

SMITHSONIAN INSTITUTION

On the Crinoid Genus
SCYPHOCRINUS
And its Bulbous Root
CAMAROCRINUS
(With 9 Plates)

BY
FRANK SPRINGER
ASSOCIATE IN PALEONTOLOGY, U. S. NATIONAL MUSEUM



(Publication 2440)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION

1917



Presented by the
Smithsonian Institution
at the
Request of the Author

2 QE
782
S680
1917
Invert.
Zool.

SMITHSONIAN INSTITUTION

On the Crinoid Genus

SCYPHOCRINUS

And its Bulbous Root

CAMAROCRINUS

(With 9 Plates)

BY

FRANK SPRINGER

ASSOCIATE IN PALEONTOLOGY, U. S. NATIONAL MUSEUM



(Publication 2440)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION

1917



The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

FOREWORD

This paper, originally intended merely as an account of a remarkable discovery in 1912, having a decisive bearing upon the distribution and morphology of the genus *Scyphocrinus*, and its relation to the bulbous organism hitherto called *Camarocrinus*, has by force of repeated further acquisitions of material expanded into a memoir requiring for its illustration nine plates and numerous text-figures. The drawings for the plates were executed by Mr. Kenneth M. Chapman, now of Santa Fé, New Mexico, with his usual skill and fidelity. The text-figures have been prepared with much care by my assistant, Mr. Herrick E. Wilson, whose studies of the structural details have greatly facilitated the present explanation of the internal characters of the *Camarocrinus* bulbs. For the valuable aids thus contributed I wish to express to both these gentlemen my acknowledgment and appreciation.

FRANK SPRINGER.

WASHINGTON, January 17, 1917.

CONTENTS

	PAGE
Introduction	I
History of discovery	3
Description of the specimens	6
Conclusion as to <i>Camarocrinus</i>	9
Construction and probable origin of the bulbs	14
Mode of union between plates in <i>Scyphocrinus</i>	19
The American species of <i>Scyphocrinus</i>	21
Description of the species	30
<i>Scyphocrinus elegans</i> Zenker (Pls. I; II; III, figs. 1-4; IV; V, figs. 1-5).....	30
Further remarks upon the fixed pinnules	40
<i>Scyphocrinus spinifer</i> , new species (Pl. IX, figs. 1a-c)	46
<i>Scyphocrinus mutabilis</i> , new species (Pls. VI, figs. 3-19; VIII, figs. 3, 4, 5).....	47
<i>Scyphocrinus stellatus</i> (Hall) (Pl. VII, figs. 4a, b)	49
<i>Scyphocrinus pratteni</i> (McChesney) (Pls. VII, figs. 1a, b; VIII, figs. 1 2a, b)....	50
<i>Scyphocrinus pyburnensis</i> , new species (Pls. VII, figs. 2a, b, 3; VIII, figs. 6a, b, 7). .	52
<i>Scyphocrinus ulrichi</i> , new species (Pl. IX, figs. 2a, b)	54
<i>Scyphocrinus gibbosus</i> , new species (Pl. IX, figs. 3a, b)	55
Explanation of plates	57

ON THE CRINOID GENUS SCYPHOCRINUS AND ITS BULBOUS ROOT CAMAROCRINUS

By FRANK SPRINGER

ASSOCIATE IN PALEONTOLOGY, U. S. NATIONAL MUSEUM

(Abstract read before the Paleontological Society of America, December, 1912. Résumé by R. S. Bassler,
Proc. U. S. National Museum, vol. 46 (Nov., 1913), pp. 57-59, plates 1 and 2)

INTRODUCTION

For more than half a century there have been known to paleontologists certain bulb-like, supposedly crinoidal or cystoidal, bodies which were described from American localities by Hall in 1869 as *Camarocrinus*. Similar structures had been known long before that from rocks in Bohemia considered of Silurian age, to which Barrande had given the name *Lobolithus*, without description. For a full account, with ample illustrations, of their morphology and occurrence, and of the pertinent literature, reference may be made to Professor Charles Schuchert's admirable paper of 1904, On Siluric and Devonic Cystidea and *Camarocrinus*.¹

These organisms may be briefly described as large bulbous, chambered bodies, with thick walls composed of irregular plates, and to one end of which are attached roots and the terminal portion of a stem similar to those of crinoids.

Hall's interpretation of this structure was that the "probable theory in regard to this fossil points to a functional similarity with a crinoidal root, * * * Viewing it in this respect it may be regarded as a large chambered bulb, with an attached column, on the distal extremity of which was a calyx having characters unknown at the present time. In this aspect it must have been a free floating organism, similar in its habits to the recent Medusæ and Comatulæ."²

This view in substance has been generally held by subsequent authors. Dr. Bather³ in 1900 definitely associated *Camarocrinus* with the Camerate genus *Scyphocrinus*, as a root, "perhaps connected with a free-floating existence." And Dr. Kirk⁴ in 1911 considered it "firmly established * * * that the

¹ Smithsonian Miscellaneous Collections, vol. 47, pt. 2, pp. 253-272, 1904.

² 28th Report New York State Museum, p. 206, 1879.

³ Lankester, Treatise on Zoology, pt. 3, p. 135, 1900.

⁴ Proc. U. S. National Museum, vol. 41, pp. 54-56.

bodies known as *Camarocrinus* or *Lobolithus* are the distal expansions of *Scyphocrinus*."

The following is a summary of the then known facts touching the occurrence and relations of *Camarocrinus* and *Lobolithus*, as marshaled by Schuchert in the work above cited, with his correlations of the horizons at that time:

1. They occur in widely separated localities; viz., in Bohemia in étage E¹ to E² of the Silurian, to be correlated with the American Rochester shales; in the Manlius division of the Silurian of New York and West Virginia; in the Helderbergian of Tennessee and Oklahoma.
2. In the Bohemian localities they occur in some beds associated with *Scyphocrinus*, and in others where no *Scyphocrinus* has been found.
3. In America *Scyphocrinus* is unknown, and the *Camarocrinus* bulbs have never been found associated with any other crinoid, except rarely the stemless *Edriocrinus* attached as to any other foreign body.
4. They are frequently found in great numbers together in beds where there is no sign of other crinoidal remains.
5. In no place throughout the formations in which these bodies occur are there corresponding beds replete with crowns, stalks, or even accumulations of separated ossicles of crinoids.
6. The great majority of the bulbs are found in the strata with the stalked end downward.

Mr. Schuchert's conclusion was as follows:

Camarocrinus thus appears to be the float of an unknown crinoid that was held together after the death of the individual by the firmly interlocked double walls of the exterior and the interior, while the crown and stalk dropped away. Under this hypothesis, the float drifted with the sea currents, was finally filled with water, and, the attenuated end being heavier, sank in that position.¹

This is substantially the same as Hall's interpretation.

The supposition that these bodies were anchored in the mud with the stalk end directed upward he thinks too much at variance with the facts stated in paragraphs 4 and 6 above.

He adds finally:

This writer realizes that the last word has not been said in regard to *Camarocrinus*, and the present work is offered with the hope that some paleontologist will attack the problem from another point of view.

In 1906 Mr. F. R. Cowper Reed² noted the occurrence of *Camarocrinus* at Yemeyé, Burma, in rocks designated as Ordovician, but of whose age he said the evidence was "not quite conclusive," and described a new species, *C. asiaticus*. In the accompanying remarks upon the genus the author observed:

The nature of this curious fossil is still a matter of discussion, but the balance of opinion is in favor of regarding it as a float of some crinoid or crinoids, as Hall originally supposed.

¹ Smithsonian Miscellaneous Collections, vol. 47, pt. 2, p. 269, 1904.

² The Lower Palaeozoic Fossils of the Northern Shan States, Burma, Mem. Geol. Surv. India, n. s., vol. 2, mem. 3, p. 88.

Later, in 1913, Mr. Reed¹ described and figured from the same locality another specimen of the same species with the base of the stem and its branching roots attached, but he still treated the stem-bearing side of the fossil as the "lower surface" and the opposite rounded side as the "upper surface"; although noting the opinions of Sardeson and others that these bodies are the specialized roots of crinoids, a question which he says "can hardly be regarded as finally settled." See also La Touche,² 1913, who definitely proves the association of *Camarocrinus* with *Scyphocrinus* in the rocks of Burma.

Upon the facts as known at the date of Schuchert's paper I concurred in his conclusion. But important information since obtained, culminating in a very remarkable recent discovery, throws new light on the question—compelling the abandonment of the above statements 3, 5, and 6, and a reconsideration of the conclusion based upon them. The newly discovered evidence shows instead:

1. That the genus *Scyphocrinus* occurs abundantly in America.
2. That the *Camarocrinus* bulbs are directly connected at the distal end of the stem with crinoids belonging to that genus.
3. That these bulbs when in their original position occur with the stalked end upward, and not downward as before supposed.

HISTORY OF DISCOVERY

The facts in support of these statements are briefly as follows:

I have had for a long time, among collections made by Wachsmuth from Helderbergian strata in Perry County, Tennessee, now designated as the Linden formation, several fragments of a large crinoid belonging to the Melocrinidae, of whose generic position we were uncertain. A few years ago, thanks to the kindness of the late Professor Whitfield, I came into possession of a cast of the type specimen of the form described by McChesney³ as *Forbesiocrinus* (*Melocrinus* in second edition⁴) *prattensis*, said to be from the Carboniferous limestone of Alabama but the actual position and locality unknown, the original of which was lost in the Chicago fire. On assembling this and the above mentioned fragments it was apparent that they all belonged to the genus *Scyphocrinus*, and I have no doubt that McChesney's specimen came from the same horizon somewhere near the Tennessee-Alabama line. Later on, among other collections made in the Linden beds of Perry and Hardin counties, Tennessee, was found an excellent large calyx, in all respects like McChesney's type, with two others probably of a different species. Some other crinoids were found in the same exposures, and a number of *Camarocrinus* bulbs, but not *in situ* or in any definite association.

¹ Rec. Geol. Surv. India, vol. 43, pt. 4, pp. 335-338.

² Mem. Geol. Surv. India, vol. 39, pt. 2, pp. 119-123.

³ Trans. Chicago Academy of Sciences, vol. 1, p. 29, 1860.

⁴ Ibid., Republication, 1868, p. 22, pl. 5, fig. 4.

During the season of 1910 Mr. Frederick Braun, while collecting for me in western Tennessee, discovered at several localities of the same horizon in Benton County numerous unmistakable fragments of *Scyphocrinus* associated with those of *Camarocrinus* in the same deposits. They were in the much disintegrated remains of what had evidently been a bed of considerable extent, and the appearance of the specimens and their mode of preservation were so similar as to indicate a common origin. All were fragmentary, and the strata from which they were derived were not located in place. In Hardin County, Dr. August F. Foerste had some years before collected from an equivalent bed a number of unusually fine specimens of *Camarocrinus*; these were very firm, globose, and heavy, much like those described by Schuchert from Oklahoma. Their occurrence was noted in his paper on Silurian and Devonian Limestones of Western Tennessee,¹ but nothing was said about any other associated remains.

Among later collections made by Dr. E. O. Ulrich in the *Camarocrinus* bed of the Haragan limestone of Oklahoma were found two good calices of *Scyphocrinus*, thus supplying the evidence of association in that region which had before been wanting. In the meantime there had also been obtained among collections made at the West Virginia locality part of the calyx of a small species of *Scyphocrinus*, which established a similar association with the *Camarocrinus* occurring in those beds. These last occurrences have been noted by Dr. Kirk² in his paper on Eleutherozoic Pelmatozoa.

In 1904 Dr. R. S. Bassler, as recorded by Schuchert, observed *Camarocrinus* associated with numerous large crinoid stems a few miles north of Cape Girardeau, Missouri, along the bluffs of the Mississippi River, in a layer belonging to strata of the Bailey limestone (considered to be about equivalent to the New Scotland beds) of Helderbergian age; and in 1911 Dr. Ulrich found a detached mass of limestone from the same layer composed almost entirely of crinoid stems cemented together, among which was imbedded the well-preserved calyx of a large *Scyphocrinus*. The condition of the specimen was so promising of favorable results as to warrant a special investigation, in hope of finding the fossiliferous bed at some place sufficiently exposed for careful collecting.

Accordingly, during the season of 1912, Mr. Braun was sent to this locality for the purpose of a thorough examination, and after protracted search for several miles along the bluffs facing the Mississippi River, he succeeded in locating the crinoidal layer at an accessible point.³ Here, with his usual

¹ Journal of Geology, vol. 11, p. 683, 1903.

² Proc. U. S. National Museum, vol. 41, p. 55, 1911.

³ Rep. U. S. National Museum, p. 80, 1913; Proc. U. S. National Museum (Bassler), vol. 46, p. 58, 1913.

skill and patience, he prosecuted quarrying operations for several weeks, which resulted not only in the recovery of some of the most remarkable specimens of fossil crinoids ever obtained, but in settling finally the facts upon which the interpretation of *Camarocrinus* must depend. It was a work of no small difficulty, as the physical obstacles were formidable. The layer could be readily traced, but it was not everywhere fossiliferous, and when it was a place had to be found with a soft seam underneath along which it could be easily separated from the one next below. Even then it still remained to be seen whether good specimens would be found exposed when the rock was lifted from its bed. Several feet of overlying material had first to be removed, and it was then found that the crinoids were limited to the lower 2 inches of a heavy bed of impure argillaceous limestone, averaging 6 to 7 inches in thickness. This could not be parted by splitting, and it was therefore necessary to remove the upper half by the slow process of chipping with hammer and chisels, in order to reduce the slabs to manageable weight. This done, the remaining part of the layer was pried up in as large pieces as possible, parting readily from the underlying rock along the line of an intervening seam of fine-grained clay, which adhered closely to the lower surface of the slabs, where alone the crinoids were found in good condition.

This fact is important to remember: that while the lower two inches of the bed is chiefly composed of a dense mass of crinoid stems, firmly cemented together with a scanty matrix passing gradually into the limestone above—the calices and other parts scattered through them crushed, broken, and distorted by pressure—it is only on the *under side*, where the adherent clay has acted as a mould and protected them from the effects of the pressure, that the crowns are found well preserved.

The material taken up was not all equally rich, some of it having to be rejected because barren. The fossiliferous part of the layer proved to be limited to a small area, and it is evident that the fossils found here are the remnant of a thickly crowded colony, suddenly killed by some change in the water or movement of the sea bottom, and imbedded in the soft mud without much disturbance by currents. Four large slabs were selected of about 500 to 1,500 pounds weight each, together with some smaller pieces, the whole weighing 4,500 pounds. Two of the slabs fit together, forming a single one of nearly 4 by 7 feet, containing the most important specimens (Pl. I).

The locality was several miles distant from any station or landing, and it was necessary to transport lumber to make strong packing cases for the slabs, bedding them in plaster to secure the specimens from injury in handling. Then a chute 60 feet long was constructed to slide the packages down with ropes and tackle over a sloping rock levee of about 35 feet (vertical) descent to the water's edge, where they were shipped on a passing river steamboat.

All this was accomplished by Mr. Braun with perfect accuracy and without the slightest mishap; and it is a pleasure to record my appreciation of the care and skill with which, under many adverse conditions, he performed this difficult and laborious work.

Some of the specimens were partially exposed upon the slabs as first taken out, but it was necessary after their arrival at the National Museum to clear away the adherent clay with fine tools before their contents could be fully seen or intelligently studied. Furthermore, the interbrachial spaces were filled with a more or less hard calcareous matrix composed of innumerable arm and pinnule joints forced down between the arms and firmly cemented by pressure from above; this had to be removed by patient chipping to expose the interesting structures in the region of the arm-bases.

DESCRIPTION OF THE SPECIMENS

The surface after removal of the clay seam was found to be in many places completely covered with the crowns and stems of a very large *Scyphocrinus*. The principal slab (Pl. I) is 47 by 65 inches in size, and contains 24 crowns, 18 of them complete and several with the stem attached for part of its length; some have the calyx fairly rotund, but most of them are considerably flattened and often much distorted by contact with the bulbs described below. All have the strong, many-branched arms more or less intact, often to a length of 12 inches, densely fringed with exceedingly fine pinnules, which are so delicate that they are not often exposed in good condition by cleaning. The distal ends of arms are so slender and fragile that they are nowhere fully preserved, but from measurement of the smallest brachials and calculation of the taper of the terminal branches as far as seen, it is certain that the arms were at least 18 or 20 inches long. The calices are remarkably regular in size, measuring about 4½ to 5 inches from base to the upper limit of fixed plates. Besides these crowns several sets of arms are partly visible belonging to calices which are entirely buried either under other individuals or in the limestone matrix which becomes firm and hard a short distance inward. Some parts of the slab are covered with a dense mass of stems lying parallel like stalks of grain in a sheaf, and many of the crowns lie with their arms pointing in the same direction, as if they had fallen over into the mud at the same time under the common impulse of a gentle current. The deposition of the specimens, however, was not wholly free from disturbance; some of them lie crosswise, and most of the stems are more or less broken; in some closely contiguous parts of the bed the crowns are much broken, the calices crushed and separated from the arms. The fossils are mostly rather light colored, and with the darker matrix for a background they present a very striking appearance.

In no case can the stem be traced to the distal end; all of them at a short distance from the crown either pass under other crowns, or become enveloped in the general mass of remains. Therefore we do not know the full length of the stem, but this must have been considerable, since incomplete portions are seen for distances of 18 to 30 inches, and the quantity of stem remains is very great in proportion to the number of crowns.

Intermingled with the crowns and stems are a number of *Camarocrinus* bulbs; some of these are well exposed and appear of good size (Pl. I, at H and I), while in many cases only a part can be seen among the other objects (Pl. I, at K). All of them are considerably flattened, and some are fractured from the pressure of the overlying mass of remains which was consolidated into the compact limestone deposit forming the main thickness of the heavy layer. For this reason none have the complete rotundity and undistorted form of the West Virginia, southern Tennessee, and Oklahoma specimens, of which the stems and crowns have been detached and swept away by currents, and the bulbs left buried in the mud. But the broken condition of many of the bulbs, and of some of the calices in contact with them, is very similar to that of the fragmentary remains found by Mr. Braun in Benton County, Tennessee, which undoubtedly came from a colony deposited under like circumstances to this one. Counting broken ones, there are about 15 of these bulbs more or less visible upon the surface as now exposed. This slab, of which a photograph is herewith given (Pl. I), is now installed for exhibition in the Hall of Invertebrate Paleontology of the National Museum.¹

In all there are about 50 of the bulbs to be seen in the material under consideration. Most of them are well exposed on the lower surface of the rock, and in general it may be remarked that in those areas where the bulbs predominate in this condition crowns are scarce, and vice versa. Where they have been lying side by side in the mud in close contact both are more or less distorted or broken, as already explained; and it is evident that the bulbs in their original condition were fragile structures, by no means so solid and rigid as they appear when free; on the contrary, their walls were relatively light, thin, and porous, easily crushed and broken, a large part of their volume consisting of compartments containing soft parts or water.

In another piece from the same bed is a cluster of five bulbs within an area of about one square foot; they are almost entirely free from stems or other remains, and the matrix passes directly into the firm limestone, thus indicating that they were near the edge of the colony; and when the forest of crinoids went down before the destroying agency, whatever it was, the stalks fell away from these roots, leaving them imbedded in the mud where they grew,

¹ Proc. U. S. National Museum (Bassler), vol. 46, p. 59, 1913.

flattened, but otherwise intact. Four show the rounded end, and one the side. And this brings us to the next important fact:

In not a single instance among the total of about 50 bulbs seen on all the slabs is the stalk end directly exposed; in a few cases the bulb lies sidewise, and indications of some of the root-branches may be seen at the edge; but in no case is the stem directly traceable from a bulb *in situ*, although rarely fragments of broken bulbs are found with the root-branches attached. This accords with Schuchert's observations of slabs from West Virginia and Oklahoma; but this fact in the light of the new knowledge we now possess leads to directly the opposite conclusion from that which he deduced from it. For it must now be recalled, as I have already emphasized, that these bulbs as we find them are upon the *under side* of the layer, and therefore their rounded, non-stalked ends, as they now appear after cleaning, were directed downward in their actual position as originally imbedded in the mud. Hence they stood *with the stalked end uppermost*, as they naturally would if growing in or resting upon the soft sea bottom.

I have no doubt that this was also the case with the specimens mentioned by Mr. Schuchert. From long experience in collecting in many formations, I have observed it to be the general rule that whenever crinoids are found adhering to a layer of hard limestone or chert, with the parts in relief bedded in a seam of softer material, they are from the under side of the layer, and not the upper; and their position as seen in the museum is exactly the reverse of their original position in the layer, or on the sea bottom. This is perfectly shown on all the slabs of *Uintacrinus*, as I have elsewhere described;¹ and I have found the same to be the case with colonies adhering to cherty layers in the Burlington and Keokuk beds, where the practice of collectors was always to strip down to the layer so as to uncover it as much as possible, and then to lift the slabs with pick or crowbar, expecting to find the crinoids on the under surface. It was so at Beachler's great locality on Indian Creek, Indiana, where over 3,000 finely preserved crinoids were obtained, most of them from the lower side of the layer.

The deposits of *Pentacrinus* at Lyme Regis, England, as described by Buckland² in 1837, were made in the same way, the perfectly preserved *Pentacrinites*, found only on the lower surface of the slabs, having been "buried in the clay that now invests them," with a mass of stems above them passing into a layer of lignite. There also, as here, "the greater number of these stems are usually parallel to one another, as if drifted in the same direction by the current."

¹ *Uintacrinus*, Mem. Mus. Comp. Zool. Harvard, vol. 25, no. 1, p. 5, 1901.

² Geology and Mineralogy (Bridgewater Treatise), p. 437.

At the famous colony of Crawfordsville, where the soft layers are much thicker and without any distinct capping of hard limestone, the crinoids were more gradually deposited, and are found more generally diffused throughout the beds. But in other cases as usually found the colonies were quickly killed by a change in the content or condition of the water, and settled quietly into the soft mud in a thick mass, followed by a calcareous or siliceous deposit producing limestone or chert above them; thus the parts next to the mud were largely preserved intact, while those above them were crushed, flattened, or consolidated by the pressure and more or less cemented into rock, which would thus form a firm backing for the specimens below it. If there were a strong current, the stems and crowns of the crinoids would be swept away, while any imbedded or firmly anchored roots would remain in the mud; and they might or might not become attached to a firm layer above them according to the character of the deposit immediately following. A limestone plate would not be so likely to form, owing to the removal of the other calcareous parts of the crinoids which would help to produce it.

The occurrence at Keyser, West Virginia, mentioned in Mr. Schuchert's paper (p. 260) where he saw ten *Camarocrini* upon a large slab detached from nearly vertical strata by blasting, must be considered in the light of these facts. I have not the least doubt that they were upon the under side of the layer as originally situated, and that the unstalked end as presented by nearly all the bulbs which he saw partly buried in the mud was the under part as they had rested in the sea bottom. The small slab from Oklahoma, with five specimens on the "upper" surface (*ibid.*, p. 261, pl. 43), was no doubt in the same condition; so that the bulbs, "not one of which had the stalk end turned upward," are actually seen from the under side, and not the upper. There is no direct evidence of the original position of these slabs in the strata from which they were derived, so that it cannot be positively asserted that the surface carrying the specimens was the upper; whereas the overwhelming probability, from analogy of similar occurrences elsewhere, is that that the reverse is true.

CONCLUSION AS TO CAMAROCRINUS

While, therefore, there can no longer be the slightest doubt that the objects known as *Camarocrinus* were the bulbous distal ends of the stems of *Scyphocrinus*, it is obvious that with the foregoing fact established as to the position of these bulbs, the theory that they served as a float loses much of its force. That supposition, always at best a somewhat forced one, is no longer necessary, since the upright position of the bulbs is perfectly consistent with the simpler and more natural idea that they served merely as enlarged roots, by which the crinoids were permanently or temporarily fixed to the sea bottom. The fact that these bulbs are often found in large beds without other accom-

panying remains does not conflict, as this would only mean that when the crinoids perished any moderate current would carry away the crowns and stems, leaving the large roots more or less imbedded in the mud where they grew, as already explained.

There was a tendency among some Paleozoic crinoids to enlargement of the root, by which the terminal stem-branches were connected by a secondary growth of calcareous matter, sometimes forming a mere flat-bottomed encrusting mass adherent to other objects, and sometimes a complicated discoid body, full of chambers or channels, resting in the mud. Such, for example, was the *Astroporites ottawensis* described by Dr. Lambe¹ from the Trenton of Canada, which I have found both attached to the rock and bedded in soft shale with the lower surface undifferentiated. Dr. Sardeson² has described various forms of such discoid roots, to which he has given the name *Podolithus*; and of which he considers *Camarocrinus* to be a modified form. He traces its probable origin by the aid of an interesting series of figures, supposing the spheroidal mass to have ultimately become free, and to have floated in an inverted position.

In another case the terminal stem-branches form a rounded mass, with lateral, hook-like projections which would admirably serve the purpose of a grapnel or anchor; hence these bodies have been named *Ancyrocrinus*.³ But no one knows to what crinoid they belong, as, though occurring quite abundantly in the Hamilton beds at the Falls of the Ohio and elsewhere, no calyx has yet been found associated with them. The statement sometimes made that they belong to *Myrtillocrinus* is without the slightest authority. A more plausible supposition would be that they belong to *Arachnocrinus*, which has a similar quadripartite canal, and one species of which occurs in the same horizon.⁴ *Ancyrocrinus* is found in the Hamilton of Clark County, Indiana; Erie County, New York, and at Thedford, Ontario; but no authentic case of it in the Onondaga. *Myrtillocrinus* occurs only in the Onondaga; *Arachnocrinus* also occurs in the Onondaga of New York, and chiefly in that formation at Louisville, Kentucky; but one species—very rare—occurs in the Hamilton at the latter locality. Except this last, no calyx having a quadripartite stem is known from the Hamilton of this country.

Other singular modifications in the distal growth of the stem are known among fossil crinoids. *Aspidocrinus* Hall,⁵ a circular disk with radiating ribs

¹ Canadian Record of Science, Jan.-Apr., p. 287, 1896. Also F. Springer, Geol. Surv. Canada, mem. 15-P (Trenton Echinoderm Fauna at Kirkfield, Ont.), p. 46, 1911.

² Journal of Geology, vol. 16, pp. 239-254, 1898.

³ Hall, 15th Rep. New York State Cabinet (1862), p. 117.

⁴ Springer (New American Fossil Crinoids), Mem. Mus. Comp. Zool. Harvard, vol. 25, no. 3, p. 122, 1911.

⁵ Nat. Hist. New York, pt. 6, Pal., vol. 3, p. 122, pl. 5, figs. 15-20, 1859.

and wavy edge, is one. *Lichenocrinus* Hall,¹ which Schuchert² says "represents the nearest approach of a modified crinoid root to *Camarocrinus*," is another. This curious disk-like body, composed of numerous rounded plates, has been the subject of much discussion, but is now known to be the encrusting root of a very small crinoid of the *Heterocrinus* type. Specimens with long stems attached were figured by Meek, but not until recently has evidence of the associated crown been obtained. This important discovery was made by Dr. George M. Austin, of Wilmington, Ohio, who has generously placed his material in my hands for description.

An analogous type of growth is seen in *Edriocrinus*,³ which has no stem, but either is attached to other objects directly by the encrusting base (like the Recent genus *Holopus*), or becomes free with the base rounded or extended downward by secondary growth into a large, conical mass which might have rested on the sea bottom or might have been moved about by currents.

That *Camarocrinus* is rounded and somewhat smooth below is not an objection to the view that it served the function of fixation of the crinoid in the mud. A perfectly analogous case may be seen in the living Alcyonarian polyps, the Pennatulids, which have a very similar kind of bulbous root by which they are habitually fixed to the bottom. In fact, a species of Pennatulid, *Umbellularia encrinus* (*Pennatula encrinus* of Pallas), was treated by Ellis⁴ in 1753, and by authors generally down to Lamarck as analogous to the stalked crinoids. To show the resemblance of its permanently fixed root to the bulbous *Camarocrinus*, I give herewith a photograph of a specimen of the Pennatulid, *Ptilosarcus brevicaulis* Nutting, from Cape Tsuika, Japan, 44 fathoms (No. 30057 of the National Museum collections. Pl. VII, fig. 5). The exterior of this bulbous root is smooth, as is that of *Camarocrinus*. Some forms of Pennatulids have a long slender stalk with a root much more elongate than this, but still of an essentially bulbous type. It is further significant that among the Coelenterates are found the same three modes of attachment as in the crinoids, namely, by branching roots, flat disks, and bulbs.

Many such enlarged roots of marine organisms tend to develop some kind of septa or partitions for greater rigidity, dividing them into chambers of more or less irregular form and size. This is the case in *Camarocrinus*, where the chambers are formed of walls which in large part seem to be double in the cross-sections, as will be explained farther on. When the specimens occur in beds by themselves, without other accompanying remains of the crinoids, they are usually rotund, solid, and heavy; whereas when mingled with the stems and

¹ 24th Rep. N. Y. St. Mus. Nat. Hist., p. 216, pl. 7, figs. 1-7, 1872; Meek, Geol. Surv. Ohio, Pal., vol. 1, pp. 44-51, pl. 3, figs. 1, 2, 1873.

² Op. cit., p. 268.

³ Nat. Hist. New York, pt. 6, Pal., vol. 3, p. 143, pl. 87, figs. 1-22, 1859.

⁴ Philosophical Transactions, vol. 48, p. 305.

crowns, as in the recent discovery, they are more or less fragile, flattened, or broken. This means that in the former case the bulbs, with the crowns and stems swept away by currents, were left resting in the mud, where they remained but little disturbed during fossilization until the organic soft parts were replaced and the cavities filled by limestone or silica, like those of shells; while in the latter they were distorted or broken by the weight of the other remains piled upon them before they had time to solidify.

Upon the evidence of all these new facts, I think it may be considered that our knowledge of the bodies called *Camarocrinus* is advanced to the extent of proving that they belong to the genus *Scyphocrinus*, of which they formed the bulbous distal end of the stem, having the functions of a root, and fixing the crinoid habitually to the sea bottom.

After the first draft of this paper had been read before the Paleontological Society in December, 1912, and the first six plates to illustrate it prepared, I learned from Dr. August Foerste that he had found some other crinoid remains associated with the *Camarocrinus* at one of the Hardin County localities mentioned in his paper of 1903, before referred to,¹ and he very kindly sent them to me for examination. They proved to be fragmentary specimens of two or three species of *Scyphocrinus*. As this is the region from which the type of *Scyphocrinus pratteni* was probably derived, and as the *Camarocrini* collected by Dr. Foerste were in an unusually fine state of preservation, this occurrence suggested the possibility of further discoveries, and I decided to defer publication until I could have the territory carefully examined, in the hope of obtaining better material for the illustration of the Tennessee species. For this purpose I was so fortunate as to secure the cooperation of Prof. W. F. Pate, of Kentucky, who had in former years made some remarkable collections for me in the Tennessee Silurian² and whose intimate acquaintance with the Silurian and Helderbergian formations of that region renders his assistance especially valuable. He spent nearly a month during the summer of 1915, and further time in 1916, chiefly in Hardin County, with extraordinary results.

Mr. Pate readily identified the *Camarocrinus* horizons mentioned by Foerste³ at localities on Horse Creek and at Pyburn's Bluff, and traced the finely preserved specimens to the layer producing them—a great bed filled with *Camarocrinus*, but no other fossils except a few adhering to the bulbs. This layer is composed of a rather friable, highly siliceous clay, interbedded among a series of white limestones, and is the mud bed in which the bulbous roots once rested on the sea bottom. Here the *Camarocrinus* occurred in great numbers, firm, rotund, showing the irregularly plated surface of the bulbs in nearly their

¹Journal of Geology, vol. 11, p. 683.

²The Late Niagaran Strata of West Tennessee, Pate and Bassler, Proc. U. S. National Museum, vol. 34, p. 407, 1908.

³Op. cit., pp. 682-685.

original condition, and little altered by chemical or other action, except in the way of silicification and the filling of the cavities with solid matter. A representative series was selected ranging from 25 to 110 mm. diameter, all with the stem attachment and roots ramifying downward into the spheroidal mass, surrounded by the peculiar projecting collar mentioned by Schuchert.¹

Except when adhering to them by growth, no other remains of *Scyphocrinus* or other crinoids were found associated with these bulbs. To some of them are attached bryozoa, small brachiopods, the base of a small species of *Edriocrinus*, and certain roots representing young stages of the *Camarocrinus* hereinafter described; these are usually confined to mature specimens. In others the surface is free from foreign organisms, being entirely composed of irregular, polygonal plates, as illustrated by Schuchert in his plate 40. Such individuals had probably been completely buried in the mud. The important fact in this connection is that no other remains of this large colony of adult crinoids were to be found in the deposit. It is thus evident that the crown and stems belonging to them had been swept away, leaving the bulbous roots imbedded in, attached to, or resting upon the mud, where their cavities became filled with matrix and solidified by infiltration of mineral solutions. Contact with the sea bottom might in many cases have been by a small area, leaving much space for attachment of bryozoa and other adhering forms; and no doubt some of the bulbs became dislodged by various agencies. The mode of occurrence at this locality is about the same as that described by Schuchert (op. cit., p. 263) for the occurrences in Oklahoma, as is shown by a large collection from that field in the National Museum.

There are other *Camarocrinus* horizons in this region, as stated by Foerste, and in these the bulbs are associated with the calices and stem fragments of *Scyphocrinus*, usually in hard or cherty limestone, with occasional partings or pockets filled with clay. Many of the remains in these beds are much disturbed, broken, and intermingled. The bulbs are often crushed, some adherent to calices (Pl. VII, figs. 2a, b); and both more or less encrusted with bryozoa—showing that the organisms had been washed out of their original bed and moved about upon the sea bottom before final deposition in the limestone sediment. Some of the bulbs in this condition are geodized, and lined with quartz and calcite crystals. No crowns were found intact, and in only a single instance was any part of the arms preserved.

At five localities the calices occurred in considerable numbers, belonging chiefly to two extremely well-marked species heretofore unrecognized in the genus, and strikingly different from those of the *Scyphocrinus elegans* type. These are the *S. pratteni* of McChesney, described from an imperfect calyx, whose important characters have not heretofore been understood; and a fine

¹ Op. cit., p. 263, pl. 41, fig. 1.

new species, *S. pyburnensis*. The former is remarkable for its extraordinary size, being among the largest of known crinoids; and in both is presented a new phase of crinoid morphology, in that the calyx is lobed by the protuberance of the interradial areas instead of the radial. Some of the specimens are very well preserved as to the calyx, and show the fixed pinnules of the interbrachial pavement more plainly than is seen in the Cape Girardeau species. A third species, *S. mutabilis*, of the *elegans* type, is well represented, and it also occurs in Perry County and other localities to the north. The associated *Camarocrinus* bulbs and *Scyphocrinus* calices in this new material confirm most beautifully the observations before made as to the relative size of the stem at the proximal and distal ends, as will be shown further on. All these occurrences are in the Ross limestone of the Linden formation (Helderbergian), which has a thickness of more than 100 feet in two principal Hardin County areas, Pyburn's Bluff on the Tennessee River and Horse Creek to the eastward. There are several beds of white, blue, and cherty limestones. The great *Camarocrinus* clay bed is included within a series of white limestones in the lower part of the formation in the Horse Creek area; these are followed by about 60 feet of hard bluish- to yellowish-brown cherty limestones, disintegrating occasionally into clay pockets, and in the upper 25 or 30 feet of these cherts is found the *S. prattensi*. *S. pyburnensis* occurs at the Pyburn Bluff area through about 35 feet of bluish-grey and cherty limestones, in the lower part of the formation down to the water's edge. Here the *prattensi* beds are not exposed, and the two species are not found in the same horizon or locality. *S. mutabilis* occurs in both areas, probably concurrent with the other two species.

So far as observed, the crinoids, both *Camarocrinus* bulbs and other remains, occur rather indiscriminately throughout their respective limestone and cherty strata, and not in a single clearly defined horizon as in the lower clays.

CONSTRUCTION AND PROBABLE ORIGIN OF THE BULBS

Before proceeding to consideration of the species, it may be well to present the result of studies upon the mechanics of these singular root structures. Schuchert's description, slightly condensed (*op. cit.*, pp. 263-264), is as follows:

Inside of the bulb is a large, more or less pentagonal, medio-basal chamber, around which are usually arranged five or six, and more rarely as many as 11, variously shaped chambers. The walls of the camarae have their origin in bifurcations of the roots beneath the stalk. The walls of the chambers are double, and are made up of small, irregularly shaped plates. Each lobe has a large opening leading to it from the axil of a root bifurcation. The inner walls are surrounded by an outer integument of innumerable small plates, devoid of regular arrangement. The origin of this outer wall is independent of the roots. At the stalked end of the bulb is a projecting collar which bounds the area occupied by the visible parts of the branching roots. Around the inner side of this collar, and in the forks of the last visible bifurcations of the roots, are the openings into the

chambers, there being thus as many openings, and as many chambers, as there are ultimate root bifurcations inside the collar. The area within the collar is composed of two sets of plates—one series consisting of larger pieces, fairly regularly arranged, and restricted to the roots that radiate from the stalk; the other, of irregularly shaped smaller pieces that fill in the spaces between the root radii. The axial canal of the stalk does not pass through the base of the bulb and into the medio-basal chamber, but ends in the primary root member, where it branches and connects with the canals of all the roots. The latter canals pass through all the bifurcations and continue into the outer wall communicating with the open space between the two parts of the walls. In this way vascular and nervous connection is maintained between all parts of the bulb. [See Schuchert's figures, op. cit., p. 264, text-fig. 43; pl. 41, figs. 1, 3; pl. 42, figs. 3, 4.]

This description is copied nearly verbatim, and except as to certain points now better understood it is in the main substantially correct; it may now be supplemented by the results of further information. Each pair of roots of the peripheral dichotom within the collar divided further into numerous ramifications which were connected with each other by growth of undifferentiated plates, producing a pair of curving, leaf-like extensions comparable to the consolidated rays of *Crotalocrinus*, which progressively met by their edges and fused, forming a short, tubular opening which expanded into an ovoid sac, composed of a single wall. Thus arose a circlet of four or more large sacs, suspended from the edge of the pavement-like area bounded by the collar, and mutually in contact toward the center. A polygonal space was left at the center between the sacs, which is the "medio-basal" chamber of Schuchert, as shown by his figure 4 of plate 42; in this there are five sacs, with the openings toward the stalked end away from the observer, not shown in the figure owing to the deep shading.

Meanwhile other systems of plates derived from the principal root members extended themselves by continuous multiplication in different directions so as to form: (1) a projecting collar bounding the area occupied by the sac openings and the root members leading to them; (2) a connecting pavement between the root members within the collar; and (3) a wall enclosing all the sacs and constituting the outer wall of the bulb as now seen. The last is also a single wall. But wherever it touched the walls of the sacs, or wherever the walls of two sacs came together, there, and only there, do we find a double wall. See Hall's figure 7 of plate 35 of the 28th Report, where in a cross-section the walls of the sacs appear single around the "medio-basal" chamber, and become double in the partitions where those of two sacs meet and where the latter meet the exterior wall. These different walls are not independent structures, but all have a common origin, being derived directly from the ramification and inter-connection of the roots; and they are innervated by a common nervous system. It is probable that the openings leading to the sacs were closed in life by some kind of membranous structure, as no foreign objects are found within the chambers except homogeneous matrix deposited during fossilization.

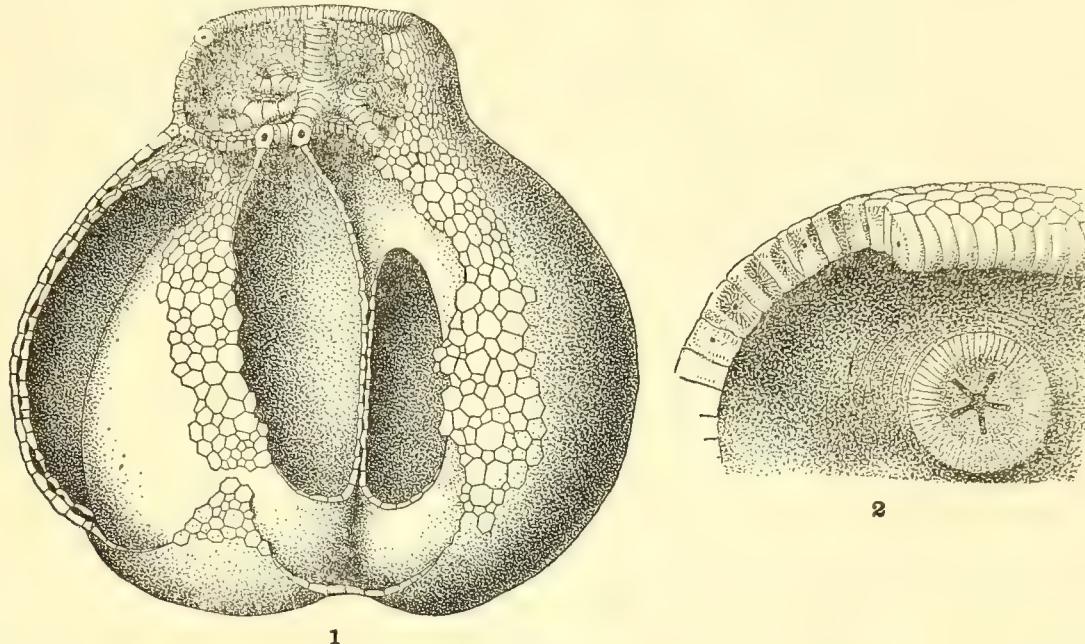
As a result of these facts the bulbous root of *Scyphocrinus (Camarocrinus)* may be definitely characterized as follows:

A rigid, hollow, chambered root, consisting of a large spheroidal bulb with a short projecting collar; a stem base with bifurcating roots resting in and forming a large part of the floor within the collar; and several internal, laterally apposed sacs which abut against the inner side of the bulb wall and open separately to the exterior by large channels located between the collar and the axils of the peripheral root branches; the whole innervated and nourished by incorporated nervous and vascular systems. Within the collar are the stem base, its proximal bifurcating roots, and a single floor-like layer of root plates formed by the branching and union of lateral rootlets. The collar and bulb wall consist of single layers of similar plates derived from rootlet systems originating at the ends of the proximal root branches, some turning upward and uniting to form the collar; others turning downward and similarly uniting to form the bulb; while still others, springing from the root axillaries and laterally coalescing, produce the internal sacs. The neurovascular systems passed downward in the stem through the roots and out into the various rootlet walls, forming a reticulated network of surprising magnitude which innervated and nourished each plate of the root.

The wall structure as above described, the origin and position of the sacs, and the relation of the collar and floor to the other walls, are illustrated by the generalized figure (text-fig. 1), constructed by Mr. Wilson from sectioned and fractured specimens in the collection, by which these details are fully disclosed, and by other figures in connection with it. One of the most instructive of these is text-figure 2, showing a part of the collar in which the plates have separated along the suture lines; the striated joint faces of the plates and the pores for the nerve cords are perfectly visible; and it is interesting to note how the upper or finishing row of plates, being rounded except where in contact with the row below it, resembles a strong root built up of radiately striated, discoid ossicles.

In connection with the development of the root branches are some further curious facts. Schuchert (op. cit., p. 264) noted that "the stalk is generally placed a little eccentrically to the high, most prominent, or primary root member." This is shown by his figure 43 on the same page; and in that, as well as in figure 44, may be seen a low, rounded cusp near the base of the stem, projecting from a root branch that is decidedly larger than the others. This cusp appears to be the remnant of what was the pointed distal end of the larval stem before its attachment to the sea bottom; and its position results from the fact that the branching of roots was not symmetrical, but took place at one side because the young stem, too thin and pliant to attach itself at the extreme point, made its lodgment at a curve a little way above, so that the stem at that place was for a short distance recumbent. Thus the terminal point of the

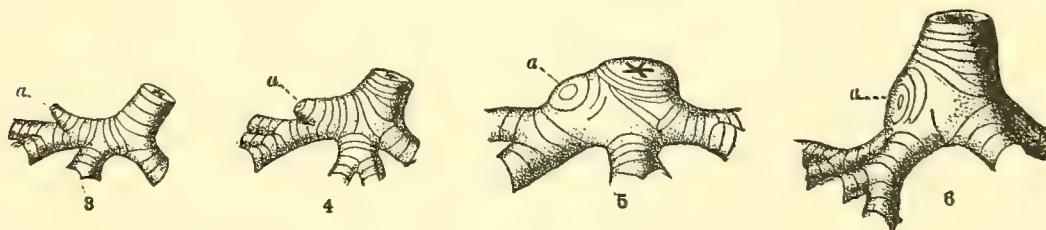
young stem was in many cases not attached or imbedded, but remained projecting above the general level of the roots, where it underwent a process of gradual suppression and disappearance, frequently leaving a scar which is to



FIGS. 1-2

1. Bulbous root (*Camarocrinus*) of *Scyphocrinus*. Generalized figure constructed from sectioned and fractured specimens in the author's collection. Showing the relation of the stem and its outgrowths, viz., the pavement, the bordering collar, the branching roots and sacs suspended from them with openings upward, all formed by extension and multiplication of root branches. Perforations for nerve cords may be seen on the exposed faces of plates. Nat. 2. Part of fractured collar belonging to a large bulb, used in constructing fig. 1; the plates have separated along the sutures, showing perforations for nerve cords. $\times \frac{3}{4}$.

be seen close to the stem upon some very mature specimens (see Hall's fig. 5, pl. 36, 28th Rep. N. Y. St. Mus. Nat. Hist.). Concurrently with this process the stem in the opposite direction gradually changed its position from



FIGS. 3-6

Stem and roots of *Scyphocrinus*, merging in bulbs not shown. Showing stages in reduction and disappearance of primary terminal root at *a*, from a projection of several segments with stem partly recumbent (3), to a mere flat scar with stem erect (6). All $\times 2$.

recumbent to erect, the latter being often not attained until the projecting point or cusp had disappeared.

Text-figures 3, 4, 5, and 6 show some of the stages of fixation of the stem and disappearance of the terminal point.

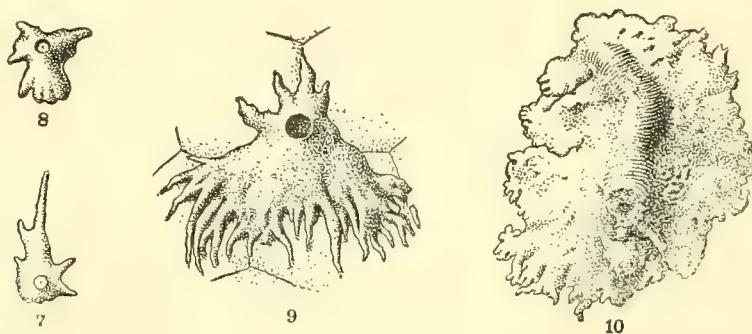
The first developed, or primary, root member usually took the same direction as the original point, and became the largest; it might divide and subdivide into strong branches at whose axils were formed one or two of the openings and resulting sacs. Two to four other strong root members are given off toward the opposite side of the point of attachment, forming with the former ones the primary sacs; these may be followed by other and younger roots giving rise to successively smaller sacs which lie around the upper periphery of the bulb, but usually do not extend to the middle or lower zone.

Such a one-sided growth of root branches is not uncommon. It appears in numerous unconsolidated roots of an otherwise unknown crinoid of the same formation; and the same thing occurs in the Recent genera *Rhizocrinus* and *Bathyocrinus*, and probably in many forms which are fixed to the sea bottom by delicate branching roots (see P. H. Carpenter, Challenger Report, Stalked Crinoids, pl. 7, fig. 1; pl. 9, fig. 1).

This mode of distribution of the roots may explain the further curious fact that whereas the axial canal in this genus is pentapetalous, the number of principal chambers or sacs in the bulbs is usually not five, but four; additional ones irregularly, and occasionally to a total of 10 or 11, may develop from younger roots, as already explained, or from further bifurcations. Therefore, while a cross-section near the stalked end of a bulb may show eight or ten chambers, a section taken toward the other end will usually have but four. This is finely shown by figures 1, 2, 3 of Schuchert's plate 44, giving three horizontal sections at different levels in the same specimen, the upper two having eight chambers, while in the lower one the number is reduced to four large chambers with a faint remnant of a fifth. In three other specimens sectioned above the middle there are four large chambers and two small ones. The weathered specimen figured by Schuchert on his plate 43, and the section in Hall's figure 8 of his plate 35, show the four primary chambers as they will be found in probably 90 per cent of the specimens at a level in the lower third of the bulb. Hall's figure 1 of the same plate shows how there were four principal lobes, with smaller ones added at the top. They are always unequal; sometimes one is much larger than the rest, and sometimes three are large and one small. Other irregularities are seen in Hall's figures 3 and 7 of his plate 35. Where there is a considerable increase in number of chambers above four or five, it will usually be found that they are developed along the recumbent part of the stem, or the primary member, as a sort of axis, instead of in a symmetric radiation from a central stem. This is excellently shown by Schuchert's figure 3, plate 42, and Hall's figures 1 and 3, plate 35.

Finally, we have some interesting information as to the growth of the roots, derived from young specimens which have lodged upon the hard surface of mature bulbs and become fixed to it. Being unable in this situation to

develop according to their tendencies, the roots, instead of spreading symmetrically as is usual with encrusting roots, assumed most irregular shapes; in some, relatively long branches are grown all on one side (text-figs. 7, 8); in others, lateral connection has produced a flat plate for a certain distance mostly on one side, beyond the edge of which the branching roots become separate again (text-fig. 9); in a case still further advanced, a flat plate has been formed with a similar one-sided growth which has followed the course of the recumbent stem for a considerable distance, the stem being as it were half buried in the plate (text-fig. 10). In this specimen some of the root branches are partly separated from the floor, as they are occasionally seen within the collar in the regular bulbs.



FIGS. 7-10

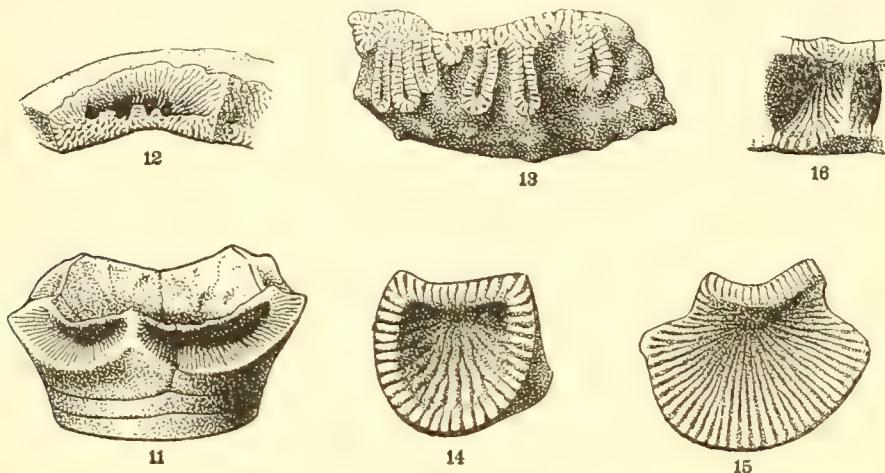
Roots of young specimens of *Scyphocrinus* attached to hard surface of mature bulbs, developing unsymmetrically and chiefly toward one side: 7, 8, long branches, $\times 2$; 9, flat plate followed by small branches, $\times \frac{3}{2}$; 10, flat plate with similar one-sided growth following course of recumbent stem, $\times \frac{3}{2}$.

These remains are not at all common considering the number of bulbs in the collection, and it seems probable from the rounded appearance of the stem joint-face where detached that the young did not long survive their fixation in so unfavorable an environment.

MODE OF UNION BETWEEN PLATES IN SCYPHOCRINUS

Examination of the material in hand has yielded some information as to the union between the various plates. Superficially each suture appears as a fine denticulate line, formed by the interlocking of closely spaced crenulae on the apposed plate facets. In the calyx the facets usually consist of two or more distinct areas for the insertion of ligaments. The first is a narrow, usually continuous, often convoluted, band surrounding one or more depressions, and forming the contact surface of the plate. The second area or areas consist of the depressions or ligament fossæ. The surface of each facet is crenulated, the crenulae originating in the deepest portion of the ligament fossæ, radiating outward and crossing the contact band at right angles. The

distal facets of the basals have single, deep, inwardly sloping fossæ (text-fig. 11). The proximal facets of the radials have single, very deep fossæ corresponding in outline to those of the basals, but with their floors divided into a lateral series of conical pits from which the crenulæ radiate (text-fig. 12). The facets of the primibrachs, lower secundibrachs, and interbrachials show still further modification, the walls of the pits having thickened, and increased in height until they came into contact with similar walls in the apposed facets. The contact areas between the upper portions of the small ligament pits are usually deeply lobed by the depression of the surface along the plate margins, thus forming a series of external pits between the plates, and leaving the ligament fossæ surrounded by narrow contact bands which



FIGS. 11-16

Mode of union between plates in *Scyphocrinus*. 11, distal face of BB. 12, proximal face of R. 13, distal face of IBr. 14, distal face of higher IIBr. 15, 16, distal and lateral faces of IIIBr. All $\times 4$.

project outwardly at right angles from the internal marginal band as a series of loops (text-fig. 13). The facets of the higher secundibrachs have single, deeply inward sloping fossæ surrounded by a broad, smoothly outlined marginal contact band (text-fig. 14), but in the tertibrachs the fossæ become very shallow, merging imperceptibly with the contact band of the outer margin, and in some examples completely surrounding the plates near the inner margin of the inner contact band (text-figs. 15, 16).

This is a type of loose suture formed largely by interlocking crenulations admitting slight mobility, similar to that between the usual discoid stem ossicles, associated with a more or less pliant tegmen of undifferentiated small plates, occurring in forms like *Reteocrinus* and *Glyptocrinus*, which exhibit variation from the Camerate calyx toward that of the Flexibilia.

The internal surface of the calyx plates of *Scyphocrinus* is ornamented by fine striæ arranged at right angles to the sutures, forming trapezoidal areas

coinciding at the plate angles, with or without folding of the surface (Pl. VI, figs. 18, 19). The fine, low ridges which cause the striation of the surface terminate in the marginal crenulæ, and are apparently formed by the continuous growth of the crenulæ during lateral increase of the plates. The internal folds have no relation to the external folds or the ligament fossæ, and their purpose is doubtful.

The stem facets of *Scyphocrinus* are circular, the contact area narrow, sloping gradually into the ligament fossa, with radiating crenulæ passing nearly to the center (Pl. V, figs. 2-5). In the root bulb (*Camarocrinus*), the plate facets are slightly concave, and the crenulæ radiate outward from the central axial canal (text-fig. 2).

THE AMERICAN SPECIES OF SCYPHOCRINUS

It is an interesting illustration of the progress of discovery, and of the liability to change of opinion resulting therefrom, that this genus, so profusely illustrated by Waagen and Jahn, and supposed by them as well as by Schuchert to be unknown outside of Bohemia,¹ now proves to be more widely distributed, and represented by a far greater variety of species, in America than in Europe.

The genus *Scyphocrinites* was proposed by Zenker² in 1833, based upon specimens from Bohemia which he described under the name *Scyphocrinites elegans*, which should therefore be the type. Schlotheim had previously, in 1820, applied the name *Pentacrinites excavatus* to certain specimens said by him to be the "Prague Encrinite," and to figure 2, plate 4, of Schroeter's *Vollständige Einleitung*, 1778, but without other description. Passing over various allusions to these fossils in the intermediate literature, we have as the chief source of technical information the elaborate work of Waagen and Jahn in 1899, based partly upon the unpublished researches of Barrande.³ Some 22 large quarto plates, with voluminous text, are devoted to the illustration and description of the Bohemian forms of this genus, including a complete résumé of antecedent literature.

For the purposes of the present paper *Scyphocrinus* may be briefly defined as a Melocrinoid, with four basals; with branching, uniserial arms; and with some of the tertibrachs, and perhaps higher brachials, incorporated in the dorsal cup by means of a network or pavement of plates connecting those of adjacent rays. This pavement is the most conspicuous feature of the calyx, producing depressed, numerously plated, interbrachial areas above the level of the axillary primibrachs, peculiarly modified by secondary growth, with

¹ Since their work appeared, fragmentary remains of *Scyphocrinus* and *Lobolithus* have been reported from Cornwall, England, and also from Poland, Prussia, the French Pyrenees, Spain, and India.

² Beiträge zur Naturgeschichte der Urwelt, p. 26.

³ Système Silurien du centre de la Bohême, vol. 7; *Scyphocrinus*, pp. 35-97.

the arm-bases strongly elevated between them. Stem round, long, terminating in a large, spheroidal, chambered body, having the functions of a root.

The literary status of the most important described species is unsatisfactory. Messrs. Waagen and Jahn profess themselves unable from the works of these authors to identify with certainty the two species of Zenker and Schlotheim, and while in one place retaining the name *elegans* as a term of convenience for a group of species, they ignore it as the name of the type species, but assign *excavatus* to a form which they redescribe as probably including that of Schlotheim and three new varieties. They also describe *Scyphocrinus subornatus* of Barrande (MS.), and another new species of their own, *S. decoratus*.

This course of the authors as to the type species was criticized by Bather¹ in 1900; but while for the purpose of a review he might afford to accept it "for the sake of concord," that cannot be done in this paper, which has to deal with important new material for which a correct name is required. Zenker gave both a description and recognizable figures of the form to which he applied the name *elegans*. As to this Waagen and Jahn say, on p. 42: "The description of *Scyphocrinus elegans* Zenker agrees perfectly with the greater part of the specimens which we arrange in three new varieties: *Scyphocrinus excavatus* var. typ., var. *Schlottheimi*, and var. *Schroeteri*; there is also a remarkable agreement between the specimens and the figures given by Zenker"; on the other hand, "the species of Zenker differs notably from the crinoids * * * described by Barrande under the name *S. subornatus* and by us under the name *S. decoratus* and *S. excavatus* var. *zenonis*." But having observed among their material several varieties no particular one of which is indicated by the earlier figures, they conclude that "we cannot then apply to our specimens either the name *excavatus* Schlotheim, which has priority, or that of *elegans*, given later by Zenker; but from respect to the memory of our predecessor we designate one of our species by the name *excavatus*." And this they proceed to do throughout, citing the species as of "Schlotheim sp. p." Now Zenker's figures and description, instead of mere arm fragments like those of Schroeter to which Schlotheim gave his name, were based upon specimens quite sufficient to afford a generic diagnosis, and to show that the species for which they formed the types is the one characterized by sharply sculptured plates. The species *S. excavatus*, as described by Waagen and Jahn, is confessedly not identifiable from the works of Schlotheim, and for the purposes of credit it must date from Waagen and Jahn, 1899. Therefore Zenker's prior name, *elegans*, must hold for those forms which they admit to agree with his description and figures—leaving *excavatus* to stand, if at all, for their variety *zenonis*, which they say does not so agree.

¹ Ann. and Mag. Nat. Hist., vol. 6, July, p. 115.

On p. 77, as a result of a general discussion of the species, they arrive at the following arrangement:

From what we have said it results that among the forms of *Scyphocrinus* there are only three which can be exactly defined; these are:

1. *S. subornatus* Barrande.

2. *S. excavatus* Schloth. sp. p. { var. *zenonis* W. and J.
var. *schlotheimi* W. and J.
var. *typica* W. and J.
var. *schroeteri* W. and J.

3. *S. decoratus* Waagen and Jahn.

As to the forms comprising no. 2 they say: "We are constrained to consider them all four only as varieties of a single species, *Scyphocrinus excavatus* Schloth."

It will be observed that while in the last arrangement they place their variety *zenonis* along with the other three in a specific group distinguished from that of *S. subornatus*, in the first arrangement, on p. 42, they consider it as "differing notably" from those three. In my view of the relative importance of the characters as elsewhere stated by them, it would be more consistent to leave *zenonis* as a separate species, and perhaps to place *decoratus* with the other three as a variety.

Waagen and Jahn were much impressed by the singular conformation of the interbrachial pavement, and through lack of understanding of its relations were led to attach undue importance to its variations when disposing of *zenonis*.

Conformably to the above suggestion, the following summary made from their detailed descriptions and figures, as well as from my own observations, will show the characters and relations of the Bohemian species; they are taken in reverse order for better comparison:

I. Group *elegans*: Calyx plates sculptured.

Species 1. *S. elegans* Zenker (*excavatus* W. and J., pars).

Calyx elongate, obconical, of medium size to very large. Plates in lower part low-convex, with several fine, continuous, parallel ridges of costæ radiating from near the center, crossing the sutures and connecting from plate to plate, forming triangular or rhombic figures. Interbrachial plates are not recognized higher than four ranges, it being considered that above that they are so small, and their sculpture so strong, that it is difficult to distinguish their contours, and that their arrangement is generally irregular. In the interbrachial areas from about the zone of the first secundibrachs the ridges either tend to coalesce into single, strongly raised, wide or narrow bands crossing the sutures with sunken areas between, giving a more or less reticulate, cancellate, stellate, or transversely banded appearance; or they may disappear, leaving the plates of the pavement smooth or granular, flat or greatly rounded. These ridges are more conspicuous toward the margin of the plates, where they sometimes form a

sort of crenulation; toward the center they are frequently somewhat effaced. This plate sculpture is all a modification of a single plan; the different varieties depend upon the degree to which the union and enlargement of the radiating costæ proceed, and they may all be more or less present in the same specimen. Some of the specimens have the brachials beyond the lower secundibrachs perfectly smooth, others with a strong transverse ridge, and still others with a girdle of detached granules.

Upon the predominance of the various kinds of plate sculpture in the interbrachial pavement Waagen and Jahn have proposed the following varieties, which they admit are not constant:

- a. Plates of pavement rather irregularly convex in lower part; passing somewhat abruptly into broad ridges forming several interrupted, transverse bands, or rows, resembling chains, more or less parallel, arched downward.
var. *schlotheimi*.
- b. Plates of pavement in upper part with more or less deep pits, forming a network of rhombs; in lower part stelliform.
var. *typica*.
- c. In lower part a complicated network into which root-like prolongations from the sides of the lower arm-brachials enter, and from which the arms appear to rise suddenly, as if they emanated from roots.
var. *schroeteri*.

Comparing the figures, it is impossible to identify these three varieties with any certainty, as they all run into one another, the characters often being all combined in one specimen.

Species 2. *S. decoratus* Waagen and Jahn.

Like *elegans*, but the radiating costæ are formed of separate granules.

Calyx very large.

These characters are found intermingled in my specimens (see Pl. II).

II. Group *subornatus*: Calyx plates not sculptured.

Species 3. *S. zenonis* Waagen and Jahn.

Plates smooth or granular, convex, with crenulated margins. Pavement as in var. *schlotheimi*.

Species 4. *S. subornatus* Barrande (MS.).

Plates smooth or granular, flat or concave in the middle, straight or irregularly plicated; interbrachial pavement of smooth, flat plates; arm plates also smooth, and but slightly raised.

To these might be added another variety under *S. elegans* from a fine specimen in my collection in which the plates of the iBr pavement are smooth except for a pustulose center.

All of these species and varieties are derived from the transition beds between étages E¹ and E² of Barrande's section in central Bohemia, hitherto called Silurian, but which Dr. Ulrich is now inclined to consider as more nearly equivalent to the lowermost Devonian (Helderbergian) formation of this country. In view of the recent discoveries in Tennessee, whereby the range

of the genus is carried down into undoubted Silurian, it may be that this correlation should await further revision by the stratigraphists. Although they figure on plate 44, figure 3, a specimen of *S. subornatus* with a part of a *Lobolithus* in contact, Messrs. Waagen and Jahn nowhere intimate the possibility of their being parts of the same organism. But in 1904, in a letter quoted in Schuchert's paper (p. 259), Professor Jahn states that "certain *Loboliths* belong to *Scyphocrinus*," he having observed them "connected by long columns to *Scyphocrinus* calices."

I have given the foregoing abridgement of Waagen and Jahn's definitions of the Bohemian species for the purpose of comparison with the American species, in view of the remarkable parallelism that exists between them.

In this country there seem to be at least eight species based upon the characters shown by the calyx, from four widely separated areas—all of Helderbergian age; one from the lower, the Keyser beds, and the others from the higher Linden, Bailey, and Haragan beds, one of which, however, goes down into the Niagaran. They are divisible into two well-marked groups, distinguished by radically different types of calyx. The Missouri form, the only one of which the arms are fully known, is in size, surface ornament, structural details, and general habitus so remarkably like the leading Bohemian species that no reliable differentiating characters can be found in the fossil state. Most of the others are well characterized.

A further remarkable modification within the limits of the genus is seen in the presence of articulated spines, as shown in *S. spinifer*.

The stratigraphic range of *Scyphocrinus* is considerable, extending from the Decatur formation of the Niagaran to the close of the Helderbergian in the Tennessee area. *S. mutabilis* occurs in Perry County in a bed of yellow, granular, crinoidal limestone referred to the Decatur limestone (the highest member of the Niagaran), associated with the genera *Clonocrinus*, *Desmidocrinus*, *Gazacrinus*, *Eucalyptocrinus*, *Marsipocrinus*, *Lecanocrinus*, and *Pisocrinus*; and another indistinct species along with frequent *Camarocrinus* has been found in a hard grey limestone underlying the yellowish layers.

Hence in these beds at the top of the Niagaran, intermingled with its characteristic species, *Scyphocrinus* begins and from there continues throughout the Linden to its highest beds in the northern part of Benton County, where it is associated with Devonian species quite different from those of the other Linden beds. Among these Devonian forms I have recently obtained a well-marked specimen of *Phimocrinus*, the ancestral form of *Synbathocrinus*, a genus not hitherto seen in America; and numerous weathered fragments indicate the presence of a form like *Stereocrinus*, which would carry the Dolatocrinites a stage lower in the stratigraphic scale than has been hitherto known.

The correlation of the different local formations containing *Scyphocrinus*, according to the latest determination of the U. S. Geological Survey, may be stated as follows:

		Tennessee	Missouri	Oklahoma	West Virginia
LOWER DEVONIAN	<i>Helderbergian</i>	Linden formation (Ross ls. at base)	Bailey ls.	Haragan ls.	Keyser ls.
SILURIAN	<i>Niagaran</i>	Decatur ls.			

It is a question how to deal with the described species of *Camarocrinus*, now that it is certain that they all belong to the genus *Scyphocrinus*. The characters on which they are based, namely, the form and proportions of the bulbous root and the different conditions of its external surface, are in my opinion of little or no diagnostic value. The root in Paleozoic crinoids, when it exists, is a generalized structure, usually not marked by specific differences (even the stem as a whole having by no means the taxonomic value which it has in the Recent crinoids); while as to surface characters, the differences hitherto noted are largely due to chemical action and the effect of weathering. This is well shown among specimens in my collection from the same locality. Those which are apparently little altered from their original condition have a smooth surface, composed of undifferentiated small plates, as shown in Hall's figure 1 of plate 36, in the 28th Report of the New York State Cabinet; if the calcareous surface of these has been dissolved and the underlying structures replaced by silica, various sorts of rugosities, more or less regular, will often appear; *e. g.*, as in Schuchert's var. *stellifer* (*op. cit.*, pl. 40, fig. *a*; pl. 41, fig. *b*).

The form and number of the lobes into which the bulbs are divided are variable, and as specific characters these are of no importance whatever. Usually the chambers developed from the root branches are represented by more or less protuberant, unequal lobes. The primary number is four, to which others may be added to a total of about 11, as already explained; and exceptionally the number is reduced to three. In case of five lobes, which is the most frequent variation, the added lobe is usually much smaller than the original four; a symmetrically quinquelobate bulb is the exception. In many cases the external lobing is quite obscure, so that the bulb appears almost regularly spheroidal. These facts are conclusively shown by the series of 70 finely preserved *Camarocrini* from the clay bed in Hardin County, Tennessee, already mentioned. They are all from a single colony, found in the place of

its original deposition, and undoubtedly belong to the same species. Of these, 46 have four lobes; 10 have four below and five above; 8 have five; 3 have six; 1 has seven; 1 has eight; while 3 have but three; thus 80 per cent have four primary lobes or less, 11 per cent have five, and 7 per cent have over five in the upper part. A similar irregularity is observed among specimens from Oklahoma, and the variable character of the roots and chambers in them is thoroughly explained by Schuchert (op. cit., p. 264). Among 45 specimens, 90 per cent have four (or exceptionally three) lobes in the lower part of the bulb; 20 per cent have five at the stalked end, and 12 per cent have more than five. At both localities the average height and width of the specimens are about as 1 to 1.20, a few being as high as wide. The tendency to increase in number of lobes is greater in the West Virginia specimens, where out of 29 about 80 per cent show more than five at the stalked end (from 6 to 10, or 11); but nevertheless 70 per cent of the whole have only four lobes or less at the lower end. The specimens here are also flatter, the average height to width being about 1 to 1.40, often 1 to 1.50; and in no case equal.

Hence while in a large collection of the bulbous roots there may be a general facies characteristic of some species, this is of little or no value when judging from individual specimens; and while the facies might distinguish the West Virginia specimens from those of Tennessee and Oklahoma, as above shown, it would not distinguish the latter from each other. The only species that I should undertake to identify with confidence from the bulbous root is *S. pratteni*, whose great size is associated with a character in the primary root member not observed in others.

As a rule, we do not know positively to which form of calyx any one of the bulbs in the different localities belongs. Nevertheless, it is fair to assume that a given bulb of *Camarocrinus* belongs to the calyx found in the same bed; and in this way some of the specific names already in use may be retained.

Following this course, where practicable, the species may be characterized as follows:

ANALYSIS OF THE AMERICAN SPECIES

(All from the Helderbergian; but *S. mutabilis* occurs also in the Niagaran)

A. Calyx turbinate, expanding to IIBr.

iBr areas not protuberant.

Plates sculptured.

Calyx elongate, very large, height to width about 1.8 to 1; deeply lobed between arm-bases.

Plates thin, low-convex, with sharp costæ, either becoming smooth or passing into coarser ornament above; interbrachial pavement either reticulate, transversely banded, stellate, irregularly rugose, or smooth.

IIBr about 20; median ridge broad.

Bailey limestone, Missouri.

1. *S. elegans* Zenker.

Calyx rather narrowly elongate.

Plates deeply sculptured; with sharp continuous costæ from base up, surmounted with slender spines.

IIBr about 12; median ridge narrow.

Linden formation, Tennessee.

2. *S. spinifer* n. sp.

Calyx variable, usually shorter than wide.

Lower part of cup turbinate, with sides usually somewhat convex.

Plates low-convex, usually without strong stellate sculpture, but with crenulate margins and pits at corners; rarely spiniferous.

IIBr about 12 to 15; median ridge broad.

Decatur and Linden formations, Tennessee.

3. *S. mutabilis* n. sp.

Calyx rather short, height to width about equal.

Plates low, more or less rugose, with prominent connecting ridges alternating with deep pits above, producing strongly stellate sculpture.

IIBr about 10; median ridge narrow.

Keyser limestone, West Virginia.

4. *S. stellatus* (Hall).

B. Calyx widest below IIBr, contracting and cylindrical toward arm-bases.

iBr areas protuberant.

Calyx broad, robust, extremely large, about as wide as high.

Plates smooth, broadly convex, often obtusely pustulose. iBr areas sharply protuberant and IBr deeply depressed between them.

IIBr about 12; median ridge broad.

Linden formation, Tennessee.

5. *S. pratteni* (McCh.).

Calyx elongate, large.

Plates strongly convex, with obtuse stellate sculpturing, not pustulose. iBr areas obtusely protuberant.

IIBr 13 to 15; median ridge rather narrow.

6. *S. pyburnensis* n. sp.

Linden formation, Tennessee.

Plates smooth and flat, some with pustulose center.

Lower part of calyx broadly curving at wide angle from base.

IIBr about 11; median ridge narrow.

Haragan limestone, Oklahoma.

7. *S. ulrichi* (Sch.).

Calyx small, spheroidal below IIBr. iBr areas not protuberant.

Plates gibbous, thick, smooth to obtusely stellate.

IIBr about 11; median ridge narrow.

Haragan limestone, Oklahoma.

8. *S. gibbosus* n. sp.

The species of group A are directly comparable with the Bohemian forms of that type; while those of group B are of a facies totally different from any

known in Bohemia, and they introduce into the genus a decidedly new form of calyx. The protuberant interbrachials are a feature thoroughly distinct from anything heretofore observed in the crinoids; a lobed form of calyx caused by the projection of the radial or brachial series is common enough, but the converse condition found here is something quite unique.

The identical occurrence of such a highly specialized species of crinoids as *S. elegans* in the two continental areas points to a remarkable parallelism of formations so great a distance apart. A like close relation has been found to exist in other fossils, notably among the Graptolites, of which I am informed by Dr. Ulrich that one species occurring in the Cape Girardeau beds can scarcely be distinguished from a Bohemian form of the corresponding stage.

DESCRIPTION OF THE SPECIES

I. SCYPHOCRINUS ELEGANS Zenker

Plates I; II; III, figs. 1-4; IV; V, figs. 1-5

1833. *Scyphocrinites elegans* Zenker; Beitr. Naturges. Urwelt, 26, pl. 4, figs. A-F.
1840. *Scyphocrinites elegans* Zenker; Münster, Beitr. Petref., pt. 3, p. 112, pl. 9, fig. 8.
1850. *Scyphocrinites elegans* Zenker; Quenst., Handb. Petref., 621, pl. 55, figs. 1-3.
1852-54. *Scyphocrinus elegans* Zenker; Roemer in Bronn's Leth. Geog., ed. 3, vol. 1, pt. 2,
p. 255, pl. 4, figs. 5a, b.
1879. *Scyphocrinus elegans* Zenker; Zittel, Handb. Pal., vol. 1, p. 372.
1881. *Scyphocrinus elegans* Zenker; Wachs. and Spr., Proc. Acad. Nat. Sci. Phil., 298
(Rev. Pal., pt. 2, p. 124).
1900. *Scyphocrinus elegans* Zenker; Bather, Ann. and Mag. Nat. Hist., ser. 7, vol. 6, July,
p. 115.

(?) Syn. *Scyphocrinus excavatus* and varieties; Waagen and Jahn in
Barrande, 1899. Système Silur. du centre Bohême, vol. 7, pt. 2, pp. 80-88.

After the most careful comparison with the prevalent Bohemian form, not only from the figures and descriptions of Waagen and Jahn, but with four good specimens of my own from Bohemia, I am unable to point out a single diagnostic character by which the Cape Girardeau specimens can be distinguished from it. In the general elongate form of the calyx (which does not appear so constantly in Waagen and Jahn's figures on account of the flattening of many of the specimens), the extraordinary shortness of the brachials beyond the secundibrachs, and the sharp sculpture of the lower plates, they are identical; while substantially every one of the styles of the interbrachial pavement upon which those authors base their three varieties of *S. excavatus* is to be found among the specimens in this collection. The parallelism in this respect is most extraordinary, as may be seen by a comparison of the figures here given with the preceding description of those structures, and with the figures of Waagen and Jahn on plates 40 to 60 of their Monograph.

The calyx is quite uniformly large and elongate, being usually from 112 to 125 mm. high, measuring from the base to the fork of the second bifurcation of the ray, and about 92 mm. in width at the level of about the fifth secundibrach, where the radial ridge leading to the arms usually begins to be prominent. Among more than 50 crowns in this collection I have not found any with calyx shorter than the smaller dimensions above stated; but there are several broken, or but partially exposed, which, from the relative size of the stem or lower plates, must have been somewhat larger. The specimens are usually considerably flattened, but several are sufficiently rotund to admit of accurate measurement; these have been utilized in constructing the restored figure on Plate IV,

figure 1, which gives the correct contour and proportions of a full-sized individual if undistorted by pressure. The magnificent crown shown by the photograph (Pl. III, fig. 1), reduced to two-thirds natural size in order to come within the limits of the plate, has the calyx almost rotund, and its surface ornament in perfect condition. Plate II shows two fine crowns with stems attached, natural size, exhibiting almost every one of the different varieties of plate sculpturing.

The surface of the plates to the level of the upper primibrachs, which are all low-convex and thin, is conspicuously marked by sharp, rather low ridges or costæ, radiating in parallel sets of five or six from plate to plate, crossing each sutural face at right angles, forming triangular or rhombic striated areas (Pl. V, fig. 1). Above this the costæ progressively coalesce through various stages to a single narrow ridge, or until they become merely a broad convex band; or they may sometimes disappear altogether. Between these parallel sets, or single ridges—that is, at the angles of the plates—there are depressed areas, or pits, which increase in depth and size concurrently with the coalescence of the costæ. These various stages of the ridges and pits produce in the interbrachial areas a stellate, reticulate, corrugated, banded, or smooth surface—sometimes two or more of these kinds of sculpturing appearing in the same specimen. If the pits enlarge about equally, and the single coalesced ridge remains narrow, the plates will have a more or less stelliform appearance (Pl. III, figs. 1 and 3); if the ridges become about equally broad, a network is produced (Pl. III, fig. 4); if the pits at the upper and lower angles are most enlarged, while the ridges develop chiefly in a transverse direction, the result will be a series of conspicuous, downwardly curved, rope-like bands traversing the space between the rays (Pl. II, figs. 1 and 2). The condition of wear at the surface of the plates during fossilization, or perhaps in life, sometimes exposing subsurface channels, has often much to do with the appearance of the sculpturing. Occasionally the sharp costæ on the lower plates tend to become interrupted, leading to rows of fine granular pustules, on which Waagen and Jahn based their species *S. decoratus*.

The number of secundibrachs is about 18 to 20, with little variation, being more regular here than it appears in the figures of Waagen and Jahn, which show variations of 15 to 25, some of them perhaps due to inaccurate observation or drawing. In this character the species differs from all the Tennessee species, which rarely have more than 15 secundibrachs. The lower secundibrachs are of about equal width and length; they diminish in length until those next to the axillary are about five or six times as wide as long, average length at this level being about 1 mm. From about the sixth or seventh secundibrach they gradually become wedge-form, the wider margin supporting a pinnule which also abuts more or less on the short margin of the alternate brachial;

as these plates become shorter the interpinnulars disappear, and the pinnules abut for their entire length (Pl. IV, fig. 1). The tertibrachs become shorter still (about 0.7 mm.), until the thinner margins are knife-like, and there is no interval between the brachials at their wider sides (Pl. IV, fig. 4). Toward the distal end of the arms the brachials become relatively longer, so that the pinnules are slightly separated (Pl. IV, fig. 10). The distal secundibrachs with which the fixed arms begin, and the succeeding brachials, may be simply convex exteriorly—the most usual case—or they may have a more or less raised transverse girdle, sometimes beaded. Laterally, the brachials often have small, buttress-like projections, which sometimes ramify into the interbrachial network, in which the base of the arms entirely disappears, as if ending in branching roots.

The arms are very strong at their bases, tapering gradually to great lengths. They are observed in several specimens for a distance of 300 mm. without reaching the ends; calculating from the taper of the ultimate divisions, and comparing this with the detached distal portions seen occasionally among the specimens, it is clear that the arms were often at least 15 to 20 inches long. They bifurcate at increasing intervals (longest at the inside of the dichotom) three or four times, and frequently one of the last pair once again, thus giving from 80 to 120 ultimate arms. The brachials from the tertibrachs up are exceedingly short and wide throughout; their extreme shortness is a very conspicuous feature, probably characteristic of the genus. The arms are highly rounded dorsally, and have a broad, shallow, ventral furrow, which becomes more deeply notched distally; the cross-section is more or less crescentic; from the truncated horns of the crescent proceed relatively large, closely abutting pinnulars. The form and relative proportions of these plates in the different divisions of an arm are shown by the series of figures on Plate IV.

There is so little difference between the anal interradius and the regular areas that it is scarcely noticeable; one more plate in the second or third, and in the fourth anal range is all that differentiates them.

The interbrachial pavement.—The most interesting morphological feature of this species is the peculiar interbrachial network, or pavement, connecting the lower portions of the arms, upon the different aspects of which Messrs. Waagen and Jahn founded three of their varieties under the name *excavatus*. They have described and figured its various forms in great detail (op. cit., pp. 63-88, pls. 43-55). These forms are all found to be substantially repeated in the Cape Girardeau specimens, among which the interbrachial areas are either (1) smooth (Pl. III, fig. 2); (2) studded with more or less stelliform plates (Pl. III, fig. 3); (3) reticulate, with round or rhombic pits (Pl. III, fig. 4); (4) transversely banded with rounded plates in parallel, crescentic, rope-like rows, arching downward as if suspended from the arms (Pl. II, and Pl. III, fig. 4).

Waagen and Jahn only recognized interbrachials *sensu str.* (interradials) up to the fourth range, of which they describe the succession as being 1-2-3-3 usually in the regular areas, and 1-2 (or 3)-4-4 usually in the anal interradius. Beyond that they found the plates to be so small, their sculpture so strong, and their arrangement so irregular, that their contours could not be distinguished (pp. 69-70). They viewed this part, constituting the *pavage* and the *réseau*, as a structure *sui generis*, and they wholly failed to understand its origin or relations. Bather, with his usual clear insight, perceived the probable significance of this structure, and in the review above cited (p. 116) pointed the way to its correct interpretation, although the material at his command did not furnish him the complete solution which is now at hand.

The superficial aspect of these areas is certainly extremely deceptive, the actual arrangement of the plates being often wholly obscured by the very conspicuous rugose surface growth. This is especially the case with that type which takes the form of transverse bands of strongly elevated plates (for example, var. *schlotheimi* W. and J., pl. 44, fig. 1; and herein Pl. II, fig. 1; Pl. III, fig. 4), which while seeming to pass out from the sides of the arms in regular rows do so in a manner altogether misleading and wholly unlike that of any kind of branches or elements ordinarily connected with arms—curving downward instead of up, and being continuous, like ropes suspended from one arm to another. Nevertheless, the chief component parts of these areas are modified pinnules, which by the upward growth of the calyx have become fixed as a part of its solid wall, and thus have lost their original function.

The complete structure and relations of these parts are perfectly shown by the natural size figure 1 on Plate IV, drawn with great care by Mr. Chapman chiefly from specimens *A*, *B*, *C*, of Plate I, and from the original of figure 1 of Plate V. There is a well-marked transition from the finely costate sculpture in the lower plates, through strongly stelliform plates in the intermediate region (lower IIBr), to the strong, rope-like bands above. In this figure, for better comparison, the plates of the pavement in one-half of an interbrachial and intersecundibrachial area are left in outline, with the interpinnulars distinguished by diagonal hatching; so that the position and relations of the pinnules may be seen at a glance. When the arrangement is once understood it may be readily traced in many specimens; in some, however, the plates have been so greatly altered by secondary growth that it is very difficult to identify the pinnules. We have carefully traced the pinnules in a number of specimens, and find that their relation as shown by these figures is constant and without exception, save for an occasional abnormal plate. They are well shown in specimens of *S. pyburnensis* (for example, Pl. VII, fig. 2b).

The extraordinary modification of the surface by which the outward semblance of pinnules is thus effaced is produced simply by the development of

the connecting ridges crossing the sutures from plate to plate, and of the sunken areas at the angles, forming pits or rhombs between them, as already explained (Pl. IV, fig. 3). Owing to fixation and loss of function, the shape of the pinnulars is more or less modified and often irregular, which adds to the difficulty of identifying them. In some cases, the reticulate or banded surface commences abruptly; in others, the sculpturing passes from the finely costate marking of the lower calyx plates through an intermediate stage of stelliform plates. This is sometimes much accentuated by erosion of the plates sufficient to expose strong radiating channels in the substance of the plates crossing the sutures (Pl. III, fig. 3; Pl. IV, fig. 2; Pl. VIII, figs. 2a, b).

Inspection of figure 1 of Plate IV shows that while the relation of the fixed pinnules to the tertibrachs as stated by Bather is confirmed, there is a further definite relation, not only with the distal secundibrachs, which he found it not so easy to trace, but also with the lower secundibrachs, as to which he thought it probable that the plates uniting them are true interbrachials. As to all these it now appears that there is a fixed rule in the position and sequence of the pinnules.

The sequence of pinnules.—The number of secundibrachs in these specimens, as already stated, is quite uniformly about 18 to 20. They begin with fairly large plates, resembling the primibrachs which precede them, with a gradually increasing rugosity of sculpturing in the first five, beyond which the surface is usually plain; there is also a gradual diminution in size, and a change in proportions from about equal length and width in the lowest ones, to that of extremely short and wide plates above. At about the fifth plate an increasing convexity begins, marking the origin of a strong median elevation which passes rapidly into the arms. At this point there is always a plainly noticeable change of direction, or "jog," in the brachials of each ramus toward the outside of the dichotom (Pl. V, fig. 1). Above this the plates rapidly become shorter and wider, changing from a proportion of about 1:1.6 to about 1:12 next to the axillary; and they gradually become cuneiform and alternating. This "jog" is a reliable guide in counting the number of secundibrachs in imperfect specimens; we know that there are always four or five plates in the series below it. For example, in Plate VI, figure 5d, with only a small fragment of the ray preserved, we can tell that there were about 16 secundibrachs.

The IIBr₂ gives off a strong pinnule toward the outer side of the dichotom, composed of elongate, more or less hexagonal plates extending to the distal margin of the calyx; IIBr₄ gives off a similar pinnule to the inside of the dichotom; IIBr₅ another to the outside. And from the fifth plate on, alternating from side to side, each brachial bears a pinnule upon its wider end, which may also abut upon the narrow end of the alternate brachial. The first three to seven pinnules are more or less separated at their bases by interpinnu-

lars diminishing in size and numbers upward; but their more distal parts, and the whole length of those succeeding them, lie side by side, closely packed, forming part of the calyx wall, until they gradually lose themselves in the tegmen. This fixation of pinnules extends throughout the tertibrachs to the quartibrachs, passing gradually into a free state, the exact limit of which cannot be seen for lack of sufficient preservation of the tegmen. All these pinnules are laterally united by what is probably a loose suture, and the plates composing them, as high up as the distal tertibrachs, are very thick and flat, forming by their union a strong wall. The proximal pinnular is joined to the brachial which supports it, and the following pinnulars to each other by a curved, non-muscular articulation, the remnant of the movable union lost by fixation.

The free pinnules continue thus alternately, one from each wider end of the brachials to the end of the arms; they are relatively short, as is the rule generally in multibrachiate arms, rounded, composed of a few elongate pinnulars; and they lie closely abutting, because of the extreme shortness of the brachials; distally they become rounded, less closely abutting, and functioning normally. The relation of these parts is shown on Plate IV by the enlarged drawings at figures 4 to 10, with further explanatory text.

Thus the law of succession of the pinnules on the secundibrachs is: $2(1+2)$ outer — $4(3+4)$ inner — 5 outer — 6 inner — 7 outer; and so on. It may be expressed by the numeral 24567+.

This arrangement appears in several of the other species, and is substantially the same as in Melocrinidae, generally where it can be observed. It is finely shown in the specimen of *Glyptocrinus dyeri* figured in my paper on *Cleioocrinus*, which I reproduce for comparison (Pl. III, figs. 5a, b). The succession of pinnules is the same, 2-4-5-6-7, etc., and their course is much more plainly defined by the sharp longitudinal ridges. In this specimen the tegmen, although distorted at one side by an imbedded stem-fragment, is well preserved, and shows how the fixed pinnules merge into the finely plated perisome, which passes into the tegmen so gradually that it is impossible to distinguish a boundary at which the pinnules should become free. In a similar manner the ridge-like series of anal plates is seen bending over, probably to a small central opening. The same plan of tegmen structure no doubt existed in *Scyphocrinus*, in which this part has not yet been found intact.

The sequence above described is also precisely the same as that of the fixed pinnules in *Uintacrinus*, except that in the latter the plates 6 and 7 form a syzygial pair, the pinnule being borne only on the hypozygal there as well as in the higher parts of the arm. In *Scyphocrinus* there are no syzygies, although it is possible that in the primitive form of these crinoids, in the intermediate stage without interbrachial structures and with free arms beginning

with the secundibrachs, the first four brachials were syzygial pairs. Or it may be considered that the first two pairs of secundibrachs were simply repetitions of the primibrachs, with the second plate of each pair an axillary, analogous to what is seen in the divisional series of Recent crinoids, as pointed out by Mr. Austin H. Clark in his luminous paper on the Homologies of the Arm-joints and Arm-divisions in the Recent Crinoids.¹

The tegmen.—This is not shown in any of our specimens, but it is certainly composed of numerous undifferentiated plates with the anal opening directly through it; and is doubtless substantially the same as that of *Glyptocrinus*, as shown by figure 5b of Plate III. It must extend quite high along the rays, doubtless to the quartibrachs, and these upper extensions may be composed almost entirely of the consolidated pinnules. Several specimens show where the interbrachial pavement begins to curve rapidly to the tegmen, and at this level the pavement is composed exclusively of fixed pinnules (Pl. IV, fig. 1). Messrs. Waagen and Jahn say that the tegmen (*voûte*) is unknown in the genus, but they direct attention to certain *voûtes isolees*, figured on their plates 49 and 64, of which they have not been able to find the calyx corresponding. I have no doubt that these belong to some of their varieties of the genus, and they clearly show the tegmen to be of the structure above indicated.

The stem.—The full length of the stem is not certainly known, but it was at least 3 feet (90 cm.). Among the Bohemian specimens described by Waagen and Jahn it was rare to find any part of the stem attached, but Professor Jahn in a letter to Mr. Schuchert quoted by him (op. cit., p. 259) states that he has "observed at Kuchelbad on the exposed surfaces of the strata *Loboliths* connected by long columns to *Scyphocrinus* calices." Schuchert (op. cit., p. 262) records having seen at the same locality near Kuchelbad, Bohemia, a poorly preserved theca of *Scyphocrinus* with a "long column probably not less than 3 feet in length, extending toward and terminating upon a *Camarocrinus*." This evidence seemed to him at the time so convincing as to remove all doubt of "*Scyphocrinus* and *Camarocrinus* belonging to one species." But a further study of the stem characters led him to revise this opinion as follows: "The writer observed that the long column of *Scyphocrinus* lying across the *Camarocrinus* was at least twice as thick as any column of the latter he had seen. Since then he has determined that the central canal in the column of *Camarocrinus* is different in shape and very much smaller in size than in the associated *Scyphocrinus* columns." These differences he illustrated by text-figure 42, showing transverse sections through the stalk of *Scyphocrinus elegans* near the theca, and a thick stalk of *Camarocrinus ulrichi* near the roots; the latter is about half the diameter of the former, and has a small, sharply stellate, axial canal, contrasted with a large quinquelobate canal

¹ Proc. U. S. National Museum, vol. 35, pp. 113-131, 1908.

in the former. And from these facts he concluded finally: "It therefore does not appear that the two parts can belong to one animal."

The material now at hand, while not furnishing any complete stem, gives a thorough exposition of its characters, and enables me to remove the doubts as to the identity of the two organisms caused by Schuchert's observations above cited.

As a matter of fact, the stem of *Scyphocrinus*—at least of the present species—tapers gradually from the calyx until its diameter is reduced to about one-half at the distal end; and it has, moreover, a form of axial canal which is perfectly consistent with the differences in this respect observed by Mr. Schuchert. The largest stems are about 10 (occasionally 12) mm. in diameter next to the calyx. The longest portion that can be traced directly from a calyx and measured is 16 inches (40 cm.), and at this distance it has diminished in diameter to 8 mm. Beyond this the dimensions cannot be traced continuously, but there are many equally long detached parts of stems belonging farther down in which the same taper is observed. Concurrently with this decrease in diameter there is a similarly gradual increase in length of the stem ossicles, or columnals. Proximal to the calyx where the stem is 10 mm. thick the columnals are very short—several specimens showing an average of 0.7 mm.; and at the distance of 40 cm., with diameter reduced to 8 mm., they have lengthened to about 1.1 mm. A detached portion of stem about 45 cm. long changes from 8 mm. in diameter with columnals 1 mm. long at the larger end to 7 mm. diameter with columnals 1.2 mm. long at the smaller; this indicates an intermediate position in the stem, where the taper is less than above. Another of about the same length tapers from 7.5 mm. in diameter with columnals 1 mm. long to 6.5 mm. diameter with columnals 1.6 mm. long—representing a more distal section. Shorter portions of stems are found with still less diameter, in some of which the columnals have increased to 2 mm. in length for a diameter of 6 mm. If this were near the distal end of an average mature specimen—as is possible for reasons appearing later—it would indicate a length of about 3 feet, estimating from the decrease in diameter, and somewhat more if calculated by the increase in length of columnals. Judging, however, from the appearance of the longest stem seen in this material, which is attached to a very large calyx but not in condition for accurate measurement, the total length in mature specimens must have been considerably more than this.

Together with these external characters must be considered that of the axial canal; it is very large, obtusely pentagonal in the upper part of the stem, often appearing to occupy two-thirds of its diameter; and it diminishes more or less (not always regularly) to a sharply stellate opening distally. This canal may be described as composed of a series of circular, bi-concave chambers, or

lenses, separated by a thin partition, or diaphragm, which is pierced by the pentapetalous or stellate canal. To form these lenses each columnal is usually excavated on both faces (the ligament fossæ), leaving an outer band of the joint-face flat (the contact area), across which the radiating crenulæ pass into the depression toward the center; the apposed concave portions of the joint-faces enclose the round lenticular chambers, resembling successive enlargements of the canal, which retains its smaller, pentagonal, or stellate form only within the thin partition in the middle portion of the columnals (Pl. V, figs. 2-5). In the upper part, where the columnals are extremely short, these chambers are very wide, leaving only a narrow peripheral band of the full thickness, and the canal through the partitions is also large; the partitions are very thin in these parts, so that when the side of the stem is broken away for a considerable distance it looks as if there were a continuous canal filled with matrix, almost the width of the stem (Pl. V, figs. 2a, b, c). It is not improbable that in these portions the partitions were so thin (perhaps membranous) that their central diaphragms were destroyed during fossilization, or are indistinguishable from the matrix. Toward the distal end the concave excavated part becomes gradually smaller, or may disappear, and the canal through the partitions is more sharply stellate (Pl. V, figs. 4a, b, 5). In some intermediate portions the chambers are sometimes as narrow as they appear at the distal part; and in some cases also the chambers appear relatively large in fragments apparently distal. There is doubtless some variation in this respect, and in some parts of the stems the chambers are absent in a number of consecutive columnals; but the general rule is undoubtedly as above stated. These structures are fully shown by the series of figures on Plate V, above cited, made from specimens ground, or naturally eroded, which will explain the facts better than any description. Now it is evident that when the canal and its enlargements have by infiltration been replaced by firm matrix, if a cross fracture in the upper part occurs along the joint-face, the resulting section will show the canal large and round; if through the middle of the columnal, the canal will appear smaller, pentagonal, or stellate. Similar cross-sections toward the distal part will show a round or sharply stellate canal, according to the position of the fracture, the latter predominating. This will account for the different varieties of stem sections and isolated stem joints seen in various parts of the material.

There is a frequent tendency in stems with a large axial opening and branching or expanding root to become more and more modified toward the distal end; and also for the columnals, after having increased in length for most of the distance, to become shorter again at the end. This may be seen in stems of *Barycrinus*, *Anomalocrinus*, and other forms.

The bi-convex chambers in this stem are similar to those in the proximal part of the stem of *Apocrinus* (see de Loriol, Pal. Française, Crinoids, vol. 1, pl. 34, fig. 3).

Among the numerous *restes indeterminés* figured by Waagen and Jahn the various stem characters above described are shown in profusion.

The terminal bulbs (*Camarocrinus*) are large, but all much flattened; some of them in this condition are 13 cm. in diameter. Since for the reasons already explained the side exposed upon the slabs is the lower or non-stalked side as it rested in the sea bottom, and the stalked side is invariably buried in a mass of stems, arms, and pinnules, compressed into a limestone matrix, we do not in any case see the actual stem attachment. Some indications of the branching roots appear in a few places, but nowhere sufficiently well preserved for intelligent study. The bulbs are seen to be divided into compartments as usual, and were probably generally similar to those found elsewhere. But comparing specimens of *Camarocrinus* from other localities in which the stem attachment is well preserved, and which are associated in occurrence with the calices of *Scyphocrinus* in large numbers, it is now very interesting to note that the size of the stem and form of the axial canal at the distal end are precisely what we should expect to find in connection with the stem above described. In upwards of 75 specimens of *Camarocrinus* bulbs from Tennessee, ranging from minimum to maximum size, all preserving the stem attachment, I find that the stem at the distal end varies from 2 mm. diameter in the smallest to 9 mm. in the largest—in those of medium size being about 5 to 6 mm.; and in none of those of maximum size does the stem equal in diameter that of the proximal columnals in specimens of *S. prattensis* found in the same beds. In the *S. pyburnensis* locality the stem attachment of the largest *Camarocrinus* does not exceed 5 mm. in diameter, while that of average sized calices of that species is 9 mm. In all cases the canal is stellate and relatively small, like that of figure 6 of Plate V.

Types.—The specimen described by Zenker is in the University of Leipzig, and those by Waagen and Jahn are in the Bohemian Museum at Prague. The American specimens here figured are in the author's collection in the U. S. National Museum.

Horizon and locality.—In America, Helderbergian; Bailey limestone, perhaps equivalent to the New Scotland formation. A single imperfect specimen among the collections from Hardin County, Tennessee, may belong to this species. Otherwise its occurrence is limited to the Cape Girardeau, Missouri, region—although it is likely to be found in the same beds farther eastward, in Illinois, where the stems have been seen.

FURTHER REMARKS UPON THE FIXED PINNULES

The study of the fixed pinnules in *Scyphocrinus*, as described in the foregoing pages, led me to review the facts bearing upon analogous structures in other genera, with some curious results:

In 1878 Wachsmuth and Springer¹ called attention for the first time to certain openings in the test of crinoids located near the base of the arms "pierced through at the edge of the plate and enclosed by the abutting margin of an adjoining plate." Those then described were observed in *Eucladocrinus*, and it was stated that they are also found in *Batocrinus*, *Actinocrinus*, etc., and "within the false arms of *Ollacrinus*" (*Gilbertsocrinus*). It was suggested that they might have respiratory functions.

In the Revision of the Palaeocrinoidea, Part I (1879), p. 11, and Part II (1881), pp. 51-53, we discussed these openings at length, giving to them at the latter place for convenience the term "respiratory pores." After stating the possibility of their being respiratory or ovarian openings, we observed (p. 52): "There are objections to this, and another interpretation is at least possible. From what we now know of the ontogeny of the Palaeozoic crinoids, we are inclined to think that the pores may have been originally pinnules, which with progressing growth were soldered into the body." We suggested the desirability of tracing the pores in genera like *Glyptocrinus*, "in which the fixed pinnules retained their forms after they became fixed"; and we also referred to a possible analogy with the proximal pinnules in the Recent crinoids (p. 53).

In North American Crinoidea Camerata (1897), p. 35, we stated that the disk in many Camerata has "small respiratory pores or slits near the arm-bases, piercing the sides of the plates"; and on p. 122 we explained that "the openings are always located between the rays and their main divisions, a little above the arm regions," and that "in *Dolatocrinus* they are slit-like, in *Batocrinus* round, and in *Gilbertsocrinus* at the end of a long tube."

Bather, in Lankester's Zoology (1900), Part III, Echinodermata, p. 130, confirms the observations of Wachsmuth and Springer, giving one of our figures and one of his own (fig. 45) which show the form and position of the slits and pores in *Dolatocrinus* and *Batocrinus*; and he says that the supposition "as to the existence in Camerata of a complicated water-vascular system, is supported by the connection of the internal passages with small pores near the arm-bases," and that "the pores may possibly have replaced the hydropore or the madreporite of certain Inadunata."

Specimens acquired since the dates of the above-cited publications have thrown new light upon the nature of these structures, and enable us, I think,

¹ Proc. Acad. Nat. Sci., Philadelphia, vol. 30, p. 248.

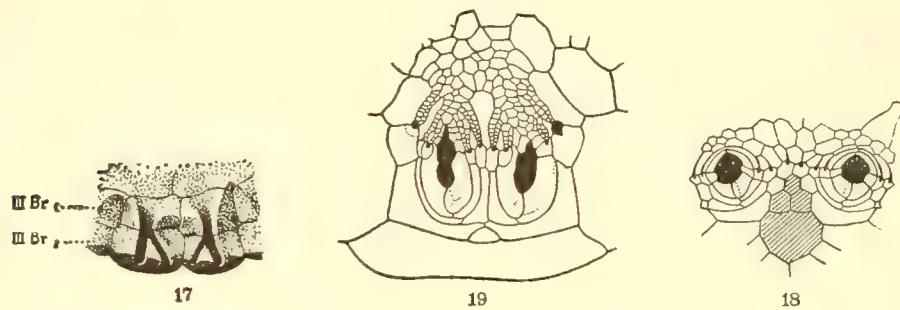
to definitely settle their relations. The descriptions of the openings given by Wachsmuth and Springer, already mentioned, are quite complete for the genera in which they had then been observed. The important points to remember are: that these openings are situated at the margin of the tegmen, in the brachial zone, where the dorsal and ventral walls meet; that they do not penetrate the plates, but lie at their angles or within the sutures; and that they stand in close relation to the arm-openings. Thus they have not the structure of madre pores. Taking *Batocrinus* as a normal example, it will be seen that the pores are small, enter the calyx wall obliquely at the side of the arm-openings by passages which connect directly with the food canals; in other words, the passages leading to the pores are branches of the food canals (see Rev. Pal., vol. 2, pl. 19, fig. 4; and N. A. Crin. Cam., pl. 27, fig. 3a). To better show the exact relation of the grooves leading from these openings to the food canals I give an enlarged transverse view of the calyx wall in *Batocrinus* at the level of the arm-openings (text-fig. 17); thus they branch from the food groove leading to the arms exactly as pinnule grooves would.

In *Dolatocrinus* the openings take the form of narrow slits, running ventrallywards from the dorsoventral margin where the main point of exit was located (N. A. Crin. Cam., pl. 25, figs. 6b, c, d; pl. 26, figs. 1a, 5b, 6a): here the number of openings is greatly increased, amounting to six or eight in *D. grandis* M. and G. (Bull. 4, Ill. St. Mus. Nat. Hist., pl. 2, figs. 2, 3). The appearance of the pores in *Eucladocrinus* and *Cactocrinus* respectively is shown in N. A. Crin. Cam., pl. 84, fig. 5; pl. 57, fig. 10; pl. 58, fig. 6.

Coming now to the new material, a very instructive case is found in the genus *Cyphocrinus* S. A. Miller (*Hyptiocrinus* W. and Sp.), one of the few crinoids in which the biserial arm structure extends down into the calyx wall—a fact which is seen only in very well-preserved specimens (text-fig. 18). The cuneiform secundibrachs give rise to a series of plates from each longer face which lead to elongate pores in the brachial zone, two pinnule ossicles being incorporated in the dorsal wall; and further incorporation of pinnules upon the tertibrachs occurs, producing as many as six pores to the interradius. The course of these series is similar to that of the fixed pinnules in *Glyptocrinus* as they would be in the early stages.

The decisive evidence, however, is found in the Silurian genus *Marsipocrinus*. On account of the silicified condition in which the specimens are usually found in the American localities, the presence of the interbrachial pores has not hitherto been noted; but some extremely fine specimens obtained in recent years from Tennessee not only show their existence in this genus, but demonstrate beyond the slightest doubt that these openings are in the sockets of pinnules originating below the bases of the free arms. The openings themselves are small, usually obscure, and there is nothing on the dorsal side to

indicate their position; but the branching ambulacra in the tegmen show it perfectly. These, corresponding in position to brachials either actual or potential on the dorsal side, have a main series of covering plates leading to the arm-openings, and from the sides of this smaller series branch off and lead to two or more pores at either side of the arm-bases. The branching ambulacra are well shown in Wachsmuth and Springer's figure of the tegmen of *Marsipocrinus radiatus* (see N. A. Crin. Cam., pl. 8, fig. 15), reproduced by Bather in Lankester's Zoology (p. 124, fig. 32). The exact relation of the smaller branches to the plates, and to the pores themselves, is better shown in text-figure 19, diagrammatized from one of the Tennessee specimens figured on Plate IX, figure 6. The first lateral branches and their pores are seen to belong to the secundibrachs, with one large pinnule ossicle incorporated, and are followed by those from the interlocking brachials of the arm. All that is needed further is to show the pinnules themselves which we now have per-



FIGS. 17-19

Fig. 17, *Batocrinus clypeatus*. Transverse section at arm-openings, plates separated at sutures; the passages from the so-called "respiratory pores" connecting with the food canals. $\times \frac{5}{2}$. 18, *Cyphocrinus gorbyi*. An interradius with adjacent arm-bases showing pores in plates corresponding in position to pinnule ossicles. $\times \frac{5}{2}$. 19, *Marsipocrinus striatus*(?). Diagram of one ray of specimen figured on Pl. IX, fig. 6, showing position of pinnule openings and ambulacra leading to them. $\times \frac{5}{2}$.

fectly preserved, both brachial and interbrachial, in the beautiful specimen of *M. tennesseensis* figured on Plate IX, figures 5a, b.

An excellent example of secundibrach pinnules is seen in *Platycrinus huntsvilleæ*, where they are often very conspicuous, and stand out distinctly larger than those upon the arms (they are well shown in N. A. Crin. Cam., pl. 73, figs. 7b and 9). In this species, as well as in the *Marsipocrinus*, it is the first secundibrach which bears the pinnule, these being forms in which the primibrach series is reduced to a single plate—the axillary.

In the foregoing text-figures 17-19 are shown various stages of development in the incorporation of pinnules, and also the different methods by which their ambulacra empty into the main ambulacra:

The first stage is that in which an arm ossicle is incorporated in the dorsal cup without incorporation of its pinnule (*Batocrinus*, fig. 17). In this

stage the ossicle still shows its axillary character, and the ambulacrum of the pinnule empties into the main ambulacrum within the ossicle.

In the second stage incorporation of the pinnulate arm ossicles is accompanied by incorporation of one (*Marsipocrinus*, fig. 19) or more (*Cyphocrinus*, fig. 18) pinnule ossicles. Various changes are here necessitated in the position of pinnule ambulacra in reference to their respective arm ossicles, as the upward shifting of the mouth has caused a separation of the ambulacra from the plates with which they were formerly in contact. Thus in *Marsipocrinus* and *Cyphocrinus* the ambulacra on the incorporated pinnules of the first and second IIIBr pass directly into the main ambulacra (note position of ambulacral covering plates in *Marsipocrinus*), without grooving the arm ossicles from which the pinnules are given off.

The third stage is that illustrated in *Glyptocrinus* and *Scyphocrinus*, in which the lowest pinnules are almost completely incorporated in the cup.

In the first and second stages the openings of the pinnule ambulacra into the cup are clearly defined; in the third stage, however, the opening is lost, as the ambulacra have probably atrophied, or the pinnules become so merged in the finely plated perisome passing into the tegmen that their openings cannot be discovered.

From all these facts it is clearly evident that the openings in question in Camerate crinoids represent the pinnules which developed immediately following the first division of the ray in the young crinoid, and became afterwards more or less incorporated by the growth of the calyx. They are comparable to the proximal pinnules in the Comatulids, which differ in many notable respects from those which succeed them. Mr. Austin H. Clark, to whom I applied for detailed information, has been kind enough to furnish me a note embodying numerous examples of this fact, which with his permission I am here inserting:

Among the Comatulids the pinnules of the first pair, usually also those of the second, frequently those of the third, and sometimes those of the fourth and fifth, are different in structure and function from those succeeding. They are invariably sterile and without ambulacral groove or tentacular apparatus, and are so modified that, instead of serving as food collectors like the distal pinnules, or as sexual organs and usually also as food collectors like the middle (genital) pinnules, they function as highly sensitive tactile organs, or as spine-like organs of defense.

In certain genera, distributed in widely different groups (for example, in *Antedon*, *Florometra*, *Pontimetra*, and *Pentametrocrinus*), the oral pinnules, composed of numerous very short segments, are greatly elongated and of extraordinary flexibility, calling to mind the antennæ of certain crustaceans. In these genera they appear to serve simply as tactile organs.

In one family (Comasteridae) the outer segments of these tactile pinnules bear long triangular processes which collectively form a prominent comb-like structure: the function of this is not clearly understood; it may serve as a cleaning apparatus, or merely to increase the intricacy and sensitiveness of the entanglement over the disk.

In a few species (mostly in the genera *Stephanometra*, *Colobometra*, and *Oxymetra*) the pinnules of the first two or three pairs are stout, extremely stiff and spine-like, sharp pointed, composed of very few elongated segments, and project diagonally outward over the disk which is thus protected by a mass of sharp thorns.¹

Usually, however, the protective function is confined to the pinnules of the second and one or two following pairs, the pinnules of the first pair remaining many-jointed, delicate and flagellate, tactile organs.

In most of the genera of the *Thlassometridæ* (as in *Thalassometra*) and in certain species of *Himerometra*, the pinnules of the first pair are very stout for most of their length, but end in a delicate flagellate tip, thus combining both tactile and protective functions in the same organ.

In the Comatulids whenever the division series consist of four segments, the second always bears a pinnule; whenever they consist of three segments (the palmar and subsequent division series in *Capillaster* and *Nemaster*), the first bears a pinnule. The pinnules borne on the division series always are of the same character as the first pinnule of the undivided arm, but with its distinctive features accentuated; thus if the first arm pinnule is larger and stouter than the second, the palmar pinnules will be in turn slightly larger and stouter than the first pinnule, and the distichal pinnules slightly larger and stouter than the palmar; if the first arm pinnule is smaller and weaker than the second, the palmar pinnules will be still smaller and weaker, and the distichal pinnules smaller and weaker than the palmar.

As the surface of the disk ordinarily reaches the level of the second brachial, it naturally follows that before becoming free the pinnules of the division series must run along over the dorsal perisome for some distance; but owing to the deep interradial incision of the disk in most multibrachiate forms this means little more than that these pinnules run diagonally upward to and beyond the edge of a much thickened brachial perisome.

In a few multibrachiate types (as in *Comaster belli* and *Comanthina schlegelii*) the disk is approximately circular, with the bases of the distichal and palmar pinnules incorporated in the dorsal perisome. This dorsal perisome may become heavily plated, in which event the pinnule bases become invariably fixed in a pavement of very irregular polygonal plates from which, however, the pinnulars are always readily distinguishable because of their height, strong convexity, and regularity in size and shape; in other words, in recent types the fundamental character of the pinnule as a free organ is never in the slightest degree masked by incorporation in the perisomic wall.

It will be observed that the condition described in the last paragraph of Mr. Clark's note is substantially the same as that of the fixed pinnules in the various fossil genera mentioned above, except for the greater tendency of the pinnules in fossil forms to merge in the perisome.

From the various examples thus given of the form and function of the proximal pinnules, it is seen that these organs frequently undergo a course of development wholly different from those succeeding them at regular intervals along the arms; and it is to this tendency to unequal growth that we must look for an explanation of the extraordinary condition found in *Gilbertsocrinus*. Most authors who have mentioned them have treated the tubular extensions in this genus as analogous to the interbrachial pores in *Batocrinus* and other

¹ See Hartlaub (Comatuliden des Indischen Archipels), Nova Acta Ksl. Leop.-Carol. Deutsch. Akad. Naturforscher, Band 58, Taf. 3, fig. 29, 1891.

genera, and as performing the same function; but it is certainly a long road from a pinnule, usually regarded as a miniature arm, to such ponderous structures as the interradially located tubes of a form like *Gilbertocrinus typus* (N. A. Crin. Cam., pl. 14, fig. 1), built up of circular segments like a stem. Nevertheless, their common origin is clear.

In their earliest stages (Devonian and the base of the Lower Carboniferous) the tubes were short (*G. spinigerus*, *G. stellaris*, and *G. fiscellus* (N. A. Crin. Cam., pl. 15, figs. 3b, e, and 4; pl. 17, fig. 2a). In *G. stellaris* (deKoninck and Lehon) we have a *Rhodocrinus* with the pores next to the arm-bases extended into small tubes, of probably very few segments, without any ventral groove; they are at the interradial sides of the ray. In other European species of Lower Carboniferous age—for example, *G. calcaratus* Phill. (N. A. Crin. Cam., pl. 15, fig. 5)—the tubes have become large, but are still separate and radially located. In the upper Burlington limestone (N. A. Crin. Cam., pl. 14, fig. 1) the tubes attained a size which dwarfs all the other parts of the crinoid, being more than twice as long as the extreme length of the calyx, and as thick as the stem. Those from adjacent rays unite above the interradius, coalesce by zigzag sutures for a distance of six or eight plates, beyond which they separate and taper gradually to a point. Thus while of radial origin, the tube where doubled is interradial in position. Each tube is perforated throughout by a central canal, and not only is it composed of circular undivided segments like the ossicles of a column, but the joint-faces are often somewhat striated like those of stems—there being no semblance of the articulation belonging to arms or pinnules, nor of any ventral groove. The construction, therefore, is that of a stem appendage rather than of an arm appendage.

In the Keokuk limestone another curious change occurs (N. A. Crin. Cam., pl. 16, figs. 1-6). The tubes from adjacent rays coalesce interradially as before for a short distance and then separate; but instead of being composed of undivided segments like a stem, they take on the construction of an arm or pinnule, so that there is one plate (brachial) dorsally and two large plates at the ventral side which interlock like covering plates. Of course, where the tubes are joined the number of these elements appears doubled. The tubes are longitudinally perforated by a fair-sized channel, but there is no ventral groove. This change marks the end of the genus; and this type of extreme aberrant growth of pore or pinnule is seen no more among the crinoids.

It is evident that this extraordinary development from a pinnule having a tendency to irregular growth must be interpreted as a pure case of hypertrophy in which the original character of the organ was wholly lost, followed by an effort at recovery in the expiring struggles of the genus. And it is now most interesting that a condition comparable to this, and which gives a clue to the strange tendencies which might give direction to the impulse of hyper-

tropy toward such a singular result, is to be found among the Recent crinoids. In *Comatulella brachiolata* (Lamarck), the delicate, regular pinnules alternate with others which are much stouter, without any ventral grooves and wholly unconnected with the ambulacral groove of the arm; they are composed of circular segments which are solid except for a minute central perforation. Mr. Austin H. Clark has figured a specimen of this rare species in *Ergebnisse der Hamburger sudwest-australischen Forschungsreise* (Supplement, 1913, pl. 4, figs. 1, 2); and in the Records of the Western Australian Museum (vol. 1, 1915, p. 117) he has given a full description based upon another fine specimen not yet figured. Speaking of the ungrooved pinnules he says (p. 118):

At first they lie horizontally, but in the distal half or third they curve dorsally into the form of a hook or spiral, exactly as do the cirri, forming tendril-like attachments all along the arm whereby the animal fixes each arm securely to the organisms on the sea floor in addition to fixing its central portion by means of its cirri. [And he adds on p. 119] It is most instructive to see that in this specimen the ungrooved pinnules have approached so closely to the cirri in structure that they have taken upon themselves the performance of exactly the same functions.

In like manner the tubes of such a form as *Gilbertocrinus typus*, while occupying the position of proximal pinnules, may be considered as representing enormously enlarged cirri.

While, therefore, the suggestion of Wachsmuth and Springer as to the probable derivation of the so-called "respiratory pores" from pinnules is confirmed, it is also true that these pinnules may have possessed respiratory functions, since the proximal pinnules in many Recent crinoids are shown to be lacking the usual functions of pinnules.

2. SCYPHOCRINUS SPINIFER n. sp.

Plate IX, figs. 1a-c

Calyx narrowly elongate, widest about arm-bases; height to width about as 4:3. Plates sharply sculptured, with conspicuous ridges traversing the plates continuously from center to center, diminishing in number from five at the base to one at the first axillary; these meet at the centers of the plates in small elevations surmounted by long spines which frequently fork. Radial series slightly elevated; median ridge of secundibrachs sharp and narrow. Secundibrachs 12 or 13.

Height of the only specimen, 40 mm.; width about level of arm-bases, 30 mm. Length of spines, 5 to 7 mm.; thickness at base, about 1 mm.

The remarkable character of this species is the spines which are entirely different from the small pustulose elevations seen on specimens of *S. pratteni*; they are relatively long, and slender at the base, many of them enlarging distally and often forking, while others taper to a point. They occur on the radial series to about the fourth secundibrach, and upon the interbrachials

(and possibly pinnulars and interpinnulars) to the height of the arm-bases; thus the interbrachial spaces appear thickly studded with the spines, which diminish in size upward. There is a certain uniformity of direction in which numbers of adjacent spines lie in clusters which leads to the conclusion that they were articulated; this is confirmed by the appearance of the small, elevated centers of the plates, which look like sockets, and by the proportions of the spines themselves. The usual fixed spines, developed from pustulose growths upon the plates, are broadest at the base, from which they taper conically; whereas these are narrow at the base, cylindrical for the greater part of their length, after which many of them expand or branch.

The species is represented by a single specimen in a remarkably good condition, all the structures being sharply preserved. In the part originally exposed only a few of the smaller spines were visible in the upper interbrachial region (Pl. IX, fig. 1a). But careful cleaning from the rather hard matrix brought to view not only the fringe of long spines lying parallel in clusters at either border of the same side, but also a good part of the opposite side of the specimen, on which a forest of spines lie in place to the level of the upper secundibrachs (Pl. IX, fig. 1b). On this side also the sharp sculpturing of the lower calyx plates is beautifully shown.

The presence of articulated spines in this isolated species of so prolific a genus is a most remarkable occurrence, suggesting comparison with the other Devonian form, *Arthracantha*, in which the character seems to be constant for all the species. The branching or distal enlargement in our species is, however, a development for which no parallel is thus far known among the crinoids. In view of the fragile nature of these structures, and the impediments to their preservation in the fossils, it is quite possible that some of the other species may have possessed similar spines; for example, *S. stellatus*, and the species represented by the fragments from Benton County, Tennessee (figured on Pl. VI), in which the sculpturing is very similar.

Type.—The holotype is in the author's collection.

Horizon and locality.—Helderbergian; Ross limestone of the Linden formation, Hardin County, Tennessee.

3. *SCYPHOCRINUS MUTABILIS* n. sp.

Plates VI, figs. 3-19; VIII, figs. 3, 4, 5

A variable species of the *elegans* group, with strong surface sculpture. Calyx of medium size, usually wider than high, but sometimes slightly elongate; lower part of cup broadly expanding, with sides usually convex, rarely about straight, or slightly concave near the base. Secundibrachs 12 to 15, the upper seven or eight very short and wide; median ridge varying from medium size

to rather broad, in some cases appearing to ramify downward. Interbrachials not protuberant. Plates low-convex, with crenulate margins, and radiating ridges changing from fine to coarse upward, but with pits at the corners almost everywhere sharp and specially conspicuous; those of the interbrachial pavement often greatly modified by the sculpturing into strong bands, irregular network, and stellate figures, in which the fixed pinnules can rarely be traced.

Dimensions of specimens as usually found: Height to axillary IIBr, 40 to 60 mm.; width at upper level, about the same; an average well-preserved, rotund specimen, slightly elongate in appearance, is 60 by 55 mm.

I have proposed this species to receive a rather variable form which is found in the Linden formation at several localities in Benton, Perry, and Hardin counties, Tennessee. Only in the latter region have I been able to obtain good specimens, but it must have been an abundant and well-distinguished species, to judge from the many fragments that have been seen in the other regions mentioned. It is distinguished from *S. elegans* by the less elongate form and fewer secundibrachs, and of course from its associated species of the *prattensi* type by the general form. *S. stellatus*, if we knew it from better specimens, might be found to include these forms. The pits at the corners of the plates seem to be the most constantly conspicuous feature in the sculpturing. In some specimens little else is seen; in some the surface is dotted more or less thickly with small knobs apparently formed by inorganic silicious deposit. Chemical action has often greatly altered the superficial appearance, producing a semblance of sculpture quite different from the normal. In some cases the knobs lie chiefly upon the suture lines, exaggerating the connecting ridges to such an extent that the plates appear to be surrounded by them. In some the striæ and crenulate margins are feebly shown; while in others they are strong and sharp, coalescing upward as usual. Erosion has sometimes made the plates appear smooth and almost flat, especially in the lower parts. In some specimens the ridge of secundibrachs is very wide, and in others rather narrow; in some the basal part of the calyx is rather narrowly conical, and in others somewhat obtusely and irregularly curved; rarely small median spines are seen. Upon some of these differences my inclination was at first to propose other species, but there is nothing constant about them. In the interbrachial pavement most of the types common to *S. elegans* are found among these forms.

The species is rather widely distributed; in Hardin County, where the best specimens were obtained, it is found chiefly in limestone layers at both the Pyburn and Horse Creek localities, more or less irregularly throughout the *pyburnensis* and *prattensi* beds. Occasional imperfect calices occur in Perry County in the Decatur and Linden horizons, while in Benton County it is numerously represented by weathered fragments from the large colony already

mentioned filled with the remains of calices and bulbous roots, all broken into small pieces. Many of these have the surface structures, both external and internal, beautifully preserved, and I have figured several of them on Plate VI, for various details. They show, among other things, pits resembling folds upon the sutural edges of the plates in a dorsoventral direction, already described; and also radiating striæ upon the inner surface of the plates.

Types.—Author's collection. The specimens figured on Plate VIII are considered the types rather than those on Plate VI, the figures of which were drawn from imperfect specimens and printed before the later material was obtained.

Horizon and locality.—Niagaran to Helderbergian, from the Decatur limestone throughout the Linden formation; Hardin, Perry, and Benton counties, Tennessee.

4. SCYPHOCRINUS STELLATUS (Hall)

Plate VII, figs. 4a, b

1879. *Camarocrinus stellatus* Hall; 28th Rep. N. Y. St. Mus. Nat. Hist., 270, pl. 35, figs. 1-8.
1904. *Camarocrinus stellatus* Hall; Schuchert, Smithson. Misc. Coll., vol. 47, pt. 2, pp. 269, 270, pl. 44, figs. 1-5.
1913. *Camarocrinus stellatus* Hall; Schuchert, Maryland Geol. Surv., Lower Devonian, 228, pl. 31, figs. 1-5.

Calyx short, obconical, spreading gradually to the arm-bases; height about equal to maximum width. Plates low, rugose, with indistinct radiating markings below, and strong connecting ridges and deep pits above, producing a low, stellate sculpture. Secundibrachs about 10, the upper ones about half as long as wide, being relatively longer than in many other species. Median ridge narrow. Arms and stem unknown.

The form of *Camarocrinus* occurring numerously at Schoharie, New York, and in the beds at Keyser, West Virginia, mentioned by Hall and Schuchert, was described by the former under the above specific name. A single imperfect calyx has been found in the Keyser locality, upon which I have undertaken to characterize the species. Some of the fragments from Benton County, Tennessee, may belong to this species. While the bulbs from the Keyser locality contain numerous examples of the primitive four lobes, and variations from that number to eleven, it must be said that taken as a whole they show a much greater tendency to increase in number of lobes than those from Oklahoma and Tennessee. Therefore, while a single bulb would prove nothing, the prevalence of the higher numbers in a considerable assemblage of specimens may be taken as a specific character. Also on an average those of this locality are relatively lower and broader than the others, and in general considerably smaller.

Holotype.—The calyx herein described is in the author's collection.

Horizon and locality.—Keyser division of Helderbergian, Schoharie, New York; Keyser, West Virginia. Possibly also the Linden formation in Benton County, Tennessee.

5. SCYPHOCRINUS PRATTENI (McChesney)

Plates VII, figs. 1a, b; VIII, figs. 1, 2a, b

- 1860. *Forbesiocrinus pratteni* McChesney; Trans. Chicago Acad. Sci., Extract No. 1, p. 29.
- 1865. *Forbesiocrinus pratteni* McChesney; plates illustrating in part new species fossils, pl. 5, fig. 4.
- 1866. *Melocrinus pratteni* (McChesney); Shumard, Trans. Acad. Sci. St. Louis, vol. 2, p. 381.
- 1868. *Melocrinus pratteni* (McChesney); McChesney, Trans. Chicago Acad. Sci., vol. 1, p. 22, pl. 5, fig. 4.
- 1881. *Melocrinus pratteni* (McChesney); Wach. and Spr., Proc. Acad. N. S. Phil., 296 (Rev. Pal., vol. 2, p. 122).
(?) Syn. *Camarocrinus saffordi* Hall, 1879, 28th Rep. N. Y. St. Cab. Nat. Hist., 208; pl. 36, figs. 1-6; pl. 37, figs. 1, 2; Schuchert, 1904, Smithsonian Misc. Coll., vol. 47, pt. 2, p. 270, pl. 40, fig. 10.

Calyx extremely large, massive, lageniform; broadly conical from base to widest part about the zone of axillary primibrach, thence contracting and becoming cylindrical toward the arm-bases. Height about equal to maximum width. Interbrachial areas at widest part strongly protuberant, with primibrachs and first secundibrachs deeply depressed between them; higher up this condition is reversed, the secundibrachs being elevated into a broad median ridge, while the interbrachial pavement (fixed pinnules) is low, rather flat, with obscure sculpturing. Secundibrachs about 12, the first being elongate, followed by gradual diminution in length until the upper ones are less than one-eighth as long as wide; median ridge begins at about the fifth plate, passing into a broadly rounded trunk toward the arms. Fixed pinnules strongly modified by surface sculpture, and not readily distinguishable. Primary interbrachials large, in about five or six ranges of 1, 2, 3, 3, 2, 1, with one or more additional plates in the posterior interradius for the ranges above the second. Plates in lower part thick, convex, smooth, with obscure connecting ridges, often pustulose or obtusely spiniferous; in the upper interbrachial region flat and without sculpturing. Arms and stem not preserved, except for a few of the proximal columnals, which are extremely thin.

Dimensions of a maximum specimen: Height of calyx to axillary secundibrach, 90 mm.; width at widest part about 100 mm., reduced above to about 75 mm.; diameter of column proximal to calyx, 12 mm. Diameter of associated root bulbs, 150 mm.

This species is the most striking example of the group to which it belongs, and is so completely distinct in facies from those of the *elegans* group as not

to require detailed comparison. Its most emphatic characters are the flask-shaped calyx, swollen interbrachial areas, and extremely large size—all of which are conspicuously shown in the unusually fine material now in my hands as the result of Mr. Pate's collecting in 1915. There are about 35 specimens, from four localities within a limited area in Hardin County, Tennessee, several of which by dint of hard cleaning have been completely freed from the matrix; none have the arms preserved, but in several the secundibrach series is intact in one or more rays up to the bifurcation. The size is remarkably constant at a height and width of about 75 mm. or more, with a contraction of 20 to 25 mm. above the strongly bulging interbrachial zone; but a single specimen was found of materially less size than that stated.

The contour, ventricose in the middle, contracted and cylindrical above, is similar to that of *S. pyburnensis*, but it is much more pronounced in this species. It is chiefly caused by the swollen condition of the interbrachial areas, projecting in some specimens as much as 10 or 12 mm. beyond the plane of the primibrachs, which lie deeply and abruptly depressed between them, as if sunken into the calyx wall.

The number of secundibrachs is a good character as distinguished from that in *S. elegans*, being quite constantly about 12 or 13 in the specimens where they can be counted—the smaller number according with the less elongate calyx. The interbrachial pavement, being in the weaker part of the calyx, is complete in but few of the specimens; so far as seen it is rather smooth, with low connecting ridges and shallow pits, which so strongly modify the plates that the fixed pinnules are with difficulty identifiable. In one specimen they are quite plain on the interior, with traces of ambulacra toward the distal ends.

The short, pustulose elevations in the center of many of the plates, while generally present, are somewhat variable, and upon a set of five specimens from a different locality from the others they are wanting; but the form is otherwise indistinguishable from the prevailing type.

The *Camarocrinus* bulbs found in the *prattensi* beds are in size commensurate with the dimensions of the calyx, far exceeding those of any other horizon or locality. Many of them are 150 mm. or more in diameter and almost as high, and none were seen less than about 100 mm., which is the usual maximum for those of other species. The average diameter in 12 specimens is 125 mm., while the average of 70 specimens from the clay beds below is 75 mm. It is also observed that the principal root members and their connecting pavement stand at an acute angle toward the stem, forming a pyramidal or conical mass within the collar, whereas in the other specimens the floor is usually almost horizontal. Also the sinus between the lobes is usually more sharply indented than in the others.

While *S. pratteni*, in its extraordinary size and the anomalous development of the interbrachial areas, represents the culmination but evidently not the close, of the genus, it is interesting to note that there is a progression in these characters within the species itself. The strata containing it consist of blue and grey limestones in the lower part, passing into cherty beds above. It is in the latter that the largest specimens with the greatest and most abrupt interbrachial projections are found; while those from the lower bluish limestones are in the average smaller and of a distinctly less rugose type.

The species was described from a fragment in which but a small part of the calyx was preserved, and the leading characters were not disclosed. In his original description McChesney stated that the horizon and locality of the unique type specimen were not clearly known, but it was supposed to have been from the Carboniferous limestone somewhere in Alabama. The horizon is, of course, wrong; but as the same Linden beds in which the Hardin County specimens occur extend along the Tennessee River into northwestern Alabama, there is no doubt that the type specimen was derived from the same source.

Holotype.—Originally in the Chicago Academy of Science, was destroyed by fire, but is represented by casts in the American Museum of Natural History, New York; the Walker Museum of the University of Chicago; and in the author's collection at the National Museum. The other specimens here figured are in the author's collection.

Horizon and locality.—Helderbergian; lower or middle part of Ross limestone of the Linden formation; Hardin County, Tennessee, at various localities along Horse Creek, near Grandview on the Tennessee River, and probably also in northwestern Alabama. The species occurs in the upper 25 or 30 feet of a series of blue-grey and cherty limestones with clay partings, of a total thickness of about 60 feet, in which are also found *Camarocrinus* of maximum size. It is not found at Pyburn's Bluff, where similar beds of cherty limestone exist, but evidently lack the *pratteni* member, which may at that locality lie below the water's edge.

6. SCYPHOCRINUS PYBURNENSIS n. sp.

Plates VII, figs. 2a, b, 3; VIII, figs. 6a, b, 7

Calyx large, elongate; low-convex in lower part, widest below secundi-brachs, contracting and cylindrical toward the arm-bases; height to width at zone of greatest width and to that above, 2.75 to 2.20 to 2. Interbrachial areas slightly protuberant, giving an obtusely pentagonal cross-section at that level, and unsymmetric by reason of greater and rather irregular enlargement of posterior interradius, which usually has two or three additional plates above

the second range. Secundibrachs about 13 to 15, with median ridge rather narrow, commencing at about the sixth or eighth plate; fixed pinnules frequently distinguishable in regular order. Plates thick, not pustulose; broadly convex in lower part, with strong stellate sculpture above, produced by rather broad connecting ridges and pits. Arms apparently rather slender.

Dimensions of a large specimen: Height of calyx, 70 mm.; width at widest interbrachial zone 57 mm., reduced directly above to 50 mm., beyond which it expands again to the arm-bases; diameter of stem at calyx, 9 mm.

This is a thoroughly well-marked and abundant species, of the type of *S. prattensis*, but differing consistently, and from a different horizon. At Pyburn's Bluff, on the Tennessee River, which is its typical locality, *prattensis* does not occur at all, while at the four localities where that species is the principal crinoid, *pyburnensis* was not found except for a single specimen in the talus, clearly derived from higher beds. The material in hand consists of 35 specimens, many of which have one or more rays intact to the bifurcation above the secundibrachs. In one an arm is preserved for two branchings, much more slender than those of *S. elegans*. All the specimens are readily distinguished from *S. prattensis* by the more elongate calyx, less prominent protuberance of the interbrachial areas, greater asymmetry of the posterior interradius, and lack of the spinose center on the plates. In very elongate specimens, such as that of Plate VII, figures 2a, b, the secundibrachs retain the elongate form and general aspect of calyx plates to the height of seven or eight plates before passing into the median ridge; above that they become very short and wide. There is not much variation in size, specimens being rarely less than 50 mm. high, unless the few which I have mentioned under *S. gibbosus* should prove to be the young of this species.

The fixed pinnules are better defined in this than in any of the other Tennessee species. I have figured two specimens in which their course is perfectly plain (Pl. VII, fig. 2b; Pl. VIII, fig. 6a). The latter of these exhibits an interesting abnormality in which the first interbrachial on the posterior side passes down to the basal, producing an anal area similar to that of the Actinocrinidae (Pl. VIII, fig. 6b). The case is the converse of that of the abnormal *Teleocrinus* mentioned by Wachsmuth and Springer¹ in which the anal plate between the radials is lacking, as in the Melocrinidae.

In the matter of surface sculpture in this and other species found in the Ross limestone, the observer must be on his guard against the effects of chemical action and weathering, by which the aspect of the plates is sometimes completely altered. Often the original calcareous surface is destroyed, while certain structures, such as the channels, or ridges connecting the plates, are replaced by silica, leaving an abrupt and rugose ornament totally different

¹ The North American Crinoidea Camerata, Mem. Mus. Comp. Zool. Harvard, vol. 20, p. 56, 1897.

from that of the unaltered plates; the latter may often be seen when exposed by cleaning in a part covered by matrix, so that the two kinds of surface appear in the same specimen. See, for example, the specimen of *S. prattensi* figured on Plate VIII, figures 2a, b.

Free specimens of the bulbous roots are not abundant at the *pyburnensis* locality; the few obtained are much smaller than those associated with *prattensi*. Hall described *Camarocrinus saffordi* and *C. clarki* upon material from this region, but as there is no evidence to indicate with which of several calices either of them is associated, the names cannot be utilized for any of these species.

Types.—In the author's collection.

Horizon and locality.—Helderbergian; Ross limestone of the Linden formation, in blue limestone and associated cherty beds for 30 or 40 feet up from the water's edge, Pyburn's Bluff, Hardin County, Tennessee.

7. SCYPHOCRINUS ULRICHI (Schuchert)

Plate IX, figs. 2a, b

1903. *Camarocrinus ulrichi* Schuchert; Amer. Geologist, vol. 32, October, p. 239.

1904. *Camarocrinus ulrichi* Schuchert; Smithson. Misc. Coll., vol. 47, pp. 263, 271, pl. 40, figs. 6-8; pls. 41-43, and text-figs. 43, 44.

Calyx large, ovoid, the larger end below, spreading by a very broad angle from the base; widest about the second range of interbrachials, and contracting slightly from there to near the zone of arm-bases. Plates flat, or low-convex, some with pustulose center; lower interbrachial areas rather unevenly and obtusely swollen, posterior area the largest. Secundibrachs relatively narrower and longer than in *S. prattensi*, and apparently less than 10 in number. Arms and stem unknown.

Dimensions of type specimen: Height of calyx, 62 mm.; greatest width, 50 mm.; width toward arm-bases, 43 mm.

This species is represented by a single calyx, found in the talus of beds containing numerous *Camarocrinus*, to which Mr. Schuchert has given the above specific name. As many of these are very large, it is assumed that they appertained to individuals of this species rather than of the smaller *S. gibbosus*.

Owing to the surface condition of the rather flat plates, it is difficult to identify the interbrachials in some places, but it is evident that the modification of the lower pinnules due to fixation has proceeded much farther in this than in the other species—so far in fact that all semblance of pinnule arrangement is lost. At the same time there is an entire absence of the surface sculpture produced by ridges or pits, so that the conspicuous *pavage* of the other species is absent here. The secundibrach series leading to the first arm bifurcation is also much less distinctly rounded.

While distinctly of the type of *S. pyburnensis*, the zone of greatest width is much lower, and the basal expansion of the calyx at a considerably wider angle. The low, flat plates and absence of distinct sculpturing also distinguish it, although this character must not be too much depended upon as the appearance may be due to erosion.

Holotype.—In U. S. National Museum.

Horizon and locality.—Helderbergian; Haragan limestone, near Dougherty, Oklahoma.

8. SCYPHOCRINUS GIBBOSUS n. sp.

Plate IX, figs. 3a, b

Calyx small, broadly spheroidal below, widest about the middle, contracting toward the arm-bases. Base very small. Interbrachials not protuberant. Plates highly tumid, with strong connecting ridges and pits.

Dimensions of type specimen: Height of calyx to IIBr₃, 25 mm.; width at IIBr, 30 mm.

A single imperfect calyx found in the *Camarocrinus* horizon of Oklahoma suggested the proposal of this species; it is preserved only to the height of the third secundibrachs, and the basal plates are wanting. Among the Hardin County, Tennessee, material from the Pyburn's Bluff locality, there are three small specimens of about the same size as this agreeing in the characters noted, one of them a perfect calyx, which I have figured for comparison, Plate VIII, figure 7. They have the facies of *S. pyburnensis*, without the projecting interbrachials, the absence of which, however, may be a juvenile character. The two forms are evidently of a closely similar type, but whether identical can only be determined by discovery of better material from the Oklahoma locality.

Holotype.—In the U. S. National Museum.

Horizon and locality.—Helderbergian; Haragan limestone, Franks, Oklahoma, and (?) Hardin County, Tennessee.

EXPLANATION OF PLATES

All figures, unless otherwise noted, are made from light prints of photographs direct from the specimens, finished with India ink brush drawings. They are reproduced by the heliotype process. Enlargements, if any, are indicated by an improper fraction placed at the right lower corner of each figure; if not so distinguished the figure is of natural size. All specimens, not otherwise noted, are in the author's collection.

SCYPHOCRINUS

PLATE I

PAGE
30

SCYPHOCRINUS ELEGANS Zenker.....
Helderbergian. Cape Girardeau, Missouri

The principal slab described in the text, about 120 by 165 cm. (4 by 5.5 ft.) in size.

It contains about 24 crowns, of which 18 have a large part of the arms intact. Those which have been specially used for the descriptions and figures are indicated by letters *A* to *G*. At *H* and *I* may be seen two *Camarocrinus* bulbs with the stemless side exposed; at *L* and *K* are parts of other bulbs broken by pressure and partly imbedded. For convenience of measurement a scale is added. Reduced by photography to $\frac{2}{11}$.

Photographed by Dr. R. S. Bassler of the National Museum, and somewhat retouched by Mr. Chapman.

The slab is from a limestone layer about 4 to 6 inches in thickness, resting upon a parting of shaly clay.

The specimens now visible were all partly imbedded in the underlying soft clay layer, being attached to and gradually passing into the firm limestone above, which for a thickness of about 2 inches is entirely composed of broken remains of stems, crowns, and bulbs. In studying this photograph it must be remembered that the surface now seen was the under surface of the slab as it lay in the formation, and that the aspect of the fossils is that of their lower side as they settled into the sea bottom.

Author's collection. Now mounted in the Hall of Invertebrate Paleontology, U. S. National Museum.





SCALE OF FEET



PLATE II

PAGE

SCYPHOCRINUS ELEGANS Zenker..... 30

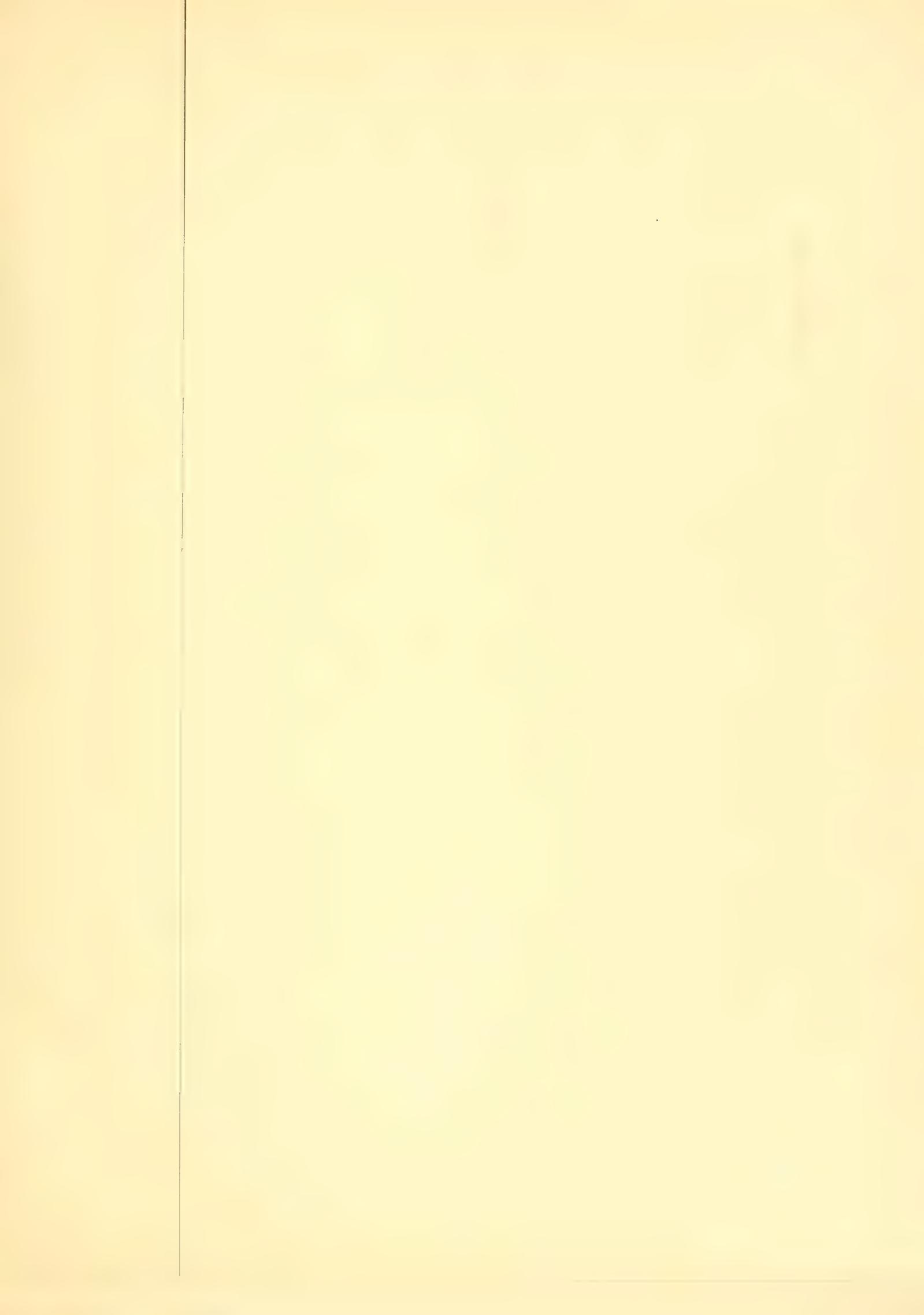
Specimens B and C of the slab shown on Pl. I. Natural size

FIG. 1, specimen B; fig. 2, specimen C. To show the various types of surface sculpturing, both on lower calyx plates and in the interbrachial pavement. In fig. 1 (B) the appearance of suspended chains is most prominent (var. *schlotheimi*). In fig. 2 (C) it is a complicated network into which enter root-like prolongations from the lower elevated brachials (var. *schroeteri*) ; and at the lower left edge the costæ are broken up into separate granules, as described under *S. decoratus* W. and J.

Photographed by Dr. R. S. Bassler and carefully retouched by Mr. Chapman.

Helderbergian.

Cape Girardeau, Missouri.





Heliotype Co Boston

PLATE III

SCYPHOCRINUS ELEGANS Zenker..... 30

- FIG. 1. Specimen A, from the slab on Pl. I. A nearly complete crown with calyx about 10 cm. high, and arms to about 25 cm. in length; part of base and proximal columnals in outline. Calyx but little flattened, and showing about the normal contour; interradial view. Interbrachial pavement has the stellate type of sculpturing produced by progressive coalescence of the slits crossing the sides of the plates; these disappear in the upper part where the surface becomes nearly smooth; this is not due to any erosion in the fossil state, as these parts were covered with a fine calcareous mud which was carefully removed with delicate tools and water. From the calculated taper of the arms to the highest part visible, it is probable that they were at least twice as long as here preserved. Reduced to $\frac{2}{3}$.
2. Detail from specimen F (Pl. I), with the smooth type of interbrachial pavement. Natural size.
 3. Detail from specimen E, interradial view, showing interbrachial pavement with slits crossing margins of plates at the sides in lower part, and depressions at angles in upper, producing both stellate and reticulate sculpture (var. *typica*). Natural size.
 4. Detail from specimen G, upper part of interbrachial pavement, showing depressed areas at corners of plates disconnected in one area, and connected in the other, producing reticulate (var. *typica*) and banded (var. *schlotheimi*) sculpture in the same specimen. Natural size.

Helderbergian.

Cape Girardeau, Missouri.

GLYPTOCRINUS DYERI Hall.....

(For comparison of fixed pinnules)

- 5a. R. ant. iR view of calyx, showing the fixed pinnules on IIBr 2-4-5-6-7, their course marked by sharp median ridges. Natural size.
- 5b. Tegmen of same, showing probable nature of the *Scyphocrinus* tegmen. The fixed pinnules are seen curving upon and merging into the tegmen. Anal series in strong median ridge also merging into the tegmen. The lower part of the tegmen is distorted by an imbedded stem fragment. $\times \frac{5}{4}$.

This figure should be compared with Pl. IV, fig. 1.

Ordovician.

Cincinnati, Ohio.

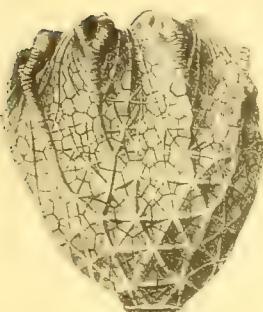
PAGE

30

35



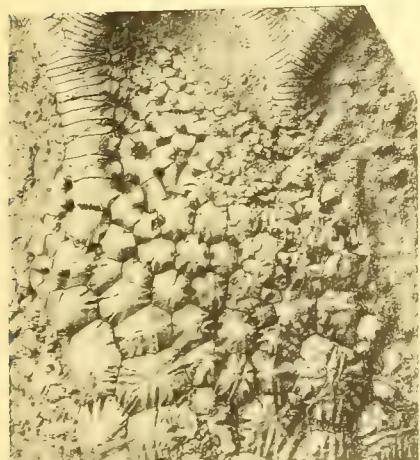
5b



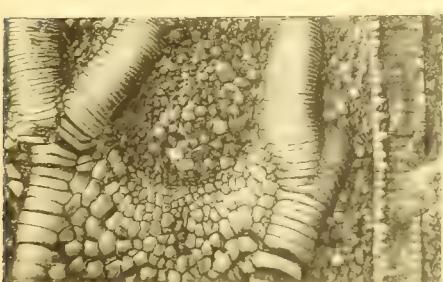
5a



4



3



2

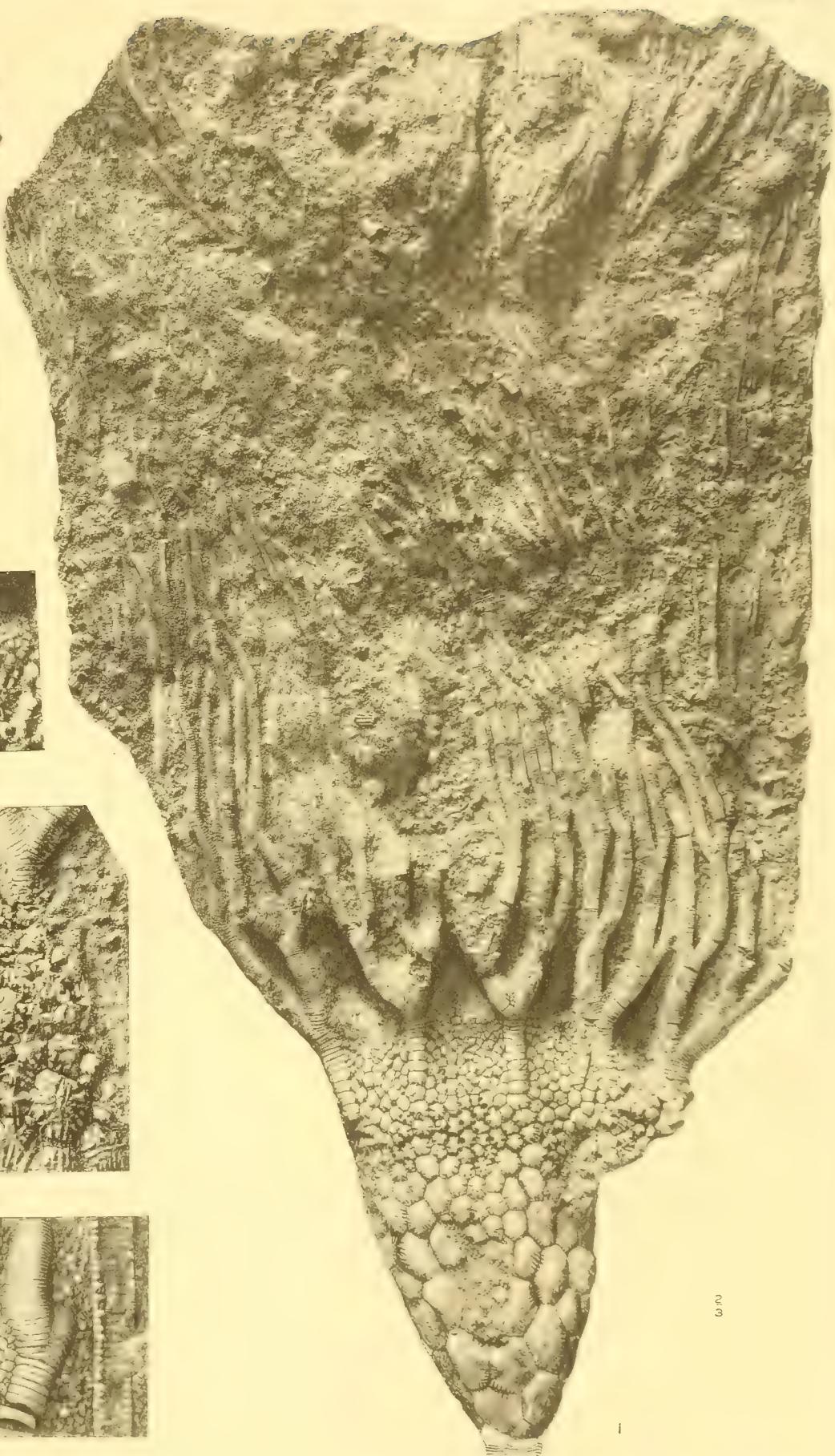


PLATE IV

CALYX PLATES, PINNULES, AND SCULPTURING
(All figures natural size unless otherwise stated)

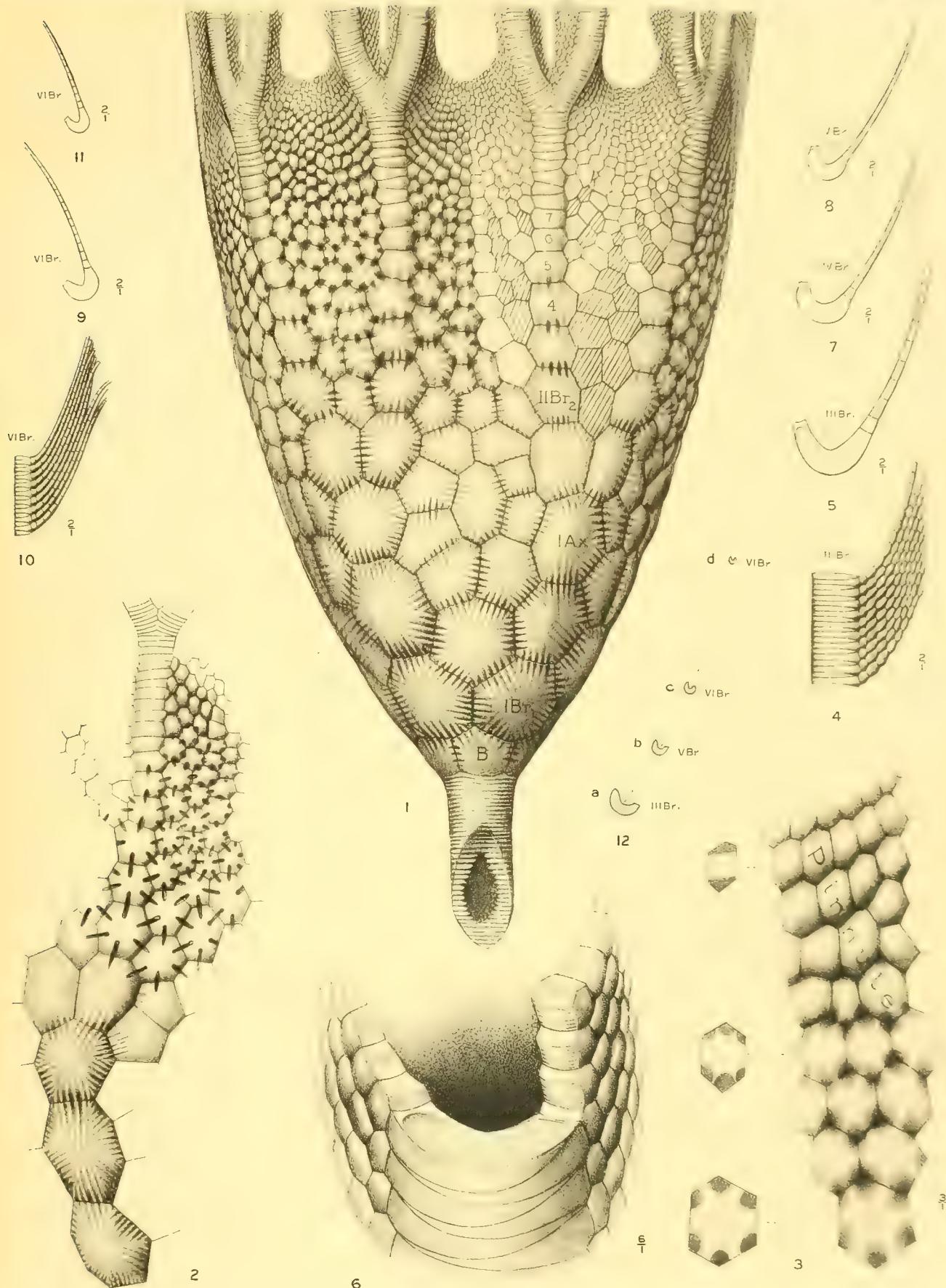
PAGE

SCYPHOCRINUS ELEGANS Zenker..... 30

FIG. 1. A composite figure, constructed from the original of fig. 1, Pl. V, and specimens A, B, C, D, E, F, G, of the slab shown on Pl. I.

To show development of the fixed pinnules, and the way in which they lose their identity by the progressive change in surface sculpturing produced by modification of fine grooves and costæ in lower part into stronger depressions and ridges upward, until the appearance becomes that of transverse bands suspended between the rami, instead of longitudinal series. In one ray and part of an interradius the surface ornament is omitted, and to facilitate identification the pinnulars are left unshaded while the interpinnulars and intersecundibrachs are indicated by diagonal hachure. Thus the succession of pinnules upon IIBr 2-4-5-6-7 is shown, until at about the eighth IIBr the interpinnulars disappear, and from there on the pinnules are packed in close lateral contact. The distal ends of the pinnules from the IIBr and lower IIIBr bend over and become merged in the tegmen, as shown in Pl. III, fig. 5b. The extreme relative shortness of the IIIBr is well shown, and also the manner in which the first few pairs of them are joined by their inner margins. The limit of the calyx distally is seen to be approximately just above the level of the IIIBr axil.

2. Part of a ray from IBr₁ to bifurcation at IIBr₂₀; showing the various styles of sculpturing at different levels caused by progressive changes in the size and form of pits and ridges passing from plate to plate. Made from specimens A and E.
3. Portion of the right side of interradius above IIBr; showing the change in superficial appearance of the interbrachial pavement due to modification of the depressed areas at the angles of the plates by lateral coalescence into continuous furrows, producing the transverse girdles or chains. Constructed from specimens A and B, and fig. 1 of Pl. V.
4. Side view of section of a ramus at the lower IIIBr, with the pinnules closely abutting proximally by angular faces. $\times 2$.
5. Cross-section of brachial and pinnule at same level. $\times 2$.
6. Oblique dorsal view of IIIBr, showing modified articular face of brachial and connecting pinnules, also the angular faces of pinnulars abutting upon those of adjoining pinnules. $\times 6$.
- 7, 8. Cross-section of pinnule on lower IVBr and VBr. $\times 2$.
9. Cross-section of pinnule at lower VIBr. $\times 2$.
10. Side view of portion of arm at VIBr between those of figs. 9 and 11, showing pinnules rounded and beginning to be free from their fellows. $\times 2$.
11. Cross-section at higher VIBr. $\times 2$.



PAGE

SCYPHOCRINUS ELEGANS Zenker—Continued 30

FIG. 12. Cross-section, natural size, of brachials at different heights, to show the taper of arm; *a*, IIIBr next above bifurcation, width 6.5 mm.; *b*, VBr an inch below bifurcation, and 10 cm. above *a*, width 2.75 mm.; *c*, VI^{Br} 15 cm. above *b*, width 2 mm. All from the same ray. *d*, a higher VI^{Br} from a similar specimen, width 1.15 mm., which at the same rate of diminution would be about 22 cm. above the last. This would give a length of about 48 cm. (18 inches) from lower IIIBr to a higher VI^{Br} of about 1 mm. width. As the distal part of the arm would probably diminish to 5 mm., this would add at least 10 cm., making the total probable length of arm in life about 55 to 60 cm., or at least 22 inches.

PLATE V

STEM CHARACTERS

(All figures natural size unless otherwise stated)

PAGE

SCYPHOCRINUS ELEGANS Zenker.....	30
Cape Girardeau, Missouri	

FIG. 1. A free calyx to the height of about IIBr_{12} , radial view; showing characteristic surface or ornament; used partly in construction of figures of Pl. IV. Note the change of direction in the rami at the fifth IIBr .

2a, b, c. a, Cross-section of column proximal to calyx (12 mm. diameter, 13 joints to the cm.) ; showing the extremely wide axial canal (lumen) and the short alternating columnals. $\times 2$.

b, Joint-face of same, showing pentagonal outline of lumen, and contact area forming the rim of the intercolumnal chamber (ligament fossa) bordering it, with the radiating crenulae traversing both. $\times 2$.

c. Oblique view of same joint-face, further enlarged, with vertical section; to show the small remaining points of stellate lumen at angles of the pentagon, and the relative thickness of the columnal from the periphery to the flange-like part extending inward as a diaphragm between the chambers. $\times 8$.

3a, b, c. Similar views of section at median part of column (8 mm. diameter, 8 joints to the cm.) ; showing much narrower lumen, with stellate radiations in the part of the columnal forming the diaphragm. Figs. a and b $\times 2$; c $\times 6$.

4a, b. Similar views of section near distal end of stem (6.5 mm. diameter, 5 joints to the cm.) ; showing smaller stellate lumen, with thicker diaphragm. $\times 6$.

5. Oblique view with vertical section of columnal of intermediate type toward the distal end, having relatively narrow chamber and small stellate lumen. $\times 6$.

SCYPHOCRINUS ULRICHI (Schuchert).....	54
---------------------------------------	----

6. Distal end of stem with branches merging into a plated area within the collar (broken away), being the upper part of a large bulb (not included in figure); showing the small stellate lumen, and position of large openings at bifurcations, leading to the chambers. U. S. National Museum.

Helderbergian. Dougherty, Oklahoma.

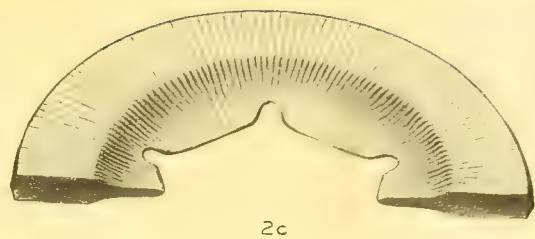
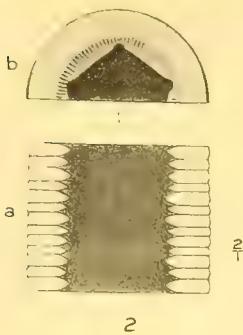
ANCYROCRINUS BULBOSUS Hall.....	10
---------------------------------	----

7, 8. Different forms of anchor-like distal end of the stem, with its four grapsnels.

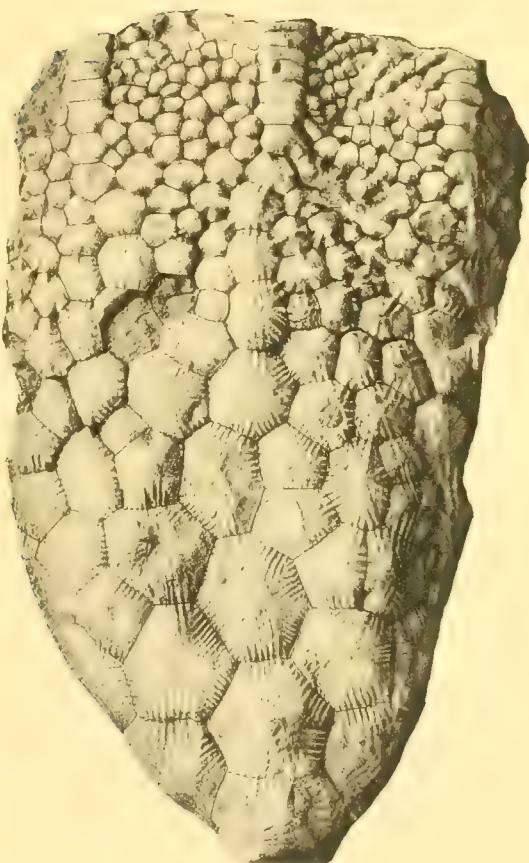
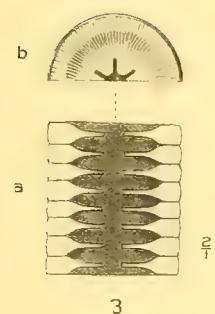
9. Proximal view of another specimen showing the quadripartite stem lumen.

10. A transversely fractured specimen showing how the stem extends to the bottom of the terminal structure.

Hamilton Group; Middle Devonian. Clark County, Indiana.



8



5

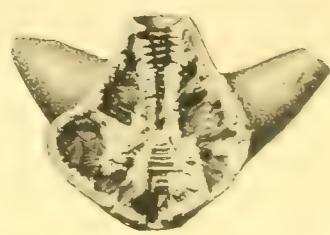
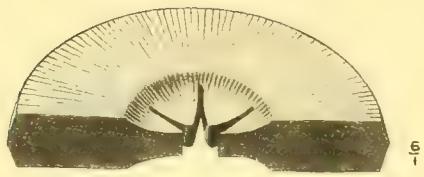
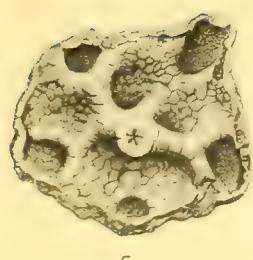
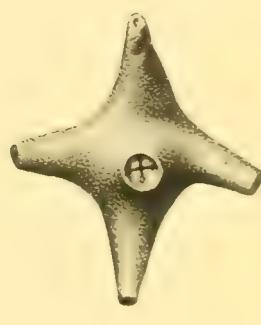
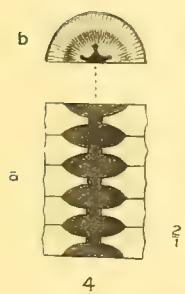


PLATE VI

(All figures natural size unless otherwise stated)

PAGE
50*SCYPHOCRINUS PRATTENI* (McChesney).....

FIG. 1. The holotype, showing base and lower part of calyx, formerly in the Chicago Academy of Science, destroyed by fire in 1870. Left anterior radial view; drawn from a sulphur cast of the original made by Whitfield, now in the author's collection.

Tennessee River, Northern Alabama.

- 2a. A large distorted calyx with rays to IIBr₇, from posterior interradius.
- 2b. Basal view of same; r. post. iR upward; shows the protuberant iBr areas.
- 2c. Restoration of same, from r. post. R, to show the natural contour, and the course of the fixed pinnules; iBr and iP from IIBr up marked by diagonal hachure. Lower part of radial series not shown sufficiently depressed.

Helderbergian.

Hardin County, Tennessee.

SCYPHOCRINUS MUTABILIS n. sp..... 47

- 3a. Lateral view of eroded calyx from l. ant. iR; base restored from other specimens.
- 3b. Basal view of same; post. iR upward.
(See more characteristic specimens on Pl. VIII.)
- 4. Fragment showing base; l. ant. iR upward.

Perry County, Tennessee.

- 5a-d. Detached fragments of calyx, not known to be from the same individual, arranged in natural order; to show sculpturing of plates.
- 5e. Part of ramus above axillary IIBr from a larger individual.
- 6, 7. Detached bases, to show costæ and grooves at margin of plates.
- 8, 9. Plates of interbrachial areas, to show sculpturing.
- 10-14. Separate plate showing surface sculpturing in different parts of the calyx.
- 15, 16. Edges of lower calyx plates, showing grooves or folds upon the margin, but not penetrating the plates.
- 17. Similar view of plate enlarged. $\times 2$.
- 18, 19. Inner floor of plates from different parts of the calyx, showing the sculpturing on the inner surface.

Helderbergian.

Benton County, Tennessee.

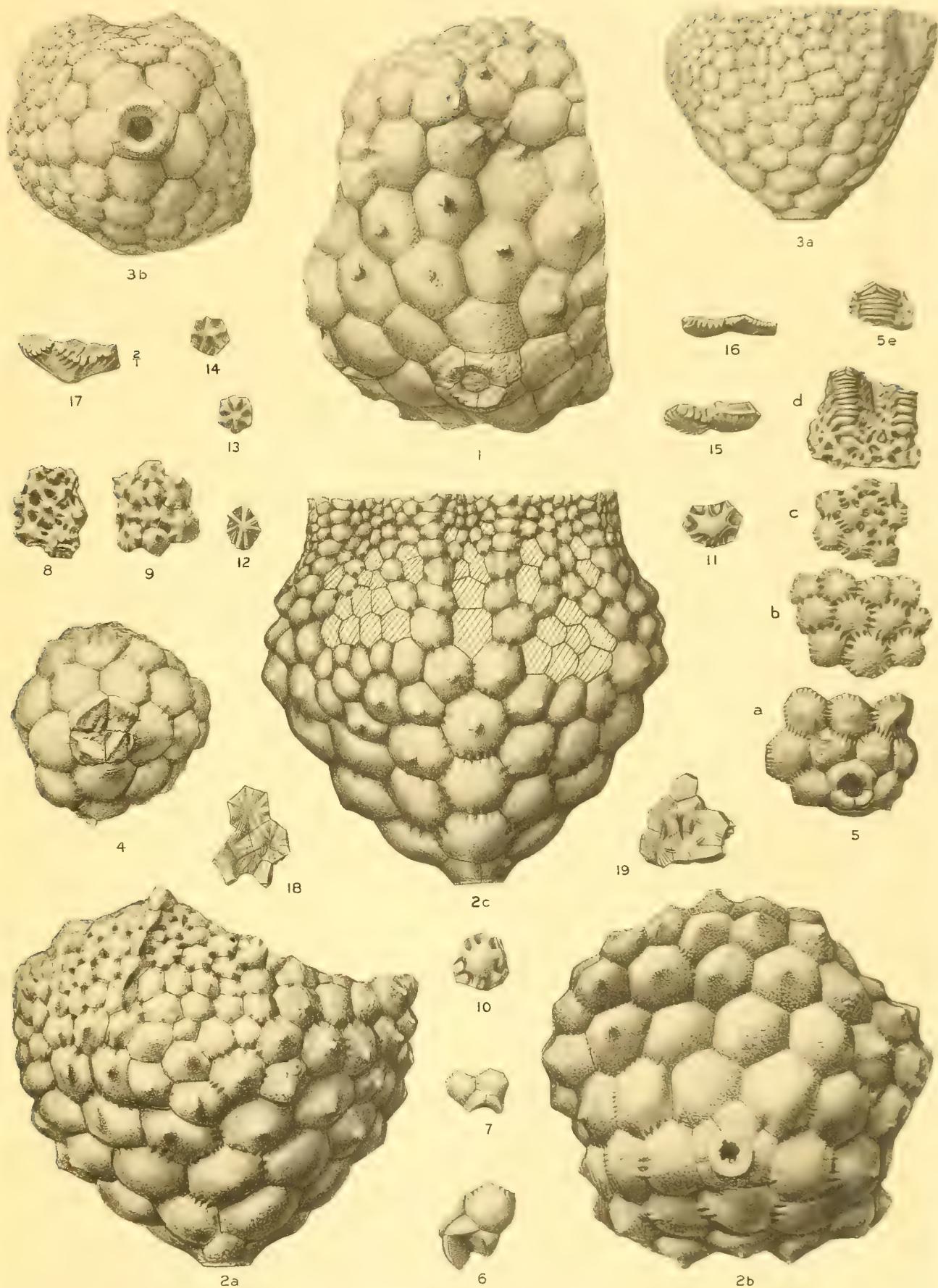


PLATE VII

(All figures natural size unless otherwise stated)

PAGE

SCYPHOCRINUS PRATTENI (McChesney) 50

FIG. 1a. Left anterior interradial view of a maximum specimen with one ray at extreme left preserved to the axillary IIBr; showing the extreme protuberance of the iBr areas, and depression of the radial series; also the contraction in width of calyx toward the arm-bases. Short pustulose spines, irregularly scattered, are shown.

1b. Basal view of same, l. ant. iR side up.

Helderbergian.

Hardin County, Tennessee.

SCYPHOCRINUS PYBURNENSIS n. sp..... 52

2a. Right anterior radial view of the principal type specimen with rays complete to the arm-bases, showing general contour of the calyx and character of the unweathered sculpture of the plates; the radiating costæ coalesced into a single large ridge in upper part, producing stellate ornamentation much modified upward by secondary growth. In the matrix above the crinoid may be seen a portion of a *Camarocrinus* bulb which was imbedded in the limestone.

2b. The same specimen from r. post. R, on which the sculpturing appears sharper from weathering, and the action of algæ in deepening the pits; the course of the fixed pinnules can be readily traced. The asymmetry due to the greater distension of the anal interradius is well shown.

3. Basal view of another specimen, posterior interradius above; showing the slight protuberance of the interbrachial areas, and the numerous connecting ridges in lower plates.

Helderbergian.

Hardin County, Tennessee.

SCYPHOCRINUS STELLATUS (Hall)..... 49

4a. Lateral interradial view of distorted calyx with plates below axillary IBr wanting. $\times \frac{5}{4}$.

4b. Oblique basal view from another side, showing the relatively narrow and long IIBr as far as the bifurcation. Basal parts restored. $\times \frac{5}{4}$.

Helderbergian.

Keyser, West Virginia.

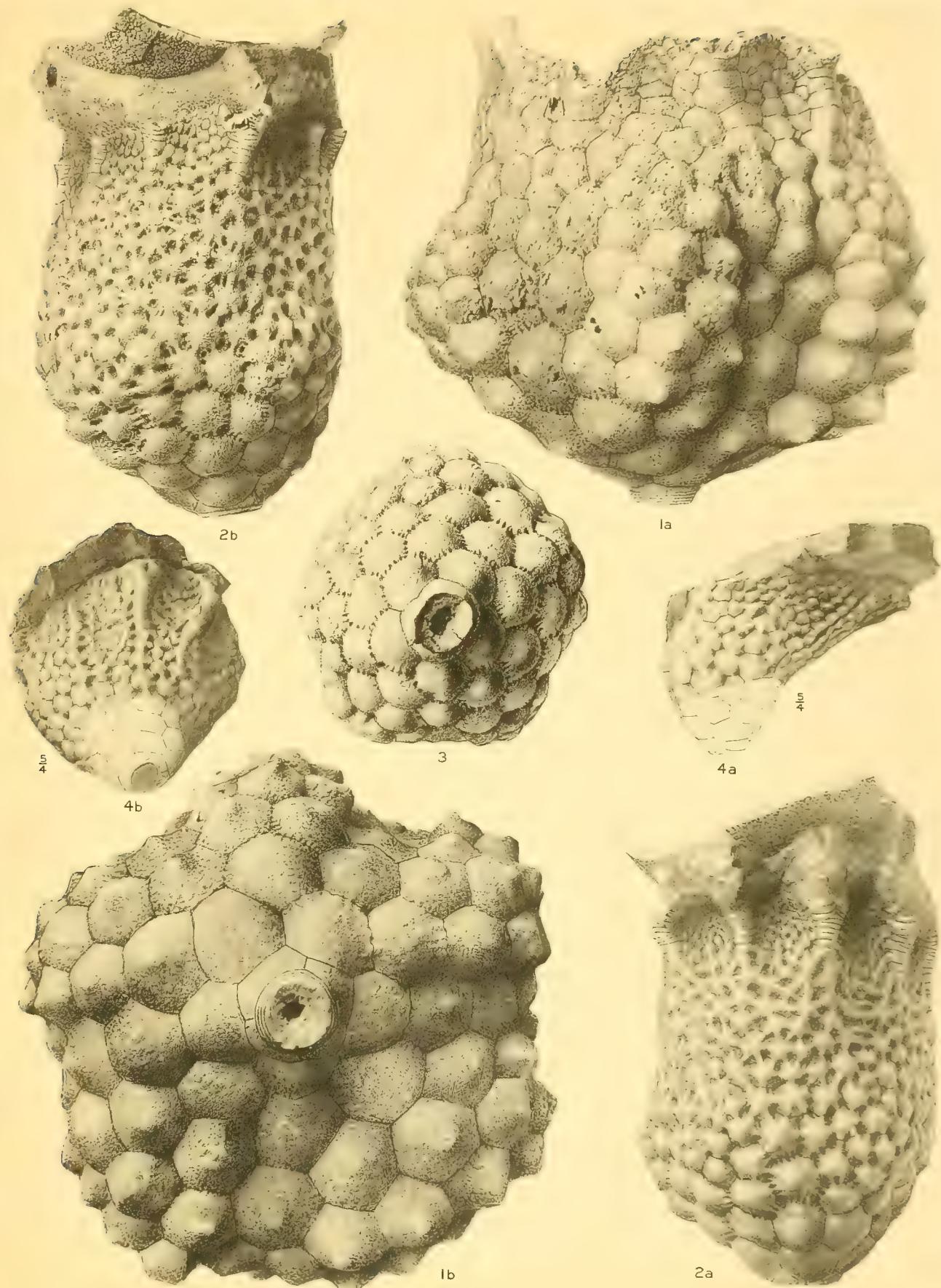


PLATE VIII

(All figures natural size unless otherwise stated)

PAGE
50

FIG. 1. Left anterior radial view of somewhat compressed specimen, showing the surface characters of the plates, which have pustulose elevations irregularly in lower part. The secundibrachs are seen in the ray to the right up to the axillary. Some small knobs along the sutures in the upper left corner may be silicious deposits made during fossilization, which in some cases greatly modify the surface.

- 2a. A small specimen in which the calcareous test has been largely replaced by silica, and much of the original surface destroyed by chemical action, producing an unnatural rugosity of the sculpturing. The specimen is uncompressed, and shows perfectly the characteristic contour of the species.
- 2b. Basal view of same, showing some unweathered plates in which the original smooth surface is preserved; small spinous pustules are well represented on the lower plates in both views.

Helderbergian.

Hardin County, Tennessee.

SCYPHOCRINUS MUTABILIS n. sp..... 47

- 3. A short specimen; from left anterior radius with surface in natural condition, having the turbinate contour of average specimens; sculpturing in interbrachial regions greatly modified by secondary growth.
- 4. A more elongate specimen; from left anterior radius with lower part of calyx less regularly conical; sculpturing intensified by weathering.
- 5. A strongly turbinate specimen; with surface studded with small knobs upon the suture lines perhaps produced by silicious deposits during fossilization. Lower part restored from other specimens.

Niagaran to Helderbergian.

Hardin, Perry, and Benton counties, Tennessee.

SCYPHOCRINUS PYBURNENSIS n. sp..... 52

- 6a. Abnormal specimen; lateral view of calyx, showing the fixed pinnules.
- 6b. Basal view, showing 6 plates in the radial circlet; posterior interradius up. The posterior interbrachial passes down to the basal which is truncated to meet it, producing an anal area similar to that of the Actinocrinidæ. Slightly enlarged.

Helderbergian.

Hardin County, Tennessee.

- 7. A small specimen, probably of this species, figured for comparison with figs. 3a, b, of Pl. IX.

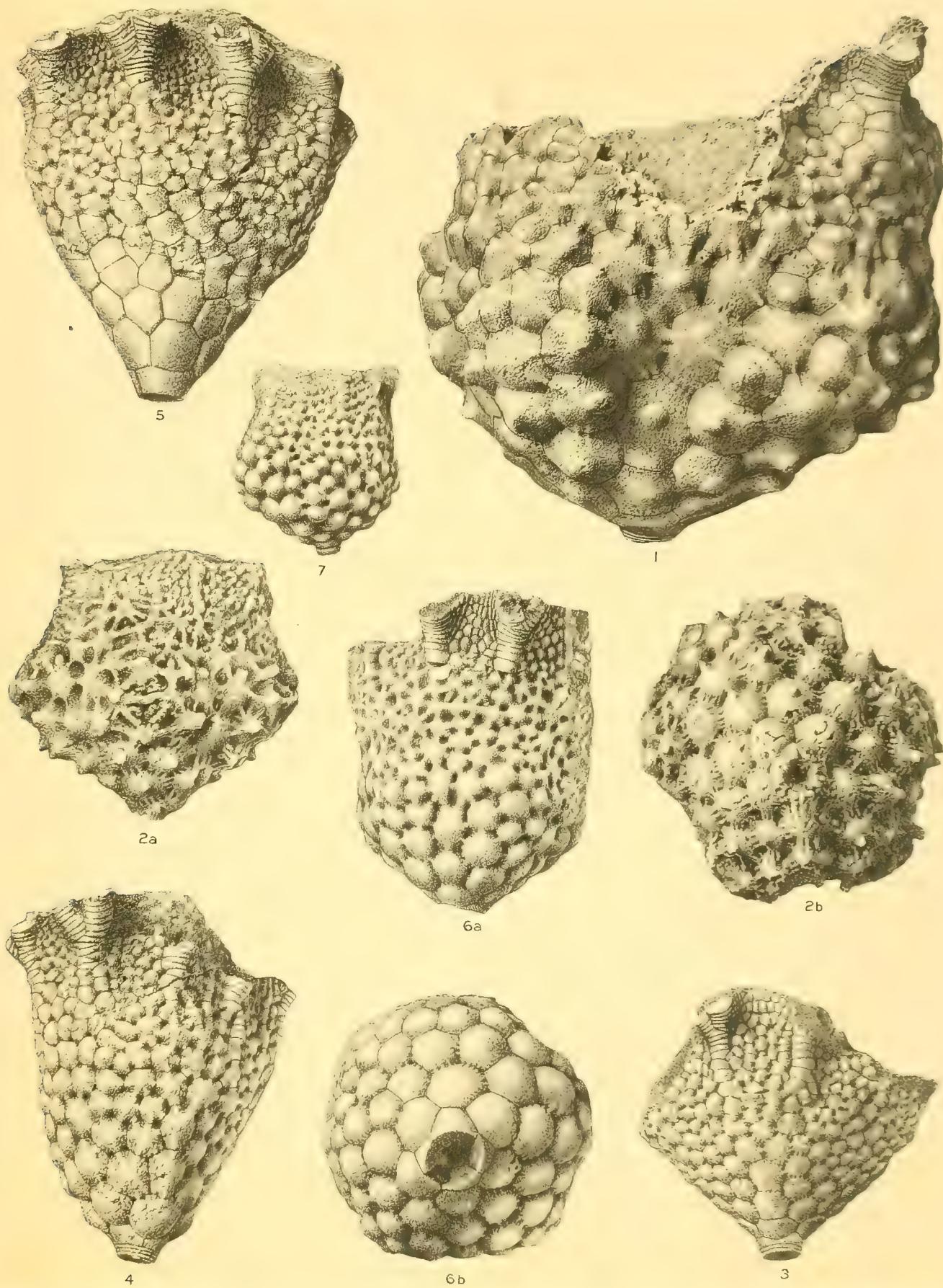


PLATE IX

(All figures natural size unless otherwise stated)

PAGE
46

FIG. 1a. The holotype as seen from the side originally exposed, showing a few scattered spines on the weathered surface in the median area, and the fringes of long spines at either margin, some of them forking, which have been brought to view by cleaning. Note the parallel position of the spines in each cluster. $\times \frac{4}{3}$.

1b. Opposite side of the specimen as exposed by cleaning, showing the sharply sculptured plates and the numerous slender spines extending to the region of the arm-bases; many of them enlarging distally, some forking, and others tapering to a point. Some are seen partially detached from their sockets. $\times \frac{4}{3}$.

1c. Detail from same view as last, further enlarged. $\times 3$.

Helderbergian. Hardin County, Tennessee.

SCYPHOCRINUS ULRICHI (Schuchert) 54

2a. Left posterior radial view of holotype; a large, broadly ovoid specimen, with calyx intact to the lower IIIBr. The fixed pinnules are greatly modified, leaving little semblance of their primitive form. U. S. National Museum.

2b. Basal view of same; l. post. R upward.

Helderbergian. Dougherty, Oklahoma.

SCYPHOCRINUS GIBBOSUS n. sp. 55

3a. Left anterior interradial view of holotype, an imperfect calyx preserved only to II B_{5} . $\times \frac{5}{4}$.

3b. Basal view of same, post. iR upward; the basals, which were very small, are wanting. $\times \frac{5}{4}$.

Helderbergian. Franks, Oklahoma.

PTILOSARCUS BREVICAULIS Nutting 11

4. Specimen of this Recent Pennatulid; for comparison, to show the form and proportion of its bulbous root. No. 30057, U. S. National Museum.

Tsiuka, Japan: 44 fathoms.

MARSIOPCRINUS TENNESSEENSIS (Roemer) 42

5a. Complete tegmen with arms and pinnules attached; r. ant. iR. upward.

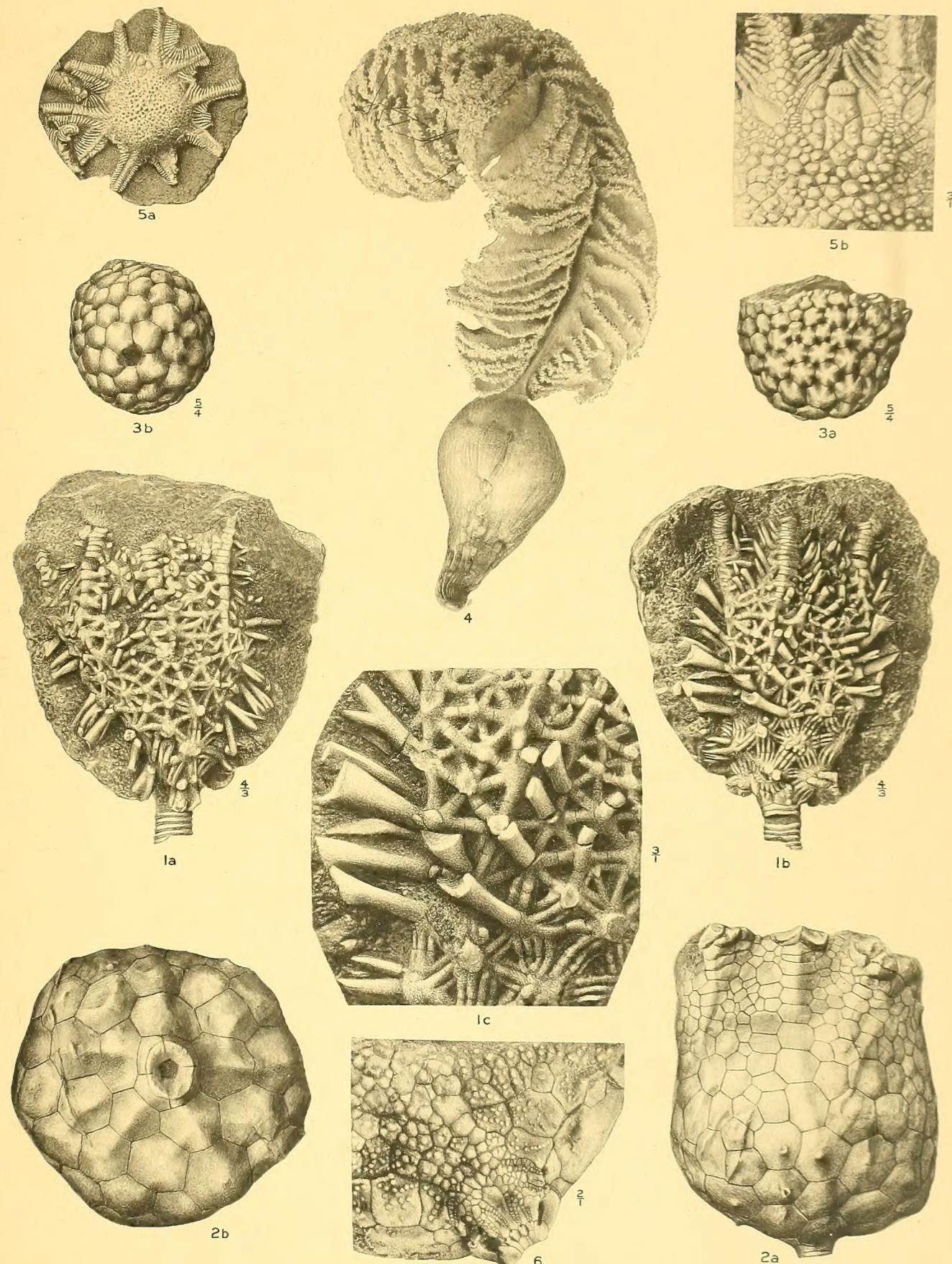
5b. Detail of same enlarged; parts of r. ant. and r. post. rays, showing the regular brachial pinnules, and the interbrachial pinnules at either side of the arms, with the ambulacra leading to them in the positions where the pores are seen in text-fig. 19. $\times 3$.

Silurian. Decatur County, Tennessee.

MARSIOPCRINUS STRIATUS? Wachsmuth and Springer 42

6. Unretouched photograph of part of tegmen of specimen from which text-fig. 19 was made, showing the ambulacra, and openings for fixed pinnules.

Silurian. Decatur County, Tennessee.



SMITHSONIAN INSTITUTION LIBRARIES



3 9088 00707 6169

