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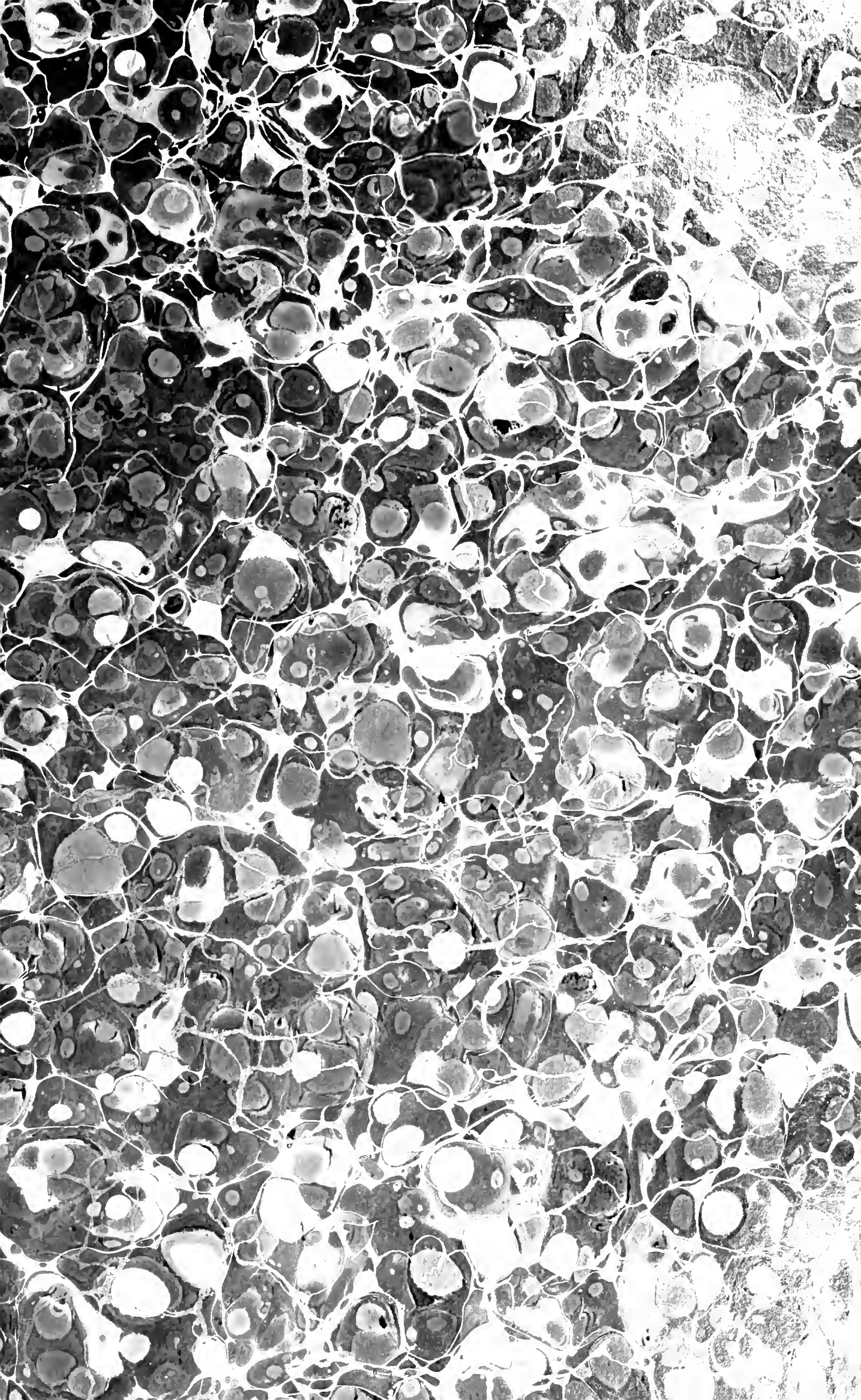
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CLEIOCRINUS.

BY

FRANK SPRINGER.

WITH ONE PLATE.

CAMBRIDGE, U. S. A.:

Printed for the Museum.

JANUARY, 1905.

With the compliments of

FRANK SPRINGER.

Comparative Zoology

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VEGAS, *New Mexico.*

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CLEIOCRINUS.

THE genus *Cleioerinus* was established by the eminent Canadian palaeontologist, E. Billings, in 1856,* to receive certain very peculiar Crinoids found in the Trenton Group of the Lower Silurian, at Ottawa, Canada. It was based upon one species, *C. regius*, which he described at the same time (*loc. cit.*, p. 277). In 1859 he published,† along with the generic diagnosis, a full description, with good figures, of *C. regius*, the only species in which the calyx was then known, and named two other species, *C. grandis* and *C. magnificus*, upon fragments of the column;—the main apparent distinction of these being their larger size, and in *C. magnificus* the less relative thickness of the column joints.

The genus has been a puzzle to Crinologists ever since.—both as to its actual structure and its systematic position. Its lowest ring of plates, described by Billings as resting on the column, consisted of ten plates,—five radially situate and five interradially,—which was so fundamentally different from the calyx plan of all other known Crinoids that it was impossible to assign a place for it without introducing hypothetical plates within the proximal ring of Billings, concealed by the column. Interpretations of the calyx based upon theories of this kind were none of them satisfactory, and left the position and relations of the genus in much doubt:

The stratigraphic position of *Cleioerinus* renders it a form of special interest, because it is one of the earliest of known Crinoids. It is associated with *Blastoiderinus*, *Palaeocrinus*, *Hyboerinus*, *Carabocrinus*, and other primitive forms, in an epoch when the Cystids were the prevailing Echinoderm type. The Trenton Limestone is one of the oldest formations in which Crinoids have been found. It is considered to be approximately

* Report Geological Survey of Canada, 1856, p. 276.

† Figures and Descriptions of Canadian Organic Remains, Dec. IV., pp. 52-54. Pl. V.

equivalent to the Middle Bala of England, and to Stage d 4 of Barrande's section of the Ordovician of Bohemia.

I have recently had the opportunity, thanks to the favor of Dr. J. F. Whiteaves, to examine all the material of the genus belonging to the Geological Survey of Canada, with results of such extraordinary interest as to warrant a special account of it, in advance of the Memoir as to which my investigations were more especially directed.

HISTORY OF THE GENUS.

Billings's account of the genus, as given in Decade IV., p. 52, is as follows:—

“*Generic characters.*—Cup, large, conical or pyriform; basal plates, five; rays, five, alternating with the basal plates; the third plate of each ray is pentagonal and bears two secondary rays, which are several times divided above. Between two of the rays a single vertical series of azygos interradial plates extends from the base to the margin of the cup. The azygos plates and rays are all firmly anchylosed together by their lateral margins up to the height of the fifth or sixth sub-division. The column is pentagonal or nearly round.

“This genus has the structure of a *Pentacrinus*, with numerously divided arms all soldered together in the walls of the cup.”

Von Zittel in 1879* referred the genus to the family *Crotalocriuidæ*.

In the same year Wachsmuth and Springer† referred it to the *Ichthyocrinidæ*, and discussed it as follows:—

“The generic description was made from a single specimen, and this was in several respects defective. *Cleiocrinus* has, according to Billings, five basals alternating with the radials, and forming with them a belt around the column. Such a structure has never been found in any Crinoid. In the typical specimen, the comparatively large column conceals from view the lower part of the calyx, a space large enough to accommodate one or two series of plates, and analogy suggests that this may have been the case. The five plates which Billings found alternating with the primary radials, and which he called basals, are certainly interradials; and as the specimen in every visible character closely resembles *Ichthyocrinus* and

* Handb. der Pal., I., p. 357.

† Revision of the Palæocrinoidea, Pt. I., pp. 35-36.

allied forms, we have good reason to suppose that it, like those forms, possessed five small basals and three underbasals, both hidden by the column. The latter were probably very minute and rudimentary, since the specimen is from the Lower Silurian, where it is almost the only representative of the family. This alone induces us to try to define generic characters from a single imperfect specimen. Notwithstanding, therefore, that some of the elements are problematic, we propose until something better is found, the following:—

“*Revised generic description.*—”

Then follows a generic diagnosis based upon the probable presence of three minute or rudimentary underbasals and five basals, all hidden by the column.

In 1886* the genus was further discussed by us, and a diagrammatic figure from the type specimen, made by Mr. Walter R. Billings, was given (*Op. cit.*, Pl. IX., Fig. 5), in which the hypothetical five basals and three infrabasals were indicated by dotted lines—thus giving the basal structure of the Ichthyocrinidæ generally. A further revised generic diagnosis was added, which did not differ greatly from the former one,—the chief new point being that the anal plates, instead of being four or five in number, extend the full length of the calyx; and that the arms are “apparently recumbent.” It was also stated, on information furnished by W. R. Billings, that “the ridges of the column are interradial in position, which confirms the supposition made by us (Part I, p. 36), that *Cleioerinus* possesses underbasals, and that the so-called basals of E. Billings are interradials. He also states that the lowest visible circlet of plates ‘apparently overlaps the column, instead of passing under it,’ which shows that the base must have been concave, with ample space for the basals and underbasals to lie concealed from view.” We further stated: “If certain parts were better known, we should make it the type of a new family, but at present, having no positive knowledge of the basal regions, nor even of the arms, we are not in a position to give a satisfactory definition of the group.”

Although E. Billings had said, in his description of *C. regius*, that it had “about forty . . . tentaculated, free rays.” it was not understood that this meant pinnulate arms until after the last mentioned discussion, when W. R. Billings sent to Dr. Wachsmuth a drawing from another specimen of that

* Revision, Pt. III., Sec. 2. pp. 152-3.

species, showing that the arms are fringed with closely packed pinnules. This pinnulate structure, if it had been appreciated at the time, would have presented a very serious obstacle to the reference of the genus to the Ichthyocrinidae, in which entire group pinnules were thought to be wanting.

Von Zittel, in his *Grundzüge der Palaeontologie*, 1895, does not seem to find any place for the genus; nor does Eastman, in his annotated translation of the work in 1900.

Bather, in Ray Lankester's *Treatise on Zoology*, Part III., p. 191, places the genus provisionally among the Flexibilia Impinnata, and gives the following diagnosis of its characters: "IBB and BB hidden by stem; RR small and separated by a large pentagonal interradial; arms isotomous to about VIIBr. and all appear to interlock and to be joined by close suture; post. IR supports a vertical series of anals, which reach the full length of the arms."

DESCRIPTION OF THE SPECIMENS.

It having become necessary for me, in connection with a general investigation of the group Flexibilia, to determine more definitely, if possible, the systematic relations of this perplexing genus, I applied to Dr. J. F. Whiteaves, Assistant Director of the Geological Survey of Canada, for the loan of the specimens of *Cleioocrinus* in the Museum of the Survey at Ottawa. With the most obliging courtesy this material was placed at my disposal, and was promptly packed and shipped to me by Dr. H. Ami, Curator of the Museum, with valuable notes giving detailed information as to the history of each specimen. I find it difficult to adequately express my sense of obligation to both these gentlemen for the cordial interest which they manifested, and their careful attention to my wishes; and I desire to here record my profound appreciation of the opportunity, for which I am indebted to them, of an intelligent investigation of these unique fossils.

The specimens reached me safely at Burlington in November, 1903. They were found to consist of all of Billings's types figured upon Plate V. of *Decade IV.*, except 2a, and some important additional material since acquired by the Canadian Survey. The latter included a crown of very large size, but poorly preserved, and a stem thirty inches long with the root attached that may belong to it; also a fragment about seven inches long of a still larger stem over one inch in diameter where not flattened. With the origi-

nal specimens found by E. Billings there is also the crown which belongs to the fragment figured by him as 1c, which is very important, as it shows most beautifully the real character of the arm structure. As these specimens call for extended study and discussion, I will, to avoid frequent repetition, designate them as follows:

- A. *C. regius*. Billings's principal type specimen. — original of Figs. 1a and 1b of Plate V., Decade IV. A splendid specimen, much flattened above the base, but otherwise beautifully preserved, with calyx complete and perfectly exposed on both sides, and having small portions of the column and arm bases attached. Billings's figure 1a shows one side complete, but 1b gives the opposite view of the base only (Pl. I., Figs. 1 and 2).
 - B. *C. regius*. Original of Billings's Fig. 1c. Part of a column with two proximal rings of plates of the calyx attached (Pl. I., Fig. 3b).
 - C. The remainder of the crown belonging to specimen B, not figured by Billings. Upper part of calyx and portion of arms and pinnules; — greatly flattened, but very perfectly preserved on one side. The fractured edge adjoining B is not quite perfect, some small pieces being broken off (Pl. I., Fig. 3a).
 - D. Several pieces of column, nearly continuous from B, with terminal root, the original of Billings's fig. 1g. Two of these are figured herein, Pl. I., Figs. 3c and 3d, and the root, Fig. 3e.
- Specimens B, C and D are parts of the same individual, which fit together very well, except at the junction of B and C, where the edges of some plates are somewhat frayed by accident in collecting; and between 3d and 3e, where a piece is wanting. The basal portion of the calyx, being of very firm and rigid construction, was only slightly affected by pressure; but above, being flexible and composed of thin plates, it was flattened out, so as to become quite fragile in the fossil condition, resulting in the fracture and loss of parts of some plates when exposed in the quarry where it was found.
- E. *C. magnificus*. A very large crown, consisting of the calyx, with a very small portion of the stem, and the bases of part of the arms. The surface of this specimen is very soft and friable, and it is considerably injured. The preservation is quite different from that of those

above mentioned, which evidently occurred in a fine grained shale, softer than the included fossils; while in this the enclosing matrix is harder, and not readily removable without carrying the surface of the fossil with it (Pl. I., Fig. 11).

- F. A large stem, thirty inches long, with the root attached. It was found in the same quarry with specimen E, and there is good reason to believe belonged to it; but a portion of the stem at the proximal end is missing, probably amounting to five or six inches.
- G. Part of another still larger stem, similar to F (Pl. I., Fig. 12).

STRUCTURE OF CALYX AND ARMS.

THE ARMS AND PINNULES.

THE first observation of these specimens made clear the fact that the arms are pinnuliferous,— a fact which has been overlooked in the discussions heretofore ; although, as already stated, Billings, in his description of *C. regius*, Dec. IV., p. 56, mentions the presence of “tentaculated, free rays.”

The structure of the arms is perfectly shown by specimen C (Pl. I., Fig. 3 *a*). They are direct continuations of ridges which follow the brachial series in the calyx, beginning at about the first bifurcation with faint linear elevations, and gradually enlarging until they pass into the free arms. These are quite angular on the back, simple, uniserial, composed of short, wedge-form plates, each of which gives off a pinnule from the longer end. The pinnules are slender, and lie close together (Pl. I., Fig. 10). At somewhat irregular distances below where the arms become free, at the outer margins of the rays, there are given off subordinate branches, which originate on a bifurcating plate and lie closely alongside the outer arms of the ray, the plates of the two abutting and interlocking. These subordinate branches are the proximal portions of fixed pinnules, which are incorporated in the calyx walls, and apparently become free between the arm bases, though they are concealed from view by the regular pinnules. In other interbrachial spaces higher up, from the last III Br or IV Br, and mostly on the outside of the dichotom, similar pinnules are given off, but not with entire regularity (Pl. I., Fig. 8).

All these are closely joined together and to the adjacent arms, and incorporated into the calyx walls, until they reach the upper margin and become free. The arms are quite clearly shown in Billings's type specimen (Pl. I., Figs. 1, 2), where the bases for a distance of several brachials are in some places well preserved, having the pinnules attached, — though neither of them is as well shown as in specimen C.

THE CALYX.

The calyx plates are all closely abutting, — the suture lines, both between successive brachials and between those of adjoining series, being marked by small pits, or crenulations, indicating a union by a sort of articulation, or loose suture, such as we see in specimens of *Forbesioerinus*. In this respect the structure is decidedly like that of the Ichthyocrinidæ. There is a complete absence of any interbrachial system, except at the anal side, where a vertical series of plates, originating on the posterior basal, rises high up between the arms, though not quite to the margin of the cup. The main general characteristic of this calyx is the manner in which the ray divisions are joined to each other by lateral union of their plates with those of their fellows, and with the plates of the anal series. Billings fully appreciated this when in his generic description he noted as a feature of the structure of the genus its “numerously divided arms all soldered together in the walls of the cup.” The plates are comparatively thin, and the mode of union between them imparts a marked degree of flexibility, — more, apparently, than in *Ichthyocrinus*.

None of the specimens disclose any portion of the disk, but it is evident, from the manner in which they are flattened, that it was very thin and pliable. Of the mouth and anal opening we know absolutely nothing.

The arms, the manner in which the radial ridges lead to them, and the structure and arrangement of the fixed pinnules, are very much like those of *Glyptocrinus* and *Retcoerinus*; but the interbrachial system of those genera is entirely wanting, — there being no supplementary plates, except at the anal side, whose vertical series bears some resemblance to theirs. The manner of compression of the calyx would indicate a disk structure more like that of *Retcoerinus o'neilli* and the Ichthyocrinidæ.

THE BASE.

Examination of the specimens as they were received did not seem to throw any new light upon the nature of the base. The column in specimen B is obtusely pentagonal, — the exterior angles being interradial, which proclaims a dicyclic base (Pl. I., Fig. 3*b*). The axial canal in this specimen, at about one inch from the base, is also pentagonal, and its angles coincide with those of the exterior of the column (Pl. I., Fig. 3*f*); which is a departure from the rule of alternation, and forms another minor exception to

the law of Wachsmuth and Springer, similar to that of *Glyptocrinus forshelli*, — a monocyclic species in which both stem and canal are radial, and which is also from the Lower Silurian, among the earliest Crinoids.

Granting that there is a dicyelic base, the question remained, what is the exact nature of it; and what are the five plates lying between the radials? Billings, with singular sagacity, called them the "true basals." His statement, in the description of *C. regius* (Dec. IV., p. 53), is as follows: "At first sight there appear to be ten small basal plates, but upon examination five of these are found to be the first plates of the five rays which rest immediately upon the upper joint of the column; the other five are the true basal plates." Wachsmuth and Springer, having classed the genus with the Ichthyocrinidæ on account of the strong resemblance of its pliant calyx to that of *Ichthyocrinus*, had supposed that it might possess the basal arrangement of the group, viz., 5 basals and 3 infrabasals, both hidden by the column; and they considered the pentagonal plates between the radials to be interradians. Since it now appeared that the genus is pinnulate, with an arm structure which differentiates it absolutely from all the known Palæozoic Flexibilia, there seemed to me equally good reason to infer the presence of five infrabasals, as in the base of the dicyelic Camerata.

The superficial aspect of the specimens furnished no information on this point; and the only important fact gathered from the first examination of them was, as had been pointed out by W. R. Billings in a letter, that the proximal plates of the calyx do not rest immediately upon the upper joint of the column, as stated by E. Billings, but they seem to overlap the column, and form a ring around its upper edge. The two specimens of *C. regius* both showed this very plainly; and they also showed the further curious fact that the five radially situate plates of this proximal ring, although having nothing to rest upon or to support them from below, at least exteriorly, are distinctly angular below.

It was apparent, however, that no further information was to be obtained, unless we could find some means of seeing what is underneath the column. My examination of the specimens gave no hope of being able to detach the column in either of them; but after a very careful study of specimen B, under a strong magnifier, I came to the conclusion that it might be possible to get at the inside of the base by removing a part of the plates above it. This specimen preserved the first two rings of plates nearly *in situ*; it was slightly flattened by pressure, and on the side opposite that shown in Bil-

lings's Fig. 1c the upper ring and some plates from the next ring above it were crushed in over the basal cavity, and cemented with a very fine, shaley matrix. If these could be removed, without destroying the rest, we might see what lies next to the column. The small size of the specimen, and the uncertainty as to how the fractures might run, rendered the operation a delicate and risky one to undertake with a type specimen; but I thought the benefit to be gained in case of success would warrant the risk.

I accordingly laid the matter fully before Dr. Whiteaves, and requested his authority to undertake it. This he gave without hesitation, and in the most liberal manner, leaving me free to act with the specimen as if it were my own. I wish here to express not only my grateful acknowledgment for the personal confidence reposed in my judgment in so delicate a matter, but also, in view of the important result attained, my thanks as a palæontologist to Dr. Whiteaves for the benefit he has conferred upon science, by furnishing the means of information which, in my opinion, there was no hope of obtaining in any other way. I give this opinion, not only on account of the rarity of the specimens, but of their poor preservation. In all others that I have ever seen the calcareous test is soft and friable, and the surrounding matrix adheres to it so closely that any kind of fine cleaning is impracticable.

The work of removing the necessary plates and *débris* from above the base of the specimen was tedious and difficult, being performed entirely under a ten-power dissecting microscope, with tools specially fashioned out of needles and fine steel pens. It was completely successful, however, without any mishap, and disclosed a structure most extraordinary and anomalous, unlike any of the previous suppositions, and wholly at variance with that of any other known Crinoid.

Instead of two, there is only one ring of plates inside of the proximal ring of so-called radials and interradials, which are seen on the outside and surrounding the column. The axial canal is very large, and obscurely pentagonal; and around it, resting on the column and occupying its full thickness, are five large, strong, quadrangular plates, sloping from within upward to a thin upper face, *radially situate*, which are followed by the first and second primibrachs, not alternating with them but in direct succession, without the interposition of other plates. The first plate visible externally in the radial series is not, as a rule, visible at all from the interior when all

plates are in place; but it, as well as the interradially situate plates, is outside of the lower ring and outside of the column, projecting downward for a distance of one to four columnars. Thus the ten plates forming the proximal ring exteriorly, do not, except as to the upper angular points of four interradials and one radial, enter into the interior of the calyx wall proper, but are suspended on the outside of it. They appear out of place, as if they might have accidentally slipped down around the column. They are rather thin, and are firmly grown to the outside of the true proximal ring of plates, the angular points of four of the interradials and of the right posterior radial rising slightly above their level. The first primibrachs are exteriorly flush with the plates of the lower outer circle, and rest upon them, being sloped at the lower corners so as to fit the angles formed by the upper points of the interradials, which are thus visible from the interior. These first primibrachs also lie directly above, but do not rest upon, the plates of the inner circle, not alternating with them but in direct succession. The successive plates are all radial in position, without any alternation whatever. Thus the five radially situate plates which rest upon the column lie within the ten plates of the outer circle, and meet them, not by their upper or distal edges, but by their outer, or dorsal, surfaces.

Now for the evidence of this: Referring to Plate I. Fig. 3*b* shows the specimen B from the right posterior side, with the lower circle of radial and interradial plates as seen from the exterior, and the first primibrachs resting upon them and flush with them. The same thing can be seen in Figs. 1 and 2, showing the two sides of the perfect calyx (Billings's 1*a* and *c*). Fig. 5*a* is from a photograph — enlarged two diameters by the camera, and retouched with the brush — of the opposite, or left lateral, side of specimen B, after removal of the plates and *débris* covering the basal cavity, — an obliquely interior view. All five of the large proximal, radially situate plates are in plain view, with the large axial canal in the middle. Two primibrachs and part of a third are *in situ* — in direct succession with the last mentioned plates — and, at the right, the first plate of the anal series, slightly displaced, resting upon the posterior interradial. Two of the radial plates of the outer circle are visible, one in the middle and one to the right, with one of the interradial plates between them. The interradial to the left has been removed, leaving the exterior face of the inner proximal plate exposed, just as it rests upon the column. On the opposite side the upper points of two of the interradials can be seen, between the lower

corners of the primibrachs, and toward the right, the corner of the right posterior radial, which differs slightly in shape from the other radials. In this figure the relative thinness of the plates of the outer circle can be readily seen. Fig. 5*b* is a more nearly side view of the same structure, enlarged four diameters. Here the angular lower edge of the radial of the outer circle can be well seen, and the drawing shows very clearly the way in which these plates hang suspended to the outside of the inner ones, and project downward over the column without anything for their angles to meet or rest upon. In both the last figures there appears a depression at the middle of the upper edge of some of the inner plates. This is actually a shallow, lip-like groove, plainly visible on three of the plates, apparently traversing the inner surface of these plates in a radial direction. I cannot trace it upon the surface of the succeeding primibrachs which are preserved, but the inner surface of these plates is somewhat obscure, and did not come out freely in cleaning. If this groove be taken as showing the position of the axial nerve cord leading into the column, it would seem to indicate that the axial canal occupies morphologically its proper radial position in the calyx, notwithstanding its interradian cross-section below the calyx. Fig. 6 is an attempt to show by a diagram of a vertical cross-section, the relative position of the plates of the inner and outer circles, and of the primibrachs succeeding them, and also how the outer plates project downward over the column.

These illustrations will give a good idea of the structure as I interpret it from the most careful study of the specimen which it was possible to make. It will be seen from them how large and strong these inner plates are. They form a rigid ring surmounting the column, of much stronger construction than the succeeding calyx plates; and as a result of this the base, reinforced by the outer circle also, usually retains its shape, while the calyx above is greatly flattened by pressure.

Now this sort of a base is absolutely anomalous, and without precedent anywhere. The five inner plates resting upon the column, being radial in position, must be taken to be the infrabasals. But what has become of the basals? It is plain to me that they are the so-called interradians, which, by some strange freak of nature, have morphologically — not accidentally — become displaced from their proper position in the calyx wall, being pushed in between the radials, and both having slipped down over the infrabasals. Or, supposing a reverse process to have taken place, we may consider that

the disturbance came from below, the base being thrust upward into the calyx, expanding it until the radials were separated, the basals forced in between them, and the infrabasals into a ring formed of the two.

It will be remembered also that the radials are angular below, although with nothing whatever in their present position to meet their angles, or for them to rest upon. The basals, on the other hand, are angular above, so that the inferior angular faces of the radials would fit between the sloping upper faces of the basals if they were brought together. If, therefore, with this idea in view, we could stretch the Criuoid up from the column, so as to make room for these two circlets of plates within the calyx wall, we should find that they would fall into their relative positions without any difficulty. This imaginary process may be indicated by the accompanying diagrams, in which the plates in question are represented by dotted lines, — Fig. 1 as they are now, and Fig. 2 as they would appear if placed in their proper position.

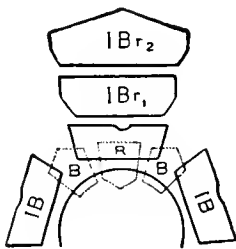


FIG. 1.

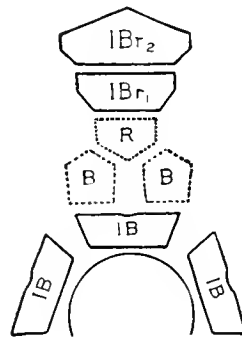


FIG. 2.

This seems to me a reasonable explanation of the relation of these structures so anomalous, — although I do not find myself able to account for it upon any teleological or evolutionary basis. I must look for enlightenment on this phase of the subject to some of my transatlantic friends, who have been admitted much farther into the mysteries of Phylogenesis than I. The structure looks like one of those experiments which we sometimes encounter in Nature, and recalls the observation of Diderot in his "Pensées de l'Interprétation de la Nature," where he says: "It seems that Nature has taken pleasure in varying the same mechanism in a thousand different ways. She never abandons any class of her creations before she has multiplied the individuals of it in as many different forms as possible." At all events the experiment was a short-lived one, for it is never heard of again. It must be

remembered that this Crinoid occurs in the lowest part of the Ordovician, or Lower Silurian, contemporaneous with the Cystids; and it may well be that it represents the end of some line of evolution in which the alternate successive arrangement of the skeletal elements has not yet been fully established. — a consideration which may also be borne in mind in connection with the abnormal orientation of the axial canal. But the fact that these plates of the exterior circle, hanging to the outside of the calyx as it were without visible office, should have just the angular faces to enable them to fit into their proper places in the normal succession, seems to me most wonderful.

Yet this case may not, after all, be much more anomalous than the converse one of the Upper Silurian genus *Calpiocrinus*, where the infrabasals, instead of being within the circle of basals, have overgrown them to such an extent as to completely envelop and conceal, not only the basals, but even sometimes the radials also.

SYSTEMATIC RELATIONS OF CLEIOCRINUS.

The prime fact suggested by these observations on the actual specimens is that *Cleioocrinus* is evidently an intermediate form between the Camerata and the Flexibilia, of a most interesting character. So far as the calyx is concerned, the general habitus of the specimens is that of an *Ichthyocrinus*; its articulate structure and flexible calyx point strongly toward the Flexibilia. On the other hand, the presence of pinnules, and of five infrabasals instead of three, differentiate it absolutely from the known Flexibilia Impinnata, to which all palaeozoic forms of the group hitherto known belong. The brachial structure — the form and arrangement of the arms and pinnules, with ridges following the radial lines and running into the arms — is, as already suggested, essentially that of *Glyptocrinus* or *Reteocrinus*. The superficial resemblance, in this respect, is perhaps greater toward such a form as *Glyptocrinus dyeri* (Pl. I., Fig. 13), but structurally the analogy is much closer with *Reteocrinus*; — although I do not mean to be understood as claiming that the two are actually at all closely related.

If we eliminate the interbrachial system from *Reteocrinus*, all except the anals, we shall have substantially the calyx of *Cleioocrinus*. The bicyelic base with five infrabasals, the longitudinal series of anal plates extending almost to the margin of the disk, and the incorporation of pinnules within the calyx

walls, are characters common to both. Of course the fixation of pinnules is accomplished in different ways, being in *Reteocrinus* by means of supplementary plates, while in *Cleioerinus* it is simply by lateral union of brachials and pinnules. Aside from the great strengthening of the radial and anal series, the calyx of *Reteocrinus* is not so very much unlike that of *Cleioerinus*. It is built up of a large number of thin plates, evidently forming a pliant wall between the rays. Its calyx was clearly pliant, and the disk conspicuously so. I have more than a hundred specimens of *R. o'nealli* which were preserved in a very fine, soft, calcareous mud, and in almost every case the calyx is flattened, and the disk more or less bulging in a variety of shapes, as if it were extremely flexible. It is really a thin integument of very small plates, without definite arrangement. I am unable, however, after close examination of a large series of well preserved disks, to find any trace of ambulacral furrows upon the surface, nor of any opening for the mouth. The anal opening is clearly indicated in some cases; it is not conspicuous, and evidently was often entirely closed, or concealed by the contraction or folding of the integument.

I have figured a number of excellent specimens of this species, for comparison on these several points (Pl. I., Figs. 14 to 21). A careful study of a large number of these specimens, in unusually good preservation, leaves no reason to doubt the correctness of the assignment of the group to which they belong to the Camerata. The mouth and ambulacra are undoubtedly subtegminal. But it seems to me that they, with the addition now of *Cleioerinus*, lie in the borderland closely approximating the Flexibilia, and should be considered as intermediate forms. This would accord with the opinion frequently expressed in private correspondence by P. H. Carpenter, who was much impressed by the strong resemblance of the Reteocrinidæ to the Ichthyocrinidæ.

DEFINITION OF THE GENUS.

The facts herein brought out necessitate a new definition of the genus, which I propose as follows:—

CLEIOCRINUS Billings.

Generic Diagnosis, amended.— Calyx large, conical, or pyriform; pliant; plates joined by loose suture. Base dieyclic; infrabasals five, invisible exteriorly. Basals and radials not in normal succession, but alternating with each other in a horizontal ring of ten plates surrounding the infrabasals and projecting downward over the column. No interbrachials, except at the anal side; anals in vertical series, resting on truncate posterior basal, and extending high up between the rays. Rays and their divisions up to the free arms contiguous and interlocking; brachials bifurcating several times in the calyx, giving off fixed pinnules, which are incorporated by lateral union with adjacent brachials and become free between the arm bases. Arms simple, uniserial, and pinnulate. Column obtusely pentagonal, or nearly round.

SPECIES.

Billings described three species of this genus:— *C. regius* from the calyx, and *C. grandis* and *C. magnificus* from stem fragments only. I see nothing to indicate any substantial distinction between the stems of *C. regius* and *C. grandis*, both being pentagonal, and the difference in size not being very great. The stem fragment which he named *C. magnificus* (Dec. IV., Pl. V., Fig. 3) is round, with proportionally much thinner columnars, and of very large size. It is probably from the lower part of the stem, where it seems to lose its angularity and become round. In the new material there is another fragment, still larger, being over an inch in diameter, which is also round; the uncrushed part of it is figured on Plate I., Fig. 12. The large crown E. (Pl. I., Fig. 11), and the long stem already mentioned—thirty inches long—came from the same quarry, and may

belong together. This stem is similar to the two last mentioned fragments, and it, together with the crown E., may well be taken as an example of *C. magnificus*, of which no portion of the calyx has been seen before. If so, it is no doubt a good species, and represents a mature development of the type of *C. regius*. The preservation of the calyx is so poor that not much can be made of it beyond its general appearance. The proximal series of plates at the base are not well defined, but the arm bases are visible for a sufficient distance around to show that it had at least one hundred free arms. As it lies flattened, the top of the calyx at the arm bases is fully five inches in width, and when in its natural form it must have been nearly four inches in diameter, — one of the largest and most magnificent stalked Crinoids known. The stem as preserved is thirty inches long, and was probably six inches longer; it is five eighths of an inch in diameter at the upper end, and seven eighths at the root; very slightly pentagonal above, and round below. It is composed of very thin columnars, much thinner than that of *C. regius*, there being about sixty to an inch generally, and probably more near the distal end. The axial canal at the upper end is obscurely pentagonal. The stem terminates in a root similar to that of *C. regius*.

The other two crowns are very much alike. Specimen B-C (Pl. I., Figs. 3 *a, b*) is the smaller of the two, and doubtless represents a younger stage. It has but six arms to the ray, so far as can be observed, or about thirty in all; whereas specimen A has eight arms in most of the rays, or about forty in all. If we had other specimens showing a constant difference in this respect, this might be ground for specific separation. But it seems very probable that, as is often the case, there is considerable variability in the number of arms, which is, indeed, indicated in specimen A, where one ray has only seven arms. It is a fact well established by observation, but persistently ignored by some describers of species, that the number of arms in Crinoids may be a good specific character in some groups, and entirely worthless in others. These two specimens have about the same form and proportions, being elongate conical and slender, whereas specimen E, with its enormous development of arms, although similarly flattened by pressure, is robust and greatly expanded, so that it is proportionately much lower and wider. Specimen B-C, therefore may be taken as another representative of *C. regius*.

The two known species may accordingly be defined as follows: —

CLEIOCRINUS REGIUS Billings.

Calyx elongate conical, gradually expanding from the base to near the top, where it is slightly contracted; plates flat and without ornamentation, except longitudinal ridges following the brachial series into the arms. Infrabasals large and strong, invisible exteriorly; standing vertically upon the edge of the column, widest and thinnest above, succeeded directly by the first primibrachs; they have a shallow groove at the middle of the upper edge. Basals pentagonal, truncate below and angular above, except the posterior one, which is quadrangular, with perhaps a slight sloping at one corner; they lie between the radials, forming with them a horizontal ring of ten plates, which envelop the infrabasals by their dorsal surfaces and conceal them from view; they also project downward over the column for a short distance, without support at the lower margins of the plates. Radials alternating horizontally with the basals, pentagonal, with the angular face below, and much smaller than the succeeding brachials. Anals in a single vertical series, interlocking with adjacent brachials, and extending well up toward the arm bases. Primibrachs two, increasing in width upward; the first one sloped at the lower corners and widening rapidly upward; the axillary primibrach followed by two to three bifurcations, giving six to eight arms to the ray, or thirty to forty in all. The ray divisions are marked by a narrow, longitudinal ridge, originating at about the first bifurcation, becoming more prominent upwards, and gradually passing into the free arms. The last bifurcating plate in the brachial series gives out at one side a fixed pinnule, incorporated in the calyx by lateral union with adjacent brachials, passing out between the arm bases and becoming free. Two of such pinnules abut at the outside of the rays; two also lie adjacent between some pairs of arm bases within the ray, between some pairs one; and sometimes two arm series are in contact without any pinnule intervening. Usually, but not uniformly, the pinnule is given off at the outside of the dichotom. Arms slender, highly angular on the back, composed of cuneiform plates narrowing alternately to a short face at the margin, the wider end supporting a pinnule alternately at either side; by reason of the thinness of the intervening plates at the margin the pinnules lie in close proximity.

Tegmen unknown, but presumably consisting of a flexible plated integument.

Column large, moderately long (over ten inches in the one specimen preserved), terminating in an expanded root for attachment to solid surfaces. It is pentagonal in the upper portions, interradially disposed, composed of rather thin ossicles, the alternate ones thicker near the calyx and slightly projecting, but becoming more uniform and thinner toward the distal end. The proximal portion does not taper, but the distal portion becomes round and suddenly enlarges near the root. Axial canal very large, pentagonal, the angles interradiial and coinciding with the exterior angles of the column.

Horizon and Locality. Ordovician; from the Trenton Limestone. City of Ottawa, Canada.

The type specimens are in the Museum of the Geological Survey of Canada at Ottawa.

CLEIOCRINUS MAGNIFICUS Billings.

Calyx very large, robust, narrow at the base and broadly expanding toward the arm bases, thus being cup-shaped instead of conical.

General structure of calyx and arms, so far as known, similar to that of *C. regius*, but with a much greater brachial development, giving rise to about one hundred free arms.

Column very large, round externally except in the upper portion, where column and axial canal are obscurely pentagonal; ossicles much thinner than in *C. regius*, averaging sixty to the inch, as compared with about thirty to forty in that species. The column is over thirty inches in length, enlarging in the specimen found from half an inch in diameter near the proximal end to seven eighths of an inch at the distal end, where it terminates in a broadly expanded root. Maximum diameter of column fragments a little over one inch.

Horizon and Locality. Ordovician; from the Trenton Limestone. Hull quarries, near the City of Ottawa, Canada.

The type specimens are in the Museum of the Geological Survey of Canada, at Ottawa.

The only specimen being much flattened and poorly preserved, I have only figured one side of it, which gives a general idea of its appearance, with such surface details as can be made out. The opposite side, on which but little of the calyx plates can be seen, shows the bases of the free arms very distinctly part way around; thirty-five of them can be counted in about three-fifths of the rim on that side, which would be about one-third of the total perimeter. This would give upwards of one hundred arms in all.

EXPLANATION OF PLATE.

CLEIOCRINUS REGIUS Billings.

Orlovician, Trenton Limestone. Ottawa, Canada.

- Fig. 1. The type specimen; from the original of Fig. 1 *a*, Pl. V., Canadian Organic Remains, Decade IV. View from right posterior interradius. The lateral faces of the anal series can be seen to the left, where they are at the thin edge of the flattened calyx; the bases of several arms are also shown. Specimen A of text.
2. Opposite side of same specimen. (Billings's Fig. 1 *b* shows only the basal portion of this view.)
 3. Another specimen, showing calyx, pinnulate arms and stem; right posterior view; composed of (*a*) crown from the second primibrach up, with a few plates broken away at either side, — not figured by Billings; (*b*) the two lower ranges of calyx plates visible exteriorly, and part of the stem attached, — being the original of Billings's 1 *c*; (*c*) the next succeeding portion of the stem; (*d*) another portion of the stem near the root; (*e*) the terminal part of the stem, with spreading root for attachment to other objects, — Billings's 1 *g*. With these are four other intermediate fragments — a portion next to the root being wanting — the whole composing a stem over ten inches long, increasing in diameter near the root, and the columnars becoming thinner; (*f*) transverse section of this stem about an inch below the calyx. (*f* is $\times 2$.) Specimens B, C, D, of text.
 4. Posterior view of 3 *b*, showing the posterior basal and first anal plate.
 5. Left lateral view of 3 *b*; the left anterior basal removed, showing the diacyelic base.
 - 5 *a*. Obliquely vertical view of same specimen; showing the interior of the calyx, the five infrabasals, and how the basals and radials, at the same level, hang on to the outer side of the infrabasals, instead of the basals resting upon their upper faces and the radials in turn upon the basals. The large axial canal is seen in the middle. $\times 2$.
 - 5 *b*. A slightly less vertical view of the same structures, in greater detail. The manner in which the basals and radials overhang the column, and also the lip-like groove at the upper edge of the infrabasals, are well shown here. The first anal plate, seen to the right, is slightly displaced by pressure. $\times 4$.
 6. Diagrammatic vertical section laterally across 5 *b*, from radial to opposite basal, showing the relative positions of the plates.
 7. Diagram showing relative position of calyx plates, for comparison with diagram in Revision of the Palaeocrinoidea, Pt. III., Pl. IX., Fig. 5.
 8. Diagram of right posterior ray and anal series, from specimen A (Figs. 1 and 2 *supra*). The relation of the eight brachial series and arms to the adjacent and intervening fixed pinnules is shown.
 9. Some calyx plates of specimen A, showing the pitting or crenulation of the articulating edges. $\times 2$.
 10. Part of arm and pinnules. $\times 2$.

CLEIOCRINUS MAGNIFICUS Billings.

- Fig. 11. A flattened calyx, with small part of stem attached, — specimen E of text. On the opposite side of the specimen the bases of thirty-five arms can be seen in a distance of about one-third the perimeter of the rim, but the calyx plates are only faintly discernible.
12. The unflattened portion of a stem fragment about seven inches long. The thinness of the columnars in this large stem is extraordinary, and the same thing is shown in Billings's Fig. 3 of another fragment.

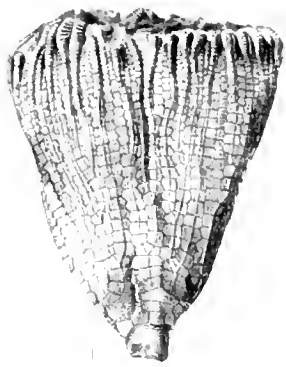
GLYPTOCRINUS DYERI Meek.

- Fig. 13. Specimen from the Hudson River Group at Cincinnati, Ohio, to show the manner of fixation of pinnules by growth of supplementary plates.

RETEOCRINUS O'NEALLI Hall.

- Fig. 14. Specimen from same horizon at Lebanon, Ohio; to show the structure of arms, pinnules, and the anal area. $\times \frac{3}{2}$.
- 15, 16. Posterior views of calyx of other specimens, showing the elongate anal series and the numerous small interbrachial plates bordering them; also the pliant and contorted tegmen. Fig. 16 shows the anal opening. $\times 2$.
17. Anterior view of another specimen, showing the structure of the interbrachial areas, and fixation of pinnules. $\times 2$.
- 18, 19, 20. Specimens showing different forms assumed by the pliant tegmen: no anal opening visible. $\times 2$.
21. Another specimen showing the same structures, and the anal opening. From Morrow, Ohio.

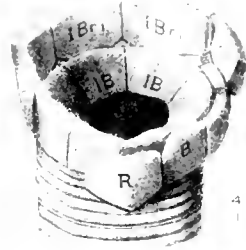
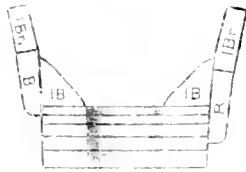
(All the specimens of *Cleioocrinus* are in the Museum of the Geological Survey of Canada, at Ottawa. The others belong to the author. All figures natural size unless otherwise stated.)



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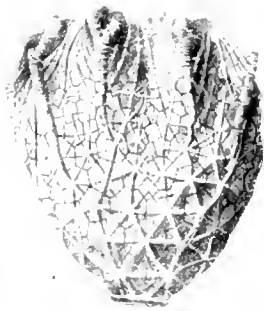
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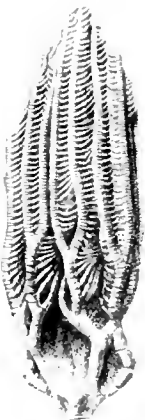
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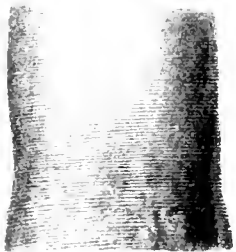
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