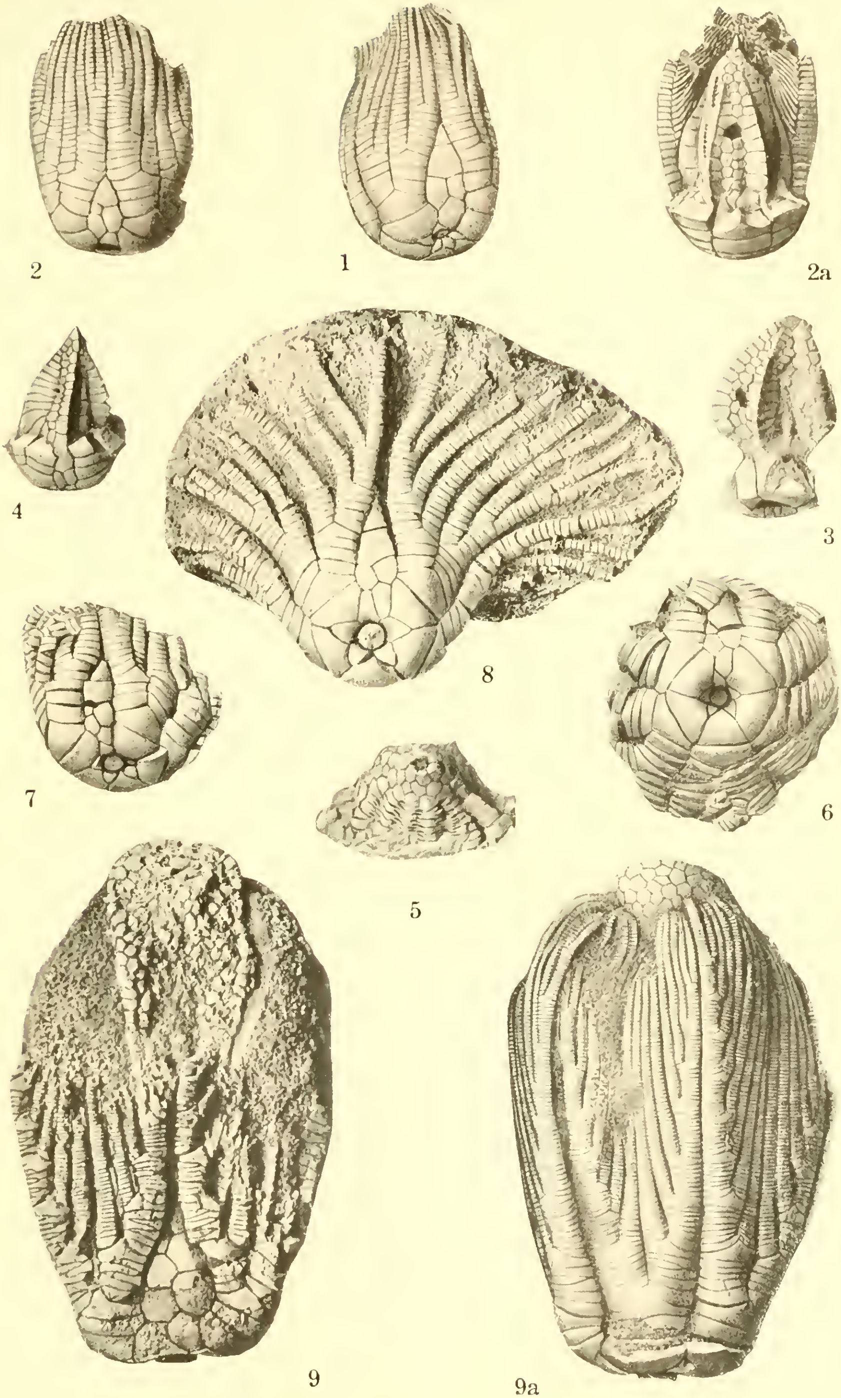
8. Basal and posterior view of maximum specimen with post. basal truncate, and anal area similar to that of *Z. magnoliaeformis*; distribution of arms is well shown.

Upper Chester, Glen Dean formation; Sloan's Valley, Kentucky.

Fig. 9. Posterior view of type, showing wide anal area, truncate post. B, with RA short and broad; and form and proportions of club-shaped sac.

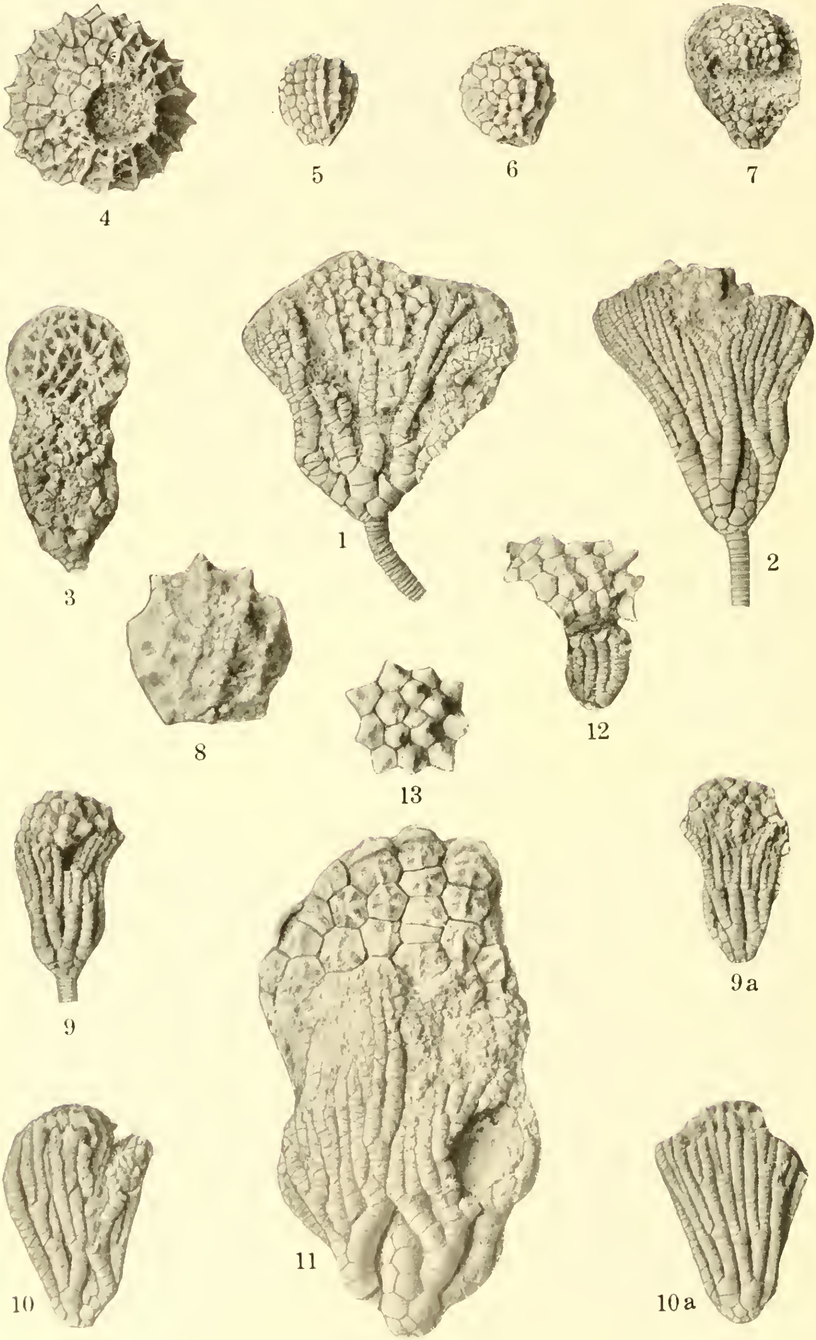
9*a*. Anterior view of same, showing complete succession of arms, and rounded distal end of sac rising beyond their extremities.

Pennsylvanian, Morrow formation; Crittenden, Oklahoma.



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 130



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 131

PLATE 24

Figures not otherwise noted natural size

FIG. 1. The type. Anterior view, showing the inflated sac with plates tending to form longitudinal ridges, and the structure and mode of bifurcation of the arms.

2. Posterior view of another complete crown, showing anal plates leading to the tube, and inflated sac rising above the arms.

3. Lateral view of specimen with most of arms removed, exposing the general form and proportions of the balloon-shaped sac.

4. Proximal view of detached inflated part of sac, showing the narrow neck connecting it with the calyx. (See fig. 1, pl. 25, for opposite view.)

5, 6, 7. Three detached inflated distal ends of sac, showing how they are formed by the bending of the tube, as indicated by the arrangement of plates in longitudinal ridges.

8. Isolated distal end of sac, from Lake Valley, New Mexico. Lower Burlington limestone; all except figure 8 from Burlington, Iowa.

FIGS. 9, 9*a*. The type. Left anterior and right posterior views of complete crown, showing relatively large size of the sac and its distal plates.

10, 10*a*. Posterior and anterior view of similar crown, showing mode of bifurcation of arms.

11. An unusually large specimen; posterior view showing arrangement of anal plates at base of tube, and large size of plates forming the inflated part.

12. Specimen showing distal part of sac with plates tending to become spiniferous.

13. Isolated distal part of a sac from Lake Valley, New Mexico. Lower Burlington limestone; all except figure 13 from Burlington, Iowa.

Plate 25

All figures natural size unless otherwise noted

Page

COELIOCRINUS VENTRICOSUS (Hall) 86

Fig. 1. Distal view of inflated ventral sac, same specimen shown on plate 24, fig. 4 (slightly enlarged).

COELIOCRINUS SUBSPINOSUS White 86

Fig. 2. Lateral view of a maximum crown, with spines projecting from flattened distal end of sac above the region of the arms.

3. Posterior view of smaller specimen with expanded summit of sac fully exposed, showing the numerous plates in the median part, bordered by peripheral spines.

3*a*. Anterior view of same specimen.

Upper Burlington limestone; Burlington, Iowa.

HYDREIONOCRINUS WETHERBYI Wachsmuth and Springer 89, 90

Figs. 4, 5, 6, 7, 8. Basal views of several specimens, showing variation in basal and radianal plates; figs. 7 and 8 show the spiniferous axillary IBr in all five rays.

9. Posterior view of crown, showing nodose or spiniferous axillaries.

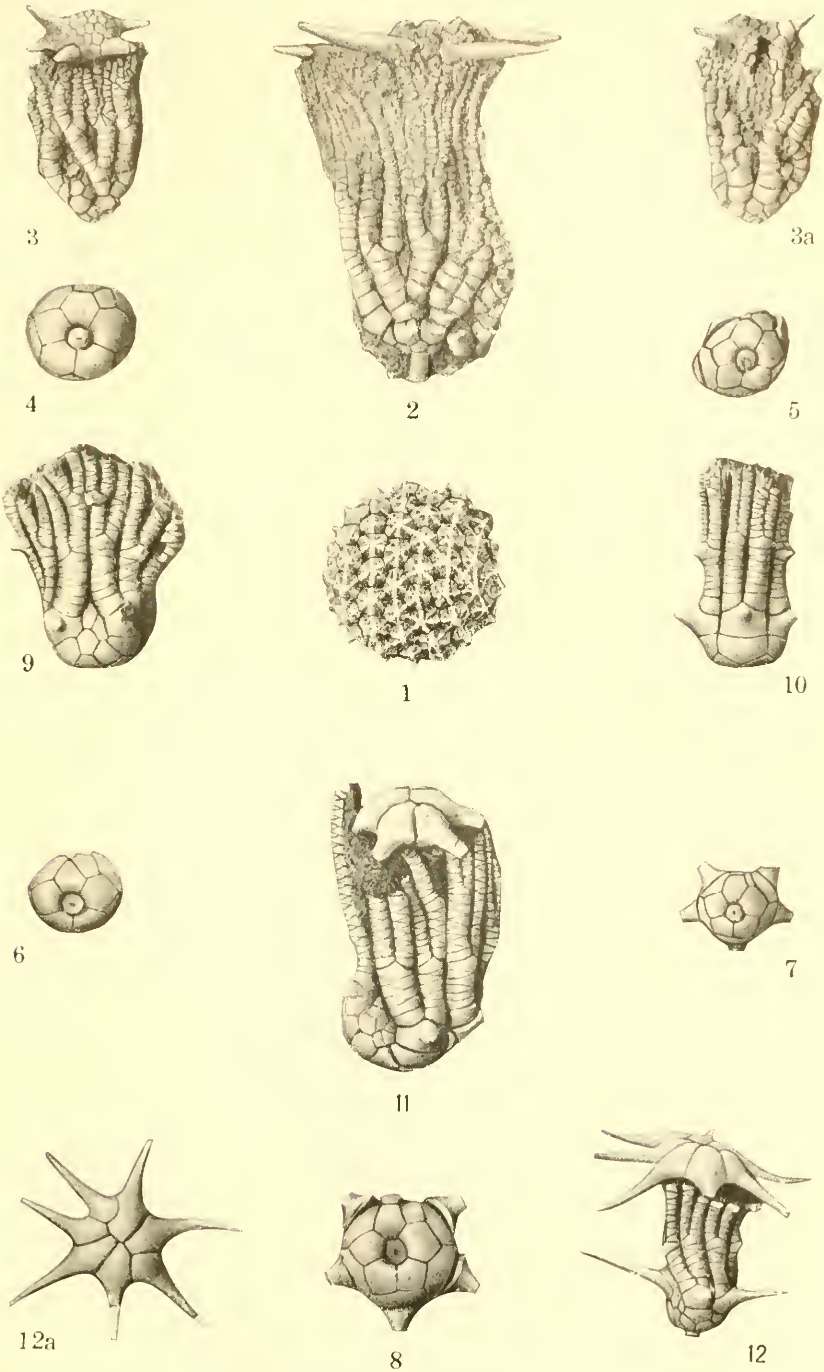
10. Anterior view of crown, showing IBr single and axillary, contrasted with structure of same ray in *H. depressus*.

11. A complete crown, somewhat distorted, with the flattened distal end of the mushroom-shaped sac fully exposed, consisting of 5 spiniferous plates meeting in the middle.

12. A similar crown, with the spiniferous canopy much larger, composed of 7 connected plates, and showing extreme development of the spiniferous primibrachs.

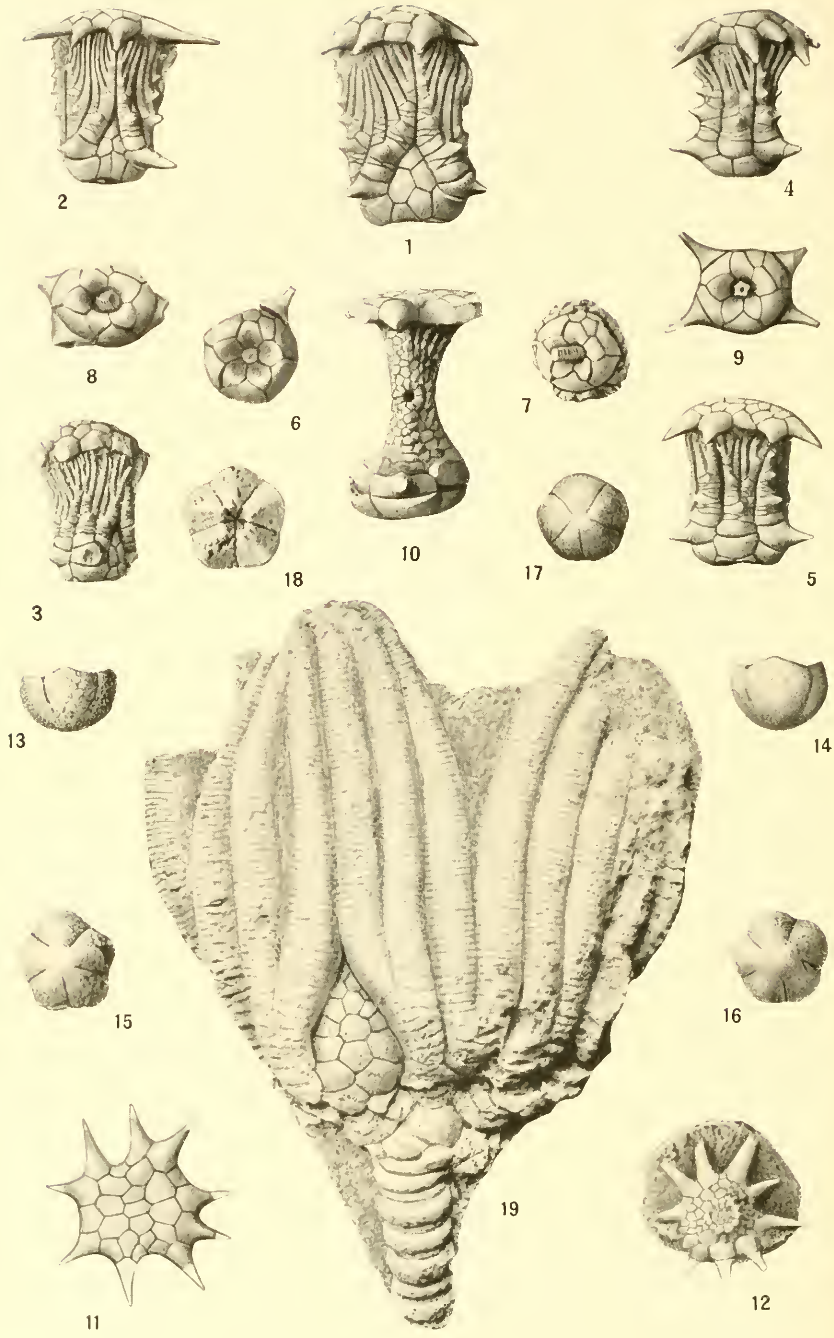
12*a*. Upper side of spiniferous canopy.

Upper Chester, Glen Dean formation; Sloan's Valley, Kentucky, except figure 11, which is from Grayson Springs.



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 132



UNUSUAL FORMS OF FOSSIL CRINOIDS

FOR EXPLANATION OF PLATE SEE PAGE 133

PLATE 26

Figures natural size unless otherwise stated

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HYDREIONOCRINUS DEPRESSUS (Hall from Troost) 89, 90

FIGS. 1, 2. Posterior views of complete crowns, showing arrangement of anal area, mode of bifurcation of arms, spiniferous axillaries, and flattened distal end of sac surmounting the whole, with spiniferous peripheral plates projecting laterally from the margin exceeding in diameter all the parts below.

3. L. post, view of similar specimen.

4, 5. Anterior views of two similar specimens, showing the non-spiniferous IBr in anterior ray, succeeded by one or more biserial pairs of brachials below the bifurcation.

6, 7, 8. Basal views of three specimens, showing pentagonal stem, and large size of basal cavity as compared with that of *H. wetherbyi*.

9. Basal view of another specimen, showing the spiniferous IBr in the four rays other than the anterior.

10. Anterior view of specimen with arms removed, exposing the entire length of ventral sac, with the anal opening half way up. $\times \frac{3}{2}$.

11. Distal view of expanded sac, showing the numerous plates in the median part and spiniferous marginal plates—about 25 in all.

12. The same parts of another specimen, seen from the under side, showing the small size of the tube leading to the calyx.

Upper Chester, Glen Dean formation; Sloan's Valley, Kentucky.

AGASSIZOCRINUS LOBATUS, new species 63

FIGS. 13, 14. Lateral views of infrabasal cone, showing the plates divided in the upper part.

15, 16. Basal views of two other specimens, showing lobation of infrabasal cone, rounded and coalesced at the base, and partially divided above.

17. A similar specimen, with plates almost completely divided, and faint trace of column facet.

18. Distal view of another specimen, showing division of infrabasals, and the axial canals passing down.

Lower part of Upper Chester, Gasper formation; Huntsville, Alabama.

WOODOCRINUS MACRODACTYLUS De Koninck 77

FIG. 19. Posterior view of typical specimen, to show the ponderous arms, extremely short brachials, and large anal area indicating a strong ventral sac.

Upper part of Lower Carboniferous; Richmond, England.

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[Synonyms in italics]