GENNAEOCRINUS VARIABILIS, A NEW SPECIES OF CRINOID FROM THE MIDDLE DEVONIAN BELL SHALE OF MICHIGAN

BY

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CONTRIBUTIONS FROM THE MUSEUM OF PALEONTOLOGY

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INTRODUCTION

ONLY RARELY are Paleozoic crinoids of one species found abundant, well preserved, restricted to a thin stratigraphic unit, and within a small exposure. In many species, the specimens are too few, too poorly preserved, and too widely disseminated stratigraphically and geographically to permit a reliable and comprehensive description. For many years, a low ledge of the Middle Devonian Bell shale in the abandoned Kelley’s Island Lime and Transport Company quarry has yielded numerous specimens of Gennaeocrinus. Gradually, these crinoids have been amassed in the Museum of Paleontology of The University of Michigan and in other museums. Now the variations within an ontogenetic series can be assessed.

All specimens in the collection belong to one species. They vary greatly in shape and ornamentation in all stages of development. If only the extremes were known, they would undoubtedly be assigned to several species. In the collection at the Museum of Paleontology, however, intermediate stages of size, elongation of the cup, height of the tegmen, and ornamental ridges, nodes, and cockscomb structures are represented. We can distinguish only one species.

The manuscript of this paper was criticized by Dr. C. A. Arnold. All specimens described and illustrated are deposited and catalogued in the Museum of Paleontology of The University of Michigan.

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All known specimens of the new species are from the following locality:

Upper part of the Middle Devonian Bell shale, 10 feet below the contact with the Rockport Quarry limestone in the abandoned “Rockport” quarry of the Kelley's Island Lime and Transport Co. (formerly Great Lakes Stone and Lime Co.), NW ¼ sec. 6, T. 32 N., R. 9 E., about ½ mi. NW of the fishing village of Rockport, northeastern corner of Alpena Co., Mich. Locality 38 of Michigan Geological Survey. The specimens are from a narrow stratum a few inches thick exposed as a small, low ledge along the east side of a drainage ditch west of the quarry buildings. The stratum is light bluish-gray shale, which weathers readily to release the fossils contained in it. Most specimens collected by Irving G. Reimann and George M. Ehlers.

SYSTEMATIC DESCRIPTION

Class Crinoidea

Subclass CAMERATA Wachsmuth and Springer, 1885
Order MONOBATHRIDA Moore and Laudon, 1943
Family Periechocrinitidae Austin and Austin, 1843
Genus Gennaeocrinus Wachsmuth and Springer, 1881

*Type species.*—By original designation of Wachsmuth and Springer, 1881, p. 161, *Actinocrinus kentuckiensis* Shumard, 1866, p. 345.

**Gennaeocrinus variabilis**, sp. nov.

(Figs. 1–2; Pl. I, Figs. 1–9; Pl. II, Figs. 1–13; Pl. III, Figs. 1–10; Pl. IV, Figs. 1–10;
Pl. V, Figs. 1–12; Pl. VI, Figs. 1–8; Pl. VII, Figs. 1–9; Pl. VIII, Figs. 1–10;
Pl. IX, Figs. 1–14)

*Shape of calyx.*—Calices of both small and large specimens ranging from low and broad (Pl. VI, Fig. 4; Pl. II, Fig. 1) to high and narrow (Pl. II, Fig. 10; Pl. V, Fig. 1). Cup at the base of RR ranging from wide, (Pl. VII, Fig. 8) to rather narrow (Pl. VII, Fig. 4); sides of cup correspondingly steep or sloping.

Cup ratio adopted as average height measured from base of RR to apices of posterior *PBrBr*₂ divided by the average interarm width measured between apices of *PBrBr*₂ on all arms. Cup ratio varying from .62 to .97, averaging .786; ratio of smallest ten specimens averaging .782, of largest ten averaging .753. Hence, larger specimens with slightly lower cups on the average; but ratios variable for calices at all sizes (Table I), and the same ratio found in small (Pl. II, Fig. 7), medium (Pl. VII, Fig. 8), and large (Pl. V, Fig. 3) specimens.

Relative height of tegmen varying with no relation to cup ratio. Tegmen ratio adopted as height measured from center of arm openings divided by
width of calyx measured at center of arm openings from posterior interradius. Tegmen ratio varying from .22 to .60, averaging .390; ratio of smallest ten specimens averaging .345, of largest ten averaging .450. Hence larger specimens with definitely higher tegmens on the average; but tegmen ratios variable for calices at all sizes (Table I), and very high ratios in both the smallest (Pl. II, Fig. 10) and largest (Pl. VI, Fig. 1) specimens. Comparable low ratios found in several small (Pl. V, Fig. 5; Pl. IX, Fig. 12) and medium (Pl. IV, Fig. 3; Pl. III, Fig. 1) specimens.

In graphs of average height (from base of RR to apices of PBrBr,) plotted vs. average interarm width (between apices of PBrBr,) and vs. posterior interarm width (Fig. 1), variable ratios apparent for calices of all sizes. The former expressing graphically the cup ratio discussed above.

Radial ridges (on RR and PBrBr) much more strongly raised in smaller specimens (Pl. VIII, Fig. 9) than in larger (Pl. VIII, Fig. 4); cup of small calyx resembling frustrum of subpentagonal pyramid, and that of large calyx resembling frustrum of cone. Posterior interradius wider (Fig. 2) and more strongly convex than other interradii (Pl. V, Figs. 4, 12; Pl. IX, Figs. 9, 14).

Plates of calyx.—Monocyclic. Cup containing three BB, five RR, ten PBrBr, twenty SBrBr, twenty TBrBr, five ISBrBr, about twenty IBrBr, and about 14 to 16 plates in the X series. Arms normally free above TBrBr,.

Boundary of tegmen and cup marked by reversal of slope, but interbrachial series extending from cup onto tegmen in many specimens without change in pattern. Periproct eccentric.

BB nearly equal, together forming a greatly expanded disk, somewhat lobate (Pl. I, Fig. 7), about half the diameter of the total calyx (Pl. IV, Fig. 9) and more than three times the diameter of the adjoining columnal of the stem (Pl. IX, Fig. 13), in large specimens more than four times the diameter of the columnal (Pl. VI, Fig. 3). BB only about half as high as RR. One suture posterior, the other two BB sutures about 120° from it. Each B wide and hexagonal in lateral view, subtriangular in basal view.

RR hexagonal, the same size and shape as X, with it forming a ring of six equal plates above the BB (Fig. 2b). Each R broader than high. RR the largest plates in the calyx.

PBrBr × 5. PBrBr, smaller than RR, each broader than high, regularly hexagonal (right posterior radius, Fig. 2b) and rarely pentagonal (left posterior radius, Fig. 2b). Each PBr, invariably directly above corresponding R, bounded laterally by IBr or, in the posterior radii, by X, and X.

PBrBr, only slightly smaller than PBrBr, axillary. Each PBr, atop a PBr and below a pair of SBrBr, laterally adjacent to IBr, (or X). PBr,
TABLE 1
CERTAIN CHARACTERISTICS OF SPECIMENS OF Gennaeocrinus variabilis

<table>
<thead>
<tr>
<th>Catalog Number</th>
<th>Plate</th>
<th>Figure</th>
<th>Width in mm</th>
<th>Cup Ratio†</th>
<th>Tegmen Ratio‡</th>
<th>Ornamentation Type</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>37854...</td>
<td>II</td>
<td>10-13</td>
<td>2.7</td>
<td>.78</td>
<td>.56</td>
<td>1</td>
<td>Strong, high RR ridges.</td>
</tr>
<tr>
<td>37853...</td>
<td>V</td>
<td>9-12</td>
<td>2.8</td>
<td>.72</td>
<td>.35</td>
<td>1</td>
<td>RR ridges acute; few IR ridges reduced.</td>
</tr>
<tr>
<td>37842...</td>
<td>...</td>
<td>...</td>
<td>3.0</td>
<td>.97</td>
<td>*</td>
<td>2</td>
<td>Some plates nearly flat with large nodes.</td>
</tr>
<tr>
<td>40530...</td>
<td>I</td>
<td>5-9</td>
<td>3.1</td>
<td>.87</td>
<td>.41</td>
<td>1</td>
<td>Ridges broad and rounded.</td>
</tr>
<tr>
<td>37386...</td>
<td>...</td>
<td>...</td>
<td>3.3</td>
<td>.67</td>
<td>*</td>
<td>1</td>
<td>Strong RR ridges.</td>
</tr>
<tr>
<td>37382...</td>
<td>...</td>
<td>...</td>
<td>3.3</td>
<td>.79</td>
<td>.29</td>
<td>1</td>
<td>RR ridges very heavy; few IR ridges reduced.</td>
</tr>
<tr>
<td>37381...</td>
<td>...</td>
<td>...</td>
<td>3.3</td>
<td>.73</td>
<td>.25</td>
<td>1</td>
<td>Nodes biserial, absent between arm bases. Calyx plates moderately thick.</td>
</tr>
<tr>
<td>37382...</td>
<td>V</td>
<td>5-8</td>
<td>3.3</td>
<td>.73</td>
<td>.32</td>
<td>1</td>
<td>Few IR ridges reduced.</td>
</tr>
<tr>
<td>40537...</td>
<td>VI</td>
<td>4-8</td>
<td>3.3</td>
<td>.73</td>
<td>.42</td>
<td>1</td>
<td>RR ridges heavy; few IR ridges reduced.</td>
</tr>
<tr>
<td>40522...</td>
<td>...</td>
<td>...</td>
<td>3.5</td>
<td>.83</td>
<td>.22</td>
<td>1</td>
<td>Strong RR ridges; some IR ridges broken.</td>
</tr>
<tr>
<td>37380...</td>
<td>...</td>
<td>...</td>
<td>3.6</td>
<td>.83</td>
<td>.25</td>
<td>1</td>
<td>All ridges low and continuous.</td>
</tr>
<tr>
<td>40529...</td>
<td>...</td>
<td>...</td>
<td>3.6</td>
<td>.78</td>
<td>.38</td>
<td>2</td>
<td>Biserial plates between arm bases. Calyx plates very thick.</td>
</tr>
<tr>
<td>37378...</td>
<td>...</td>
<td>...</td>
<td>3.7</td>
<td>.76</td>
<td>.33</td>
<td>1</td>
<td>Biserial plates between arm bases. Calyx plates slightly thickened.</td>
</tr>
<tr>
<td>40528...</td>
<td>VIII</td>
<td>6-10</td>
<td>3.7</td>
<td>.76</td>
<td>.46</td>
<td>1</td>
<td>All ridges very strong.</td>
</tr>
<tr>
<td>40526...</td>
<td>II</td>
<td>5-9</td>
<td>3.7</td>
<td>.81</td>
<td>.36</td>
<td>1</td>
<td>RR ridges heavy.</td>
</tr>
<tr>
<td>40525...</td>
<td>III</td>
<td>6-10</td>
<td>3.7</td>
<td>.84</td>
<td>.38</td>
<td>1</td>
<td>RR ridges heavy; few IR ridges reduced.</td>
</tr>
<tr>
<td>37384...</td>
<td>IX</td>
<td>1-5</td>
<td>3.9</td>
<td>.69</td>
<td>.40</td>
<td>1</td>
<td>RR ridges heavy. Plates moderately thick.</td>
</tr>
<tr>
<td>37355...</td>
<td>IX</td>
<td>10-14</td>
<td>4.1</td>
<td>.76</td>
<td>.30</td>
<td>1</td>
<td>All ridges broken. Plates very thick.</td>
</tr>
<tr>
<td>40533...</td>
<td>IX</td>
<td>6-10</td>
<td>4.1</td>
<td>.88</td>
<td>.50</td>
<td>1</td>
<td>Heavy nodes on tegmen.</td>
</tr>
<tr>
<td>37397...</td>
<td>...</td>
<td>...</td>
<td>4.2</td>
<td>.84</td>
<td>.38</td>
<td>1</td>
<td>RR ridges heavy; few IR ridges reduced.</td>
</tr>
<tr>
<td>40524...</td>
<td>IV</td>
<td>6-9</td>
<td>4.2</td>
<td>.84</td>
<td>.44</td>
<td>1</td>
<td>Few IR ridges reduced.</td>
</tr>
<tr>
<td>40532...</td>
<td>IX</td>
<td>6-9</td>
<td>4.3</td>
<td>.75</td>
<td>.40</td>
<td>1</td>
<td>Plates slightly thickened.</td>
</tr>
<tr>
<td>37393...</td>
<td>IX</td>
<td>6-9</td>
<td>4.3</td>
<td>.79</td>
<td>.30</td>
<td>2</td>
<td>IR ridges partially broken. Large calyx nodes.</td>
</tr>
<tr>
<td>37398...</td>
<td>IX</td>
<td>6-9</td>
<td>4.3</td>
<td>.84</td>
<td>.40</td>
<td>2</td>
<td>Ridges broken. Plates thick.</td>
</tr>
<tr>
<td>37396...</td>
<td></td>
<td></td>
<td>4.3</td>
<td>.91</td>
<td>.36</td>
<td>2</td>
<td>Most ridges broken.</td>
</tr>
<tr>
<td>37392...</td>
<td></td>
<td></td>
<td>4.5</td>
<td>.82</td>
<td>.30</td>
<td>2</td>
<td>Not all ridges broken. Plates very thick.</td>
</tr>
<tr>
<td>37400...</td>
<td></td>
<td></td>
<td>4.5</td>
<td>.82</td>
<td>.45</td>
<td>2</td>
<td>Plates moderately thick. Vertical ridge on anal IR.</td>
</tr>
</tbody>
</table>

* Calyx and/or tegmen crushed or incomplete.
† Average interarm width in mm between apices of PBrBrz on all arms.
‡ Average height in mm from base of RR to apices of posterior PBrBrz divided by average interarm width in mm between apices of PBrBrz on all arms.
§ Height of tegmen in mm from center of arm openings divided by width of calyx in mm at center of arm openings measured from posterior interradius.
∥ Types of ornamentation arbitrarily set as follows:
Type 1: RR ridges generally broad, rounded, and continuous. Most IR ridges continuous. Calyx plates not conspicuously thickened. Tegmen plates usually with single, central node.
Type 2: RR ridges broken or depressed at sutures forming nodes or elevated area in center of plate. IR ridges usually reduced or broken at sutures; remainder of each ridge causing plate to thicken conspicuously toward its center, often forming node. Tegmen plates with central node or several nodes that may concrece.
Type 3: Ridges reduced to nodes or thin and steep-sided. Calyx nodes large. Plate surfaces evenly convex and not thickened toward center by ridges. Tegmen plates with large nodes or cockscombs.
TABLE I (Continued)

<table>
<thead>
<tr>
<th>Catalog Number</th>
<th>Plate</th>
<th>Figure</th>
<th>Width in mm</th>
<th>Cup Ratio</th>
<th>Tegmen Ratio</th>
<th>Ornamentation Type</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>37843</td>
<td></td>
<td></td>
<td>4.5</td>
<td>.82</td>
<td>.50</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>37850</td>
<td></td>
<td></td>
<td>4.5</td>
<td>.89</td>
<td>.45</td>
<td>2</td>
<td>All ridges broken. Plates thick.</td>
</tr>
<tr>
<td>37857</td>
<td></td>
<td></td>
<td>4.5</td>
<td>.92</td>
<td>*</td>
<td>2</td>
<td>Few IR ridges unbroken.</td>
</tr>
<tr>
<td>37847</td>
<td></td>
<td></td>
<td>4.6</td>
<td>.74</td>
<td>.30</td>
<td>2</td>
<td>Some ridges unbroken. Biserial plates between arm bases. Several nodes on tegmen plates.</td>
</tr>
<tr>
<td>37849</td>
<td></td>
<td></td>
<td>4.7</td>
<td>.72</td>
<td>.25</td>
<td>2</td>
<td>Plates very thick. Vertical anal ridge.</td>
</tr>
<tr>
<td>37844</td>
<td></td>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks**

- Biserial plates between arm bases. RR ridges partially broken. Few IR ridges unbroken.
- All ridges broken. Plates very thick. Vertical anal ridge.
- All ridges broken. Plates extremely thick.
- All ridges broken; plates very thick; plates between arm bases nearly biserial.
- Several nodes on each tegmen plate.
- All ridges broken. Plates moderately thick. Several nodes on each tegmen plate.
- Ridges partially broken. Very thick plates.
- More IR ridges unbroken. Ridges high and thin. Large flared nodes on tegmen.
- Large calyx nodes. Low acute ridges.
- High, thin, broken ridges.
- Plates very thick. Most ridges broken. Biserial plates between arm bases.
- Most ridges broken. Biserial plates between arm bases.
- Several ridges unbroken.
- Plates very thick. Most ridges broken.
- Large central nodes on calyx plates. Some ridges reduced to nodes, others complete.
- Very heavy calyx nodes. Few ridges. Large cockscombs on tegmen.
- Ridges low and thin or reduced to nodes.
- Low, thin ridges and large calyx nodes.
- Few low, thin, unbroken ridges.
- Ridges, nearly reduced. Large calyx nodes. Large and small nodes on tegmen plates.
- Nodes on tegmen.
- Plates moderately thick.
- Ridges broken.
- Ridges broken.
- Ridges broken. Biserial plates without nodes between arm bases.
Average interarm width between apices of $PBrB_2$ on posterior arms

Posterior interarm width between apices of $PBrB_2$ on posterior arms

**Fig. 1.** Graphs of measurements of 63 specimens of *Gennaeocrinus variabilis*, sp. nov. Average height plotted vs. average interarm width (above) and against posterior interarm width (below). Average height measured from base of RR to apices of $PBrBr_2$ on posterior arms, average interarm width measured between apices of $PBrBr_2$ on all arms, and posterior interarm width between apices of $PBrB_2$ on posterior arms. From inspection of all specimens, these parameters were adjudged to be the least affected by distortion due to crushing. A binocular microscope with a calibrated eye-piece was used to measure the specimens. Large dots represent one specimen; dots within circles, two specimens; and dots within triangles, three.
therefore normally pentagonal, but rarely hexagonal where adjacent to IBr1 and IBr2 (left posterior radius, Fig. 2b).

SBrBr 2 × 10. SBrBr1 almost as large as PBrBr2 on which they rest; each plate broader than high, normally hexagonal, bounded by PBr2, IBr2, IBr3, SBr2, ISBr, and the other SBr1 of the pair, rarely pentagonal where adjacent laterally to IBr2 only. SBrBr next to anal series bounded by X2 and X3 (Fig. 2b). In right anterior radius of one specimen (Pl. IV, Fig. 10) SBrBr2 not in contact and ISBr extending down to PBr2.

SBrBr2 nearly the same size as SBrBr3, axillary, followed by a pair of TBrBr1. Each SBr2 normally pentagonal, laterally bordered by ISBr and IBr3 or X3; in the left posterior ray of the holotype (Fig. 2b), the left SBr2 also in contact with IBr2.

TBrBr at least 2 × 20. TBrBr1 normally the last of the radial series definitely a part of the cup, with arms becoming free in succeeding plates. Each TBr1 a broad disk, subpentagonal in lateral view, adjoining the paired TBr1 through about two-thirds of its height, extending around the outer part of the food groove as a thick crescent (Pl. I, Fig. 3; Pl. III, Fig. 3; Pl. IV, Fig. 3).

In some series TBr2 axillary, giving rise to QBrBr; in others 5 or 6 TBrBr observed with none axillary. Insofar as observed, all axillary TBrBr2 on the inner side of the half-ray.

Arms four to six per ray, 20 to 30 per crinoid. Each half-ray with two or three arms, not in a regular branching pattern. Plates biserial above TBr5 or TBr6, or, where TBr2 on inner side of half-ray is axillary, biserial above QBr5 or QBr6. Arms with relatively flat backs. Pinnules long and slender.

Interbrachials in small specimens distinctly below strong radial ridges, in large specimens only slightly lower if at all. IBrBr1 large, only slightly smaller than RR, normally hexagonal, with lower apex between RR, upper apex between IBrBr3, and sides adjacent to PBrBr1. In left posterior ray of holotype (Fig. 2b) IBr1 septagonal, also in contact with PBr2. Successive rows of IBrBr with smaller plates, most specimens with two IBrBr2 and two IBrBr3, a few with an extra plate in one or more rows. Most plates hexagonal or septagonal, arranged opposite or offset. IBrBr series merging with tegmen above third or fourth row.

Anal series wider than other interbrachial series, in its center almost twice as wide (Fig. 2b). X the same size and shape as the RR with which it is laterally aligned. Successive rows of XX smaller. Three XX1, hexagonal; five XX2, variously pentagonal, hexagonal, or septagonal; four or five XX4, more irregular than preceding row; and two or three XX6, various shapes. Series merging with tegmen above fourth row.
One large, vertically elongate ISBr in each radius (Fig. 2b) extending up between SBrBr and TBrBr to tegmen in most specimens (Pl. IV, Fig. 1;
Pl. V, Fig. 1); in a few rays replaced by two plates of nearly equal size (Pl. III, Fig. 5; Pl. VII, Fig. 1) or even three (Pl. VIII, Fig. 1). Some series with one narrow ITBr, others without any plate between TBrBr.

Tegminal plates varying in number, shape, and arrangement. In some specimens, biserial plates extending regularly from cup onto tegmen in interradii (Pl. III, Fig. 2; Pl. IV, Fig. 2; especially Pl. VII, Fig. 2; and Pl. VIII, Fig. 2). In others, plates in interradii with no biserial arrangement. Radial plates normally much smaller and less regular than interradial.

Periproct eccentric, displaced toward the posterior side, consisting of very small plates around the anus and a ring of larger plates bearing strong ornamentation to form a wreath, the whole having the shape of a rosette. In small specimens (Pl. I, Fig. 5; Pl. II, Fig. 11; Pl. V, Fig. 10) the ornamentation on the outer ring of plates not strongly differentiated from that on other plates of the tegmen; in large specimens (Pl. I, Fig. 2; Pl. V, Fig. 2) plates increasing in size from anus outward, with the plates of the outer ring bearing cockscomb structures flared outward like petals of a flower.

Uppermost columnal of stem leaving a distinct impression on center of BB disk, in small specimens about one-third the diameter of the disk (Pl. I, Fig. 7; Pl. II, Fig. 12), in medium specimens about one-fourth (Pl. IV, Fig. 9; Pl. VIII, Fig. 4; Pl. IX, Figs. 4, 13), and in large specimens about one-fifth (Pl. VI, Fig. 3), but with exceptions. Outer margin of impression radially grooved. Central opening of columnals quinqulobate, about one-fourth the diameter of the columnal.

Ornamentation.—In general, strongly developed vertical ridges through the middle of each plate in the radial series as far as arm bases, and smaller and narrower ridges radiating from the center of each cup plate to the centers of adjoining plates. Ornamentation of cup and tegmen variable at each size of calyx, but generally increasing in thickness with increase in size of calyx. Ornamentation of calyx classified in three ornamentation types (Table I).

Type 1, characteristic of small calices: radial ridges broad, high, rounded, and continuous. Most interradial ridges distinct, sharp, and continuous. Tegminal plates with small central spines, very small specimens with a single, central spine on each plate. Typical specimens shown in Pl. V, Figs. 9–12; Pl. VIII, Figs. 6–10.

Type 2, characteristic of medium calices: radial ridges interrupted or depressed at sutures, forming node or elevated bar in middle of each plate. Interradial ridges interrupted at sutures, many further dissected into segments, centers of plates conspicuously thickened at junctions of ridges. Tegminal plates with central nodes, fused nodes, and/or cockscomb struc-
tures, with the central plates bearing the more complex ornamentation. Typical specimens shown in Pl. III, Figs. 1–5; Pl. IV, Figs. 1–5; Pl. VIII, Figs. 1–5.

Type 3, characteristic of large calices: radial ridges reduced to nodes or very thin and steep-sided. Interradial ridges very discontinuous, in some specimens expressed only as central large nodes or cockscomb structures. Remainder of plate surfaces evenly convex, not thicker in positions of ridges. Tegmental plates thick in center, with groove along sutures, bearing large nodes, irregular vermiform nodes, or large cockscomb structures. Typical specimens shown in Pl. I, Figs. 1–4; Pl. V, Figs. 1–4; Pl. VI, Figs. 1–3.

Cockscomb structures on tegmen apparently result of fusion of several small nodes or spines. Interradial plates of tegmen in some specimens biserial and unornamented (Pl. VII, Fig. 2; Pl. VIII, Fig. 2).

Remarks.—The variable nature of this species is well documented in the plate illustrations. Calices of the same size vary in shape (Fig. 1). The number of plates varies in the $IBrBr$ series and in the arms.

The most pronounced variation is in the number of arms. A specimen may have two or three arms in each half-ray. There is invariably only one arm in the outer part of each half-ray in the $TBrBr$ series, but the inner part (nearest the median line of the ray) may have either a uniserial $TBrBr$ series forming one arm, or the $TBr_2$ may be axillary giving rise to two arms of the $QBrBr$ series. The two halves of one ray may or may not have the same number of arms. We found no indication of branching in the $QBrBr$ series. In the specimens studied, no ray has a constant number of arms.

The unusually large range in ornamentation indicates that the species followed a general trend toward coalescence and simplification of elements, but exceptions were found. It would appear imperative, in studying a species of *Gennaeocrinus*, to include specimens of as many growth stages as possible.

Comparison with other species.—The distinguishing characters of all described species are tabulated in Table II. Much of the desired information about several species is not available in literature, and we hope to complete a more thorough study of *Gennaeocrinus* based on our own observations.

Our new species is readily differentiated from the other species that have two $SBrBr$. It has a variable number of arms and smooth margins on the $PBrBr$, $SBrBr$, and $TBrBr$, whereas *G. arkonensis* is reported to have 20 arms and crenulate margins on the bacular plates. *G. variabilis*, sp. nov., has one or two arms on the inner half-ray, but *G. decorus* has only one in known specimens. Our crinoid differs from *G. kentuckiensis* in that it has
one or two arms on the inner half-ray, the tegmen lacks a central spine, and the ornamentation is coarse. The absence of five long spines around the periproct (at the summit of the tegmen) distinguishes *G. variabilis* from *G. mourantae*. Further, the anal series in *G. variabilis* is ornamented with ridges comparable to those in other interbrachial series, whereas the anal series in *G. mourantae* is ornamented with much stronger ridges than the other interbrachial series. The smooth basals and one or two arms on the inner half-ray separate *G. variabilis* from *G. similis*, which has tuberculated margins on the basals and invariably only one arm on the inner half-ray. On *G. similis* the radial ridge bifurcates at the center of the RR to form an inverted V.


**LITERATURE CITED**


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<table>
<thead>
<tr>
<th>Species</th>
<th>Secundibrachts</th>
<th>Arm Branching Pattern Above Secundibrachts</th>
<th>Arms Per Ray</th>
<th>Total Number of Arms</th>
<th>Interbrachial series</th>
<th>Anal Series</th>
<th>Distinctive Ornamentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>arkonensis</td>
<td>2 × 10</td>
<td>One arm, biserial above TBr₁</td>
<td>One arm, biserial above TBr₂</td>
<td>4</td>
<td>20</td>
<td>?</td>
<td>1–3–5 Dorsal cup finely pitted, forming reticulate pattern; crenulate margin on PBrBr, SBrBr, TBrBr.</td>
</tr>
<tr>
<td>Wood</td>
<td>1 × 10</td>
<td>One arm, biserial above TBr₁</td>
<td>One arm, biserial above TBr₂</td>
<td>6</td>
<td>30</td>
<td>1–2–3 or 1–3–4</td>
<td>1–3–4 or 1–3–5 Strong spine surrounded by smaller spines on ambulacral area adjacent to free arms.</td>
</tr>
<tr>
<td>carinatus var.</td>
<td>1 × 10</td>
<td>Axillary TBr with two arms</td>
<td>One arm, biserial above TBr₂</td>
<td>6</td>
<td>30</td>
<td>1–2–3 or 1–3–4</td>
<td>1–3–4 or 1–3–5 Tegmen spines longer and stouter.</td>
</tr>
<tr>
<td>crassicoostatus</td>
<td>1 × 10</td>
<td>Axillary TBr with two arms</td>
<td>One arm, biserial above TBr₂</td>
<td>6</td>
<td>30</td>
<td>1–2–3 or 1–3–4</td>
<td>1–3–4 or 1–3–5 Tegmen spines longer and stouter.</td>
</tr>
<tr>
<td>Rowley</td>
<td>One arm</td>
<td>6</td>
<td>1–3–3</td>
<td>1–3–5</td>
<td></td>
<td>!</td>
<td>Short, stout central spine; smooth ventral plates.</td>
</tr>
<tr>
<td>comptus var.</td>
<td>1 × 10</td>
<td>One arm</td>
<td>6</td>
<td>1–3–3</td>
<td>1–3–5</td>
<td></td>
<td>Short, stout central spine directed slightly backward; five stout amb. spines directed slightly outward; smooth ventral plates.</td>
</tr>
<tr>
<td>spiniferus</td>
<td>One arm</td>
<td>6</td>
<td>1–3–3</td>
<td>1–3–5</td>
<td></td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>Rowley</td>
<td>One arm</td>
<td>6</td>
<td>1–3–3</td>
<td>1–3–5</td>
<td></td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>decorus</td>
<td>2 × 10</td>
<td>One arm, biserial above TBr₁ or TBr₂</td>
<td>Two TBrBr, 2d axillary with two arms</td>
<td>6</td>
<td>30</td>
<td>1–2–3</td>
<td>unknown No spines or nodes on plates of dorsal cup and arms.</td>
</tr>
<tr>
<td>Goldring</td>
<td>One arm</td>
<td>6</td>
<td>1–2–3</td>
<td>1–3–5</td>
<td></td>
<td>!</td>
<td>Small node or tubercle on outer side of each brachial above place of attachment of each arm pinnule.</td>
</tr>
<tr>
<td>eucharis</td>
<td>1 × 10</td>
<td>One axil. TBr with 3–4 QBrBr on each face;</td>
<td>One arm, biserial above TBr₂</td>
<td>8</td>
<td>40</td>
<td>1–2–3–2 (or 3)–?2</td>
<td>1–3–5</td>
</tr>
<tr>
<td>Hall</td>
<td>One arm</td>
<td>6</td>
<td>1–3–5</td>
<td>1–3–5</td>
<td></td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>facetus</td>
<td>1 × 10</td>
<td>One axillary TBr with two arms</td>
<td>One arm</td>
<td>6</td>
<td>30</td>
<td>1–3–2</td>
<td>1–3–5–5–(5)</td>
</tr>
<tr>
<td>Rowley</td>
<td>One arm</td>
<td>6</td>
<td>1–3–2</td>
<td>1–3–5</td>
<td></td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>goldringae</td>
<td>1 × 10</td>
<td>Two TBrBr with two arms</td>
<td>Two TBrBr with two arms; TBr₂ indicates arm bifurcation on two rays</td>
<td>4?†</td>
<td>20?</td>
<td>1–2–3–2</td>
<td>1–3–3–2 (or 3)–2 Prominent spines at or near center of RR, PBrBr, IBBr, X and X₁ series.</td>
</tr>
<tr>
<td>Ehlers</td>
<td>Two TBrBr with two arms; TBr₂ indicates arm bifurcation on two rays</td>
<td>4?†</td>
<td>20?</td>
<td>1–2–3–2</td>
<td>1–3–3–2 (or 3)–2 Prominent spines at or near center of RR, PBrBr, IBBr, X and X₁ series.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>kentuckienensis</td>
<td>1 × 10 or 2 × 10‡</td>
<td>One arm, biserial above TBr₁</td>
<td>TBrBr with one arm</td>
<td>8</td>
<td>40</td>
<td>1–3–4 (or 5) or 1–2–4</td>
<td>1–3–5–5 (or more) Long central spine on tegmen.</td>
</tr>
<tr>
<td>(Shumard)</td>
<td>Axillary TBr on face nearest median line with two QBrBr on each face; QBrᵢ away from median line axillary with quinquebrachus series on each face</td>
<td>TBrBr with one arm</td>
<td>8</td>
<td>40</td>
<td>1–3–4 (or 5) or 1–2–4</td>
<td>1–3–5–5 (or more) Long central spine on tegmen.</td>
<td></td>
</tr>
<tr>
<td>Species</td>
<td>$moureutacae$ Goldring</td>
<td>$nyssa$ Hall</td>
<td>$peculiaris$ Goldring</td>
<td>$percarinatus$ Goldring</td>
<td>$sculptus$ Rowley</td>
<td>$similis$ Goldring</td>
<td>$simulans$ Rowley</td>
</tr>
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<td>------------------</td>
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<td>-------------------------</td>
<td>------------------</td>
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<td>-------------------</td>
</tr>
<tr>
<td></td>
<td>2 x 10</td>
<td>1 x 10</td>
<td>Variable, 1 x 10 or 2 x 10 on same specimen</td>
<td>Number and character of arms unknown</td>
<td>1 x 10</td>
<td>2 x 10</td>
<td>2 x 10</td>
</tr>
<tr>
<td></td>
<td>Two $TBrBr$, 2d axillary with two arms, biserial above $QBrr$-$QBrr_s$</td>
<td>Axillary $TBr$ with two arms; arm away from median line bifurcates near calyx</td>
<td>Usually one axillary $TBr$ with two arms</td>
<td>Number and character of arms unknown</td>
<td>§</td>
<td>§</td>
<td>§</td>
</tr>
<tr>
<td></td>
<td>One arm, biserial above $TBr_s$</td>
<td>One arm, biserial above $TBr_s$-$TBr_s$</td>
<td>One arm</td>
<td>One arm, biserial above $TBr_s$-$QBrr$-$QBrr_s$</td>
<td>One arm, biserial above $TBr_s$</td>
<td>One arm, biserial above $TBr_s$</td>
<td>One arm</td>
</tr>
<tr>
<td></td>
<td>6 (8 on posterior radii)</td>
<td>8</td>
<td>5-6</td>
<td>1-2-3 (to 5)</td>
<td>1-2-3-4</td>
<td>1-2-2</td>
<td>1-2-3-4</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>40</td>
<td>30?</td>
<td>1-2-3-5-6</td>
<td>unknown</td>
<td>1-2-4</td>
<td>1-3-4</td>
</tr>
<tr>
<td></td>
<td>1-2-2</td>
<td>1-2-3</td>
<td>1-3-5</td>
<td>1-2-3-5-6</td>
<td>1-2-3-5-6</td>
<td>1-2-3-4</td>
<td>1-3-4</td>
</tr>
</tbody>
</table>

|                  | Five stout, vertical spines on summit of tegmen; strong, star-shaped nodes on center anal series plates. | Prominent nodes on radial series up to $SBrBr$; spinose nodes on $PBr_r$. | Strong, continuous radial ridge without nodes at center of plates; concave, three sided pyramid on center of each radial, extending beyond basals. | Ridges and carinae sharply defined; 2d and often 3d well-defined carinae parallels main one; scattered or broken lines of tubercles in angles between coarse and fine carinae. | Five short amb. spines and probably low central spine; strong central node on $RR$, projecting outward. | Surface reticulated or granulose; tuberculated margins on projecting basals. | Right and left radial ridges fork at center or radial and form inverted V. | Flaring extensions on large plates around anus forming rosette; tegmen plates with central protuberance ranging from node to elevated cockscomb structure; node to elevated cockscomb structure on dorsal plates. |

* All species have three $BR$, five $RR$, and two $PBrBr$.
† "The seeming axillary nature of the two tertibrachs may indicate the presence of more than four arms to the ray" (Ehlers, 1925, p. 104).
‡ "The single secundibrach is probably the fusion of two secundibrachs" (Kirk in Goldring, 1923, p. 211).
§ "Like $G. comptus$ and $G. facetus$, it has thirty arm bases . . ." (Rowley in Greene, 1903, p. 104).
EXPLANATION OF PLATE I

(All figures x 3)

Gennaeocrinus variabilis, sp. nov. ........................................... 174

Figs. 1-4. Anterior, tegminal, posterior, and basal stereograms of paratype, UMMP 40521. Cup plates are greatly thickened by nodes at junctions of ornamental ridges, ridges are thin and discontinuous (Fig. 4). Tegmen is ornamented by large cockscomb structures (Fig. 2). In Figs. 2 and 4, posterior is at the lower left. Ornamentation is type 3.

Figs. 5-9. Tegminal, anterior, basal, posterior, and inclined right posterior stereograms of paratype, UMMP 40530. Radial ridges are broad and strongly developed (Fig. 9), and interbrachial ridges are complete (Fig. 8). Tegmen ornamented by spines, nodes, and small cockscomb structures; rosette around periproct not as strongly developed as in larger specimens (Fig. 5). Disk of BB trilobate (Fig. 7).
Gennaeocrinus variabilis, sp. nov. ............................. 174

Figs. 1-4. Anterior, tegminal, posterior, and basal stereograms of paratype, UMMP 40520. Ornamental ridges of cup with nodes at their junctions, making plates very thick in their centers (Fig. 4). Ridges interrupted at sutures (Figs. 1, 3). Tegmen crushed down over edge of cup anteriorly (Fig. 1). Interbrachial plates extending onto tegmen in biserial arrangement (Fig. 2). In Figs. 2 and 4, posterior at the lower left. BB very wide in relation to adjacent columnal of stem (Fig. 4).

Figs. 5-9. Anterior, tegminal, posterior, basal, and inclined left posterior stereograms of paratype, UMMP 40526. Radial ridges are strongly developed, other ridges of the cup nearly complete; ornamentation of type 1. Most tegminal plates with single spines, a few with cockcomb structures (Fig. 6).

Figs. 10-13. Anterior, tegminal, posterior, basal, and posterior stereograms of paratype, UMMP 37854, the smallest specimen studied. BB nearly complete (Fig. 12). Periproct rosette of ornamented plates not sharply differentiated from other tegminal plates (Fig. 11).
EXPLANATION OF PLATE III

(All figures x 3)

*Gennaeocrinus variabilis*, sp. nov. ........................................... 174

**Figs. 1-5.** Posterior, tegminal, anterior, basal, and inclined right posterior stereograms of paratype, UMMP 40539. Tegmen ornamented with small nodes, some of which are fused to form incipient cockscomb structures (Fig. 2). Some ridges on cup uninterrupted; plates moderately thickened at centers; ornamentation type 2 (Fig. 5).

**Figs. 6-10.** Posterior, tegminal, anterior, basal, and inclined right posterior stereograms of paratype, UMMP 40525. Radial ridges strongly developed, other ridges for the most part continuous; ornamentation type 1.
EXPLANATION OF PLATE IV

(All figures x 3)

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FIGS. 1–5. Anterior, tegminal, posterior, basal, and inclined right posterior stereograms of paratype, UMMP 40523. Calyx low and broad, with wide interarm areas (Fig. 1). The two SBrBr and ISBr in right anterior and right posterior radii readily distinguished (Fig. 5). Nearly all ridges interrupted; ornamentation type 2. Unornamented interbrachial plates extending onto tegmen in biserial arrangement (Fig. 2).

FIGS. 6–10. Anterior, tegminal, posterior, basal, and inclined right posterior stereograms of paratype, UMMP 40524. BB with flaring trilobate rim (Fig. 9). Most ornamental ridges complete; ornamentation type 1. Rosette around periproct not well developed (Fig. 7).
EXPLANATION OF PLATE V

(All figures x 3)

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Figs. 1-4. Anterior, tegminal, posterior, and basal stereograms of holotype, UMMP 40535, one of the large specimens. The pattern of ornamentation on the cup is distinct, although the ridges are narrow and in part reduced to knobs and nodes. Sutures are exceptionally distinct. Both nodes and cockcomb structures are present on the elevated tegmen (Fig. 2).

Figs. 5-8. Anterior, tegminal, posterior, and basal stereograms of paratype, UMMP 37852, one of the small specimens. The ornamentation is distinct and the radial ridges strong. The disk of BB is trilobate (Fig. 8).

Figs. 9-12. Anterior, tegminal, posterior, and basal stereograms of paratype, UMMP 37853, the smallest of the types. Note the strong radial ridges and well-developed ornamentation.
**GENNAEOCRINUS VARIABILIS**

**EXPLANATION OF PLATE VI**

(All figures x 3)

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**Figs. 1–3.** Anterior, posterior, and basal stereograms of paratype, UMMP 40536, the largest specimen found and presumably gerontic. Ornamental ridges on plates of the cup are reduced to small nodes and large cockscomb structures (Fig. 1). The flaring *BB* are complete on the left side of the specimen (Figs. 2–3). Anteriorly the tegmen is ornamented with small nodes (Fig. 1) and posteriorly with large nodes and cockscomb structures (Fig. 2). The right half of the right anterior ray has two single arms with a *TBrBr* series; the left half of the anterior ray has a single arm on the outside and an axillary *TBr* on the inside, which would give rise to two arms (Fig. 1).

**Figs. 4–8.** Anterior, basal, posterior, tegmental, and inclined left anterior stereograms of paratype, UMMP 40537. The *BB* are nearly complete (Fig. 5). Radial ridges are strongly developed (Fig. 8).
EXPLANATION OF PLATE VII

(All figures x 3)

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Figs. 1–5. Anterior, tegmental, inclined left posterior, posterior, and basal stereograms of paratype, UMMP 40527. Wide, biserial, unornamented plates extend far onto the tegmen in regular series in the interambulacra (Fig. 2). The eccentric anal rosette is bordered by flaring plates (Fig. 2). Centers of cup plates are thickened conspicuously by nodes developed at junctions of the discontinuous ridges (Fig. 5).

Figs. 6–9. Tegmental, anterior, posterior, and basal stereograms of paratype, UMMP 40538. In Figs. 6 and 9, posterior is at the lower left. Ornamentation on the cup is well defined, with the ridges more continuous than those in UMMP 40527 (compare Figs. 1 and 7, 4 and 8).
EXPLANATION OF PLATE VIII

(All figures x 3)

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Figs. 1–5. Anterior, tegminal, posterior, basal, and inclined left posterior stereograms of paratype, UMMP 40542. Arm plates above the $TBr_5$–$TBr_8$ level are biserial (Fig. 2). Most of the tegmen plates have a single central node (Fig. 2). Unornamented biserial plates extend onto the tegmen (Figs. 1–2).

Figs. 6–10. Anterior, tegminal, posterior, basal, and inclined left anterior stereograms of paratype, UMMP 40528. Radial ridges are strong in contrast to the interradial ridges. High, pointed nodes are present near the center of the tegmen (Fig. 10). The $BB$ are complete (Fig. 9).
EXPLANATION OF PLATE IX

(All figures x 3)

Gennaeocrinus variabilis, sp. nov. .............................................. 174

Figs. 1–5. Anterior, tegmental, posterior, basal, and inclined right posterior stereograms of paratype, UMMP 40531.

Figs. 6–9. Anterior, tegmental, posterior, and inclined right anterior stereograms of paratype, UMMP 40532.

Figs. 10–14. Anterior, tegmental, posterior, basal, and inclined right anterior stereograms of paratype, UMMP 40533.