48

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Reprinted from
JOURNAL OF PALEONTOLOGY
Vol. 40, No. 5, September, 1966

JOURNAL OF PALEONTOLOGY, V. 40, NO. 5, P. 1157–1166, PLS. 151–153, 2 TEXT-FIGS., SEPTEMBER 1966

# *CALLIASTERELLA AMERICANA*, A NEW STARFISH FROM THE PENNSYLVANIAN OF ILLINOIS

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ABSTRACT—Starfish from the Pennsylvanian (Missourian) LaSalle Limestone of Illinois are the first species of *Calliasterella* to be found outside of Russia. The type and only previously known species, *C. mira*, was described in 1879 from Pennsylvanian (Moscovian) strata near Moscow. Our specimens are much better preserved than those of *C. mira*, even though in death the arms curled inward to conceal the ambulacrals and most of the adambulacrals. The madrepore is known for the first time in the genus, and the shape of the aboral side of the disk is established. Our species differs from *C. mira* in having less acuminate corners on disk plates, scattered tubercles instead of a paxillary ridge on each aboral arm plate, and differently shaped supramarginals, axillaries, and adambulacrals. Aborally, this hemizonidan starfish bears a striking similarity in plate arrangement to the phanerozonidan *Protopalaeaster*, and many plates appear to be homologous.

## INTRODUCTION

DISCOVERY of a second species almost invariably leads to better knowledge of the genus and revision of the description. This is the case for our new *Calliasterella*, based on five starfish recently found in Pennsylvanian beds in Illinois.

Specimens were discovered in the Wagner Stone Quarry at Ocoya, five miles southwest of Pontiac in Livingston County, Illinois. They were in the Pennsylvanian (Missourian) LaSalle Limestone. Mrs. Christina Cleburn found two of the paratypes and the junior author found the holotype and two other paratypes. One paratype is deposited in the paleontological collection of the State University of Iowa, and the holotype and other paratypes in the Illinois Geological Survey.

We are extremely grateful to Mrs. Cleburn for making the two specimens available for study. Mr. Karoly Kutasi assisted greatly with photography, and Mrs. Helen Mysyk with typing.

## PREVIOUS WORK ON *CALLIASTERELLA*

Trautschold (1879, p. 108) based his genus *Calliaster* and species *C. mirus* on one distorted and incomplete specimen and three fragments of starfish from the Upper Carboniferous (Moscovian) near Moscow. His description was adequate to indicate his generic diagnosis, but was not detailed.

Current concepts stem from the meticulous work of Schöndorf (1909), who studied a specimen from the paleontological collections of Petersburg University. In this starfish, exactingly prepared over a period of years by Professor Otto Jaekel, plates of the disk were disarranged and "auseinandergefallen" (p. 327). Two arms were practically complete and part of another was so preserved in place that it showed the relationship of adambulacrals and ambulacrals; in the rest of the matrix, arm plates were disassociated helter-skelter. So many individual plates were present, however, that various sides and surfaces of each kind of plate were exposed for examination. Assiduously, Schöndorf studied each plate type, determined how it fitted against neighboring plates, and described it at length. His impressive, well-executed reconstructions of the starfish (1909, pl. 23, figs. 2,3; pl. 24, fig. 18) have been accepted without change or question by all subsequent authors.

Schöndorf was content to keep terminology very generalized (table 1). Plates of the disk he designated by number, and aboral plates of the arms he called Dorsal- and Seitenplatten. Technical terms were reserved for adambulacrals and ambulacrals.

The following year (1910, p. 251), Schöndorf set up the family Calliasteridae for *Calliaster* exclusively. His family was placed in the Cryptozonia of the class Asteroidea.

In 1914 (p. 14) Schuchert created *Calliasterella* to replace the invalid *Calliaster* Trautschold, a junior homonym of *Calliaster* Gray, 1840.

In 1915, Schuchert (p. 190) reported *Calliasterella* as a new name (although he had already named it the previous year) and assigned it to his new family Calliasterellidae (Cryptozonia, subclass Asteroidea). His ardent respect for Schöndorf's reconstructions is attested by his statement (p. 191), "There is no other Paleozoic asterid worked out in such detail as is *Calliasterella*. Not only is the gross skeleton known, but the detailed construction of all the essential ossicles and spines as well." Insofar as we know, Schuchert never saw a specimen of *Calliasterella*.

Difficulties in terminology were encountered but not overcome. In his description, Schuchert said (1915, p. 190):

> Around the central plate is a first ring of five larger basal radial plates. Then comes a second ring of ten plates, five of which are the second basal radialia; the other five are interradial in position and give rise *in the next ring* to the ten *basal inframarginal* ossicles. (*Our italics*).

Yet on the opposite page in his explanation of figure 11 (copied from Schöndorf), Schuchert identified the central plate as the centrodorsal the plates of the *second ring* as second radialia alternating with *basal inframarginals*, and the plates of the third ring as five third radialia and ten paired inframarginals. According to his analysis, the arms consist of radials, supramarginals, adambulacralia, and ambulacralia, no inframarginals.

In his long-continued series on Paleozoic Asterozoa, Spencer (1918) set up the subfamily Calliasterellinae to receive *Calliasterella* and assigned it to the family Arthrasteridae. His analysis of disk plates reveals his convictions on the history of Paleozoic starfish. From inspection of Schöndorf's figures and comparison with certain selected other starfish, Spencer classified the plates of *Calliasterella mira* (table 1) as a central surrounded by successive rings of five first radials, five second radials plus five fused adradials, and five third radials plus ten inframarginals. The aboral plates of the arms he termed one row of radials and two rows of inframarginals (p. 166). He defined the family Arthrasteridae (p. 125, 162) as having small disk and long arms, at least one row of marginal plates on the arms, apical madrepore, stout adambulacrals normally covering whole of aboral surface and in some genera forming the margin, paxillar projections on all external arm plates with associated prominent spines, and inframarginals on the aboral sides of the arms. He differentiated the Arthrasteridae from the Urasterellidae by its single interradial plate immediately distal to the primary circlet.

Strand (1928, p. 38), reviewing nomenclatural changes, credited Schuchert with the authorship of *Calliasterella* in the *United States National Museum Bulletin 88* of 1914; this publication bears the year 1915 on the title page and according to page ii was issued March 20, 1915.

Later authors have followed the description and figures of Schöndorf and the classification of Spencer.

## TERMINOLOGY

For starfish with strongly plated disks and well-developed symmetry, the division between disk and arm must be arbitrarily placed. Radials on the aboral side of the disk continue onto the arms without change in form. So do other series of plates. Nevertheless, descriptions and discussions of starfish are replete with abrupt changes in terminology at the disk-arm boundary. Confusion and inconsistency result. Plates of *Calliasterella* have been analyzed so many ways, that an explanation is needed here.

There is no denying that our ideas on terminology are strongly influenced by the morphology of *Protopalaeaster*, a Middle Ordovician starfish with several striking similarities to *Calliasterella*. Among them we emphasize: (1) top of disk flat, sides declivitous; (2) plates of disk more or less stellate, joined at apices; (3) arms rela-

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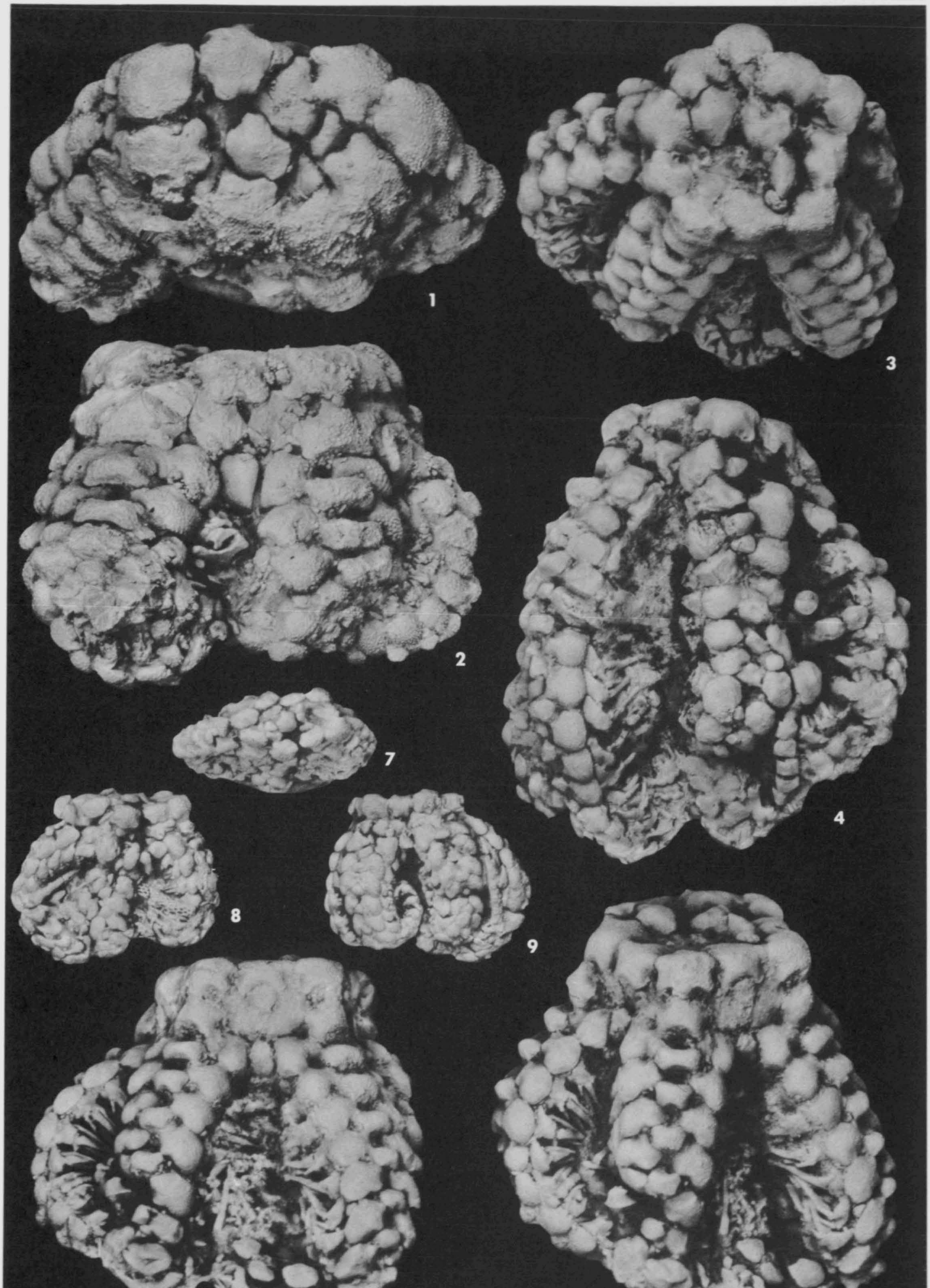
### Explanation of Plate 151

(All figures ×3; specimens coated with ammonium chloride)

Figs. *1–9*—*Calliasterella americana*, n. sp. *1,2*, aboral and lateral views of largest specimen, paratype SUI 12336; another lateral view in pl. 152, fig. 7; broken circular structure inset in $R_2$ of arm at left appears to be abnormal madrepore; tubercles are numerous and well developed. *3–6*, aboral, two inclined lateral, and lateral views, paratype IGS 42P2; madrepore at base of disk in aboral view, at right in fig. 5, and centered in fig. 6 (see pl. 153, fig. 2); although central plates are disarranged, this specimen preserves all plates of the coronet (first radials and supramarginals) and shows adambulacral spines particularly well (see also pl. 153, figs. 3–4). *7–9*, aboral and two lateral views of immature specimen, paratype IGS 42P3; supramarginal plates of arms differ somewhat from those in larger specimens, being more distally inclined; madrepore not preserved.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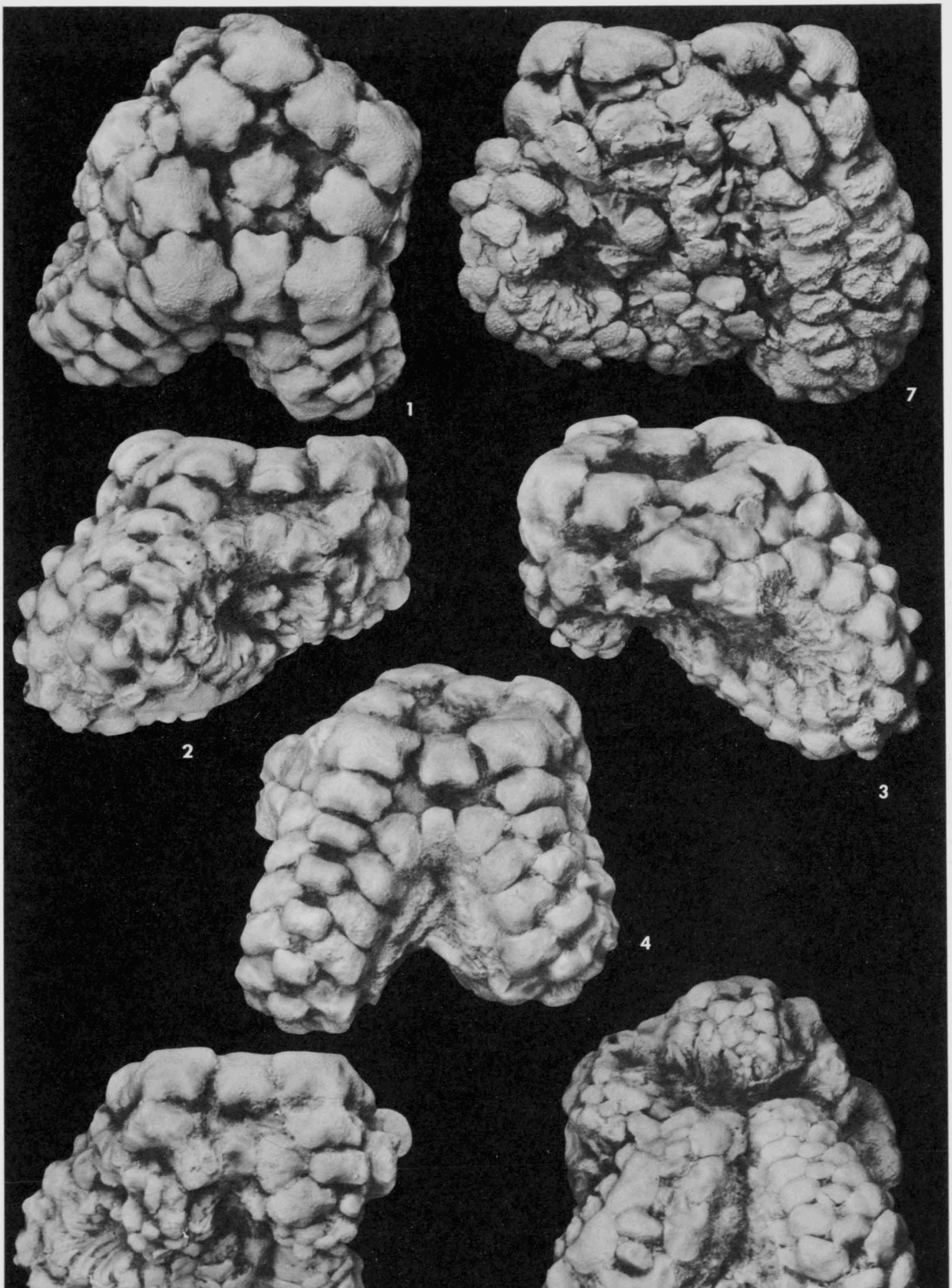
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TABLE *1*.—TERMS APPLIED TO PLATES OF *CALLIASTERELLA*

| Herein | Schöndorf, 1909 | Schuchert, 1915 | Spencer, 1918 |
|---|---|---|---|
| Disk | | | |
| *C*—central | Zentralplatte, Platte No. 1 | central (p. 190), centrodorsal (p. 191) | central |
| *cR*—centroradial | Platte No. 2 | basal radial | first radial |
| $R_1$—first (primary) radial | Platte No. 3 | second basal radialia | second radial |
| $R_2$—second radial | Platte No. 4 | third radialia | |
| $Sm_1$—first supramarginal | Platte No. 5, primäre Interradialplatte | basal inframarginal (p. 191) | fused adradialia |
| $Sm_2$—second supramarginal | Platte No. 6 | basal inframarginal (p. 190), paired inframarginals (p. 191) | infero-marginalia |
| *Ax*—axillary, or odontophore | Platte No. 7, Oralplatte | interradial disk plate | odontophor |
| Arm | | | |
| *R*—radial | Dorsalplatte | radial | radial |
| *Sm*—supramarginal | Seitenplatte | supramarginal | infero-marginalia |
| *Ad*—adambulacral | Adambulacren | adambulacral | adambulacralia |

tively long, strongly constructed; (4) middle of aboral surface occupied by subpentagonal plate; (5) disk surmounted by coronet of ten stellate, tumid plates; (6) area between central plate and coronet filled by regularly arranged plates (15 in *Protopalaeaster*, 5 in *Calliasterella*); (7) each side of disk with pair of interradial plates; (8) madrepore interradial, between one plate of coronet and the paired plates; (9) one series of plates radiating from one of coronet onto the arm, there forming median apex or roof; and (10) a series of wide, sloping plates high up on each side of arm, proximally aligned with paired plates of interradius. Other points could be listed. Such overwhelming similarities between *Protopalaeaster* and *Calliasterella* call for explanation.

Spencer (1918) looked for justification to connect *Calliasterella* with other starfish having short, very broad adambulacrals and only one row of marginal plates on each side of the arm. He said (p. 163):

> Schöndorf regarded the "single" interradial plates of *Calliasterella* as primary interradialia homologous to the similar plates of the Asteroidea of Section A [Hudsonasteridae, Promopalaeasteridae, Xenasteridae, Uranasteridae]. This cannot be, as the primary interradialia are always proximal to the primary radialia, whereas in this form the plates are distinctly distal. It seems much more reasonable to suppose that the plates have arisen from a suppression of one of each of the paired proximal adradialia of the Urasterellidae, . . . and that a circlet of primary interradialia is not present in *Calliasterella* just as is the case in *Urasterella*.

EXPLANATION OF PLATE 152

(All figures ×3; specimens coated with ammonium chloride)

FIGS. *1–7*—*Calliasterella americana*, n. sp. *1–6*, aboral, lateral, two inclined lateral, lateral, and oral views of holotype IGS 42P4; madrepore at left in oral view, at right in fig. 3 (see pl. 153, fig. *1*); specimen crippled, one arm completely missing (fig. 5), two showing regeneration on stumps (figs. 5,6), and one with abnormal supramarginals presumed to mark old injury (left in fig. 6); where one $R_1$ is missing (fig. *3* foreground), beveled edges of $Sm_1$'s show nature of junctions in coronet; views of specimen submersed in xylol in pl. 153, figs. 5–6. *7*, lateral view of paratype SUI 12336; arm at right shows irregular furrows with tubercles, presumably healed injuries of some kind; other views in pl. 151, figs. 1,2.

We are quite aware that evolution has provided many examples in which bizarre structures and complex arrangements have been remarkably simulated. Yet for the disks and aboral arm plates of *Protopalaeaster* and *Calliasterella* to have evolved by convergence would require a highly complicated procedure. According to Spencer, from such "primitive" starfish as the Middle Ordovician *Protopalaeaster*, the primary interradial plate (which we call first supramarginal, $Sm_1$) in time dwindled and disappeared and its place was taken either by one surviving plate of a pair of "adradialia" (1918, p. 163) or by fusion of the pair (1918, p. 166). As shown in our text-figure 1, both *Protopalaeaster* and *Calliasterella* feature a coronet of ten prominent plates around the top of the disk. One of the interradial plates of the coronet lies immediately proximal to the madrepore in *Protopalaeaster*. By Spencer's theory, the madrepore retained its interradial position while the proximal plate disappeared and one or two plates from below migrated around it and assumed a place in the coronet, thus producing *Calliasterella*. A simpler and possibly more logical explanation is that the coronet plates of the two genera are entirely homologous, consisting of five primary radials and five first supramarginals (text-fig. 1*c*).

By our accouting, *Protopalaeaster* has 15 plates between the central plate and the coronet, whereas *Calliasterella* has only five. The central part of the disk manifests many variations in plate development and arrangement in Paleozoic starfish; in the Silurian *Palaeaster*, the central plate and the primary radials are isolated and surrounded by a mosaic of small accessory plates, and in the Devonian *Devonaster*, the central, primary radials, and first supramarginals are diminutive and obscured among numerous tiny accessory disk ossicles. In the Pennsylvanian *Calliasterella*, therefore, it is not necessary to account the first plate in a radial position as the primary radial.

In the arms of *Calliasterella*, the plates bordering the radials were called infero-marginalia by Spencer (1918), p. 166). By this choice of term, he could compare and homologize the plates with those of such genera as *Urasterella*, in which the prominent row of dorsolateral plates lies near the side of the arm, in contact with the adambulacrals and widely separated from the radials. In *Calliasterella*, however, the dorsolateral plates extend under the edges of the radials, those of left and right sides separated by a very narrow median space (text-fig. 2). We agree with Schuchert (1915, p. 191) that this genus has supramarginals but no inframarginals.

Order HEMIZONIDA Spencer, 1951
Suborder URASTERINA Spencer, 1951
Family CALLIASTERELLIDAE Schöndorf, 1910

[*nom. correct.* SCHUCHERT, 1915, p. 190 (*pro* Calliasteridae SCHÖNDORF, 1910, p. 251)]

Spencer (1918, p. 166) regarded *Calliasterella* as type genus of subfamily Calliasterellinae of family Arthrasteridae. Aboral arm plates in the Cretaceous *Arthraster*, however, differ considerably from those of *Calliasterella*, so much so that we prefer to place the two genera in separate families.

Genus CALLIASTERELLA Schuchert, 1914

[*nom. substit. pro Callisater* TRAUTSCHOLD, 1879 (*non* GRAY, 1840); = *Calliastrella* PRESTON, 1917 (*nom. null.*)]

*Calliaster* TRAUTSCHOLD, 1879, p. 108 (*non* GRAY, 1840, p. 280, *etiam* Stelleroidea); SCHÖNDORF, 1909, p. 327; 1910, p. 251.

*Calliasterella* SCHUCHERT, 1914, p. 14; 1915, p. 190; SPENCER, 1918, p. 166; STRAND, 1928, p. 38; NEAVE, 1939, p. 529, CUÉNOT, 1948, p. 236; UBAGHS, 1953, p. 829; IVANOVA, 1958, p. 134, 190, 231; TERMIER & TERMIER, 1960, p. 182; MÜLLER, 1963, p. 444.

CALLIASTRELLA PRESTON, 1917, p. 22; SHARP *et al.*, 1917, p. 3; SCHULTZE *et al.*, 1929, p. 496.

*Revised description.*—Disk small, flat-topped. Arms long, exceptionally flexible. Subpentagonal to stellate *C* plate in center of disk, surrounded by five *cR*'s in about the same plane (text-fig. 1*c*). Second ring of plates more tumid than those enclosed, consisting of ten six-rayed stellate plates, five $R_1$'s and five $Sm_1$'s, forming a prominent coronet around top of disk. Third ring of plates made of ten $Sm_2$'s in interradial positions and five $R_2$'s; $Sm_2$ stellate; $R_2$ wider than long, subquadrate with slight projections along radius. *Ax* (axillary or odontophore) in each interradius, vertically elongate, bordered above by pair of $Sm_2$'s and laterally by two $Sm_3$'s. *M* subcircular, close-set in $Sm_1$-$Sm_2$-$Sm_2$ interstice. Plates of disk joined at apices, leaving interstices apparently originally filled only with integument; interstices around plates of coronet especially large.

Aboral plates of arms extending without demarkation from disk, consisting of central row or *R*'s and lateral rows of *Sm*'s, all with tubercles. *R*'s alternating with *Sm*'s, subquadrate, rapidly diminishing in size, distally becoming farther and farther separated. *Sm*'s very wide and short, proximally extending under edges of *R*'s and distally bordered by exposed edges of *Ad*'s. *Ad* plates wide and short with broad facing surfaces, set in echelon, particularly in distal part of arm. Long spines attached to *Ad*'s, set perpendicular to arm. *Am*'s in opposing rows, equal in number to *Ad*'s.

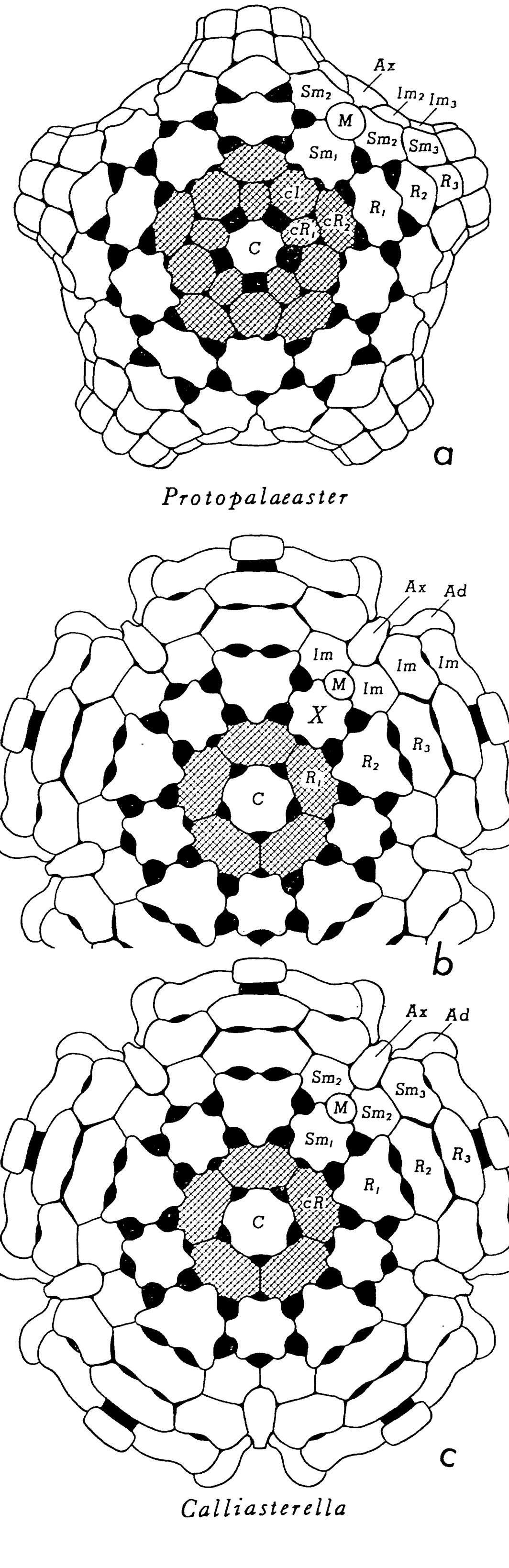
CALLIASTERELLA AMERICANA, n. sp.
Pls. 151–153; text-fig. 2

*Description.*—Arms long and large in relation to disk. Disk flat-topped. sides declivitous. surmounted by prominent coronet of ten plates. rather strongly constructed despite interstices occasioned by junction of stellate plates at their apices.

*C* convex, pentagonal. slightly stellate by reason of embayments on the sides, its apices joined to the five surrounding *cR*'s (text-fig. 2). In the right posterior interradius (first interradius to right of that containing madrepore). side of *C* especially wide (pl. 153, fig. 5), suggesting location of anus in adjacent interstice. *cR* plates forming circlet in plane, slightly convex, each with fairly wide sutures with *C*, $R_1$, $Sm_1$'s and adjacent *cR*'s.

Subpentagonal coronet of ten tumid plates (pl. 152, fig. 1; pl. 153, fig. 5), rising above the *C* and *cR* plates and forming rounded crest on disk as viewed laterally (pl. 151, figs. 2, 6; pl. 152 figs. 2, 5, 7), consisting of five $R_1$'s alternating with five $Sm_1$'s. Each $R_1$ forming corner of coronet, thick, shaped like a stellate biscuit, joined at apices to *cR*, two $Sm_1$'s, two $Sm_2$'s, and $R_2$, its lateral apices angularly undercut to fit over beveled corners of *Sm* plates. Each $Sm_1$ forming side of coronet, thick, set slightly below level of $R_1$'s (pl. 152, figs. 3,4), with lateral apices angularly beveled to fit under corners of $R_1$ plates (pl. 152, fig. 3; pl. 153, fig. 5); other apices in contact with two *cR*'s and two $Sm_2$'s (text-fig. 2). One $Sm_1$ plate forming proximal boundary of *M* (pl. 153, figs. 1,2).

$Sm_2$ plates substellate, forming sloping sides of disk, a pair in each interradius in contact, those in one interradius forming lateral and lower borders of *M* (pl. 153, figs. 1,2); each $Sm_2$ in contact with $Sm_1$, $R_1$, $R_2$, $Sm_3$, *Ax*, and the other




TEXT-FIG. *1*—Labeled aboral plate diagrams of disk and proximal parts of arms for comparison of two genera. Distal parts somewhat distorted; the margin of oral surface "untolled" to show plates adjoining aboral edge. *a*, *Protopalaeaster* with plate analysis (after Kesling, 1962, p. 936-41, text-figs. 1, 2). *b*, *c*, *Calliasterella; b*, plate analysis after Spencer (1918, p. 166–68, text-fig. 110); *c*, plate analysis used herein. Plate symbols: *Ad*—adambulacral, *Ax*—axillary or odontophore, *C*—central or centrodorsal, *cI*—centrointerradial, *cR*—centroradial, *Im*—inframarginal or infero-marginal, *M*—madrepore or madreporite, $R_1$—primary radial, $R_2$, $R_3$, second and third radials, *Sm*—supramarginal, *X*, fused adradialia.

$Sm_2$ of the interradius. $Sm_3$ plates part of disk, set at sides of *Ax* and aligned with *Sm* plates of arms (pl. 151, figs. 5,6; pl. 152, figs. 2,4,5).

Each $R_2$ intermediate in size and shape between the large stellate $R_1$ above and the smaller quadrate $R_3$ of the arm, with nearly straight distal border; $R_2$'s set well above level of intervening $Sm_2$'s, in contact with corners of $Sm_3$'s.

*Ax* subquadrate, vertically elongate, its lower end tapered, forming vertical side of disk in interradius, set below a pair of $Sm_2$'s and between $Sm_3$'s. Proximal exposed *Ad* plates seem to reach ventral tapered ends of *Ax*, but adjoining with short sutures. Oral side of disk not seen.

Arms long, tapering, highly flexible. *R* plates of arms laterally elongate, subquadrate, each distinctly separated from others of the row; distally, *R*'s taper rapidly and become farther separated, those near end of arm becoming subelliptical (pl. 153, fig. 6). *Sm* plates forming upper sides of arms, large, robust, in contact throughout the row; each *Sm* subquadrate to subpyriform, smaller end fitting under edges of the two adjacent *R*'s (pl. 153, fig. 5), the larger end sloping orally and distally to contact with *Ad* (pl. 153, figs. 3,4). *Sm* plates on opposite sides of arm not meeting medially between *R*'s; in interstices between *Sm* paired plates, two parallel, radially elongate bars (pl. 153, fig. 6) apparently upper edges of *Am* plates.

*Ad*'s very large, projecting laterally beyond borders of arm; exposed ends of *Ad*'s subquadrate in proximal part of arm, distally becoming narrower and curved strongly outward and down (pl. 153, figs. 3,4). Each *Ad* semicircular as viewed in cross section of arm, very broad, with concave proximal surface and convex distal surface. Long close-set spines along oral border of *Ad* (pl. 153, fig. 3), set nearly perpendicular to arm. Insofar as can be determined, number of *R*, *Sm*, *Ad*, and *Am* plates equal in arm.

*M* subcircular (pl. 153, fig. 2) to subtriangular (pl. 153, fig. 1), outer surface apparently with irregular perforations (pl. 153, fig. 2) and underlying radiating and anastomosing pores or tiny channels (pl. 153, fig. 1), constituting an efficient strainer. *M* bounded by $Sm_1$ proximally and above, by a pair of $Sm_2$'s laterally and below.

*Ontogeny.*—A very young specimen (pl. 151, figs. 7–9) differs from the larger and presumably mature specimens in having somewhat shorter arms in relation to the disk, more elliptical *R*'s in the proximal parts of the arms, more ovate and perhaps slightly overlapping *Sm*'s, and smaller *Ax*'s. It already has developed prominent stellate plates in the coronet of the disk.

One paratype is much larger than any of the other specimens and may display some gerontic tendencies (pl. 151, figs. 1,2). Proximal *R*'s of the arms are not only quadrate, but have slightly incurved sides (pl. 151, fig. 2). Tubercles are especially well developed, although this may be due to more favorable preservation.

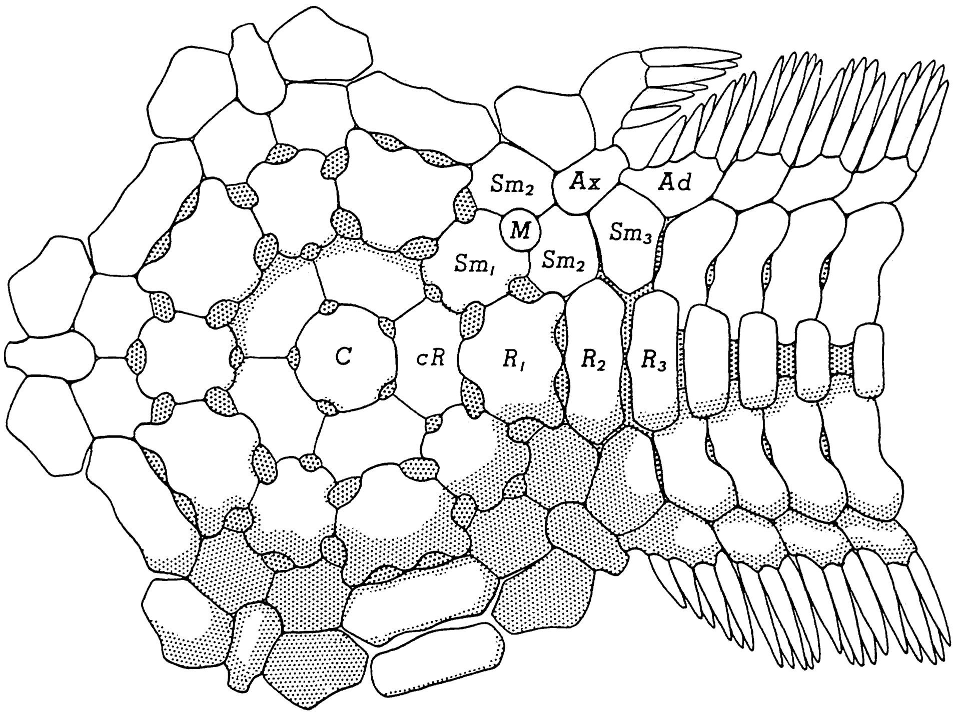
*Abnormality.*—Although the big specimen has large plates of the coronet jammed down over some of the interradial plates, thus obscuring some of the $Sm_1$-$Sm_2$-$Sm_2$ interstices, it appears that the *M* is abnormally developed. Part of a broken plate appears to be the remnant of a circular plate inset in a proximal corner of $R_2$ (pl. 151, fig. 2). When submersed in xylol, this circular structure shows a dark central spot. No other structure that we can imagine would have this appearance except a madrepore. The nearest interstice in interradial position, $Sm_1$-$Sm_2$-$Sm_2$, clearly encloses no *M*. The clear accommodation for the circular plate by the $R_2$ indicates that the *M* came to occupy the wrong position during very early development, before plate junctions were formed.

*Scars.*—*Calliasterella americana*, as represented by our available sample of the population, seems to have suffered an exceptional number of accidents to the arms. The three large illustrated specimens show irregularities which we think represent scars from old injuries.

In proximal part of one arm, specimen SUI 12336 (pl. 152, fig. 7) shows irregular subparallel grooves across the *R*'s and *Sm*'s of one side. The plates were probably gouged or raked across when the starfish was young, for the bottom of each groove has developed tubercles like those on the unaffected parts of the plates. Presumably such regeneration must have taken considerable time.

Another specimen, IGS 42P2, shows abnormal sequence of plates in one arm (pl. 151, fig. 4, middle arm). The *Sm* plates do not taper regularly, and two *R*'s occupy the space normally used by one. Especially the occurrence of large *Sm* plates distal to smaller ones cannot be attributed to accidents of preservation.

In life, specimen IGS 42P4 was most unfortunate. Only one arm is normal. The adjacent arm bears signs of injury in youth; in two places, very large supramarginals appear to be products of damage and subsequent fusion (pl. 153, fig. 6). The third and fourth arms were severed near the disk, probably at the same time; since the ends of both are capped by tiny plates (pl. 152, figs. 5–6), regeneration was under way before the animal died. The last arm was taken off so close to the disk that the primary radial was dislodged; it shows no regeneration (pl. 152, fig. 5). We do not know what kind of animal excised the starfish's arms. Perhaps a fish ate them, or perhaps a




TEXT-FIG. 2—*Calliasterella americana*, n. sp. Labeled plate diagram of disk and part of one arm. Margin of oral surface "unrolled" to show spines along edges of adambulacrals. Same plate symbols as text-figure 1.

powerful clam nipped them off. At any rate, whether from offensive or defensive action, the starfish was left with only two functional arms, side-by-side, one of which had lost some of its flexibility. Death may have come from a combination of injury and starvation.

*Remarks.*—Notable differences between this species and the type species are summarized in table 2. Schöndorf's remarkable and much copied restoration of *Calliasterella mira* (1909, pl. 23, fig. 2) showed the top of the disk to be domed. The definite flat-topped condition in *C. americana* raises some question about this aspect of the reconstruction.

*Occurrence.*—LaSalle Limestone, Pennsylvanian (Missourian), cropping out in Wagner

TABLE 2—Differences between the two species of *Calliasterella*.

| Character | *C. mira* | *C. americana* |
|---|---|---|
| General construction | Delicate | Robust |
| *C* (central) | Primarily stellate | Primarily pentagonal |
| *cR* (centroradial) | Strongly stellate | Broad junctions in ring, subpolygonal |
| $R_1$ (primary radial) | Strongly stellate, ends long and sharp, body wide and short | Weakly stellate, ends blunt, body equidimensional |
| $Sm_1$ (first supramarginal) | All ends sharp | Ends blunt, lateral ends beveled to fit under $R_1$'s |
| $R_2$ | Distal edge with median projection | Distal edge smooth |
| *Ax* | Strongly elongate, mediolateral projections | Subquadrate, no mediolateral projections |
| *Sm* of arms | Narrow, median processes | Broad, no conspicuous protuberances |
| *Ad* of arms | Outer ends small, vertically elongate | Outer ends subquadrate to subpyriform, wide and inclined |
| *Ad* spines | Short, one exposed at outer end of *Ad* | Long, several exposed at outer end of *Ad* |
| Number of *Ad*'s in each arm | More than 60 | Less than 30 |

Stone Quarry at Ocoya, Livingston County, Illinois. Paratypes IGS 42P1 and IGS 42P2 found by Mrs. Christina Cleburn; holotype and other paratypes found by junior author.

*Types.*—Holotype IGS 42P4, well-preserved specimen with crippled arms. Paratype IGS 42P1, disarticulated disk plates and section of arm (not illustrated). Paratype IGS 42P2, well-preserved specimen with arms practically complete. Paratype IGS 42P3, small and presumably immature starfish. Paratype SUI 12336, a very large individual.

## PALEOBIOLOGY

Very little evidence is available by which to reconstruct the manner in which this starfish lived, apart from the morphology of the fossil remains. The development of long, flexible arms, aboral spines, and long adambulacral spines seems to have functional significance.

The long, tapering, highly flexible arms, extending from a relatively small disk, do not seem to be structurally designed to exert strong pull, such as that employed by living *Asterias* to open bivalves. Furthermore, the numerous long spines, set perpendicular to the thick, rounded adambulacrals, must have kept the ambulacral groove at an appreciable distance from any hard, dense object. Podia long enough to extend beyond the ends of the adambulacral spines would seem poorly designed for pulling action, particularly prolonged pulling necessary to open bivalves.

*Calliasterella* resembles *Urasterella* in having aboral spines on disk and arms. Spencer commented on the use of aboral spines or paxillae (1951, p. 123):

> Many fossil Asteroidea appear to have lived under the sea bottom. Evidence for this is afforded by the presence of paxillae or an epiproctal cone. . . . The arrangement of the aboral spines of *Astropecten* is specially adapted for respiration when the starfish retires under the sea-bottom. The spines, placed on shafts, form an extensive paxillary umbrella which protects the aboral surface from overlying mud. . . . Many early Asteroidea belonging to widely different groups carry a paxillary umbrella. It is found in the Platanasteridae, Schuchertiidae and the Urasterellidae. In the last group it is almost universal.

As defined by Spencer (1918, p. 131), paxillae consist of base, shaft, and crown (of spinose processes). The structures atop the radials in *Calliasterella mira* described by Schöndorf (1909, p. 335–36) appear to be short spines rather than paxillae. Those of *C. americana*, to judge from a few fragments, are also short spines, which presumably were attached to the numerous low scattered tubercles on aboral plates. These tubercles can be seen much better on some plates than others, from which they seem to have been abraded. The holotype (pl. 151, figs. 1,2; pl. 152, fig. 7) displays them best, but on other specimens they are clearly discernible.

If all the tubercles on the disk plates of *Calliasterella americana* (pl. 153, fig. 5) possessed spines, undoubtedly they would provide an efficient insulating shield or "umbrella" to hold sediments away from the body of the starfish.

The long spines perpendicular to the adambul acrals give the arms the appearance of stiff-bristled brushes. Thus equipped, the arms seem well suited to rake through bottom sediments and debris. In addition, if the proximal sections of the arms were partly buried in bottom silts, the downward-radiating rows of spines might provide a subway conduit for passage of food particles orad from the emergent ends of the arms.

If the starfish burrowed into the sea floor, it probably did not penetrate deeply or into consolidated sediment. In death, each specimen rolled the arms down and inward. Possibly this was due to contraction of inter-adambulacral muscles in rigor mortis, but the animal seems not to have been hindered by the weight or consistency of overlying mud.

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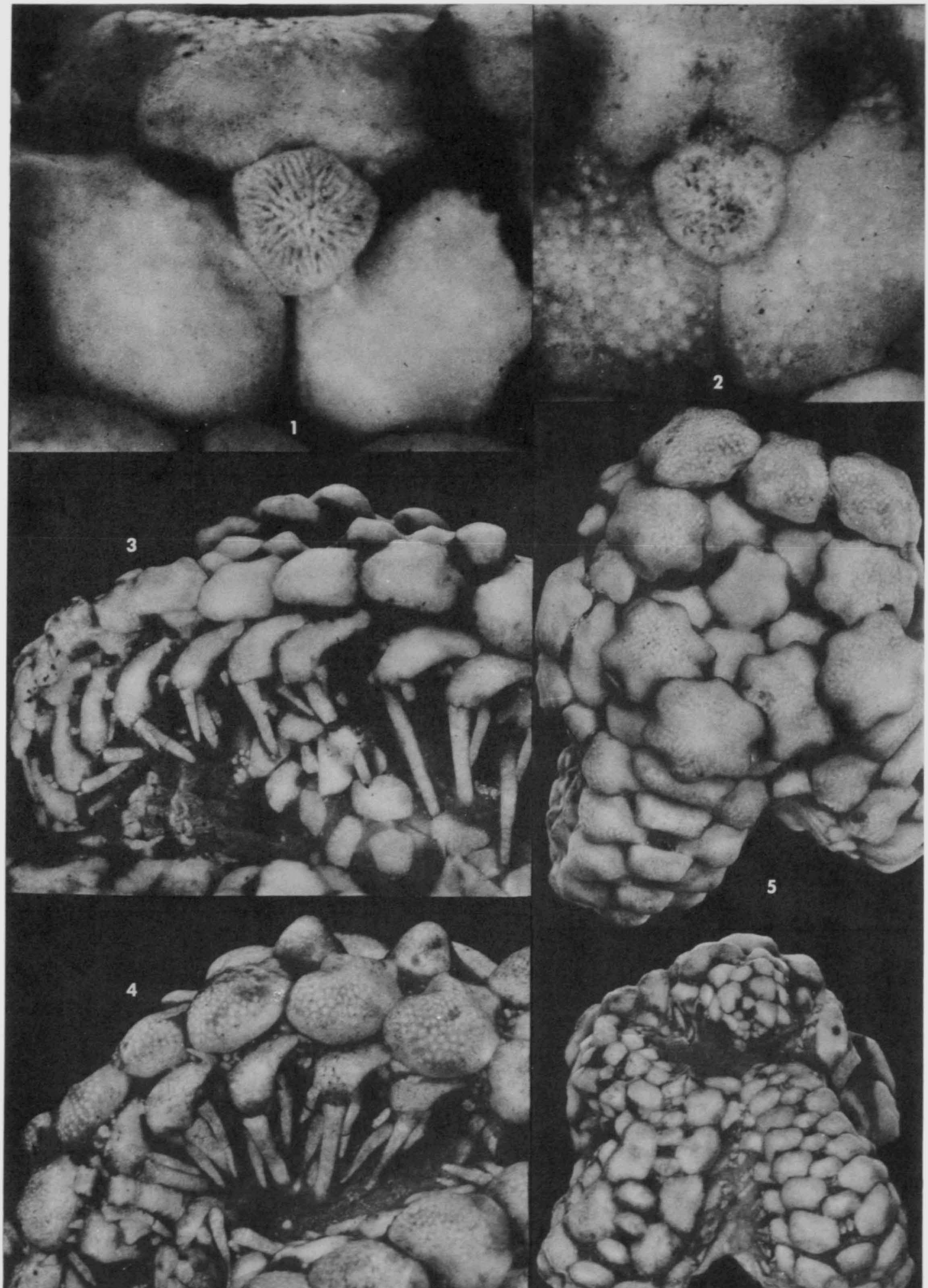
MANUSCRIPT RECEIVED MARCH 2, 1966

(*Explanation of Plate 153 appears on the following page*)

EXPLANATION OF PLATE 153

(All specimens photographed while submersed in xylol)

FIGS. *1–6*—*Calliasterella americana*, n. sp. *1*, madrepore and surrounding plates, holotype IGS 42P4, ×15; compare with pl. 152, fig. 3. *2*, madrepore and surrounding plates, paratype IGS 42P2, ×15; compare with pl. 151, figs. 5,6. *3,4*, sections of arms showing outer edges of adambulacrals with attached spines, paratype IGS 42P2, ×7½; compare with pl. 151, figs. 4–6. *5*, aboral view of paratype IGS 42P4, ×3¾; first radial missing at left, just above madrepore; broad indentation in central plate may mark position of anus; spacing of centroradials clearly shown; compare with pl. 152, fig. 1. *6*, oral view of holotype IGS 42P4, ×3; note abnormally large supramarginals in arm at lower left and regeneration in arm at top; paired bars visible between supramarginals of normal arm at lower right probably are top edges of ambulacra.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