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UNIQUE STALKED CRINOIDS FROM UPPER CRETACEOUS OF MISSISSIPPI

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ABSTRACT

A new genus and species of stem-bearing crinoids, based on numerous exceptionally well-preserved specimens which include nearly complete crowns associated with abundant parts of columns, is described from the Prairie Bluff Chalk of northeastern Mississippi. The fossils come from beds of Maastrichtian age near the summit of the Upper Cretaceous section in this region. They are readily identified as unique representatives of the widely distributed family Bourgueticrinidae—unique in that they are the only yet-discovered fossils belonging to this group from any part of the world in which long pinnulate arms are attached to the dorsal cups. Also, proximal-intermediate and distal regions of the column are shown to be markedly dissimilar, the former being evenly cylindrical in shape with columnals of subequal diameter and height, and the latter being distinguished by striking zigzag longitudinal profiles. At bottom of the stalk are robust rootlike branches for fixation to the substrate. Morphological descriptions are followed by discussions of the ontogeny and paleoecology of these crinoids.

INTRODUCTION

The new Upper Cretaceous crinoid described in this paper has a tall slender crown supported by a long stem which was anchored in shallow sea-bottom mud by rootlike branches. It is named *Dunnicrinus mississippiensis,* both in honor of Mississippi State University's Professor Paul H. Dunn, who with some of his students discovered and collected many specimens, and in recognition of the State of Mississippi as region which has yielded the only adequately complete stalked Cretaceous crinoids found anywhere in the world.

The crinoids have a diminutive, steeply conical dorsal cup and five delicate unbranched arms which give off long pinnules from opposite sides of alternate uniserially arranged wedge-shaped brachials (Fig. 1). Numerous brachials, distributed in random manner, are distinguished by the peculiarity of being divided transversely into two parts, with union of the lower and upper halves by a type of suture termed syzygy. The syzygial brachials are readily seen to differ from the non-syzygial ones. These and other characteristics of the crinoids will be described with accompanying illustrations in the section on Morphology of *Dunnicrinus*.

OCCURRENCE OF CRETACEOUS CRINOIDS

Cretaceous crinoids are uncommon fossils, especially in comparison with the hosts of mollusks and abundant echinoids found in some deposits of this system. It is true that museums in many places contain displays of *Uintacrinus* specimens crowded together so as to cover large areas of thin limestone slabs, but all of these come from a single small area in western Kansas. Most described species of Cretaceous crinoids (approximately 212 in total number), are represented by only a few specimens—some by the holotype alone (RASMUSSEN, 1961). These species are almost equally divided between stem-bearing and stemless genera and a preponderant majority of both have been recorded from localities in Europe.

Stalked Cretaceous crinoids include 106 species which are confined to Europe and only 12 species, counting the new form described in this paper, from other parts of the world, North America, 6; Africa, 4; Australia, 2 (Table 1).

TABLE 1.—*Occurrence of Cretaceous Species of Stalked Crinoids*

[Italics show number of species based solely on characters of column or proximale]

GENERA	EUROPE	ELSEWHERE
Isocrinus	28 *(27)*	Africa, 1 *(1)*
Bourgueticrinus	18	USA (Ala.), 1 *(1)*
Nielsenicrinus	7 *(3)*	
Eugeniacrinites	6 *(1)*	
Apiocrinites	6 *(6)*	
Phyllocrinus	5	
Isselicrinus	5 *(4)*	Africa, 3 *(3)*; N. Am. (N.J.-Greenl.), 2 *(2)*
Austinocrinus	4 *(3)*	N. Am. (Mexico-Cuba), 2 *(2)*
Doreckicrinus	4 *(4)*	
Balanocrinus	4 *(4)*	
Democrinus	3	
Cyathidium	3	
Monachocrinus	2	
Sclerocrinus	2	
Hemicrinus	2	
Cyclocrinus	2 *(2)*	
Neocrinus	1 *(1)*	Australia, 2
Thiolliericrinus	1	
Burdigalocrinus	1	
Proholopus	1	
Pilocrinus	1	
Dunnicrinus		USA (Miss.), 1
Total, 22 genera	106 *(55)*	N. Am., 6 *(5)*; Africa, 4 *(4)*; Australia, 2

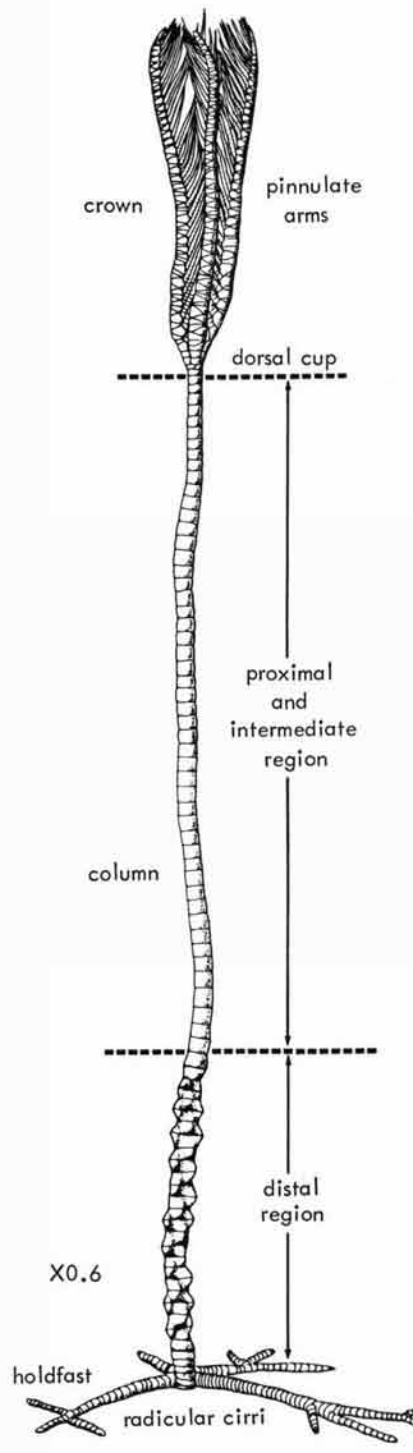


FIG. 1. Complete individual of *Dunnicrinus mississippiensis* (reconstr.), approx. X0.6.

It is noteworthy that the 48 species of *Isocrinus* and *Bourqueticrinus* recorded in Table 1 account for 41 percent of all known Cretaceous stalked crinoids (118), and further, that 29 of these 48 species (60 percent) have been differentiated solely on characteristics of their columns. Including *Dunnicrinus*, 5 genera are each represented by a single described species and 3 by 2 species. Among all, 64 species are based on stem parts.

As might be expected, free-swimming crinoids (91 species) have wider geographic distribution than bottom-attached forms, which include no species found on two or more continents. A total of 76 species has been reported from Europe, among which 6 species classed as members of 5 different genera, occur also in North America, and one of these *(Marsupites testudinarius)* in Africa, Asia, and Australia as well (Table 2). North American Cretaceous planktonic crinoids include 23 species, belonging to 9 genera. Numbers of specimens generally are small. Widely distributed and locally abundant are saccocomid crinoid fragments identified in thin sections of Cretaceous rocks under the name *Lombardia* (=*Saccocoma* or *Pseudosaccocoma*) (POKORNÝ, 1958, v. 2, p. 328).

TABLE 2.—*Occurrence of Cretaceous Species of Stemless Crinoids*

GENERA	EUROPE	ELSEWHERE
Solanocrinites	16	
Semiometra	10	
Glenotremites	8	
Amphorametra	7	Africa, 1
Jaekelometra	6	
Bruennichometra	3	
Hertha	3	
Placometra	3	
Roveacrinus	5[a]	USA (Tex.-Okla.), 7[a]
Schlueterometra	2	
Palaeocomaster	2	
Orthogonocrinus	2[b]	USA (Tex.-Okla.), 1[b]
Uintacrinus	2	N. Am.-Australia, 1
Marsupites	2[b]	N. Am.-Australia-Asia-Africa, 1[b]
Loriolometra	1	
Discocrinus	1	USA (Tex.-Okla.), 1
Pseudosaccocoma	1	
Saccocoma	1[b]	USA (Tex.-Okla.), 1[b]
Styracocrinus	1[b]	USA (Tex.-Okla.), 1[b]
Poecillocrinus		USA (Tex.-Okla.), 5
Plotocrinus		USA (Tex.-Okla.), 4
Roiometra		S. Am. (Colombia), 1
Total, 22 genera	76[c]	N. Am., 23[c]; Australia, 2; Africa, 2; Asia, 1; S. Am., 1

[a] Includes 2 species common to Europe and North America.
[b] Includes 1 species common to Europe and North America.
[c] Includes 6 species common to Europe and North America.

CRINOIDS IN UPPER CRETACEOUS OF MISSISSIPPI

The first crinoid remains discovered in Upper Cretaceous deposits of Mississippi are a single well-preserved theca of the stemless, large-plated crinoid named *Marsupites* and with it a fragment belonging to the same genus. The specimens were found by FREDERICK BRAUN, a fossil collector employed by the well-known crinoid specialist, FRANK SPRINGER, and they were reported to have come from the west bank of Tombigbee River at a locality in Lowndes County known as Plymouth Bluff (sec. 14, T. 19 N., R. 17 E.). The theca and dissociated plates were described and figured by SPRINGER in 1911 (p. 159, pl. 6, fig. 4a,b, 5) with information that the fossils came from the Tombigbee Sandstone exposed in Plymouth Bluff. The rock unit now is included in the Eutaw Formation, which unconformably underlies the Selma Chalk and in the area of the crinoid locality is approximately 700 feet below the Prairie Bluff Chalk (Fig. 2). Subsequently, STEPHENSON & MONROE (1940, p. 73-74) were able to determine that the Eutaw crinoid remains, named *Marsupites americanus* by SPRINGER, came from a 1-foot layer of resistant calcareous glauconitic sandstone 23 feet below the Eutaw-Selma unconformity. They found additional dissociated thecal plates of *Marsupites* in this bed, but only a very few. *M. testudinarius* is a widely distributed, moderately common crinoid in the Cretaceous chalk of Europe, especially England; it has been identified in Africa, Asia, and Australia, and now is thought to be conspecific with *M. americanus*, known only from Mississippi.

In 1936 STEPHENSON and MONROE discovered a small area in Chickasaw County, Mississippi, where the Prairie Bluff Chalk yielded abundant dissociated parts of crinoid skeletons consisting mostly of single small columnals but including some articulated radial circlets, brachials, fragments of stems with columnals joined together,

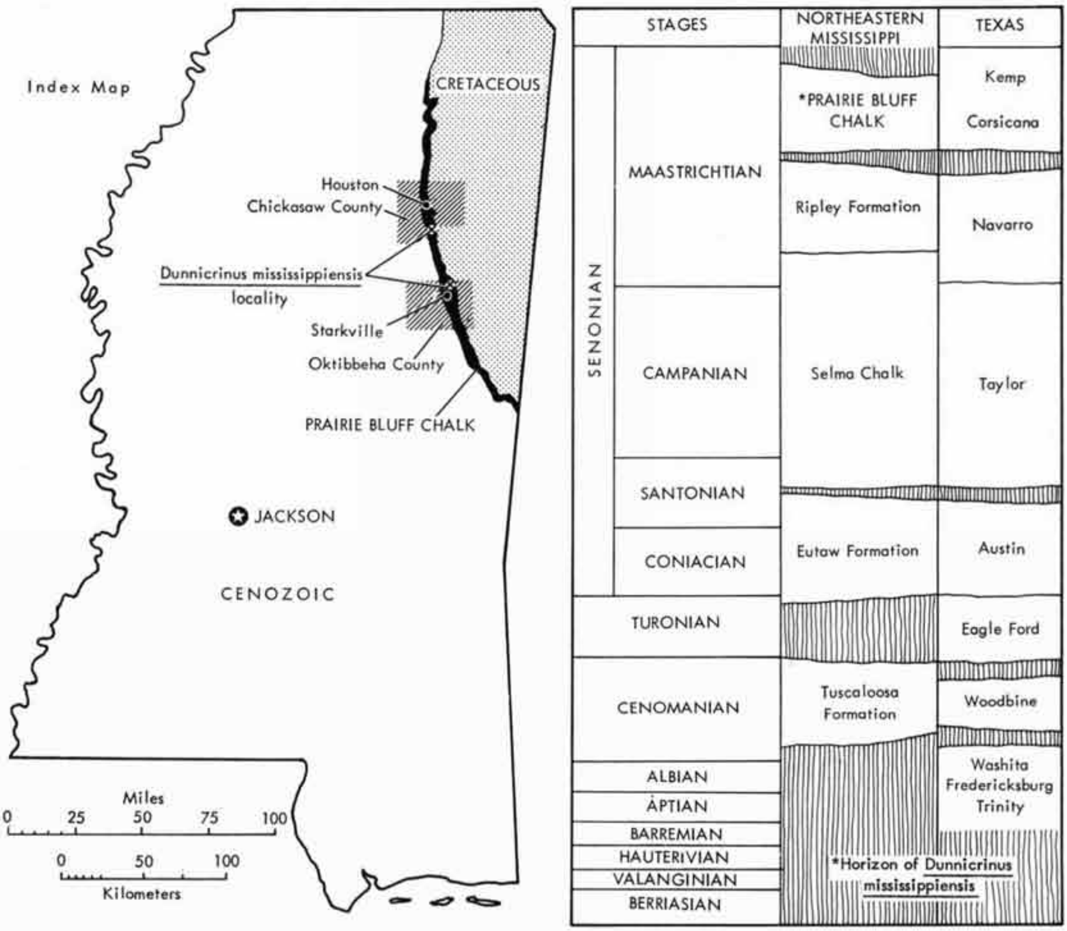


FIG. 2. Index map showing crinoid localities and chart indicating horizon of *Dunnicrinus mississippiensis*, marked by asterisk (*).

and stout rootlike holdfasts. The locality (USGS loc. 17235, here indicated as KJI) is described as a bald spot in field at roadside and cut on the Houston road (sec. 10, T. 15 S., R. 3 E.), 1.25 mile north of Sparta. The crinoid was considered by STEPHENSON & MONROE (1940, chart opp. p. 208, p. 247) to be a new genus and species allied to *Mesocrinus*. RASMUSSEN (1961, p. 166) has considered *Mesocrinus* (CARPENTER, 1881, p. 128) to be a misapprehended taxon not separable from *Bourgueticrinus* D'ORBIGNY (1840, p. 95). The entire collection of crinoid remains from STEPHENSON & MONROE's locality 17235 was loaned to me by Dr. PORTER M. KIER, Smithsonian Institution, and the specimens here are assigned to the new genus and species named *Dunnicrinus mississippiensis*.

The new genus of Upper Cretaceous stalked crinoids introduced in this paper under the name of *Dunnicrinus* and its type species designated as *D. mississippiensis* MOORE, n. sp., are mainly based on fossils collected in 1948 and shortly thereafter by Professor PAUL H. DUNN and some of his students at Mississippi State University. Discovery of the crinoid locality is credited especially to GEORGE H. SPIVEY and E. L. REDDOCH, JR., who found the fossils on bedding planes in thin calcareous siltstones of the upper Prairie Bluff Chalk along the west side of Josey Creek near its confluence with Trim Cane Creek in the SW¼, SW¼, sec. 20, T. 19 N., R. 14 E., Oktibbeha County, Mississippi. The exposures occur approximately 3.2 miles northwest of the County Court House in Starkville. The specimens were sent to me for study. At the time, partly because much work was needed to prepare the fossils adequately, and partly because the crinoids belonged to a group with which I was then little acquainted, the specimens were put aside. They were not forgotten, yet I failed to realize their uniqueness and importance as representatives of Mesozoic echinoderms. Now, work is proceeding for preparation of the *Treatise on Invertebrate Paleontology* volumes allotted to the Crinoidea and it seems highly desirable to include information on the Upper Cretaceous crinoids from Mississippi.

SYSTEMATIC DESCRIPTIONS

Dunnicrinus is assigned to the family Bourgueticrinidae in the suborder Bourgueticrinina and order Millericrinida. The chief distinction between bourgueticrinids and members of a separately distinguished group designated as Bathycrinidae (BATHER, 1899, p. 922) is supposed to be the occurrence of a definite proximale, formed by fusion of a variable number of proximal columnals next below the dorsal cup, as seen in species of *Bourgueticrinus*, and absence of such an element in bathycrinid genera. Taxonomically, this is a dubious basis for distinction, 1) because some species of *Bourgueticrinus* (*B. fischeri*, from the Upper Cretaceous of England; RASMUSSEN, 1961, p. 185, pl. 27, fig. 12-14) lack a proximal columnal thicker than others, 2) because some individuals of *Dunnicrinus* possess a much enlarged proximal columnal which may or may not faintly show evidence of fused components, whereas most specimens clearly lack any columnal ossicle resembling a proximale composed of fused columnals, and 3) because nearly all morphological features of representative so-called bathycrinids are found in the Bourgueticrinidae, particularly if *Dunnicrinus* is accepted in the latter family.

The most noteworthy common characteristics of *Dunnicrinus*, *Bourgueticrinus*, *Bathycrinus*, *Rhizocrinus*, and other bourgueticrinids are structure of the dorsal cup, nature of the proximal brachials, cylindrical to elliptical columnals with synarthrial articula having regularly strong displacement in orientation of the fulcral ridges, and presence of a ramified, rootlike holdfast with lack of cirri above the holdfast. Distinctive pairs of syzygially united brachial elements may be cited as another commonly observed attribute, not known in *Bourgueticrinus* but abundant in *Dunnicrinus* and found in *Bathycrinus* and *Rhizocrinus*. As discussed later, the nature and distribution of pinnules certainly link *Dunnicrinus* with genera which have been assigned to the Bathycrinidae, but this is not helpful in comparison with *Bourgueticrinus*, since no pinnule-bearing specimen of any species of this genus has yet been discovered, indeed no specimen with more than the first two brachials above the radial. Almost innumerable articulated arms of *Dunnicrinus* with attached pinnules are available for study.

Order MILLERICRINIDA Sieverts-Doreck in Ubaghs, 1953

[Millericrinida SIEVERTS-DORECK in UBAGHS, 1953, p. 761] [=Apiocrinacea STEINMANN, 1907, p. 204]

Dorsal cup monocyclic or cryptodicyclic, with or without proximale next below it, radial facets mostly occupying entire distal extremity of plates; column composed of circular to elliptical columnals, lacking cirri but with branched rootlike holdfast or discoid expansion at base of stem; arms invariably uniserial, isotomously branched or unbranched. [Commonly living in colonies.] *M. Trias.-Rec.*

The name Millericrinida is preferable to Apiocrinida, in spite of priority assignable to the latter as modified from STEINMANN, because the Millericrinidae are a large family characterized by normal articulate attributes, whereas the Apiocrinitidae comprise a small aberrant group.

Suborder BOURGUETICRININA Sieverts-Doreck in Ubaghs, 1953

[Bourgueticrinina SIEVERTS-DORECK in UBAGHS, 1953, p. 762]

Plates of dorsal cup separate or fused, infrabasals mostly not distinguishable, fusion affecting entire cup or discernible only in basal and radial circlets; columnals circular to elliptical, joined by ankylosis or synostosis in proximal region and by synarthry in distal region or by synarthry throughout stem, fixation by radicular cirri at base, not by holdfast plate. *M. Trias.-Rec.*

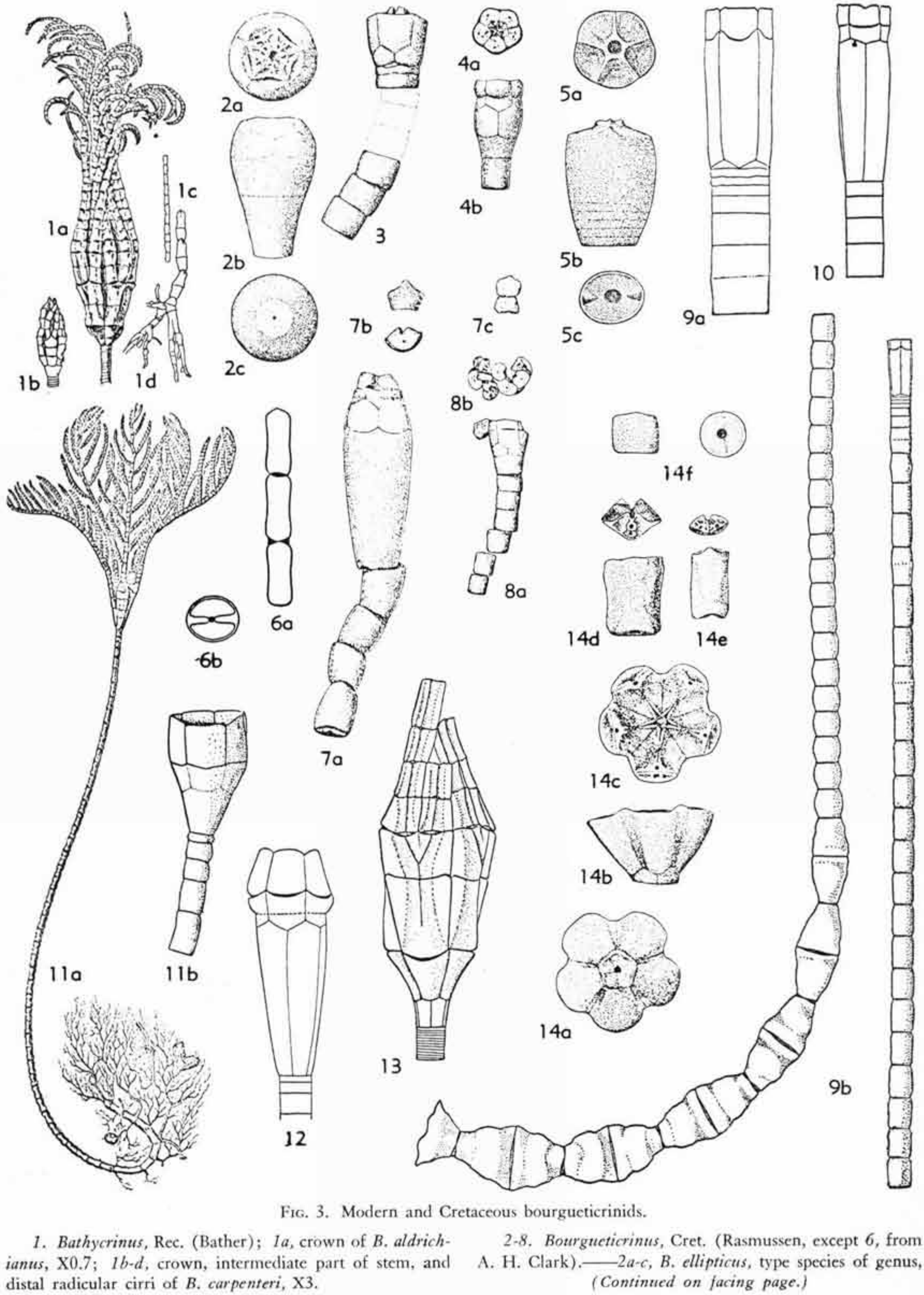


FIG. 3. Modern and Cretaceous bourgueticrinids.

1. Bathycrinus, Rec. (Bather); *1a*, crown of *B. aldrichianus*, X0.7; *1b-d*, crown, intermediate part of stem, and distal radicular cirri of *B. carpenteri*, X3.

2-8. Bourgueticrinus, Cret. (Rasmussen, except *6*, from A. H. Clark).——*2a-c*, *B. ellipticus*, type species of genus, *(Continued on facing page.)*

Family BOURGUETICRINIDAE de Loriol, 1884

[Bourgueticrinidae de Loriol, 1884, p. 435] [incl. Bathycrinidae Bather, 1899, p. 922; Rhizocrinidae Jaekel, 1918, p. 72]

Small crinoids with conical, cylindrical, or fusiform dorsal cup that varies in proportions of component plates, which may include infrabasals (rarely visible externally) or none known, and closed circlets of basals and radials, articular facets of radials wide, with high muscle plates; proximale composed of fused topmost columnals possibly incorporated with fused infrabasals in some and thus forming apical part of cup, or proximale not clearly differentiated from topmost columnals, some of which may have synostosial articula, but typically most columnals (and lower extremity of proximale) have synarthrial articulation with well-defined fulcral ridges which in alternate pairs of conjoined articula display moderate to strong displacement of ridge orientation; cirri lacking except for slender to stout radicular cirri at and near distal extremity of stem, these cirri commonly branching in rootlike manner. [Habitat shallow, current-affected seas of continental platforms to abyssal depths in oceans.] *M. Trias.-Rec.*

Classification of the stalked crinoids here grouped together in the Bourgueticrinidae has varied considerably as treated by different authors in the past 75 years. Zittel (1880, p. 346) included *Bourgueticrinus* in the Apiocrinidae [*recte* Apiocrinitidae] with genera only very distantly related to it and clearly very dissimilar in most important morphological features, such as nature of the columnal articula. P. H. Carpenter (1884, p. 225) recognized the Bourgueticrinidae as containing *Bourgueticrinus* d'Orbigny (1840, p. 95) (Fig. 3,*2-8*), *Rhizocrinus* M. Sars (1864, p. 127) (Fig. 3,*11*), and *Bathycrinus* Wyville-Thomson (1872, p. 772) (Fig. 3,*1,14*). In his view, *Conocrinus* d'Orbigny (1849 [1850], p. 332), first described as a *Bourgueticrinus* lacking basals and without a named species, but later fixed by d'Orbigny to the single species *Bourgueticrinus thorenti* d'Archiac (1846, p. 200), which possesses basals, is an unrecognizable taxon that may be synonymized with *Rhizocrinus*. According to Carpenter (1884, p. 268), *Ilycrinus* Danelssen & Koren (1877, p. 45) is a synonym of *Bathycrinus* and *Democrinus* Perrier (1883, p. 450) (Fig. 3,*10*), is equivalent to *Rhizocrinus*. In the opinion of Clark (1913, p. 229, 1915, p. 203; 1919, p. 2) and Rasmussen (1961, p. 204), *Democrinus* is a valid genus separate from others. Finally, *Mesocrinus* Carpenter (1881, p. 130) was stated to be probably the same as *Bourgueticrinus* and thus readily abandoned (Carpenter, 1884, p. 256) (a view accepted by Rasmussen, 1961, p. 165). Ac-

Fig. 3. *(Continued from facing page.)*

Eng., ventral, side, and dorsal views of theca, last showing smooth (synostosial) articulum, X2.——*3, B. fischeri,* type species of *Mesocrinus*, Eng., theca and part of stem showing low proximal columnals, X2.——*4a,b, B. bruennichinielseni,* Denm., ventral and side views, former showing synarthrial articula of first brachials, X4.——*5a-c, B. alabamensis,* USA, ventral, side, and dorsal views of proximale, *5c* showing synarthrial articulum, X4.——*6a,b, B.* sp., diagr. side view of columnals indicating 90° displacement of fulcral ridges of successive apposed articular pairs and face of elliptical articulum, not to scale.——*7a,b, B. danicus,* Denm., side view of theca with attached brachials and proximal columnals and axillary second brachial showing side and proximal articulum; *7c,* side view of first two brachials of same, X4.——*8a-c, B. fischeri,* Eng., side view of specimen with attached brachials with distal facets of brachials, X2.

9. Naumachocrinus hawaiiensis, Rec. (Clark).——*9a,* side view of theca and proximal columnals, first brachials attached to elongate radials, enl.——*9b,* same with intermediate and distal parts of stem, showing changes in shape of columnals and strongly twisted nature of large distal columnals which have narrowly elliptical synarthrial articula; genus classed in Phrynocrinidae.

10. Democrinus rawsoni, Rec., Barbados (A. H. Clark), characterized by its elongate basals and low proximal columnals.

11. Rhizocrinus lofotensis, Rec., abyssal crinoid from North Sea.——*11a,* complete specimen showing five-armed crown with pinnules, elongate twisted columnals in most of stem, and highly branched slender radicular cirri at distal extremity of stem, X1.5 (Bather).——*11b,* theca with first brachials and proximal columnals, X12 (Gislén).

12. Bythocrinus conifer, Rec., off Brazil, theca with elongate basals, radials constricted at mid-height, and quadrangular first brachials, enl. (A. H. Clark).

13. Monachocrinus paradoxus, Rec., Bay of Bengal, side view of crown with attached very low columnals, quadrangular second primibrachs axillary, enl. (A. H. Clark).

14. Bathycrinus windi, Paleogene (U. Danian), Denm., X7.5 (Rasmussen).——*14a-c,* dorsal, side, and ventral views of dorsal cup.——*14d,e,* side and distal views of primibrachs 1 and 2, latter axillary.——*14f,* side and articular view of columnal.

cordingly, *Bourgueticrinus, Rhizocrinus, Bathycrinus,* and *Democrinus* are recognized as members of the family.

Other classifications may be summarized more briefly and without discussion.

1) Wachsmuth in Zittel (1896, p. 229): Bourgueticrinidae, *Bourgueticrinus, Rhizocrinus (=Conocrinus).*

2) Bather (1899, p. 922; 1900, p. 185, 193): Bourgueticrinidae, *Bourgueticrinus, Rhizocrinus, Conocrinus, Mesocrinus, Democrinus*; Bathycrinidae Bather (1899, p. 922), *Bathycrinus.*

3) Clark in Zittel (1913, p. 229): Bourgueticrinidae, *Bourgueticrinus Rhizocrinus, Bathycrinus (=Ilycrinus), Mesocrinus, Democrinus, ?Dolichocrinus* (de Loriol, 1891, p. 130), *Bythocrinus* (Döderlein, 1912, p. 4) (Fig. 3,*12*), *Monachocrinus* (A. H. Clark, 1913, p. 230) (Fig. 3,*13*).

4) Jaekel (1918, p. 72): Rhizocrinidae (Jaekel, 1918, p. 72). *Rhizocrinus, Bourgueticrinus, Bathycrinus, Loriolicrinus* (Jaekel, 1918, p. 72), *Drepanocrinus* (Jaekel, 1918, p. 72), *Tormocrinus* (Jaekel, 1891, p. 657).

5) Clark (1919, p. 2): Bourgueticrinidae, *Bourgueticrinus, Rhizocrinus, Bathycrinus, Ilycrinus, Democrinus, Bythocrinus, Monachocrinus.*

6) Cuénot (1948, p. 74): Bourgueticrinidae, *Bourgueticrinus, Rhizocrinus, Mesocrinus;* Bathycrinidae, *Bathycrinus, Democrinus.*

7) Ubaghs (1953, p. 762): Bourgueticrinidae, *Bourgueticrinus, M e s o c r i n u s*; Bathycrinidae, *Bathycrinus, Conocrinus, Rhizocrinus, Democrinus.*

8) Rasmussen (1961, p. 165, 200): Bourgueticrinidae, *Bourgueticrinus (=Mesocrinus, Metapiocrinus* Jaekel, 1918, p. 70); Bathycrinidae, *Bathycrinus, Democrinus, Monachocrinus.*

In my opinion, no good grounds exist for recognizing families named Bathycrinidae and Rhizocrinidae. Contrariwise, significant morphological similarities—most notably in characteristics of the stem and its radicular holdfast—support recognition as members of the Bourgueticrinidae the genera *Bourgueticrinus, Rhizocrinus, Bathycrinus, Democrinus, Bythocrinus, Monachocrinus, Tormocrinus, Loriolicrinus,* and the new genus *Dunnicrinus.* Thus defined, the family is represented in the Middle Triassic of Europe *(Monachocrinus),* Upper Jurassic of Europe *(Bourgueticrinus, Loriolicrinus),* Upper Cretaceous of Europe *(Bourgueticrinus, Democrinus, ?Monachocrinus)* and North America *(Bourgueticrinus, Dunnicrinus),* lower Paleogene of Europe *(Tormocrinus, Rhizocrinus, Bathycrinus),* and North America *(Rhizocrinus),* and Recent oceans *(Rhizocrinus, Bathycrinus, Bythocrinus, Monachocrinus).*

Genus DUNNICRINUS Moore, new genus

Crown slender, elongate, composed of diminutive, steeply conical dorsal cup and five uniserial pinnulate arms; basal and radial circlets with clearly evident sutures between subequal-sized plates, infrabasals represented by externally visible, low plates next below interbasal sutures (seen in some specimens but entirely concealed or lacking in most); first brachial quadrangular, equal in width and height to radial, invariably nonpinnulate, muscular articulation between radial and first brachial and between all brachials except between lower and upper elements of syzygial brachial, with second brachial larger than first, laterally in contact with second brachs of adjoining rays, oblique muscular articular facet occupying most of distal extremity, narrow steeply inclined facet for support of first pinnule mostly on right distal extremity but may be to left, first pinnule invariably borne by second brach, which never is divided by syzygy; otherwise syzygies are common on brachials, but not distributed in any systematic fashion, as many as 12 syzygial brach pairs in some arms; muscularly articulated pinnules given off from opposite sides of arms very evenly, every brach (except hypozygal of syzygial brach pair) having one pinnule, which is long, tapering very gradually, and composed of subquadrate, muscularly articulated pinnulars. Column relatively long and moderately stout, cylindrical in proximal region, with thin to thick columnals, proximale of fused columnals developed in some individuals but not in others, columnal articula near dorsal cup synostosial, throughout remainder of stem synarthrial; columnals of distal region wider than high, with distinctly elliptical articula that bear differently oriented fulcral ridges on alternate junctions of columnals, similarly discordant orientations of fulcral ridges present also in proximal, cylindrical part of stem. Stout radicular cirri developed from most distal columnals, each growing out from narrow edge of columnal in line with fulcral ridge and each tapering somewhat outward from stem, with or without bifurcations;

radicular cirri circular in transverse section and pierced by axial canal. *U. Cret. (Prairie Bluff Chalk)*, Oktibbeha and Chickasaw Counties, Mississippi.

Type species.—Dunnicrinus mississippiensis MOORE, new species.

Discussion.—No genus of stalked Cretaceous crinoids is comparable even remotely to *Dunnicrinus* in the amount of information that can be made available on morphological features of the entire skeleton, including a reasonably adequate survey of individual variations. Among isocrinids, where forms competing in completeness might be looked for, nearly every described species is based on very few and incomplete specimens. Only dorsal cups, some associated with one or two lowermost brachials without pinnules, a few columnals and proximales supply knowledge of Cretaceous bourgueticrinids, excluding *Dunnicrinus*. The characteristics of this genus from Mississippi will be described and illustrated in a following section on Morphology of *Dunnicrinus*.

DUNNICRINUS MISSISSIPPIENSIS Moore, new species

Plates 1-7, Plate 8, figures 3-8; Figures 1-8

With characteristics of the genus.

Occurrence.—Prairie Bluff Chalk, Upper Cretaceous; Oktibbeha County, Mississippi, JKA locality on Josey Creek, northwest of Starkville, collected by P. H. DUNN and students, Mississippi State University; also in same formation at JKI locality (=U.S. Geol. Survey loc. 17235) at roadside and cut on Houston road (sec. 10, T. 15 S., R. 3 E.), 1.25 mile north of Sparta, Chickasaw County, Mississippi, collected by L. W. STEPHENSON and W. H. MONROE, 1936.

Holotype.—Kansas University Museum Invertebrate Paleontology KJA-6.

MORPHOLOGY OF DUNNICRINUS

CROWN

As a whole, the crown of *Dunnicrinus* is characterized by its slenderness and proportionally considerable height (Fig. 1; Pl. 1), with unbranched arms held erect and close together. The height of an adult complete crown is estimated to be 75 to 80 mm. and its average width approximately 13 mm. or a little more in living position. Fossil specimens with arms somewhat appressed to one another have a width of 9 or 10 mm. The proximal parts of arms flare evenly and steeply outward in line with the steep-sided conical dorsal cup, but very shortly a subvertical attitude is assumed and maintained to the summit of the crown. The brachials are strongly cuneate and fitted together uniserially. Counting syzygial brachials as equivalent to nonsyzygial ones, every brachial above the first bears a long slender pinnule, given off in alternation from opposite sides of the arm.

DORSAL CUP

The dorsal cup of *Dunnicrinus* forms a very small, inconspicuous part of the crown, 4 or 5 mm. in diameter and slightly less in height. It is truncate conical in shape, with very steep sides that slope downward to meet the topmost columnal, 3 or 4 mm. in diameter (see Fig. 6). On the basis of external appearance, especially the compact arrangement of plate circlets, the cup might logically be interpreted to contain all skeletal elements between the lowermost pinnule-bearing arm plate (second brachial) and the stem, for the quadrangular first brachials are laterally joined closely together and rest snugly on the radials, which they approximately equal in size. All brachials must be excluded from the cup, however, since articulation of the first brachials on the radials is definitely muscular, with apposed facets showing well-defined transverse ridges, ligament fossae, and muscle fields.

Prevailing in Paleozoic crinoids (paleocrinoids) but less so in Mesozoic and Cenozoic crinoids (neocrinoids), the circlet of radial plates is considered to form the upper rim of the dorsal cup. Actually, as was pointed out by CLARK (1915, p. 349), "the crinoid radial is not a calyx plate at all, but a true arm plate . . ." that differs from other arm plates (brachials) in its proximal position and lateral union by sutures with adjoining radials. In such crinoids as *Bathycrinus*, however, the radials may be loosely united or well separated from each other (CARPENTER, 1884, p. 37). Even so, the radials are commonly considered to be elements of the dorsal cup. Accepting this for *Dunnicrinus*, and at present excluding consideration

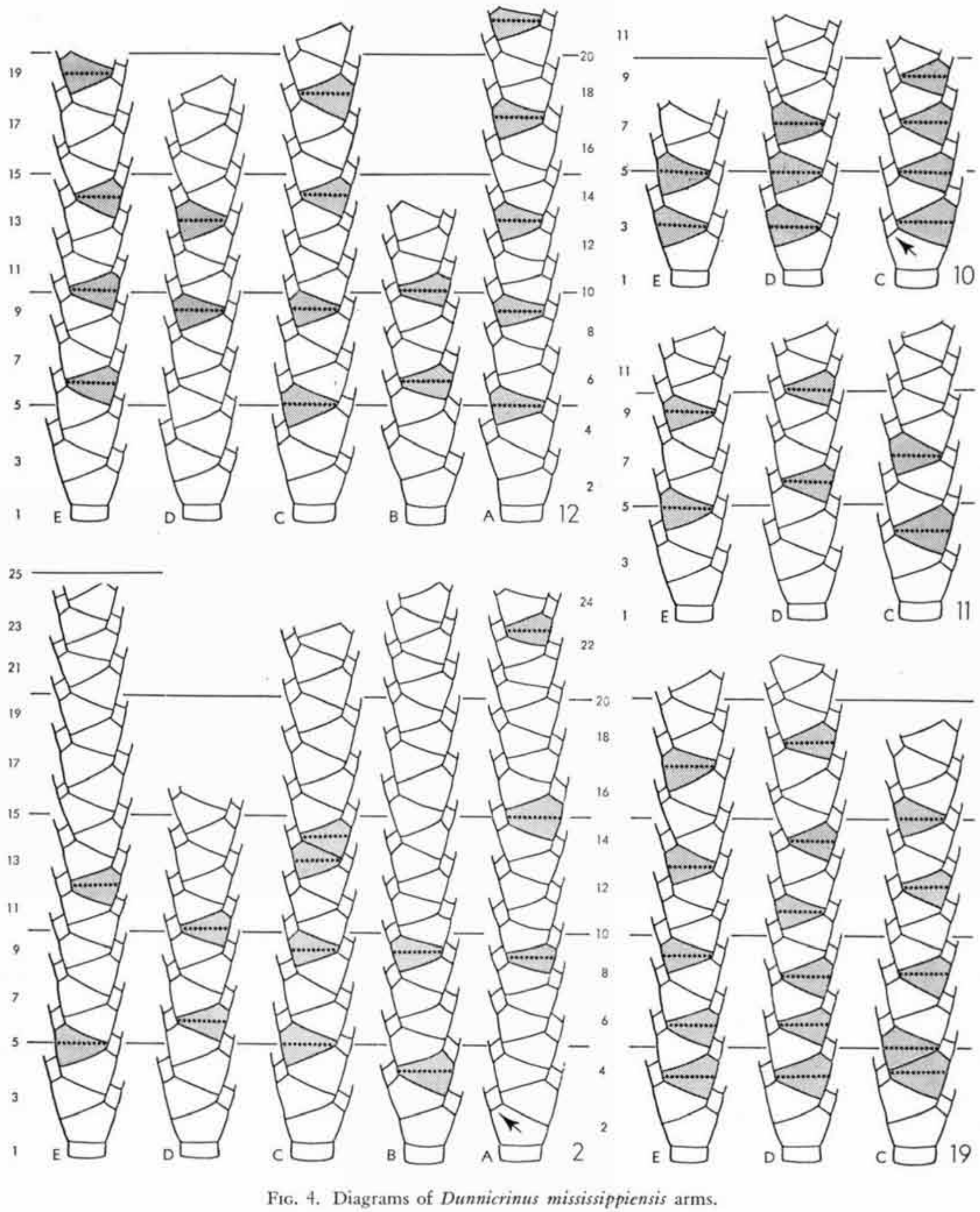


FIG. 4. Diagrams of *Dunnicrinus mississippiensis* arms.

Occurrence of brachials consisting of syzygially united hypozygal element lacking pinnule and epizygal element bearing pinnule is indicated, syzygial brachials (shaded) serially numbered with others upward from arm base; first brachial invariably quadrangular and lacking pinnule, second brachial invariably lacking syzygial division and bearing first pinnule (generally at its right distal extremity but uncommonly at left, such brachials indicated by large arrows). Arms of individual crinoids (specimen numbers at lower right of arm groups) are assigned Carpenter letters *A-E* in arbitrary manner for correlation with photographs shown on plates (perfect radial symmetry of crowns not allowing identification of anterior ray and posterior interray). Not to scale.

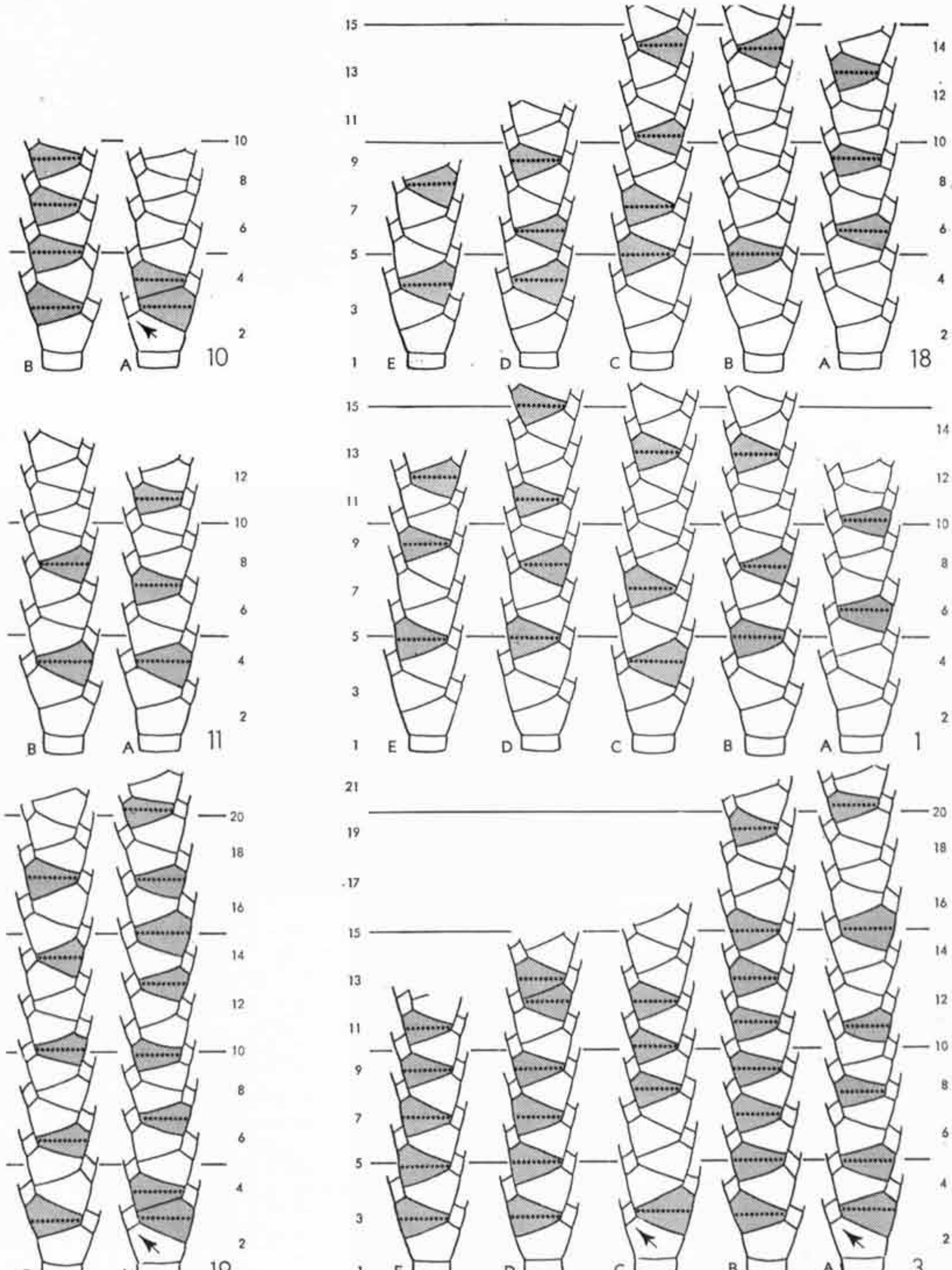


FIG. 4. Diagrams of *Dunnicrinus mississippiensis* arms *(continued)*.

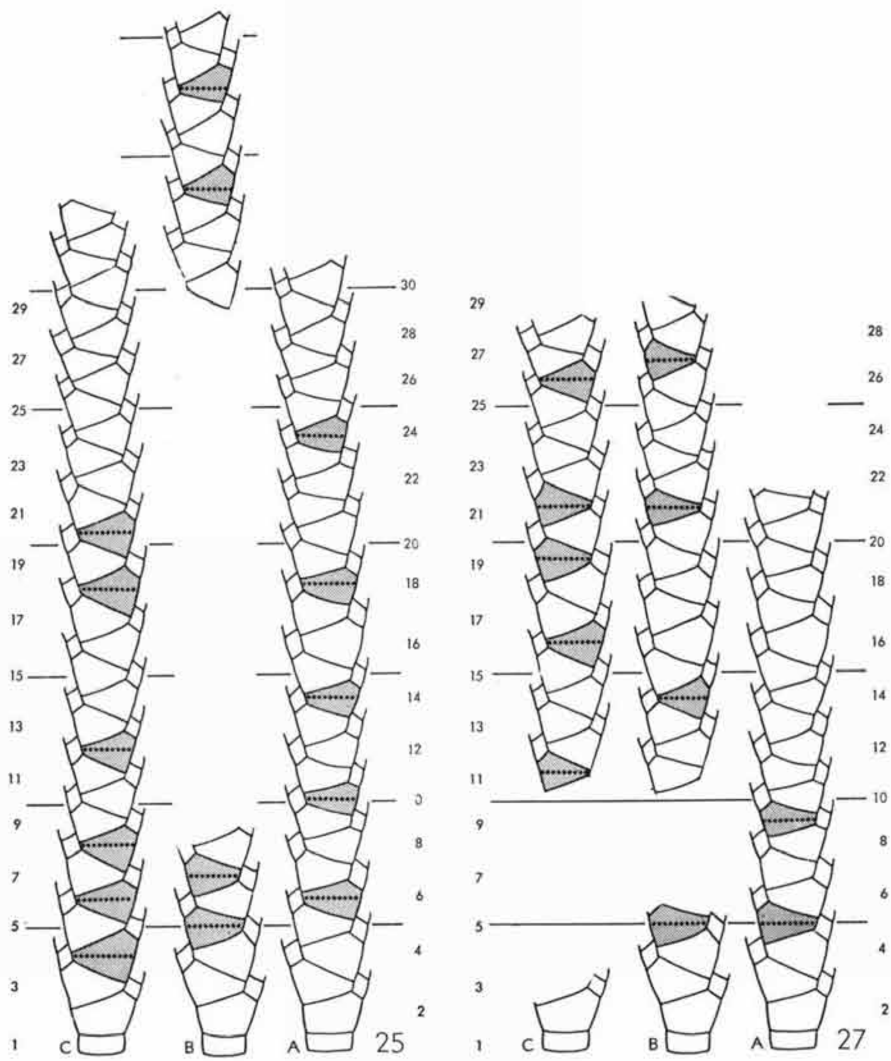
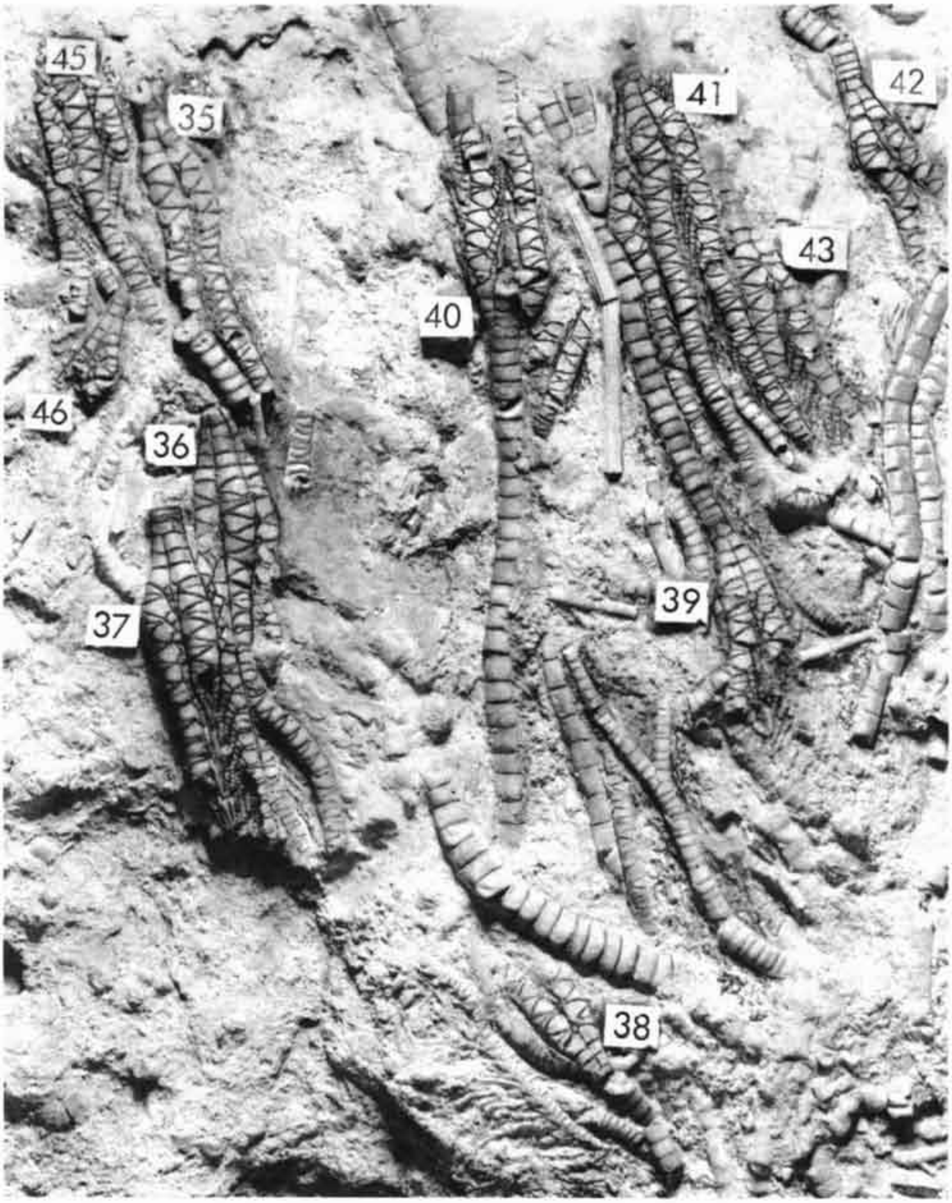


FIG. 4. Diagrams of *Dunnicrinus mississippiensis* arms *(continued)*.

EXPLANATION OF PLATE 1

Part of slab of Prairie Bluff Chalk, Upper Cretaceous, from locality KJA near Starkville, Oktibbeha County, Mississippi, showing current-aligned crowns, parts of columns, and radicular cirri of *Dunnicrinus mississippiensis*, n. gen., n. sp., X1.2.

As here oriented, nine of the 11 more or less complete crowns have their summits directed downward and slightly toward right, whereas the remaining two are pointed oppositely. On the premise that the crowns prevailingly were carried down-current ahead of the dragging columns, the dominant current direction is indicated by orientation of the nine crowns, but then it is difficult to account for the positions of specimens KJA-38 and KJA-40. Possibly the whole assemblage reflects opposite directions of ebb-and-flow water movements, as influenced by on- and off-shore winds or tides. In any case, conclusion that the crinoids lived in a shallow-sea environment, perhaps only a few meters in depth, is hardly escapable.


45
35
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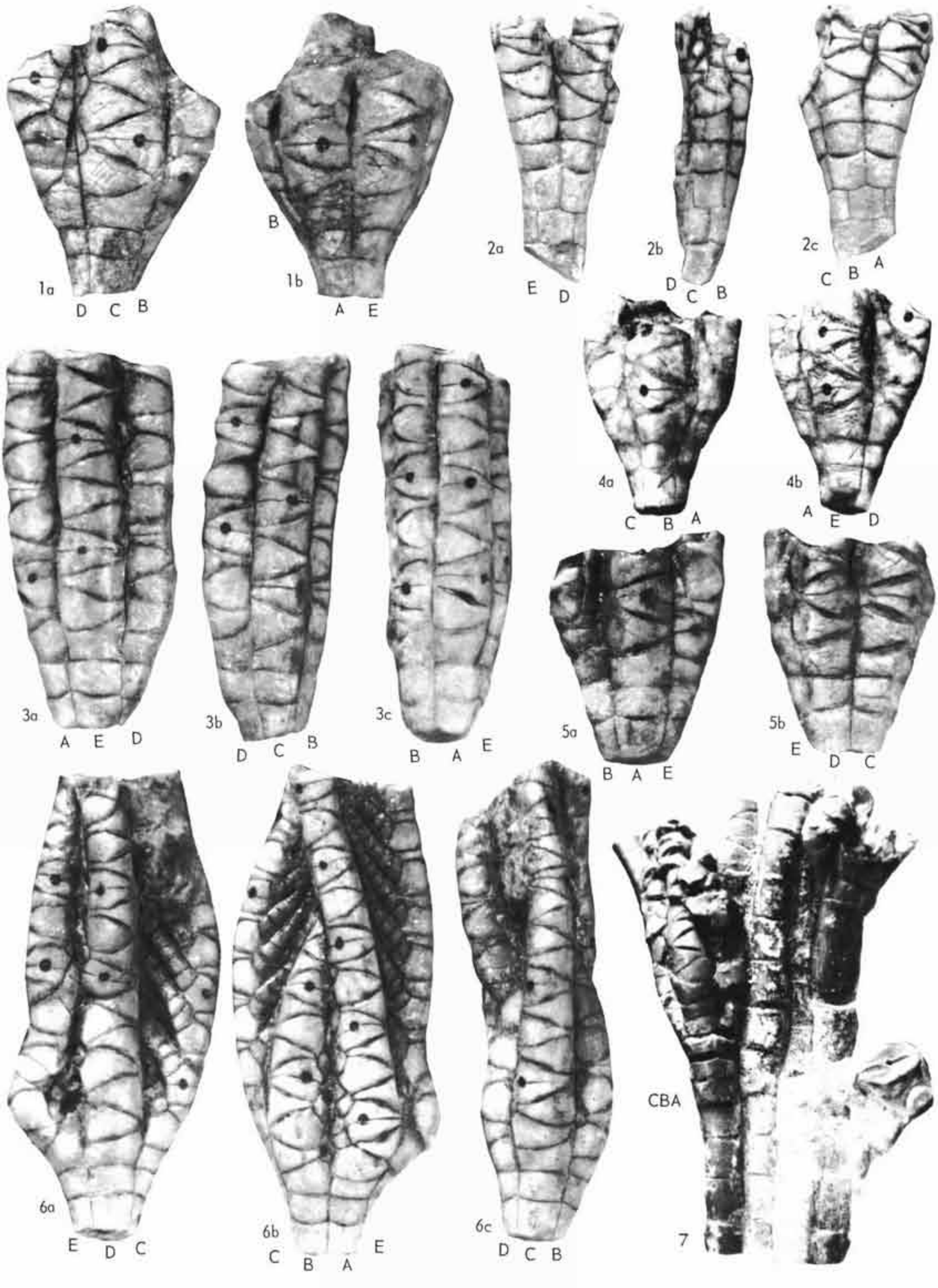
41
42
43
46
36
37
39
38


1a
D C B
1b
B
A E
2a
E D
2b
D C B
2c
C B A
4a
C B A
4b
A E D
3a
A E D
3b
D C B
3c
B A E
5a
B A E
5b
E D C
6a
E D C
6b
C B A E
6c
D C B
CBA
7

of infrabasals, the dorsal cup may be defined as formed by two circlets of subequal plates, radials above and basals below, but a degree of arbitrariness in such an acceptance needs to be observed, inasmuch as fully 90 percent of the available crowns of *D. mississippiensis* have the circlet of radials as lowermost plates. This means that separation at the contact of the radial and basal

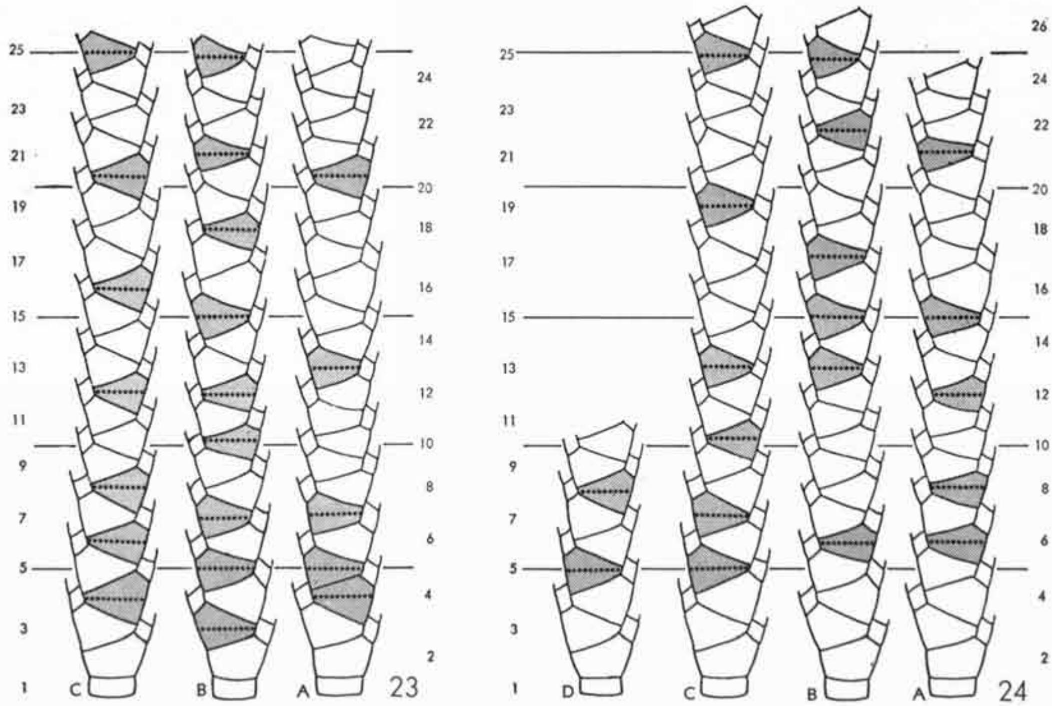


FIG. 4. Diagrams of *Dunnicrinus mississippiensis* arms *(continued)*.

EXPLANATION OF PLATE 2

Parts of crowns, some with attached proximal columnals, belonging to *Dunnicrinus mississippiensis*, n. gen., n. sp., from Prairie Bluff Chalk at locality KJA near Starkville, Oktibbeha County, Mississippi, collected by Paul H. Dunn and students at Mississippi State University.

Carpenter letters *A-E* arbitrarily assigned to rays may be correlated with diagrams in Figure 4 and summary of occurrence of syzygial brachials given in Table 3 (inked dots on photographs mark brachials divided by syzygy), all except Figure *7* X3.3.

FIGURES

1a,b. Specimen KJA-6.

2a-c. Specimen KJA-15, showing all plates with well-defined sutures; basals, radials, and first brachials subequal in size; no trace of infrabasals.

3a-c. Specimen KJA-11, showing radials and first brachials wider than high.

4a,b. Specimen KJA-17, very incomplete crown lacking basal circlet of dorsal cup, radials distinctly larger and taller than first brachials, second brachial of *D* ray (4b) with pinnule given off toward left.

5a,b. Specimen KJA-8, another incomplete crown with quadrangular first brachials smaller than radials.

FIGURES

6a-c. Specimen KJA-12, selected as holotype (despite its lack of basals and proximal columnals) because of excellent representation of arm structure and pinnules (compare Fig. 4).

7. Specimen KJA-34 (at left) and KJA-34A (at right) with part of stem composed of even-sized columnals having height subequal to diameter. Both crowns have well-defined basal circlets in the dorsal cup, beneath which in KJA-34 is a moderately low proximal columnal followed by taller ones, whereas specimen KJA-34A has a proximal columnal (proximale) much taller than columnals below it. The proximale lacks any visible trace of component fused columnals, X1.7. Note dissociated elliptical columnal at extreme right, showing small circular lumen flanked by fulcral ridge with narrow trough on its summit.

circlets is vastly easier than anywhere else in the upper skeleton of the crinoid. No specimens have been found showing complete or incomplete crowns with basals but lacking proximal columnals, and none shows first or second brachials as lowermost preserved plates. Such evidence would support exclusion of radials from the dorsal cup. In some modern stalked crinoids (e.g., *Bathycrinus poculum* Döderlein, 1907, p. 12) only basals and attached columnals are known, yet radials are interpreted to belong with the cup. It is observed that deep-water species of *Bathycrinus* very readily lose their radials, arms, and visceral mass and then regenerate these parts from the basal ring (Clark, 1919, p. 12), whereas in *Rhizocrinus, Bythocrinus,* and *Democrinus* separation most commonly occurs at the arm bases.

In most specimens of *Dunnicrinus* with preserved circlet of basals, these plates rest on a faintly scalloped upper surface of the proximal columnal, as illustrated in Plate 5, figures 2a-c. Such fossils afford no hint of the existence of an infrabasal circlet and grinding the basal part of one or two dorsal cups attached to stems did not reveal the presence of hidden infrabasals. On the other hand, specimens KJA-37, KJA-39, KJA-42 (Fig. 6), KJA-29 (Pl. 8, fig. 7), and KJA-46 (Pl. 1), a juvenile crown described in the section on Ontogeny of *Dunnicrinus*, possess externally visible, suture-bounded elements next below interbasal boundaries where infrabasal plates belong. Sutures between the suspected infrabasals of the adult crowns (first four specimens just listed) are not known to separate them, except that grinding of specimen KJA-29 has revealed their presence, with a measure of uncertainty. Typically, *Dunnicrinus* lacks observable infrabasals, but thin remnants of these plates are concluded to persist in some specimens.

ARMS

Dunnicrinus is a five-armed crinoid. Among more than 40 available crowns, some very incomplete, none shows the occurrence of a bifurcation in any ray. Accordingly, the unbranched nature of the arms is a significant generic attribute (Fig. 1).

The arms are slender and nearly uniform in width throughout their length, but they taper gradually in the distal region. They are rounded on their outer (dorsal) side and laterally, whereas their inner (ventral) side is rounded truncate, with a comparatively narrow troughlike median groove reaching less than one-third of the distance to the outer surface (Pl. 8, fig. 9-10). A small nerve canal, subelliptical in transverse section, with its long axis normal to the dorsoventral midline, is located about halfway between the outer arm surface and the bottom of the ambulacral groove.

As previously noted, the arms are uniserial throughout, with relatively long pinnules on opposite sides given off from alternate brachials, beginning with the second one.

Mainly for the purpose of recording variable features of individual arms, such as occurrence of

EXPLANATION OF PLATE 3

Parts of crowns and stems of *Dunnicrinus mississippiensis*, n. gen., n. sp., from Prairie Bluff Chalk, Upper Cretaceous, at locality KJA near Starkville, Oktibbeha County Mississippi, collected by Paul H. Dunn and students at Mississippi State University.

Carpenter letters *A-E* arbitrarily assigned to rays may be correlated with diagrams in Figure 4 and summary of occurrence of syzygial brachials given in Table 3 (inked dots on photographs mark brachials divided by syzygy).

FIGURE

1. Specimen KJA-27, lacking basals, part of radials, and portions of arms, X2 (compare Fig. 4).

2a,b. Specimen KJA-4, with lowermost plates consisting of radials, X1.7.

3. Specimen KJA-25, part of crown with very tall proximal columnals, associated with three parallel stem fragments (KJA-25A, -25B, -25C, left to right), all columnals cylindrical, X1.7 (compare Fig. 4).

4. Specimen KJA-23 (crown with attached low proximal columnals) with part of column and arm fragment with parallel elongate pinnules belonging to other crinoids, X2 (compare Fig. 4).

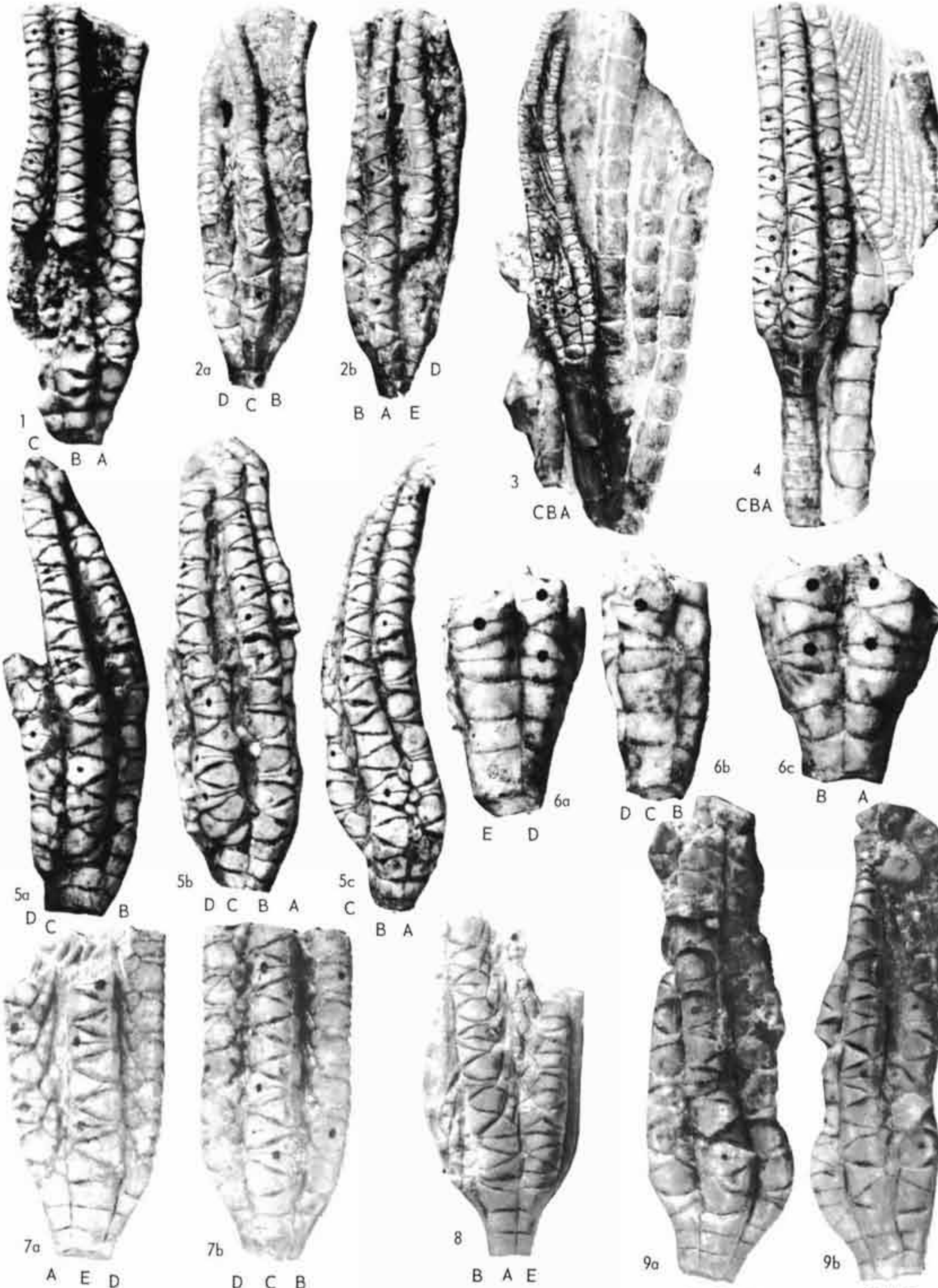
5a-c. Specimen KJA-24, basal circlet lacking, X2 (compare Fig. 4).

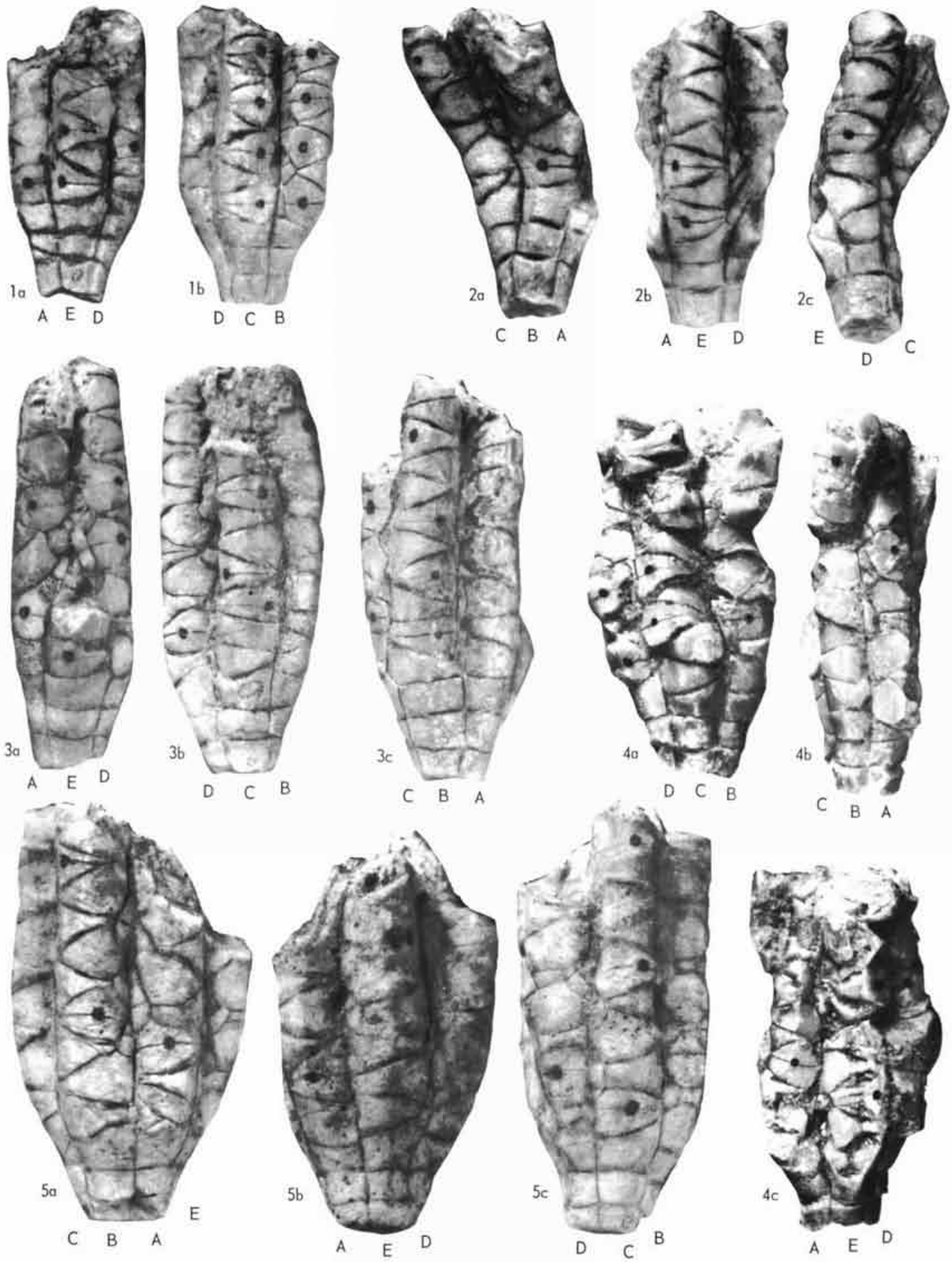
6a-c. Specimen KJA-16, very incomplete crown with radials larger than first brachials, basals lacking, X3.3.

7a,b. Specimen KJA-1, radials and first brachials subequal, no basals, X2 (compared Fig. 4).

8. Specimen KJA-3, similar to KJA-1, X2.

9a,b. Specimen KJA-2, no basals, second brachial of *A* ray giving off pinnule toward left, X2 (compare Fig. 4).


1
C B A
2a
D C B
2b
B A E D
3
CBA
4
CBA
5a
D C B
5b
D C B A
5c
C B A
6a
E D
6b
D C B
6c
B A
7a
A E D
7b
D C B
8
B A E
9a
D C B
9b
B A E


1a
A E D
1b
D C B
2a
C B A
2b
A E D
2c
E D C
3a
A E D
3b
D C B
3c
C B A
4a
D C B
4b
C B A
5a
C B A E
5b
A E D
5c
D C B
4c
A E D

"left-handed" second brachials and distribution of brachials divided by syzygy, each is identified by one of the Carpenter letters *A* to *E*. In dorsal views of crowns, these belong in counter-clockwise sequence, and consequently, in side views of crowns arrangement of the letters go from *A* on the right to *E* on the left. Because the dorsal cup and arms of *Dunnicrinus* display perfect pentameral symmetry, the Carpenter letters can only be assigned arbitrarily, from which it follows that the so-called *A* ray of one specimen may be the actual morphological equivalent of a differently lettered ray in another specimen.

BRACHIALS

As many as 70 brachials, or even more, may be present in each arm of an adult individual of *Dunnicrinus mississippiensis*, counting syzygially divided brachials as units equivalent to undivided ones. Both types of brachials bear a pinnule, except the quadrangular lowermost one which articulates with a radial, and thus the total complement of pinnules belonging to an arm corresponds to its aggregate number of brachials, less one.

In any view of an arm from the exterior—directly toward its mid-line or as far as the outer side of the arm is visible from left or right viewpoints—the brachials from the second one upward appear strongly wedge-shaped, commonly with the attenuated edge of the wedge drawn out so that its lower and upper margins are nearly parallel, or entirely so (e.g., Pl. 2, fig. 3a-c, 6a-c; Pl. 3, fig. 1, 2-5, 7, 9; Pl. 4, fig. 1-5; Pl. 5, fig. 1, 3-5). The thin edge of the outer surface of brachials typically abuts the proximal pinnular of the pinnule borne by the brachial next beneath it. Very rarely does it fail to reach this far (Pl. 2, fig. 7; Pl. 3, fig. 6c). The uniserial succession of the *Dunnicrinus* brachials is clearly defined in all individuals, without a tendency toward becoming biserial.

The shape of brachials in transverse section has been noted in description of the arms. Their width ranges from 2.5 to 4.2 mm. (average approximately 3.3 mm.) for proximal ones and 1.3 to 2.5 mm. (average approximately 2 mm.) for distal ones. Dorsoventral thickness is about the same. Any pair of contiguous brachials above the first one forms an arm part of uniform height extending across it obliquely, such height being a little less than the arm width and averaging 2.8 to 2.9 mm.

Articulations of the brachials, excepting that between the first and second and counting syzygially paired brachials as units, are all oblique muscular. The surfaces of both proximal and distal articula display a shallow to moderately deep, arcuate outer ligament fossa, with or without a distinguishable medially placed ligament pit next to the transverse ridge, which is narrow and straight or slightly angulated, with crest that may be finely denticulate or faintly grooved. A relatively large subelliptical nerve canal with elevated rim partly interrupts the transverse ridge. The inner, ventral surface of the articula comprises two broad muscle fields, divided by the ambulacral troughlike indentation on the inner margin of the brachial. Variations in the appearance of brachial articula are illustrated (Pl. 7, fig. 14b, 15a,b, 16a,b; Pl. 8, fig. 7a,b, 8a,b).

Articulations on brachials for attachment of pinnules are located on the abaxial distal tips of the brachials, with surfaces facing outward and upward (e.g., Pl. 2, fig. 6a,b). These articula are somewhat elongate oval in outline, with long axis parallel to the outer surface of the brachial. They are crossed by a narrow transverse ridge disposed normal to the outer face of the brachial and other-

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EXPLANATION OF PLATE 4

Parts of crowns and stems of *Dunnicrinus mississippiensis*, n. gen., n. sp., from Prairie Bluff Chalk, Upper Cretaceous, at locality KJA near Starkville, Oktibbeha County, Mississippi, collected by Paul H. Dunn and students at Mississippi State University.

Carpenter letters *A-E* arbitrarily assigned to rays may be correlated with diagrams in Figure 4 and summary of occurrence of syzygial brachials given in Table 3 (inked dots on photographs mark brachials divided by syzygy). Lowermost plates are radials in all specimens, which (except *4*) are X3.3.

FIGURE

1a,b. Specimen KJA-10, second brachials of *A* and *C* rays giving off pinnule toward left, instead of right (compare Fig. 4).

2a-c. Specimen KJA-13.

3a-c. Specimen KJA-9.

4a-c. Specimen KJA-18 (compare Fig. 4), X2.7.

5a-c. Specimen KJA-7.

FIG. 5. *(Explanation on facing page.)*

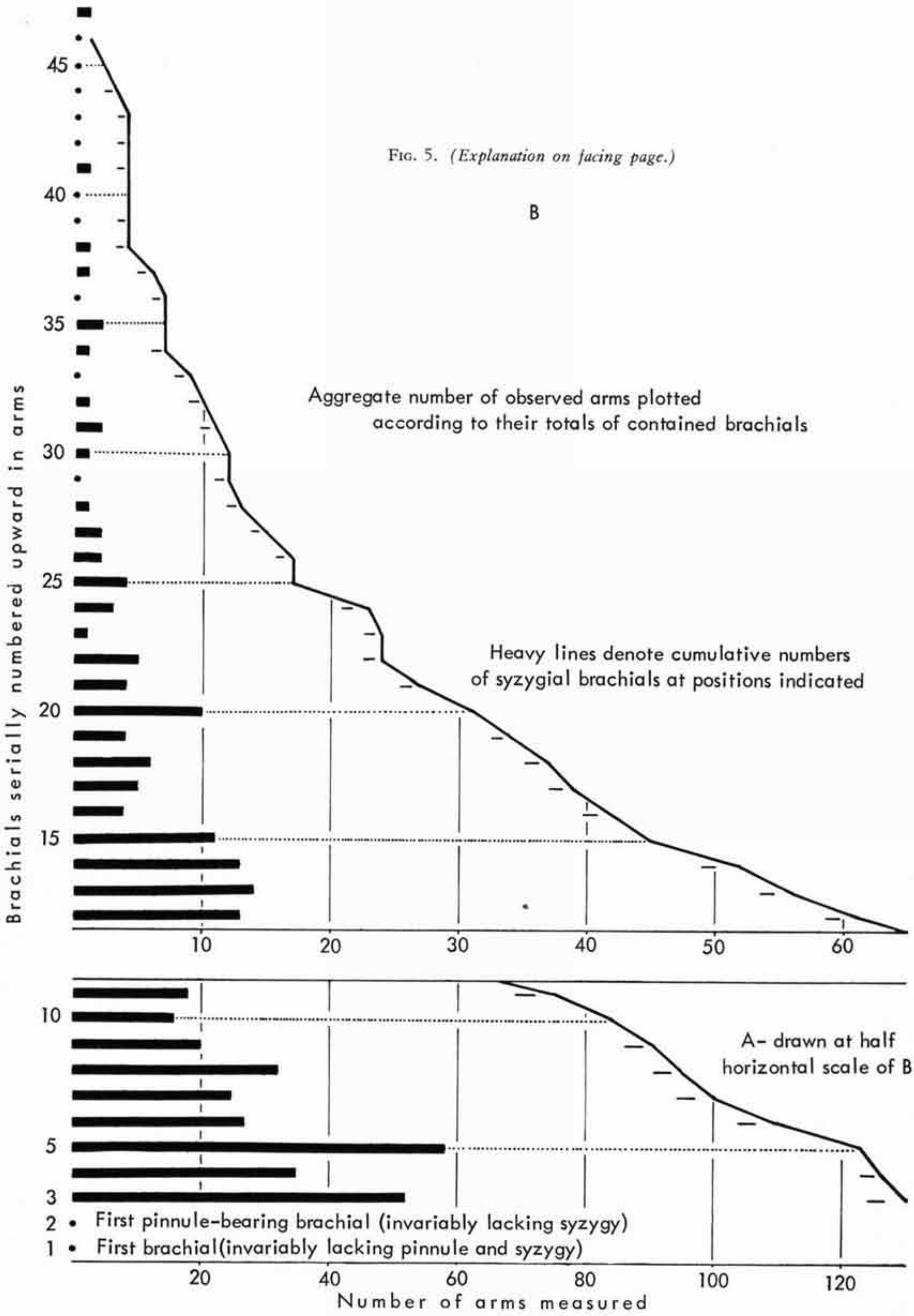
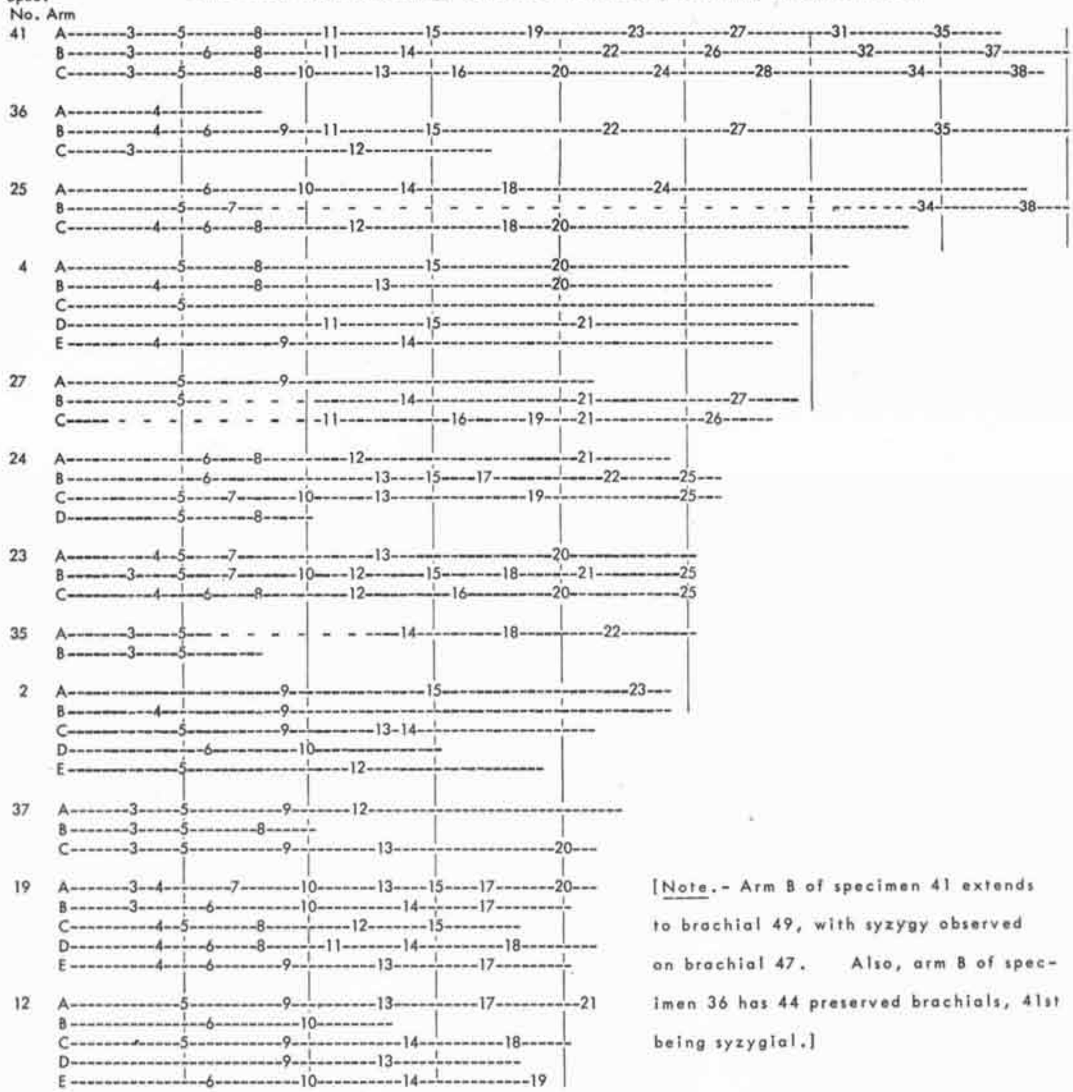


TABLE 3.

SYZYGIES ON BRACHIALS SERIALLY NUMBERED UPWARD FROM RADIALS



wise essentially duplicate features of the muscular articulation between brachials in having an outer (abaxial) shallow ligament fossa, nerve canal in inner edge of the transverse ridge, and small muscle fields which appear more or less clearly paired. A trough or notch is located on the inner (ventral) margin of the brachial where the pinnule facet meets the oblique interbrachial facet.

FIG. 5. Graph of individual arms of *Dunnicrinus mississippiensis* studied to determine distribution of syzygial brachials.

Total specimens having indicated numbers of brachial components (e.g., 130 specimens with only three brachials preserved, 45 specimens with 15 brachials preserved, 4 specimens with 40 brachials preserved) shown by line farthest to right and cumulative total occurrences of syzygial brachials at each serially numbered position above arm base indicated by heavy bars at left (e.g., 58 syzygial brachials in fifth position above arm base, 10 such brachials in position of 20th brachial). The diagram emphasizes absence of a distinguishable pattern in distribution of syzygial brachials.

TABLE 3. *(Continued.)*

SYZYGIES ON BRACHIALS SERIALLY NUMBERED UPWARD FROM RADIALS

Spec. No.	Arm	Syzygies on brachials
3	A	3, 5, 8, 11, 15, 20
	B	3, 5, 7, 9, 11, 13, 16
	C	3, 8, 10, 12
	D	3, 5, 7, 9, 12, 13
	E	3, 5, 7, 9, 11
40	A	3, 5, 8, 11, 14, 19
	B	3, 5, 7, 11
5	A	4, 5, 9
	B	7, 10
	C	6, 10, 14
	D	4, 7, 10, 14
	E	5, 8
42	A	4, 7, 10
	B	5, 8
43	A	3, 5, 8, 11
	B	3, 5, 8, 15
1	A	6, 10
	B	5, 8, 13
	C	4, 7, 13
	D	5, 8, 11, 15
	E	5, 9, 12
18	A	6, 9, 13
	B	5, 14
	C	5, 7, 10, 14
	D	4, 6, 9
	E	4, 8
39	A	3, 5, 8, 11
	B	3, 5, 8
44	A	3, 5, 7, 9, 11
	B	3
7	A	5
	B	6, 11
	C	3, 7, 11
	D	4
	E	6, 8
9	A	4, 8
	B	4, 6, 8, 11
	C	3, 5, 8
	D	4, 7
	E	3
11	A	4, 7, 11
	B	4, 8
	C	4, 7
	D	6, 10
	E	5, 9
38	A	3, 5
	B	3, 5, 7, 9
	C	3, 5
10	A	3, 4
	B	3, 5, 7, 9
	C	3, 5, 7, 9
	D	3, 5, 7
	E	3, 5
13	A	
	B	3
	C	
	D	3, 6
	E	5, 8
6	A	4
	B	3
	C	4, 7
	D	4, 6
	E	4
15	A	4, 6
	B	5
	C	
	D	6
	E	6
8	A	4
	B	6
	C	4
	D	5
	E	3, 6
14	A	3
	B	
	C	5
	D	4
	E	
16	A	3, 5
	B	3, 5
	C	3, 5
	D	3, 5
	E	3, 4
17	A	
	B	3, 5
	C	
	D	3, 6
	E	3, 5
46	A	3
	B	3, 5

PINNULES

A typical complete pinnule of *Dunnicrinus mississippiensis* is 10 to 12 mm. in length and contains approximately 25 pinnulars. Such a pinnule has greatest width of 1 mm. or slightly more at its proximal extremity, measured in adaxial-abaxial direction with respect to the arm bearing it, and 0.6 to 0.8 mm. at right angles to this plane. The pinnule tapers very gradually and evenly to a distal diameter of 0.25 or 0.3 mm.

As stated previously, all brachials including syzygial ones but excluding the quadrangular first brachial, bear pinnules. Hence, the number of pinnules carried by each complete arm of a fully grown individual of this Upper Cretaceous bourgueticrinid may range from 65 to perhaps 75, and a whole crown would have 250 to 300 of these food-gathering small appendages.

Each pinnular is quadrangular in side view, with length equal to width. It is rounded on the side away from the arm (dorsally) and narrowly grooved on the side toward the arm (ventrally). A centrally located tiny nerve canal penetrates the pinnulars longitudinally. Cover plates associated with pinnules have not been observed.

The articulations between all observed pinnulars where their proximal or distal surfaces can be studied are straight muscular. A narrow transverse ridge crosses the articula about midway between the outer and inner surfaces, with small arcuate outer ligament area and inner muscular fields divided by the ambulacral groove. A small nerve canal borders the ridge on its inner side.

SYZYGIES

A distinctive feature of *Dunnicrinus* is abundance of brachial syzygies coupled with lack of discernible pattern in their distributions (Fig. 4-5, Table 3). Most of the syzygial articulations are easily recognized in viewing the arm surfaces, especially if crowns have been ever so slightly exposed to weathering. The syzygies appear as narrow straight lines at mid-height of brachials extending transversely across them and precisely bisecting the narrow extremity of the wedge-shaped arm plate (e.g., Pl. 1; Pl. 2, fig. 1a,b, 4a,b; Pl. 3, fig. 4, 5a-c). The lower (hypozygal) half of syzygially divided brachials invariably lacks an attached pinnule, whereas the upper half (epizygal) corresponds exactly to the distal part of nonsyzygial brachials in giving rise to a proximally stout pinnule. The pinnules borne by syzygial brachials are exactly like all others, just as the combined hypo- and epizygals of any syzygial brachial precisely match undivided brachials. Consequently, it has seemed both natural and greatly preferable to treat the paired hypo- and epizygals as brachial units which together are equivalent to nonsyzygial brachials. In numbering brachials serially upward from the arm base, a syzygial brachial thus is given its own numerical designation, instead of numbering hypozygals and epizygals separately.

The chief virtue of procedure just explained is simplicity, as may be illustrated by numerical designations for lower parts of the identical two compared arms 1) in the manner adopted here and 2) in the system of Gislén (1922, p. 12, 1924, p. 12), who numbered each arm plate separately and denoted syzygial articulation by a plus sign (+):

1) Only unit numbers for syzygially paired brachials given (present paper)
   Arm A, - - 3 4 - - - - 9 - 11
   Arm B, - - 3 - 5 - 7 - - 10 -

2) Separate numbers for hypo- and epizygals, syzygies indicated by plus sign (+)
   Arm A, 1 2 3+4 5+6 7 8 9 10 11+12 13 14+15
   Arm B, 1 2 3+4 5 6+7 8 9+10 11 12 13+14 15

The observed distribution of syzygial brachials in numerous representative specimens of *Dunnicrinus mississippiensis* is shown by photographs (Pl. 1-5), diagrams (Fig. 4, 5), and Table 3. These are self-explanatory, for both severally and collectively they leave no doubt as to the lack of any consistent pattern of occurrence. Distribution of brachial syzygies in some crinoids is sufficiently constant to warrant recognition of its as a useful generic attribute, but certainly this does not apply to *Dunnicrinus*. Indeed, the apparently random occurrence of syzygial brachials cannot be explained by me. One arm having 67 brachials, not included in illustrations or Table 3, shows syzygial sutures on brachials numbered 6, 9, 13, 17, 23, 29, 36, 40, 44, 49, 56, and 62.

The nature of the articular connection between hypozygal and epizygal pairs in syzygial brachials of *Dunnicrinus* is extremely difficult to determine. No specimen in the collection, either a crown or separated arm fragment, shows a parting at mid-height of a syzygial brach, with half of this arm component gone. Somewhat weathered specimens do not allow dissection for the purpose of exposing the distal articular surface of a hypozygal or proximal surface of an epizygal. The fine straight line of the suture seen from the outer side of the brachial indicates that these surfaces are very closely appressed and probably perfectly plane. Careful preparation of two specimens has revealed the correctness of this deduction and in addition has shown that the surfaces appear to bear fine markings disposed radiately from the nerve canal, associated with moderately coarse granules in inner lateral areas. The syzygies have the nature of firm closely bonded sutures resembling those of cup plates in many crinoids.

COLUMN

The column, or stalk, of a robust, fully grown individual of *Dunnicrinus mississippiensis* is estimated to be 300 to 320 mm. (12 to 14 in.) in overall length, with branched radicular cirri at its

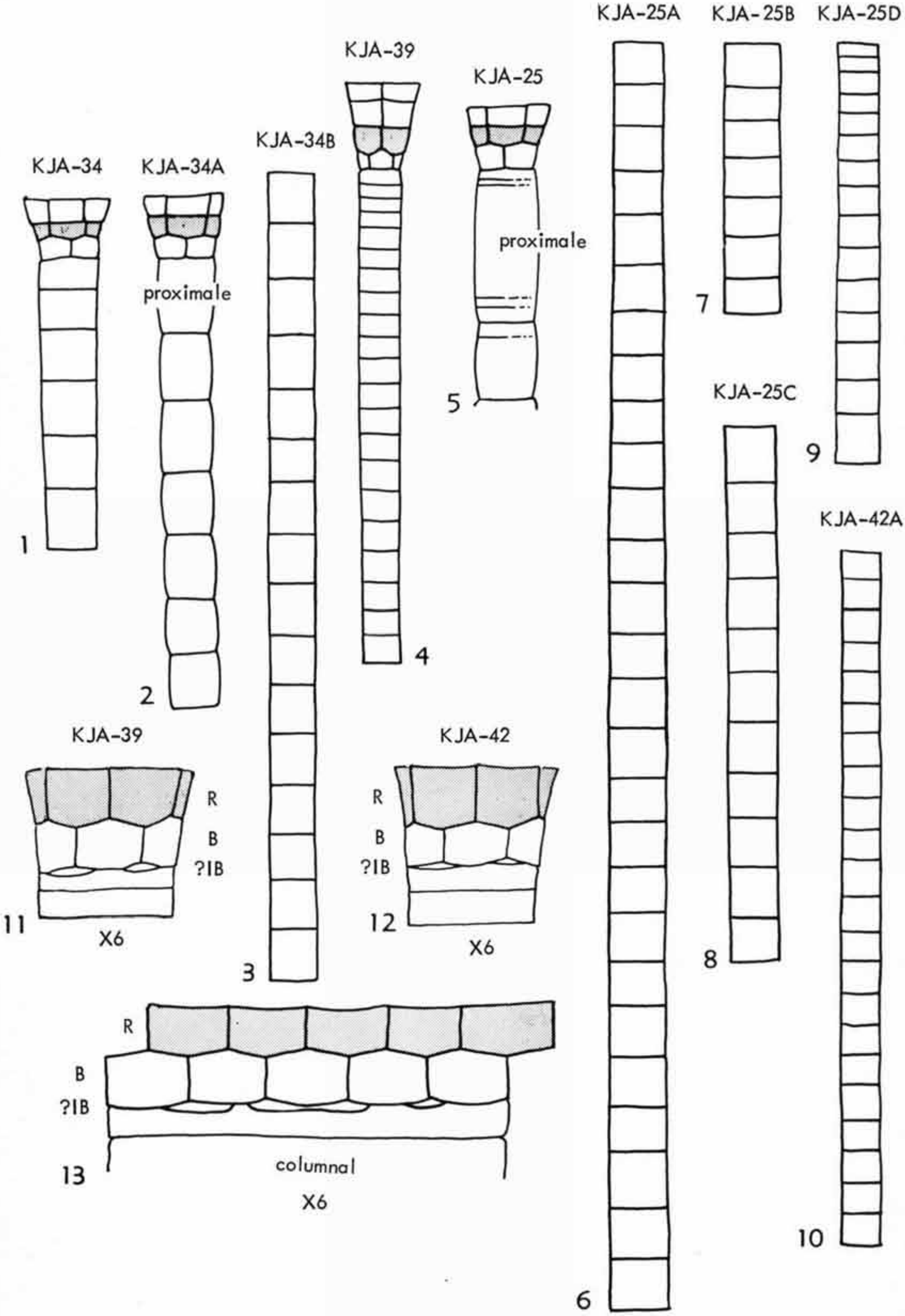


FIG. 6. *(Explanation on facing page.)*

lower end up to 50 mm. (2 in.) or a little more in spread from their stem attachment to outer extremities (Fig. 1). If these figures are correct, or nearly so, the living crinoid reached to a height of some 375 or possibly 400 mm. (15 or 16 in.) above the calcareous mud of the sea bottom. The span of the rootlike holdfast shallowly embedded in sediment was 100 to 125 mm. (4 or 5 in.), which is roughly one-fourth of the crinoid's height and seemingly quite adequate for anchorage.

The column is divisible into two rather distinct parts—a proximal-and-intermediate region, comprising the upper two-thirds of the stem, and a distal region, forming the lower one-third (Fig. 1). These proportions are based on estimates, however, and the fact that the regions are not abruptly set off but intergrade makes delimitation of them appreciably indefinite. Even so, parts of stems belonging to the proximal-and-intermediate region are readily distinguished by the cylindrical shape of the columnals, with diameter nearly or exactly the same as height (Fig. 6). In transverse section these columnals are circular to broadly oval, with the long diameter of the oval barely greater than the short one. The sides of proximal-intermediate columnals are straight to faintly convex longitudinally and mostly they are parallel to the axial canal which penetrates the center of the stem. In the lower part of the intermediate region, the columnals possess more elliptical articula and sides which are slightly to distinctly inclined from parallel to the axial canal.

Accentuation of these characteristics leads to typical columnals of the distal region, which have decidedly elliptical to almost lozenge-shaped articular facets and very strongly inclined sides. Also, the distal columnals are joined to one another in manner that produces a striking zigzag profile of the column in this region. The height of distal columnals seems to be smaller on the average than that of proximal-intermediate columnals but numerous measurements show that this is more apparent than real. It is greater diameter of these columnals next to each of their two articula which mainly distinguishes them, although some specimens of distal-region columnals are definitely lower in height than average columnals farther up in the stem. This appears both in groups which remain joined together (Pl. 8, fig. 6a,b) and in dissociated individual columnals (Pl. 6, fig. 1-2, 6-7).

A feature of the *Dunicrinus* columnals which characterizes bourgueticrinids in general is well-defined synarthrial articula and associated with this a moderate to strong displacement in orientation of fulcral ridges on successive pairs of apposed articula. In so far as observable, these features are universal attributes of the columnals of *Dunnicrinus*, both in the proximal-intermediate region and the distal region. The only difference in articula representing the two regions is ellipticity of outline.

In order to explore possible significant relationships of the height of *Dunnicrinus* columnals to outlines of their articula and orientation of their fulcral ridges, many specimens were measured. Some of the results of this study are presented graphically in Figures 7 and 8. They demonstrate that size and shape of columnal articula exhibit weak correlation or none at all with columnal height (e.g., Fig. 8,*1-2*, low columnals with well-defined elliptical articula compared with Fig. 8, *34,36*, tall ones with articula of similar shape; Fig. 8,*6*, low columnals with nearly circular articula, compared with Fig. 8,*19,21,24,29,32,35*, relatively tall columnals with articula of similar shape). In groups of attached columnals, the direction and amount of shifts in orientation of fulcral ridges appears reasonably consistent in some (e.g., Fig. 8, *3-4,6,8,11,12,14,25,28,32-33*) but inconsistent in others. Finally, the angular divergence of fulcral ridges on opposite articula of individual columnals is found to range from less than 60 degrees (Fig. 8,*2,7,9,14-16,23,29,35*) to 89 or 90 degrees (Fig. 8, *3-4,7,9,13,16,25,31-33,37*). The smallest observed angular discordance is 35 degrees (Fig. 8,*16*).

Longitudinal sections of *Dunnicrinus* columnals appear not to have value for identification of this genus but they reveal some features of morphological interest. Sections of parts of stems be-

FIG. 6. Parts of columns and some lower parts of attached crowns of *Dunnicrinus mississippiensis* drawn to scale.

Most specimens lack a notably tall topmost columnal (proximale). Diagrams of specimens 37, 39, and 42 show the appearance of elements bounded by visible sutures observed next below clearly defined basals; these may be exposed edges of an incompletely developed topmost young columnal, rather than infrabasals, for in only one specimen sutures separating these elements are indicated by grinding. [Radials shaded.]

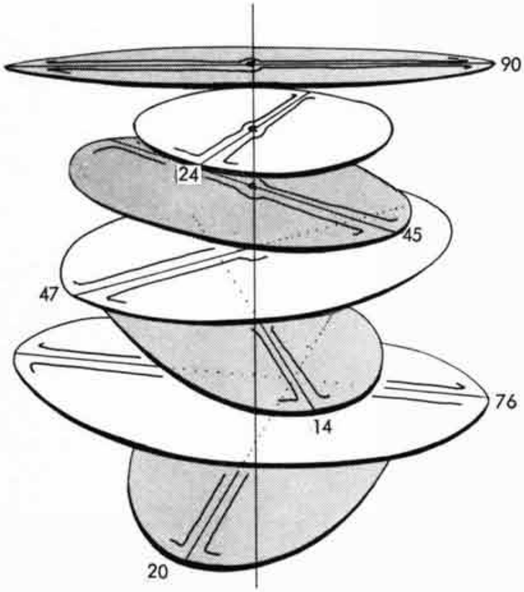


FIG. 7. Oblique perspective diagram of upward facing successive columnal articula in distal region of stalk of *Dunnicrinus mississippiensis*, numbers showing degrees of rotation of one end of fulcral ridges of articula from plane through axial canal oriented in viewer's line of sight (designed and drawn by R. B. Williams). Measurements derived from specimen KJA-33.

longing to the proximal-intermediate region cut through or closely adjacent to the axial canal show next to opposite articula of each columnal an arcuate zone of differentiated calcite which under the microscope reveals a fine reticulation produced by intersecting longitudinal and transverse microlamellae. The zone is more porous than the dense central body of the columnal and thus may receive brownish deposits of hydrous iron oxide which appear dark in the longitudinal section (Pl. 8, fig. 4). Where precipitation of foreign material is less pronounced, the arcuate zones are still discernible (Pl. 8, fig. 3a, 5, 6b). Apposed pairs of these zones have a lanceolate outline in section, with the plane of the articula appearing as a light or dark line bisecting the combined zones. In sections of attached columnals from the distal region of *Dunnicrinus* stems cut longitudinally through the axial canal, the arcuate zones appear only along alternate pairs of apposed articula where the section lies parallel or cuts through the fulcral ridges (Pl. 8, fig. 3a). Where the plane of the section is normal to fulcral ridges, no arcuate zones are seen.

RADICULAR CIRRI

At the base of the column of *Dunnicrinus* is a rootlike holdfast consisting of clustered lateral outgrowths from pairs of distal columnals. As many as four such pairs are seen in some specimens to give off a single side branch or two oppositely directed ones (Pl. 6, fig. 13-15). The branches are termed radicular cirri, though they are not at all like the cirri borne by nodal columnals of many crinoids or the centrodorsal of comatulids. The only common denominator of radicular cirri and true cirri is that both are columnal outgrowths.

The radicular cirri of *Dunnicrinus* are relatively very stout, extremely so in corparison with corresponding anchorage structures seen in *Rhizocrinus* and *Bathycrinus*. *Bourgueticrinus* may be expected to possess robust radicular cirri, but they are only mentioned (without description or illustration) in a single species (*B. globularis* RASMUSSEN, 1961, p. 187) from the Upper Cretaceous of

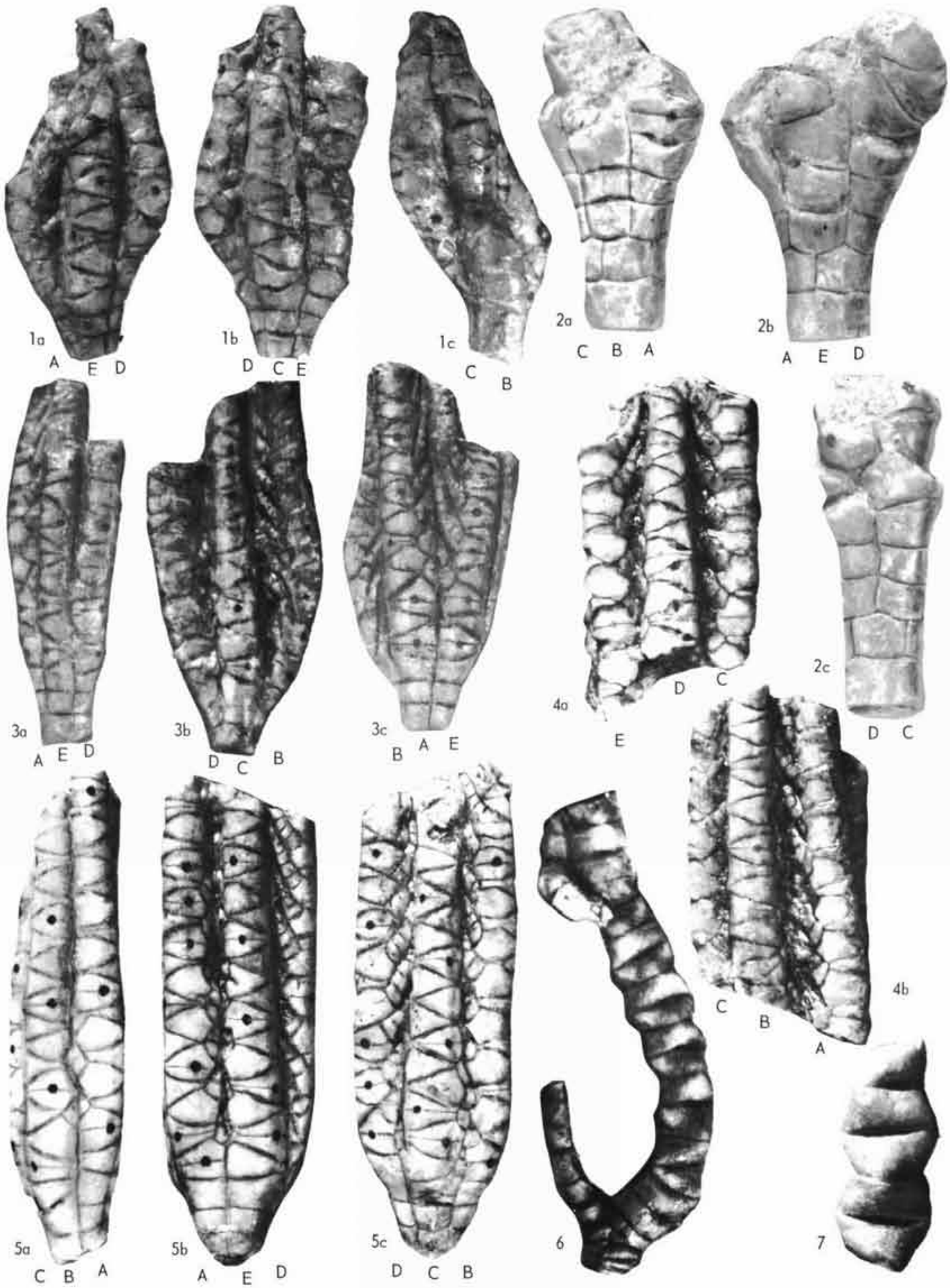
EXPLANATION OF PLATE 5

Parts of crowns and stems of *Dunnicrinus mississippiensis*, n. gen., n. sp., from Prairie Bluff Chalk, Upper Cretaceous, at locality KJA near Starkville, Oktibbeha County, Mississippi, collected by Paul H. Dunn and students at Mississippi State University.

Carpenter letters *A-E* arbitrarily assigned to rays may be correlated with diagrams in Figure 4 and summary of occurrence of syzygial brachials given in Table 3 (inked dots on photographs mark brachials divided by syzygy).

FIGURE

- 1a-c. Specimen KJA-5, lowermost plates radials, X2.
- 2a-c. Specimen KJA-14, very incomplete crown but clearly showing circlet of basals without hint of infrabasals above tall proximal columnal, X3.3.
- 3a-c. Specimen KJA-3, lowermost plates radials, two "left-handed" second brachials (*A* and *C* rays) (compared Fig. 4), X2.
- 4a,b. Specimen KJA-20, consisting of five associated parts of arms but lacking dorsal cup, X2.7.
- 5a-c. Specimen KJA-19, lowermost plates radials, second brachial of *A* ray bearing left-directed pinnule (compare Fig. 4), X2.7.
- 6, 7. Specimens KJA-26 and KJA-51 from distal region of stem, 6 showing single radicular cirrus, X2, X2.7.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1c
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2a
C B A
2b
A E D
3a
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3c
B A E
4a
D C
E
2c
D C
4b
C B A
5a
C B A
5b
A E D
5c
D C B
6
7


1a
80.5°
1b
2a
2b
78.5°
3a
68°
3b
3c
3d
75.5°
4a
4b
54.5°
5a
5b
6a
6b
81.5°
7a
7b
77°
8a
8b
82°
9a
9b
10a
10b
81°
11
12a
12b
13
14a
14b
15

Germany.[1] Where joined to the stem the root branches of *Dunnicrinus* range in diameter from 3 to 4.5 mm. They are circular in cross section and perforated centrally by a minute but very distinct axial canal, also circular in section. The cirri taper evenly and gradually toward their outer extremities, although parts of them may have undiminished diameter for distances of 10 mm. or more (Pl. 6, fig. 15). Bifurcations of the cirri are effected by the development of axillary cirrals, next to which the first cirrals of the branches commonly abut one another with a sutural interface (Pl. 2, fig. 13, 15). Some axillary cirrals give off three branches, instead of two, and viewed from the bottom side of the root six or seven radicular cirri may appear to be given off simultaneously (Pl. 2, fig. 15). Near their outer extremities the branches have diameters of 2 mm. or less. The length of radicular cirrals is notably variable, both in different parts of the same radix and from one specimen to another, but typically length is less than diameter. A range of length-to-diameter ratios is observed to be approximately 0.3 to 2.

As stated in the general description of this crinoid, the radicular cirri of an adult individual are estimated to have spread out fanwise over an area of sea-bottom mud not less than 100 mm. (4 in.) across. The span of rootlike anchorage afforded to *Dunnicrinus* may have been appreciably greater, even twice the measurement just given.

[1] RASMUSSEN (1961, p. 190) overlooked mention of a specimen of *Bourgueticrinus hagenowi* (GOLDFUSS) with attached radicular cirri figured by NIELSEN (1913, pl. 1, fig. 15) from the Maastrichtian of Denmark. The distal columnals of this crinoid are much taller and more massive than those of *Dunnicrinus mississippiensis* and the radicular cirri are more slender.

ONTOGENY OF DUNNICRINUS

Very little can be said with any confidence about the development of individuals of *Dunnicrinus* in growing from small juvenile forms to adult size. Certainly, the dorsal cup and crown gradually increased in height and the stem became lengthened, along with outward expansion of the radicular cirri, which in early life must have been shorter and more slender than those belonging to adults. Cup plates and brachials may be presumed to have added growth increments until height, width, and thickness attained adult dimensions, thus increasing in volume. New brachials were introduced at arm tips until the full height of the crown was reached and at the same time pinnules must have been added and lengthened by addition of distal small pinnulars.

EXPLANATION OF PLATE 6

Parts of stems and radicular cirri belonging to *Dunnicrinus mississippiensis*, n. gen., n. sp., from Prairie Bluff Chalk, Upper Cretaceous, at localites KJA (near Starville, Oktibbeha County) and KJI (=USGA loc. 17235) (near Sparta, Chickasaw County) in Mississippi. Angular divergence of fulcral ridges on opposite articula of columnals indicated in degrees.

FIGURE

- 1a,b. Specimen KJI-1e, distal column, X4.
- 2a,b. Specimen KJI-1f, X4.
- 3a-c. Specimen KJA-58, small portion of stem from distal region, articulum (3a) showing furrow in position of fulcral ridge, X3.7, different side views of stem (3b,s), X3.7, X2.7.
- 4a,b. Specimen KJA-52, columnal from intermediate region of stem, X4.
- 5a,b. Specimen KJI-6, distal extremity of robust stem with attached ends of radicular cirri, X2.
- 6a,b. Specimen KJI-1d, columnal with almost lozenge-shaped narrowly elliptical articula, X4.
- 7a,b. Specimen KJI-1c, low distal columnal with markedly quadrangular outline in articular view, X4.
- 8a,b. Specimen KJI-2c, moderately tall columnal from upper part of distal region, X5.3.
- 9a,b. Specimen KJI-2b, columnal similar to KJI-2c but showing finely denticulate fulcral ridge with slitlike summit, X5.3.
- 10a,b. Specimen KJI-2a, columnal showing growth lines in ligament fields, X5.3.
- 11. Specimen KJA-28, radicular cirri with longer than average cirrals, X2.
- 12a,b. Specimen KJA-58, part of column not far above distal region showing moderately tall, broadly elliptical columnals with perceptible shift in orientation of fulcral ridges on alternate pairs of apposed articula, side view of stem (12a) X3.3, articulum, X6.7.
- 13. Specimen KJA-33, distal end of stem with attached branching radicular cirri, X1.7.
- 14a,b. Specimen KJA-50, another distal end of stem with large radicular cirri, X2.7.
- 15. Specimen KJI-7, bottom of radicular cirri, extremity of stem opposite and not visible, X2.

As for the column, no evidence is found indicating increase in the number of columnals by intercalation between previously formed ones, such as occurs in many stalked crinoids, but after each columnal was initated it grew in girth and height by increments of microstructured calcium carbonate. Sections of well-preserved stems reveal the presence of growth rings which are closely comparable to tree rings and they denote a volumetric expansion of the columnals. As in the stalk of larval comatulids and modern bourgueticrinids, all new columnals are judged to have been introduced at the proximal extremity of the stem next to the dorsal cup. The suggestion by some authors (e.g., BATHER, 1900, p. 108) that in some crinoids new columnals arise next below the cup-attached skeletal element called proximale and not at the base of the up is rejected by others (e.g., CLARK, 1915, p. 213; RASMUSSEN, 1961, p. 167) on the evidence that the proximale is produced by fusion of antecedent thin proximal columnals and marks the end of stem growth. The stalk of *Dunnicrinus*, composed of 80 to 100 or more columnals, is judged to have developed rapidly by successive additions of new columnals, one by one, at the base of the dorsal cup with subsequent enlargement of each during life of the crinoid. From this it follows that the most distal columnals, which are associated with the radix, are ontogenetically oldest parts of the stem and most proximal ones are youngest.

Since the newly added columnals next below the cup in nearly all observed specimens of *Dunnicrinus* are low, with height much smaller than diameter, the increased height of average columnals throughout the remainder of the proximal-intermediate region, with height equal to or greater than diameter, can be understood to reflect normal growth. These columnals have cylindrical shapes, with straight sides parallel to the axial canal. In the lower intermediate region, however, the beginning of a wobbly longitudinal profile of the stem appears. This results from slight to quite obvious moderate inclination of two opposed sides of the columnals differently oriented in azimuth on successive stem segments. Strong accentuation of such change in form distinguishes columnals of the distal region where the stem displays markedly zigzag profiles. When introduced early in life of the crinoid, the zigzag distal columnals of its adult stage must have been like all newly formed columnals near the base of

EXPLANATION OF PLATE 7

Columnals, radial circlets, and brachials of *Dunnicrinus mississippiensis*, n. gen., n. sp., from Prairie Bluff Chalk, Upper Cretaceous, *4* and *8* from locality KJA near Starkville, Oktibbeha County, all others from locality KJI (=USGS loc. 17235) near Sparta, Chickasaw County, Mississippi. Angular divergence of fulcral ridges on opposite articula indicated in degrees.

FIGURE

1a,b. Specimen KJI-3e, columnal with distinctly concave ligament fields, X6.

2a,b. Specimen KJI-2a, typical columnal from gradational zone between intermediate and distal regions of stem, X5.3.

3a,b. Specimen KJI-3c, columnal from lower part of intermediate region of stem, X6.

4a,b. Specimen KJA-22, columnal with concave sides, articulum showing large elliptical lumen and narrow denticulate and furrowed fulcral ridge, X2.7.

5a,b. Specimen KJI-3b, columnal with exceptionally large lumen, X6.

6a,b. Specimen KJI-1b, nearly circular tall columnal, but like strongly elliptical ones, showing marked divergence of fulcral ridges on opposite articula, X4.5.

7a,b. Specimen KJI-1a, columnal with long axis of axial canal normal to fulcral ridge, X4.5.

8a-c. Specimen KJA-21, articular and side views of elliptical columnal, X2.7.

FIGURE

9a,b. Specimen KJI-3a, columnal of lower intermediate region of stem, X6.

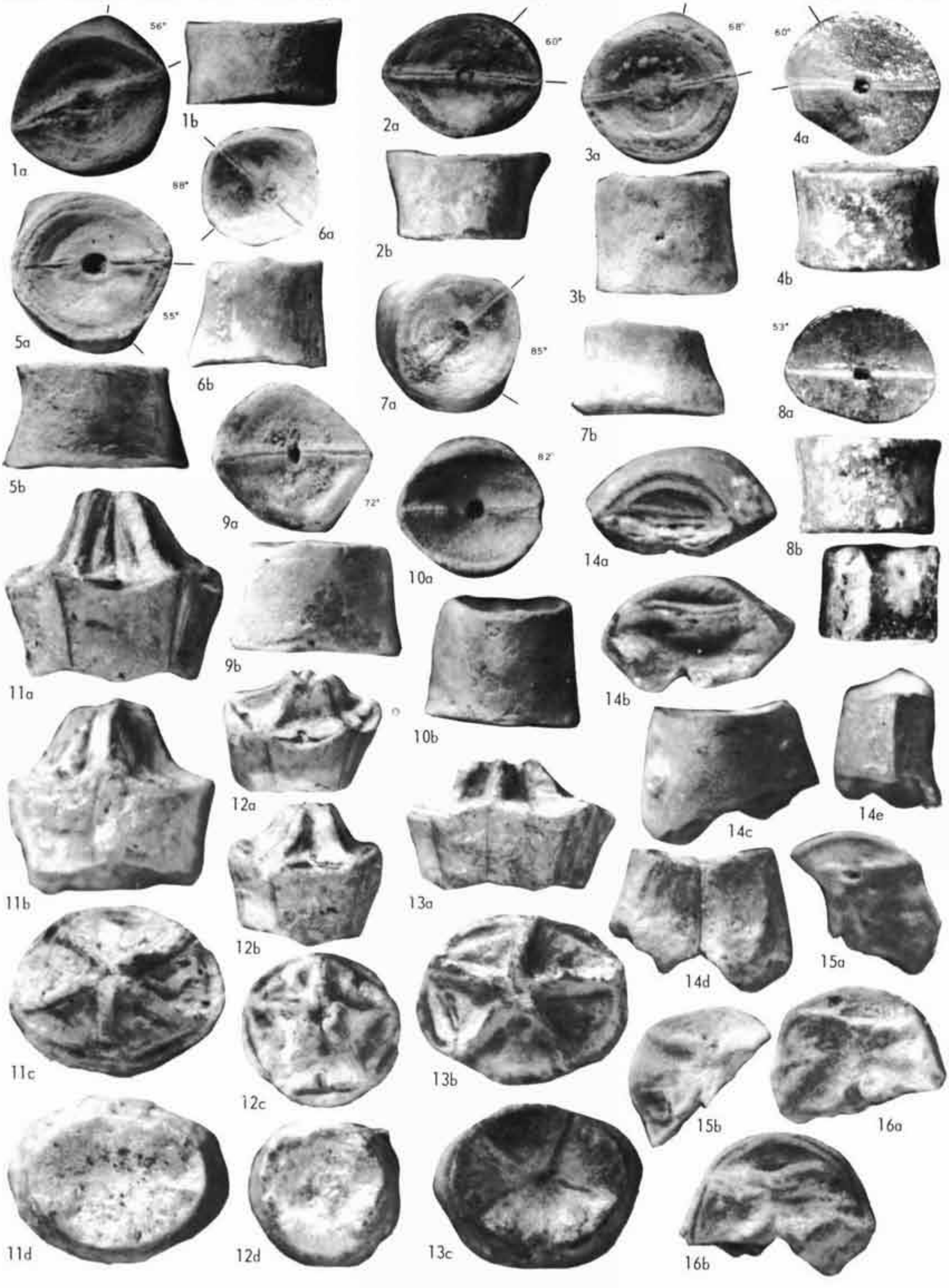
10a,b. Specimen KJI-3d, columnal similar to KJI-3a but taller, with more excavate articulum, and nearly circular large lumen, X6.

11a-d. Specimen KJI-4b, radial circlet, side views from radial and interradial positions (11a,b) showing strongly elevated inner parts of muscle fields separated by narrow furrow, ventral view (11c) showing crests along interradial sutures and narrow outer ligament furrows with pits, and dorsal view (11d) showing nearly featureless surface with positions of interbasal sutures faintly indicated by ridges, X6.7.

12a-d, 13a-c. Specimens KJI-4c and KJI-4a in views similar to those of 11a-d.

14a-e. Specimen KJI-5b, facetal, outer, inner, and side views of brachial (possibly second), X8.5.

15a,b., 16a,b. Specimens KJI-5d and KJI-5c, facetal views of other brachials, X8.5.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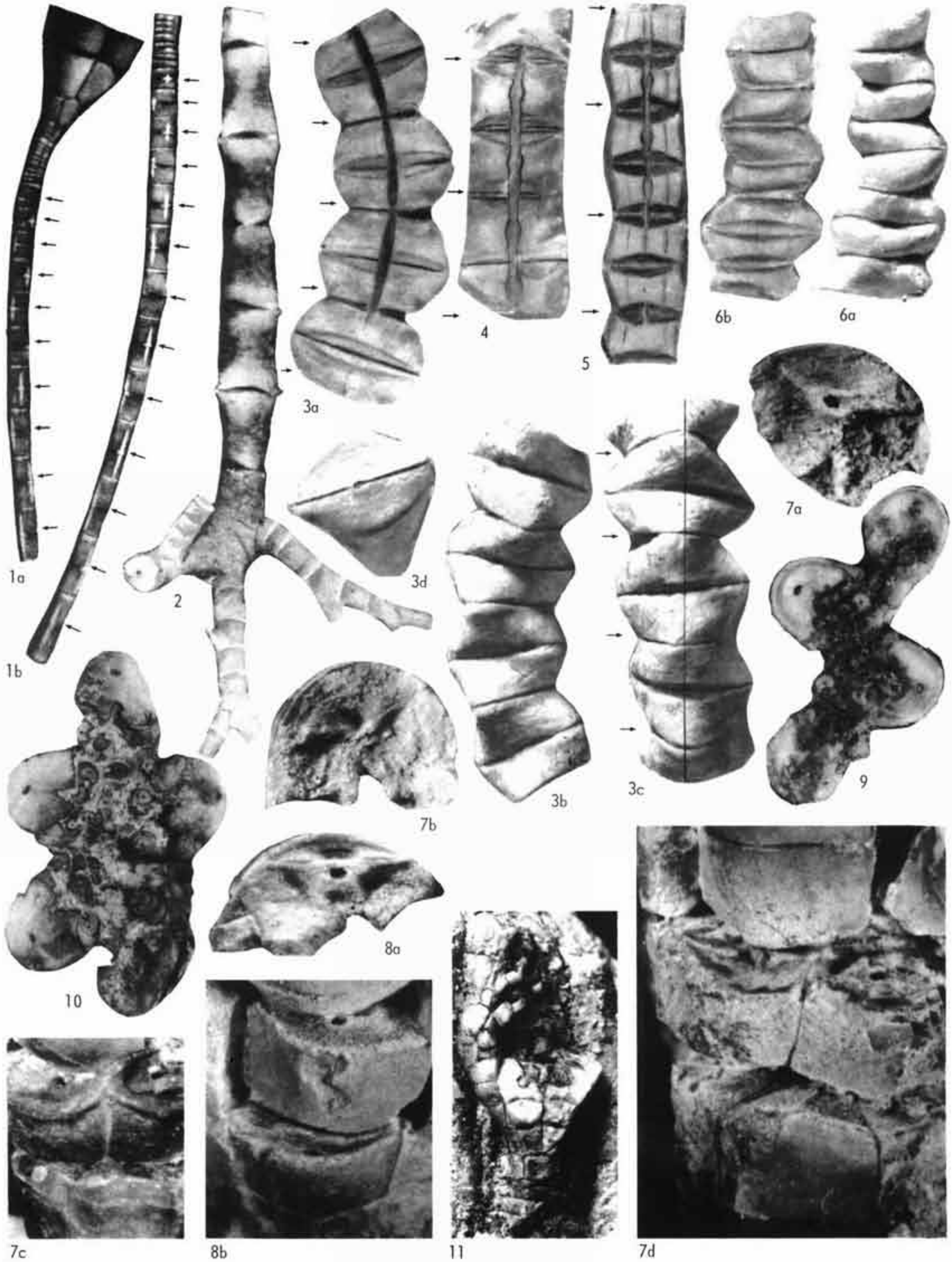
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the cup, that is, low vertical-sided cylinders. Therefore, we must conclude that a distinctive feature in the ontogeny of *Dunnicrinus* is a systematic directionally controlled differential increase in columnal diameter which is concentrated next to the columnal articula in line with the fulcral ridges.

Growth of the radicular cirri during the life of *Dunnicrinus* individuals doubtless proceeded gradually and steadily by expansion in dimensions of cirrals near the base of the stem and addition of new cirrals in outer branches at their tips. Presumably, the increase in number of radicular cirri, their branches, and component cirrals was the result of a sort of vegetative duplication of these skeletal elements and as such it probably continued until death of the crinoid.

A search for concrete indications of ontogenetic changes in the development of *Dunnicrinus* that may be found in available fossil specimens shows parts of stems and radicular cirri of varying length which are smaller in diameter than most. These may belong to juvenile individuals, but if so, because their morphological features are the same as in more robust specimens, little can be learned. Mere increase in size is unimportant even though it does accompany growth. Differences in the dimensions of crowns, particularly the lower parts

EXPLANATION OF PLATE 8

Recent and Upper Cretaceous bourgueticrinids.

FIGURE

1. *Bathycrinus australis* A. H. Clark, Rec., off Enderbyland, Antarctica.——1a,b, views of stem immersed in toluol and photographed with transmitted light, in 1a with dorsal cup and attached first brachials; apposed synarthrial articula of successive longer columnals marked by small arrows. Ligament strands appear as nearly white short bars in planes of articula but penetrate columnals longitudinally almost to transverse sutures which demonstrate that each columnal is actually a double skeletal element of the stalk. Displacement of the ligament bundles from one articulation to the next (and consequently of fulcral ridges disposed midway between ligament fields of each articulum) amounts to approximately 90 degrees; positions of fulcral ridges not directly visible in the photographs and not determinable in articula between thin proximal columnals. *1a* X5.5, *1b* X6 (Döderlein, 1912).

2. *Bythocrinus weberi* (Döderlein), Rec., East Indies; distal part of stalk and radicular cirri, immersed in oil and photographed with incident light, X4.7. Synarthrial articulations show orientation of fulcral ridges between successive columnals displaced approximately 90 degrees (Döderlein, 1907).

3-11. *Dunnicrinus mississippiensis*, n. gen., n. sp., Prairie Bluff Chalk, Upper Cretaceous, from locality KJA near Starkville, Oktibbeha County, Mississippi.——3a-d. Specimen KJA-31, distal part of stem showing median longitudinal section (3a), side views before sectioning (3b,c with position of section indicated in 3c), and articulum of columnal at one extremity (3d), X3.3. Arrows along the edge of 3a mark articula with fulcral ridges normal to plane of the section, others lying in this plane.——4,5. Longitudinal median sections of specimens KJA-30 and KJA-30A showing brown-stained fibrous calcite adjoining articula and slight rounded expansions of axial canal at mid-height of columnals, both X4. Although these stems, from intermediate region of column, are nearly cylindrical and and the arcuate dark-appearing tracts next to articular planes are very similar in the sections, orientation of fulcral ridges at positions marked by small arrows is approximately normal to the plane of the sections, whereas those of others are in this plane.——6a,b. Specimen KJA-31 showing side view of distal stem portion before grinding (6a) and polished longitudinal section about midway between surface and axial canal (6b), X3.3.——7. Specimen KJA-34; 7a,b, distal articula of brachials from upper part of arm, X10; 7c,d, distal surface of basals (below) and oblique view of radial articula (above) X8, X11 (compare Pl. 2, fig. 7, crown at left).——8. Specimen KJA-34A; 8a, distal articula of third brachial in *B* ray, with end view of pinnule borne by second brachial at lower left, X10; 8b, oblique views of *A* ray radial (below) and first brachial (above), both showing distal articula of muscular type, X10.——9. Specimen KJA-20, transverse polished section of arms surrounding several pinnules, X6.——10. Specimen KJA-7, transverse polished section similar to fig. 9, X5.——11. Specimen KJA-29, a damaged crown which shows oblique-fractured first and second brachials near center and right below cavity (dark) between arms, with ambulacral trough of second brachial clearly visible. Radials and basals subequal in size to first brachials; barely discernible circlet of infrabasals equal to basals in width but very low, sutures between infrabasals not quite certainly confirmed by grinding. Parts of three proximal columnals preserved, X2.7.

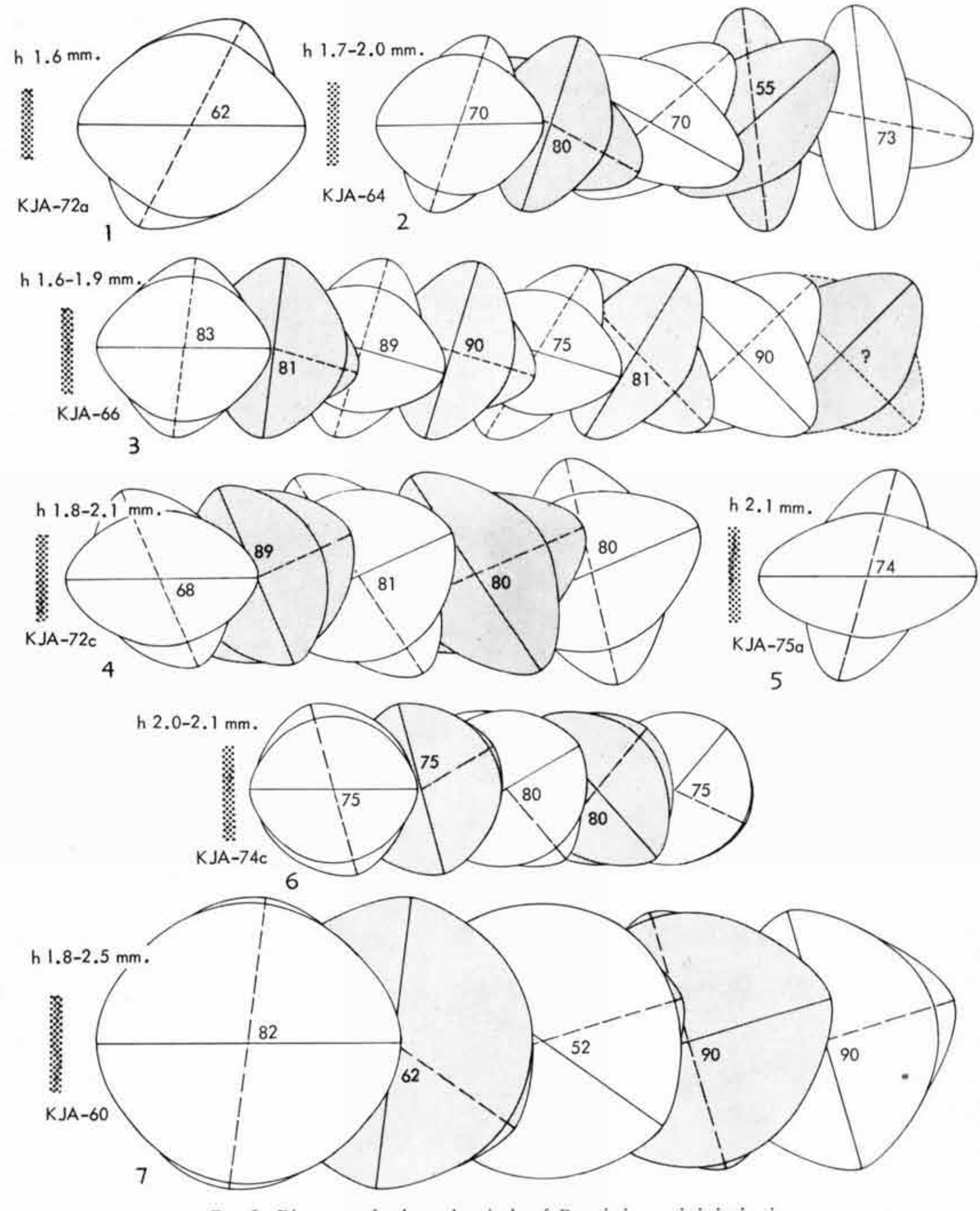

FIG. 8. Diagrams of columnal articula of *Dunnicrinus mississippiensis.*

Outlines of articula and orientation of fulcral ridges on opposite sides of individual columnals or on apposed pairs of successive articula in attached groups of columnals are shown. Height (h) of columnals is plotted as patterned vertical bar, for groups of columnals given as average. All X7 (measurements by Mervin Kontrovitz, drawings by R. B. Williams).

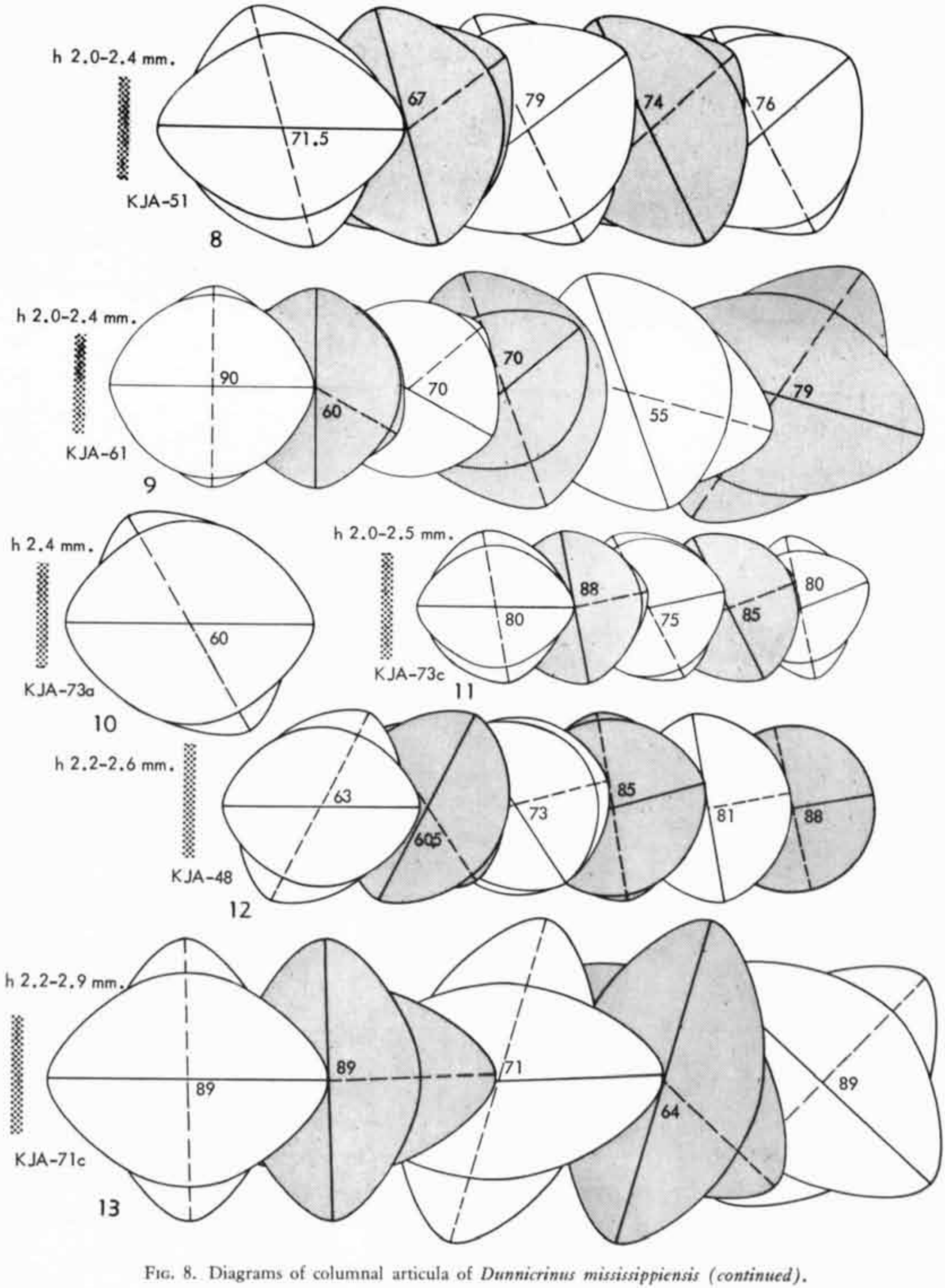

FIG. 8. Diagrams of columnal articula of *Dunnicrinus mississippiensis (continued).*

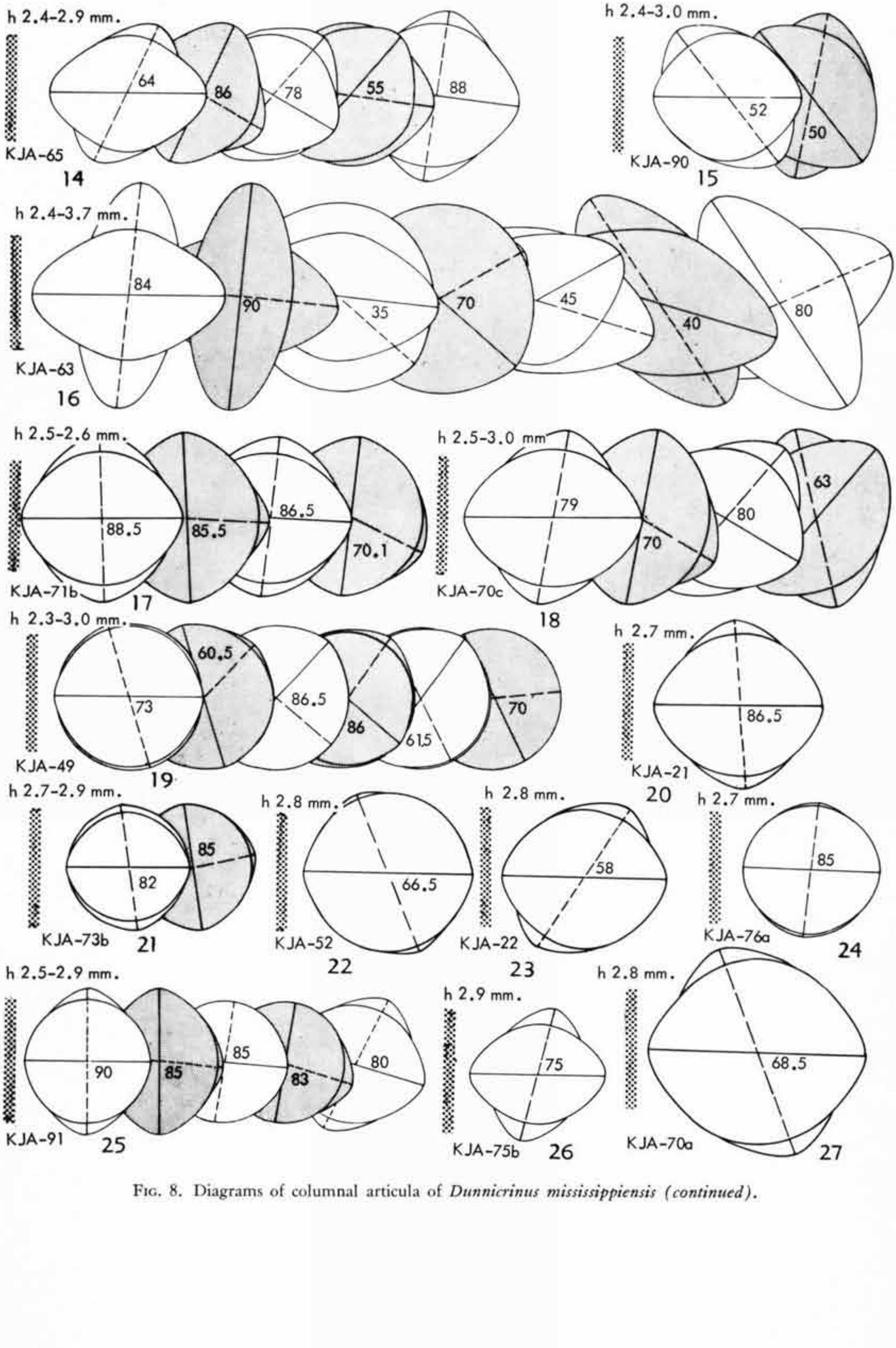

FIG. 8. Diagrams of columnal articula of *Dunnicrinus mississippiensis (continued)*.

of crowns (for height of fossil crowns mainly depends on accidents of preservation), suggest that some specimens are older, more fully grown adults than others.

Only one fossil in the collection seems to be distinguishable as a truly juvenile crinoid. This is specimen KJA-46 (Pl. 1), consisting of the lower part of a crown barely 11 mm. in height. Attached to the crown are three columnals and slightly displaced from these are the next three proximal columnals. In order to see this specimen from all sides, the crown and columnals were undercut and removed from the slab. When freed, the crown broke easily and cleanly along the smooth sutures separating the basal and radial circlets, confirming the previously reached conclusion that crowns of *Dunnicrinus* are weakest at the contact of basals with radials. Already noted

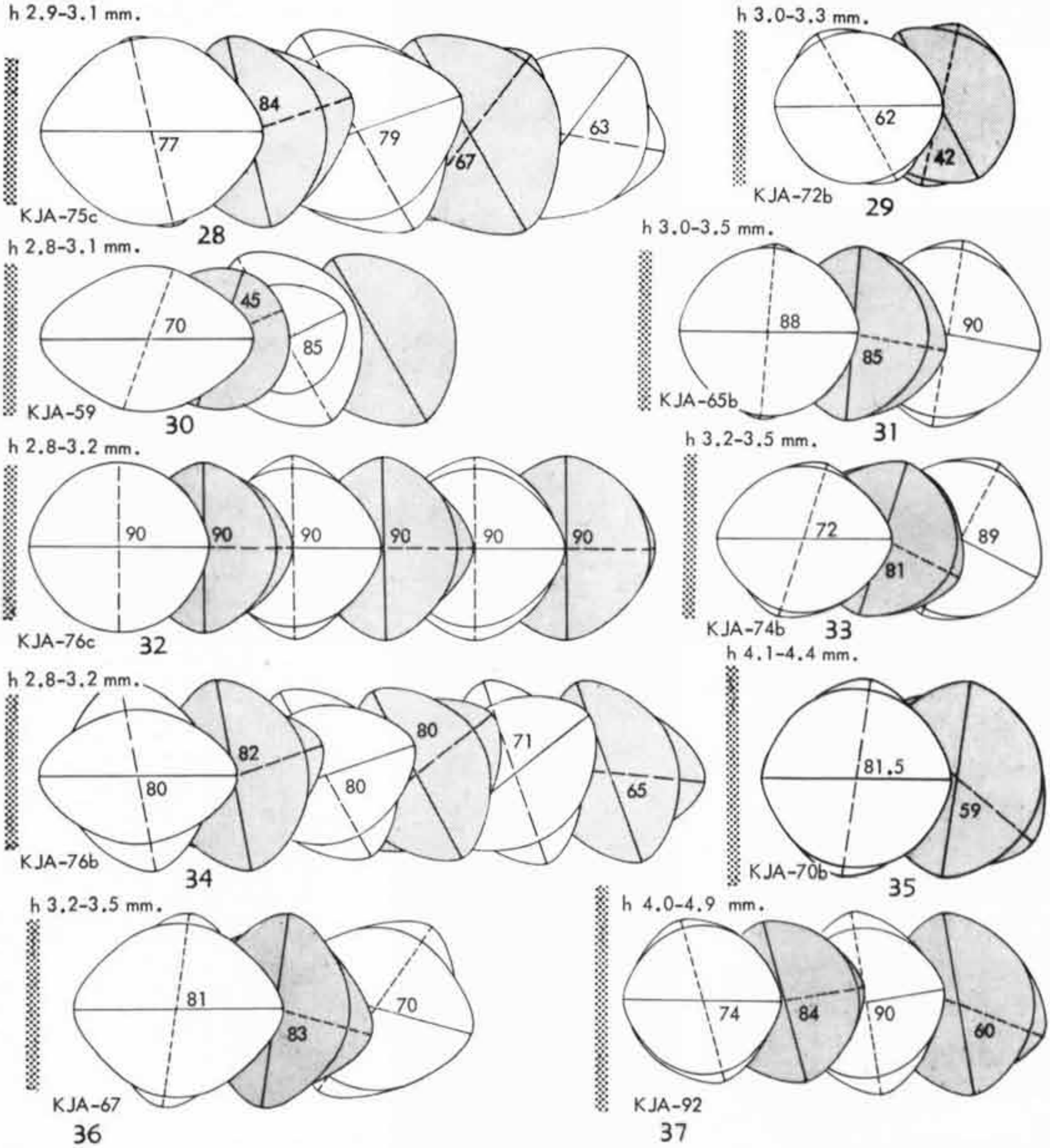

FIG. 8. Diagrams of columnal articula of *Dunnicrinus mississippiensis (continued)*.

is the fact that a preponderant majority of crowns not embedded in matrix lack parts below the radials.

A first distinctive feature of specimen KJA-46, shown in the photograph of it (Pl. 1), is the proportionally very tall and narrow radial plates. They are 2.2 mm. in height and 1.2 mm. in width. The quadrangular first brachials next above them are 1.1 mm. tall and equal to the radials in width. In fully grown adults the height and width of these two plates is the same, or very nearly so. Therefore, ontogenetic development may be correlated with the ratio in height of radials to first brachials. In the juvenile KJA-46 this ratio is 2; specimen KJA-17 (Pl. 2, fig. 4) has such a ratio of 1.5; specimens with a ratio of 1.4 include KJA-6 (Pl. 2, fig. 1), KJA-8 (Pl. 2, fig. 5), KJA-16 (Pl. 3, fig. 6), and KJA-13 (Pl. 4, fig. 2); ratios of 1.3 are indicated in specimens KJA-35 (Pl. 1), KJA-15 (Pl. 2, fig. 2), and KJA-14 (Pl. 5, fig. 2). Ratios appreciably greater than 1 may be interpreted to mark immature adults and juvenile individuals.

Another characteristic of specimen KJA-46 that may be inferred to indicate an early ontogenetic stage of development is the presence of a complete circlet of infrabasals which is visible externally. These plates have width equal to that of the basals (1.4 mm.) but their height is only 0.3 mm. as compared to height of basals amounting to 1.2 mm. The sutures between infrabasals are located beneath mid-lines of the basals and run vertically. They are obscurely determinable but when viewed with a thin coating of oil and low oblique illumination, each of the five sutures can be distinguished. Plates of the young infrabasal circlet are nearly fused together. In a few adult specimens small portions of this ring can be seen (Fig. 6,*11-13*) but generally infrabasal plates are concealed or vanished in *Dunnicrinus*.

The half dozen proximal columnals belonging to specimen KJA-46 are perfectly circular in transverse outline. They are low and vertically straight-sided, with successive heights (in downward order) of 0.3, 0.4, 0.6, 0.7, 0.8, and 0.9 mm. Their articular facets are plane and perfectly smooth. The distance below the dorsal cup at which fulcral ridges and paired ligament fields make appearance has not been ascertained in *Dunnicrinus*. Evidently, however, the development of synarthrial articulation between columnals is a feature of ontogeny and needs study.

Summarizing, both increase in size and number of skeletal elements in the crown (brachials, pinnulars), stem (columnals), and radix (radicular cirrals) mark growth of *Dunnicrinus* individuals from early youth to adulthood and ultimate death of the crinoids. In addition, some morphological changes appear discernible in the height ratio of radials to first brachials, in probable fusion and certainly diminution or disappearance of infrabasals, and in changes in shape of columnals trending toward the strongly marked zigzag stem pattern in the distal region.

PALEOECOLOGY OF DUNNICRINUS

Inferences concerning the environment in which the crinoids named *Dunnicrinus mississippiensis* lived can be derived from 1) physical attributes of the sedimentary deposits in which specimens have been found, 2) local and regional stratigraphic relationships of the Prairie Bluff Chalk in which they form part of the known fauna, 3) the nature of associated invertebrates, particularly those considered to be best indicators of the surroundings in which they lived, and 4) evidence furnished by the crinoids themselves.

EVIDENCE FROM LITHOLOGY OF PRAIRIE BLUFF SEDIMENTS

The Prairie Bluff Chalk is everywhere a calcareous deposit, as indicated by its designation as chalk, but its average content of calcium carbonate is only 70 percent (Stephenson & Monroe, 1940, p. 205). Analyses show that the remaining 30 percent consists of silica, mainly quartz sand and silt grains (19 percent), and alumina combined with iron oxide, chiefly representing ferriginous clay. Sohl (1960, p. 26) has reported that 20 random samples of Prairie Bluff Chalk in Mississippi showed a calcium-carbonate content ranging from 15 to 72 percent, with the higher percentages found toward the south. Mica and glauconite are common minerals; also, phosphatic nodules and molds of fossils are locally abundant. The deposits are interpreted to have been laid down in clear water (Stephenson & Monroe, 1940, p. 258), prevailing at shallow depths. The chalk is massive at many exposures and elsewhere variably thin-bedded, with evidence of accumulation of the sediment both in quiet and current-agitated waters. Cross-bedded sandy deposits evidently denote transportation of sea-bottom materials by currents.

STRATIGRAPHIC RELATIONS

The occurrence of inconspicuous but widely traceable discontinuities in the Upper Cretaceous strata of the Gulf of Mexico region, especially including Tennessee, Mississippi, and Alabama, furnishes evidence of repeated emergences of the sea bottom that affected very large areas. The breaks in sedimentation varied in duration. Disconformities are present at both lower and upper boundaries of the Prairie Bluff Chalk and probably some of smaller magnitude occur within the formation. The importance of these widespread interruptions of sedimentation is in appraising their significance as indicators of crustal or sea-level oscillations, or both in combination, that can hardly have had much vertical magnitude. Regional flatness of areas of sedimentation accounts very adequately for the considerable geographic shifts in tracts alternately covered and uncovered by the sea. When present at any given locality, as in northeastern Mississippi near the close of Cretaceous time, the transgressing sea must have been shallow—not scores or hundreds of meters deep. If this is so, stratigraphic evidence indicates that *Dunnicrinus* was by no means a deep-water crinoid.

Northward the Prairie Bluff Chalk becomes increasingly sandy until the formation disappears by grading into the nonchalky marine sands of the Owl Creek Formation. This marks a facies change of age-equivalent deposits and further supports conclusion that the Prairie Bluff was laid down in shallow water. Sediment in the present outcrop belt of the formation in all probability accumulated not very far offshore.

ASSOCIATED INVERTEBRATE FOSSILS

Oysters and oyster-like bivalves are much the most abundant invertebrates observed in and weathered out from outcrops of the Prairie Bluff Chalk in Mississippi. Some of these, such as *Exogyra costata*, which gives its name to the zone containing the Prairie Bluff strata at its top, are exceptionally thick-shelled and robust. Others including *Gryphaea mutabilis, Gryphaeostrea vomer,* and *Ostrea tecticosta*, are little less stout and are myriad in numbers at some localities. *Inoceramus argenteus* is a large, moderately thick-shelled Prairie Bluff bivalve also. *Diploschiza melleni* characterizes a zone in the uppermost Cretaceous which is traceable throughout most of the Gulf region. Even such normally reef-building rudists as *Sauvagesia* and *Titanosarcolites* occur in the Prairie Bluff bivalve assemblege. The recorded bivalve fauna includes more than 40 species (STEPHENSON & MONROE, 1940, p. opp. 208, 247), nearly all of which are distinguished as shallow-water forms.

Gastropods are highly varied but mostly are preserved as phosphatic molds. Until studied by SOHL (1960, 1964) only 11 species of Prairie Bluff gastropods, distributed among eight genera were known. This part of the fauna now is recognized to contain 125 species classified in 89 genera. They are normal shelf-sea inhabitants, many of which have wide geographic distribution.

Additional invertebrates from this formation include 13 cephalopods, bryozoans, a widely distributed shelf-sea brachiopod *(Terebratulina floridana)*, five echinoids, three species of corals, three of worms, two sponges, and a half dozen crustaceans—among the last a species of the well-known shrimplike *Callianassa*, which burrows in tidal flats and the mud of estuaries and shallow sea bottoms.

Taken all together, the Prairie Bluff invertebrate assemblage clearly indicates a shallow-water environment and possibly in some places barely submerged mud flats.

EVIDENCE FURNISHED BY CRINOIDS

OKTIBBEHA COUNTY LOCALITY (KJA)

Despite the richness of crinoid remains found locally in the Prairie Bluff Chalk, it is needful in study of their paleoecological significance to emphasize the fact that at present these echinoderms are known from only two small outcrop areas, one (KJA) in north central Oktibbeha County not far from the campus of Mississippi State University and the other (KJI) some 20 miles farther north in Chickasaw County. Obviously, these spots are mere pinpoints which may not be typical of Prairie

Bluff sea bottoms generally. We may hope that search specially aimed at finding additional crinoid localities will yield significant new paleoecological information.

Important observations derived from crinoid fossils at the KJA locality near Starkville are 1) relative abundance of nearly complete articulated crowns associated with numerous long portions of columns, 2) preponderance of "loose" crowns (that is, free of adherent matrix) which lack plates below the circlet of radials, 3) fairly common occurrence of articulated radicular holdfasts, some attached to distal parts of stems, and 4) well-marked tendency of adjacent crowns and stems to lie parallel to one another as found on slabs. The paleoecological significance of these features is discussed briefly in the sequence just presented.

ARTICULATED CROWNS, COLUMNS, AND RADICES

1) The large number of discovered crowns and long sections of stems with columnals joined together surely indicates lack of any strong agitation of the sea water where the crinoids were anchored to bottom muds during life and where ultimately they came to be buried. Otherwise, the living crinoids would have been dislodged and torn apart. Remains of the fallen crinoids would have been disarticulated, mixed together, and scattered. Instead, cup plates and arms are found together intact, the latter with their numerous delicate pinnules all in place like neatly combed hair. Preservation of crinoids in this way is comparable to that only found uncommonly in such localities as Crawfordsville, Indiana. Quiet water and unagitated sea bottom signifies at least moderate water depth. The Upper Cretaceous crinoids of locality KJA are judged to represent such an environment.

CROWNS LACKING PLATES BELOW RADIALS

2) The separation of crowns into very unequal portions, one consisting of skeletal elements (radials, arms, pinnules) above the circlet of basals and the other composed only of basals with possibly adherent infrabasals and proximal columnals is seen in so many KJA crinoids that explanation is called for. Are these breakings apart at a particular level in the crown related in any way to environmental conditions either during life or after death of the crinoids? Decapitation of crowns at the level of the basal-radial sutures is known to occur in living *Bathycrinus* and *Rhizocrinus*, considered to belong in the same family with *Dunnicrinus* and *Bourgueticrinus*, and after such impairment the lost parts are regenerated. If individuals of *Dunnicrinus* encountered "accidents" of this sort, they cannot be determined. At least no specimens showing evidence of regenerated radials and arms have been seen, and if they should be found, only morphological, not paleoecological significance seemingly could be inferred. Possibly the Prairie Bluff crowns lacking basals were damaged by breaking at the time when they were collected or by less than most careful handling after they were collected. Incorrectness of this supposition is indicated by a survey of available specimens, for they include 18 crowns with basal part intact, 19 crowns with weathered or matrix-covered surface at bottom of radials, and only 5 crowns with clean sutures beneath radials. The 19 specimens evidently had suffered fracture in some unknown manner before they were collected. The five crowns may have possessed basal circlets when brought to the laboratory, but this is not certain. In any case, the crowns incomplete at the base are not thought to have any special paleoecological significance, for the remnant major fraction of the original crowns held together like the crinoids with attached columnals.

ARTICULATED RADICULAR HOLDFASTS

3) The several specimens of radicular cirri with cirrals joined firmly together, branches preserved, and some attached to the stem base from which they grew correspond to the many long portions of stems with well-united columnals and to the crowns showing undisturbed articulation of their parts. They denote lack of very appreciable agitation of near-bottom sea water. Some individual cirri, separated from the whole radix, were shifted from their place of growth (e.g., slender branched cirrus just below crown KJA-39 shown in Plate 1), doubtless by currents.

PARALLEL ARRANGEMENTS OF CROWNS AND COLUMNS

4) The parallel or near-parallel arrangement of crowns, moderately long portions of stems, and some displaced radicular cirri is a striking peculiarity of specimens of *Dunnicrinus mississippiensis* on slabs collected at the KJA locality near Mississippi State University (Pl. 1, Pl. 2, fig. 7). It furnishes hardly deniable proof of the existence of bottom currents where the crinoids lived in the

Prairie Bluff sea. The alignment of the fossils shows the direction of current movement, but because the compass orientation of the parallel specimens was not noticed and recorded in the field, how the indicated currents relate to the trend of Prairie Bluff outcrops is unknown. From paleoecological viewpoints, it would be interesting to have information which would guide conclusions as to the probable longshore or on-and-offshore direction of bottom-water movement at the crinoid locality. The fact that the crowns are not oriented uniformly, some having their base with attached stem pointed oppositely from others (Pl. 1), suggests that currents moved back and forth in two directions and probably that one alternated in time with the other. This favors the postulate of on-and-offshore currents, induced either by landward and seaward breezes or by tides.

On the slab containing crowns KJA-35 to KJA-46 (Pl. 1) it may be observed that (as oriented in the photograph) nine specimens with stem end pointing upward include KJA-35, KJA-36, KJA-37, KJA-39, KJA-41, KJA-42, KJA-43, KJA-45, KJA-46 whereas only two crowns (KJA-38, KJA-40) show the base pointed downward. Current movement for all should be in the direction of stem to summit of crown and thus the dominant current direction is indicated to be downward. The cirrus fragment below KJA-39 and the pinnule-bearing arm below KJA-38 suggest opposite currents, adding slightly to the evidence of KJA-38 and KJA-40. A small slab carrying crowns KJA-34 and KJA-34A (Pl. 2, fig. 7) has a third crown (KJA-34B) on its opposite side. Seven moderately long parts of columns unattached to crowns lie parallel to the numbered crowns. As oriented in the photograph (Pl. 2, fig. 7), the stem end of the two crowns points downward, but in the unillustrated specimen KJA-34B orientation is opposite. The pinnules of the isolated arm at right of KJA-34A show that its upper end corresponds to position in life, being directed upward. The small slab thus furnishes evidence agreeing with the large one—dominant currents in one direction and less dominant currents in the opposite direction.

In addition to the examples cited, a crown with attached stem (specimen KJA-23) lies closely parallel to seven cylindrical stems of other crinoids separated from crowns and a small slab (KJA-58) has eight parallel portions of stems 40 to 60 mm. in length exposed by weathering and several others embedded in the matrix. All represent the proximal-intermediate region.

CHICKASAW COUNTY LOCALITY (KJI)

The crinoid locality in southern Chickasaw County, Mississippi (KJI=USGS loc. 17235), has yielded many hundred dissociated columnals, a smaller number of dissociated brachials, very few radial circlets with plates joined together but separated from other parts of the crown, and a few articulated radicular cirri.

From a paleoecological viewpoint, the nature of the Chickasaw County crinoid remains, nearly all of which consist of skeletal parts separated from each other, scattered about, and thoroughly mixed, contrasts greatly with the Oktibbeha County locality where articulated more or less complete crowns and large parts of stems are the rule and disarticulated remains unimportant.

Interpretation of the environment in which the KJI crinoids lived and plausible explanation of the conditions that affected burial of their remains are difficult to formulate. The localized occurrence of the fossils points to the existence in Prairie Bluff time of a *Dunnicrinus mississippiensis* colony at or very near the spot where the remains were found. This is indicated most definitely by such specimens of distal stem sections and well-preserved radicular cirri as are contained in the collection (Pl. 6, fig. 5a,b, 15), even though these are few. The specimens are not disarticulated and must have become covered by sediment approximately where the crinoids were attached to the sea bottom. Their relative stoutness may account for escape from being torn to pieces. The abundant loose ossicles probably represent effects of repeated wave-and-current-induced agitation of completely rotted crinoids without transportation of the fragments sufficient to scatter them widely. Water depth must have been small.

Many of the dissociated crinoid fragments obtained at the KJI locality are well enough preserved to show growth lines on columnal articular surfaces (Pl. 6, fig. 1-2, 6-10; Pl. 7, fig. 1-3) and even fine denticulation of fulcral ridges (Pl. 7, fig. 2a, 10a), but a proponderant majority of them are obviously considerably weathered. Rounding of edges indicates abrasion. Isolated columnals far outnumber small portions of stems consisting of two to four or five columnals joined together. These and the much less common brachials seem to have suffered a great deal of rolling about. Brachials should be more numerous if their share in the skeletal makeup of whole crinoids were represented in the disintegrated remains of the Chickasaw County colony, and this suggests that the smaller, lighter ossicles have been winnowed out. No fragments of pinnules, including isolated pinnulars, have been seen in the collection. Such observations confirm judgment that the remains have suffered being worked over again and again by movement of bottom waters.

It is conceivable that the KJI crinoid occurrence was produced by disintegration and reworking of skeletons considerably later than the death of individuals and disappearance of the colony. If articulated crowns and stems comparable to those preserved at the KJA locality became exposed by scour at some time after burial of them in bottom mud, dissociation of the crinoid skeletons could have been effected by processes and agencies unrelated to the environment of the living colony. Such an explanation is entirely conjectural, but it indicates that inferred paleoecological conditions in an area may be unrelated to those affecting life and burial of a group of animals.

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