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SPECIES OF THE CRINOID *DOLATOCRINUS* FROM THE MIDDLE DEVONIAN DOCK STREET CLAY OF MICHIGAN

BY

ROBERT V. KESLING and LEIGH W. MINTZ

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CONTENTS

INTRODUCTION

ALTHOUGH crinoids of the genus *Dolatocrinus* are relatively abundant and exceptionally well preserved in the Dock Street Clay of Michigan, they present a challenge in taxonomy. They have great diversity in details of plate proportions and ornamentation, as well as size and shape of the dorsal cup. In our investigation of these crinoids, we were immediately confronted with the species problem in one of its most perplexing forms.

Discernment of species in *Dolatocrinus* depends upon evaluation of the differences rather than the similarities. No two specimens are quite alike; but some of the variations can be accounted as individual and some as specific. Paleontologists have ample opportunity with this genus to engage in species-naming by regarding each observable difference as specific, or they can very broadly and loosely define a species to encompass many morphologic kinds. Our analysis has been steered somewhere between "splitting" and "lumping." We trust that our modest number of species approaches genetic reality more closely than previous taxonomic treatments of these crinoids.

Despite the short geologic range of the camerate crinoid *Dolatocrinus,* an extraordinary number of specific and varietal names have been applied to it. *Dolatocrinus* ranges from late Onondaga to late Traverse and includes 90 different specific or varietal names, in addition to several other names assigned to synonymous genera. Although the success of *Dolatocrinus* was quick, it was not that spectacular. By our count, 19 names have been proposed for these crinoids from Onondaga rocks in Indiana, Kentucky, New York, and Ohio, 68 for those from Hamilton and Traverse beds in Michigan, Indiana, Kentucky, New York, and Ontario, and 3 reported from strata of both ages. The initial task was to judge the validity of these names, relegate to synonymy as required, and improve the concept of the remainder by revised definitions. Only after bringing some semblance of order to the taxonomic chaos could we proceed to classify the Michigan crinoids.

The specimens which are the main object of this study were collected from the Dock Street Clay Member, the lower part of the Four Mile Dam Formation in the Traverse Group of Michigan. The Traverse Group is mostly Hamilton in age and the Four Mile Dam Formation is equivalent to the Centerfield Limestone of New York, the Beechwood Limestone (Sellersburg Group) in the vicinity of the Falls of the Ohio, and the Hungry Hollow Formation of Ontario. *Dolatocrinus* is present in all these formations, notably the Beechwood Limestone, from which S. A. Miller and W. F. E. Gurley described new species from 1894 to 1897.

The extensive collection of *Dolatocrinus* in the Museum of Paleontology of The University of Michigan was made, for the most part, by Professor G. M. Ehlers of the Museum and a local collector, Mr. Leon Pettyes. Pettyes amassed a large number of crinoids from the Alpena region in the early 1930's and his collection was purchased by The University of Michigan from his widow in 1936. From 1935 through 1937, and sporadically thereafter, Professor Ehlers worked in the vicinity and added many more specimens to the Museum's collection.

Numerous well-preserved specimens of *Dolatocrinus* from the Dock Street Clay which were collected by Irving G. and Georgine C. Reimann were deposited in the Buffalo Society of Natural Sciences. They were made available by that institution. Some of the specimens are illustrated (Pl. IV, Figs. 4, 12; Pl. V, Fig. 2; and Pl. VI, Figs. 14, 17, 19, 22).

Because Miller and Gurley were largely responsible for the multiplicity of names of *Dolatocrinus,* we deemed it imperative to study their type specimens. Dr. J. Marvin Weller of the University of Chicago Walker Museum kindly placed these critical specimens at our disposal. Many of these well-preserved specimens are illustrated (Pl. I, Figs. 1–14, 17–22;

and Pl. II, Figs. 1–13) for comparison with one another and with the Dock Street Clay specimens. They are designated "UCWM."

Dr. Porter M. Kier of the United States National Museum loaned many excellent specimens for study from the extensive collections of that institution, two of which we illustrate (Pl. I, Figs. 15, 16). They are designated "USNM."

Our sincere appreciation is extended to Dr. Lewis B. Kellum and Dr. Chester A. Arnold for reading and criticizing this manuscript. Dr. George M. Ehlers, Professor Emeritus, graciously supplied information on the history of the specimens in the Museum of Paleontology collection. Mr. Karoly Kutasi helped prepare some of the photographs utilized in the plates.

All specimens here illustrated from the Museum of Paleontology are designated "UMMP" and catalogued in that museum.

LOCALITY

All Michigan specimens are from the following locality:

Dock Street Clay Member, Four Mile Dam Formation, Middle Devonian, exposed in the quarry of the Thunder Bay Quarries Company (now abandoned), Alpena, Michigan. The bed is exposed along the south and west walls of the quarry, SE¼ sec. 14, T.31N., R.8E., eastern Alpena County. Most of the specimens were obtained from weathered clay dumped along the shore of Lake Huron, in sec. 23 just south of the quarry.

PREVIOUS WORK

In a communication to the *American Journal of Science and Arts,* Gerard Troost (1849, p. 419) proposed the name *Cacabocrinites sculptus* for an Onondaga crinoid from Tennessee. Unfortunately, Troost died before he could publish a description of the new genus, so that *Cacabocrinites* became a *nomen nudum.* In 1857 (p. 482), S. S. Lyon founded the genus *Dolatocrinus* and described *D. lacus,* the type, from the Onondaga of Kentucky. In 1862, James Hall, who by that time had obtained Troost's specimens and manuscript (by means which are said not to reflect high ideals), ignored Lyon's work and published his synonymous genus *Cacabocrinus.* Hall (1862, pp. 137–42) described seven species and varieties of *Cacabocrinus* from New York, of which four were from the Hamilton, two from the Onondaga, and one found in both groups. In 1866 (p. 367) Shumard corrected Hall's oversight and assigned all seven species and varieties of *Cacabocrinus* to Lyon's genus *Dolatocrinus.*

Lyon (1869, p. 461) established a new species of *Dolatocrinus* from the Onondaga of Kentucky; Meek (1871, p. 57) one from the Onondaga

of Ohio; Barris (1885, *in* Wachsmuth and Barris, p. 25) one from the Traverse of Michigan; and Whiteaves (1887, p. 99) one from the Hamilton of Ontario. *Dolatocrinus triadactylus* of Barris, described from the Thunder Bay Limestone, was the first record of the genus in Michigan.

By far the greatest number of species of *Dolatocrinus* was named and described by Miller and Gurley in the Bulletins of the Illinois State Museum from 1894 through 1897. Forty species and varieties were established by these authors, who used the number of arms and their grouping as the chief means of differentiation. Thirty-five of these were from the Beechwood Limestone of Hamilton age and came from a small area around Louisville, Kentucky, and Silver Creek, Clark County, Indiana (Springer, 1921, p. 19). In addition, Miller and Gurley described three new species of *Dolatocrinus* from the Onondaga beds and one species from both Onondaga and Hamilton strata, all from this region.

In their monographic work, *The North American Crinoidea Camerata,* Wachsmuth and Springer (1897) further encumbered the literature by adding six new species of *Dolatocrinus* to the growing list, some of which were synonymous with Miller and Gurley's species. Insofar as we may judge the sentiment of S. A. Miller from published comments, he was strongly estranged from Charles Wachsmuth, to say the least. This is attested by his sarcastic statements in Miller, 1891 (p. 630, 637), and his vitriolic attack in Miller and Gurley, 1894*b* (p. 37). The regrettable outcome of this feud was that Wachsmuth and Springer refused to recognize the works of Miller and Gurley, and both pairs of authors proceeded to describe crinoids on their own.

J. F. Whiteaves (1898, p. 95) described a second species, *D. subaculeatus,* from the beds of Hamilton age at Thedford, Ontario.

In Greene's *Contributions to Indiana Paleontology,* published from 1898 through 1906, S. A. Miller (Vol. 1, p. 6) established yet another species from the Hamilton, and R. R. Rowley (Vols. 1 and 2), although a more perceptive worker, swelled the ranks of *Dolatocrinus* with 11 new species and varieties from the Hamilton, six from the Onondaga, and one occurring in both groups. Even though he recognized that differences in the number of arms might not have specific importance, Rowley regarded minor variations in ornamentation as being specific criteria.

In 1902 (p. 195), A. W. Grabau reported *D. triadactylus* and *D.* sp. from either the limestone of the Four Mile Dam or the Norway Point Formation. We find that the specimen Grabau referred to *D. triadactylus* is actually *D. liratus* and his *D.* sp. consists of one specimen of *D. asterias* and one of *D. stellifer.*

Elvira Wood (1904) described two new species of *Dolatocrinus* from

the Alpena Limestone of Michigan. One of them, *D. costatus,* ranged upward into the Dock Street Clay. She also supplied a new name for Wachsmuth and Springer's (1897) *D. lyoni,* which was a junior homonym of Miller and Gurley's (1896) species.

In the first major effort to make a logical analysis from the bewildering number of species names which had been created to that time, Frank Springer in 1921 published his important paper "The Fossil Crinoid Genus *Dolatocrinus* and Its Allies." Springer studied nearly all available specimens of *Dolatocrinus,* including many from Michigan, and made some extensive reductions by synonymy. He tried to utilize all characters instead of a particular one in defining species. He pared the number of previously-named forms down to 30 valid species. At the same time, however, he also created four new species (three Onondaga, one Hamilton) and raised one of Miller and Gurley's varieties to the species level.

To these 35 species, Winifred Goldring (1923, 1936) added five more species and varieties from New York; three of these were from Hamilton and two from Onondaga strata. She also removed *Dolatocrinus troosti* (Hall) from the genus and made it the type of a new genus, *Clarkeocrinus.*

Bassler and Moodey (1943, pp. 432–39) listed 43 valid species and varieties of *Dolatocrinus,* including six from Michigan. In 1946 (p. 267), Edwin Kirk established a new species from the Potter Farm Formation of the Traverse Group in Michigan. In his "Check List of Fossil Invertebrates Described from the Traverse Group of Michigan," Erwin C. Stumm (1951) recorded seven species of *Dolatocrinus.* Four of these came from the Dock Street Clay: *D. amplus, D. costatus, D. triadactylus,* and *D. venustus.* Thus, at the time when this study started, 44 species were considered valid, 45 were relegated to the status of synonyms, and one was rendered invalid as a junior homonym. We were skeptical of any and all reported species of *Dolatocrinus.* The Michigan specimens were compared with the types and other available specimens of related species.

DEFINITION OF THE GENUS

Dolatocrinus is included in the monocyclic camerate family Dolatocrinidae with *Stereocrinus, Clarkeocrinus, Comanthocrinus, Himerocrinus, Hadriocrinus,* and *Centriocrinus.* This family is characterized by three unequal basals (*BB*), radials (*RR*) in contact all around, very large first interbrachial plates ($IBrBr_1$), no anal plates in the cup, globose and rounded calyx, and anal vent through the tegmen (Moore and Laudon, 1943, pp. 97, 99).

Lyon's original description of the genus (1857, p. 482) was based solely upon the type species, *D. lacus,* and is not adequate for all species that

were added subsequently. An excellent detailed description and discussion was presented by Springer (1921, pp. 3, 16–26).

In addition to the familial characters, the genus *Dolatocrinus* is distinguished by possessing a depressed dorsal cup which is broader than high, a low to convex tegmen which is nearly symmetrical, apertures between the arm openings in the calyx, and the location of the small *BB* (anchylosed in many specimens) in a conical depression in the base of the calyx (Pl. I, Fig. 7; Pl. II, Figs. 14–18). *Dolatocrinus* can be distinguished from *Stereocrinus* only by the possession of two primibrachs to each ray instead of one.

The shape and arrangement of the major plates in *Dolatocrinus* is as follows: *BB* three, may be anchylosed, two pentagonal and the other quadrangular; *RR* five, hexagonal, wider than high, in contact all around; $PBrBr_1$ quadrangular, wider than high; $PBrBr_2$ axillary, pentagonal, supporting two $SBrBr_1$, which are commonly hexagonal; $IBrBr_1$ very large, 9-sided in many interrays, 10– or 11–sided in other interrays of the same

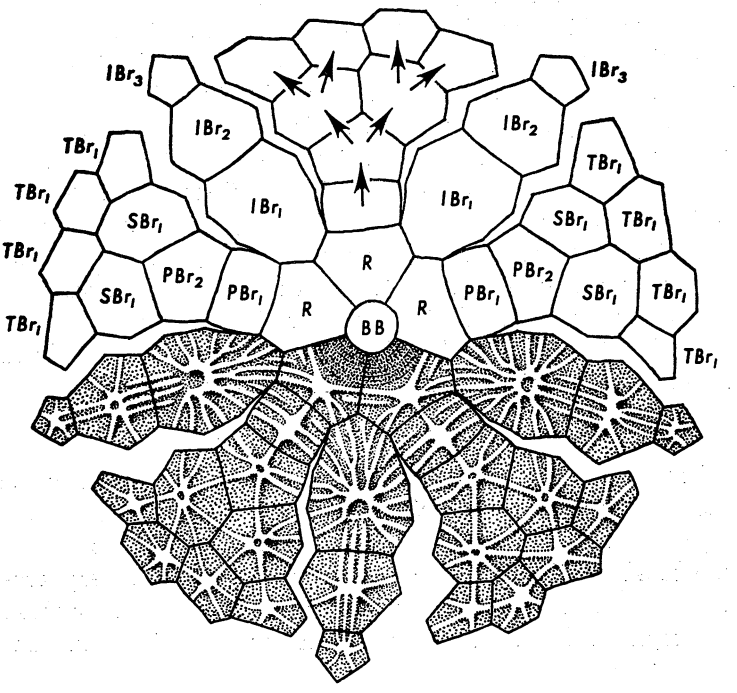

FIG. 1. Generalized plate and ornamentation diagram of *Dolatocrinus* Lyon from basal view. Arrows represent the ridges on the plates of the ray leading to the arm bases.

or other specimens, supporting either (1) one IBr_2, (2) one IBr_2 and one TBr_1, or (3) one IBr_2 and two TBr_1 above. Because of these variations, even within the same specimen, generalized plate diagrams (Figs. 1, 2) are somewhat better than diagrams of individual specimens.

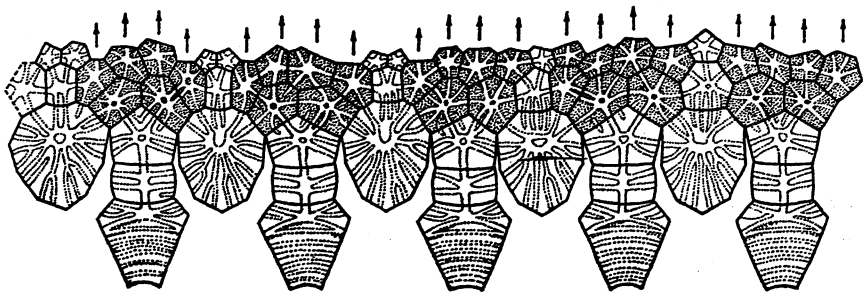

FIG. 2. Generalized plate and ornamentation diagram of *Dolatocrinus* Lyon from lateral view. Arrows represent the position of the arms. $IBrBr_1$ with 9, 10, and 11 sides are shown.

The arms of *Dolatocrinus* are biserial and unbranched. Ten arms (two to each ray) is the usual number in most Onondaga species; according to Springer (1921, pp. 27, 28), four Onondaga species have 20 arms and one has 40 arms. In Hamilton times the number of arms increased markedly and their grouping became highly variable. Fifteen to 20 arms characterize most Hamilton species.

Because specimens with arms and pinnules preserved are rare, little is known of the detailed structure of these crinoid parts. Pinnules are found not only on the arms but also extending out from between the arm openings through apertures in the calyx, according to Springer's analysis (1921, p. 24). Two Michigan specimens from the Dock Street Clay were found with appreciable portions of the arms intact. The specimen of *D. liratus* (Pl. III, Fig. 9) retains only large fragments of some arms, but that of *D. stellifer* (Pl. VII, Figs. 4, 6) has nearly complete arms. The biserial arms are very long in proportion to the calyx and possess knobby protuberances at various points along their extent. The pinnules are numerous on the arms, but none can be seen associated with the apertures between the arms.

The so-called pinnule apertures in the interray areas along the junction of calyx and tegmen vary in size and shape in different species. In some they are long slits which are quite obvious (Pl. I, Figs. 10–12; Pl. VI, Figs. 13, 22), but in others they are small and inconspicuous, lying very close to the edges of the arms (Pl. II, Fig. 11). Springer (1921, pp. 24, 25)

stated that these "elongate slits represent the ambulacral grooves leading to the openings, from which the minute covering pieces have fallen away. . . . If the arm becomes free on the first secundibrach, there may be no pores through the calyx wall, or only a single one at one or both sides of the arm base; if higher secundibrachs are incorporated, the number correspondingly increases." The presence or absence of apertures, as well as their number, have been used to differentiate species. Probably, all species of *Dolatocrinus* possess these openings. In specimens in which they are said to be absent, closer inspection reveals their presence, either very close beside the arm bases or still covered by minute covering pieces. The number of pores varies, of course, with the number of arms. As will later be demonstrated, arm number is unreliable as an indicator of species; nor do we believe that the number of pinnule apertures is specifically important.

The column of *Dolatocrinus* is described in detail by Springer (1921, pp. 16–18). Only one specimen from Michigan has an appreciable portion of the column preserved (Pl. VII, Fig. 5). In this specimen of *D. stellifer,* two kinds of columnals are present. In the proximal section of the column, thick columnals with large radii and rounded margins alternate with thinner ones having smaller radii. In the distal section, only the former type are present. These large columnals of the distal section vary in thickness, apparently without regularity. The column in this specimen does not agree in most respects with Springer's description or illustrations (1921, Pl. IV, Figs. 6–13; Pl. X, Figs. 3–7). Apparently, different species of *Dolatocrinus* possess distinctive columns; but since columns are so seldom articulated with the calices, their taxonomic value remains to be determined.

The tegmen of *Dolatocrinus* may be low (Pl. III, Fig. 1) or quite convex (Pl. VI, Fig. 17); smooth (Pl. IV, Figs. 11, 12), pustulose (Pl. III, Fig. 2), or very rugose (Pl. IV, Fig. 7); unlobed or very slightly lobed (Pl. I, Figs. 8, 11; Pl. IV, Figs. 11, 12) or very prominently lobed (Pl. I, Figs. 20, 22; Pl. III, Fig. 2). An excellent illustration of the arrangement of the tegminal plates is given by Wood (1904, Pl. XVI, Fig. 6).

The dorsal cup of *Dolatocrinus* is highly ornamented. In general, the ornamentation can be divided into two varieties. In the first, a longitudinal median ridge occurs on the plates of each ray. Beginning near the lower margin of each *R,* it extends to a node on the center of each PBr_2 where it divides, with a branch to the center of each SBr_1; there another division occurs and a branch crosses each *TBr* to the arm base (Pl. III, Fig. 10). This is the general pattern in the first variety of ornamentation, but modifications appear in those specimens which do not have the 20 arms produced by such branching. If there are more than 20 arms, additional bifurcations occur and *QBrBr* are present; if there are less, certain ridges

do not bifurcate or, if they bifurcate, one branch terminates before reaching the general level of the arms (Pl. IV, Fig. 2); in either case, *ISBrBr* may occur in the dorsal cup in place of *TBrBr*. These ridges on the plates of the rays may be low, rounded, and inconspicuous (Pl. III, Fig. 14), they may be high, sharp, and quite prominent (Pl. I, Fig. 18), they may be continuous (Pl. II, Fig. 4), or they may be discontinuous (Pl. I, Figs. 17, 18). On some specimens, notably those of the rugose kind of *D. stellifer*, they may be faint and intermittent throughout most of their length (Pl. VI, Fig. 24). Typically each plate in the ray has a central node on the ridge and the nodes are elongate in the direction of the ridge. In some specimens, the nodes are very prominent and the ridges consist of several parallel fine ridges (Pl. I, Fig. 21). In *D. grabaui* from the Potter Farm Formation, the nodes are absent and several fine ridges cross the plates of the rays (Springer, 1921, Pl. 12, Figs. 8, 9).

The second kind of ornamentation is that which radiates from the centers to the sides of the plates of the dorsal cup, thereby forming triangles. Within each triangle there are several additional lines of ornamentation parallel to each side which make a set of concentric triangles. This kind of ornamentation may consist of continuous ridges (Pl. I, Fig. 16), discontinuous ridges (Pl. II, Fig. 5), straight ridges (Pl. I, Fig. 16), wrinkled ridges (Pl. I, Fig. 18), or rows of pustules (Pl. II, Fig. 10). If the ridges coalesce in the center of the plates, prominent nodes are formed (Pl. I, Figs. 1, 2). If they do not attain the center, as in the case of $IBrBr_1$ of most specimens, they may join to form a small subcircular (Pl. V, Figs. 1, 2, 4) or semicircular (Pl. III, Figs. 10, 13) ridge around the central spot, which therefore appears as a pit, although it is actually not depressed much, if any, below the general level of the plate except in the rugose forms of *D. stellifer* (Pl. VI, Figs. 21–24). Springer (1921, p. 23) said:

> Primarily the ridges connecting the centers of both radial and interbrachial sets of plates are the external representatives of the nerve cords which innervate the growing skeleton and the triangular arrangement results mechanically from the mutual arrangement of the plates. With age they may become variously modified by secondary growth, reduplicated, intensified, or broken up into nodes by which the original fine lines are interrupted, obscured, or obliterated.

Because intergradation between any two selected varieties can be found, extreme caution must be used in defining species on the basis of minor ornamentation differences.

Due to the great variability in the characters noted above, *Dolatocrinus* is an exceptionally difficult genus to break up into species.

SPECIFIC CHARACTERS

In the past, authors have tended to create a new species of *Dolatocrinus* for nearly every well-preserved specimen that has been found. This concept of species, or philosophy of taxonomy, was carried to an extreme; to us it seems that within each population the individuals of a generation were made separate species, and those of succeeding generations were classified as still other species. The absurdity of this approach was not recognized by previous taxonomists. They were intent upon looking for minor differences to justify erection of more species; they overlooked the basic similarities which characterize members of a population and identify them as one species. Simply stated, each species of *Dolatocrinus* possesses a high degree of variability and cannot be differentiated by use of a millimeter scale, a simple arm count, or diagram of ornamentation.

Before analyzing the variations in extinct crinoids, one should learn about the species that exist today. Because living crinoids are virtually absent along the shores of nations where the most interest in paleontology and zoology has centered, they have been largely ignored. This lack of knowledge about living crinoids has hampered scientific classification of fossil faunas. In the first volume of his monumental *Monograph of the Existing Crinoids,* A. H. Clark (1915, p. 124) stated: "History has shown that too often ... recent forms have been ignored or slighted by paleontologists."

Clark studied in detail every species of living crinoid known to science and was supplied with specimens from all the great collections of the world. In addition, his travel on oceanographic vessels gave him an opportunity to relate species to their ecology. From his experiences in these expeditions he surmised that crinoids are presently an extremely abundant group of animals contrary to the ideas expressed by paleontologists that the living representatives are merely the decadent survivors of a once great class. In his analysis, Clark liberated himself from preconceived interpretations; he laid aside the literature and worked first with the specimens. Such an approach is nearly indispensable also in paleontologic work.

Several conclusions reached by Clark have an important bearing on the species concept in *Dolatocrinus*. He noted that characters perfectly reliable as indicators of species in one group of crinoids are unsatisfactory or even worthless in other groups. He also found (1915, p. 10) a tremendous increase in the number of variants under optimum conditions, a sort of incipient species formation. Springer (1921, pp. 22, 52), who also had some acquaintance with living crinoids, reached the same conclusion with regard to the Hamilton species of *Dolatocrinus*. One statement by Clark

(1915, p. 13) has special bearing on the taxonomy of *Dolatocrinus*: "The degree of instability of the generic and specific characters and of the correlation of the characters presented by the several sets of structures and organs is broadly speaking inversely proportional to the fixity of habits of the adults and therefore in general to the number of arms possessed by the adults."

This concept is a telling blow to the classification system of Miller and Gurley, who defined species of the many-armed sessile genus *Dolatocrinus* on the number and grouping of arms or slight differences in the number and position of plates; to that of Rowley, who considered minor details of ornamentation as being of specific value; and to that of Springer, who based species on little differences in proportion and form. Clark demonstrated clearly that each of these characters alone is unreliable and cannot be used for specific differentiation of living crinoids unless it is correlated with several others. He said (1915, p. 14) that individual characters are "... unstable and uncertain and are liable to sudden and extreme deviations from the normal resulting in all sorts of grotesque mixtures, not only within a family or genus, but even within a group of specimens of the same species from the same locality."

The Dock Street Clay and its equivalents, particularly the Beechwood Limestone from the Falls of the Ohio area from which the greatest percentage of species is described, are thin beds exposed in very limited areas. The multitude of species reported from these beds is highly unlikely in view of the evidence presented by Clark. In our study of the Dock Street Clay fauna, therefore, we set aside the previous literature on *Dolatocrinus* and, with Clark's principles as a guide, grouped the specimens on the basis of the association of consistent characters. After this correlation of morphological features and grouping of specimens, we consulted the literature. It was immediately obvious that the number of species was much less than the number of names, many of which should be relegated to synonymy. According to our classification, some of the "species" assigned to different groups within the genus on the basis of trivial dissimilarities in unstable characters were in reality one species. In the great number of specimens at our disposal, intergradations were observed which led to further reduction of "species." The main result of our investigation has been redefinition of all species of *Dolatocrinus* occurring in the Dock Street Clay and its equivalents, and reduction of the number of taxonomic divisions to a more realistic and natural level.

The characters which we regard as significant are summarized in Table I. The most important of these are the lobation and ornamentation of the tegmen, the form of the basal concavity, certain consistent patterns

and features of ornamentation in the dorsal cup, the nature of the pinnule apertures between arm bases, and details of the rim around the base connecting the centers of the *RR* plates. Within the natural groupings based on constant associations of these characters, great variations have been observed in the size of heads, number and grouping of arms, constrictions beneath the arms, height of the tegmen, proportions of plates, and fine details of ornamentation. These characters vary sporadically and have no diagnostic value. In fact, more than one variation in ornamentation, arm constriction, and plate proportion occurs in the different sectors of the same specimen.

To avoid filling the bulk of this paper with synonymy, we have economized to the extent of citing only the initial reference to each name in the systematic descriptions below. Goldring (1923) and Bassler and Moodey (1943) contain fairly complete synonymies. Springer (1921) offers pertinent observations on all the species he considered valid at the time of his paper.

SYSTEMATIC DESCRIPTIONS

Subclass CAMERATA Washsmuth and Springer, 1897
Order MONOBATHRA Moore and Laudon, 1943
Family Dolatocrinidae Bather, 1899
Genus *Dolatocrinus* Lyon, 1857

Cacabocrinites Troost, 1849, p. 419 (*nom. nud.*)
Dolatocrinus Lyon, 1857, p. 482.
Cacabocrinus Hall, 1862, p. 137.

Type species.—By monotypy, *D. lacus* Lyon, 1857, p. 482, Pl. 4, Figs. 2*a–c*.

Dolatocrinus bulbaceous Miller and Gurley
(Pl. I, Figs. 1–4; Pl. VII, Figs. 1–3)

Dolatocrinus bulbaceous Miller and Gurley, 1894*a*, p. 22, Pl. II, Figs. 13–15.
Dolatocrinus pulchellus Miller and Gurley, 1895*a*, p. 55, Pl. V, Figs. 13–15.
Dolatocrinus argutus Miller and Gurley, 1896*a*, p. 41, Pl. III, Figs. 4–6.
Dolatocrinus aspratilis Miller and Gurley, 1896*b*, p. 49, Pl. III, Figs. 16–18.
Dolatocrinus subaculeatus Whiteaves, 1898, p. 369, Pl. XLVIII, Fig. 6.

This species is distinguished by its small size and by the very prominent ridge on the plates of the rays accentuated by strong central nodes on these plates (Pl. I, Figs. 1–3; Pl. VII, Fig. 1), a very strong central node on $IBrBr_1$ (Pl. I, Figs. 1–3; Pl. VII, Figs. 1, 2) from which fine ridges radiate in well-preserved specimens (Pl. I, Figs. 1, 3), a broadly and deeply concave, funnel-shaped basal pit (Pl. I, Fig. 2; Pl. VII, Fig. 2),

TABLE I

CHARACTERISTICS OF *Dolatocrinus* SPECIES FROM THE DOCK STREET CLAY OF MICHIGAN

Character	D. triadactylus	D. michiganensis	D. bulbaceous	D. stellifer	D. liratus
General size	Medium		Small	Medium to large	
Basal pit	Broadly and deeply concave, somewhat funnel-shaped			Deeply concave	Small, nearly all retaining part of column
Tegmen ornamentation	Rugose, studded with knobby protuberances		Finely pustulose, smooth in specimens that may be worn		
Tegmen lobation	Strongly lobed			Slightly lobed	Pronounced lobes
Pinnule openings between arm bases	Prominent, typically 2 on each side of every arm		Small, not easily seen, typically 1 on each side of every arm	Very prominent, typically 2 on each side of every arm	Obscure, not exposed in most, close beside arm bases and covered with plates
Rim around base connecting *RR*	Medium pentagonal	Medium- to strongly-developed pentagonal	Very prominent pentagonal	Fine pentagonal	Strong circular as well as fine pentagonal
Dorsal cup ornamentation	Stellate pattern like that of *D. stellifer*	Very pronounced nodose ridges giving cup a spinose appearance; thicker, higher than in *D. triadactylus*	Ridges on rays accentuated by central nodes on plates; very strong central node on $IBrBr_1$ with weak radiating ridges	Basic stellate pattern, numerous variations in rugosity and width of ridges	Intricate patterns of radiating ridges on plates, many variations
Arms	About 15	15	Most 10, one known with 11	11 to 20, most near 20	10 to 22, most near 15

a very prominent pentagonal rim around the basal cavity formed by ridges connecting the nodes on the center of each *R* (Pl. I, Fig. 2; Pl. VII, Fig. 2), and a strongly-lobed tegmen, either smooth or finely pustulose depending upon the degree of preservation (Pl. VII, Fig. 3). Size is ordinarily not a good indicator of species, but in the case of *D. bulbaceous* no medium or large specimens possessing these distinctive characters have been found. Since we have identified the young of all other known species of Dock Street age and find them quite different (Pl. III, Fig. 11; Pl. VII, Figs. 10, 13–18), we are convinced that this species could not possibly be an immature form of one of them. Most specimens of this species possess ten arms (two to each ray), the only deviant noted being the specimen described by Miller and Gurley as *D. aspratilis* (Pl. I, Figs. 1, 2) which has 11 arms, one ray possessing an extra arm. The ornamentation of *D. bulbaceous* is distinctive and consistent in the general terms outlined above, although numerous minor variations can be noted even in the illustrations. The pinnule apertures are small and not easily detectable in this species. There is one on each side of every arm in most well-preserved specimens.

Miller and Gurley differentiated *D. pulchellus* from *D. bulbaceous* because it possesses pinnule apertures while the latter species supposedly had none and by slight differences between the two in ornamentation and shape. *D. argutus* of Miller and Gurley (our Pl. I, Fig. 4) consists of nothing more than well-worn specimens of *D. bulbaceous*. *D. aspratilis* was distinguished by Miller and Gurley because it possesses 11 arms, one more than *D. bulbaceous*. Whiteaves differentiated *D. subaculeatus* because it supposedly possessed a different number of pinnule apertures from *D. pulchellus*. All of these deviations are minor and not of specific value as Rowley (1903, p. 109) was the first to realize.

This is the first report of this species from Michigan and is based upon a single specimen, UMMP 45018 (Pl. VII, Figs. 1–3). The Dock Street Clay specimen has a more depressed dorsal cup, a higher tegmen, a more prominent node on IBr_2, and a smoother surface than the Indiana types of Miller and Gurley (our Pl. I, Figs. 1–4), but these differences are not worthy of specific rank when one notes the variation among the Indiana specimens. No pinnule openings are visible in the Michigan specimen.

Occurence.—Dock Street Clay, Four Mile Dam Formation, Traverse Group, Alpena, Michigan; Beechwood Limestone, Sellersburg Group, Clark County, Indiana (Miller and Gurley, 1894*a*, p. 23); Hungry Hollow Formation, Thedford-Arkona region, Ontario (Whiteaves, 1878, p. 369).

Dolatocrinus stellifer Miller and Gurley

(Pl. I, Figs. 5–14; Pl. II, Figs. 14–18; Pl. IV, Figs. 11–20; Pl. V, Figs. 1–12; Pl. VI, Figs. 13–24; Pl. VII, Figs. 4–6)

Dolatocrinus stellifer Miller and Gurley, 1894*a*, p. 20, Pl. II, Figs. 10–12.
Dolatocrinus amplus Miller and Gurley, 1894*b*, p. 45, Pl. IV, Figs. 6–8.
Dolatocrinus hammelli Miller and Gurley, 1895*a*, p. 52, Pl. V, Figs. 4–6.
Dolatocrinus vasculum Miller and Gurley, 1895*a*, p. 53, Pl. V, Figs. 7–9.
Dolatocrinus aplatus Miller and Gurley, 1896*a*, p. 48, Pl. III, Figs. 16–18.
Dolatocrinus laguncula Miller and Gurley, 1896*b*, p. 51, Pl. III, Figs. 19–21.
Dolatocrinus dissimilaris Miller and Gurley, 1896*b*, p. 54, Pl. III, Figs. 25–27.
Dolatocrinus peculiaris Miller and Gurley, 1896*b*, p. 56, Pl. III, Figs. 28–30.
Dolatocrinus neglectus Miller and Gurley, 1897, p. 37, Pl. II, Figs. 27–29.
Dolatocrinus lyoni Wachsmuth and Springer, 1897, p. 314, Pl. XXX, Fig. 6.
Dolatocrinus pernodosus Rowley, 1903, p. 113, Pl. III, Figs. 4–6.
Dolatocrinus costatus Wood, 1904, p. 70, Pl. XVI, Fig. 6.
Dolatocrinus wachsmuthi Wood, 1904, p. 77.

This species may be distinguished by its broadly and deeply concave basal pit (Pl. I, Figs. 9, 13; Pl. V, Figs. 1–12) surrounded by a fine pentagonal rim (contrary to Springer, 1921, p. 39), its very slightly lobed, smooth to finely pustulose tegmen (Pl. I, Figs. 8, 11; Pl. IV, Figs. 11, 12), its broadly truncate base (Pl. I, Figs. 10, 12; Pl. VI, Figs. 13, 17, 20), and its very prominent pinnule openings between the arms (Pl. I. Figs. 10, 12, 14; Pl. VI, Figs. 13, 17). Typically there are two of these openings on each side of every arm. This species shows considerable variation in the character of the surface of the cup plates and many of the forms have been designated species. With the large number of specimens available for this study, it can be shown that all these "species" intergrade. The species previously described as *D. amplus* and *D. stellifer* are the two end members of the series. In *D. amplus* all the plates of the dorsal cup are extremely rugose, being high in the center and sloping away to radially furrowed margins (Pl. I, Fig. 12), whereas in *D. stellifer* the plates are smooth except for the fine sharp ridges which give the species its characteristic stellate ornamentation (Pl. I, Fig. 9). Plates V and VI illustrate representative intergradations in a series of Michigan specimens. At the top of Plate V, specimens characteristic of the *stellifer* type of dorsal cup are shown, while those near the bottom of Plate VI would be referrable to *D. amplus*. Intermediate forms described by Miller and Gurley such as *D. laguncula* (Pl. I, Fig. 6), *D. aplatus* (Pl. I, Fig. 5), and *D. hammelli* are nearer to *D. stellifer*. Michigan specimens are similar (Pl. V, Figs. 7–12). Wood's species described from Michigan, *D. costatus,* is closer to *D. amplus* and would be represented by certain Dock Street Clay specimens (Pl. VI, Figs. 13–19). It can be seen in Plates V and VI that the

ornamentation of the dorsal cup does not vary significantly from a basic pattern. These crinoids constitute one species. Although the ridges forming the ornamentation do vary in height, width, and number, these differences do not correlate with any other character and, hence, are not of specific importance.

The arrangement of tertibrachs and interbrachial plates is also variable in this species. IBr_1 may have nine sides as in most species of *Dolatocrinus,* or it may have 10 or 11 sides. These differences are due to variation in the number of plates lying immediately above it from one to three. Only one plate above IBr_1, and IBr_2, is the usual arrangement in this genus, but in *D. stellifer* one or even two tertibrachs may be moved down on either side of IBr_2 to contact the upper surface of IBr_1. Such variation is not of specific value since it is found not only in different individuals, but in different sides of the same specimen. UMMP 45014 possesses all three types of relationships between tertibrachs and interbrachial plates; those with two and three plates above IBr_1 are illustrated (Pl. VI, Fig. 20).

Another problem that arises in defining this species is the variation in the form of the calyx. Aside from the nearly smooth, slightly lobed tegmen, broadly and deeply concave basal pit, and its truncate base, this species does not have clearly definable limits of shape. Two specimens that are indistinguishable on the basis of any other character show a notable difference in shape (common in *D. stellifer*): UMMP 45000 (Pl. IV, Fig. 19) exhibits a marked constriction below the arms but UMMP 44995 (Pl. IV, Fig. 20) is broadly flaring in that area. One can account for this difference in shape by noting that one specimen (Fig. 19) has the arms and their accessory minor plates broken off at their junction with the calyx, whereas the other (Fig. 20) preserves the arms and accessory plates out to a considerable distance from the calyx. These differences appear also in a tegminal view; where portions of the arms are preserved (Pl. IV, Fig. 11), the pinnule openings are not visible, being covered by plates, and the dorsal cup cannot be seen; yet where the arms are broken away at their bases (Pl. IV, Fig. 12), the pinnule openings are visible, being freed of their covering plates, and portions of the dorsal cup can be seen protruding beneath the arm bases.

Two other specimens demonstrate another difference in shape (Pl. VI, Figs. 13, 17). The tegmen is considerably higher in BSNS E11930 (Fig. 17). Such individual variation is not uncommon in many species of *Dolatocrinus* and is not correlated with any other characters. Inasmuch as most larger specimens have low tegmens and broader bases, these characters appear to be typical of gerontic individuals, though a few smaller specimens also have this form.

Immature individuals of this species are in most respects just smaller versions of the adults. Of the very young individuals, some have the *stellifer* (Pl. IV, Fig. 13) and others the *amplus* or *costatus* (Pl. IV, Figs. 14–18) types of plate surfaces.

D. hammelli, D. aplatus (Pl. I, Fig. 5), *D. laguncula* (Pl. I, Fig. 6), *D. dissimilaris,* and *D. neglectus* (Pl. I, Figs. 9, 10) were distinguished by Miller and Gurley from *D. stellifer* largely on the basis of the number of arms. They possess respectively 16, 15, 14, 13, and 17 arms compared with 11 arms of the type of *D. stellifer* (Pl. I, Fig. 8). Miller and Gurley distinguished *D. vasculum* (18 arms; Pl. I, Fig. 13) and *D. peculiaris* (17 arms; Pl. I, Figs. 11, 14) from *D. amplus* (20 arms; P. I, Fig. 12) solely on the number of arms. *D. lyoni* was a species proposed by Wachsmuth and Springer in defiance of Miller and Gurley because of the antipathy between Wachsmuth and Miller. Because this name was preoccupied by Miller and Gurley for a different form, Wood in 1904 proposed the name *D. wachsmuthi* for the type specimen. After Wachsmuth's death, Springer (1921, p. 47) correctly synonymized these names with *D. amplus*. Rowley's 17-armed species, *D. pernodosus,* was based upon a different arm arrangement from *D. peculiaris. D. costatus* was differentiated from *D. amplus* by Wood on the basis of slight differences in ornamentation and rugosity of the cup plates.

As mentioned above, specimens of this exceedingly abundant species from the Dock Street Clay of Michigan represent practically all the variations in ornamentation, shape, and plate surfaces known in *D. stellifer* and its synonyms. Nearly all the specimens from Michigan, regardless of the surface character of their cup plates, possess 20 arms, while those from the Falls of the Ohio area have from 11 to 20 arms. Of the specimens from the Falls of the Ohio area, those with lower numbers of arms all possess the *stellifer* type of plate surfaces and indicate that this is probably the original form of the species as it evolved from one of the uniformly 10-armed species of *Dolatocrinus* in the Onondaga. All the specimens with 18 or more arms from the Falls of the Ohio area possess the *amplus* type of plate surfaces indicating that increasing rugosity of cup plates with increasing number of arms was a definite trend of the species in that area. That this was not a universal tendency can be shown by two examples: Springer (1921, p. 47) reported a 16-armed specimen of *D. amplus,* and *D. neglectus,* which is almost identical with the type specimen of *D. stellifer,* has 17 arms.

Occurrence.—Dock Street Clay, Four Mile Dam Formation and Alpena Limestone (Wood, 1904, p. 70), Traverse Group, Alpena, Michigan;

Beechwood Limestone, Sellersburg Group, Clark County, Indiana, and Louisville, Kentucky (Miller and Gurley, 1894*a*, p. 21).

Dolatocrinus liratus (Hall)

(Pl. I, Figs. 17–22; Pl. II, Figs. 1–13; Pl. III, Figs. 1–16)

Cacabocrinus liratus Hall, 1862, p. 139.
Cacabocrinus liratus var. *multilira* Hall, 1862, p. 139.
Cacabocrinus glyptus Hall, 1862, p. 140.
Cacabocrinus glyptus var. *intermedius* Hall, 1862, p. 140.
Dolatocrinus glyptus Shumard, 1866, p. 367.
Dolatocrinus glyptus var. *intermedius* Shumard, 1866, p. 367.
Dolatocrinus liratus Shumard, 1866, p. 367.
Dolatocrinus liratus var. *multilira* Shumard, 1866, p. 367.
Dolatocrinus ornatus Meek, 1871, p. 57.
Dolatocrinus canadensis Whiteaves, 1887, p. 99, Pl. 12, Fig. 3.
Dolatocrinus magnificus Miller and Gurley, 1894*a*, p. 5, Pl. I, Figs. 1–3.
Dolatocrinus ornatus var. *asperatus* Miller and Gurley, 1894*a*, p. 15, Pl. III, Figs. 4–6.
Dolatocrinus venustus Miller and Gurley, 1894*a*, p. 23, Pl. II, Figs. 16–18.
Dolatocrinus aureatus Miller and Gurley, 1894*a*, p. 24, Pl. III, Figs. 1, 2.
Dolatocrinus lineolatus Miller and Gurley, 1894*a*, p. 27, Pl. III, Figs. 7–9.
Dolatocrinus greenei Miller and Gurley, 1894*a*, p. 28, Pl. III, Figs. 10–12.
Dolatocrinus corporosus Miller and Gurley, 1895*a*, p. 50, Pl. V, Figs. 1–3.
Dolatocrinus exornatus Miller and Gurley, 1895*a*, p. 54, Pl. V, Figs. 10–12.
Dolatocrinus bellulus Miller and Gurley, 1895*a*, p. 57, Pl. V, Figs. 16–18.
Dolatocrinus nodosus Miller and Gurley, 1895*b*, p. 56, Pl. III, Figs. 1–3.
Dolatocrinus sacculus Miller and Gurley, 1895*b*, p. 58, Pl. III, Figs. 11, 12.
Dolatocrinus salebrosus Miller and Gurley, 1895*b*, p. 59, Pl. III, Figs. 13–15.
Dolatocrinus indianensis Miller and Gurley, 1896*a*, p. 40, Pl. III, Figs. 1–3.
Dolatocrinus bellarugosus Miller and Gurley, 1896*a*, p. 43, Pl. III, Figs. 7–9.
Dolatocrinus charlestownensis Miller and Gurley, 1896*a*, p. 44, Pl. III, Figs. 10–12.
Dolatocrinus caelatus Miller and Gurley, 1896*a*, p. 46, Pl. III, Figs. 13–15.
Dolatocrinus dispar Miller and Gurley, 1896*b*, p. 40, Pl. II, Figs. 27–29.
Dolatocrinus preciosus Miller and Gurley, 1896*b*, p. 41, Pl. II, Figs. 30–32.
Dolatocrinus basilicus Miller and Gurley, 1896*b*, p. 43, Pl. III, Figs. 1–3.
Dolatocrinus lyoni Miller and Gurley, 1896*b*, p. 44, Pl. III, Figs. 4–6.
Dolatocrinus cistula Miller and Gurley, 1896*b*, p. 46, Pl. III, Figs. 7–9.
Dolatocrinus asper Miller and Gurley, 1896*b*, p. 47, Pl. III, Figs. 10–12.
Dolatocrinus arrosus Miller and Gurley, 1896*b*, p. 52, Pl. III, Figs. 22–24.
Dolatocrinus marshi var. *hamiltonensis* Wachsmuth and Springer, 1897, p. 314, Pl. XXV, Fig. 2.
Dolatocrinus icosodactylus Wachsmuth and Springer, 1897, p. 319, Pl. XXVI, Fig. 5.
Dolatocrinus tuberculatus Wachsmuth and Springer, 1897, p. 324, Pl. XXV, Fig. 3.
Dolatocrinus depressus Miller, 1898, p. 6, Pl. II, Figs. 4–6.
Dolatocrinus springeri Rowley, 1903, p. 136, Pl. XXXIX, Figs. 9, 10.
Dolatocrinus arrosus var. *cognatus* Rowley, 1903, p. 137, Pl. XXXIX, Figs. 12–14.
Dolatocrinus noduliferous Rowley, 1903, p. 140, Pl. XLI, Figs. 1–3.
Dolatocrinus welleri Rowley, 1903, p. 143, Pl. XLI, Fig. 14.
Dolatocrinus multinodosus Rowley, 1903, p. 147, Pl. XLIV, Figs. 1–3.

Dolatocrinus corporosus var. *concinnus* Rowley, 1903, p. 148, Pl. XLIV, Figs. 1–6.
Dolatocrinus corporosus var. *decoratus* Rowley, 1903, p. 149, Pl. XLIV, Figs. 7–9.
Dolatocrinus elegantulus Rowley, 1903, p. 150, Pl. XLIV, Figs. 10–12.
Dolatocrinus corbuliformis Rowley, 1903, p. 151, Pl. XLIV, Figs. 13–15.
Dolatocrinus asperatus Springer, 1921, p. 41, Pl. VI, Figs. 5–12.
?*Dolatocrinus liratus* var. *parvulus* Goldring, 1923, p. 164, Pl. XVII, Fig. 14.

This species is distinguished by its small basal pit surrounded by a circular as well as a pentagonal rim (Pl. I, Figs. 18, 19; Pl. II, Fig. 4; Pl. III, Figs. 5, 8, 11), finely pustulose and distinctly lobate tegmen (Pl. I, Figs. 20, 22; Pl. III, Figs. 2, 12), intricate ornamentation (Pl. II, Fig. 4, Pl. III, Fig. 10), and its obscure pinnule openings which are not exposed in most specimens. In contrast to all other species in the Dock Street Clay, *D. liratus* does not have a broadly and deeply concave basal pit, but instead a very narrow and shallow one that is exposed in only a few specimens (Pl. III, Fig. 8). In nearly all specimens, a portion of the column is still retained in the basal pit owing to its narrow diameter. In most specimens of the other species, the broadly concave base precluded retention of the proximal section of the column, which apparently was easily detached or fell away upon the death of the animal. The basal pit of *D. liratus* is surrounded by a strong circular rim on the *RR,* which in most specimens is more prominent than the pentagonal rim. In this species the pentagonal rim is actually a number of parallel fine ridges and is circumscribed about the circular rim (Pl. I, Figs. 18, 19, 21; Pl. II, Figs. 1, 3, 4, 13; Pl. III, Figs. 5, 8, 11, 14). The tegmen is quite distinct from that of other species of Hamilton age (except the small species *D. bulbaceous*) in being pronouncedly lobed and covered with fine pustules (Pl. I, Figs. 20, 22; Pl. III, Figs. 2, 12), instead of being slightly lobate as in *D. stellifer* (Pl. I, Figs. 8, 11; Pl. IV, Figs. 11, 12) or covered with coarse knobs as in *D. triadactylus* Barris (Pl. I, Fig. 16; Pl. IV, Fig. 2), *D. asterias* Wood, *D. incisus* Springer, *D. grabaui* Kirk, and *D. michiganensis,* sp. nov. (Pl. IV, Figs. 6, 7). The tegmen is low in *D. liratus* (Pl. I, Fig. 17; Pl. II, Figs. 11, 12; Pl. III, Fig. 1) unless the specimen has been laterally compressed (Pl. III, Fig. 6). The ornamentation is very intricate in this species, particularly the variety consisting of ridges radiating from the centers of the plates. These ridges may be continuous (Pl. II, Fig. 13), discontinuous (Pl. I, Fig. 18), nodose (Pl. III, Fig. 13), or composed of rows of pustules (Pl. II, Fig. 10). They may also be more or less straight and regular (Pl. II, Fig. 13) or irregular, contorted, and vermiform (Pl. I, Fig. 18; Pl. II, Fig. 4). These radiating ridges coalesce in the center of the $IBrBr_1$ of some specimens to form nodes (Pl. I, Fig. 19). The ridges crossing the plates of the rays may be quite pronounced (Pl. I, Fig. 18;

Pl. III, Figs. 4, 5) or only as prominent as the other ornamentation (Pl. III, Figs. 8, 10, 14, 16). Despite the variety of forms taken by this ornamentation, the basic plan is the same as can be seen from the illustrations. Because of this basic plan, specimens of this species when viewed from the basal side show a striking pattern of geometric figures, most noticeable of which are five sets of concentric triangles that form a star when considered together. The pinnule openings in *D. liratus* are close beside the arm bases (Pl. II, Fig. 11) and are covered with plates in most specimens. Because they are not readily discernible, many previous observers missed seeing them in the species they described. The usual pattern is one on each side of the individual arms and an extra one on either side of each ambulacrum.

This species has a variable form depending upon the size of the specimen and, hence, its growth stage. The smaller specimens are shaped like a mixing bowl, sloping evenly upward from the base to the arms (Pl. I, Fig. 17; Pl. II, Fig. 2; Pl. III, Fig. 10). In larger specimens, the base becomes truncate and flat (Pl. II, Figs. 6, 8, 11; Pl. III, Fig. 1). In most gerontic specimens, the sides of the dorsal cup bulge out beneath the arm bases giving the appearance of a constriction below the arms (Pl. II, Fig. 5). The difference in form between these medium and large specimens has been used in the past to differentiate this species into two totally distinct groups of species (Springer, 1921, pp. 49, 51). The *magnificus* group included all those species that showed constriction below the arms, while the bowl-shaped specimens were put in the *venustus* group. Despite Springer's claim (1921, p. 53) that he could see constrictions below the arms in all specimens, large or small, which he placed in the *magnificus* group, certain specimens disclose that he was mistaken (for example, Pl. II, Fig. 6). Springer ignored the original descriptions of many of the species listed in the above synonymy when erecting his groups of species according to the presence or absence of constrictions below the arms. Even in large specimens such constriction is present on one side of the specimen and not the other (Pl. III, Fig. 1). Within both the *magnificus* and *venustus* groups, Springer (1921, pp. 50, 53) admitted that he himself could not separate the species on any consistent basis. Nevertheless, he retained many of them on very feeble grounds, even though he stated that "... it is probable that a far more drastic cutting down of species, even to the extent of throwing them all into one, would be the more logical course." Springer's *magnificus* group formerly included the following species: *D. magnificus* (22 arms), *D. corporosus* (20 arms; our Pl. II, Fig. 4), *D. corporosus* var. *decoratus* (16 arms), *D. indianensis* (17 arms), *D. preciosus* (15 arms; Pl. II, Figs. 10, 11), *D. greenei* (19 arms; Pl. II,

Figs. 5, 6), *D. corporosus* var. *concinnus* (20 arms), *D. lineolatus* (14 arms), *D. sacculus* (20 arms; Pl. II, Fig. 3), *D. salebrosus* (16 arms), *D. charlestownensis* (15 arms), *D. cistula* (16 arms), *D. asper* (15 arms), *D. icosodactylus* (20 arms), *D. springeri* (22 arms), *D. bellulus* (17 arms; Pl. II, Figs. 12, 13), *D. basilicus* (17 arms; Pl. II, Fig. 8), *D. nodulifer-ous* (16 arms), *D. nodosus* (16 arms; Pl. II, Fig. 9), *D. tuberculatus* (arms unknown), *D. multinodosus* (18 arms), and *D. elegantulus* (18 arms). Springer (1921, pp. 54–56) recognized that the number of arms and their grouping were poor criteria on which to establish species, so he synonymized the above species until only seven remained, all based upon very minor differences in ornamentation. His *venustus* group contained *D. venustus* (18 arms; our Pl. I, Figs. 17, 18), *D. aureatus* (17 arms), *D. lyoni* (13 arms), *D. corbuliformis* (18 arms), *D. bellarugosus* (17 arms; Pl. II, Figs. 1, 2), *D. caelatus* (16 arms; Pl. I, Figs. 19, 20), *D. arrosus* (16 arms; Pl. I, Figs. 21, 22), *D. arrosus* var. *cognatus* (19 arms), *D. exornatus* (19 arms), *D. dispar* (16 arms; Pl. II, Fig. 7), and *D. canadensis* (15 arms). Springer overlooked *D. depressus* (18 arms) in his summary, but by his criteria it would have been placed in the *venustus* group. He (1921, pp. 50–51) reduced this group to four species, separated by minor differences in ornamentation as were those of the magnificus group. It is remarkable that all these species have been classified in differ-ent groups so long when the obvious similarities between them were noted even by the original authors.

It is also remarkable that the New York species and varieties, *D. liratus, D. liratus* var. *multilira, D. liratus* var. *parvulus* (?), *D. glyptus, D. glyptus* var. *intermedius, D. ornatus,* and *D. marshi* var. *hamiltonensis,* have been separated from all the above species. These species and varieties were differentiated from one another only by slight differences in orna-mentation which seem to have no specific value because they do not corre-late with other characters. In all the characters of specific importance as defined previously, these species and varieties agree with the species of the former *magnificus* and *venustus* groups. The only feature that has kept the New York species from being included with these two groups has been the fact that they possess only 10 arms and, hence, are holdovers from the Onondaga. The illusion that the number of arms is of specific value has already been dispelled, particularly by the occurrence of otherwise similar specimens with many different numbers of arms in the same bed, as in the Dock Street Clay. Two specimens of *D. liratus* from the Dock Street Clay that are alike in all respects save arm number are illustrated on Plate III: UMMP 23891 (Fig. 8) possesses 12 arms, UMMP 44978 (Figs. 1, 2) has 17 arms. Several other specimens which are otherwise indistinguishable

from these two have intermediate numbers of arms. Thus it appears that in Onondaga time *D. liratus* had 10 arms, whereas in Hamilton time the number of arms increased and became exceedingly variable, although 10-armed individuals still persisted (Springer, 1921, p. 41).

Lyon (1869, pp. 443–44) mentioned that *D. liratus* and its allies were found at the Falls of the Ohio, a fact which escaped later authors. Undoubtedly he based his observations on specimens which subsequent authors assigned to species that Springer placed in his *venustus* or *magnificus* groups, because *D. liratus* and its allies were not noted from that area by anyone else. Once again, this demonstrates that specimens from the three groups, *magnificus, venustus,* and *liratus,* cannot be distinguished from each other.

Two very young individuals (Pl. III, Figs. 11, 12) show the characteristics of the species well and are bowl-shaped like all other known young individuals. They differ from the adults only in the simpler ornamentation of their dorsal cups. Goldring (1923, Pl. XVII) illustrated several specimens which are supposedly the young of *D. liratus*. Most of these specimens do not resemble our specimens of very young individuals, nor do they resemble the adults. In reality, they closely resemble adults of *D. bulbaceous* both in ornamentation and their broadly and deeply concave bases. Inasmuch as we have not seen these specimens, we cannot judge the accuracy of the illustrations and, therefore, reserve opinion at this time as to which species these specimens belong, except to say that it is not likely that they belong to *D. liratus*.

Occurrence.—Onondaga Limestone of western New York (Goldring, 1923, p. 172); Columbus Limestone, Columbus, Ohio (Meek, 1871, p. 57); Jeffersonville Limestone, Falls of the Ohio (Bassler and Moodey, 1943, p. 437); Beechwood Limestone, Sellersburg Group, Clark County, Indiana, and Louisville, Kentucky (Miller and Gurley, 1894*a*, pp. 7, 9); Hungry Hollow Formation near Arkona, Ontario (Whiteaves, 1887, p. 99); Dock Street Clay, Four Mile Dam Formation and Alpena Limestone (Bassler and Moodey, 1943, p. 439), Traverse Group, Alpena, Michigan; Tichenor Limestone, western New York (Bassler and Moodey, 1943, p. 434); Moscow Shale, New York (Goldring, 1923, p. 156); and Tully Limestone, New York (Goldring, 1923, p. 163).

Dolatocrinus triadactylus Barris

(Pl. I, Figs. 15, 16; Pl. IV, Figs. 1–3)

Dolatocrinus triadactylus Barris in Wachsmuth and Barris, 1885, p. 25, Pl. II, Figs. 5–7. (Repeated in Proc. Davenport Acad. Sci., 1886.)

This species is similar to nonrugose specimens of *D. stellifer* from which it may be distinguished by the character of the tegmen. The tegmen

in this species is studded with large, knobby protuberances and is distinctly lobed, being elevated over the ambulacra and depressed in the interrays (Pl. 1, Fig. 16; Pl. IV, Fig. 2), as in *D. liratus*. *D. triadactylus* has a broadly and deeply concave basal pit (Pl. I, Fig. 15; Pl. IV, Figs. 1, 3) as does *D. stellifer,* the species it most closely resembles in surface ornamentation. Thus, *D. triadactylus* is an intermediate species between *D. stellifer* and *D. liratus* in many respects. It has the broad basal concavity and stellate ornamentation of the former and the strongly-lobed tegmen of the latter. It differs from both in having a rugose tegmen such as that found in *D. asterias, D. incisus, D. grabaui,* and *D. michiganensis*. The pinnule openings between the arms are prominent as in *D. stellifer* (Pl. IV, Fig. 2). Typically there are two on each side of every arm.

Despite the excellent description and illustrations of Barris (*in* Wachsmuth and Barris, 1885, p. 25, Pl. II, Figs. 5–7), this species has been the object of much misunderstanding. Both Wood (1904, p. 74) and Springer (1921, p. 46) have considered it to be a species nearly identical to *D. stellifer* and differing from it only slightly in proportions and the number of plates. Wood went so far as to synonymize *D. triadactylus* and *D. aplatus,* a synonym of *D. stellifer*. Springer wrongly stated that the tegmen is smooth in both *D. triadactylus* and *D. stellifer,* although he did note the strongly lobate tegmen in the former. For some reason, many specimens of *D. triadactylus* have been strongly compressed laterally which tends to accentuate the height of the tegmen (Pl. I, Fig. 16). Because of this, many authors have said that this species can be distinguished by its unusually high tegmen. Several specimens in the University of Michigan Museum of Paleontology which are not compressed show this statement to be erroneous (Pl. IV, Fig. 2); the tegmen in this species is no more elevated than that of *D. stellifer*.

Occurrence.—Dock Street Clay of the Four Mile Dam Formation, Potter Farm Formation (Grabau, 1902, p. 194), and Thunder Bay Limestone (*Ibid.,* p. 195), Traverse Group, Alpena, Michigan; Beechwood Limestone, Sellersburg Group, Falls of the Ohio (Bassler and Moodey, 1943, p. 438); and Hungry Hollow Formation near Arkona, Ontario (Bassler and Moodey, 1943, p. 438).

Dolatocrinus michiganensis, sp. nov.
(Pl. IV, Figs. 4–10)

This species is represented in the University of Michigan Museum of Paleontology by the holotype UMMP 23890, which is presumed to be an adult (Pl. IV, Figs. 5–7); two immature paratypes, UMMP 44992 (Pl. IV, Fig. 8) and UMMP 44993 (Pl. IV, Fig. 9); and a very young

paratype, UMMP 44994 (Pl. IV, Fig. 10); and in the Buffalo Society of Natural Sciences by an immature paratype, BSNS E15270 (Pl. IV, Fig. 4).

All these specimens show consistent characters. The calyx is considerably depressed (Pl. IV, Fig. 6); the tegmen is strongly lobed and studded with numerous strong, knobby protuberances (Pl. IV, Figs. 6, 7); the base is broadly and deeply concave and is surrounded by a medium to strongly-developed pentagonal rim (Pl. IV, Figs. 4, 8, 9); and the ornamentation is of the same pattern as in *D. triadactylus,* but differs from that species in being much thicker and more highly elevated into a series of very pronounced nodose ridges which give the whole cup a spinose appearance (Pl. IV, Figs. 4–6, 8–10). The spines and ridges are so strong that they cause the cup plates to appear rugose. All known specimens of this species possess 15 arms, three to each ray. The pinnule openings between the arms are prominent (Pl. IV, Fig. 6) as in *D. stellifer* and *D. triadactylus.* Typically there are two openings on each side of every arm.

From the description and illustrations of the new species, it is apparent that it is closely related and probably derived from *D. triadactylus,* or its close ancestors, by extreme development of the ornamentation of the dorsal cup. Specimens of many sizes show this particular development of ornamentation, discounting the possibility that it is only an ontogenetic feature.

The holotype, so designated because it is probably an adult, does not show the characteristic cup ornamentation as well as BSNS E15270 (Pl. IV, Fig. 4). This is due to the fact that some previous worker, in cleaning the holotype, chipped away portions of several ridges, thus accentuating the spinosity of the dorsal cup.

Occurrence.—Dock Street Clay, Four Mile Dam Formation, Traverse Group, Alpena, Michigan.

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PLATES

EXPLANATION OF PLATE I

(All figures × 1)

PAGE

Dolatocrinus bulbaceous Miller and Gurley 78

All specimens from Beechwood Limestone, Charlestown, Indiana.

FIGS. 1–2. Lateral and basal views of the type of *D. aspratilis* Miller and Gurley, UCWM 6102.

FIG. 3. Lateral view of one of the types of *D. bulbaceous* Miller and Gurley, UCWM 6083.

FIG. 4. Lateral view of the type of *D. argutus* Miller and Gurley, UCWM 6079.

Dolatocrinus stellifer Miller and Gurley 81

All specimens from Beechwood Limestone, Charlestown, Indiana, except UCWM 6088 (Two specimens; Figs. 7, 8) which are from Louisville, Kentucky.

FIG. 5. Basal view of the type of *D. aplatus* Miller and Gurley, UCWM 6084.

FIG. 6. Basal view of the type of *D. laguncula* Miller and Gurley, UCWM 6089.

FIG. 7. Interior of the base of one of the types of *D. stellifer* Miller and Gurley, UCWM 6088.

FIG. 8. Tegminal view of one of the types of *D. stellifer* Miller and Gurley, UCWM 6088.

FIGS. 9–10. Basal and lateral views of the type of *D. neglectus* Miller and Gurley, UCWM 6091.

FIGS. 11, 14. Tegminal and basolateral views of the type of *D. peculiaris* Miller and Gurley, UCWM 6085.

FIG. 12. Lateral view of the type of *D. amplus* Miller and Gurley, UCWM 6097.

FIG. 13. Basal view of the type of *D. vasculum* Miller and Gurley, UCWM 6096.

Dolatocrinus triadactylus Barris 88

All specimens from Thunder Bay Limestone, Alpena, Michigan.

FIG. 15 Basal view of one of the specimens of USNM 36024.

FIG. 16. Lateral view of another specimen of USNM 36024.

Dolatocrinus liratus (Hall) 84

All specimens from Beechwood Limestone, Charlestown, Ind.

FIGS. 17–18. Lateral and basal views of the type of *D. venustus* Miller and Gurley, UCWM 6094.

FIGS. 19–20. Basal and tegminal views of the type of *D. caelatus* Miller and Gurley, UCWM 6093.

FIGS. 21–22. Basal and tegminal views of the type of *D. arrosus* Miller and Gurley, UCWM 6105.

PLATE I

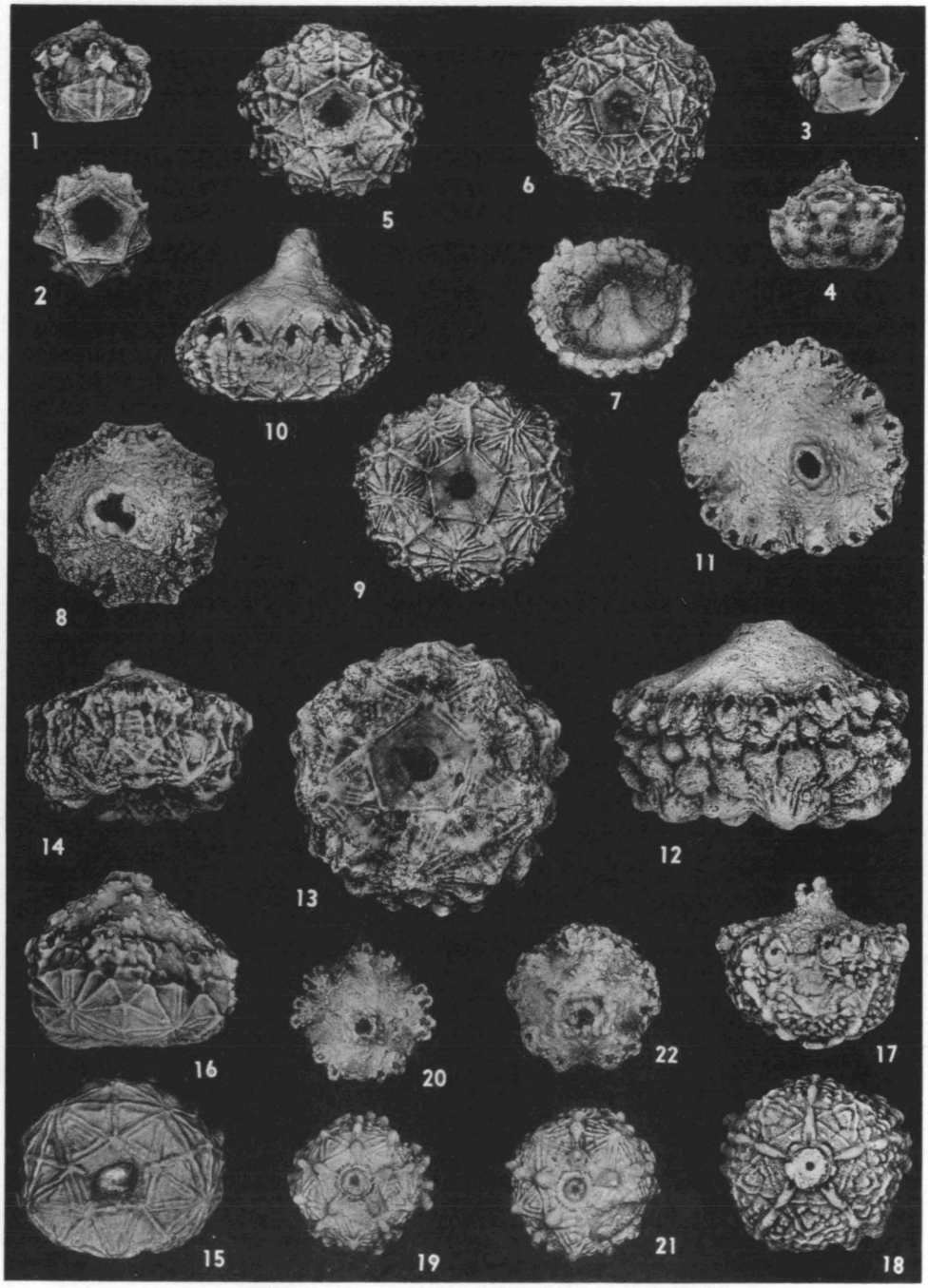
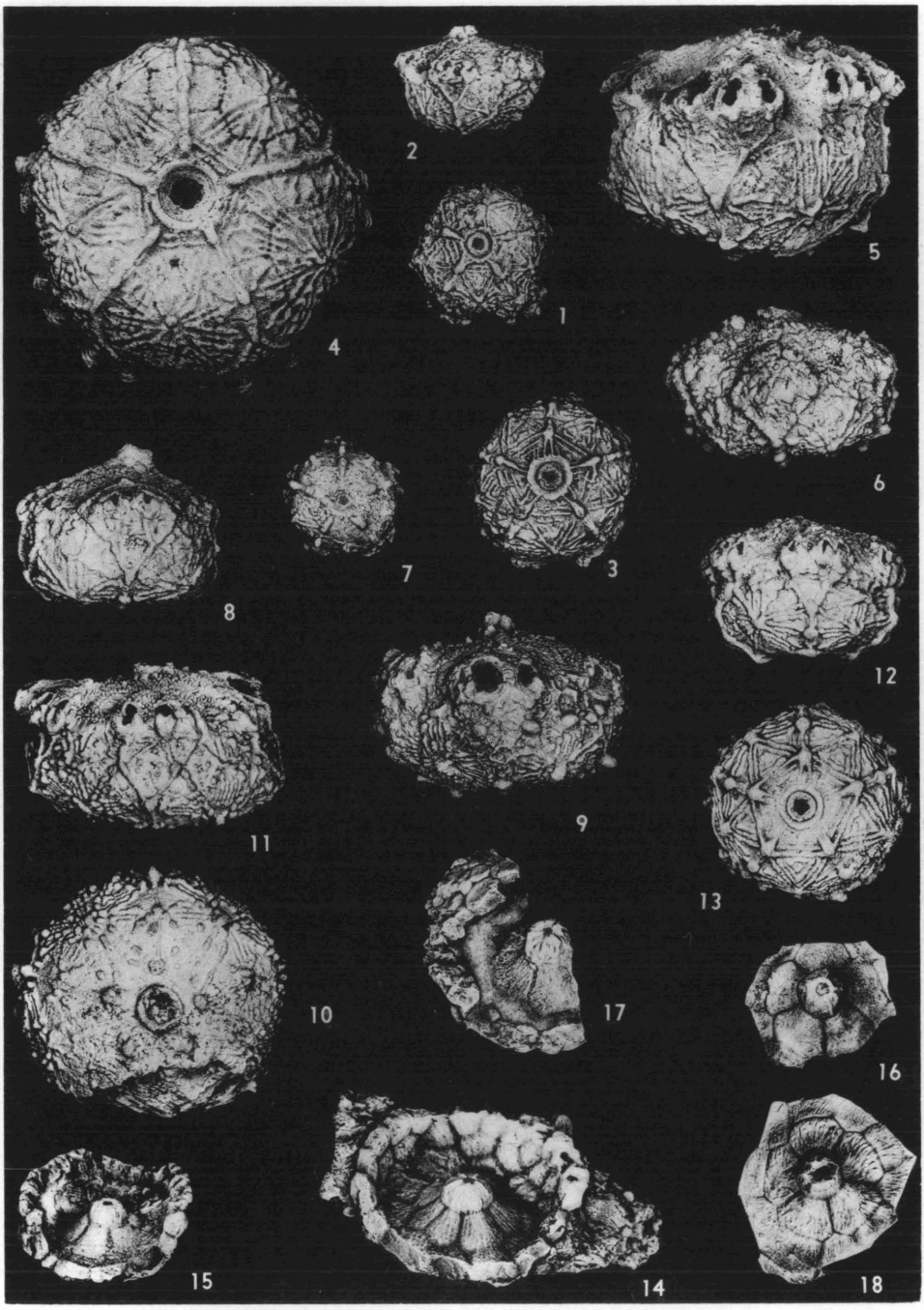


PLATE II



EXPLANATION OF PLATE II

(All figures × 1)

PAGE

Dolatocrinus liratus (Hall) 84

All specimens from Beechwood Limestone, Charlestown, Indiana.

FIGS. 1–2. Basal and lateral views of the type of *D. bellarugosus* Miller and Gurley, UCWM 6087.

FIG. 3. Basal view of the type of *D. sacculus* Miller and Gurley, UCWM 6070.

FIG. 4. Basal view of the type of *D. corporosus* Miller and Gurley, UCWM 6106.

FIGS. 5–6. Lateral views of two specimens of *D. greenei* Miller and Gurley, UCWM 29862.

FIG. 7. Basal view of the type of *D. dispar* Miller and Gurley, UCWM 6092.

FIG. 8. Lateral view of the type of *D. basilicus* Miller and Gurley, UCWM 6090.

FIG. 9. Lateral view of the type of *D. nodosus* Miller and Gurley, UCWM 6081.

FIGS. 10–11. Basal and lateral views of the type of *D. preciosus* Miller and Gurley, UCWM 6072.

FIGS. 12–13. Lateral and basal views of the type of *D. bellulus* Miller and Gurley, UCWM 29852.

Dolatocrinus stellifer Miller and Gurley 81

All specimens from Dock Street Clay, Alpena, Michigan.

FIGS. 14–18. Interior views of calyx bases which are typical of the genus. Note small, anchylosed basals and five hexagonal radials which form the basal cavity. Fig. 14, UMMP 44973; Fig. 15, UMMP 44974; Fig. 16, UMMP 44975; Fig. 17, UMMP 44976; Fig. 18, UMMP 44977.

EXPLANATION OF PLATE III

(All figures × 1)

PAGE

Dolatocrinus liratus (Hall) 84

All specimens from the Dock Street Clay, Alpena, Michigan.

FIGS. 1–2. Lateral and tegminal views of UMMP 44978. Fig. 1 shows the difference in shape between two sides of the same specimen; Fig. 2, the very lobate tegmen covered with fine pustules.

FIG. 3. Basal view of UMMP 44979 showing circular rim around small basal pit and the basal star formed by concentric triangles.

FIG. 4. Basal view of immature individual, UMMP 44980, showing strong development of ridges on plates of the rays.

FIG. 5. Basal view of immature individual, UMMP 44981 showing strong development of spinose ridges on plates of the rays.

FIGS. 6–7. Lateral and basal views of UMMP 44982, a specimen which has been laterally compressed. Fig. 6 shows the greatly exaggerated height of the tegmen; Fig. 7, the vermiform ornamentation of the dorsal cup.

FIG. 8. Basal view of UMMP 23891 showing strong circular rim around the narrow basal concavity. This specimen is unique because the column has fallen away exposing the basal pit.

FIG. 9. Lateral view of UMMP 23895 showing vermiform ornamentation and portions of the biserial arms attached.

FIG. 10. Basolateral view of UMMP 44983 showing typical intricate ornamentation of the dorsal cup. Note weak ridges on plates of the rays and slight shape difference between opposite sides of specimen.

FIG. 11. Basal view of very young individual, UMMP 44984. Note simpler ornamentation as compared with adult.

FIG. 12. Tegminal view of very young individual, UMMP 23896. Note finely pustulose and very lobate tegmen.

FIG. 13. Lateral view of piece of calyx, UMMP 44985 showing extreme development of nodes on plates of the rays.

FIG. 14. Basal view of UMMP 44986 showing intricate ornamentation of the species.

FIG. 15. Basal view of an immature specimen, UMMP 44987.

FIG. 16. Basal view of crushed specimen, UMMP 44988, showing small basal pit characteristic of the species.

PLATE III

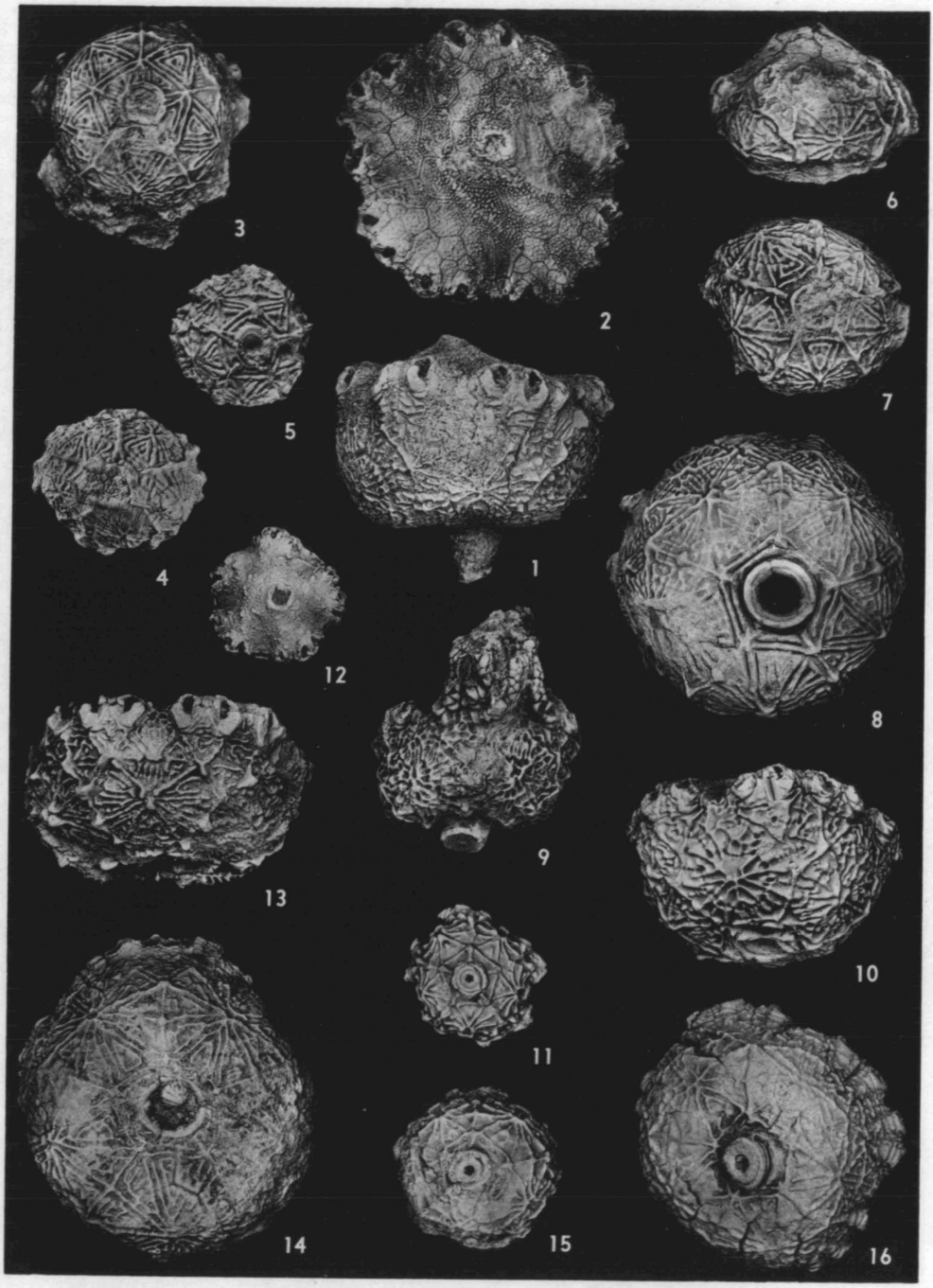
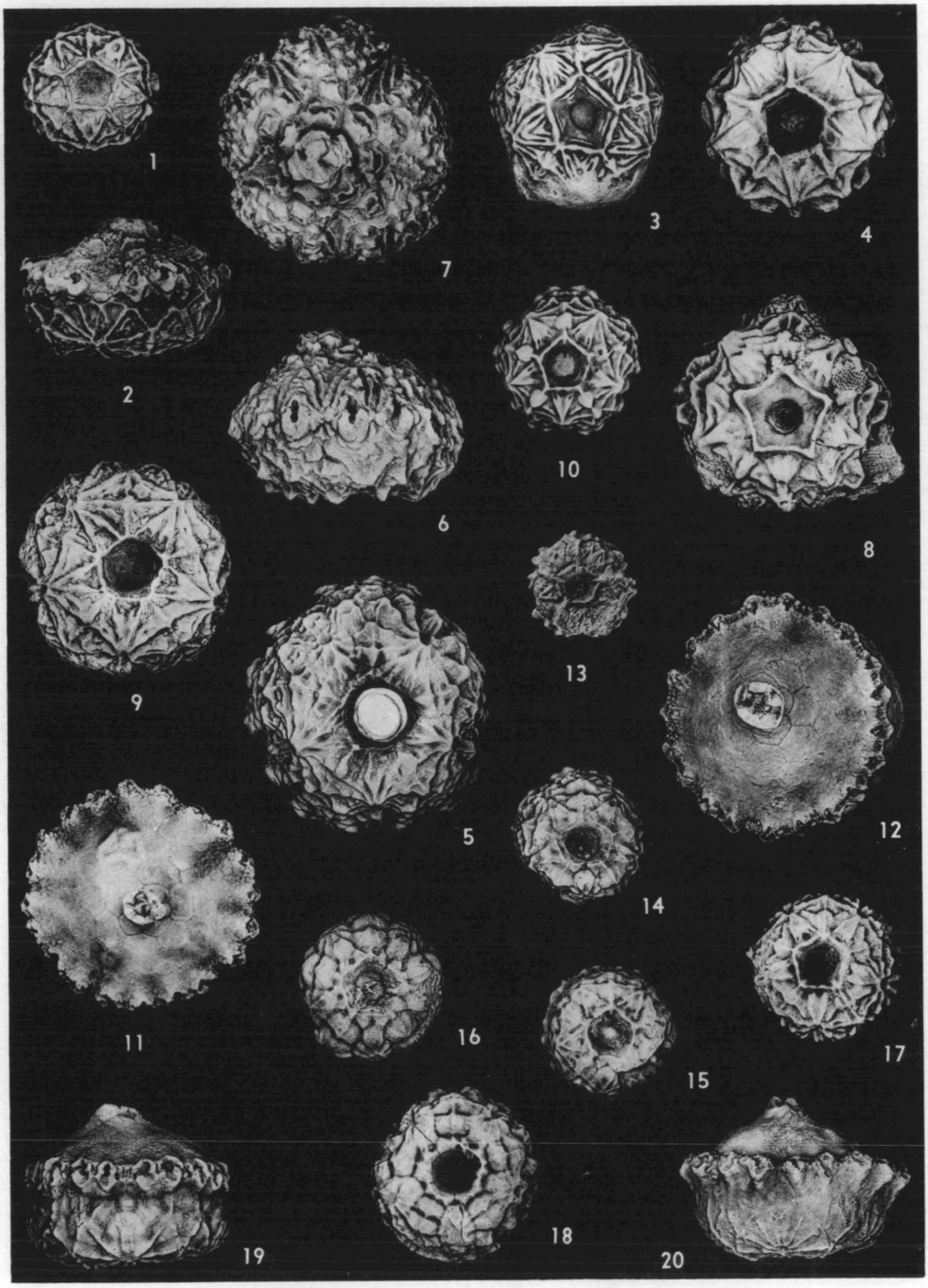


PLATE IV



EXPLANATION OF PLATE IV

(All figures × 1)

PAGE

Dolatocrinus triadactylus Barris 88

All specimens from the Dock Street Clay, Alpena, Mich.

FIG. 1. Basal view of an immature individual, UMMP 44989, showing ornamentation, pentagonal rim, and broad basal pit.

FIG. 2. Lateral view of UMMP 44990 showing ornamentation and knobby, lobate tegmen.

FIG. 3. Basal view of UMMP 44991 showing broad basal pit, pentagonal rim, and ornamentation.

Dolatocrinus michiganensis, sp. nov. 89

All specimens from the Dock Street Clay, Alpena, Mich.

FIG. 4. Basal view of paratype, BSNS E15270. This is the best-preserved specimen of the species and shows the characteristic dorsal cup rugosity to good advantage.

FIGS. 5–7. Basal, lateral, and tegminal views of the holotype, UMMP 23890. In Fig. 5, note the spinose nature of the dorsal cup; the spinosity has been exaggerated because a previous worker chipped away much of the connecting ridges and most of the pentagonal rim around the basal pit. The preservation of a portion of the stem as in this specimen is rare in the species because the base is so broadly concave. In Fig. 6, note the depressed calyx, spinose dorsal cup, rugose tegmen, and prominent pinnule openings between the arms. In Fig. 7, note the knobby tegmen and its lobate nature.

FIG. 8. Basal view of paratype, UMMP 44992, showing the well-developed pentagonal rim of the specimen. This is the most rugose individual of this species known.

FIG. 9. Basal view of paratype, UMMP 44993. Note rugose dorsal cup, broadly concave base, pentagonal rim. This is the least rugose specimen of the species known.

FIG. 10. Basal view of paratype, UMMP 44994, a very young individual with characteristic rugosity.

Dolatocrinus stellifer Miller and Gurley 81

All specimens from the Dock Street Clay, Alpena, Mich.

FIG. 11. Tegminal view of UMMP 44995 showing appearance of specimen that is broadly flaring beneath the arms.

FIG. 12. Tegminal view of BSNS E11928 showing appearance of specimen constricted below the arms. Compare with Fig. 11 and refer to page 19 for the explanation of the phenomenon.

FIG. 13. Very young individual, BSNS E15267, with *stellifer* type of cup plates.

FIGS. 14–18. Immature individuals with *amplus* type of cup plates. Fig. 14, UMMP 44996; Fig. 15, UMMP 44997; Fig. 16, UMMP 23889; Fig. 17, UMMP 44998; Fig. 18, UMMP 44999.

FIGS. 19–20. Lateral views of UMMP 45000 and UMMP 44995 showing different points of arm breakage.

EXPLANATION OF PLATE V

(All figures × 1)

PAGE

Dolatocrinus stellifer Miller and Gurley 81

All specimens from Dock Street Clay, Alpena, Michigan.

A nearly complete sequence of specimens showing the intergradations between the *stellifer* and *amplus* types of dorsal cup surfaces is illustrated on this and the following plate. The specimens with the lowest numbers are characteristic of the *stellifer* type, with smooth cup plates except for the ornamentation, whereas those with the highest numbers are characteristic of the *amplus* type, with very rugose dorsal cups. Note the general similarity in ornamentation of specimens of this species despite minor differences among individuals and the broadly concave base surrounded by a fine pentagonal rim, a characteristic of this species. Refer to pages 17–18 for a more detailed explanation of the variation portrayed on these two plates.

FIG. 1. UMMP 45002. Note the growth lines on the plates and the fine stellate ornamentation.

FIG. 2. BSNS E11936. Compare with Plate I, Fig. 9.

FIG. 3. UMMP 45001. Note broadly flaring calyx beneath the arm bases.

FIG. 4. UMMP 45004. Plates of the rays slightly rugose. Compare with Plate I, Figure 6.

FIG. 5. UMMP 45000. Plates of the rays slightly rugose.

FIG. 6. UMMP 45006. All plates slightly tumid and furrowed. Specimen is worn. *RR* and *BB* missing.

FIG. 7. UMMP 45005. Plates of the rays very rugose, others rugose. Base is damaged.

FIG. 8. UMMP 45007. More rugose than previous specimen.

FIG. 9. UMMP 23892. All plates medium rugose. Compare with Plate I, Figure 5.

FIG. 10. UMMP 45008. Medium rugose specimen showing growth lines on the plates of the cup.

FIG. 11. UMMP 45010. Medium rugose and delicately ornamented specimen.

FIG. 12. UMMP 45009. Large, medium rugose specimen.

PLATE V

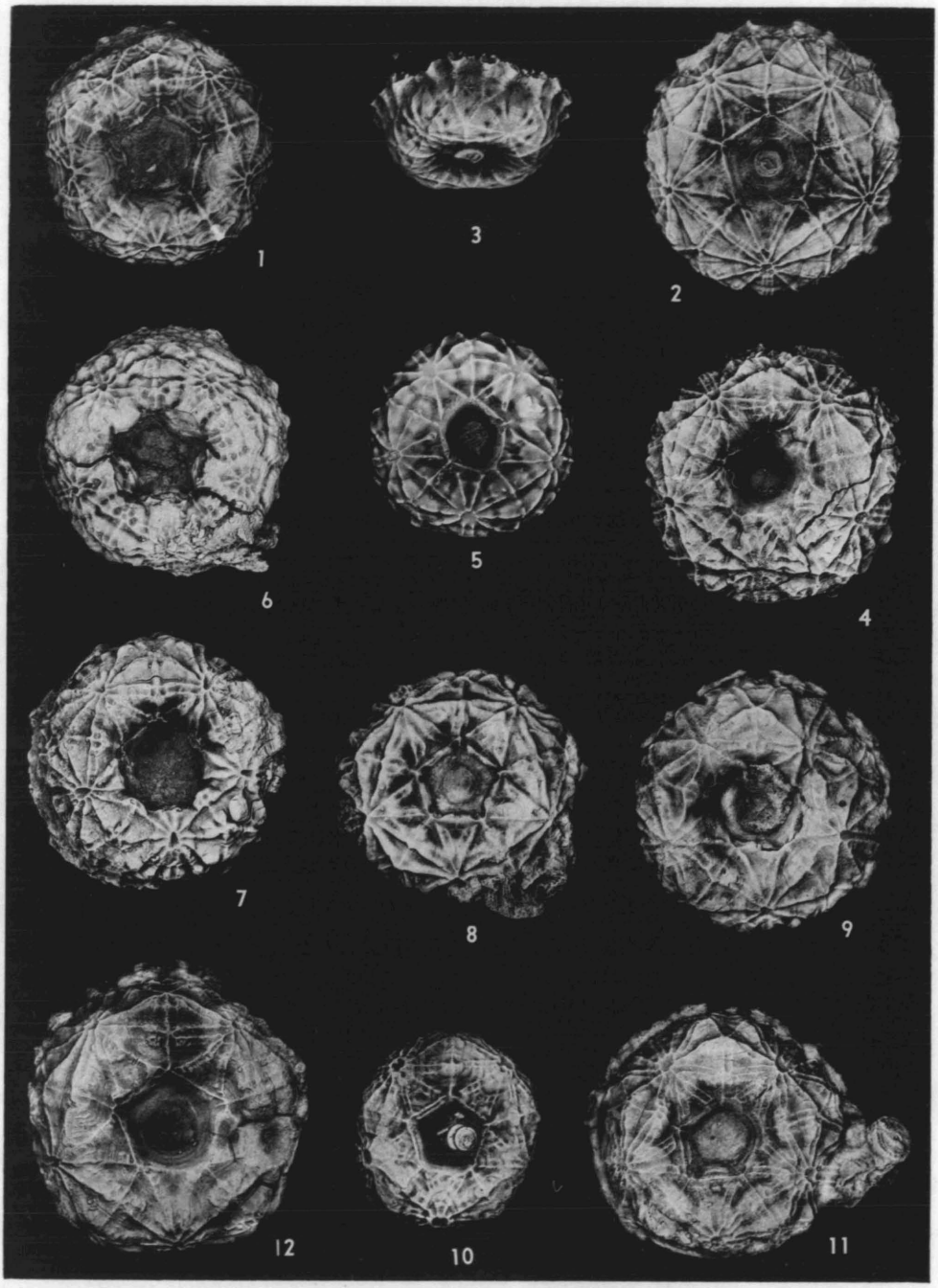
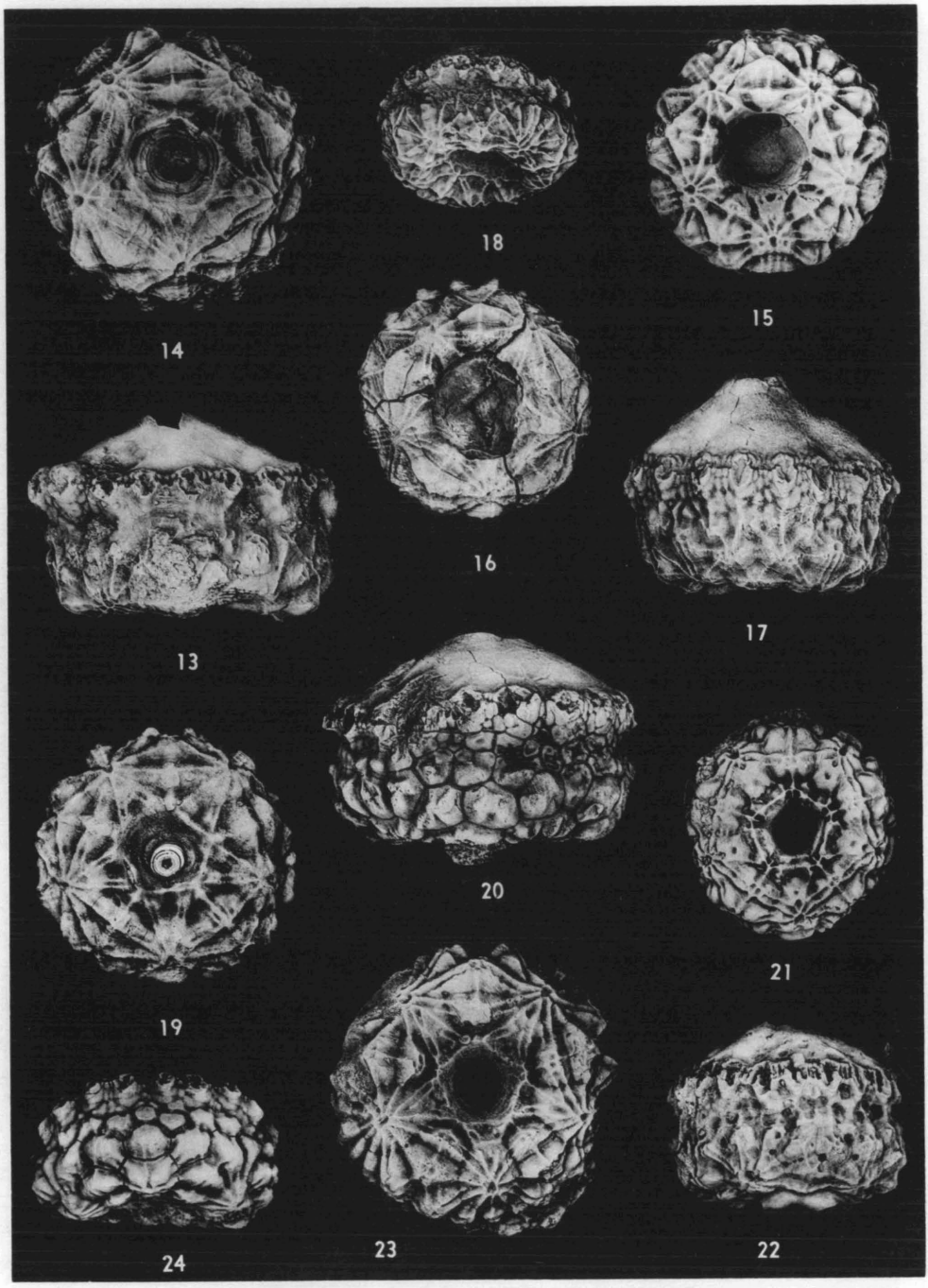


PLATE VI



EXPLANATION OF PLATE VI

(All figures × 1)

PAGE

Dolatocrinus stellifer Miller and Gurley 81

All specimens from Dock Street Clay, Alpena, Michigan.

See discussion under Plate V.

FIG. 13. Lateral view of UMMP 45009 showing prominent pinnule openings between the arms, smooth and slightly lobed tegmen, and medium rugose plates.

FIG. 14. BSNS E11930. All plates of the cup very rugose and irregularly furrowed. Note very deep basal pit.

FIG. 15. UMMP 45012. Very rugose dorsal cup.

FIG. 16. UMMP 45013. Very rugose, damaged specimen.

FIG. 17. Lateral view of BSNS 11930. Note high, smooth tegmen which is slightly lobed, prominent pinnule openings between the arms, and very rugose dorsal cup.

FIG. 18. UMMP 45011. Basolateral view of very rugose specimen. Note broad basal concavity in this species.

FIG. 19. BSNS E15258. Very rugose specimen with a portion of the column preserved. Broad basal concavity makes retention of the column unlikely in this species.

FIG. 20. UMMP 45014. *IBrBr*$_1$ with two and three plates immediately above them are shown. This specimen also possesses an *IBr*$_1$ with a single plate above it. Dorsal cup is very rugose in this damaged specimen.

FIG. 21. UMMP 45014. Extremely rugose dorsal cup is ornamented by a pattern of fine furrows.

FIG. 22. BSNS E11928. Note extremely rugose dorsal cup, prominent pinnule openings between the arms, and smooth tegmen. Compare with Plate I, Figures 12, 14.

FIG. 23. UMMP 45016. Extremely rugose dorsal cup showing furrowed plates. Compare with Plate I, Figure 13.

FIG. 24. Fragment of a dorsal cup, UMMP 45017. Plates are extremely rugose. Compare with Plate I, Figure 12.

EXPLANATION OF PLATE VII

(All figures × 1 except Fig. 6, which is × 2)

PAGE

Dolatocrinus bulbaceous Miller and Gurley 78

Specimen from the Dock Street Clay, Alpena, Michigan.

FIGS. 1–3. Lateral, basal, and tegminal views of UMMP 45018. Fig. 1 shows the prominent node on each IBr_1 and the prominent ridges on the plates of the rays; Fig. 2, the prominent pentagonal rim around the basal pit, the strong node on each IBr_1, and the prominent ridges on the plates of the rays; and Fig. 3, the strongly lobate tegmen.

Dolatocrinus stellifer Miller and Gurley 81

Specimen from the Dock Street Clay, Alpena, Michigan.

FIGS. 4–6. Lateral views of UMMP 45019, a specimen with rugose cup plates. Refer to pages 7–9 for a detailed explanation of Figs. 4–6. In Fig. 4, note the long, biserial arms, which are unbranched. Knobby protuberances are seen at certain points along the arms and pinnules are found all along the arms. Shell on tegmen is a *Placenticeras*. Fig. 5 shows a portion of the column. Note the two varieties of columnals near the calyx and only one variety of columnals distally. Fig. 6 (× 2) is an enlargement of the region where the arms join the calyx and shows details of the arms and pinnules.

PLATE VII