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Taphonomic Analysis and Systematic Descriptions of Some Late Pennsylvanian and Early Permian Crinoids from Southeastern Nebraska, Eastern Kansas and Southwestern Iowa

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Factors for Converting English Units to the International System of Units (SI)

Multiply English units	By	To obtain SI units
	Length	
inches (in.)	25.4	millimeters (mm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
acres	4047	square meters (m^2)
square miles (mi^2)	2.590	square kilometers (km^2)
	Volume	
gallons (gal)	3.785	liters (L)
acre-feet (acre-ft)	1233	cubic meters (c^3)
	Flow	
gallons per minute (gpm)	.00006309	cubic meters per second (m^3/s)

December 2002

Contents

Abstract / iv
Introduction / 1
Previous Work / 1
Environments of Deposition / 1
Characterization of Epifauna and Predators / 1
    Encrustations / 3
    Borings/Pits / 16
    Roving Organisms – Sinuous Grooves and Marks / 16
    Predatory Organisms – Sharply Delineated Cuts and Gouges / 16
    Diseased Tissue / 16
Acknowledgments / 16
Systematic Paleontology / 17
Conclusions / 38
References / 39
Appendix / 45

Illustrations

Text-figure
1. Map showing locations where specimens used in this study were collected / 2
2. *Delocrinus vulgatus* Moore and Plummer / 4
3. *Delocrinus vulgatus* Moore and Plummer, *Delocrinus admirensis* Strimple, and *Sublobalocrinus kaseri* Pabian and Strimple / 5
4. *Sublobalocrinus kaseri* Pabian and Strimple, and *Arrectocrinus iowensis* Pabian and Strimple / 6
5. *Graffhamicrinus magnificus* (Strimple), and *Graffhamicrinus subcoronatus* (Moore and Plummer) / 7
6. *Graffhamicrinus boellstorffi* Pabian and Strimple, *Erisocrinus* sp. cf. *E. typus* Meek and Worthen, *Synarmocrinus iatani* (Strimple), *Parethelocrinus* sp. cf. *P variabilis* (Strimple), *Parulocrinus blairi* (Miller and Gurley), and *Ulocrinus* sp. / 8
7. *Parethelocrinus* sp. cf. *P. variabilis* (Strimple), *Parulocrinus* sp. cf. *P. blairi* (Miller and Gurley), and *Aglaocrinus compactus* (Moore and Plummer) / 9
8. *Aglaocrinus compactus* (Moore and Plummer), *Synarmocrinus iatani* (Strimple), *Plaxocrinus crassidiscus* (Miller and Gurley), *Vertigocrinus parilis* (Moore and Plummer), *Triceracrinus* sp., and *Sciadiocrinus humilis* Strimple / 10
9. *Bathronocrinus wolfriverensis* Pabian and Strimple, *Galateacrinus gossameri* Pabian and Strimple, *Adacrinus edema* Pabian and Rushlau new species, and *Aesiocrinus* sp. cf. *A. detrusus* Strimple / 11
10. *Allosocrinus bronaughi* Strimple, *Polusocrinus rosa* Strimple, and *Haeretocrinus* sp. cf. *H. missouriensis* Moore and Plummer / 12
11. *Glaukosocrinus berryi* Pabian and Rushlau, new species, *Stellarocrinus stillativus* (White), *Exocrinus multirami* Strimple and *Paramphicrunus* sp. / 13
12. *Apographiocrinus typicalis* Moore and Plummer, *Apographiocrinus platybasis* Pabian and Strimple, *Contocrinus* sp. cf. *C. stantonensis* (Strimple), untetermined pirasocrinid, and *Glaukosocrinus* sp. / 14
13. Indeterminate pirasocrinid species A, B, and C, *Erisocrinus* sp. cf. *longwelli* Lane and Webster / 15

Tables

1. Species assigned to *Delocrinus* Miller and Gurley, 1890 / 17
2. Summary of epifauna on *Delocrinus vulgatus* Moore and Plummer, 1940 / 18
3. Species assigned to *Sublobalocrinus* Knapp, 1969 / 19
4. Species assigned to *Arrectocrinus* Knapp, 1969 / 20
5. Species assigned to *Graffhamicrinus* Strimple, 1961 / 20
6. Summary of epifauna on *Graffhamicrinus magnificus* (Strimple), 1947 / 21
7. Summary of epifauna on *Graffhamicrinus subcoronatus* (Moore and Plummer), 1940 / 22
8. Species assigned to *Erisocrinus* Meek and Worthen, 1865 / 23

9. Species assigned to *Aglaocrinus* Strimple, 1961 / 26
10. Species assigned to *Vertigocrinus* Knapp, 1969 / 27
11. Species assigned to *Sciadiocrinus* Moore and Plummer, 1938 / 28
12. Genera assigned to Laudonocrinidae Moore and Strimple, 1973 / 29
13. Species assigned to *Bathronocrinus* Strimple, 1962a / 30
14. Species assigned to *Adacrinus* Pabian and Strimple, 1985 / 30
15. Measurements of *Adacrinus edema* Pabian and Rushlau, new species / 31
16. Species assigned to *Allosocrinus* Strimple, 1949c / 31
17. Species assigned to *Aesiocrinus* Miller and Gurley, 1890 / 32
18. Genera assigned to Scytalocrinidae Moore and Laudon, 1943 / 32
19. Species assigned to Haeretocrinus Moore and Plummer, 1940 / 33
20. Species assigned to *Moundocrinus* Strimple, 1939a / 34
21. Species assigned to *Polusocrinus* Strimple, 1951b / 34
22. Species assigned to *Glaukosocrinus* Strimple, 1951d / 35
23. Measurements of *Glaukosocrinus berryi* Pabian and Rushlau, new species / 35
24. Species assigned to *Apographiocrinus* Moore and Plummer, 1940 / 36
25. Species assigned to *Contocrinus* Knapp, 1969 / 36
26. Genera assigned to Stellarocrinidae Strimple, 1961 / 37
27. Species assigned to *Stellarocrinus* Strimple, 1940 / 37
28. Species assigned to *Exocrinus* Strimple, 1949c / 38

Abstract

Throughout most of the Late Pennsylvanian (late Virgilian) and Early Permian (Wolfcampian), crinoids reach their lowest numbers in both abundance and diversity in the North American Midcontinent. Part of this observation may be based on collecting bias, as collecting efforts have been focused mainly in the older Late Pennsylvanian (Missourian), where crinoids are more abundant and more diverse. In addition to systematic treatment of the sample, we have attempted to characterize the epifauna observed on these crinoids and to provide evidence for parasitic, commensal, and predatory relations among crinoids and their associated flora and fauna. We have observed 34 species that are assigned to 26 genera. *Adacrinus edema* Pabian and Rushlau new species and *Glaukosocrinus berryi* Pabian and Rushlau new species are recorded here for the first time.

Introduction

Crinoids are infrequent yet ubiquitous fossils in the late Pennsylvanian and early Permian cyclic platform deposits of the North American Midcontinent, but they are fairly diverse; some 50 genera and 200 species have been recorded from the region. This study fills in additional details of crinoid occurrences in southeastern Nebraska, southwestern Iowa, and eastern Kansas and adds completeness to the systematic record of known species. Materials included in this study were collected from 22 different localities in Nebraska, Iowa, and Kansas, as shown on the locality map (text-fig. 1). Localities are listed in the appendix.

Besides the systematic descriptions, we have studied and categorized the evidence for epifauna and predator-prey relationships among crinoids and other organisms in the environment. Species assigned to the 30 genera discussed in this study are listed in tables 1, 3-5, 8-17, 19-22, 24, 25, 27 and 28; genera that are assigned to the families Scytalocrinidae and Stellarocrinidae are listed in tables 18 and 26. Measurements for the holotype specimens of *Adacrinus edema* Pabian and Rushlau new species and *Glaukosocrinus berryi* Pabian and Rushlau new species are given in tables 15 and 23, respectively. Epifauna associated with *Delocrinus vulgatus* Moore and Plummer, *Graffhamicrinus magnificus* (Strimple), and *G. subcoronatus* (Moore and Plummer) are listed in tables 2, 6 and 7, respectively.

Previous Work

Most previous studies of Pennsylvanian and Permian crinoids of the North American Midcontinent have been based on cups or crowns. This has likely made them appear scarcer than they really are. Newly acquired knowledge about these fossils has made it possible to identify at least to the generic level, and often to the specific level, loose radial plates and some infrabasal circlets. These fossils are quite useful. However, with the exception of the Subclass Flexibilia, loose stems have so far proved to have little, if any, taxonomic value.

The first documented crinoid from Nebraska was probably *Erisocrinus typus* Meek and Worthen (1865a), described from the Late Pennsylvanian. Other early reports include Woodruff's (1904, 1906) descriptions of *Ceriocrinus* (now regarded as *Delocrinus*) from the Late Pennsylvanian in the Platte River valley of Nebraska.

More recently, Late Pennsylvanian crinoids from southeastern Nebraska and southwestern Iowa and Early Permian crinoids from southeastern Nebraska have been described in several reports by Strimple (1949a) and Pabian (1979), and Pabian and Strimple (1969, 1974a, 1974b, 1977, 1978a, 1978b, 1979, 1980a, 1980b, 1982, 1985, 1993) published works dealing with crinoid systematics, paleoecology and biostratigraphy. Burke and Pabian (1978) compared examples of *Cibolocrinus conicus* Strimple (1951b) from Nebraska with examples of *C. patriciae* Burke (1975) from Bolivia. Holterhoff (1988) reported on the paleoecology of these animals from the Stanton Formation in the Midcontinent. Pabian and Strimple (1969, 1985) recorded large, ornate species that inhabited shallow, warm water environments and small, inornate species that lived in cold, deep-water habitats. Heckel and Pabian (1981) discussed the compatibility of crinoid faunas with eustatic models of deposition in Midcontinent cyclothems in the Late Pennsylvanian.

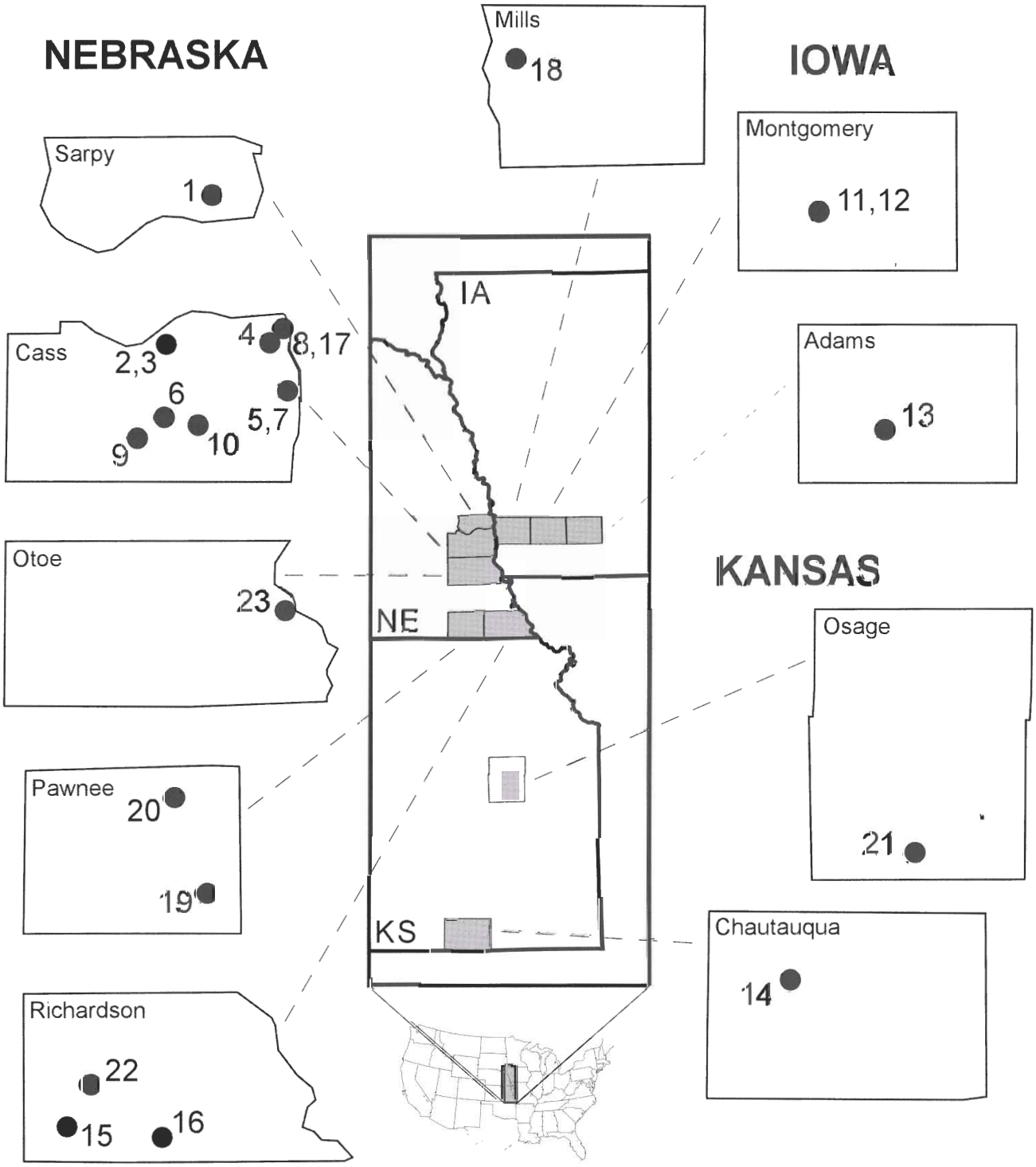
Environments of Deposition

Late Pennsylvanian and Early Permian platform deposits in the North American Midcontinent are eustatically controlled by fluctuations in sea level brought about by advance and retreat of the seaway caused by continental glaciation (Heckel, 1980, 1986). Such deposits have continental and marine facies called *cyclothems* and have been described and interpreted by Wanless (1931, 1950, 1964), Wanless and Shepard (1936), Wanless and Weller (1932), Weller (1930, 1931, 1958, 1964), Moore (1931, 1936, 1950, 1964, 1965), Stout (1974, 1978), Heckel (1977, 1980, 1984, 1986), and Heckel and Baesemann (1975). Pabian and Diffendal (1991) described the cyclic deposits in Richardson and Pawnee counties, and they related the advances and retreats of the seaways to Gondwanan glaciation as demonstrated by Veevers and Powell (1987).

Pabian and Strimple (1969) described two distinct crinoid faunas from the Midcontinent (Type I: large, robust, ornamented crinoids) from warm, shallow water deposits and (Type II: small, fragile, unornamented crinoids) from deep, cold water deposits. Heckel and Pabian (1981, p. 281) stated that the large, ornate crinoid species were found in the upper parts of regressive limestones and in the marine parts of near-shore shales. Heckel and Pabian (1981, p. 281) further noted that small, inornate species of inadunate and flexible crinoids were found near the top of the transgressive limestone, in the non-black part of the offshore shale, and near the base of the regressive limestone of the cyclothemic model provided by Heckel and Baesemann (1975) and Heckel (1977). Pabian and Strimple (1985, p. 9) expanded on their own 1970 study and on the Heckel and Pabian (1981) study and referred the Type I faunas to warm, shallow-water, near-shore assemblages because of their position within the cyclothem and the Type II faunas to cold, deep-water, off-shore assemblages.

Characterization of Epifauna and Predators

Hageman and Kaesler (2002, p. 181) studied damage on fusulinid tests from the Hughes Creek Shale Member of the Foraker Formation exposed near Paxico, Kansas, and suggested four causes: mutation, disease, physical processes, and predation. All of these causes can also be observed on damaged crinoid crowns, cups, and ossicles. In addition to these causes given by Hageman and Kaesler, parasitization is an important cause of damage to crinoids. Hageman and Kaesler further suggested that the damage to the fusulinid tests is manifested by removal of material from the test by the predator that was followed by the prey organism secreting new calcite to repair the damage. Many of the damaged crinoids



Text-fig. 1. Map showing locations where specimens used in this study were collected.

show evidence of healing by new calcite secretions in the voids left by the attacker. In the case of many parasites, however, the damage may leave heavily scarred areas that are shown as galls or swellings and these may affect the normal appearance of the crinoid.

Pabian and Strimple (1969, 1985) and Heckel and Pabian (1981) characterized deep, cold-water crinoid assemblages and shallow, warm-water crinoid assemblages; the former were made up of small, inornate crinoids and the latter of large, ornate species. Subsequent examination of associated fauna, including corals, brachiopods, bivalves, snails, cephalopods, trilobites, and echinoids, shows the small, thin-shelled fauna is common to deep, cold-water environments (transgressive limestone and offshore shale) and the large, thick-shelled fauna is common to shallow, warm-water environments (near-shore shale and regressive limestone).

There is currently no standardized terminology to describe the epifauna or kinds of scars that have been observed on fossil crinoids. Some workers (for example, Brett, 1978) attempted to standardize the terminology for the kinds of pits he observed on Silurian crinoids. Similar features to those described by Brett on fossil crinoids have been interpreted as burrows (Breimer, 1978, p. 325). Terms such as *encruster* have been used (for example, Molineux, 1995), but many such terms have not been used consistently between different workers.

Brett and Baird (1986) have shown the importance of comparative taphonomy in the role of interpreting paleoenvironments. Brett and Baird (1986) have characterized skeletal types and their susceptibility to biostratonomic processes, as well as demonstrated the value that various invertebrate skeletal types may have as indicators of the importance of transport, environmental energy and burial rates. Of the parameters discussed by Brett and Baird (1986), skeletal disarticulation, skeletal fragmentation, corrasion and bioerosion are most applicable to the materials we have covered in this study.

We have characterized epiflora and epifauna on the crinoids here into several categories:

1. Encrustations: these include algae, foraminifera, sponges, brachiopods, clams, worms, and other crinoids.

2. Borings or pits: these include worms, possibly snails, and borings by other organisms of unknown affinity. These may also include puncture wounds.

3. Sinuous grooves or cuts: this category includes trails that may or may not have been fatal to the crinoid. The responsible organisms are not known.

4. Sharply delineated deep cuts or slashes: this category includes deep cuts and gouges that may have proved fatal in many cases. Possible candidates include carnivorous gastropods, cephalopods, large arthropods, and fish.

5. Others: this includes marks that have not yet been associated with some organism and may include diseased animals.

Epifauna associated with individual species of crinoids examined in this study are treated in the remarks in the systematic paleontology; see also tables 2, 6, and 7. Some general observations regarding each group of epifauna listed above follow. It should be pointed out that any host may show examples of one or more of the different kinds of epifauna; for example, an encrusted specimen may also have pits or borings in it.

Encrustations

Crinoids in our sample show encrustations by algae, sponges, bryozoans, brachiopods, worms, and other crinoids. Algae and worms are the most common encrusting organisms. The position of the encrusting organism may be of some paleoecological value but of probably much less taphonomic value. For example, an encrustation across an articular facet or suture face would imply the encrustation was *post mortem*. However, an encrustation that crosses none of the above does not necessarily imply that it happened while the host was living. It is not possible to determine if a heavy encrustation of algae brought about the death of a crinoid as the encrustation may have occured after the crinoid died.

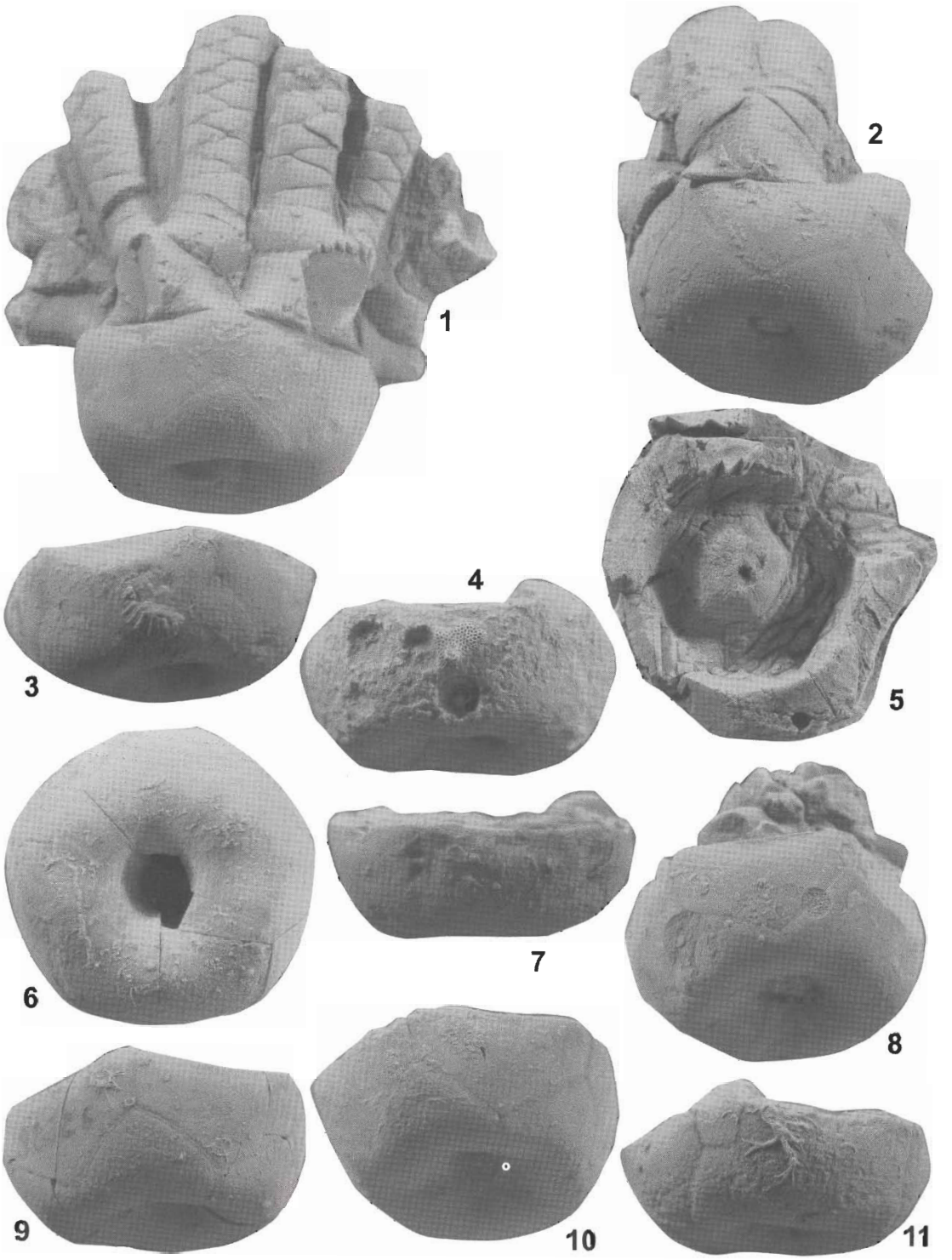
Sponges commonly appear as traces in the form of sometimes numerous small cuneiform-like "chop marks" (text-figs. 2, *10*; 3, *3*; 4, *2, 13*; and 5, *9*). The cup shown in text-figure 5, *9* carries two kinds of epifauna, sponges and bryozoans. There may be other kinds of sponges encrusting crinoids but we have not yet recognized them.

Bryozoan encrustations may be either the holdfasts of colonies of fenestrates, or they may be massive encrusting forms (text-fig. 5, *9*). There does not seem to be any specificity. Many of the bryozoa colonies cut across articular facets or suture faces of loose plates suggesting *post-mortem* attachment or encrustation.

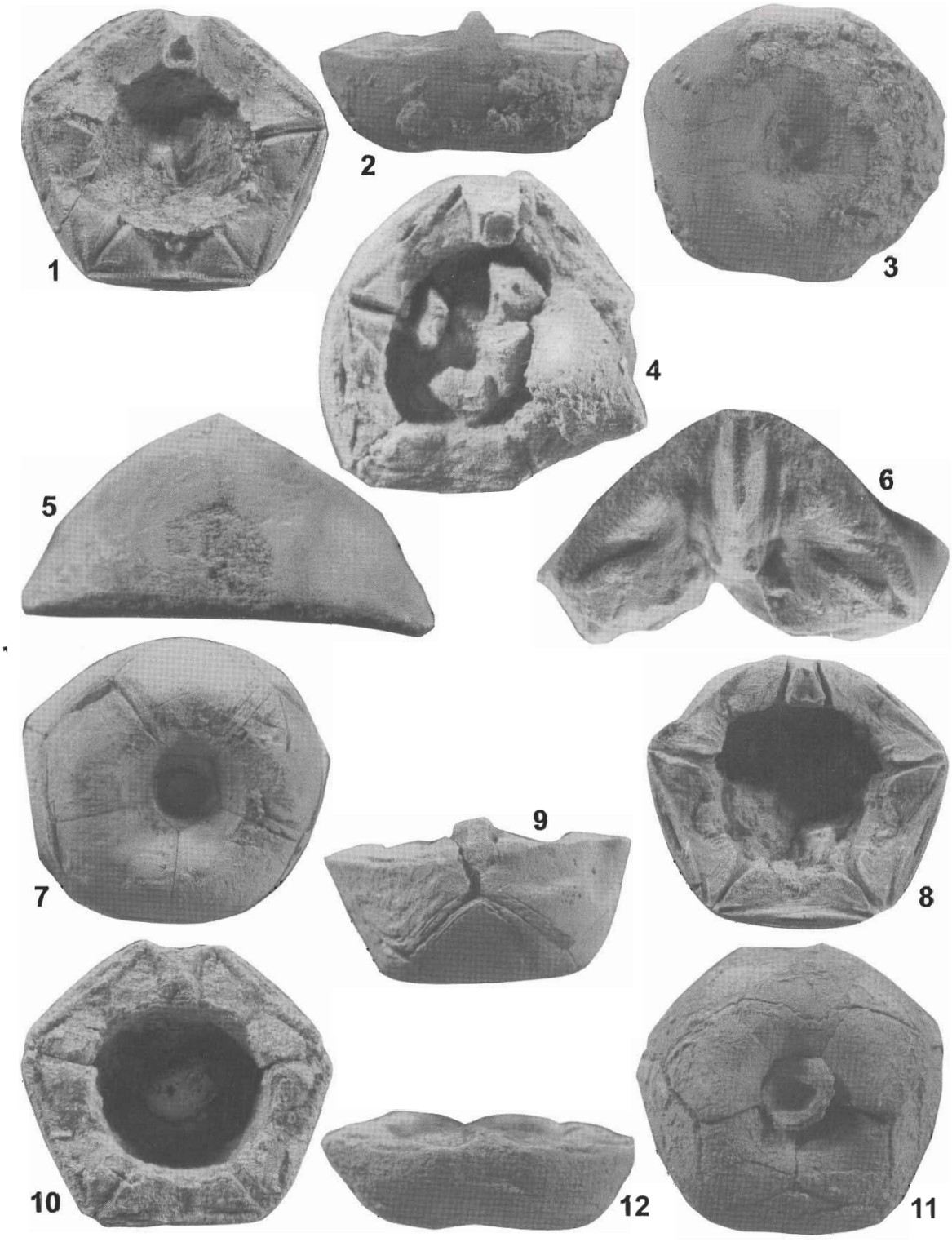
We have observed only strophomenoid (text-fig. 5, *3*) and productoid (text-figs. 2, *3, 9*; 5, *8*) brachiopods encrusting the crinoids we examined. These brachiopods are nonspecific for selecting a host as they have been observed encrusting clams, other brachiopods, and fragments of other large invertebrates. None of the kinds of encrusting brachiopods have pedicle openings, and they may have only selected a crinoid because it afforded solid substrate.

Worms (text-fig. 12, *9,10*) are usually serpulids (probably *Serpulopsis*), but an ocassional spirorbid worm may be observed. This is a sharp contrast to some worm epifauna (for example, the Silica Formation of Middle Devonian age, Kesling and Chilman, 1975) in which spirorbids are the dominant form. Meyer and Ausich (1983, p. 400) recorded *Spirorbis* only on crinoids of Mississippian age but suggested the commensal relationship may have existed at times other than Mississippian.

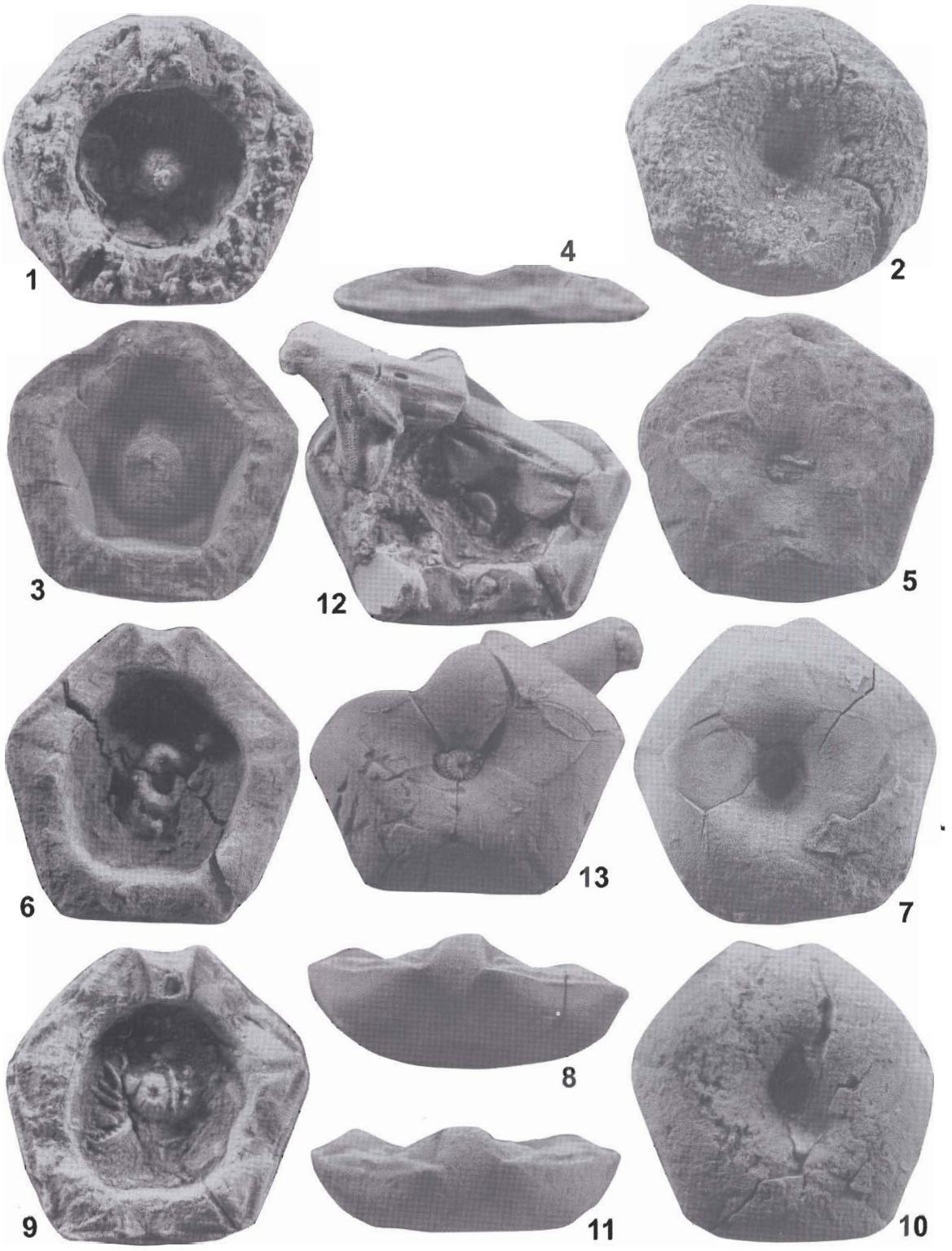
Mapes and others (1986, p. 400-404) observed the Mississippian microcrinoid *Allagecrinus coronarius* Gutschick that colonized the living chamber of a nautiloid. They suggested that the nautiloid shell furnished the hard substrate



Text-fig. 2. *Delocrinus vulgatus* Moore & Plummer, 1940, all hypotypes: *1*. Partial crown, left-anterior view, UNSM 38321, Stull Shale, Ace Hill Quarry. x 3. *2*. Dorsal cup with lower brachials, UNSM 38322, Stull Shale, Ace Hill Quarry, x 2.5. *3*. Dorsal cup with productoid brachiopod, *Leptolosia* attached near proximal tip of basal plate, UNSM 8017, Stull Shale, north of Weeping Water, Nebraska, x 3. *4*. Dorsal cup with large, cylindrical borings, UNSM 8021, Stull Shale, north of Weeping Water, Nebraska, x 2.2. *5*. Partial dorsal cup with boring on articular facet of A radial, SUI 55942, Emporia Formation, near Table Rock, Nebraska, x 2.5. *6*. Basal view of dorsal cup with serpulid worm tube, UNSM 38324, Stull Shale, Ace Hill Quarry, x 2. *7*. Dorsal cup, left lateral view showing gnawings on radial plates, Stull Shale, north of Weeping Water, Nebraska, x 3. *8*. Profile view of dorsal cup showing healed? borings near RR/BB sutures, UNSM 12491, Stull Shale, Ace Hill Quarry, x 3. *9*. Dorsal cup with productoid brachiopod, *Leptolosia* attached near summit of basal plate, UNSM 38326, Stull Shale, Ace Hill Quarry, x 2. *10*. Dorsal cup, profile view, showing small gouge in RR plate, UNSM 12485, Stull Shale, Ace Hill Quarry, x 2.5. *11*. Dorsal cup, right posterior view, showing holdfast of crinoid attached to radial, UNSM 12478, Stull Shale, Ace Hill Quarry, x 2.

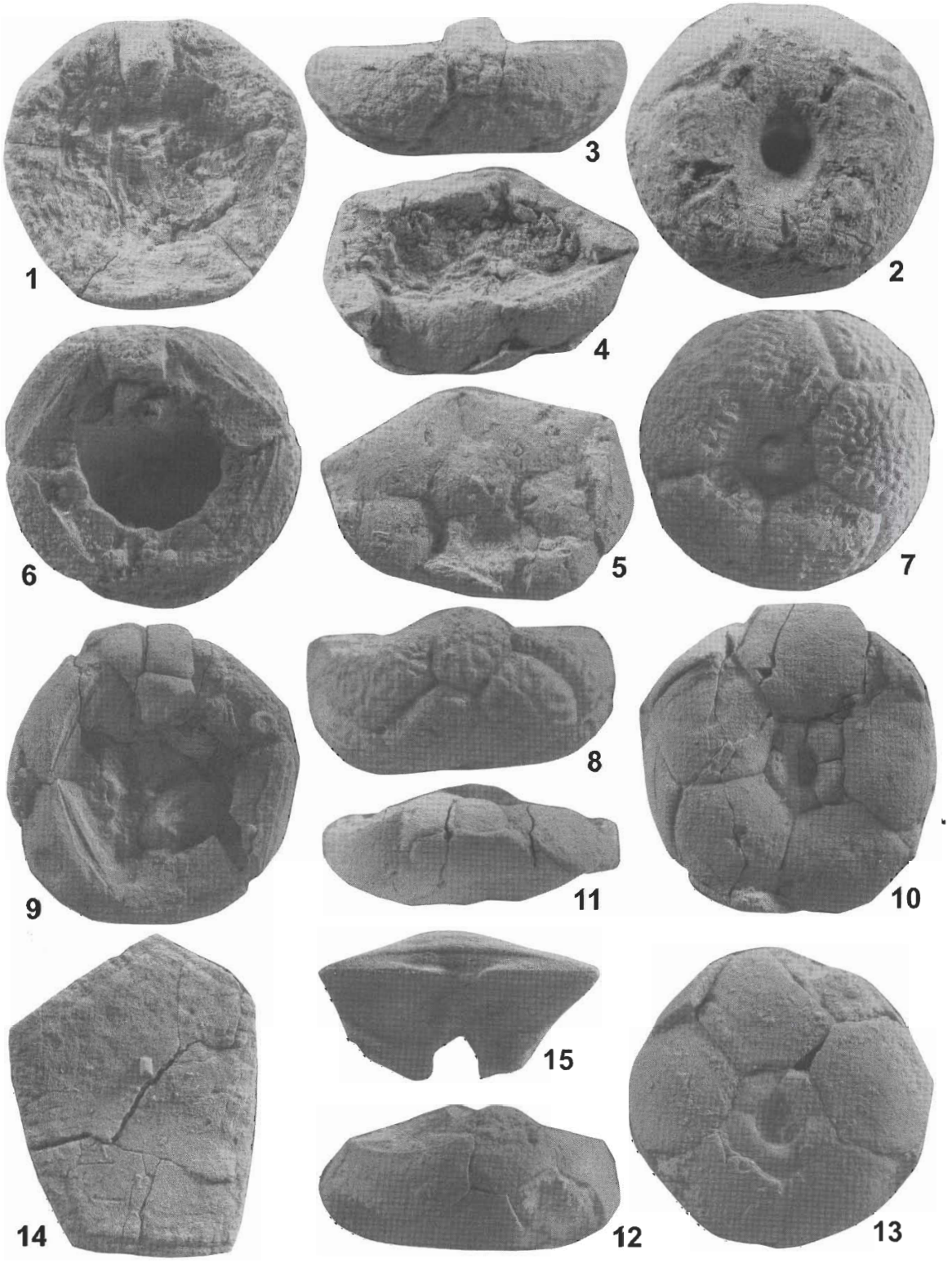


Text-fig. 3. *1-4, Delocrinus vulgatus* Moore & Plummer; *5-9, Delocrinus admirensis* Strimple; *10-12, Sublobalocrinus kaseri* Pabian & Strimple. *1-3,* Dorsal cup, summit, posterior and basal views showing heavy algae coating, UNSM 26037, Kanwaka Formation, Chataqua County, Kansas, x 2.5; *4,* Dorsal cup, summit view, with light algae coating on articular facets, UNSM 26036, Kanwaka Formation, Chataqua County, Kansas, x 3. 5, 6, *D. admirensis,* PBr1 plate, outer and summit views, showing healed? boring, UNSM 38344, Miles Limestone, near Humboldt, Nebraska, x 5. *7-9,* Dorsal cup, basal, posterior and summit views, showing gnawed C radial, UNSM 38344, Miles Limestone near Humboldt, Nebraska, x 2.5. *10-12,* Dorsal cup, summit, left lateral and basal views, showing very light algae coating on articular facets, UNSM 26039, Kanwaka Formation, Chataqua County, Kansas, x 2.5.

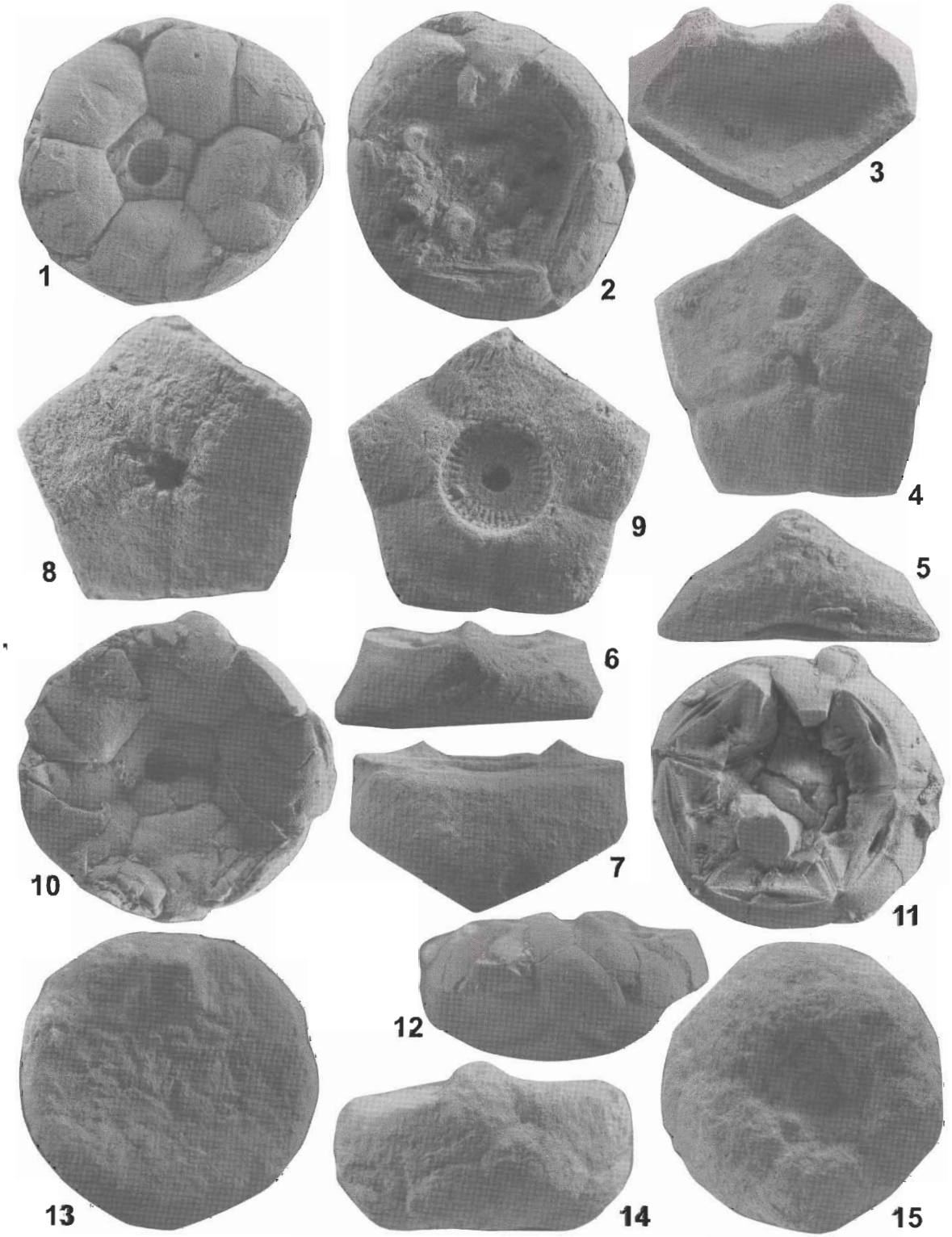


Text-fig. 4. *1-11, Sublobalocrinus kaseri* Pabian and Strimple; *12, 13, Arrectocrinus iowensis* Pabian and Strimple, all hypotypes. *1, 2,* dorsal cup, summit and basal views of cup with heavy algae coating, UNSM 26040, Kanwaka Formation, Chataqua County, Kansas, x 3. *3-5,* dorsal cup, summit, posterior and basal views of diseased? cup with extremely thin plates, UNSM 38383, Stull Shale, Kanwaka Formation, Montgomery County, Iowa, x 4. *6-8,* dorsal cup, summit, basal, and posterior views, showing algae coating on AB basal and A and B radials and slight cuts on DE basal, UNSM 38382, Stull Shale?, Kanwaka Formation, Montgomery County, Iowa, x 3. *9-11,* dorsal cup, summit, basal and posterior views showing boring on anal X plate and tiny boring on several basals, UNSM 38381, Stull Shale?, Kanwaka Formation, Montgomery County, Iowa, x 3. *12, 13,* dorsal cup with PBr1 plate attached on C radial, showing cuts on D radial, UNSM 38347, Stull Shale?, Kanwaka Formation, Montgomery County, Iowa, x 3.

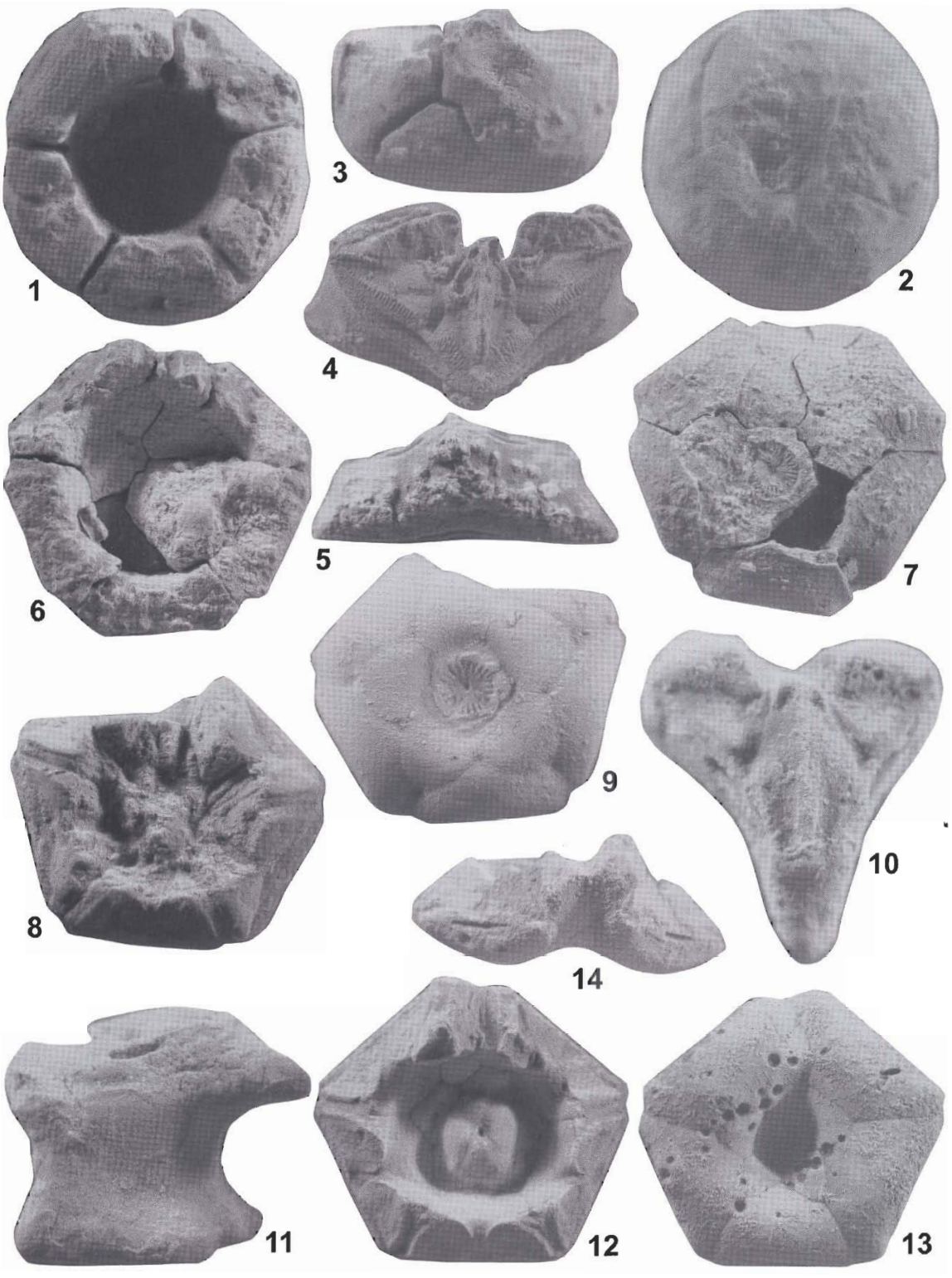
Text-fig. 5. *1-3, Graffhamicrinus magnificus* (Strimple); *4-12, Graffhamcrinus subcoronatus* (Moore & Plummer), all hypotypes: *1,* dorsal cup, basal view showing tiny boring in DE basal, UNSM 38293, Stull Shale, Ace Hill Quarry, x 3. *2,* dorsal cup, right posterior view, showing unknown epizoan on C radial, UNSM 38290, Stull Shale, Ace Hill Quarry, x 3. *3,* radial plate showing attached strophomenoid brachiopod, ?*Derbyia*, UNSM 38304, Stull Shale, Ace Hill Quarry, x 6. *4,* dorsal cup, basal view, showing tiny borings in BC and CD basals, UNSM 12469, Stull Shale, Kanwaka Formation, locality 4, x 6. *5,* dorsal cup, profile view showing large, cylindrical borings, UNSM 12453, Stull Shale, Kanwaka Formation, locality 4, x 3. *6, 7,* dorsal cup, basal and summit views of badly gnawed cup, UNSM 12448, Stull Shale, Ace Hill Quarry, x 2.5. *8,* dorsal cup, left posterior view showing attached productoid brachiopod, *Leptolosia,* UNSM 12454, Stull Shale, Kanwaka Formation, locality 4, x 3. *9,* dorsal cup, left lateral view showing "chop marks" on radials and basals, UNSM 12444, Stull Shale, Kanwaka Formation, locality 4, x 2.5. *10-12,* dorsal cup, summit, basal and posterior views showing light algae coating on articular facets and on outer cup walls, UNSM 12442, UNSM 12442, Stull Shale, Ace Hill Quarry, x 3.



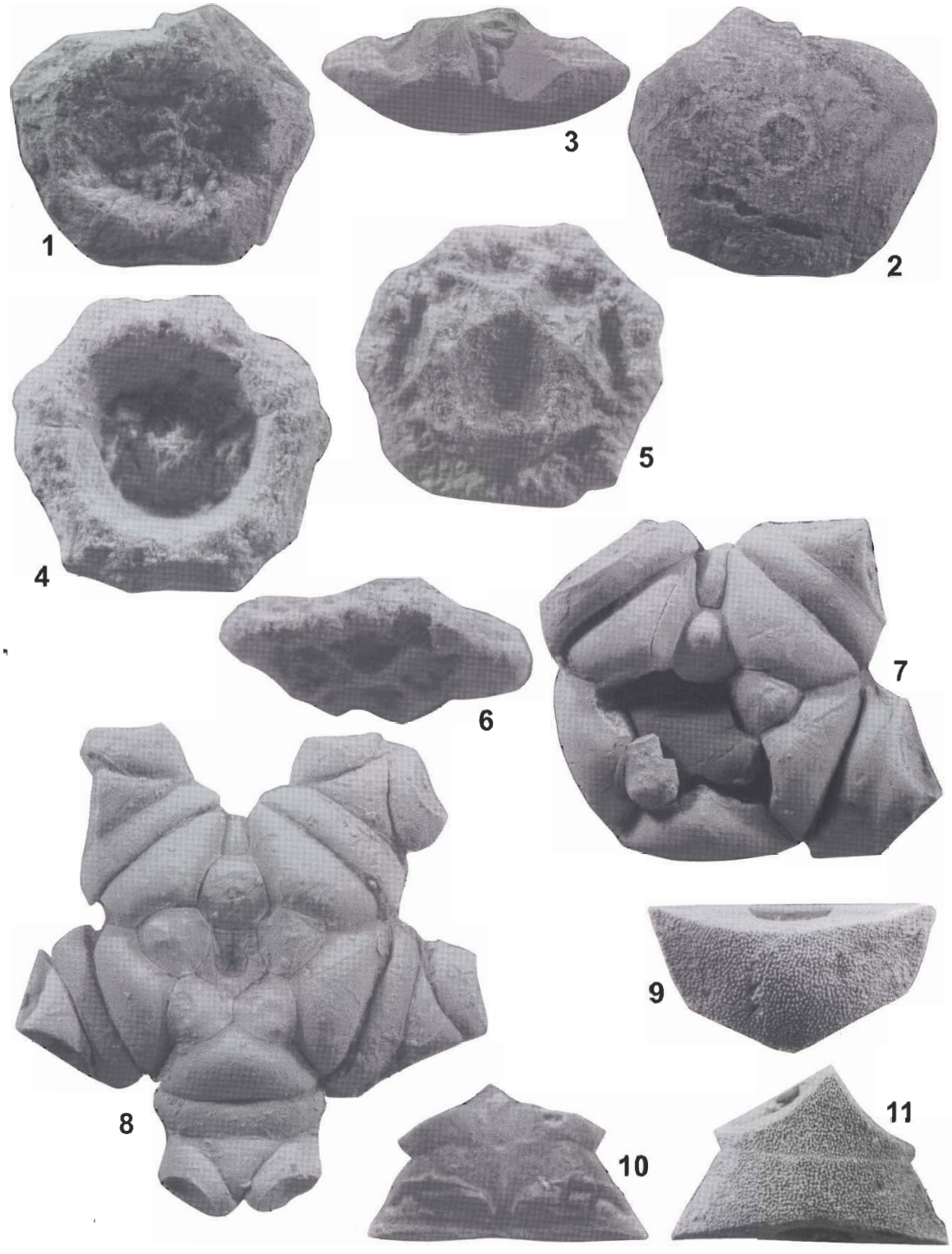
Text-fig. 6. *1-3, Graffhamicrinus boellstorffi* Pabian & Strimple; *4, 5, Erisocrinus* sp. cf. *E. typus* Meek & Worthen; *6-8, Synarmocrinus iatani* (Strimple); *9-11, Parethelocrinus* sp. cf. *P. variabilis* (Strimple); *12, 13, Parulocrinus blairi* (Miller & Gurley); *14, 15, Ulocrinus* sp., all hypotypes. *1-3,* dorsal cup, summit, basal, and posterior views showing some gnawing and algae coating, UNSM 38340, Hughes Creek Shale near Salem, Nebraska, x 2. *4, 5,* dorsal cup, oblique summit and basal views, UNSM 38377, Ervine Creek Limestone Member, Queen Hill Quarry, Cass County, Nebrasaka, x 3. *6-8,* dorsal cup, summit, basal and posterior views, UNSM 38363, Merriam Limestone, Plattsburg Formation, Cass County, Nebraska, x 1.5. *9-11,* dorsal cup, summit, basal and posterior views, UNSM 38359, Bethany Falls Limestone Member, Swope Formation, near La Platte, Sarpy County, Nebraska, x 2. *12, 13,* dorsal cup, posterior and basal views, UNSM 38361, Plattsmouth Limestone Member, Oread Formation, Cass County, Nebraska, locality 8, x 2. *14,* basal plate, interior, UNSM 38368, x 3.



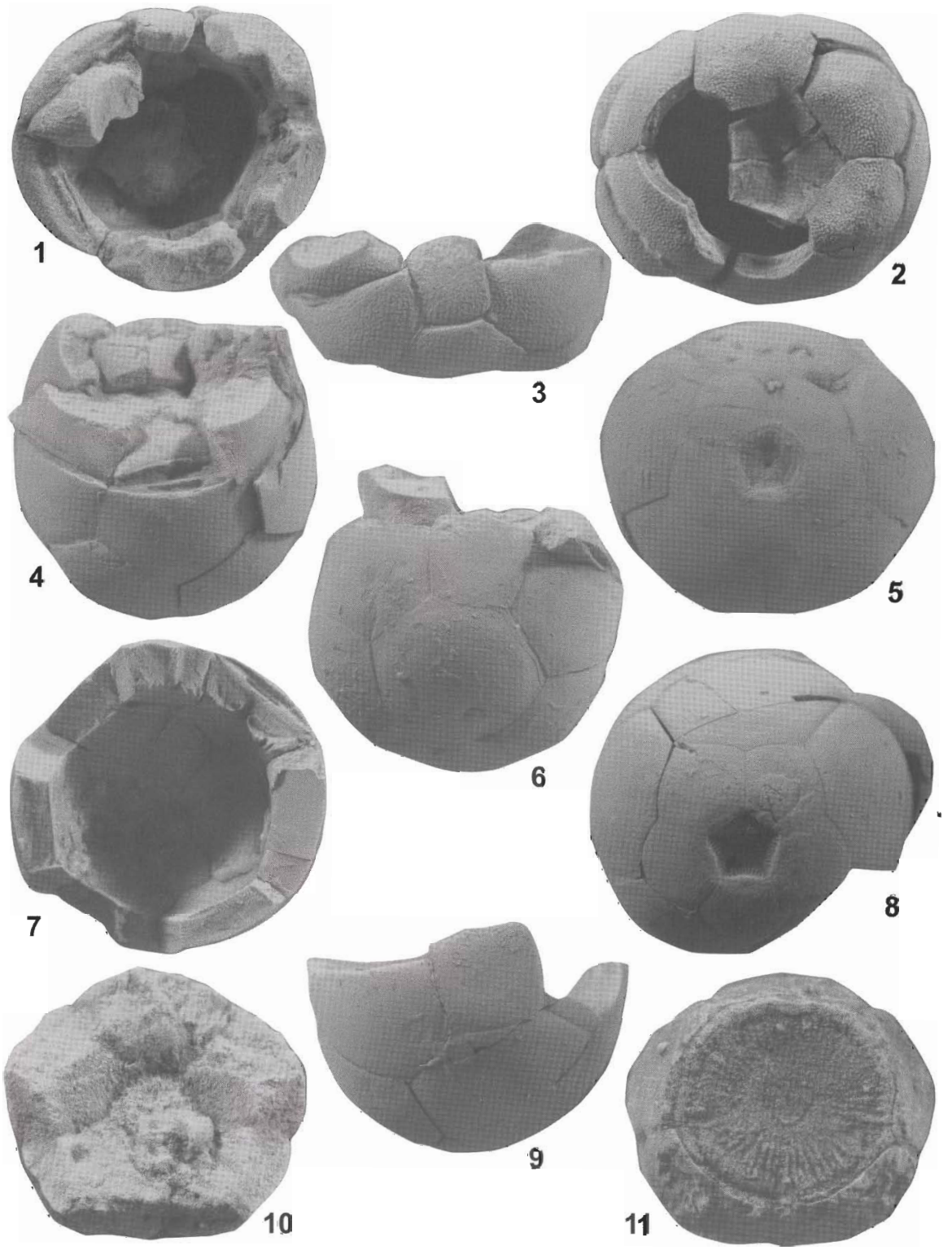
Text-fig. 7. *1, 2, 10-12, Parethelocrinus* sp. cf. *P. variabilis* (Strimple); *3-7, Parulocrinus* sp. cf. *P. blairi* (Miller and Gurley), 1894; *8, 9, 13-15,* A*glaocrinus compactus* (Moore & *Plummer*), all hypotypes. *1, 2,* dorsal cup, basal and summit views, UNSM 38360, Bethany Falls Limestone Member, Swope Formation, near La Platte, Nebraska, x 2; *3,* radial plate, interior view showing gouges, UNSM 38362, Stull Shale, Kanwaka Formation, Cass County, Nebraska, locality 4, x 3. *4,* infrabasal circlet, inner view, showing boring, UNSM 38358, x 4; *5, 6,* PBr1 plate and *7,* RR plate, UNSM 38362, Stull Shale, Ace Hill Quarry, Nebraska, x 3; *8, 9,* infrabasal circlet, outer and inner views, UNSM 38358, Stull Shale, Kanwaka Formation, Montgomery County, Iowa, locality 12, x 4. *10 - 12,* dorsal cup, basal, summit and posterior views, UNSM 38355, Stull Shale, Kanwaka Formation, Montgomery County, Iowa, locality 12, x 2. *13-15.* dorsal cup, summit, basal and posterior views, UNSM 38357, Stull Shale, Ace Hill Quarry, Nebraska, x 1.5.



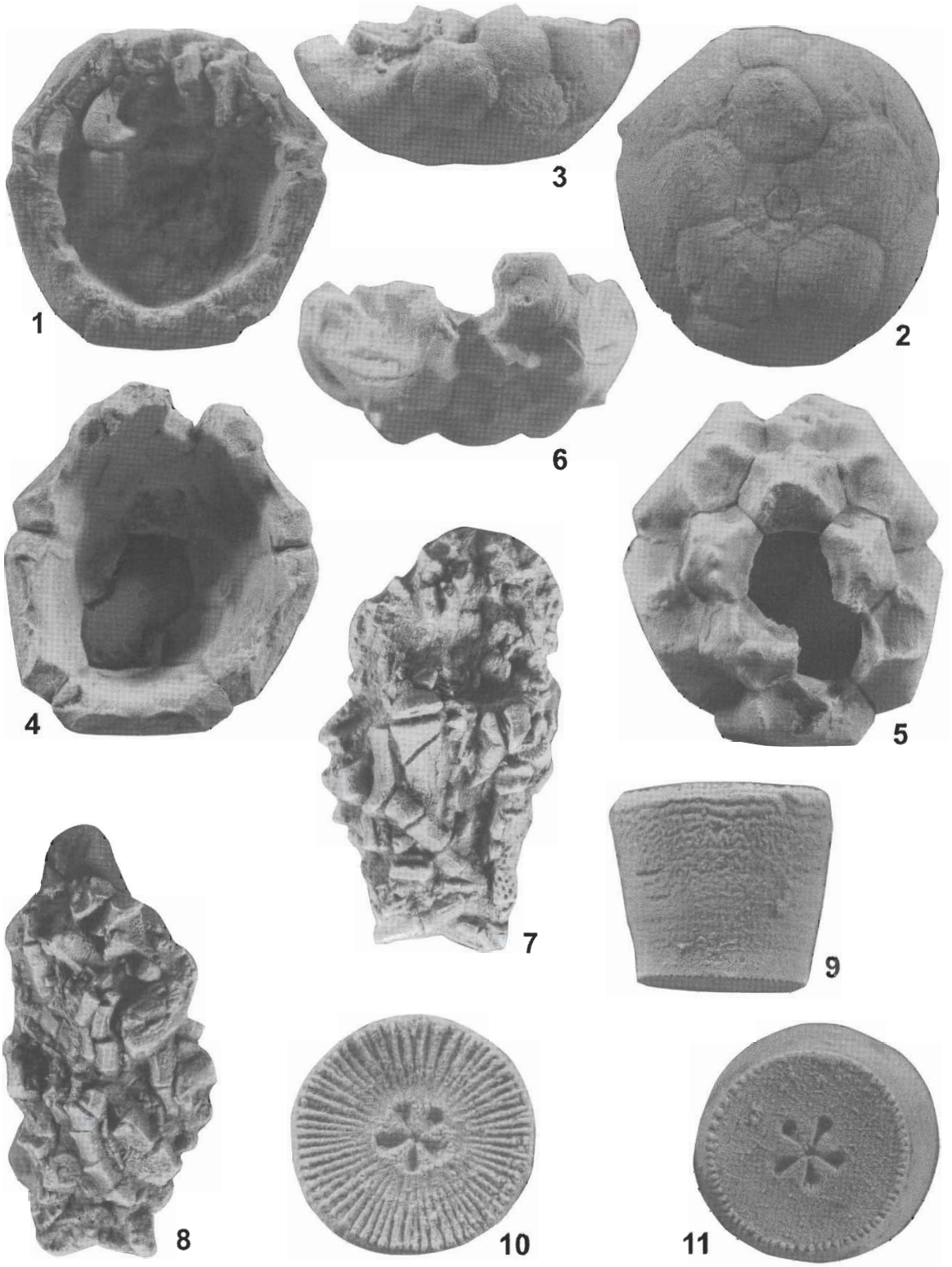
Text-fig. 8. *1-3, Aglaocrinus compactus* (Moore & Plummer); *4, 5, Synarmocrinus iatani* (Strimple); *6, 7, Plaxocrinus crassidiscus* (Miller & Gurley); *8, 9, Vertigocrinus parilis* (Moore and Plummer); *10,11, Triceracrinus* sp.; *12-14, Sciadiocrinus humilis* Strimple. *1-3,* dorsal cup of immature specimen, UNSM 38356, Stull Shale, Ace Hill Quarry, Nebraska, x 6. *4, 5,* ornamented PBr1 plate, UNSM 26034, Kanwaka Formation, Chataqua County, Kansas, x 3. *6, 7,* dorsal cup, summit and basal views, UNSM 38367, Haynies Limestone Bed, Queen Hill Quarry, Nebraska, x 3. *8, 9,* partial dorsal cup, summit and basal views, UNSM 38366, Stull Shale Member, Kanwaka Formation, Nebraska, x 4. *10, 11,* PBr1 plate, summit and oblique views, UNSM 38346, Hughes Creek Shale, locality 16, x 6. *12-14,* dorsal cup, summit, basal, and posterior views of hypotype, UNSM 38364, x 2.



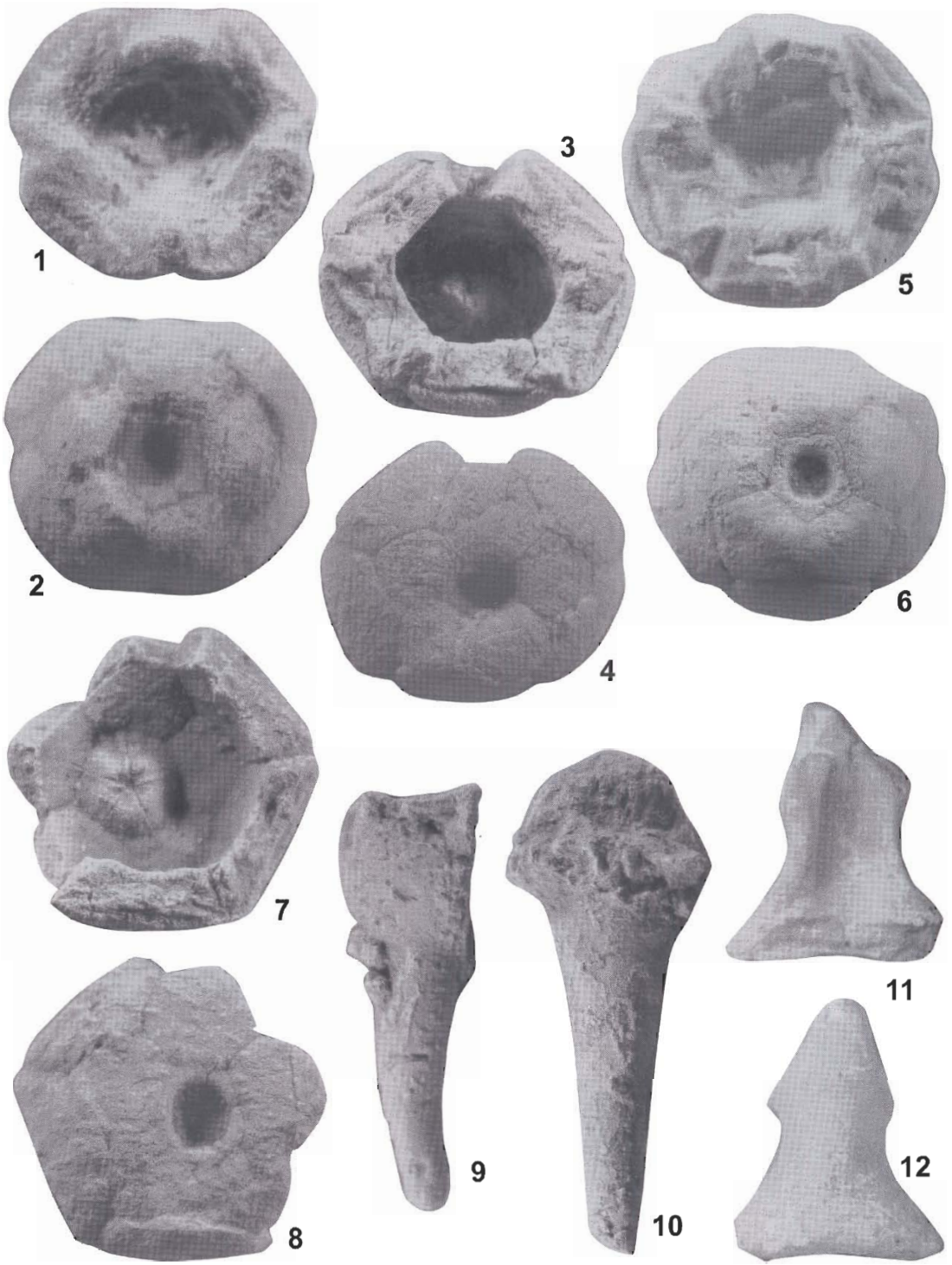
Text-fig. 9, *1-3, Bathronocrinus wolfriverensis* Pabian & Strimple; *4-6, Galateacrinus gossameri* Pabian & Strimple; *7, 8, Adacrinus edema* Pabian & Rushlau, new species; *9-11, Aesiocrinus* sp. cf. *A. detrusus* Strimple. *1-3,* dorsal cup, summit, basal and posterior views, showing cut in A radius, UNSM 38365, Plattsmouth Limestone Member, Oread Formation, near Plattsmouth, Nebraska, x 2. *4-6,* dorsal cup, summit, basal and posterior views, UNSM 38378, Haynies limestone bed, Adams County, Iowa, x 6. *7,* dorsal cup, basal view, with proximal brachials attached, paratype, UNSM 38354, Stull Shale, Ace Hill Quarry, Nebraska, x 2. *8,* dorsal cup, basal view of holotype, UNSM 38353, Stull Shale, Ace Hill Quarry, Nebraska, x 2. *9,* radial plate, outer view, showing small gouges, UNSM 38385, Stull Shale, Ace Hill Quarry, Nebraska, x 4. *10, 11,* PBr1 and PBr2 plates, inner and outer views showing partial fusion and small boring, UNSM 38385, Stull Shale, Ace Hill Quarry, Nebraska, x 4.



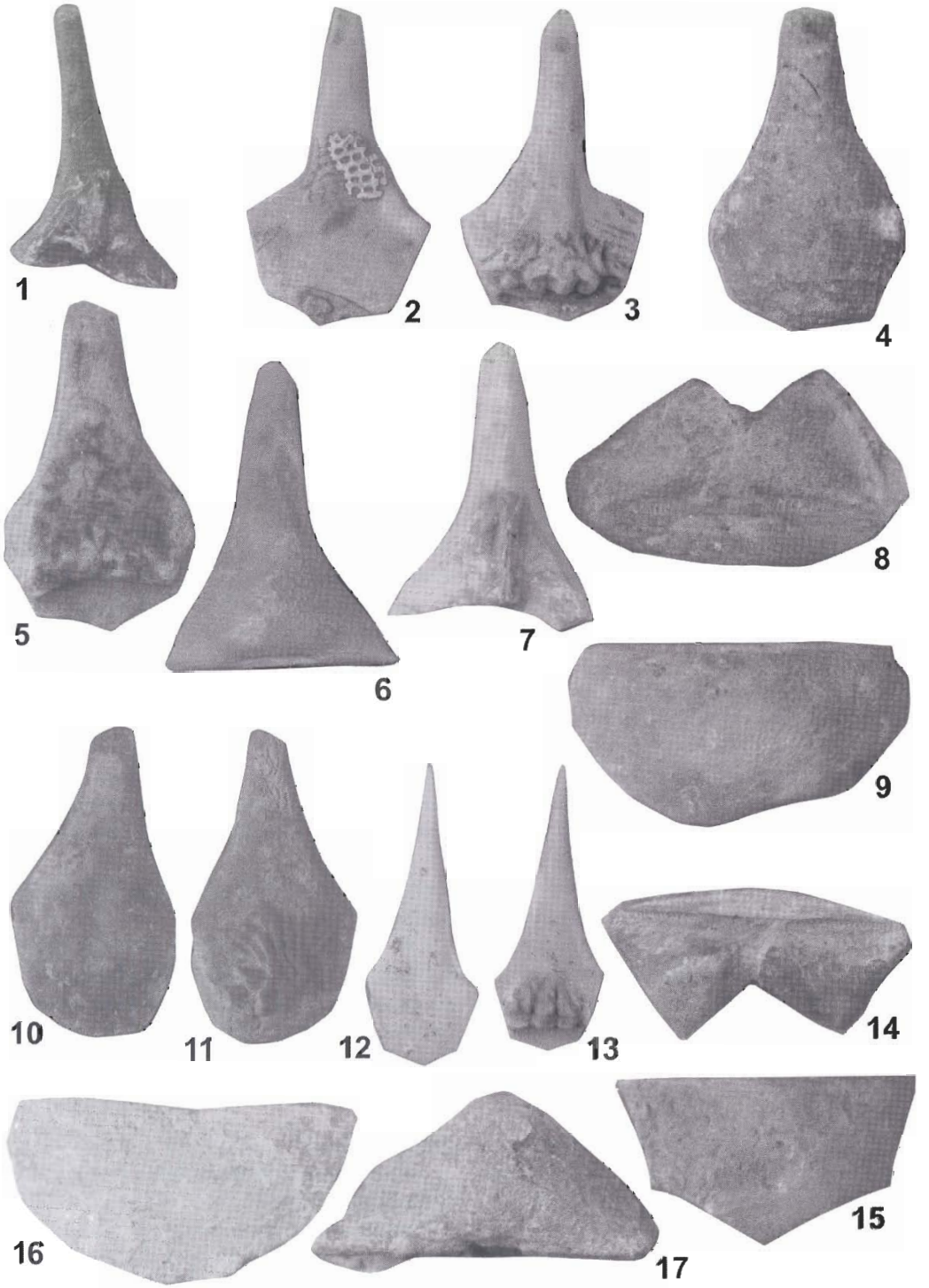
Text-fig. 10, *1-3, Allosocrinus bronaughi* Strimple; *4-9, Polusocrinus rosa* Strimple; *10, 11, Haeretocrinus* sp. cf. *H. missouriensis* Moore & Plummer. *1-3,* dorsal cup, summit, basal and posterior views; UNSM 38380, Stull Shale, Ace Hill Quarry, Nebraska, x 3. *4-6,* dorsal cup, oblique summit, basal and posterior views, showing small cuts and worm tubes on basal area, UNSM 38378, Plattsmouth Limestone, locality 11, x 3. *7-9,* partial cup, summit, basal and posterior views showing worm tubes near posterior interradius, UNSM 38379, Stull Shale, Ace Hill Quarry, Nebraska, x 3. *10, 11,* infrabasal circlet, summit and basal views, UNSM 38386, Stull Shale, Montgomery County, Iowa, x 5.



Text-fig. 11: *1-3, Glaukosocrinus berryi* Pabian & Rushlau, new species; *4-6, Stellarocrinus stillativus* (White); *7, 8, Exocrinus multirami* Strimple; *9-11, Paramphicrinus* sp. *1-3,* dorsal cup, summit, basal and posterior views, holotype, UNSM 38377, South Bend Limestone, near Louisville, Nebraska, x 2.5. *4-6,* dorsal cup, summit, basal and posterior views showing tiny boring on right tube plate, UNSM 38373, Stull Shale, Ace Hill Quarry, Nebraska, x 3. *7, 8,* disarticulated crown, posterior and anterior views, UNSM 38399, Stull Shale, Montgomery County, Iowa, x 8. *9-11,* proximal column section, lateral, proximal and distal ends, UNSM 38345, Hughes Creek Shale, near Salem, Nebraska, x 5.



Text-fig. 12: *1-4, Apographiocrinus typicalis* Moore & Plummer; *5, 6, Apographiocrinus platybasis* Pabian & Strimple; *7, 8, Contocrinus* sp. cf. *C. stantonensis* (Strimple); *9, 10,* undetermined Pirasocrinid; *11, 12, Glaukosocrinus* sp. *1, 2,* dorsal cup, summit and basal views; note only four radial plates in cup, UNSM 38387, Haynies limestone bed, Queen Hill Quarry, Nebraska, x 8. *3, 4,* dorsal cup, summit and basal views showing worm tube in A radius of basal circlet, UNSM 38388, Haynies limestone bed, Queen Hill Quarry, Nebraska, x 8. *5, 6,* dorsal cup, summit and basal views showing tiny boring in CD basal, UNSM 38391, Haynies limestone bed, Queen Hill Quarry, Nebraska, x 8. *7, 8,* partial dorsal cup, summit and basal views, UNSM 38392, Haynies limestone bed, Queen Hill Quarry, Nebraska, x 8. *9,* PBr1 plate, lateral view with small gouge, UNSM 26033, Kanwaka Formation, Chataqua County, Kansas, x 3. *10,* sac spine with attached worm tubes, UNSM 26033, Kanwaka Formation, Chataqua County, Kansas, x 3. *11, 12, Glaukosocrinus* sp., interior and exterior views of primibrachial, Hughes Creek Shale Member, Foraker Formation, northeast of Humboldt, Nebraska, locality 22, x 5.



Text-fig. 13: *1-5,* Indeterminate pirasocrinid, species A, all from Kanwaka Shale, Montgomery County, Iowa, locality 12; *6-9,* indeterminate pirasocrinid, species B, all from Hughes Creek Shale, Richardson County, Nebraska, locality 22; *10-13,* indeterminate pirasocrinid, species C, all from Hughes Creek Shale, Richardson County, Nebraska, locality 22; *14-17, Erisocrinus sp. cf. longwell* Lane and Webster; all from Hughes Creek Shale, Richardson County, Nebraska, locality 22. *1,* spinose PBr1 plate with gouges, pits, hypotype, UNSM 38375, x 2. *2, 3,* sac spine showing irregular gouges, hypotype, UNSM 38376, x 2. *4, 5,* sac spine with worm and gouges, hypotype, UNSM 38374, x 2. *6-9,* indeterminate pirasocrinid, species B, from Hughes Creek shale Member, Foraker Formation, northeast of Humboldt, locality 22, x 4. *6, 7,* PBr1 plate, hypotype, UNSM 38395, x 2. *8, 9,* radial plate, hypotype, UNSM 38395, x 4. *10-13,* indeterminate pirasocrinid, species C, sac spine, UNSM 38396a, x 2. *12, 13,* sac spine, hypotype, UNSM 38396b, x 4. *14, 15,* radial plate, hypotype, UNSM 38393, Hughes Creek Shalemember, Foraker Formation, northeast of Humboldt, Nebraska, locality 22, x 4; *16,* radial plate, and *17,* PBr1 plate, hypotype, UNSM 38397, Hughes Creek Shale member, Foraker Formation, south of Salem, Nebraska, locality 16.

needed to support the microcrinoid. We are unable to determine whether the crinoid holdfast attached to a cup of *Delocrinus vulgatus* Moore & Plummer (text-fig. 2, *11*) was from a microcrinoid or a larval form of a macrocrinoid.

Bexfield and Lescinsky (1998, p. 6) studied epifauna on host shells from several facies in the Upper Ordovician (Cincinnatian) of Ohio and Indiana. They found that maximum epibiont diversity occurred in mid-shelf facies where hosts are large and most diverse. They also stated that deep shelf environments are characterized by fewer encrusting epibionts on small hosts. Preliminary data indicates that encrusting epibiont diversity in the samples examined here is greatest in the near-shore environments where hosts are generally larger than in the offshore environments and where hosts are generally smaller.

Borings/Pits

Whether the holes that have been observed in many crinoid plates and stems have been caused by the removal of stereom from the animal or a build-up of stereom around an intruding organism is a difficult question to answer. These features (pits/borings) have a similar appearance on the surface of the crinoid and may have to be examined on a case-by-case basis.

Welch (1976, p. 218-225) assigned many of the pits/borings he observed on Paleozoic crinoids to *Phosphannulus*, and he differentiated these from myzostomes. Brett (1978) has characterized pit-forming epizoans on Silurian crinoids from New York and Ontario and established some host-specific relationships. Brett (1978) used the term *pit* for what have commonly been called either *borings* or *pits*. Brett (1978) suggested that the crinoid added stereom around an organism that had settled on it and this produced a circular, parabolic pit. Brett (1978) based this on Macurda and Meyer's (1974) observation that endoskeletal crinoid plates are permeated with living tissue and none of the pits that he had observed on Silurian crinoids extended into areas of the plates that had living tissue.

Several different forms of pits have been observed on the crinoids in our sample. Circular, parabolic pits similar to those recorded by Brett (1978) have been more commonly observed on pirasocrinids (text-fig. 8, *13*). Catacrinids and diphuicrinids more commonly have circular, cylindrical pits (cf. text-fig. 2, *4*), some of which appear to have healed or filled in after the site was abandoned by the epizoan (text-figs. 2, *8;* 3, *5*).

The smallest crinoid cups in our sample to have pits are about 8 mm in diameter. Brett suggested selective distribution of pits on crinoid cups, and our sample suggests that size of the cup may have been one of the most important features; that is to say, a certain mass of the host was required to physically support the epifaunal organism.

In one cup of *Delocrinus vulgatus* Moore & Plummer, there is a boring or puncture that crosses the radial articular facet (text-fig. 2, *5*), and this may actually be a post-mortem boring in order to reach enclosed tissue.

Kabat (1990) has studied the predatory ecology of naticid gastropods and borehole predation. He reported no examples of naticid predation on echinoderms. Although there are some naticid-like gastropods in the Pennsylvanian (aff. *Naticopsis*), naticids probably do not predate the Triassic and Jurassic. Also, naticid systematics are not well understood. Further, naticids are infaunal and sought prey such as bivalves within the substrate and not above it.

Roving Organisms – Sinuous Grooves and Marks

Some evidence of epibionts appears as sinuous tracks or grooves across crinoid plates. These marks are usually fairly shallow but wide, as seen on a cup of *Bathronocrinus wolfriverensis* Pabian & Strimple (text-fig. 9, *2*). We do not know what kind of organism made these marks but some form of algae-eating grazer is possible. A cup of *D. vulgatus* Moore & Plummer (text-fig. 2, 7) shows irregular gnawings in the D and E radials, as does a cup of *Graffhamicrinus subcoronatus* (Moore & Plummer) (text-fig. 5, *6*) on the basal area. These kinds of marks are usually the least common.

Lutzen (1972) recorded epibiont snails on 25 species of recent crinoids and assigned these to seven genera. Three snails were not assigned to any genus. Each species of crinoid had a separate species of snail attached to it. Snails were commonly found in the ambulacral grooves of the arms, but some were attached to cup plates. The snails apparently moved over the body of the crinoid and some left suction marks, but one appeared to have inserted its proboscis into crinoid tissue and the latter should be considered a borer.

Predatory Organisms – Sharply Delineated Cuts and Gouges

A cup of *Sublobalocrinus kaseri* Pabian and Strimple has deep, straight cuts or gashes (text-fig. 4, *2*) across the cup plates, and a cup of *Arrectocrinus iowensis* Pabian and Strimple appears to have pieces bitten out (text-fig. 4, *13*). These marks may indicate attacks by fish or predatory invertebrates such as gastropods or nautiloids.

Diseased Tissue

Several of the specimens under study here show evidence of degenerative disease. A cup of *Delocrinus vulgatus* Moore & Plummer is extremely flattened and has very thin plates (text-fig. 4, *3-5*). Since all of the other crinoids and invertebrates that have been found associated with this specimen are normal, we do not think the cup appearance has been altered in later diagenesis. The degenerative condition of articular facets on one cup of *Graffhamicrinus subcoronatus* (Moore & Plummer) (text-fig. 5, *7*) has also been noted.

Acknowledgments

W. D. "Ted" White, of Omaha, Nebraska, provided many of the specimens from southwestern Iowa and southeastern Nebraska that we used in this study. Barry Sutton and Mark

Vanheel also provided specimens from the outcrop area in Richardson and Pawnee counties, Nebraska. Dee Ebbeka drafted the text figures, Charles Flowerday edited the publication, and the Conservation and Survey Division furnished darkroom facilities. Robert F. Diffendal, Jr. and Hannan LaGarry reviewed earlier drafts of the manuscript and furnished many useful comments and criticisms. We are alone in accepting responsibility for errors and misinterpretations of the data we present here.

Systematic Paleontology

Phylum **ECHINODERMATA** Bruguiere, 1791
Subphylum **CRINOZOA** Matsumoto, 1929
Class **CRINOIDEA** Miller, 1821
Subclass **INADUNATA** Wachsmuth and Springer, 1885
Order **CLADIDA** Moore and Laudon, 1943
Superfamily **ERISOCRINACEA** Wachsmuth and Springer, 1886
Family **CATACRINIDAE** Knapp, 1969
Genus **DELOCRINUS** Miller and Gurley, 1888 [1890]

Synonym – *Endelocrinus* Moore and Plummer, 1940.

Diagnosis – Cup low, bowl-shaped, deep basal concavity. Infrabasals (IBB) down-flared; basals (BB) down-flared proximally, re-curving medially, forming base of cup; distal tips extend about half the cup height. Radials (RR) five, pentagonal. Anals, 1 in cup, sac weak. Articular facets plenary, horizontal. Arms ten, biserial in mature individuals, but uniserial in lower parts of immature arms.

Table 1. Species assigned to *Delocrinus* Miller & Gurley

Taxon, Author	Range, Distribution
Delocrinus subhemisphericus Moore & Plummer, 1940, neotype species	Late Pennsylvanian (Missourian, Virgilian), TX, OK, KS, NE, IA, IL
Delocrinus craigi (Worthen, 1875)	Late Pennsylvanian (Missourian), IL
Delocrinus extraneous Strimple, 1949c	Late Pennsylvanian (Virgilian), KS
Delocrinus inflexus (Geinitz, 1866)	Late Pennsylvanian (Virgilian), NE
Delocrinus pendens Moore & Plummer, 1938	Early Pennsylvanian (Morrowan), AK, OK?
Delocrinus ponderosus Strimple, 1949a	Late Pennsylvanian (Virgilian), OK
Delocrinus segedii Burke, 1974	Late Pennsylvanian (Conemaugh), OH, WV
Delocrinus vastus Lane & Webster, 1966	Early Permian (Wolfcampian), NV, NE, KS?
Delocrinus verus Moore & Plummer, 1940	Late Pennsylvanian (Missourian), TX, KS
Delocrinus vulgatus Moore & Plummer, 1940	Late Pennsylvanian (Virgilian),TX, OK, KS, NE

Remarks – *Delocrinus hemisphericus* (Shumard), 1858, was originally designated as the type species by Miller and Gurley (1888 [1890]). Moore and Strimple (1970) petitioned the International Commission of Zoological Nomenclature to fixate a neotype species, *D. subhemisphericus* Moore and Plummer, since Shumard's original type was destroyed in a fire.

Delocrinus vulgatus Moore & Plummer, 1940
Text-figs. 2, *1-11*; 3, *1-4*

Remarks – Of the 10 species of *Delocrinus* recognized here (table 1), *D. vulgatus* appears to be the most important in the Virgilian. It is most common in near-shore facies, unlike the Missourian species, *D. subhemisphericus,* that persisted in offshore facies.

The large, cylindrical borings that are fairly common on *D. subhemisphericus* from the older Kiewitz shale bed of the Stoner Limestone, Stanton Formation, appear to be less common on examples of *D. vulgatus* from the Stull Shale. Of the 92 specimens of *D. vulgatus* that were studied by Pabian and Strimple (1985), five have the large cylindrical borings, six have serpulid worm tubes, and one has either a holdfast or hydroid attached. Unfortunately, the above examples recorded by Pabian and Strimple (1985) were prepared with air-abrasive tools, and much of the epifauna was destroyed and only the pits or borings remain for the main part.

Pabian & Strimple's (1985, p. 37-40) specimens of *D. vulgatus* from the Stull Shale Member of the Kanwaka Formation in Nebraska, Iowa and Kansas provided a detailed explanation of interspecific variation in this species. They suggested (1993, p. 18) that *D. vulgatus* was the more common species in Virgilian strata, whereas *D. subhemisphericus* was more common in older Missourian strata. Pabian and Strimple (1985, p. 37-40) showed that *D. subhemisphericus* had longer, more spinose first primibrachial (PBr1) plates than *D. vulgatus* and (1993, p. 16-18) illustrated a transitional form between the two species. They did not discuss the epifauna on *D. vulgatus*, but a re-examination of their sample shows that 44 cups had traces of epifauna or attacks by predators or parasites. Worm tubes and light algae coatings were the most common encrusters, but one cup may have a hydroid colony attached (text-fig. 2, *10*). Minor encrusters included bryozoans and the productoid brachiopod *Leptalosia ovalis* Dunbar & Condra (1932). One example of a holdfast was observed attached to the C radial of one specimen (text-fig. 2, *11*). Twelve cups had large cylindrical borings. Some of the borings were partially filled with a foamy stereom and appear to have been partially healed. Fourteen cups had cuts or slashes and one specimen appears to have been partially healed.

The current samples that are under investigation have two partial crowns (text-fig. 2, *1, 2*), and 20 cups from the Stull Shale at Ace Hill (locality 4) and two cups from the Stull Shale at Queen Hill (locality 5). Five cups have serpulid worm tubes (cf. text-fig. 2, *6*), five have light to medium

algae coatings, and two had tiny productoid brachiopods, *Leptalosia ovalis* Dunbar & Condra (1932) encrusting them (text-fig. 2, *3, 9*).

One cup from Ace Hill has large, cylindrical borings and an encrusting bryozoa colony (text-fig. 2, *4*). Another cup from Ace Hill (text-fig. 2, *8*) has several large, cylindrical borings that appear to be partially healed, as they are filled with spongy stereom. Another cup from Ace Hill (text-fig. 2, *9*) appears to have a pair of punctures on the E radial.

Four cups have small gouges on their outer surfaces. A small, single cup from the Stull Shale near the Plattsmouth bridge on the Missouri River has a fairly heavy encrustation of serpulid worms.

One cup, probably from the Elmont Limestone Member of the Emporia Formation near Table Rock, Nebraska, has a boring near the transverse ridge and ligament pit on the articular facet of the A radial (text-fig. 2, *5*).

Four cups from the Kanwaka Shale in Chataqua County, Kansas (locality 14), have rather heavy algae coatings (text-fig. 3, *1-4*). This epiflora differs from that on essentially unprepared specimens from Nebraska and Iowa, which have very light, if any, algae encrusting the cups. Other delocrinids from the Kansas locality also have rather heavy algae coatings.

Table 2. Summary of epifauna on *Delocrinus vulgatus* Moore & Plummer.

Locality	N	Encrusters, N–%	Pits/Borings	Slashes/Cuts
Weeping Water	82	All, 36–44% Algae, 18–22% Worms, 20–24% Crinoid, 1 Hydroid? 1 Brachiopods, 2–2%	13–16%	13–16%
Ace Hill	32	All, 16–50% Algae, 7–22% Worms, 9–28% Brachiopods, 2–6%	3–9%	5–16%
Plattsmouth Bridge	1			1
Queen Hill	7	All, 5–71% Algae, 1–14% Worms, 5–71%		
Total from above localities	122	Algae, 26–21% Worms, 34–28% Brachiopods, 4–3%	16–13%	19–15%

Table 2.-continued. Summary of epifauna on *Delocrinus vulgatus* Moore & Plummer.

Material studied – Hypotypes: UNSM 12534 - UNSM 12537, UNSM 12539, UNSM 17442-1, UNSM 17442-2, UNSM 38317 - UNSM 38339, Ace Hill Quarry, SW 1/4, sec. 33, T. 12 N., R. 14 E., Cass County, Nebraska; UNSM 16940 - UNSM 16942, UNSM 38341 - UNSM 38343, Queen Hill Quarry, SW 1/4, sec. 9, T. 11 N., R. 14 E., Cass County, Nebraska; UNSM 17424-1, UNSM 17424-2, Stull Shale Member, Kanwaka Formation, near Plattsmouth, Nebraska, locality 8; UNSM 10490, Stull Shale Member, Kanwaka Formation, near Red Oak, Iowa, locality 12; UNSM 17425, Stull Shale Member, Kanwaka Formation, near Folsom, Iowa, locality 18. UNSM 38369 - UNSM 38672, Ervine Creek Limestone Member, Deer Creek Formation, Queen Hill Quarry, locality 7. UNSM 38400, Dover Limestone Member, Stotler Formation, Nebraska City, Nebraska, locality 23

Delocrinus admirensis Strimple, 1963
Text-fig. 3, *5-9*

Synonyms – *Delocrinus admirensis* Strimple, 1963, p. 69, 70, pl. 12, figs. 9, 12, fig. 29.

Remarks – Strimple (1963, p. 69, 70) described *D. admirensis* on the basis of a single cup from the Falls City Limestone exposed in Pottawattamie County, Kansas. Our specimen in nearly every respect is identical to the holotype described by Strimple (1963, p. 69, 70). The anal X plate has lost contact with the CD basal on the outside of the cup but retains contact with it on the interior of the cup. This condition was recorded by Pabian and Strimple (1985, p. 31-34) for examples of *D. vulgatus* and *Graffhamicrinus magnificus* (Strimple) and was shown to produce an apparent but not real expulsion of the anal X plate from the dorsal cup. In our specimen, the C and D radials and CD basal have wrapped around but have not expelled the anal plate (text-fig. 3, *9*). The cup appears to have been gnawed along the C radial (text-fig. 3, *8, 9*), and one of the primibrachials found inside the cup (text-fig. 3, *5, 6*) appears to have a partially healed, large, cylindrical boring that is filled with spongy stereom (cf. *D. vulgatus,* text-fig. 2, *8*).

A PBr1 and SBr1 plate and a biserial arm segment were removed from the inside of the cup, which appears to con-

tain at least one more brachial. The PBr1 plate is a slightly protruded, regularly quadrilateral plate with a proximal articular facet that is a mirror image of the radial articular facet. The distal end has two smaller articular facets that have transverse ridges, furrows and denticles (text-fig. 3, *6*).

Material studied – Hypotype, UNSM 38344, Miles Limestone Member, Falls City Formation, 6.5 mi south of Humboldt, Nebraska, locality 15.

Genus **SUBARRECTOCRINUS** Knapp, 1969

Type species – *Delocrinus perexcavatus* Moore & Plummer, 1940.

Remarks – Knapp (1969, p. 364) erected the genus *Subarrectocrinus* to include delocrinids with steeply downflared infrabasals and suggested that the genus arose from *Graffhamicrinus*. He included *Delocrinus vulgatus* Moore & Plummer (1940); *D. admirensis* Strimple (1963); *D. densus* Strimple (1963); and *Erisocrinus inflexus* Geinitz (1866), in *Subarrectocrinus*. Knapp (1969) paid no attention to the arms of any of the crinoid genera he erected. Moore and Plummer assigned the species *perexcavatus* to the genus *Delocrinus* with some reservations. The cup of the holotype had the lower parts of uniserial arms attached to slightly protruded PBr1 plates. They observed that the arms were typical for *Endelocrinus* but not for *Delocrinus*. They were also indecisive as to whether they were viewing the anterior or posterior of *D. perexcavatus* as the holotype contains only about three rays with no anal X plate present. These somewhat inconsistent taxonomic practices have created a great deal of misunderstanding about this genus, and its uniserial arms suggest it may not even belong in the Catacrinidae.

While Moore and Plummer (1940) and Knapp (1969) were aware that *D. perexcavatus* had uniserial arms, neither assigned them any taxonomic value. The illustration of the holotype (*in* Moore and Plummer, 1940, pl. 4, fig. 6a-b, p. 424) is magnified twice and suggests the measurable diameter of the cup is about 22 mm. This falls well in the lower range of adult *Delocrinus*, which generally have developed fully biserial arms. The preserved arms of Moore and Plummer's (1940) holotype are uniserial all the way to the SBr6 plate. These observations suggest that *Subarrectocrinus* should be assigned to a family other than the Catacrinidae and the genus may not be very closely related to either *Delocrinus* or *Graffhamicrinus*. *Subarrectocrinus* may be more closely related to a genus similar to *Contocrinus* that is in the Graphiocrinidae. We can not solve this problem until additional specimens of *Subarrectocrinus*, preferably a growth series, can be studied.

Genus SUBLOBALOCRINUS Knapp, 1969

Diagnosis – (Modified after Knapp, 1969, p. 365.) Basal concavity narrow, deep; IBB steeply downflaring; BB transversely concave; arms 10, biserial, branching on PBr1.

Table 3. Species assigned to *Sublobalocrinus* Knapp.

Taxon, Author	Range, Distribution
Sublobalocrinus iolaensis Strimple, 1949b, type species	Late Pennsylvanian (Missourian), KS
Sublobalocrinus kaseri Pabian & Strimple, 1980a	Late Pennsylvanian (Missourian, Virgilian), IA, NE
Sublobalocrinus planus (White, 1883)	Late Pennsylvanian (Virgilian), KS

Remarks – We only recognize three species of *Sublobalocrinus* (table 3). This genus has not yet been identified outside of the Midcontinent outcrop area.

Sublobalocrinus kaseri Pabian & Strimple, 1980a
Text-figs. 3, *10-12*; 4, *1-11*

Remarks – This species has been described by Pabian & Strimple (1980a, 1993). They examined samples from both Missourian and Virgilian units. Two of the Missourian age specimens have large, cylindrical borings, fairly common to delocrinids, on their outer surfaces, and one has a hemispherical boring on an articular facet. One Missourian specimen has a healed gall at the tripartite junction between the B radial and the AB and BC basals on the interior of the cup. The Virgilian specimens that were recorded by Pabian and Strimple (1980a, p. 11-13) are nearly free of parasites or predatory scars with only a few worm tubes having been observed on one specimen.

Pabian and Strimple (1980a, p. 13) recorded *S. kaseri* as coming from the Jackson Park Shale Member of the Kanwaka Formation in Montgomery County, Iowa. The specimens in the current sample are simply recorded as being from the Kanwaka Formation, Montgomery County, Iowa. The adhering matrix more closely resembles the Stull Shale than the Jackson Park, but the specimens can still be placed within about a 3 m (10 ft) interval.

The specimens of *S. kaseri* in this sample that are from the Kanwaka in Chataqua County, Kansas, have medium to fairly heavy algae coatings. (text-figs. 3, *10-12*; 4, *1-3*). Those from the Kanwaka Shale in southwestern Iowa have shown little evidence of algae encrustation, with the exception of the cup shown in text-figure 4, *6-8*. One specimen of *S. kaseri* from Iowa appears to have diseased plates (cf. osteoporosis); the cup is very low and has very thin plates (text-fig. 4, *3-5*). One of the Iowa specimens shows evidence of borings (text-fig. 4, *9-11*).

Material studied – Hypotypes: UNSM 38347- UNSM 38350, Stull Shale Member? Kanwaka Formation, sec. 5, T. 73 N., R. 36 W., Montgomery County, Iowa; UNSM 26039 – UNSM 26042, Kanwaka Shale Formation? NE ¼, SW ¼, sec. 3, T. 33 S., R. 10 E., Chataqua County, Kansas.

Genus **ARRECTOCRINUS** Knapp, 1969

Diagnosis – Infrabasals 5, in fairly shallow concavity.

Basal plane of cup formed by proximal parts of 5 basals. Radials 5, with plenary facets. Anal X barrel shaped. Arms biserial.

Table 4. Species assigned to *Arrectocrinus* Knapp.

Taxon, Author	Range, Distribution
Arrectocrinus abruptus (Moore & Plummer 1940), type species	EarlyPermian (Wolfcampian), KS,TX
Arrectocrinus comminutus Pabian & Strimple, 1974a	Late Pennsylvanian (Virgilian), NE
Arrectocrinus stanleyi Pabian & Strimple, 1977	Late Pennsylvanian (Virgilian), IA
Arrectocrinus hopperi Pabian & Strimple, 1977	Late Pennsylvanian (Virgilian), NE
Arrectocrinus iowensis Pabian & Strimple, 1980a	Late Pennsylvanian (Virgilian), IA, NE

Arrectocrinus* sp.** cf. ***A. iowensis Pabian & Strimple, 1980a

Text-fig. 4, *12, 13*

Remarks – Pabian and Strimple (1980a, p. 709, and 1985, p. 44) recorded *Arrectocrinus iowensis* from the Plattsmouth Limestone Member of the Oread Formation, Montgomery County, Iowa (1985, p. 44), the Spring Branch Limestone Member of the Lecompton Formation, Mills County, Iowa, and the Stull Shale Member, Kanwaka Formation, Cass County, Nebraska. We have a single cup with a PBr1 plate attached in the C ray of a cup that has a somewhat shallower cup than any of the specimens described by Pabian and Strimple above. The cup is smaller than any of those recorded by Pabian and Strimple (1980, 1985) and may represent a less mature example of this species.

This species may be one of the scarcer catacrinids in the Virgilian of the Midcontinent. It is fairly easy to identify because of its shallow basal concavity and the proximal regions of the basals involved in the basal plane of the cup. The B radial of our specimen has several deep gouges on the outside (text-fig. 4, *13*) and may have a puncture wound of the articular facet of the A radial (text-fig. 4, *12*).

Material studied – Hypotype, UNSM 38347, Kanwaka Shale Shale, Red Oak, Iowa, locality 12.

Family **DIPHUICRINIDAE** Strimple & Knapp, 1966

Genus **GRAFFHAMICRINUS** Strimple, 1961

Diagnosis – Crown usually tall, arms closely apposed, each brachial with pinnule. Arms cuneate to biserial. Cup wider than high, covered with pustules, granules or ridges. Base deeply concave, IBB downflared. Anal X followed by 2 tube plates. RR facets plenary, sub-horizontal. Stem transversely round.

Remarks – Our diagnosis is based on the diagnosis of Diphuicrinidae of Strimple and Moore, 1971b. There are currently 34 species of *Graffhamicrinus* in rocks ranging in age from Middle Pennsylvanian to Late Permian (table 5). Several of these species are based on single or few specimens on criteria such as ornamentation or size.

Table 5. Species assigned to *Graffhamicrinus* Strimple.

Taxon, Author	Range, Distribution
Graffhamicrinus acutus Strimple, 1961, type species	Middle Pennsylvanian (Desmoinesian), OK
Graffhamicrinus acutus Strimple, 1961 var. *spicatus* Strimple, 1961	Middle Pennsylvanian (Desmoinesian), OK
Graffhamicrinus antiquus Strimple & Watkins, 1969	Middle Pennsylvanian (Atokan), TX, OK
Graffhamicrinus aristatus (Strimple, 1949a)	Middle Pennsylvanian (Desmoinesian), OK
Graffhamicrinus armatura (Strimple, 1949a)	Middle Pennsylvanian (Desmoinesian), OK
Graffhamicrinus bifidus (Moore & Plummer, 1940)	Late Pennsylvanian (Missourian), TX
Graffhamicrinus bispinosus (Moore & Plummer, 1940)	Middle Pennsylvanian (Desmoinesian), OK, TX
Graffhamicrinus boellstorffi Pabian & Strimple, 1974a	Early Permian (Council Grove), NE
Graffhamicrinus brookensis (Burke, 1970)	Late Pennsylvanian, WV
Graffhamicrinus bullatus (Moore & Plummer, 1940)	Middle Pennsylvanian (Desmoinesian), TX
Graffhamicrinus decapodos (Strimple & Priest, 1969)	Late Pennsylvanian (Virgilian), NE
Graffhamicrinus decoratus (Burke, 1970)	Late Pennsylvanian, WV
Graffhamicrinus graphicus (Moore & Plummer, 1940)	Late Pennsylvanian (Missourian), TX
Graffhamicrinus granulosus Moore & Plummer, 1940	Middle Pennsylvanian (Atokan, Desmoinesian), TX, OK
Graffhamicrinus granulosus var. *moniliformis* Moore & Plummer, 1940	Middle Pennsylvanian (Desmoinesian), TX, OK
Graffhamicrinus granulosus var. *zonatus* Moore & Plummer, 1940	Middle Pennsylvanian (Desmoinesian), TX, OK
Graffhamicrinus magnificus (Strimple, 1947)	Late Pennsylvanian (Missourian - Virgilian), OK, NE, KS
Graffhamicrinus nodosarius (Strimple, 1939a)	Late Pennsylvanian (Missourian), OK
Graffhamicrinus papulosus (Moore & Plummer, 1940)	Late Pennsylvanian (Missourian), TX

Table 5-continued. Species assigned to *Graffhamicrinus* Strimple

Taxon, Author	Range, Distribution
Graffhamicrinus parinodosarius (Strimple, 1940)	Middle Pennsylvanian (Desmoinesian), OK
Graffhamicrinus paucinodus (Moore & Plummer, 1940)	Late Pennsylvanian (Missourian), TX
Graffhamicrinus pennsylvanicus (Burke, 1970)	Late Pennsylvanian, PA
Graffhamicrinus pictus (Moore & Plummer, 1940)	Middle Pennsylvanian (Desmoinesian), TX
Graffhamicrinus profundus Strimple, 1971	Late Pennsylvanian (Virgilian), KS
Graffhamicrinus rectus (Moore & Plummer, 1940)	Middle Pennsylvanian (Desmoinesian), TX
Graffhamicrinus rimulatus (Strimple, 1962a)	Middle Pennsylvanian (Desmoinesian), OK
Graffhamicrinus somersi Whitfield, 1882	Middle Pennsylvanian (?Desmoinesian), OH
Graffhamicrinus subcoronatus (Moore & Plummer, 1940)	Late Pennsylvanian (Missourian - Virgilian), TX, NE
Graffhamicrinus tetraspinosus Pabian & Strimple, 1974a	Late Pennsylvanian (Virgilian), NE
Graffhamicrinus tulsaensis Strimple, 1962a	Middle Pennsylvanian (Desmoinesian), OK
Graffhamicrinus undulatus (Strimple, 1961)	Middle Pennsylvanian (Desmoinesian), OK
Graffhamicrinus variabilis Strimple, 1962a	Middle Pennsylvanian (Desmoinesian), OK
Graffhamicrinus waughi Moore & Strimple, 1941	Early Permian (Wolfcampian), KS
Graffhamicrinus wolforum (Moore & Plummer, 1940)	Late Pennsylvanian (Virgilian), TX

Graffhamicrinus magnificus (Strimple, 1947)
Text-fig. 5, *1 - 3*

Remarks – This species appears to have arisen in the Missourian, probably from *G. nodosarius,* where the latter is common, especially in offshore units. Older Missourian examples appear to be smaller than their Virgilian counterparts. In the Virgilian, *G. magnificus* appears to be more common in near-shore units, especially outside shales, and the examples appear to be larger. Pabian & Strimple (1993, p. 25, 26) compared a specimen to *G. magnificus*, stating that they were ocassionally found in offshore facies, and suggested these had finer ornamentation than their near-shore counterparts.

Epifauna on seven cups of *Graffhamicrinus magnificus* from the Stull Shale at Queen Hill (locality 5) include three cups with light to medium algae coatings and two with small gouges (text-fig. 5, *1*). We examined 23 cups from the Stull at Ace Hill (locality 4) and found seven with light-to-medium algae coatings. One loose radial plate has an immature strophomenoid brachiopod *Derbyia* sp. attached to it (text-fig. 5, *3*). It is of note that the only brachiopods that appear to have attached to crinoids are the productoid, *Leptalosia,* or the strophomenoid, *Derbyia.* One cup showed an unusual encrustation on the C radial (text-fig. 5, *2*) of an unknown organism, possibly a larval edrioasteroid. Other diphuicrinids and delocrinids from the Kansas locality also have rather heavy algae coatings.

Table 6. Summary of epifauna on *Graffhamicrinus magnificus* (Strimple)

Locality	N	Encrusters, N–%	Pits/Borings	Slashes/Cuts
Weeping Water	26	All, 11–43% Algae, 9–35% Worms, 2–8% Bryozoans, 1	5–20%	4–16%
Ace Hill	24	All, 12–50% Algae, 7–30% Worms, 3	6–19%	4–17%
Queen Hill Stull	7	All, 3–43% Algae, 3–43%	2–21%	
Grant, IA	7	All, 3	2–30%	3–43%
Montgomery County, IA	1			1
Melvern, KS	1	Algae		
Queen Hill, Ervine Creek	1	Algae		
Total from above localities	67	All, 31–46% Algae, 21–31% Worms, 5–7%	15–19%	12–21%

Material studied – UNSM 38275 - UNSM 38290, Stull Shale Member, Kanwaka Formation, Queen Hill Quarry, SW 1/4, sec. 9, T. 11 N., R. 14 E., Cass County, Nebraska, locality 5; UNSM 38305, Haynies bed, Ervine Creek Limestone Member, Deer Creek Formation, Queen Hill Quarry, SW 1/4, sec. 9, T. 11 N., R. 14 E., Cass County, Nebraska, locality 7; UNSM 38306, Stull Shale Member, Kanwaka Formation, abandoned quarry, SE 1/4, sec. 34, T. 11 N., R. 11 E., Cass County, Nebraska, locality 9; UNSM 8028 - UNSM 8044,

Stull Shale Member, Kanwaka Formation, abandoned quarry north of Weeping Water, Nebraska, locality 6; UNSM 38283 - UNSM 38304, Ace Hill Quarry, SW 1/4, sec. 33, T. 12 N., R. 14 E., Cass County, Nebraska, locality 4; UNSM 38306 – UNSM 38312, Stull Shale Member, Kanwaka Formation, sec. 5, T. 73 N., R. 36 W., near Red Oak, Montgomery County, Iowa, locality 12; UNSM 17419, Stull Shale Member, Kanwaksa Formation, near Plattsmouth, Nebraska, locality 8. UNSM 10492, Montgomery County, Iowa; locality 12; UNSM 28344, Stull Shale Member, Kanwaka Formation, near Melvern, Kansas, locality 21. UNSM 23155, UNSM 23156, Severy Shale Formation, near DuBois, Nebraska, locality 19.

Graffhamicrinus subcoronatus (Moore & Plummer), 1940

Text-fig. 5, *4-12*

Remarks – Pabian and Strimple (1985) showed that *G. subcoronatus* had a differing crown morphology and followed a different evolutionary trend than *G. magnificus*. Both species are fairly common in the Stull Shale. The additional specimens in our sample showed no tendency for *G. subcoronatus* to expel or absorb the anal X plate, but the anal X was narrow in two examples and had not lost contact with the CD basal.

Epifauna associated with *G. subcoronatus* includes algae coatings (text-fig. 5, *6, 7, 10 - 12*), sponge borings (text-fig. 5, *9*), serpulid worms, and bryozoa. Several cups have the large diameter, shallow, cylindrical borings (text-fig. 5, *5*), and many have short slashes, gouges, or cuts.

Of 42 cups of *G. subcoronatus* from the Stull Shale at Ace Hill (locality 4), 30 had light to heavy coatings of algae (text-fig. 5, *10-12*); three had bryozoans (cf. text-fig. 5, *9*) and two had serpulid worms (text-fig. 5, *6*). The tiny productoid brachiopod *Leptalosia* was observed on one specimen (text-fig. 5, *8*), and one had a large bryozoa colony and sponge borings (text-fig. 5, *9*). Large, cylindrical borings (text-fig. 5, *5*) were counted on three cups, and several cups had small borings. Five specimens had deep gouges, and one was badly gnawed at the BC interradial on the radial circlet and on the DE interray on the DE basal (text-fig. 5, *7*).

We studied 14 cups of *G. subcoronatus* from the quarry north of Weeping Water, and four had light-to-medium algae coatings. One had a bryozoa encrustation and another a small brachiopod, *Leptalosia* sp. Two cups had borings and one had a small slash. *G. subcoronatus* was represented by two cups from the Stull Shale at Queen Hill (locality 5), one of which had a bryozoan encrustation and by one cup from the Stull at Red Oak (locality 12) that had an algae coating.

Table 7. Summary of epifauna on *Graffhamicrinus subcornonatus* (Moore & Plummer).

Locality	N	Encrusters, N–%	Pits/Borings	Slashes/Cuts
Weeping Water	19	All, 10–53% Algae, 8–42% Bryozoans, 2–11% Brachiopods, 1	2–10%	5–26%
Ace Hill	45	All, 34–75% Algae, 31–70% Worms, 3–7% Bryozoans, 5–11% Brachiopods, 1	14–31%	9–20%
Queen Hill	6	All, 5–84% Algae, 5–84% Bryozoans, 1	2–33%	1
Red Oak, IA	2	All, 1 Algae, 1		
Total from above localities	72	All, 50–70% Algae, 45–62% Bryozoans, 8–11% Brachiopods, 2–3%	18–25%	15–28%

Material studied – Hypotypes: UNSM 12438 - UNSM 12472, UNSM 38313, UNSM 38314, UNSM 17446-1 - UNSM 17446-6, Stull Shale Member, Kanwaka Formation, Ace Hill Quarry, Cass County, Nebraska, locality 4; UNSM 8045 - UNSM 8058, UNSM 8075 - UNSM 8077, Stull Shale Member, Kanwaka Formation, abandoned quarry north and east of Weeping Water, Nebraska, locality 6; UNSM 38343, Plattsmouth Limestone Member, Oread Formation, near Missouri River bridge, Cass County, Nebraska, locality 8; UNSM 38313 - UNSM 38316, Stull Shale Member, Kanwaka Formation, Queen Hill Quarry, Cass County, Nebraska, locality 5; UNSM 10493, UNSM 10494, Stull Shale Member, Kanwaka Formation, near Red Oak, Iowa, locality 12.

Graffhamicrinus boellstorffi Pabian and Strimple, 1974a

Text-fig. 6, *1 - 3*

Remarks – The studied specimen has a thick coating of algae on most of the plates and on most of the articular facets. There are numerous tiny chop marks that extend through the algae coating to the cup plates below it. The basal concavity of the specimen examined is very deep and narrow.

The radial articular facets are mostly covered with algae and their details are unclear. The holotype has several small worm tubes on the B radial, whereas the hypotype under study has worm tubes on the A, B, and C radials and on the CD basal.

The volume of the cup of the current specimen is much larger (ca. 3.96 cm^3) than that of the holotype, UNSM 7992 (ca. 1.03 cm^3) that was collected from the Hughes Creek Shale in Nemaha County, Nebraska.

Material studied – Holotype, UNSM 7992, Hughes Creek Shale Member, Foraker Formation, Charles Boellstorff Farm, Nemaha County, Nebraska, locality 19; hypotype, UNSM 38340, Hughes Creek Shale Member, Foraker Formation, south of Salem, Nebraska, locality 16.

Family **ERISOCRINIDAE** Wachsmuth & Springer, 1886

Genus **ERISOCRINUS** Meek & Worthen, 1865a

Type species – *Erisocrinus typus* Meek & Worthen, 1865a.

Diagnosis – See Strimple & Moore, 1971a, p. 10.

Table 8. Species assigned to *Erisocrinus* Meek & Worthen.

Taxon, Author	Range, Distribution
Erisocrinus typus Meek & Worthen, 1865a	Late Pennsylvanian (Missourian), IL, NE, IA, KS, MO, OK
Erisocrinus araxensis Yakovlev, 1933	Permian, Russia
Erisocrinus elevatus Moore & Plummer, 1940	Late Pennsylvanian (Missourian), TX
Erisocrinus georgeae Strimple & Watkins, 1969	Middle Pennsylvanian (Atokan), TX
Erisocrinus granulatus Wanner, 1916	Permian, Timor
Erisocrinus healdae Pabian & Strimple, 1974a	Late Pennsylvanian (Virgilian), NE
Erisocrinus knoxvillensis Strimple, 1975b	Late Mississippian (Meramecan), IA
Erisocrinus loczyi Lane & Webster, 1966	Early Permian (Wolfcampian), NV
Erisocrinus longwelli Lane & Webster, 1966	Early Permian (Wolfcampian), NV, NE
Erisocrinus lustrum Strimple, 1951b	Late Pennsylvanian (Missourian), KS
Erisocrinus pentangulatus Yakovlev, 1938	Permian, Sicily
Erisocrinus propinquus Weller, 1909	Early Permian (Wolfcampian), TX
Erisocrinus steffani Yakovlev, 1934	Permian, Sicily

Erisocrinus* sp.** cf. ***E. typus Meek & Worthen, 1865a

Text-fig. 6, *4, 5*

Synomyms – *Erisocrinus typus* Meek & Worthen, 1865a; Meek, 1872; Meek and Worthen, 1873; Strimple, 1938; Moore & Plummer, 1940; Moore & Laudon, 1944; Strimple, 1938, *reprinted* 1959; Tischler, 1963; Strimple & Moore, 1971a; Pabian & Strimple, 1993.

Erisocrinus nebrascensis Meek & Worthen, 1865a, *non* 1965 *in* Pabian & Strimple, 1993, p. 22.

Erisocrinus pelvis (Meek & Worthen, 1865a).

Remarks – Of the 12 recognized species of *Erisocrinus* (table 8), *E. typus* is the most common in the study area. It appears to continue through the Virgilian in the Midcontinent, but its numbers are far fewer than they were in the Missourian. Recent collections made by Lewis and others (unpublished data) and under examination by Pabian show numerous *E. typus* from the Barnsdall Formation (late Missourian? - early Virgilian?) in Oklahoma. The species' numbers appear to decline almost immediately after this time, although it persists throughout the Virgilian.

The radial articular facets of the specimen under study (UNSM 38377) are rather narrow compared to those in older examples of *E. typus*. *E. healdae* Pabian & Strimple (1974a) has rather narrow articular facets, but the cup walls flare outward near the summit, a feature not observed on our specimen. The cup under study has several small chop marks on the radial and basal plates that may be sponge borings (text-fig. 6, *5*).

Material studied – Hypotypes: UNSM 38377, Haynies Limestone bed, Ervine Creek Limestone Member, Deer Creek Formation, Queen Hill Quarry, SW 1/4, sec. 9, T. 11 N., R. 14 E., Cass County, Nebraska, locality 7. USNM 38411, Dover Limestone Member, Stotler Formation, Otoe County, Nebraska, locality 23.

Erisocrinus* sp.** cf. ***E. longwelli Lane and Webster, 1966

Text-fig. 13, *14-17*

Remarks – *Erisocrinus* is uncommon in the early Permian of Nebraska, but Pabian and Strimple (1978b, p. 1393) recorded a partial cup of *E. longwelli* from the Hughes Creek Shale at a site about 7.6 mi south of Humboldt, Nebraska. The RR plate at hand has been gnawed some and has a worm tube crossing the articular facet, suggesting post-mortem colonization.

Material studied – Hypotype, UNSM 38393, Hughes Creek Shale, northeast of Humboldt, Nebraska, locality 22; UNSM 38397, loose plates, Hughes Creek Shale, south of Salem, Nebraska, locality 16.

Superfamily **CROMYOCRINACEA** Bather, 1890

Family **CROMYOCRINIDAE** Bather, 1890

Diagnosis – See Pabian and Strimple, 1985, p. 61.

Genera – *Aaglaocrinus* Webster, 1981; *Aglaocrinus* Strimple, 1961; *Cromyocrinus* Trautschold, 1867; *Dicromyocrinus* Jaekel, 1918; *Ethelocrinus* Kirk, 1937;

Goleocrinus Strimple & Watkins, 1969; *Mantikosocrinus* Strimple, 1951d; *Mathericrinus* Webster, 1981; *Metacromyocrinus* Strimple, 1961; *Mooreocrinus* Wright & Strimple, 1945; *Parethelocrinus* Strimple, 1961; *Parulocrinus* Moore & Plummer, 1940; *Probletocrinus* Strimple & Moore, 1971; *Synarmocrinus* Lane, 1964b; *Tarachiocrinus* Strimple, 1962b; *Tyrieocrinus* Wright, 1945; *Ureocrinus* Wright & Strimple, 1945.

Genus **SYNARMOCRINUS** Lane, 1964b

Type species – *Synarmocrinus brachiatus* Lane, 1964b.

Diagnosis – (After Webster, 1981) Cup medium truncate bowl-shaped, widest at apices of basals with shallow-basal invagination; infrabasals sub-horizontal or slightly down-flared; radial facets sub-horizontal; cup plates with coarse nodes or ridges; sutures impressed; 2 anals present; uniserial arms 10; column round, heteromorphic.

Other species included – *Synarmocrinus adornatus* Strimple & Watkins, 1969; *S. brachiatus* Lane, 1964b; *S. carrizoensis* Webster & Lane, 1970; *S. depressus* Washburn, 1968; *S. fundundus* Strimple, 1966; *S. iatani* (Strimple, 1949a); *S. molasensis* (Strimple & Miller, 1971); *S. oklahomaensis* (Moore & Plummer, 1938); *S. papulosus* (Moore & Plummer, 1938).

Range – Pennsylvanian (Morrowan - Missourian), USA: Texas, Oklahoma, Kansas, Nebraska, Utah; Brazil

Synarmocrinus iatani (Strimple), 1949

Text-figs. 6, *6-8;* 8, *4, 5*

Description – Cups large, mature, and round in outline, widest at medial distal points of basals/medial points of radials. Cross section low globe; base somewhat concave, IBB 5, downflared, confined to basal concavity. Stem round and columnar cicatrix about half the diameter of IBB circlet. BB 5, pentagonal, except for CD, which is modified to receive rectangular RA plate; swollen; proximal tips in basal concavity; medial areas make up basal plane of cup; distal tips rise slightly above half the cup height. RR 5, epaulette-shaped; proximal tips reach to about 1/3 cup height above basal plane; inflated in cross section, curving inward sharply near summit. Cup surface ornamented with coarse nodes.

Forefacetal areas narrow, sloping outward at about 45 degrees. Outer marginal ridge and outer ligament furrows faint; transverse ridge not well defined and ligament pit narrow, shallow. Lateral ridge low and adsutural slope nearly flat; lateral lobes large, crescentic, with sharply cuspate intermuscular notch.

Remarks – A highly ornamented PBr1 plate (text-fig. 8, *4, 5*) from the Kanwaka Formation in Chatauqua County, Kansas, locality 14, probably belongs to *S. iatani.*

There is some confusion as to the exact unit from which Robert Berry collected the holotype specimen that Strimple subsequently described. Strimple (1949a, p. 344) stated the holotype was collected from the Iatan Formation, Douglas Group, Missouri Series, Pennsylvanian, near Richfield, Nebraska. Lithostratigraphers (Condra and Reed, 1959; Burchett and Reed, 1967) and biostratigraphers (Pabian and Strimple, 1993) have not recognized the Iatan Limestone in the lower Platte River valley of Nebraska, and it appears to be a locally thickened carbonate sequence that does not extend far from its type area. To further complicate matters, the section at Richfield includes only the older Missourian units and the Iatan is very latest Missourian or very earliest Virgilian. It is most likely that Strimple's type specimen actually was collected from the Westerville Limestone Member of the Sarpy Formation of Burchett and Reed (1967). Webster's (1981) given range for this genus extends only through about the lower Missourian, and our youngest specimen is from the Kiewitz shale bed of the Stoner Limestone Member of the Stanton Formation; this extends the range of *Synarmocrinus* to near the top of the Missourian.

Material studied – Hypotypes, UNSM 38363, Merriam Limestone Member, Plattsburg Formation, Ash Grove Cement Company Quarry, SE ¼, sec. 14, T. 12 N., R. 12 E., Cass County, Nebraska; UNSM 26034, Kanwaka Formation, Chataqua County, Kansas, locality 14.

Genus **PARETHELOCRINUS** Strimple, 1961

Type species – *Parethelocrinus ellipticus* Strimple, 1961.

Diagnosis – (After Webster, 1981.) Cup low, broad bowl- or globe-shaped, widest at apices of basals with shallow basal invagination. Infrabasals sub-horizontal; radial facets sub-horizontal; cup plates smooth; sutures slightly impressed; 2 anals present, biserial arms 12 - 16; column round, heteromorphic with pentalobate lumen.

Other species included – *Parethelocrinus crassus* (Meek & Worthen, 1860); *P. plattsburgensis* (Strimple, 1938); *P. variabilis* (Strimple, 1949a); *P. watkinsi* (Strimple, 1949a).

Range – Pennsylvanian (Morrowan - Missourian), USA, Nebraska, Kansas, Oklahoma, Texas.

Remarks – Webster (1981) suggested that the range of *Parethelocrinus* extended from the Morrowan through the Desmoinesian, but at least one of the species he included in the genus, *P. plattsburgensis,* is from the late Missourian of northeastern Oklahoma.

Parethelocrinus* sp.** cf. ***variabilis (Strimple), 1949a

Text-figs. 6, *9 –11*; 7, *1, 2, 10 - 12*

Description – Both dorsal cups at hand are crushed, and although it is not possible to determine their cross sections, both are probably round in outline. The basal concavity appears broad and fairly shallow with 5 slightly downflared IBB plates; columnar cicatrix about half the diameter of the IBB circlet; stem round, impression deep with cylindrical walls; lumen pentalobate. BB 5, proximal tips in basal concavity; medial areas form basal plane of cup; pentagonal except CD.

Radianal triangular to quadrangular, large, followed by large anal X and smaller tube plate. RR 5, epaulette shaped,

inflated in cross section, recurving sharply near cup summit. Cup surface smooth.

Articular facets plenary, generally sloping inward. Forefacetal area fairly narrow, sloping outward at about 45 degrees. Outer marginal ridge broad, indistinct, followed by shallow outer ligament furrow. Outer ligament and transverse ridges fairly well defined; ligament pit shallow but readily visible. Lateral ridge, lateral slopes indistinct, flat, and lateral lobes large, sub-triangular.

Remarks – The material is insufficient and preservation too poor to provide other than a comparison to one of the younger species of this genus. Apparently, the height-to-diameter ratio *P. variabilis* cups from Nebraska may actually be a bit lower than the slightly older cups of the same species from Oklahoma. Both have a few small worm borings. They appear to be healed over in one specimen.

One example has a small puncture on the BC basal (text-fig. 7, *7*) and a larger puncture on the D radial (text-fig. 7, *8*).

Material studied – Hypotypes, UNSM 38359 - UNSM 38360, Bethany Falls Limestone Member, Swope Formation, City Wide Limestone Quarry, SW 1/4, sec. 20 or NW 1/4, sec. 29, T. 13 N., R. 13 E., Sarpy County, Nebraska.

Genus **ULOCRINUS** Miller & Gurley, 1888 [1890]

Type species – *Ulocrinus buttsi* Miller & Gurley, 1888 [1890]

Diagnosis – (After Webster, 1981.) Cup globose or urn-shaped, widest at apices of basals; base rounded or constricted; infrabasals up-flaring; radial facets sub-horizontal; cup plates smooth; sutures impressed; 2 anals present (rarely 3); biserial arms 10; column round, heteromorphic with pentalobate lumen.

Other species included – *Ulocrinus convexus* (Strimple, 1939a); *U. elongatus* Strimple, 1961; *U. extrorsus* Strimple & Watkins, 1969; *U. fistulosus* Strimple & Moore, 1971a; *U. occidentalis* Miller & Gurley, 1894; *U. rockymontanus* Strimple & Moore, 1973; *U. zeschi* Strimple & Watkins, 1969.

Range – Pennsylvanian (Atokan - Virgilian), USA: Illinois, Iowa, Missouri, Nebraska, Kansas, Oklahoma, Texas, Colorado.

***Ulocrinus* sp. A**
Text-fig. 6, *14, 15*

Remarks – A partial basal plate and a primibrachial plate have been recorded from the Stull Shale Member of the Kanwaka Formation, Montgomery County, Iowa. This extends the range of the genus into the early Virgilian. Both plates have encrusting worm tubes and irregular slash marks.

Material studied – Hypotypes, UNSM 38368, Stull Shale Member, Kanwaka Formation, approximate sec. 5, T. 73 N., R. 36 W., Montgomery County, Iowa.

Genus **PARULOCRINUS** Moore & Plummer, 1940

Type species – *Parulocrinus blairi* (Miller & Gurley), 1894.

Diagnosis – (After Webster, 1981). Cup sub-globose, widest at apices of basals; base broad but not invaginated; infrabasals sub-horizontal; cup plates smooth; sutures distinct to faintly impressed; 2 anals present (rarely 3), biserial arms 14 to 18; column round, heteromorphic and lumen pentalobate.

Other species included – *Parulocrinus beedei* Moore & Plummer, 1940; *P. caverna* (Strimple, 1949c); *P.? planus* Strimple & Moore, 1973; *P. pontiacensis* Strimple & Moore, 1971a; *P. rectilatus* (Lane & Webster, 1966); *P. tapajos* (Strimple, 1960).

Range – Middle - Upper Pennsylvanian (Desmoinesian - Virgilian) - Early Permian (Wolfcampian), USA: Illinois, Iowa, Nebraska, Kansas, Oklahoma, Texas; Brazil.

Parulocrinus* sp.** cf. ***P. blairi Miller & Gurley, 1894
Text-figs. 6, *12, 13*; 7, *3 - 7*

Description – Cup low bowl; IBB 5, forming pentagonal, slightly upflared circlet with round columnar cicatrix. Outline circular, broadest at about basal apices or medial points of radials. BB 5, pentagonal except CD modified to retain quadrangular RA plate above; proximal tips extend to nearly basal plane of cup, curve upward in sub-parabolic cross section to about half the cup height. RR 5, pentagonal; proximal tips about 1/3 cup height above basal plane; they curve upward in circular cross section, recurving sharply at cup summit. Cup surface smooth; sutures, not deeply impressed.

Articular facets plenary, nearly flat lying; forefacetal area slopes outward at about 45 degrees. Outer marginal and outer ligament ridges bound shallow, distinct furrow. Transverse ridge sharp, ligament pit deep, well defined. Lateral slope and lateral ridges show little topography; lateral lobes sub-triangular and intermuscular notch an obtuse angle. Muscle areas deeply concave.

Remarks – *Parulocrinus blairi* is one of the more common cromyocrinids to be found in the Virgilian of the Midcontinent. Only *Ulocrinus convexus* and *Aglaocrinus compactus* appear to be more common. Cromyocrinids are found mostly in nearshore facies in the midcontinent and Holterhoff (1988) showed that these environments were preferred by crinoids that have complex filtration fans. Examples of punctures on the insides of plates of *P. blairi* may suggest post-mortem scavenging (text-figs. 7, *3, 6*).

Material studied – Hypotypes, UNSM 38361, Plattsmouth Limestone Member, Oread Formation, N 1/2, SE 1/4, sec. 10, T. 10 N., R. 12 E., Cass County, Nebraska. UNSM 38362, Stull Shale Member, Kanwaka Formation, Ace Hill Quarry, SW 1/4, sec. 33, T. 12 N., R. 14 E., Cass County, Nebraska.

Genus **AGLAOCRINUS** Strimple, 1961

Type species – *Aglaocrinus magnus* (Strimple), 1949a.

Diagnosis – (After Webster, 1981.) Cup low, broad, bowl-shaped, widest at apices of basals with flat base or very shallow concavity; infrabasals sub-horizontal; radial facets

slope inward; basals form outer half of basal plane; walls sub-vertical; sutures deeply impressed; cup plates with granules or nodose ornament; 2 anals present; 10-12 biserial arms present; column round, heteromorphic with pentalobatte lumen.

Remarks – Aglaocrinus has 11 recognized species. They range from Middle Pennsylvanian (Desmoinesian) to Late Pennsylvanian (Virgilian) (see table 9).

Table 9. Species assigned to *Aglaocrinus* Strimple.

Taxon, Author	Range, Distribution
Aglaocrinus compactus (Moore & Plummer, 1940)	Late Pennsylvanian (Missourian -Virgilian), MO, NE, KS, OK, TX
Aglaocrinus cranei Strimple, 1971	Late Pennsylvanian (Virgilian), KS
A. konecnyorum (Webster, 1981)	Middle Pennsylvanian (Desmoinesian), AZ
Aglaocrinus magnus, Strimple 1949a, type species	Middle Pennsylvanian (Desmoinesian), OK
A. marquisi (Moore & Plummer, 1940)	Late Pennsylvanian (Missourian), TX
A. millsapensis (Moore & Plummer, 1940)	Middle Pennsylvanian (Desmoinesian), TX
Aglaocrinus nacoensis Webster, 1981	Middle Pennsylvanian (Desmoinesian), AZ
A. pustulosus (Moore & Plummer, 1940)	Late Pennsylvanian (Missourian), TX
A. sutherlandi Strimple, 1980	Middle Pennsylvanian (Desmoinesian), NM
A. tuberculatus (Meek & Worthen, 1866)	Late Pennsylvanian (Missourian), IL
A. verrucosus (White & St. John, 1868)	Pennsylvanian, IA

Aglaocrinus compactus (Moore & Plummer), 1940
Text-figs. 7, *8, 9, 13 - 15*; 8, *1 - 3*

Description – Dorsal cup low bowl, round to sub-elliptical in outline; base very slightly concave to nearly flat, restricted to inner half of basal plane. IBB 5, kite-shaped, forming pentagonal circlet; columnar cicatrix round with nearly vertical walls, about 2/3 to 1/3 diameter of IBB circlet; columnar cicatrix crennulated; lumen stellate. BB 5, pentagonal but CD modified to receive radianal and anal X above; proximal ends included in basal cup plane; medial areas curve upward in parabolic cross-section, extending slightly over 2 the cup height; distal ends nearly vertical. RR 5, irregularly pentagonal, about twice as wide as long; proximal tips extend about half way to basal plane; they recurve sharply near cup summit; C and D separated by anal X.

Sutures between plates somewhat impressed and cup surface mildly granulose.

Forefacetal areas narrow, slope outward at about 45 degrees. Outer ligament and transverse ridges well-defined; outer ligament ridge poorly defined and outer ligament furrow and ligament pits deep. Lateral ridge low and lateral slope not well defined topographically. Lateral lobes triangular, forming deep intermuscular notch. Muscle areas large, sloping inward slightly.

Remarks – *Aglaocrinus compactus* is probably the most common, most widely distributed, and longest ranging cromyocrinid species in the Midcontinent (see table 9). An infrabasal circlet (text-fig. 7, 9) shows several short, straight gouges. Several examples show medium to heavy coatings of algae (text-fig. 7, *13 - 15*).

In addition to being fairly common, a large observed range of cup diameters for *A. compactus* may make this species a prime target for constructing a growth series for a Late Pennsylvanian cromyocrinid. The smallest cup in our sample (text-fig. 8, *1 - 3*) is 8.3 mm in diameter (posterior to anterior), and the largest (text-fig. 7, *13 - 15*) is 32.8 mm in diameter (posterior to anterior). Even by the time the cup reached the smallest diameter above, it appears to have acquired fully adult morphologic features.

Material studied – Hypotypes: UNSM 38355, Plattsmouth Limestone Member, Oread Formation, sec. 5, T. 73 N., R. 36 W., Montgomery County, Iowa, about 1 mi N. and 1 mi W. of Grant; UNSM 38356 - UNSM 38357, Stull Shale Member, Kanwaka Formation, Ace Hill Quarry, SW 1/4, sec. 33, T. 12 N., R. 14 E., Cass County, Nebraska; UNSM 38358, Stull Shale Member, Kanwaka Formation, sec. 5, T. 73 N., R. 36 W., Montgomery County, Iowa, about 1 mi N. and 1 mi W. of Grant.

Superfamily **PIRASOCRINACEA** Moore & Laudon, 1943
Family **PIRASOCRINIDAE** Moore & Laudon, 1943
Diagnosis – See Pabian & Strimple (1985, p. 54)
Genera – See Pabian & Strimple (1985, p. 54)
Genus **PLAXOCRINUS** Moore & Plummer, 1938
Type species – *Plaxocrinus crassidiscus* (Miller & Gurley), 1894

Diagnosis – Dorsal cup round to sub-pentagonal, with broad, shallow basal concavity and wide interradial notches. IBB 5, proximal tips downflared, covered with crennulated columnar cicatris; lumen pentalobate. BB 5, proximal tips included in concavity; distal portions flare upwards and outwards, readily visible in side view of cup. RR 5, wide, slightly tumid; proximal tips included in basal plane. Posterior interradius narrow; RA in direct posterior position; anal X directly above. RR articular facets peneplenary, sloping outward. Arms uniserial, multibranching.

Other species included – *Plaxocrinus aplatus* Moore & Plummer, 1940; *P. beggsi* Strimple, 1961; *P. brasilensis* Lane, 1964a; *P. crassidiscus* Miller & Gurley, 1894; *P. discus* (Meek & Worthen, 1860); *P. kansasensis* (Weller, 1898); *P. macrospiniferus* Pabian & Strimple, 1974b; *P. octarius* Strimple, 1961; *P. oeconomicus* Strimple, 1951a; *P. orthodoxus* Moore, 1939; *P. normalis* Strimple, 1961; *P. piutae* Lane & Webster, 1966; *P. puteus* Strimple, 1949a; *P.*

strigosus Moore & Plummer, 1938; *P. virginarius* Moore, 1939.

Range – Middle Pennsylvanian (Atokan) - Late Pennsylvanian (Virgilian), Early Permian (Wolfcampian), USA, Nevada, Texas, Oklahoma, Kansas, Nebraska, Missouri, Iowa, Illinois; Brazil.

Plaxocrinus crassidiscus (Miller & Gurley), 1894
Text-fig. 8, *6, 7*

Description – Dorsal cup flat to low truncated bowl; outline sub-hexagonal due to wide posterior interradius. Notches between RR more prominent in larger than smaller cups. IBB 5, kite-shaped, forming flat to slightly conical circlet with round columnar cicatrix with vertical walls. Stem impression about half diameter of IBB circlet, crennulated, with penatlobate lumen. BB 5, pentagonal, but BC and CD may be modified to receive RA and anal X plates; proximal tips in very shallow concavity, medial areas form basal plane of cup, and distal tips rise about 1/5 cup height. RR 5, tapered pentagons, except C may be modified to receive RA below; proximal tips extend to basal plane and may be included therein; cross section hyperbolic, becoming asymptotic near basal plane and nearly vertical toward cup summit. Cup plates generally smooth; fine granules may be in depressed areas such as posterior interradius. Sutures distinct, somewhat impressed, but cup plates not bulbous even in smaller examples.

Forefacetal area broad, nearly vertical; outer marginal ridge wide and outer ligament furrow narrow, deep in smaller cups and wide, shallow, nearly vertical in larger cups. Facetal areas peneplenary, sloping outward at about 15 degrees in smaller cups and as high as 45 degrees in larger. Outer ligament and transverse ridges fairly well defined, surrounding fairly deep ligament pit furrow and ligament pit. Lateral ridges and adsutural slopes of fairly high relief, forming v-shaped depression the length of the facetal area between adjacent RR plates. Muscle areas large, triangular, merging to form a wide intermuscular notch that connects to a central pit via a short furrow. PBr1 plates axillary, spinose, with articular facet that is similar, but smaller, to that on the RR plates.

Remarks – There appears to be a change in attitude of the radial articular facets from small to large cups, where they slope outward at about 15 degrees in juvenile cups and up to about 45 degrees in large cups. The presence of fine granulation on cup plates only in depressed areas may suggest that the cups underwent some agitation and abrasion after the death of the animal. The cups appear to be relatively free of epifauna but two of them have healed, round scars and at least one cup appears to have an unhealed laceration.

Material studied – Hypotypes, UNSM 38366, Stull Shale Member, Kanwaka Formation, Ace Hill Quarry, SW 1/4, sec. 33, T. 12 N., R. 14 E., Cass County, Nebraska. UNSM 38367, Haynies Limestone Bed, Ervine Creek Limestone Member, Deer Creek Formation, Queen Hill Quarry, SW 1/4, sec. 9, T. 11, N., R. 14 E., Cass County, Nebraska.

Genus **VERTIGOCRINUS** Knapp, 1969

Type species – *Perimestocrinus subtilis* Moore, 1939

Diagnosis – Basal concavity narrow, distinct; notches between facets narrow, giving the cup a hexagonal outline; sutures impressed. Cup smooth. Modified after Knapp (1969, p. 378)

Table 10. Species assigned to *Vertigocrinus* Knapp.

Taxon, Author	Range, Distribution
Vertigocrinus calyculus (Moore & Plummer, 1940)	Middle Pennsylvanian (Desmoinesian), TX
Vertigocrinus gloukosensis (Strimple, 1951b)	Late Pennsylvanian (Virgilian), KS
Vertigocrinus parilis (Moore & Plummer, 1940)	Late Pennsylvanian (Missourian), TX
Vertigocrinus politus (Moore, 1939)	Late Pennsylvanian (Virgilian), OK
Vertigocrinus subtilis, (Moore, 1939), type species	Late Pennsylvanian (Virgilian), OK

Remarks – *Vertigocrinus* appears to be in a lineage including *Plaxocrinus, Simocrinus, Affinocrinus, Retusocrinus,* and *Platyfundocrinus.* The lineage appears to have developed by change in attitude of IBB and BB plates rather than by thickening of BB plates to produce a moderate concavity.

Vertigocrinus parilis (Moore & Plummer, 1940)
Text-fig. 8, *8, 9*

Description – Dorsal cup flat to low basally impressed bowl; outline sub-hexagonal. Posterior interradius wide, deep; notches between radials fairly distinct, even in smaller specimen. IBB 5, kite-shaped, downflaring, confined to basal concavity and forming sub-spherical circlet. Columnar cicatrix round, crennulated; lumen round. BB 5, mostly pentagonal except BC and CD may be modified to receive RA and anal X plates above; proximal tips in basal concavity; medial portions form basal plane of cup and distal tips rise about half distance to cup summit. RR 5, usually pentagonal except C may be modified; proximal tips reach to basal plane; upward curvature more or less hyperbolic. RR geniculate sharply inward near cup summit and peneplenary articular facet slopes outward at about 45 degrees. Cup plates generally smooth; sutures distinct and may be impressed.

Forefacetal area long, flat, sloping inward slightly to nearly vertical. Outer marginal ridge broad; outer ligament furrow wide. Ligament and transverse ridges bound fairly deep ligament pit and furrow. Lateral ridge and lateral slopes form area of high relief, and they converge from adjacent radials to form deep v-shaped notch. Muscle areas pie-slice-like, slightly concave; intermuscular notch broad, and intermuscular furrow wide and connected to large central pit.

Remarks – Ornamentation in the form of fine granules may be present on depressed areas of cup (cf. *Plaxocrinus*

crassidiscus, above) and this may be due to tumbling and abrasion. One cup has a large, round boring near the IBB circlet and another has small, round cylindrical boring on the anal X plate.

Material studied – Hypotypes: UNSM 38352, Stull Shale Member, Kanwaka Formation, Ace Hill Quarry, SW 1/4, sec. 33, T. 12 N., R. 14 E., Cass County, Nebraska.

Genus **TRICERACRINUS** Bramlette, 1943

Type species – *Triceracrinus moorei* Bramlette, 1943, p. 550

Diagnosis – Basal and radial plates bulbous or spinose. No external ligament area present. Anal series in natural arrangement.

Other species included – *Triceracrinus quinquactus* (Moore) 1939, *T. fabulosus* (Strimple) 1950, *T. spinosus* (Strimple), 1950, *T. habitus* (Strimple) 1950, *T. facilis* (Strimple) 1950, *T. granulosus* (Strimple) 1939b, *T. bulbosus* (Strimple) 1962a, *T. altamontensis* (Strimple) 1950, *Triceracrinus* sp., Pabian and Rushlau, 2002.

Range – Middle Pennsylvanian (Desmoinesian) - Lower Permian (Wolfcampian), USA; TX, OK, KS, IA, NE.

***Triceracrinus* sp.**
Text-fig. 8, *10, 11*

Remarks – The short but bluntly spinose primibrachial from the Hughes Creek Shale near Salem, Nebraska, appears to be most closely related to *Triceracrinus*. This genus has not been previously recorded from Nebraska, although it is known from the Virgilian and Wolfcampian of Kansas. The PBr1 plate under study has several tiny punctures and worm tubes attached to it (text-fig. 8, *10, 11*).

Material studied – Hypotype, UNSM 38346, Hughes Creek Shale Member, Foraker Formation, NE ¼ NW ¼, sec 15, T. 1 N., R. 15 E., Richardson County, Nebraska.

Indeterminate Pirasocrinid Plates
Species A
Text-fig. 12, *9, 10;* 13, *1-5*

Remarks – Two sac spines and a primibrachial from an undetermined pirasocrinid have irregular borings, gouges, slashes and worm tubes on their outer surfaces. Insufficient data is currently available to determine the impact of parasites and commensals on later Pennsylvanian crinoids, but future studies should be geared to document the epifauna, evidence for predation and scavenging, and other pertinent paleoecological and taphonomic data.

Material studied – Hypotypes, UNSM 38374 - 38376, Kanwaka Formation, sec. 5, T. 73 N., R. 36 W., Montgomery County, Iowa.

Species B
Text-fig. 13, *6 - 9*

Remarks – A bulbous radial plate and long, spinose PBr1 plate appear to be of the same species and they are characterized by the granulation on the distal part of the RR and the proximal part of the PBr1 (text-figs. 13, *8, 9*).

Material studied – Hypotypes, UNSM 38395, Hughes Creek Shale, northeast of Humboldt, Nebraska, locality 22.

Species C
Text-fig. 13, *10 - 13*

Remarks – These are terminal sac spines that lack ornamentation. They may or may not belong to species B above, as these plates are not commonly ornamented even on species that have highly ornamented cups and proximal brachials.

Material studied – Hypotypes, UNSM 38396, Hughes Creek Shale, northeast of Humboldt, Nebraska, locality 22.

Family **ANOBASICRINIDAE,** Strimple, 1961

Genus **SCIADIOCRINUS** Moore & Plummer, 1938

Synonym – *Schistocrinus*, in part.

Type species – *Zeacrinus (Hydreionocrinus) acanthophorus* Meek & Worthen, 1865b?

Table 11. Species assigned to *Sciadiocrinus* Moore & Plummer.

Taxon, Author	Range, Distribution
Sciadiocrinus acanthophorus (Meek & Worthen, 1865b?)	Middle Pennsylvanian (Desmoinesian), IL
Sciadiocrinus abolitus Strimple & Cocke, 1973	Late Pennsylvanian (Missourian), OK
Sciadiocrinus cascus Moore & Strimple, 1973	Early Pennsylvanian (Morrowan), OK
Sciadiocrinus confertus (Moore & Plummer, 1940)	Middle Pennsylvanian (Desmoinesian), TX
?Sciadiocrinus crassacanthus Moore & Plummer, 1938	Early Pennsylvanian (Morrowan), OK, AK
Sciadiocrinus disculus Moore & Plummer, 1940	Late Pennsylvanian (Missourian), TX
Sciadiocrinus harrisae Moore & Plummer, 1940	Middle-Late Pennsylvanian (Desmoinesian-Missourian), TX, OK, KS
Sciadiocrinus humilis Strimple, 1951b	Late Pennsylvanian, (Virgilian), KS, NE
Sciadiocrinus invaginatus (Strimple, 1951b)	Late Pennsylvanian (Missourian), TX
Sciadiocrinus llanoensis Strimple & Watkins, 1969	Middle Pennsylvanian (Desmoinesian), TX, OK

Table 11-continued. Species assigned to *Sciadiocrinus* Moore & Plummer.

Taxon, Author	Range, Distribution
Sciadiocrinus obesus (Moore & Plummer, 1940)	Middle - Late Pennsylvanian (Desmoinesian - Missourian), TX
Sciadiocrinus parvus (Moore & Plummer, 1940)	Middle Pennsylvanian (Desmoinesian), TX
Sciadiocrinus pentagonus (Miller & Gurley, 1894)	Late Pennsylvanian (Missourian), MO, KS
Sciadiocrinus planulatus? (Moore & Plummer, 1940)	Middle Pennsylvanian (Desmoinesian), TX
Sciadiocrinus platybasis (White, 1876)	Middle Pennsylvanian? (Desmoinesian), UT
Sciadiocrinus plautus Strimple, 1975a	Middle Pennsylvanian (Atokan), MO
Sciadiocrinus tegillum Strimple & Moore, 1971a	Late Pennsylvanian (Missourian), IL
Sciadiocrinus wipsorum Webster and Houck, 1998	Early Pennsylvanian (Morrowan), CO

Diagnosis – (From Moore & Plummer, 1938, p. 275) Crown short, somewhat expanded. Dorsal cup very low, with basal concavity; IBB 5, not visible from side; BB 5, generally not visible from side except at posterior; RR 5, facets slightly less than width of plates; anal plates 3, x and rt entering dorsal cup only slightly. Anal sac as in *Hydreionocrinus*, with prominent marginal spines at distal extremity, forming an eave-like overhang; genotype shows rounded anal vent on anterior side of sac at about mid-height (shown by cleaning of Meek and Worthen's holotype). Arms rounded, isotomous, branching two or more times on each ray, segments uniserial, quadrangular, branches not laterally in contact. Stem round.

Remarks – Lewis and Strimple (1990, p. 293-300) suggested that *Sciadiocrinus* and *Schistocrinus* were synonyms and that the former had priority. They further suggested that *Sciadiocrinus* be assigned to the Anobasicrinidae rather than the Pirasocrinidae. There are considerable differences in the nature of the bases of the cups of the two genera aside from shortening of the basal sutures such that the proximal tips of the radials contact the infrabasals.

Sciadiocrinus has a hexagonal outline with v-shaped notches between radials and both infrabasals and most of the basals confined to the basal concavity of the cup; the cup is generally a low, basally impressed bowl. *Schistocrinus* has a nearly round outline with rounded notches between radials and both basals and infrabasals visible from the side of the cup; the cup is generally a low bowl in cross section. The latter has a deep, cylindrical basal concavity that appears to have been almost entirely filled by stem.

The arm structure of the two genera is similar, suggesting a close relationship between them. We are retaining the two separate genera but are tentatively assigning *Sciadiocrinus* to the Anobasicrinidae, but for slightly different reasons, above, than given by Lewis and Strimple (1990).

Webster and Houck (1998) and Itano (1999) retained *Sciadiocrinus* in the Pirasocrinidae. Their evaluation of the genus may be correct. We are retaining *Sciadiocrinus* in the Anobasicrinidae with some reservations as the familial placement of this genus is beyond the scope of this study.

The number of species tentatively assigned to *Sciadiocrinus* and the relatively low number of specimens suggest that this genus is not yet well understood. Most of the species are based on loose cups or plates without regard to crowns or to variation that might be shown in complete ontogenetic series. Some of the species (including the holotype of the type species) appear to be based on immature individuals. Therefore, most of the above species (table 11) are retained with some reluctance.

Sciadiocrinus humilis Strimple, 1951b
Text-fig. 8, *12 - 14*

Synonyms – *Sciadiocrinus humilis* Strimple, 1951b, p. 373; Knapp, 1969, p. 378; Pabian & Strimple, 1974a, p. 284; Pabian & Strimple, 1980a, p. 18; 1985, p. 56, 57.

Description – See Pabian & Strimple (1985, p. 56, 57)

Remarks – The specimen at hand is about the same size and geometry as one from the Stull Shale near Weeping Water, Nebraska, that was described by Pabian & Strimple (1985, p. 56, 57). It has at least 24 sub-hemispherical borings on the outer surface. All but two of the borings have no surrounding topography but one (and possibly two) borings on the E radial show a great degree of swelling. The swelling appears to surround the larger of the two borings, and the smaller boring may show some swelling that really belongs to the larger boring. There is also a deep, narrow, elliptical gouge on the C radial that may have been produced by a sponge. There are also the remnants of several worm tubes on the cup surface.

This species is rather easy to identify since the basal plane of the cup is situated near the proximal tips of the radial plates.

Material studied – Hypotype, UNSM 38364, Stull Shale Member, Kanwaka Formation, SW 1/4, sec. 33, T. 12 N., R. 14 E., Cass County, Nebraska.

Superfamily **LOPHOCRINACEA** Bather, 1899
Family **LAUDONOCRINIDAE** Moore & Strimple, 1973

Diagnosis – (Modified after Moore & Strimple, 1973, p. 20) Cup low bowl-shaped, with flat or faintly convex base and sub-vertical sides near rim, arm facets peneplenary, interradial notches seen in dorsal and ventral views; 2 or 3 anals in cup; anal sac mushroom-like with horizontal girdling spines at summit; arms endotomous.

Table 12. Genera assigned to Laudonocrinidae.

Taxon, Author	Range, Distribution
Laudonocrinus Moore & Plummer, 1940	Pennsylvnian (Desmoinesian - Virgilian) TX, OK, KS, NE, IL
Anchicrinus Strimple & Watkins, 1969	Pennsylvanian (Atokan - Desmoinesian), TX
Athlocrinus Moore & Plummer, 1940	Pennsylvanian (Desmoinesian - Missourian), TX, OK, KS, NE
Bathronocrinus Strimple, 1962a	Pennsylvanian (Desmoinesian - Virgilian), Lower Permian), TX, OK, KS, NE, Russia
Paianocrinus Strimple, 1951d	Mississippian (Chesteran), Pennsylvanian (Atokan - Virgilian), OK, AK, TX

Genus **BATHRONOCRINUS** Strimple, 1962a

Type species – *Bathronocrinus turioformis* Strimple, 1962a

Diagnosis – Cup low cone to low bowl, saucer-like; posterior interradius wide, outline of cup hexagonal. IBB 5, visible in side view of cup. Column round. BB, RR, 5 each. Anals, 3 in cup.

Table 13. Species assigned to *Bathronocrinus* Strimple.

Taxon, Author	Range, Distribution
Bathronocrinus deweyensis (Strimple, 1939a)	Pennsylvanian (Missourian), OK
Bathronocrinus madisonensis Pabian & Strimple, 1980a	Late Pennsylvanian (Missourian), IA, NE
Bathronocrinus magnospinosus Arendt, 1968	Permian, Russia
Bathronocrinus wolfriverensis Pabian & Strimple, 1974a	Late Pennsylvanian (Virgilian), NE

Bathronocrinus wolfriverensis Pabian & Strimple, 1974a

Text-fig. 9, *1 - 3*

Remarks – This is the first example of *Bathronocrinus wolfriverensis* to be recorded since the original description of Pabian & Strimple (1974a, p. 281, 282). This genus and its several included species may be rather scarce, as few of their parts have been recorded. The few specimens at hand suggest that the genus may have preferred deeper waters, but more data are needed in order to determine the environments it preferred. Our specimen shows a light coating of algae, a few worm tubes and a very deep gouge that extends across the entire width of the A radial onto the EA basal and the E radial (text-fig. 9, *3*).

Material studied – Hypotype: UNSM 38365, Plattsmouth Limestone Member, Oread Formation, Late Pennsylvanian, Virgilian, collected by G. E. Condra and M. K. Elias from outcrops described as about 2 mi east of the Missouri River Bridge, Plattsmouth, Nebraska. This is in about C, sec. 20, T. 12 N., R. 14 E., Cass County, Nebraska.

Superfamily **TEXACRINACEA** Strimple, 1961

Family **GALATEACRINIDAE** Knapp, 1969

Genus **GALATEACRINUS** Moore, 1940

Galateacrinus gossameri Pabian & Strimple, 1974b

Text-fig. 9, *4 - 6*

Remarks – Pabian and Strimple (1974b, p. 25, 26) recorded this species from the Beil Limestone Member of the Lecompton Formation. They then recorded it from the Coal Creek Limestone Member of the Topeka Formation in Fremont County, Iowa; specimens are also known from the Haynies limestone bed of the Ervine Creek Limestone Member of the Deer Creek Formation. Current collections suggest it may range no higher than the Coal Creek, but its lower boundary is not yet known. The specimen under examination appears to have a light-to-medium coating of algae.

Material studied – Hypotype: UNSM 38378, Haynies limestone bed, Ervine Creek Limestone Member, Deer Creek Formation, SW 1/4, sec. 3, T. 71 N., R. 34 W., Adams County, Iowa.

Family **CYMBIOCRINIDAE** Strimple & Watkins, 1969

Type genus – *Cymbiocrinus* Kirk, 1944, (Upper Mississippian)

Other general included – *Adacrinus* Pabian & Strimple, 1985; *Aenigmocrinus* Strimple, 1973, (Upper Mississippian); *Aesiocrinus* Miller & Gurley 1888 [1890], [=*Pentadelocrinus* Strimple, 1939], (Upper Pennsylvanian); *Allosocrinus* Strimple, 1949c (Middle-Upper Pennsylvanian); *Kansacrinus* Pabian & Strimple, 1985; *Lecobasicrinus* Strimple & Watkins, 1969 (Pennsylvanian); *Proallosocrinus* Moore & Strimple, 1973 (Lower Pennsylvanian); *Oklahomacrinus* Moore, 1939 (Middle-Upper Pennsylvanian); *Sardinocrinus* Pabian & Strimple, 1985.

Genus **ADACRINUS** Pabian & Strimple, 1985

Type species – *Adacrinus loeblichi* (Moore, 1939)

Diagnosis – Cup low, pentagonal, infrabasals 5, flat to downflared; basals 5; basals and infrabasals confined to basal concavity; radial articular facets plenary; outer ligament area nearly vertical. PBr1 short, trapezoidal; PBr2 triangular, axillary, may be resorbed, axillary. Arms 10, short, uniserial.

Table 14. Species assigned to *Adacrinus* Pabian & Strimple.

Taxon, Author	Range, Distribution
Adacrinus loeblichi (Moore, 1939), type species	Late Pennsylvanian (Missourian), OK
Adacrinus bowsheri (Moore, 1939)	Late Pennsylvanian (Virgilian), OK

Table 14-continued. Species assigned to *Adacrinus* Pabian & Strimple.

Taxon, Author	Range, Distribution
Adacrinus canyonensis Strimple & Nassichuk, 1974	Middle Pennsylvanian (Atokan?), Ellesmere Island, Canada
Adacrinus edema Pabian & Rushlau, new species	Late Pennsylvanian, NE
Adacrinus ellesmerensis Strimple & Nassichuk, 1974	Early/Middle Pennsylvanian (Atokan - Desmoinesian) Ellesmere Island, Canada
Adacrinus stevensi Moore, 1939	Late Pennsylvanian (Virgilian), OK

Adacrinus edema Pabian and Rushlau 2002, new species
Text-fig. 9, *7, 8*

Description – Dorsal cup flat, basally impressed bowl; strongly pentagonal in outline. IBB 5, kite shaped, slightly downflared, with pentagonal, crenullated columnar cicatrix; lumen round. IBB circlet sub-stellate, confined to broad deep basal concavity. BB 5, pentagonal, except CD hexagonal to receive narrow quadrangular anal X distally; proximal 2/3 in basal concavity, then swelling near distal tips, which rise upwardly about 1/4 the cup height. RR 5, tapered pentagons; CD separated by anal X; proximal tips in basal concavity; medial areas are swollen and form basal plane of cup, and distal area rises upward in a circular cross section. There is an obtuse geniculation at about half the cup height where outer facetal areas slope upward and inward at about 85 degrees. Cup plates are generally smooth and sutures distinct but not impressed.

Outer marginal ridge well defined, followed by shallow, long furrow and faint outer ligament ridge. Shallow ligament pit furrow and deep ligament pit between faint outer ligament and transverse ridges. Muscle areas narrow, parabolic, nearly flat lying, separated by wide intermuscular notch and furrow. Central pit indistinct. Adsutural slope and lateral ridge in fairly low relief but well defined.

PBr1 plates trapezoidal, non-axillary, with proximal articular facet that is mirror image of one on radial. Distal articular facet similar to proximal except smaller. PBr2 triangular, axillary; outer surface narrower than preceding PBr1 below but inner surface of same width. Articular facets on PBr2 similar to, but smaller than, preceding ones. SBr1 irregularly trapezoidal with proximal articular facet a mirror image of that on PBr1 below, but distal facet large, nearly flat, bean-shaped, with small peripheral denticles.

Remarks – The specific name *edema* is derived from the swollen nature of the basal and radial plates; we selected this feature inasmuch as the type locality and horizon names have been well used for crinoid and other invertebrate species in other genera. The swollen nature of the basal and radial plates characterizes the species. This is the youngest occurrence of *Adacrinus* so far documented.

The PBr1 - PBr2 plates on the paratype specimen (text-fig. 9, 7) appear to be fused, at least on the outside in the B? ray of paratype UNSM 38354.

The holotype specimen appears to have one worm tube on the C radial and the paratype appears to be free of epifauna.

Table 15. Measurements of *Adacrinus edema* Pabian and Rushlau, new species.
Measurements, in mm, are based on Pabian and Strimple, 1985

Specimen	Dpa	Ha	Wa	La
Holotype				
UNSM 38353	22.2	6.7	13.7	6.8
Paratype				
UNSM 38354	23.8	8.2	14.5	6.2

Dpa = diameter of cup, posterior to anterior
Ha = height of cup, anterior
Wa = width of A radial plate
Ha = height of A radial.

Material studied – Holotype, UNSM 38353 and paratype, UNSM 38354, both from Stull Shale Member, Ace Hill Quarry, SW 1/4, sec. 33, T. 12 N., R. 14 E., Cass County, Nebraska.

Genus **ALLOSOCRINUS** Strimple, 1949c

Type species – *Allosocrinus bronaughi* Strimple, 1949c.

Diagnosis – Cup large, bowl-shaped, with broad shallow basal concavity. Arms 5, brachials with many syzygial pairs.

Table 16. Species assigned to *Allosocrinus* Strimple.

Taxon, Author	Range, Distribution
Allosocrinus bronaughi Strimple, 1949c	Late Pennsylvanian (Missourian), OK, KS, NE, IL
Allosocrinus sp. cf. *bronaughi* Pabian & Strimple, 1974a	Late Pennsylvanian (Virgilian), NE
Allosocrinus libratus Strimple, 1961	Middle Pennsylvanian (Desmoinesian), OK
Allosocrinus porus Strimple, 1951c	Late Pennsylvanian (Missourian), OK
Allosocrinus quinarius Lane & Webster, 1966	Early Permian (Wolfcampian), NV

Allosocrinus bronaughi Strimple, 1949c
Text-fig. 10, *1 - 3*

Synonyms – *Allosocrinus bronaughi* Strimple, 1949c, p. 18, 19; Strimple & Moore, 1971, p. 27, 28; Pabian & Strimple, 1974b; p. 12; 1974a, p. 262, 263.

Description – Dorsal cup low bowl, nearly round outline. Basal depression wide, fairly shallow. IBB 5, kite-

shaped, with round, very faint columnar cicatrix. IBB circlet confined to basal concavity. BB 5, with proximal tips in basal depression; medial areas form basal plane; distal tips rise about ½ cup height. CD basal truncated to receive nearly square, thin radianal? with two distal facets. Radials irregularly pentagonal with proximal tips reaching to nearly basal plane; distal areas nearly vertical. Sutures between plates distinct. Plates covered with fine granules.

Forefacetal and facetal areas slope inward. Forefacetal area wide; outer marginal ridge broad; outer ligament furrow shallow, wide. Outer ligament and transverse ridges fairly well defined; ligament pit deep. Muscle areas short; intermuscular notch narrow, short; intermuscular furrow fairly well defined.

Remarks – *Allosocrinus bronaughi* is probably more common in the Nebraska Pennsylvanian section than the number of known cups or complete specimens would indicate since numerous loose plates of this species have been recovered. These plates are all thin, with short facetal areas and finely granular ornamentation.

The cup at hand has almost no trace of a columnar cicatrix. This may have been brought about by a deciduous stem, and the crinoid may have spent part of its life moving about the substrate in a vagrant lifestyle.

A reconstructed cup under study has a somewhat broad, shallow base and short articular facets. The radianal? plate is in an anal X position and appears to have two facets. This is not sufficient criteria to erect a new species. The cup bears superficial resemblance to *Moundocrinus* but the ornamentation on the current example is strong and distinct, whereas *Moundocrinus* has smooth plates.

Material studied – Hypotypes: UNSM 38380, Stull Shale Member, Kanwaka Formation, Ace Hill Quarry, Cass County, Nebraska, locality 4.

Genus **AESIOCRINUS** Miller & Gurley, 1888 [1890]

Type species – *Aesiocrinus magnificus* Miller & Gurley, 1888 [1890].

Diagnosis – Cup low bowl, slightly concave to planar base. Radial articular facets long, quite wide, sloping inward. Anal plate usually large, extending above cup summit. Anal sac long, well developed, with four rows of plates. Arms 10, long, usually branching at PBr2.

Table 17. Species assigned to *Aesiocrinus* Miller & Gurley.

Taxon, Author	Range, Distribution
Aesiocrinus barydactylus Keyes, 1894	Middle - Late Pennsylvanian (Desmoinesian - Missourian), TX, MO
Aesiocrinus basilicus Miller & Gurley, 1888 [1890]	Middle Pennsylvanian (Desmoinesian - Missourian), MO, OK
Aesiocrinus detrusus Strimple, 1951c	Late Pennsylvanian (Missourian), OK

Table 17-continued. Species assigned to *Aesiocrinus* Miller & Gurley.

Taxon, Author	Range, Distribution
Aesiocrinus delicatulus Lane & Webster, 1966	Early Permian (Wolfcampian), NV
Aesiocrinus erectus Strimple, 1951c	Middle Pennsylvanian (Desmoinesian), OK
Aesiocrinus harri [1] Miller & Gurley, 1888 [1890]	Late Pennsylvanian (Missourian), MO
Aesiocrinus inornatus Lane & Webster, 1966	Early Permian (Wolfcampian), NV
Aesiocrinus ivanovi Yakovlev, 1956 (*in* Yakovley & Ivanov)	Carboniferous (C_2m), Moscow Basin, Russia
Aesiocrinus magnificus Miller & Gurley, 1888 [1890]	Late Pennsylvanian (Missourian), MO, NE
Aesiocrinus nodosus Webster & Lane, 1967	Early Permian (Wolfcampian), NV
Aesiocrinus patens (Trautschold), 1879	Middle Carboniferous (C_2m), Moscow Basin, Russia

1. Listed as A. harei *in Webster (1968, p. 40).*

Aesiocrinus* sp.** cf. ***A. detrusus Strimple, 1951c
Text-fig. 9, *9 - 11*

Remarks – This species is characterized by fairly robust plates with short, narrow sutures between them. This architecture creates a fairly unstable cup that most likely will not remain intact after death, especially in shallow, fairly agitated water. Pabian and others (in review) have recorded some examples of *A. detrusus* from the Barnsdall Formation (Pennsylvanian, late Missourian/early Virgilian).

The nature of the ornamentation is shown well on loose plates (text-fig. 9, *9, 11*); the radial plate has several tiny punctures; the non-axillary PRr1 plate is partially fused to an axillary PBr2, and it has several tiny cuts across the articular facet (text-fig. 9, *10*).

Material studied – Hypotypes: UNSM 38385, Stull Shale Member, Kanwaka Formation, Ace Hill Quarry, SW 1/4, sec. 33, T. 12 N., R. 14 E., Cass County, Nebraska.

Superfamily **SCYTALOCRINACEA** Moore & Laudon, 1943

Family **SCYTALOCRINIDAE** Moore & Laudon, 1943

Table 18. Genera assigned to Scytalocrinidae Moore & Laudon.

Taxon, Author	Range, Distribution
Scytalocrinus Wachsmuth & Springer, 1878 (1880), type genus	Upper Devonian - Upper Pennsylvanian, Europe, North America

Table 18-continued. Genera assigned to Scytalocrinidae Moore & Laudon.

Taxon, Author	Range, Distribution
Anametocrinus Wright, 1938	Lower Carboniferous, Scotland?
Bollandicrinus Wright, 1951	Lower Carboniferous, Scotland?
Bridgerocrinus Laudon & Severson, 1953	Upper Devonian - Lower Mississippian, MT
Corematocrinus Goldring, 1923	Upper Devonian - Lower Mississippian, NY
Gilmocrinus Laudon, 1933	Lower Mississippian, IA
Haeretocrinus Moore & Plummer, 1940	Middle Pennsylvanian - Upper Pennsylvanian, MO, NE, KS, OK, TX
Histocrinus Kirk, 1940	Lower Mississippian, IN
Hydriocrinus Trautschold, 1867	Upper Carboniferous, Middle - Upper Pennsylvanian, Russia, NE, IA, KS, IL, OK, TX
Hypselocrinus Kirk, 1940	Lower Mississippian, Scotland, England, IN, UT, IL, IA, MT, TX
Linobrachiocrinus Goldring, 1939 [= *Linocrinus* Goldring, 1938 Aug. *non* Kirk, 1938 April]	Upper Devonian, Russia, NY
Logocrinus Goldring, 1923	Middle Devonian, Russia, MI, NY
Melbacrinus Strimple, 1939a	Upper Pennsylvanian, OK, NE, KS
Morrowcrinus Moore & Plummer, 1938	Lower Pennsylvanian (Morrowan), AR
Ophiurocrinus Jaekel, 1918	Upper Carboniferous
Pegocrinus Kirk, 1940	Upper Carboniferous, England, Ireland
Phacelocrinus Kirk, 1940	Upper Mississippian - Lower Pennsylvanian, Lower Carboniferous, Russia, UK, MO, IL, IN
Roemerocrinus Wanner, 1916	Upper Permian, Timor
Sostronocrinus Strimple & McGinnis, 1969	Lower Mississippian, IA
Tundracrinus Yakovlev, 1928	Lower Permian, Russia

Genus **HAERETOCRINUS** Moore & Plummer, 1940

Type species – *Haeretocrinus missouriensis* Moore & Plummer, 1940.

Diagnosis – Cup conical, evenly sloping sides, about half as high as wide. Infrabasals visible in side view. Anals, 3 in cup. Articular facets plenary. Arms branching endotomously?

Table 19. Species assigned to *Haeretocrinus* Moore & Plummer.

Taxon, Author	Range, Distribution
Haeretocrinus depressus Strimple, 1962a	Middle Pennsylvanian (Desmoinesian), OK
Haeretocrinus intermedius Strimple, 1961	Middle Pennsylvanian (Desmoinesian) OK
Haeretocrinus macoupinensis (Worthen, 1873)	Late Pennsylvanian (Missourian), IL
Haeretocrinus magnus Moore & Plummer, 1940	Middle Pennsylvanian (Desmoinesian), TX
Haeretocrinus missouriensis, Moore & Plummer, 1940, type species	Late Pennsylvanian (Missourian, Virgilian?), MO, KS, NE, OK, TX
Haeretocrinus turbinatus Strimple, 1952	Late Pennsylvanian (Missourian), OK
Haeretocrinus wagneri Strimple & Moore, 1971a	Late Pennsylvanian (Missourian), IL
Haeretocrinus washburni (Beede, 1899)	Late Pennsylvanian (Virgilian), KS

Haeretocrinus* sp.** cf. ***H. missouriensis Moore & Plummer, 1940

Text-fig. 10, *10, 11*

Remarks – *Haeretocrinus missouriensis* may be more common in Missourian strata of the Midcontinent than previously thought. Many infrabasal circlets that are low with short infrabasals have been found in these strata. It appears that only a cone- or bowl-shaped cup could arise from these because of the short, upflared infrabasals. One infrabasal plate is usually longer than the other four. Moore and Plummer's holotype specimen of the type species appears to have a longer IBB in the C ray, and it is possible that these longer IBB plates were all in the C ray.

Material studied – Hypotypes: UNSM 38386, Kanwaka Shale, SE 1/4, sec. 5, T. 73 N., R. 36 W., Montgomery County, Iowa.

Superfamily **AGASSIZOCRINACEA** S.A. Miller, 1888

Family **AMPELOCRINIDAE** Kirk, 1942

Type genus – *Ampelocrinus* Kirk, 1942 (Upper Mississippian - Lower Pennsylvanian).

Genera – *Armenocrinus* Strimple & Horowitz, 1971 (Lower Mississippian - Upper Mississippian); *Arroyocrinus* Lane & Webster, 1966 (Lower Permian); *Chlidonocrinus*

Strimple & Watkins, 1969 (Upper Mississippian - Upper Pennsylvanian); *Halogetocrinus* Strimple & Moore, 1971a (Middle Pennsylvanian - Lower Permian); *Moundocrinus* Strimple, 1939a (Upper Pennsylvanian); *Polusocrinus* Strimple, 1951c (Upper Pennsylvanian - Lower Permian); *Spheniscocrinus* Wanner, 1937 (Upper Permian).

Genus **MOUNDOCRINUS** Strimple, 1939a

Type species – *Moundocrinus osagensis* Strimple, 1939a.

Diagnosis – Cup low bowl; basal depression shallow, wide. IBB 5; circlet stellate, columnar cicatrix round. BB 5, large, shield shaped. RR 5, large, irregularly pentagonal. RA included in radial circlet. Articular facets plenary, short. Arms 10.

Table 20. Species assigned to *Moundocrinus* Strimple.

Taxon, Author	Range, Distribution
Moundocrinus luxuris (Strimple, 1951c)	Late Pennsylvanian (Missourian-Virgilian), OK, NE
Moundocrinus sp. cf. *osagensis* Strimple & Moore, 1971a	Late Pennsylvanian (Missourian), IL
Moundocrinus sp. Pabian & Strimple, 1985	Late Pennsylvanian (Virgilian), NE

Remarks – Pabian & Strimple (1980a, p. 16) moved *Aesiocrinus luxuris* (Strimple, 1951c) to *Moundocrinus,* making the combination *Moundocrinus luxuris* (Strimple, 1951), but they erroneously recorded the diagnosis of the species as Strimple, 1949.

Genus **POLUSOCRINUS** Strimple, 1951b.

Type species – *Polusocrinus avanti* Strimple, 1951b

Diagnosis – Ampelocrinids with round, low to medium globe cups with IBB visible in side view of cup. Arms 14?, uniserial. Anal plate large, quadrangular with two distal facets.

Table 21. Species assigned to *Polusocrinus* Strimple.

Taxon, Author	Range, Distribution
Polusocrinus avanti Strimple, 1951b, type species	Middle Pennsylvanian (Desmoinesian), OK
Polusocrinus ampulus (Webster & Lane, 1967)	Early Permian (Wolfcampian), NV
Polusocrinus calyculoides Lane, 1964b	Early Pennsylvanian (Morrowan), CA
Polusocrinus ochelataensis Strimple, 1952	Late Pennsylvanian (Missourian), OK

Table 21-continued. Species assigned to *Polusocrinus* Strimple.

Taxon, Author	Range, Distribution
Polusocrinus pachyplax Lane, 1964b	Early Pennsylvanian (Morrowan), CA
Polusocrinus rosa Strimple, 1951b	Late Pennsylvanian (Virgilian), OK
Polusocrinus tactilis (Strimple, 1951c)	Late Pennsylvanian (Missourian), KS

Polusocrinus rosa Strimple, 1951b

Text-fig. 10, *4 - 9*

Description – Cup low to medium globe, round outline. IBB 5, kite-shaped, circlet visible in side view of cup. Columnar cicatrix pentagonal, step-like with short crennellae on outer perimeter; lumen round. BB 5, shield-like, hexagonal; CD truncated distally with large, quadrangular RA? above. Tips of BB may slightly above basal plane; BB curve upward in broad, circular cross section to about 2/3 cup height. RR 5, pentagonal, curving upward in continuation of arc of BB below. Sutures distinct, not impressed. Cup plates smooth.

Outer ligament area flat lying, short. Outer marginal and outer ligament ridges sharp, bound deep outer furrow. Transverse ridge well defined, ligament pit deep and wide. Inner facetal area slopes inward, little relief on adsutural slope or lateral ridge. Muscle areas fairly narrow, separated by wide intermuscular notch; intermuscular furrow deep, short, terminating at nearly circular central pit.

Remarks – Two cups from the Stull Shale of Nebraska have worm tubes attached to them (text-fig. 10, *6, 9*). That all of the worm tubes are on only one side of the cup in text-figure 10, *6* suggests that the worms may have established residence on the crinoid after its death. Another cup has several small borings on the outer surface (text-fig. 10, *5*).

Polusocrinus rosa appears to be closely related to *P. ochelataensis*, from which it may have been derived. *P. rosa* has much more robust plates, giving longer but similar articular facets, and the infrabasal circlet is taller, such that the IBB plates are readily visible in side view. *P. ochelataensis* has much thinner plates. Pabian and Strimple (1980a, p. 16) suggested that *P. rosa* first appeared in the Virgilian, and the examples at hand support this observation.

Material studied – Hypotypes: UNSM 38378, Plattsmouth Limestone Member, Oread Formation, approx. sec. 5, T. 73 N., R. 36 W., Montgomery County, Iowa; UNSM 38379, Stull Shale Member, Strimple, Kanwaka Formation, Ace Hill Quarry, SW 1/4, sec. 33, T. 12 N., R. 14 E., Cass County, Nebraska.

Family **DECADOCRINIDAE** Bather, 1890

Genus **GLAUKOSOCRINUS** Strimple, 1951d

Table 22. Species assigned to *Glaukosocrinus* Strimple.

Taxon, Author	Range, Distribution
Glaukosocrinus forneyi Pabian & Strimple, 1974b	Late Pennsylvanian (Virgilian), NE, IA
Glaukosocrinus middalyaensis Webster and Jell, 1999	Permian, Australia
Glaukosocrinus parvisculus, (Moore & Plummer, 1940), type species	Middle Pennsylvanian (Desmoinesian), TX, KS, OK
Glaukosocrinus planus Strimple & Moore, 1971a	Late Pennsylvanian (Missourian), IL
Glaukosocrinus sp. Pabian & Strimple, 1980	Late Pennsylvanian (Missouarian? - Virgilian?), NE
Glaukosocrinus sp. Pabian & Strimple, 1993	Late Pennsylvanian (Missourian), KS

Diagnosis – (After Strimple & Moore, 1971a.) Dorsal cup low, truncate bowl-shaped with evenly rounded sides and small basal concavity. Three anal plates in posterior interradius, short radial articular facets, small round stem.

Remarks – *Glaukosocrinus* appears to be closely related to *Clathrocrinus* – they may be congeneric. *Clathrocrinus* has thinner plates and much finer arms than *Glaukosocrinus,* and the former appears to be more common in offshore environments, whereas the latter may prefer near-shore habitats in less quiet water.

Glaukosocrinus berryi Pabian and Rushlau, 2002, new species

Text-fig. 11, *1-3*

Description – Dorsal cup flat to low truncated bowl, about 1/3 as high as wide. Outline sub-hexagonal; fairly deep notches between RR. IBB plates 5, kite-shaped, forming pentagonal circlet that is confined to very shallow concavity; columnar cicatrix small, round, crenulated. BB 5, proximal tips in shallow concavity; medial areas form basal plane; distal tips rise to about half the cup height. BB pentagonal except BC and CD truncated distally to accommodate pentagonal RA and anal X plates above. RR 5, irregularly pentagonal; proximal tips extend from nearly basal plane (D) up to about 1/3 cup height above basal plane (A); cross section round to parabolic. Forefacetal area somewhat rounded with indistinct features. Cup plates generally smooth; sutures impressed.

Articular facets short; transverse ridge and ligament pit fairly well defined. Lateral areas in low relief; muscle areas triangular? and intermuscular furrow short; central pit triangular. PBr plates not preserved but several SBr plates within the cup show a zig-zag orientation.

Remarks – *Glaukosocrinus berryi* n. sp. has a smooth cup, whereas the slightly younger *G. forneyi* has finely granulose ornamentation on the cup surface. There are several large, round healed scars on the A radial and anal X plate of the holotype specimen. The plates of the cup are rather robust, as should be expected since the specimen came from an upper bed of the South Bend Limestone Member of the Stanton Formation, a nearshore unit (Pabian & Strimple, 1993). The columnar cicatrix is very small in relation to the cup diameter, which is characteristic of the genus *Glaukosocrinus.*

There are also many tiny inter-radial platelets between the A and B radials that cover the lateral areas. Similar plates have been observed on the holotype of *G. forneyi,* and Strimple (1973, p. 28) demonstrated such platelets between radials in the not closely related *Stellarocrinus bilineatus.*

The species is named in honor of Bob Berry, who collected many of the crinoids that were subsequently described by the late Harrell L. Strimple.

Table 23. Measurements of *Glaukosocrinus berryi* Pabian and Rushlau, new species.
Measurements, in mm, based on Pabian and Strimple, 1985.

Specimen	Dpa	Ha	Wa	La
Holotype				
UNSM 38377	23.6	8.7	12.2	7.3

Dpa = diameter, posterior to anterior
Ha = height of cup, anterior
Wa = width of A radial
La = length of A radial

Material studied – Holotype (Monotype): UNSM 38377, South Bend Limestone Member, Stanton Formation, Ash Grove Cement Company Quarry, NE 1/4, sec. 13, T. 12 N., R. 11 E., Cass County, Nebraska.

Glaukosocrinus sp.

Text-fig. 12, *11, 12*

Remarks – We are referring to *Glaukosocrinus* a large PBr1 plate from the Hughes Creek Shale exposed in a road cut north and east of Humboldt, Nebraska. The plate is large and thick, and it appears to have been from a specimen that is about the same size of *G. berryi* above, but our data are insufficient to assign it to a species.

As we go to press, we have observed several PBr1 plates from immature examples of *Glaukosocrinus* from the Severy Shale in Pawnee County, Nebraska, that have a well-defined keel that may be only an ontogenetic feature. Any specimens of *Glaukosocrinus* from the latest Pennsylvanian or earliest Permian will help fill the record of this genus from late Pennsylvanian through middle Permian.

Material studied – Hypotype, UNSM 38394, Hughes Creek Shale northeast of Humboldt, Nebraska, locality 22. UNSM 38401, Severy Shale Formation, near Table Rock,

Pawnee County, Nebraska, locality 20.

Superfamily **APOGRAPHIOCRINACEA** Moore & Laudon, 1943

Family **APOGRAPHIOCRINIDAE** Moore & Laudon, 1943

Genus **APOGRAPHIOCRINUS** Moore & Plummer, 1940

Type species – *Apographiocrinus typicalis* Moore & Plummer, 1940

Diagnosis – Crown ranges from about twice as long as wide (juveniles) to 4 times as long as wide (adults). Cup dicyclic, hemispherical, nearly flat base (juveniles) to somewhat concave base (adults); outline with deep interradial notches (juveniles) to nearly circular (adults). Arms 10, branching on PBr1, followed with up to about 25 cuneiform segments in most mature crowns. Cup surface smooth to finely granular.

Table 24. Species assigned to *Apographiocrinus* Moore & Plummer.

Taxon, Author	Range, Distribution
Apographiocrinus typicalis Moore & Plummer, 1940, type species	Late Pennsylvanian (Missourian), TX, OK, KS, NE, MO, IA, IL
A. calycinus Moore & Plummer, 1940	Late Pennsylvanian (Missourian), TX
A. decoratus Moore & Plummer, 1940	Late Pennsylvanian (Missourian), TX
A. facetus Moore & Plummer, 1940	Late Pennsylvanian (Missourian), TX
A. kokumensis Webster & Jell, 1993	Early Permian, Thailand
A. obtusus Strimple, 1948	Middle Pennsylvanian (Desmoinesian), OK, MI?
A. platybasis Pabian & Strimple, 1980a	Late Pennsylvanian (Virgilian), NE
A. quinquelobus (Wanner, 1916)	Late Permian (Sakmarian?), Asia, Island of Timor
A. raderi Strimple, 1975a	Early Pennsylvanian (Morrowan), TX, AK?
A. rotundus Strimple, 1948	Middle Pennsylvanian (Desmoinesian), OK
A. verbeeki var. *pumila* (Wanner, 1916)	Late Permian (Sakmarian?), Asia, Island of Timor
A. virgilicus Pabian & Strimple, 1974a	Late Pennsylvanian (Virgilian), NE, IA
A. wolfcampensis Moore & Plummer, 1940	Early Permian (Wolfcampian), TX

Apographiocrinus typicalis Moore & Plummer, 1940
Text-fig. 12, *1 - 4*

Synonyms – *Apographiocrinus typicalis* Moore & Plummer, 1940; Moore & Laudon, 1944; Strimple, 1959; Strimple & Moore, 1971a; Pabian & Strimple, 1974b, 1993. *Graphiocrinus carbonarious* (Meek & Worthen, 1862) Strimple, 1938.

Remarks – One cup under examination has only four radial plates. It appears that the E radial is missing and the EA basal is somewhat foreshortened and truncated (text-fig. 12, *1, 2*). Another has a worm tube along the A radius (text-fig. 12, *4*).

Material studied – Hypotypes: UNSM 38387 - UNSM 38390, Haynies limestone bed, Ervine Creek Limestone Member, Deer Creek Formation, Queen Hill Quarry, SW 1/4, sec. 9, T. 11 N., R. 14 E., Cass County, Nebraska.

Apographiocrinus platybasis Pabian & Strimple, 1980a
Text-fig. 12, *5, 6*

Remarks – Pabian and Strimple (1980a, p. 15) described this species to include *Apographiocrinus* with cups having broad, flat bases. The holotype specimen was collected from the Beil Limestone Member of the Lecompton Formation in Cass County, Nebraska.

Material studied – Hypotype: UNSM 38391, Ervine Creek Limestone Member, Deer Creek Formation, Queen Hill Quarry, locality 7.

Genus **CONTOCRINUS** Knapp, 1969

Type species – *Contocrinus stantonensis* (Strimple, 1939a).

Diagnosis – See Pabian & Strimple, 1993, p. 26.

Table 25. Species assigned to *Contocrinus* Knapp.

Taxon, Author	Range, Distribution
Contocrinus stantonensis (Strimple), 1939a, type species	Late Pennsylvanian (Missourian), OK, KS, NE
Contocrinus andamanensis Webster & Jell, 1993	Early Permian, Thailand
C. bridgeportensis (Strimple), 1951a	Late Pennsylvanian (Missourian), TX
C. coupi Strimple & Moore, 1971a	Late Pennsylvanian (Missourian), IL
C. deflectus (Strimple), 1962a	Middle Pennsylvanian (Desmoinesian), OK
C. invaginatus Pabian & Strimple, 1980a	Late Pennsylvanian (Virgilian), IA
C. kingi (Moore & Plummer), 1940	Late Pennsylvanian (Missourian), TX
C. lineatus (Strimple), 1963	Late Pennsylvanian (Missourian), OK
C. scopulus (Lane and Webster), 1966	Early Permian (Wolfcampian), NV

Remarks – Although the range of *Contocrinus* extends from the Desmoinesian through the Wolfcampian, the genus appears to have reached its peak in late Missourian.

Contocrinus stantonensis (Strimple) is the most common crinoid species in the fauna from the Wann Shale near Ochelata, Oklahoma, that was recorded by Pabian (1979). *Contocrinus* normally preferred to live in offshore environments, and the genus is typified by having a crown composed of small, thin plates and a simple filtration fan.

Range – Pennsylvanian (Desmoinesian-Virgilian)-Permian (Wolfcampian), USA: Nevada, Texas, Oklahoma, Nebraska, Kansas, Iowa, Missouri, Illinois.

Contocrinus* sp.** cf. ***stantonensis (Strimple), 1939a
Text-fig. 12, *7, 8*

Remarks – Crowns of this species superficially resemble crowns of *Apographiocrinus typicalis;* the latter are typified by more bulbous plates and by having interradial prongs that extend above the cup summit and are distally separated at the interradius by a tiny wedge-shaped plate. The examples of *A. typicalis* from the Kiewitz shale bed (above) show a tendency to reduce these features. Nonetheless, *A. typicalis* has much longer articular facets and a longer, and more prominent forefacetal area than does *Contocrinus stantonensis.*

The partial cup under examination has a boring and a small worm tube on the D radial. The cup has a roughened surface and is quite flat compared to most other examples of *Contocrinus*.

Material studied – Hypotype: UNSM 38392, Ervine Creek Limestone member, Deer Creek Formation, Queen Hill Quarry, locality 7.

Family **STELLAROCRINIDAE** Strimple, 1961
Type genus – *Stellarocrinus* Strimple, 1940, p. 1.
Diagnosis – See Strimple & Moore, 1971a, p. 30.

Table 26. Genera assigned to Stellarocrinidae Strimple.

Taxon, Author	Range, Distribution
Stellarocrinus Strimple, 1940	Pennsylvanian (Desmoinesian - Virgilian), TX, OK, KS, MO, NE, IL
Brabeocrinus Strimple & Moore, 1971a	Pennsylvanian (Atokan - Virgilian) – Permian (Wolfcampian), OK, KS, NE, IL, NV
Brychiocrinus Moore & Plummer, 1940	Pennsylvanian (Desmoinesian), TX
Celonocrinus Lane & Webster, 1966	Late Pennsylvanian (Missourian) – Early Permian (Wolfcampian), KS, TX, NV, OK
Undescribed genus Pabian *et al.*, n. g.	Late Pennsylvanian (Missourian), OK
Heliosocrinus Strimple, 1951d	Mississippian (Chesteran), OK

Genus **STELLAROCRINUS** Strimple, 1940

Table 27. Species assigned to *Stellarocrinus* Strimple

Taxon, Author	Range, Distribution
Stellarocrinus stillativus (White, 1880), type species	Late Pennsylvanian (Missourian - Virgilian), OK, KS, NE
Stellarocrinus angulatus (Miller & Gurley, 1894)	Late Pennsylvanian (Missourian), MO
Stellarocrinus bilineatus Strimple & Moore, 1971a	Late Pennsylvanian (Missourian), OK
Stellarocrinus bulbus Strimple & Watkins, 1969	Middle Pennsylvanian (Desmoinesian), TX
Stellarocrinus comptus Webster & Lane, 1968	Early Permian (Wolfcampian), NV
Stellarocrinus cuneatus Lane & Webster, 1966	Early Permian (Wolfcampian), NV
Stellarocrinus distinctus Strimple, 1940	Late Pennsylvanian (Missourian), OK
Stellarocrinus exsculptus (Strimple, 1939b)	Late Pennsylvanian (Missourian), OK
Stellarocrinus florealis (Moore & Plummer, 1940)	Middle Pennsylvanian (Desmoinesian), TX
Stellarocrinus geometricus (Moore & Plummer, 1940)	Late Pennsylvanian (Missourian), KS
Stellarocrinus minimus Strimple, 1962a	Middle Pennsylvanian (Desmoinesian), OK
Stellarocrinus petalosus Strimple, 1961	Middle Pennsylvanian (Desmoinesian), OK
Stellarocrinus primus (Strimple, 1975a)	Middle Pennsylvanian (Atokan), OK
Stellarocrinus texani Strimple, 1951a	Late Pennsylvanian (Missourian), TX
Stellarocrinus texanus (Moore & Plummer, 1940)	Middle Pennsylvanian (Desmoinesian), TX
Stellarocrinus virgilensis Strimple, 1951d	Late Pennsylvanian (Missourian), OK, NE

Remarks – *Stellarocrinus* is a fairly common form in Late Pennsylvanian strata, and it is possible to construct growth series from several localities, including this sample, as well as the slightly older LaSalle fauna from Illinois.

We suggest that *Brabeocrinus* represents immature *Stellarocrinus*. The former is distinguished by cuneate brachials that typify juveniles of several groups of crinoids.

Stellarocrinus stillativus (White), 1880
Text-fig. 11, *4 - 6*

Remarks – Pabian & Strimple (1985, p. 65) only recorded *S. stillativus* from the Stull Shale Member of the Kanwaka Formation at outcrops near Melvern, Kansas. This occurrence confirms the existence of this species in the Stull of Nebraska. *S. stillativus* has a relatively low cup compared to other species of *Stellarocrinus*. The range of *S. stillativus*

in Nebraska is extended to the Severy Shale with the discovery of a PBr1 plate from an outcrop near Table Rock in Pawnee County.

The articular facets of the specimen at hand are very well preserved, and they have a very deep and narrow forefacetal area. The outer ligament ridge is strongly denticulate, the ligament pit is deep, and the transverse ridge is non-denticulate. The muscle areas are quite large and are nearly vertical. The muscle areas are sub-triangular and the intermuscular notch is broad and U-shaped. Our example appears to be free of epifauna.

Material studied – Hypotypes: UNSM 38373, Ace Hill Quarry, SW 1/4, sec. 33, T. 12 N., R. 14 E., Cass County, Nebraska; UNSM 38402, Severy Shale Formation, near Table Rock, Pawnee County, Nebraska, locality 20.

Superfamily **ZEACRINITACEA** Bassler & Moodey, 1943

Family **EXOCRINIDAE** Strimple & Watkins, 1969

Genus **EXOCRINUS** Strimple, 1949c

Type species – *Exocrinus multirami* Strimple, 1949c, p. 9

Diagnosis – Crown compact, medium length; dorsal cup shallow, truncate cone with slight basal concavity containing 5 downflared IBBs; BB 5, proximal tips in basal concavity, recurving, outward and upward to about half cup height; RR 5, pentagonal; anals 3, in cup; articular facets plenary, sloping outward at about 30 degrees.

PBr1 normally axillary, followed by one or more axillary SBr plates; up to 3 divisions of branching per ray. Arms stout, short, pinnulate.

Table 28. Species assigned to *Exocrinus* Strimple

Taxon, Author	Range, Distribution
Exocrinus multirami Strimple, 1949c, type species	Late Pennsylvanian (Missourian), OK, KS, NE
Exocrinus desmoinesesis Strimple, 1949c	Middle Pennsylvanian (Desmoinesian), OK
Exocrinus pallium Strimple, 1949c	Late Pennsylvanian (Mis sourian), OK
Exocrinus virgilensis Strimple, 1949c	Late Pennsylvanian (Virgilian), OK
Exocrinus wanni Strimple, 1949c	Late Pennsylvanian (Mis sourian), OK

Remarks – *Exocrinus* is a very common genus in transgressive facies of the late Missourian in the Midcontinent. It is easily recognized by its flat, basally impressed, truncate-cone cup and its short, multibranching arms.

Exocrinus multirami Strimple, 1949c

Text-fig. 11, *7, 8*

Remarks – From a large sample collected by Lewis and others (unpublished data), Pabian has observed that on specimens of *Exocrinus multirami* from the Barnsdall Formation (Missourian/Virgilian) of northeastern Oklahoma, the PBr1 plates were shortened in the B and E radii and extended in the A ray. Although the PBr1 plates were shorter in B and E, the total arm length in these rays was the same as in the A ray because additional SBr plates were present in B and E.

Exocrinus multirami probably makes up a larger component of the echinoderm fauna than the available cups/crowns suggest because many disarticulated crowns are attributed to *Exocrinus*. *E. multirami* appears to be most common in transgressive facies, but at least two examples from the Kanwaka Shale in Iowa and Nebraska are from nearshore environments.

Material studied – Hypotypes: UNSM 38398, Stull Shale, Kanwaka Formation, sec. 5, T. 73 N., R. 36 W, Montgomery County, Iowa. UNSM 38399, Stull Shale Member, Kanwaka Formation, Ace Hill Quarry, SW 1/4, sec. 33, T. 12 N., R 14 E., Cass County, Nebraska.

Subclass **FLEXIBILIA** Zittel, 1895

Order **SAGENOCRINOIDEA** Springer, 1913

Superfamily **SAGENOCRINITACEA** Bassler, 1938

Family **EURYOCRINIDAE** Moore and Strimple, 1973

Genus **PARAMPHICRINUS** Strimple & Moore, 1971a

Type species – *Paramphicrinus oklahomaensis* (Strimple, 1940)

Diagnosis – See Strimple & Moore (1971a, p. 40)

Other species included – *Paramphicrinus oklahomaensis* Strimple, 1940; *P magnus* Moore & Strimple, 1973; *P. poundi* Strimple, 1940.

***Paramphicrinus* sp.**

Text-fig. 11, *9 - 11*

Remarks – Flexible crinoids are rather rare fossils in Virgilian and post-Virgilian strata. The proximal portions of their stems are, however, quite easy to identify by the crinkly nature of the sutures between the very thin proximal columnals, the tapering of the proximal columnals and the disappearance of the crenellae except on the outer edge of distal columnal (text-fig. 11, *9 - 11*). This is one of the latest occurrences of a flexible crinoid from the Midcontinent. Lane and Webster (1966) have documented flexibles from the slightly younger Battleship Wash crinoid fauna in Nevada.

Material studied – Hypotype, UNSM 38345, Hughes Creek Shale Member, Foraker Formation, near Salem, Richardson County, Nebraska, locality 16.

Conclusions

Although crinoid cups or crowns are scarce in post-Missourian strata in the North American Midcontinent, they are found in ample numbers to provide a great deal of taphonomic and paleoecological data. This study demonstrates the need for developing a more uniform terminology for describing the taphonomic features observed on the many fossil crinoids

and for developing more accurate systems for collecting and recording such data.

Most of the crinoids studied here were collected from near-shore facies where most post-Missourian crinoid samples have been recorded. The paucity of offshore crinoid faunas in the post-Missourian strata is possibly an artifact of collection bias as exposures of these units (e.g. Leavenworth Limestone and Big Springs Limestone) in the northern Midcontinent usually have not been available for detailed collecting.

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Appendix

Register of Localities

1. Bethany Falls Limestone Member, Swope Formation, old City Wide Quarry, SW ¼ sec. 20 or NW ¼, sec. 29, T. 13 N., R. 13 E., Sarpy County, Nebraska
2. Merriam Limestone Member, Plattsburg Formation, Ash Grove Cement Company Quarry, SE ¼, sec. 14, T. 12 N., R. 12 E., Cass County, Nebraska.
3. Kitaki Limestone Member, South Bend Formation, Ash Grove Cement Company Quarry, SE ¼, sec. 14, T. 12 N., R. 12 E., Cass County, Nebraska
4. Stull Shale Member, Kanwaka Formation, Ace Hill Quarry, SW ¼, sec. 33, T. 12 N., . 14 E., Cass County, Nebraska.
5. Stull Shale Member, Kanwaka Formation, Queen Hill Quarry, SW ¼, sec. 9, T. 11 N., R. 14 E., Cass County, Nebraska
6. Stull Shale Member, Kanwaka Formation, abandoned quarry, Weeping Water North, SW ¼, SE ¼, sec. 30, T. 11 N., R. 12 E., Cass County, Nebraska.
7. Haynies limestone bed, Deer Creek Formation, Queen Hill Quarry, SW ¼, sec. 9, T. 11 N., R. 14 E., Cass County, Nebraska.
8. Plattsmouth Limestone Member, Oread Formation, approx. NW ¼, sec. 20, T. 12 N., R. 14 E., Cass County, Nebraska.
9. Stull Shale Member, Kanwaka Formation, old Hopper Brothers Quarry, SE ¼, sec. 34, T. 11 N., R. 11 E., Cass County, Nebraska
10. Stull Shale Member, Kanwaka Formation, old Snyderville Quarry, N ½, SE ¼, sec. 10, T. 10 N., R. 12 E., Cass County, Nebraska
11. Lower part of Plattsmouth Limestone, Kaser Construction Company Quarry, NW ¼, NE ¼, sec. 5, T. 73 N., R. 36 W., Montgomery County, Iowa.
12. Kanwaka Shale, Kaser Construction Company Quarry, NW ¼, NE ¼, sec. 5, T. 73 N., R. 36 W., Montgomery County, Iowa.
13. Haynies limestone bed, Ervine Creek Limestone Member, Deer Creek Formation, SW 1/4, sec. 3, T. 71 N., R. 34 W., Adams County, Iowa
14. Kanwaka Formation, Emergency Spillway of Dam on Middle Caney Creek, NE ¼, SW ¼, sec. 3, T. 33 S., R. 10 E., Chataqua County, Kansas
15. Miles Limestone Member, Falls City Formation, NE ¼, SE ¼, SE ¼, sec. 9, T. 1 N., R. 13 E., Richardson County, Nebraska
16. Hughes Creek Shale Member, Foraker Formation, NE ¼, NW ¼, sec. 15, T. 1 N., R. 15 E., Richardson County, Nebraska
17. Stull Shale Member, Kanwaka Formation, near Plattsmouth Bridge, W ½, SE ¼, sec. 20, T. 12 N., R.12 E., Cass County, Nebraska.
18. Stull Shale Member, Kanwaka Formation, N ½, SW ¼, NW ¼, sec. 29, T. 73 N., R. 43 W., Mills County, Iowa.
19. Severy Shale Formation, SW ¼, SE ¼, sec. 14, T. 1 N., R. 12 E., Pawnee County, Nebraska.
20. Severy Shale Formation, NW ¼, NE ¼, sec. 20, T. 3 N., R. 12 E., Pawnee County, Nebraska.
21. Stull Shale Member, Kanwaka Formation, NE ¼, SW ¼, NW ¼, sec. 33, T. 17 S., R. 16 E., Osage County, Kansas.
22. Hughes Creek Shale Member, Foraker Formation, C, EL, sec. 34, T. 3 N., R. 13 E., Richardson County, Nebraska.
23. Dover Limestone Member, Stotler Formation, Western Brick Company Pit, SE ¼, SW ¼, sec. 10, T. 8 N., R. 14 E., Otoe County, Nebraska.