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OCCURRENCE AND VARIATIONS OF *BOTRYOCRINUS THOMASI* LAUDON IN THE THUNDER BAY LIMESTONE OF MICHIGAN

BY
ROBERT V. KESLING

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Volume XVIII

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CONTENTS

INTRODUCTION

Three specimens of *Botryocrinus thomasi* Laudon from Michigan have stratigraphic and taxonomic significance. Their occurrence in the Thunder Bay Limestone strengthens the correlation of this formation with the Cedar Valley Formation of Iowa, from which the species was first described. Their variations include an exception to the current generic description of *Botryocrinus* and to the familial description of Botryocrinidae.

In studying crinoids collected from the Thunder Bay Limestone at Partridge Point, a few miles south of Alpena, Michigan, I found two specimens of *Botryocrinus* from that place in the Museum of Paleontology of The University of Michigan and one in a group of specimens on loan from Buffalo Museum of Natural Sciences. The latter was among crinoids loaned for study by Dr. Fred Hall, Director of the Museum, to whom I am indebted for this favor. The three specimens are highly ornate and obviously conspecific. Through the courtesy of Mr. Harrel Strimple, Curator of Fossil Invertebrates at the State University of Iowa, I was permitted to compare them with the type specimens of *Botryocrinus thomasi* Laudon from the Cedar Valley Formation near Iowa City, Iowa. In my opinion, the Michigan and Iowa crinoids are one species.

The correlation of the Thunder Bay Limestone and the Cedar Valley Formation was suggested many years ago, because of similarities of their fossil faunas. In 1885, the Reverend W. H. Barris established the occurrence of *Dolatocrinus triangulatus* (Barris) in both formations. Cooper and others (1942, p. 1786) stated that certain brachiopods, as well as the trilobite *Scutellum tullium depressum* Cooper and Cloud, are common to the two faunas. Bassler and Moodey (1943) reported that the crinoids *Dolatocrinus triangulatus* (Barris), *Euryocrinus barrisi* Springer, and *Megistocrinus nodosus* Barris and the blastoids *Nucleocrinus meloniformis* (Barris) and *N. obovatus* (Barris) are confined to the two formations. Hence, the discovery of *Botryocrinus thomasi* in the Thunder Bay Limestone was not surprising.

The variations, however, were not expected. In the posterior region, anomalies are present in two of the three Michigan specimens. One has two *IBB* fused, so that only four exist. The other has its *RA* greatly enlarged, hexagonal instead of quadrate, and extending dorsally to a junction with an *IB*, thus interrupting the *BB* circlet. This specimen, UMMP No. 47113, also has the ornamentation noticeably shallower than that in the other two specimens, but it agrees closely with them in size, shape, and pattern of ridges. If, as I believe, it is conspecific with the other Michigan crinoids and with the Iowa specimens, then it is an example of an anomaly that technically contradicts the definition of the family Botryocrinidae as given by Moore and Laudon (1943, p. 54); according to their classification, a small quadrate *RA* is an essential feature of Botryocrinidae, and a large hexagonal *RA* extending to the *IBB* circlet characterizes the family Thenarocrinidae of Silurian age. Occurrence of the two anomalous specimens is thought to indicate that the region of the posterior interray and C-ray is relatively unstable in this species.

Of the three specimens described in this paper, one is catalogued and deposited in the Buffalo Museum of Natural Sciences as BMNS No. E-16584. The other two are in the Museum of Paleontolgy of The University of Michigan as UMMP Nos. 47113 and 47114.

LOCALITY

The specimens described here are all from the same locality.

Bluffs on the northeast side of Patridge Point, about 4 miles south of Alpena, Michigan, extending from the center of Sec. 11 into its SE¼, T. 30 N., R. 8 E., type locality of Thunder Bay Limestone. One specimen, UMMP No. 47114, found by Dr. Carl L. Rominger many years ago, probably in August, 1898, at which time he made a large collection of crinoids at this place. Two specimens, BMNS No. E16584 and UMMP No. 47113, found by Mr. I. G. Reimann, the former in 1945 and the latter on June 8, 1953.

SYSTEMATIC DESCRIPTION

Subclass INADUNATA Wachsmuth and Springer, 1885
Order CLADIDA Moore and Laudon, 1943
Suborder DENDROCRINOIDEA Bather, 1899
Family Botryocrinidae Bather, 1899
Genus *Botryocrinus* Angelin, 1878
Botryocrinus thomasi Laudon, 1936
(Figs. 1–2; Pls. I–III)

Botryocrinus thomasi Laudon, 1936, p. 62, Figs. 4–6; Bassler and Moodey, 1943, p. 339.

Known specimens show character of all plates of dorsal cup, attached proximal columnal, and arms beyond PBr_3. Detached section of column several centimeters long on slab bearing holotype is probably part of the specimen represented by the dorsal cup. Tegmen and anal sac are unknown.

Dorsal cup.—Cup bowl-shaped, not conical. Average diameter about 1½ times height. Columnar facet more than ⅕ diameter of cup. Plates normally consisting of five *IBB*, five *BB*, five *RR*, one *RA*, and one *X*. Plates strongly convex, with corners indented and centers of adjacent plates linked by ridges.

IBB small, forming complete circlet, five equal plates in normal specimens (Pl. I, Fig. 4). Each *IB* pentagonal with its upper (ventral) corner inserted between adjacent *BB*, ornamented with a U-shaped ridge having each end directed toward the center of the *B*; in lateral view, ridges of *IBB* extending well below columnar facet, forming "feet" upon which dorsal cup may rest when disarticulated from column (Pl. I, Fig. 2). Anomalous development in UMMP No. 47114, in which only four *IBB* are present, those of C- and D-rays being fused (Pl. III, Fig. 5); from center of fused *IB*, about twice the size of other *IBB*, diagonal ridges leading to *BB* of BC- and DE-interrays and short vertical ridge to *B* of CD-interray.

BB circlet complete, consisting of nearly equal plates. Each *B* bordered below by two *IBB*, laterally by two other *BB*, and above by two *RR*; in addition, *BB* of BC- and CD-interrays bordered by *RA*, thus being septagonal instead of hexagonal as other *BB*. *BB* nearly as large as *RR*, their convexity producing the bowl shape of the dorsal cup. From the center of each plate, one ridge to each side. Anomalous development of *IBB* in UMMP No. 47114, wherein two plates are fused, producing hexagonal shape in *B* of CD-interray (Fig. 2*b*). Anomalous enlargement of *RA* in UMMP No. 47113, extending to junction with *IB* of C-ray, interrupting the *BB* circlet and causing *B* of BC-interray to be pentagonal and *B* of CD-interray to be hexagonal (Fig. 2*c*).

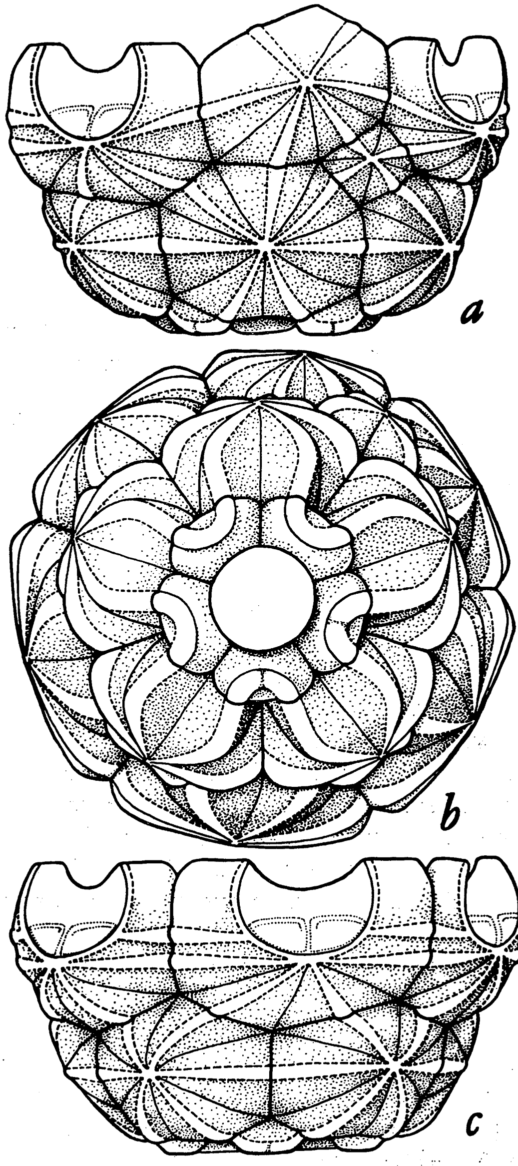

FIG. 1. Reconstruction of *Botryocrinus thomasi* Laudon. *a,* posterior view (centered on CD-interray), with *X* at center of upper margin and quadrate *RA* below and to the right. *b,* basal view with CD-interray at top; central blank circle represents junction with the column. *c,* view centered on A-ray. Approximately $\times$ 6.

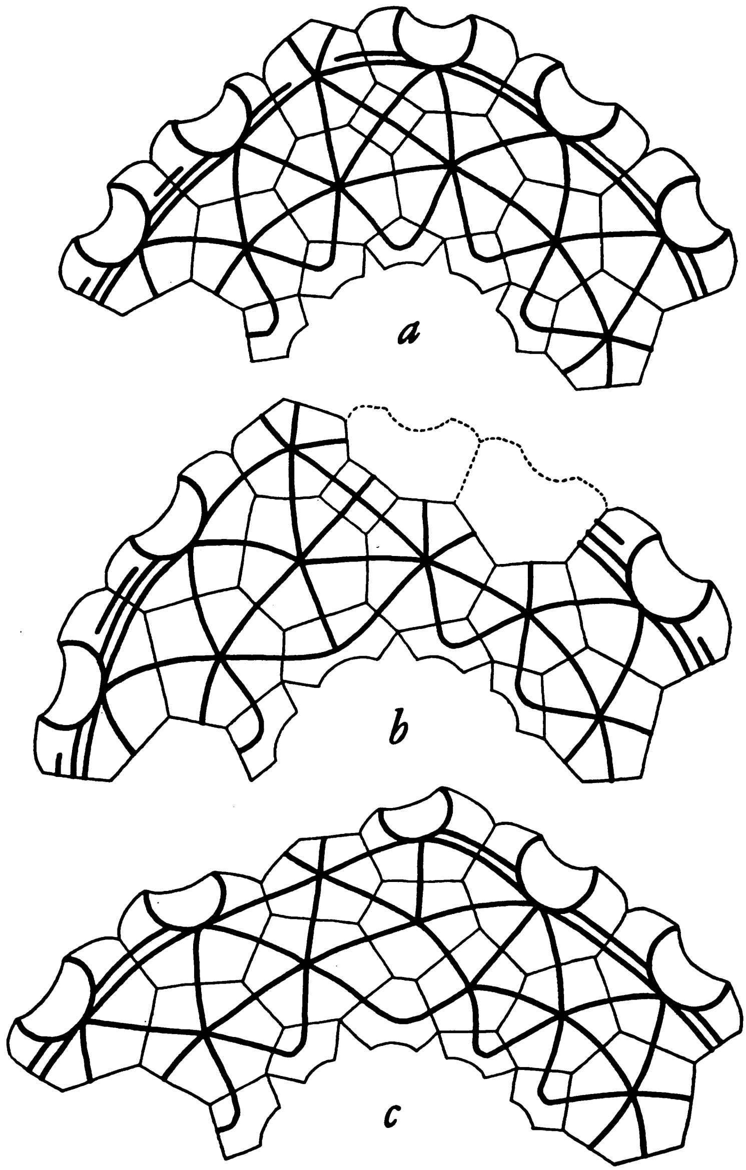

FIG. 2. Plate diagrams of three specimens of *Botryocrinus thomasi* Laudon from the Thunder Bay Limestone of Michigan. *a*, BMNS No. E16584. *b*, UMMP No. 47114. *c*, UMMP No. 47113. In each diagram, the *R* of the A-ray is at the extreme right. Ornamental ridges are indicated by heavy black lines. Approximately $\times$ 4.

RR circlet interrupted by *X*. *R* of C-ray smaller than other four *RR* as result of placement of *RA* at its lower left edge. Each *R* bordered laterally by two other *RR* or by one other *R* and *X*, and below (dorsally) by two *BB* or by one *B* and *RA*; thus, all *RR* pentagonal, wider than high, small one about the size of *B* and the others slightly larger than *BB*. Arm facet large, subcircular, concave, nearly half the width of *R*; low horizontal ridge crossing middle of facet, interrupted in center (Pl. I, Fig. 1; Pl. III, Figs. 1, 4), presumably for attachment of muscles used in articulation of arm; margin (particularly lower part) of facet crenulated or corrugated by fine radial ridges and intervening grooves of the same width (Pl. II, Fig. 2), apparently interlocking with similar but offset structures on the proximal face of PBr_1. Narrow ridge around edge of facet; from nadir (dorsal-most point) of this ridge, horizontal ridges extend to sides, aligned with similar ridges of adjacent *RR* or *R* and *X*; above each of these ridges and parallel to it, one or two other ridges extend from circular ridge to side of plate (Pl. I, Fig. 1; Pl. II, Figs. 1–4; Pl. III, Figs. 1, 4), except to sides of the two *RR* bordering *X*, which have only single horizontal ridges (Pl. I, Fig. 3; Pl. III, Figs. 2–3). From nadir of circular ridge on each *R*, diagonal ridges extend down to sides next to *BB* (Pl. I, Fig. 1; Pl. II, Fig. 4; Pl. III, Figs. 1, 4) or to *B* and *RA* (Pl. I, Fig. 2). In UMMP No. 47113, with anomalous enlargement of *RA*, *R* of C-ray bordered ventrally only by *RA* (Pl. II, Fig. 1), so that only one ridge is directed downward; in addition, this *R* has its arm facet directed toward the upper left instead of vertical, and projects above both adjacent plates. Upper (ventral) corners of each *R* beveled or rounded; middle of upper border indented by a deep notch.

RA normally small and subquadrate, nearly square (Figs. 1*a*, 2*a-b*; Pl. I, Fig. 2; Pl. III, Figs. 2–3), its right corner inserted between *R* of C-ray and *B* of BC-interray, its left corner between *X* and *B* of CD-interray. Surface of *RA* divided into four subsquare areas by ridges radiating from center to sides, thus forming an X. Anomalous *RA* in UMMP No. 47113 large and hexagonal (Fig. 2*c*; Pl. II, Fig. 1), bordered above by *R* of C-ray, on right by *R* of B-ray and *B* of BC-interray, below by *IB* of C-ray, and one left by *B* of CD-interray and X; this *RA* larger than *R* of C-ray, nearly as large as *X*, with ridges radiating from center to each side except that bordered by *IB*.

X interrupting *RR* circlet in CD-interray, hexagonal, bordered by *RR* of C- and D-rays, *RA*, and *B* of CD-interray, apparently supporting two anal plates on its distal (upper or ventral) border. Surface ornamented by ridges radiating from center to each side. *X* normally extending above level of *RR*. In UMMP No. 47113, *X* with short sides (at *RR*) and long lower borders (next to *B* and anomalous *RA*), not extending as high as *R* of C-ray (Pl. II, Fig. 1); ridges radiating from center to each side, and two additional parallel ridges to side bordered by *B*.

Arms.—Laudon (1936, p. 62) stated: "Fragments of two arms preserved in one specimen; arms branch once on the third primibrach; brachials higher than wide, slightly over 1 mm. high." In the paratype, SUI No. 1991A, one *PBr* is retained on the A-ray. It appears to be complete; its height is considerably less than its width, although somewhat greater than shown in the original, diagrammatic figure (Laudon, 1936, Fig. 5). The *R* of D-ray in UMMP No. 47113 has an isolated plate near its facet (Pl. II, Fig. 2) that appears to be PBr_1; it also is wider than high. I have not seen the specimen of Laudon which preserves arms beyond the axillary; it is not catalogued at The State University of Iowa among the type specimens.

Column.—Proximal columnal (Pl. I, Figs. 2–4; Pl. II, Figs. 1–5; Pl. III, Figs. 1–5) retained by each of the specimens from Michigan. The columnar facet (Pl. I, Fig. 4) is marked by radial ridges. The columnal is relatively thin but bears a wide flange, so that the greatest diameter of the plate is about 1½ times the diameter of the two articulating surfaces. According to the original description, the proximal section of column has alternating nodal and internodal columnals, whereas the distal section has plates nearly equal in width. Apparently, Laudon considered that the unattached section of column, nearly 5½ cm long, on the slab with the holotype was part of the specimen represented by the dorsal cup. This is uncertain.

Ornamentation.—Great variation can be seen in the ornamentation of the three Michigan specimens. On BMNS No. E16584 (Pl. I, Figs. 1–4), the ridges are tumid, rounded in cross section; on UMMP No. 47113 (Pl. II, Figs. 1–5), they are narrow and low; and on UMMP No. 47114 (Pl. III, Figs. 1–5), they are sharp-crested and high. From the effaced nature of the arm facets on BMNS No. E16584, I presume that the specimen is worn or weathered; nevertheless, it is similar to UMMP No. 47114. The major difference between the ridges of UMMP No. 47113 and UMMP No. 47114 is that the corners of the plates are very little indented in the former and deeply indented in the latter. In addition, the plates of UMMP No. 47113 (Pl. II, Fig. 5) show closely spaced small spinules in the areas between ridges. Similar variations in other species of *Botryocrinus* have been regarded as varieties or subspecies. Possibly, ornamentation of these crinoids is strongly affected by some ecological factor.

Illustrated specimens.—Three hypotypes: BMNS No. E16584, collected by I. G. Reimann in 1945; UMMP No. 47113, collected by I. G.

Reimann in 1953; and UMMP No. 47114, collected by C. L. Rominger, probably in 1898. All from the Thunder Bay Limestone at Partridge Point, Alpena County, Michigan.

ORNAMENTATION IN *Botryocrinus*

Ornamentation seems to have developed in several lineages of *Botryocrinus*. In the Middle Devonian species of North America, no progressive increase in ornamentation is apparent. Thus, early Middle Devonian species include the smooth *B. americanus* Rowley from the Sellersburg Limestone of southern Indiana, the costate *B. reimanni* Goldring from the Arkona Shale of Ontario, and the deeply sculptured *B. arkonensis* Goldring, also from the Arkona Shale. Further, in the late Middle Devonian Moscow Formation of western New York, *Botryocrinus* species occur with varying degrees of ornamentation, including *B. obconicus* Goldring with nearly smooth plates, *B. nycteus* (Hall) and *B. bethaniensis* Goldring with very weak costae, *B. ornatus* Goldring with shagreen ornament, *B. angularis* Goldring with medium costae (particularly the Y-shaped ridges on the *BB*), and *B. costatus* Goldring with stout, broad costae.

The strongly ornate, deeply sculptured species do not appear to be closely related. They include *Botryocrinus arkonensis* Goldring from the Arkona Shale of Ontario, *B. costatus* Goldring from the Moscow Formation (Kashong member) of western New York, and *B. thomasi* Laudon from the Cedar Valley Formation of Iowa and the Thunder Bay Limestone of Michigan. *B. arkonensis* has a conical cup and narrow ridges, *B. costatus* has a conical cup and broad, rounded ridges, and *B. thomasi* has a bowl-shaped cup and broad, narrow-crested ridges. These three crinoids show no chronological sequence in development of ornamentation or in shape of the cup.

Ultimately, the crinoids now placed in *Botryocrinus* may be separated into additional genera on the basis of ornamentation. The species named *B. angularis* by Goldring (1954, pp. 18–20, Pl. 2, Figs. 5–7) seems to fulfill the requirements for the genus *Jahnocrinus* of Jaekel (1918, p. 54, Fig. 45); at any rate, its relatively high *BB* ornamented with Y-shaped ridges and its small *IBB* are very similar to those in *J. minutus* Jaekel, the type species of *Jahnocrinus* from the Middle Devonian of Bohemia. American paleontologists have tended to disregard the genera created by Jaekel and to place nearly all botryocrinid crinoids in the genus *Botryocrinus*. Undoubtedly, when more species are made known, the generic boundaries will be revised and made more distinct.

TAXONOMIC SIGNIFICANCE OF QUADRATE *RA*

Inasmuch as one of the specimens of *Botryocrinus thomasi* Laudon described here, UMMP No. 47113 (Fig. 2*c*; Pl. II, Figs. 1–5), has an anomalous *RA*, some comments on the occurrence of quadrate *RA* among inadunate cladid crinoids are in order.

Crinoids of the order Cladida with quadrate *RA* are not restricted to the Botryocrinidae. Those of several other families have RA of this shape set in the CD-interray at the lower (dorsal) right of *X*. These include, among other genera, those listed in Table I. Considerable uncertainty has prevailed about the familial assignments of some of these crinoids. For example, *Bactrocrinites* has been assigned to the Cyathocrinitidae (Springer, 1913, p. 218), Bactrocrinidae (Jaekel, 1918, p. 55), Palaeocrinidae (Bassler, 1938, p. 18), and Dendrocrinidae (Moore and Laudon, 1943, p. 52). *Barycrinus* has been shuffled from Cyathocrinidae (Wachsmuth and Springer, 1886, p. 224) to Botryocrinidae (Bather, 1900, p. 179) to Barycrinidae (Moore and Laudon, 1943, p. 51). *Lasiocrinus* has been placed in Homocrinidae (Bassler, 1938, p. 17), Ottawacrinidae (Moore and Laudon, 1943, p. 55), and Dendrocrinidae (Moore, 1962, p. 37). Such changes reflect the indecision of crinoid workers regarding familial distinctions and cast doubt on the taxonomic value of the quadrate shape of the *RA*.

TABLE I

SOME INADUNATE CLADID CRINOIDS WITH QUADRATE *RA*

Suborder	Family	Genus
Dendro-crinoidea	Botryocrinidae	*Botryocrinus* Angelin 1878 *Rhadinocrinus* Jaekel 1895 *Bathericrinus* Jaekel 1918 *Jahnocrinus* Jaekel 1918 *Nassoviocrinus* Jaekel 1918 *Kophinocrinus* Goldring 1954
		Lasiocrinus Kirk 1914
	Dendrocrinidae	*Bactrocrinites* Schnur 1849
	Mollocrinidae	*Mollocrinus* Wanner 1916
	Cromyocrinidae	*Ulocrinus* Miller and Gurley 1890
	Eupachycrinidae	*Parulocrinus* Moore and Plummer 1940
Cyatho-crinoidea	Palaeocrinidae	*Palaeocrinus* Billings 1859 *Thalamocrinus* Miller and Gurley 1895
	Barycrinidae	*Barycrinus* Wachsmuth 1868

The shape of the *RA* is directly related to the number, location, and shape of the bordering plates in the dorsal cup. Only crinoids having adequate space between the *R* of the C-ray, *X* of the CD-interray, and the *BB* of the BC- and CD-interrays can accommodate a quadrate *RA*. In other words, to have a quadrate shape, *RA* can only be in contact with one *X* plate. This amounts to defining the crinoids with quadrate *RA* as those having only anal-*X* of the anal series incorporated in the dorsal cup.

In the latest work on inadunate crinoids, Moore (1962) has published some studies preliminary to the preparation of the Crinoidea volume of the *Treatise on Invertebrate Paleontology*. In it, he has based certain familial distinctions on the nature of the symmetry of the dorsal cup and the structure of radial plates. He has introduced a significant advance in inadunate morphology by distinguishing radianal, aniradial, and brachianal plates and noting the occurrences of fixed-brachials in contrast to free-brachials. Under the heading "Families Characterized by a Single Multiple Radial," Moore states (1962, p. 37):

> Different genera show a wide variety of posterior interray arrangement of plates and dissimilar orientations of planes of bilateral symmetry. It is necessary to remember that "one compound radial only" invariably refers to the C-ray and signifies radianal (inferradial in origin) and radial (superradial in origin). Whether the radianal occurs more or less directly beneath the C-radial, obliquely below it at the left, or even with it at the left makes no difference. The presence of a radianal qualifies an inadunate for classification in the category here considered . . .

Thus, at least on a suprafamilial level, the exact position and shape of the *RA* have no taxonomic importance.

The import of this concept will be known with publication of the *Treatise*. It appears likely that the diagnosis of the Botryocrinidae will no longer include the presence of a small quadrate *RA*, as given by Moore and Laudon (1943, p. 54). Whereas I must regard the large hexagonal *RA* of UMMP No. 47113 as an anomaly for the genus and for the species, such anomalies need not raise doubt about the classification of the specimen in which they occur.

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PLATES

EXPLANATION OF PLATE I

(All figures $\times$ 4)

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Four stereograms of BMNS No. E16584. Collected by I. G. Reimann in 1945.

Compare with Figure *2a* in text.

FIG. 1. Stereogram centered on B-ray. *RR* and associated *BB* only slightly distorted in this region.

FIG. 2. Inclined stereogram centered on right edge of *RA* in CD-interray. Proximal columnal offset from normal position.

FIG. 3. Stereogram centered on left side of *X* in CD-interray.

FIG. 4. Basal stereogram, showing relationship of *IBB* and *BB* particularly well because of offset proximal columnal. *RA* at left side, A-ray at right side.

PLATE I

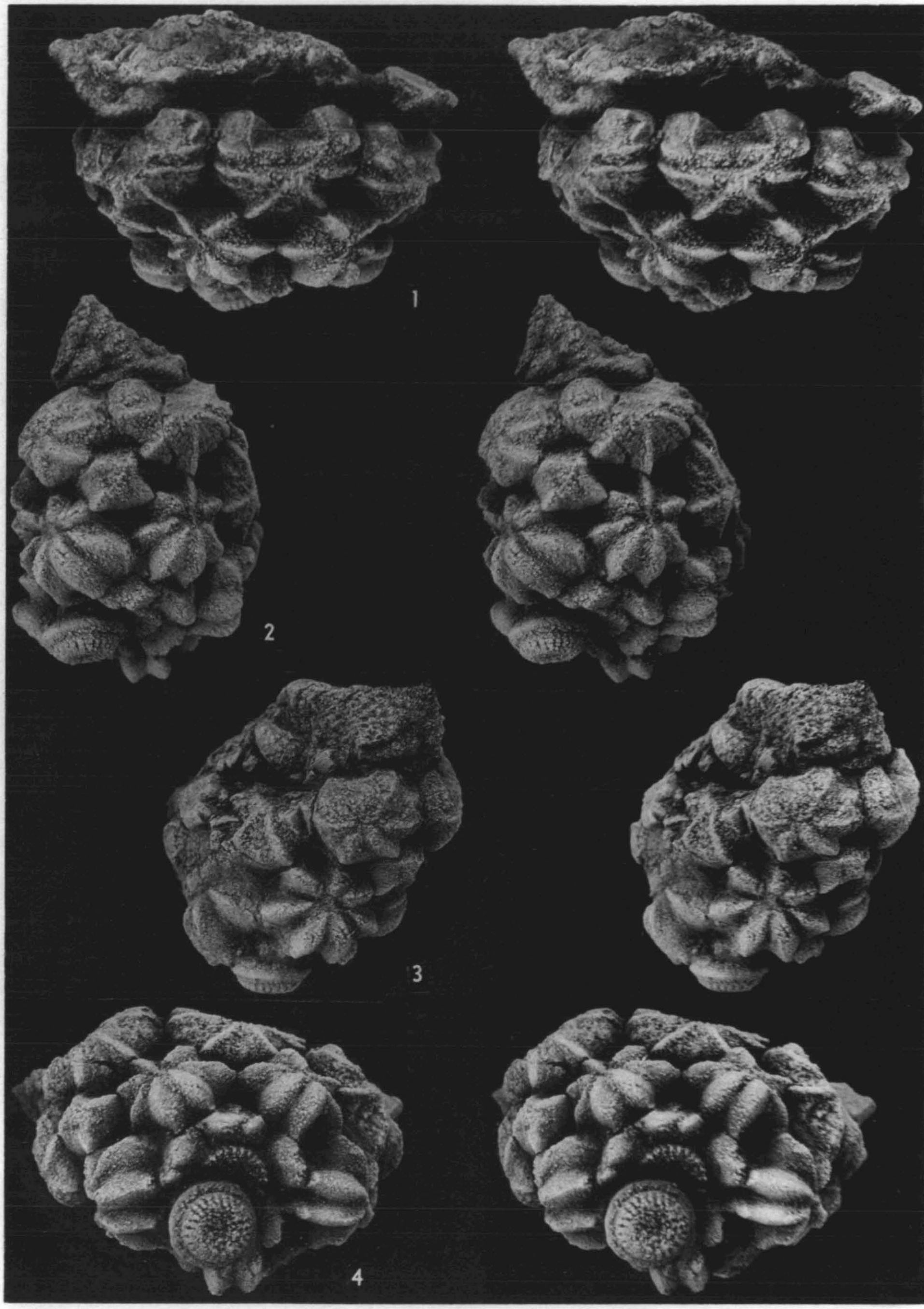
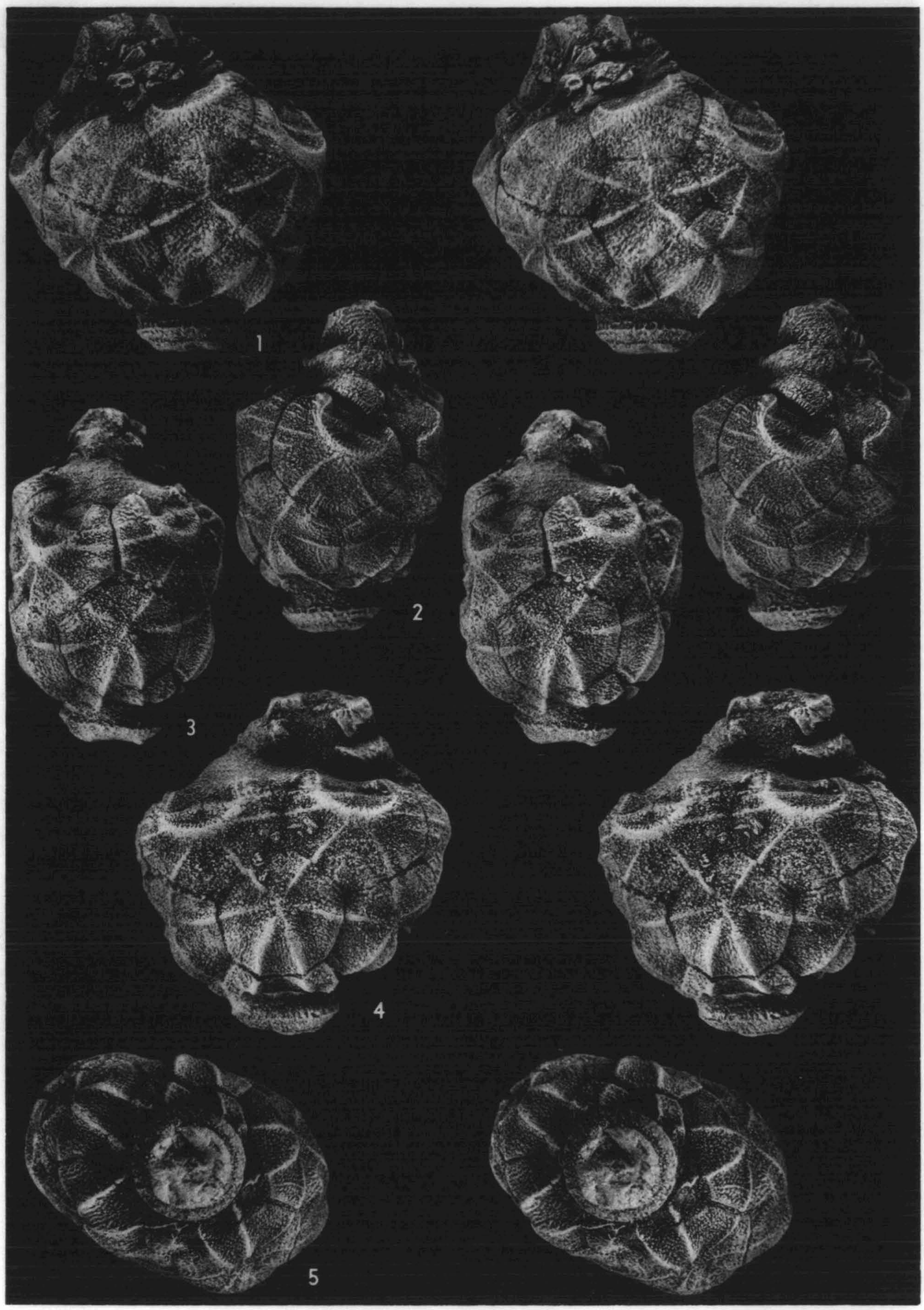


PLATE II



EXPLANATION OF PLATE II

(All figures $\times$ 4)

Five stereograms of UMMP No. 47113. Collected by I. G. Reimann on June 8, 1953. Compare with Figure 2*c* in text.

FIG. 1. Stereogram centered on C-ray, showing abnormal *RA* extending to junction with *IB* and interrupting BB circlet. *RA* lies below *R* in C-ray, and is bounded by two *RR* (B- and C-rays), two *BB* (BC- and CD-interrays), *IB* (C-ray), and *X*.

FIGS. 2–3. Stereograms centered on D-ray and on AB-interray. Figure 2 shows the arm facet particularly well; the displaced plate above appears to be PBr_1.

FIG. 4. Stereogram centered on AE-interray, showing radial crenulations of the arm facets on *RR* in A- and E-rays.

FIG. 5. Basal stereogram, with AE-interray at the top. The flange on the proximal columnal conceals much of the *IBB* circlet. This view shows the small spinules that ornament the plates between the radial ridges in this specimen.

EXPLANATION OF PLATE III

(All figures $\times$ 4)

PAGE

Botryocrinus thomasi Laudon 233

Five stereograms of UMMP No. 47114. Collected by Carl L. Rominger, probably in August, 1898, at which time he made a large collection of crinoids at Partridge Point. Compare with Figure 2*b* in text.

FIG. 1. Stereogram centered on DE-interray, showing radial crenulations on arm facet of *R* in D-ray (at right).

FIGS. 2–3. Lateral and inclined stereograms centered on *RA*. The *RR* are missing in the B- and C-rays. *IBB* in C- and D-rays are fused.

FIG. 4. Stereogram centered on E-ray, showing size and spacing of arm facets.

FIG. 5. Basal stereogram, with CD-interray at top. Due to fusion of *IBB*, *B* in CD-interray has only one ridge to the *IBB* circlet instead of two.

PLATE III