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A LOWER MISSISSIPPIAN (KINDERHOOKIAN-OSAGIAN) CRINOID FAUNA
FROM THE CUYAHOGA FORMATION OF NORTHEASTERN OHIO

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A LOWER MISSISSIPPIAN (KINDERHOOKIAN-OSAGIAN)
CRINOID FAUNA FROM THE CUYAHOGA FORMATION
OF NORTHEASTERN OHIO

A thesis submitted to the

Division of Graduate Studies and Research
of the University of Cincinnati

in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

in the Department of Geology
of the College of Arts and Sciences

1986

by

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B.S., Cleveland State University, 1979

UNIVERSITY OF CINCINNATI

April 22 19 86

I hereby recommend that the thesis prepared under my supervision by Edgar Roeser

entitled A Lower Mississippian (Kinderhookian-Osagian) Crinoid Fauna from the Cuyahoga Formation of Northeastern Ohio

be accepted as fulfilling this part of the requirements for the degree of Master of Science

Approved by:

David L. Meyer

Wayne A. Pryor

Paul E. Potter

ABSTRACT

A well preserved crinoid fauna is described from Lower Mississippian strata of the Meadville Member, Cuyahoga Formation in northeastern Ohio. Twenty-three species of crinoids are recognized. Analysis of camerate and inadunate crinoid groups reveals five new species, Platycrinites burki, Cyathocrinites exertus, Cyathocrinites simplex, Goniocrinus sceletus and Logocrinus martini, and seven new combinations of genera, Histocrinus aegina (Hall), Ascetocrinus subcarinatus (Hall), Paracosmetocrinus richfieldensis (Worthen), Paracosmetocrinus corycia (Hall), Pachylocrinus subtortuosus (Hall), Acylocrinus lyriope (Hall), and Linocrinus merope (Hall). Ontogenetic variation in three camerates, Aorocrinus helice (Hall), Cusacrinus daphne (Hall), and Platycrinites contritus (Hall) was examined by allometric analysis.

Monobathrid camerates dominated the crinoid community in numbers of individuals but poteriocrine inadunates showed the greatest species diversity. Flexible crinoids rank third in both abundance and species diversity. The fauna shows its strongest correlation with Lower Mississippian crinoid faunas of the Lodgepole and Banff Formations of the Western Interior, and Wassonville Limestone and Lower Burlington Limestone of the Mississippi Valley, indicating a late Kinderhookian to early Osagian age. This is consistent with its overall proximal location on the westerly to southwesterly prograding Mississippian (Waverly) deltaic complex.

The crinoid community flourished on an upper prodeltaic to distal bar facies in well-oxygenated, tropical waters above storm wave base within the Ohio Mississippian marine embayment. The paleoenvironment was subject to periodic rapid changes in sedimentation and localized reducing conditions. Excellent preservation of crinoids together with the character of sedimentary features lead to the conclusions that the crinoid community was buried catastrophically by a turbidity flow.

ACKNOWLEDGMENTS

I extend my sincere thanks to my research committee, David L. Meyer (major advisor), Paul E. Potter and Wayne A. Pryor, for their much appreciated assistance. I wish to personally thank Kenneth E. Caster and Anneliese S. Caster for their continual unfailing support and encouragement. A special thanks is given to Jerry Martin, landowner who provided access to crinoid-bearing beds examined in this study. And, Wanda Osborne who was invaluable in typing the final manuscript.

I would also like to thank Ed Landing (New York State Museum at Albany) for the loan of type specimens; George C. McIntosh (Rochester Museum of Science) for remarks on inadunate crinoid genera; William I. Ausich (Ohio State Univ.), Gary Webster (Washington State Univ.), and Joe T. Hannibal (Cleveland Museum of Natural History) for their helpful comments and suggestions.

Financial assistance was provided by Sigma-Xi - research grant (1983) and by the University of Cincinnati - GSA travel fund (1985).

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INTRODUCTION AND PURPOSE

Mississippian age strata in North America has long been recognized for abundant, well preserved crinoid faunas. One of the lesser known of these faunas from the shales of the Waverly Group, at Richfield, Ohio was first described by Hall (1863) and Hall and Whitfield (1875). Later, Worthen (1882) and Springer (1920) described two additional crinoids from these beds. Subsequent revisions were made by Wachsmuth and Springer (1881, 1897), Springer (1920), Kirk (1941), Bassler and Moodey (1943), Strimple (1967), and others. Exact location of the crinoid bearing beds in Summit Co., Ohio were never published.

The purpose of this study is to document an important Mississippian crinoid locality. Previous unknown aspects of the crinoid fauna concerning its taphonomy, synecology, and the local depositional environment are discussed. Twenty-three species of crinoids are recognized. Analysis of camerate and inadunate crinoid groups reveals five new species, *Platycrinites burki*, *Cyathocrinites exertus*, *Cyathocrinites simplex*, *Goniocrinus sceletus*, and *Logocrinus martini*; and seven new combinations of genera, *Histocrinus aegina* (Hall), *Ascetocrinus subcarinatus* (Hall), *Paracosmetocrinus richfieldensis* (Worthen), *Paracosmetocrinus corycia* (Hall), *Pachylocrinus subtortuosus* (Hall), *Acylocrinus lyriope* (Hall), and *Linocrinus merope* (Hall). Crinoids in the subclass Flexibilia (Zittel, 1895) were identified and photographed (Pl. 13) for purposes of crinoid community reconstruction, however taxonomic evaluation was not possible at this time. Springer (1920, p. 245-248, 313, and 387-389; Pl. XX, figs. 4-8, Pl. XL1, fig. 11, Pl. LII, fig. 1-5) in his well known monograph on Flexible crinoids recognized four species, *Dactylocrinus tardus* (Hall), *Forbesiocrinus communis* (Hall), *Taxocrinus communis* (Springer), and *Taxocrinus kellogi* (Hall). A list of fossil synonyms is reproduced in the section immediately proceeding analysis of inadunate crinoids.

LOCALITY

Through the guidance of a skilled local collector I was able to investigate beds believed to approximate Hall's primary crinoid-bearing horizon. Crinoid material forming the basis of this study was collected along a small tributary creek of Furnace Run in the northern one-half of Richfield Township: T4N, R12W; 66,250 m N and 46,300 m E (Text Fig. 1). The local stratigraphic section consists of an intercalated shale and siltstone sequence located in the upper part of the Meadville Member of the Cuyahoga Formation (Text Fig. 2). Underlying contact with the Orangeville, Sharpsville, and Strongsville Members is not found along the measured section, but may be found elsewhere in Summit County at topographically lower elevations of Szmuc's (1970) Everett Road and Cuyahoga River gorge sections. Overlying transition with the Rittman Member is found a short distance westward in northeastern Medina County near Hinkley, Ohio. The crinoid-bearing horizons near Richfield correlates closely in a stratigraphic and ecological sense to starfish beds described by Kesling and LeVasseur (1971) along State Route 80 near North Royalton, Ohio.

METHODS AND MATERIALS

Preliminary collection of crinoids as stream float and easily accessible slabs that continued into the stream bank produced about one-third of the specimens collected. The remaining specimens were obtained from excavations made during September of 1980, and July and August of the following year. A bulk sample of eight square meters, distributed between three lensoidal units (B,C,M) was brought back to the laboratory for analysis.

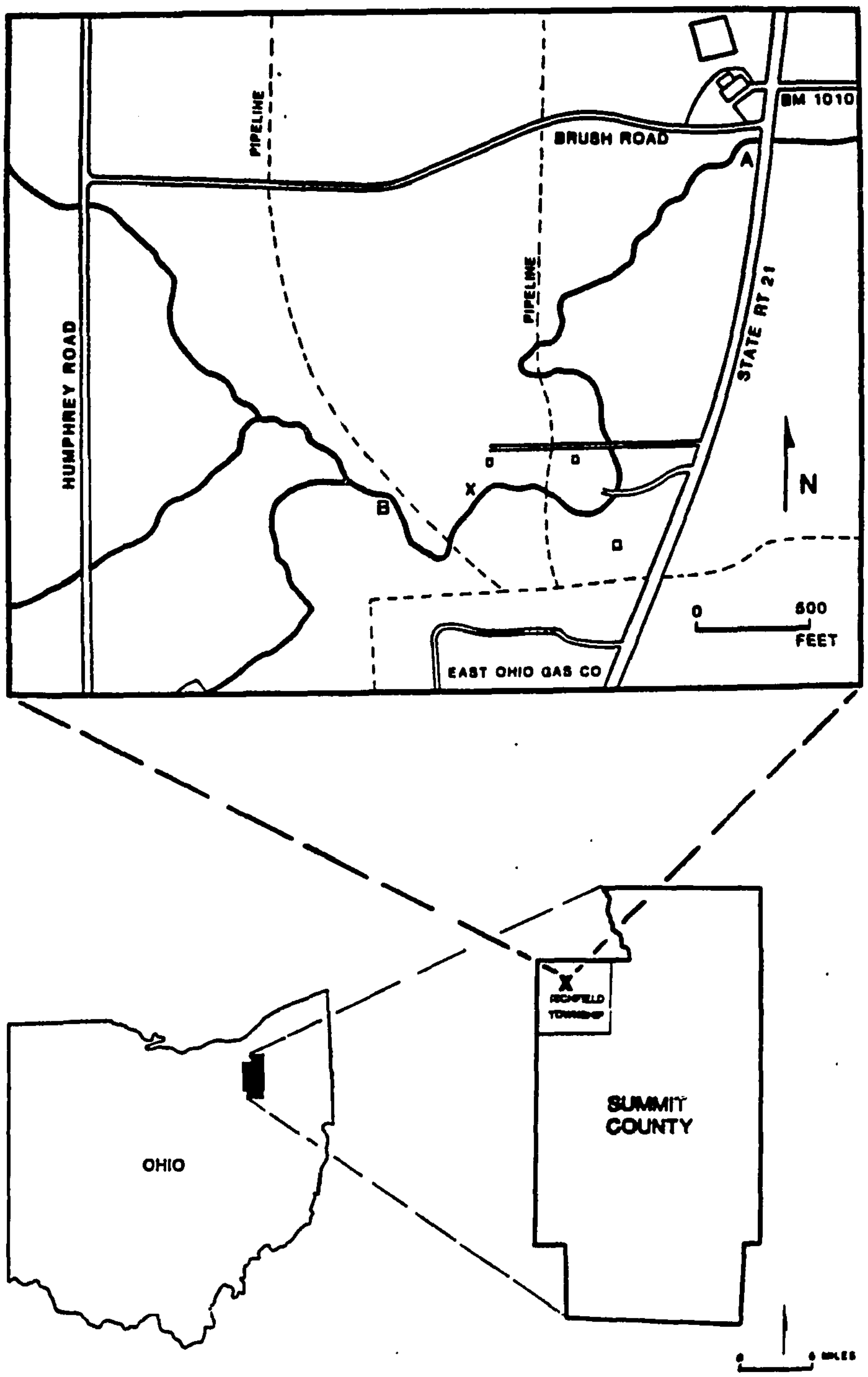
Initial stages of the excavation involved removal of approximately one meter thickness of coarse glacial alluvium, soil, and local vegetation with hatchet, pick axe, shovel, and a wheelbarrow. Upon reaching the fossiliferous horizon the surface of the bed was carefully cleaned and photographed (Text Fig. 3). Field orientations were recorded with Brunton compass and engraved along the top surface of the bed. The lensoidal siltstone units were then pried loose and plastic sheet overlays used to trace the "fit" of individual pieces in the lens (Text Fig. 4). In the laboratory overlays allowed the reconstruction of fossil orientations.

Vertical sections through the siltstone lens were cut, polished, and photographed. Photographs reveal a "coarse-tail" calcisiltite with concretionary horizons, shale partings, and mudstone intraclasts which grade upward into a finely laminated siltstone (Text Figs. 5 and 6). Following photography, individual pieces of the lens were carefully split and another set of plastic overlays used to record fossil orientation. Rose diagrams constructed from the orientation of crinoid crowns, columns, and miscellaneous elongate bodies (i.e., carbonized plant material and mudstone intraclasts) reveal a bimodal distribution with the major axis oriented NE-SW approximately centered N50°E, and the minor axis NW-SE nearly perpendicular to the major axis (Text Fig. 7). Orientation is largely consistent with regional paleocurrent patterns recorded from sole marks and rippled beds in the Cuyahoga Formation of northern Ohio (Text Fig. 8; adapted after Szmuc 1970, p. 53).

Crinoids were cleaned with vibratory tools, needles, and an air abrasive unit. Cleaning difficulties encountered by strongly cemented siltstone matrix made the successful removal of some crinoids impossible. Fortunately, a large number of crinoids were found in impure shale-rich siltstones that greatly facilitated preparation. Short soakings in Stoddard's solvent and water helped to soften the surrounding matrix.

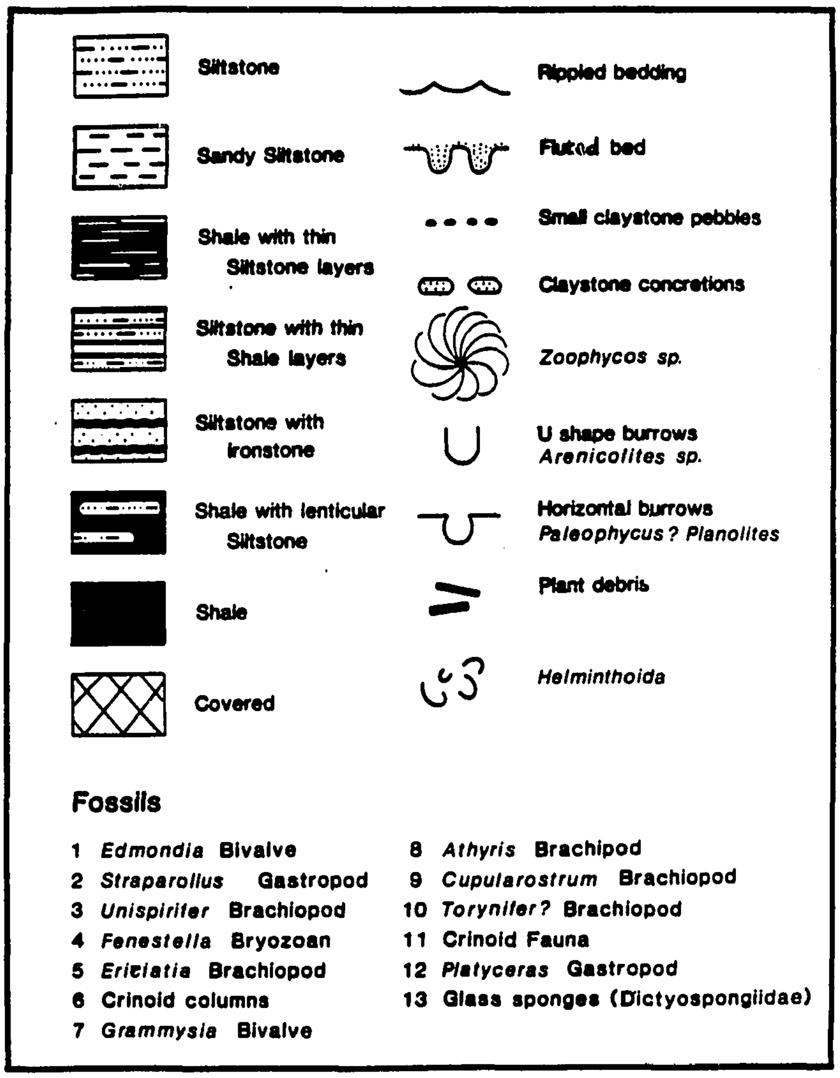
Text Figure 1. Area of Investigation

Measured section taken from points A to B. Crinoid-bearing horizon occurs at point marked X.

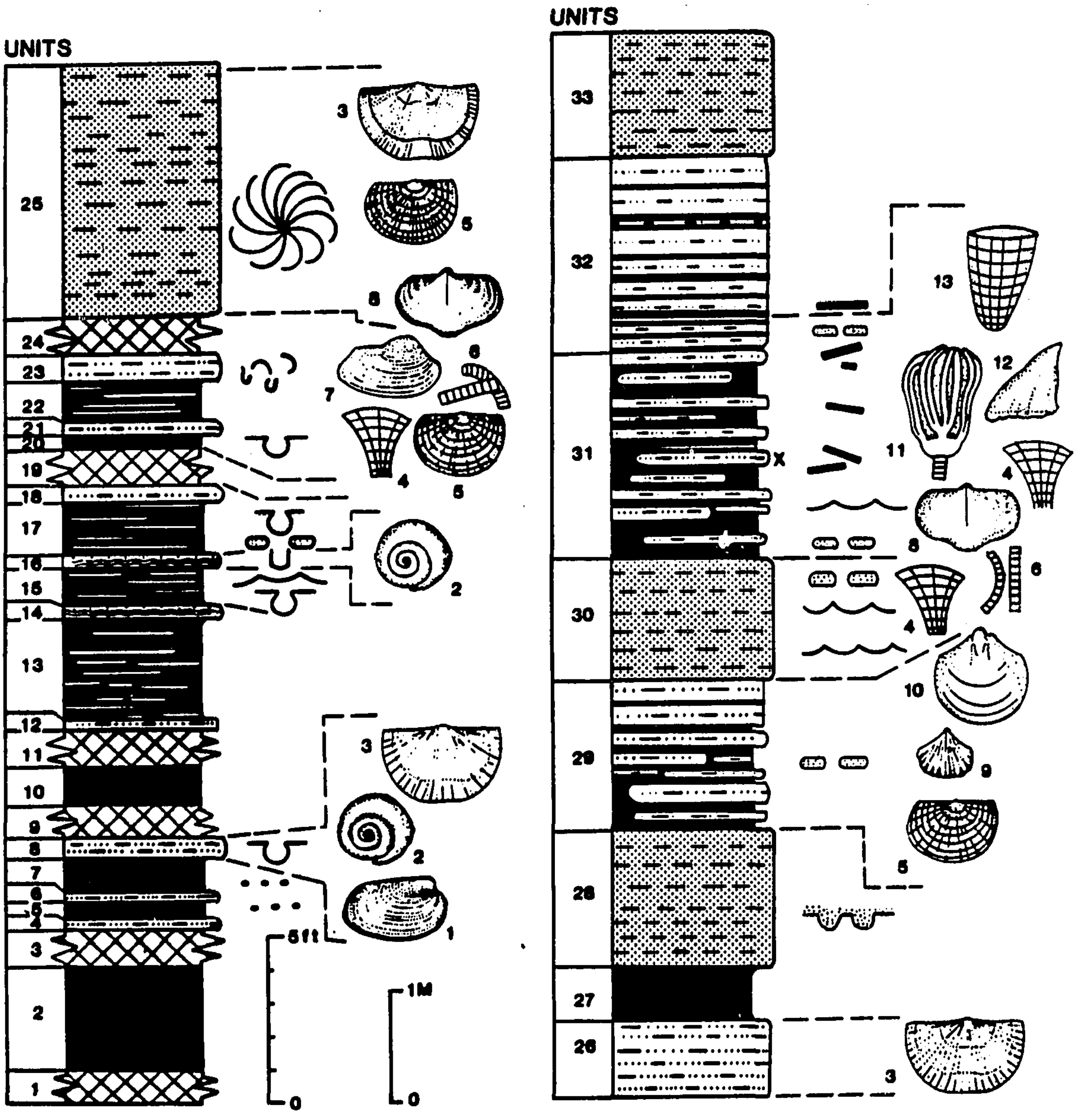

PIPELINE
PIPELINE
BRUSH ROAD
BM 1010
A
HUMPHREY ROAD
STATE RT 21
N
X
B
0
600
FEET
EAST OHIO GAS CO
X
SUMMIT
COUNTY
OHIO

Text Figure 2 Measured section along tributary of Furnace Run in Richfield Township, Summit County.

LEGEND



MEASURED SECTION



Text Figure 3. Crinoid Locality

A. Crinoid-bearing siltstone beds exposed along creek surface.

B. Excavation pit made during the summer of 1981. Pick ax for scale.

C. Author following a crinoid siltstone bed into alluvium covered creek bank.


A


B

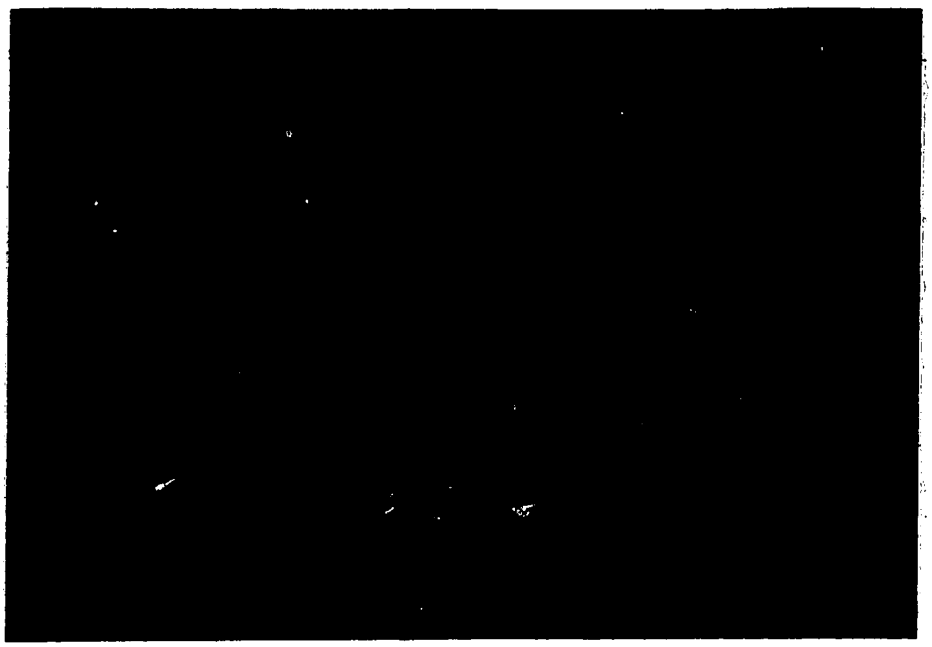

C

Text Figure 4. Method of recording orientation in bulk siltstone samples.

A. Pried up siltstone bed with north direction arrows (inscribed in blue), and top surface indicated by red paint.

B. Plastic overlay used to trace the "fit" of pieces in the lens.

A

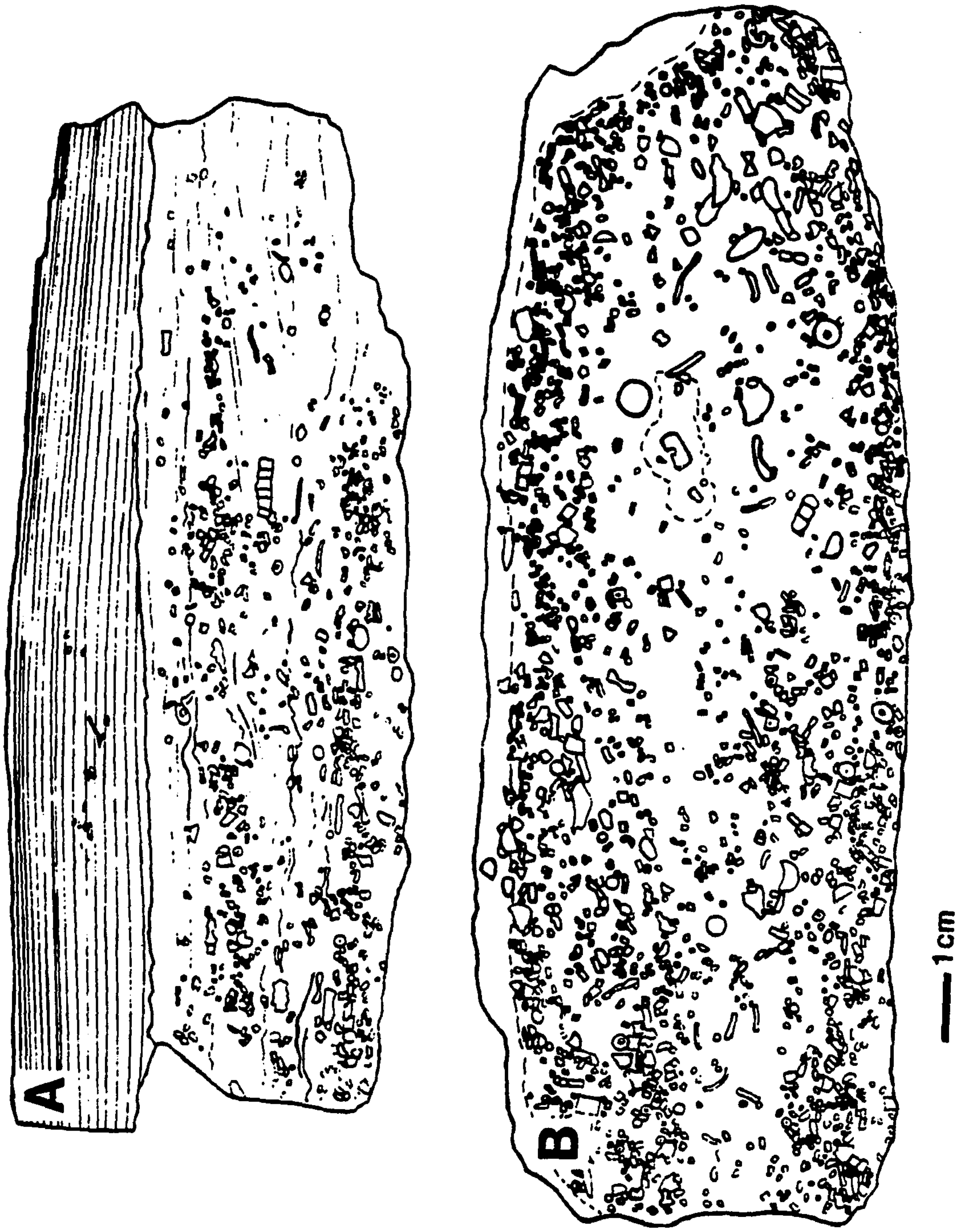


B

Text Figure 5. Vertical section through crinoid-bearing siltstone beds in Unit 31.

A. Impure, or "shale-mixed" siltstone showing poorly sorted bioclastic layer, and finely laminated upper layer.

B. Bioclastic sideritic siltstone. Fine dashed line below top indicates thickness of post-depositional weathering rim; whereas, the dashed line in the interior of the bed indicates a zone of pyrite. The laminated upper siltstone layer is absent. Presence of the upper weathering rim along the top of the bed suggests it may have been lost to erosion.


A
B
1cm

Text Figure 6. Vertical sections through crinoidal beds in Unit 31.

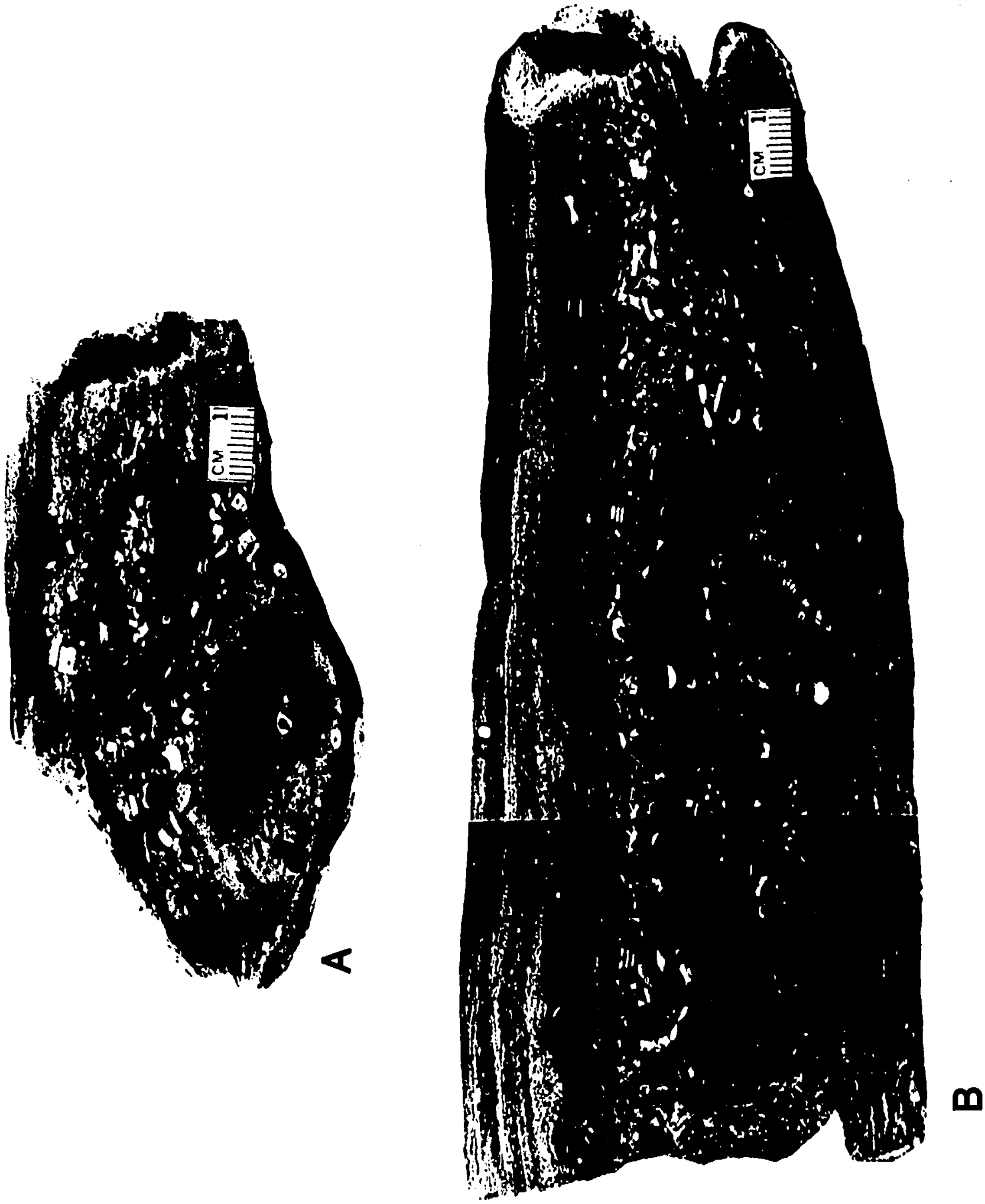
A. Calcisiltite with concretionary debris infilled glass sponge. Zone of cementation restricted to inside of sponge.

B. Calcisilitite showing three horizons:

1) a mud-rich laminated underbed,

2) a poorly sorted, well cemented bioclastic layer,

3) a fossil poor, finely laminated siltstone layer.

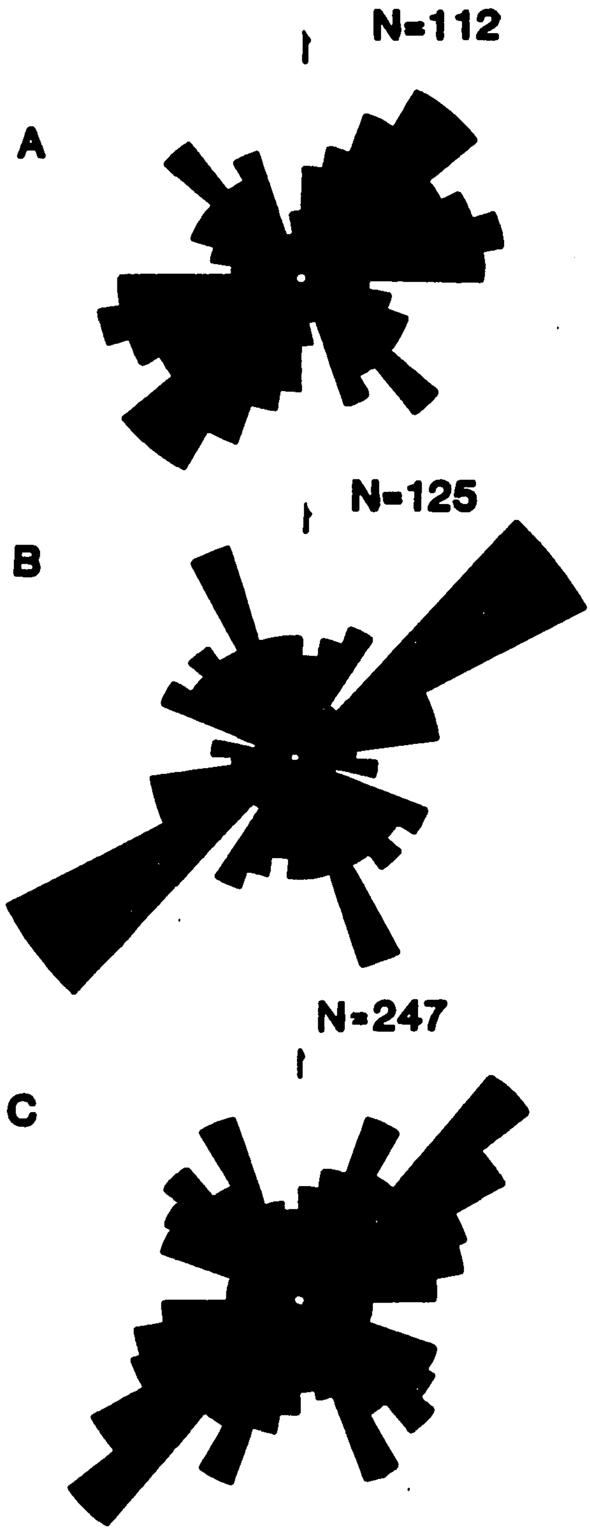

A
B
CM

Text Figure 7. Paleocurrent rose diagram of elongate objects in the excavated beds of Unit 31. Rose diagram plotted in 10 degree increments to emphasize peak direction trends.

A. Crinoid crowns

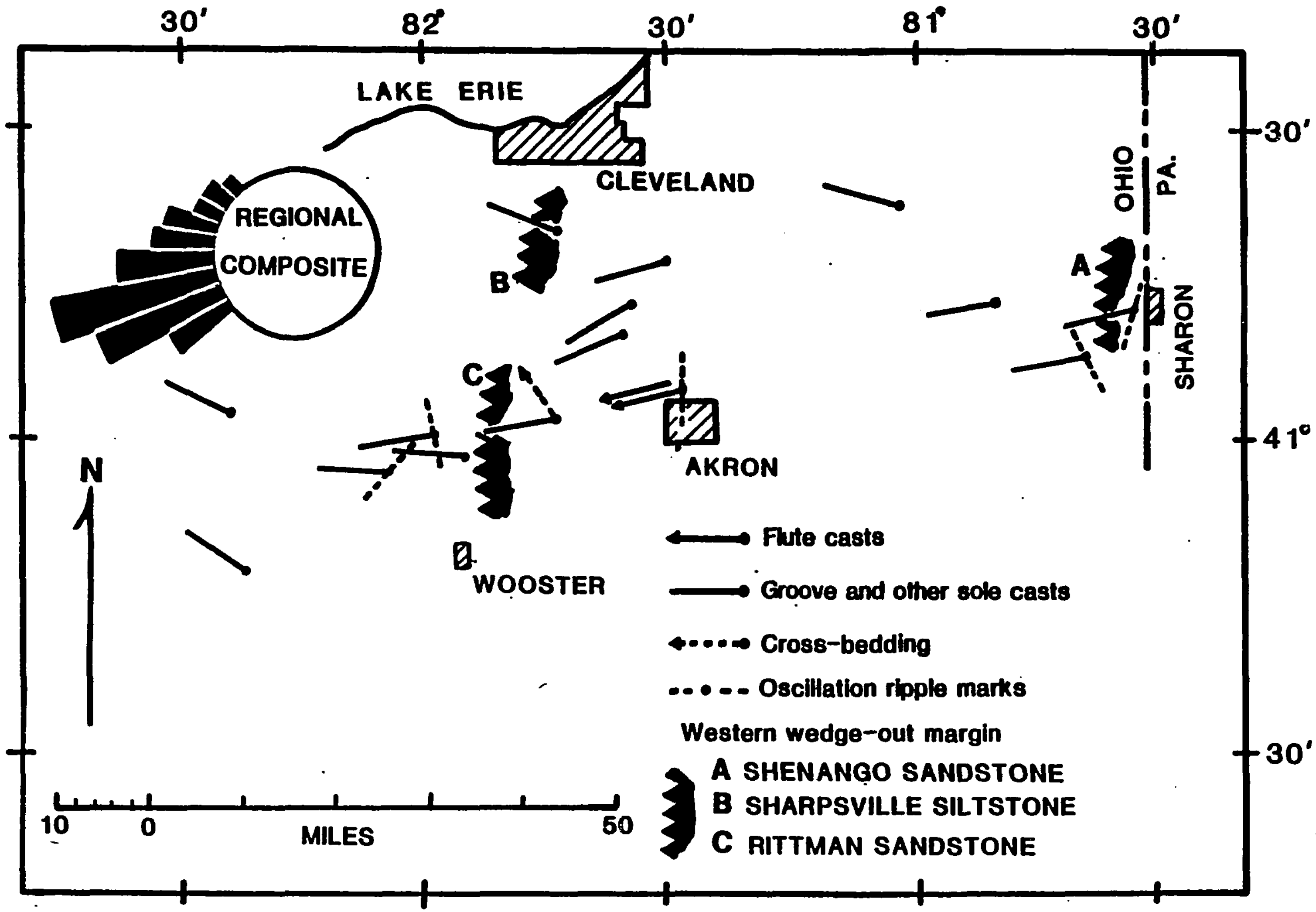
B. Crinoid columns

C. Composite: crinoid crowns, columns, plus some wood fragments and elongate mudstone intraclasts.


N=112
A
N=125
B
N=247
C

Text Figure 8. Orientation of sole markings, ripple marks, and cross beds in Cuyahoga and Shenango strata of northeastern Ohio. Wedge-out margins of the Rittman, Sharpsville, and Shenango beds indicated (adapted from Szmuc, 1970).

REGIONAL PALEOCURRENTS



STRATIGRAPHY

Stratigraphic investigations important to an understanding of the Mississippian System of northeastern and central Ohio include the works of Newberry (1870, 1873), Prosser (1912), Hyde (1915, 1921), Conrey (1921), Chadwick (1925), Cushing et al. (1931), Holden (1942), deWitt (1946, 1951), Ver Steeg (1947), Pepper et al. (1954), Szmuc (1959, 1970), Osgood and Szmuc (1972), and Bork and Malcuit (1979). In this study primary credit for a regional environmental setting and stratigraphy must go to Szmuc (1957, 1959, 1970) and Osgood and Szmuc (1972).

The Cuyahoga beds were first named by J. S. Newberry (1870, p. 15; 1873, p. 184-186). In northeastern Ohio the Cuyahoga Formation crops out as an irregular east-west trending belt from Trumbull and Ashtabula counties to Huron and Crawford counties. South of its northern axis the Cuyahoga Formation is confined to a east-central belt which extends to the Ohio River. Along the northern edge of its outcrop the Cuyahoga Formation is cut out in part, or entirely by the irregular pre-Pottsville erosion surface, which is overlain by the Sharon Conglomerate (Pennsylvanian) and other lithologic units of the Pottsville Series. Thickness of beds in northeastern Ohio range from less than 100 feet to about 350 to 375 feet (Szmuc, 1970). Southward, the erosion surface ascends stratigraphically and rests upon the Logan Formation in central Ohio. In Wayne and Ashland counties the Cuyahoga beds reach a maximum thickness of 550 to 625 feet (Szmuc, 1970). A composite section of lithologic members comprising the Cuyahoga Formation is given in Text Figure 9. The Meadville Shale Member is the unit of primary interest in this study.

The name Meadville was first used by White (1881, p. 83-90) for strata occurring between the Sharpsville and Shenango Sandstone in Crawford County, Pennsylvania. Later, Caster (1934) renamed White's subdivisions of the Meadville Shale as the Byham Limestone, the Harvest Home Shale, the French Creek Limestone, and the Custards Shale. Szmuc (1959, p. 1684; 1970, p. 23) equated the Shenango Sandstone and overlying Hempfield Shale of northwestern Pennsylvania to upper beds of the Meadville Member in the Cuyahoga River Valley region of Ohio.

In Cuyahoga and surrounding counties the Meadville Member reaches a maximum thickness of 210 to 250 feet (Szmuc, 1970). The lower 90-100 feet consists of a light blue gray to gray shale that is intercalated with relatively few siltstone beds. Conversely, the upper part coarsens showing well developed shale and siltstone intercalations which largely resemble those of the Sharpsville Member. Upper horizons of the Meadville Member have been observed to grade laterally into the Rittman Member, a coarse clastic conglomerate-sandstone unit interpreted as a deltaic bar-finger deposit (Osgood and Szmuc 1971, p. 11). The Rittman Member is found along a north-south trending belt from Wayne to northern Medina Counties, and is geographically closely adjacent to the crinoid-bearing beds described in this study (Text

Figure 10).

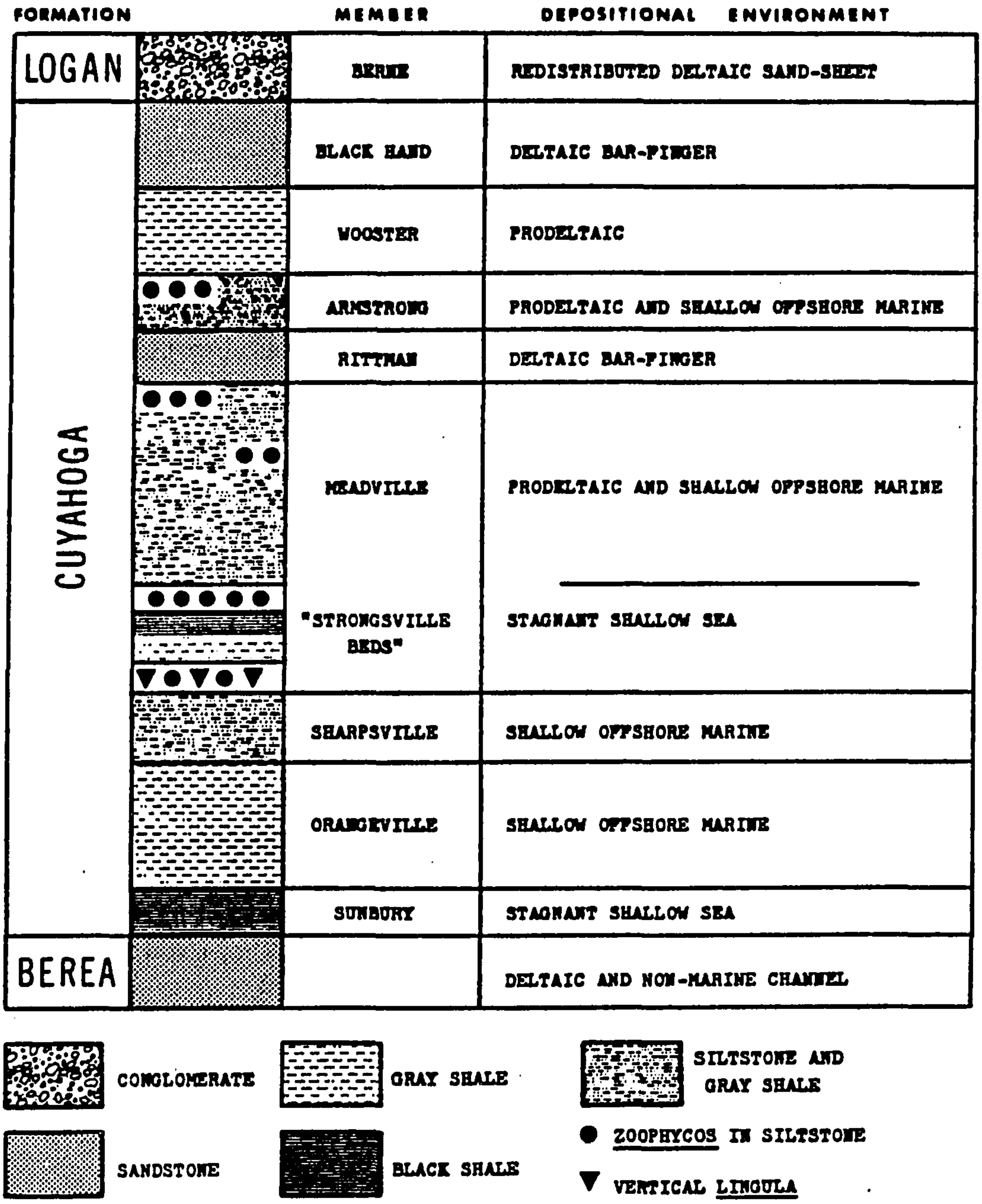
PALEOGEOGRAPHY

During early Mississippian time northeastern Ohio was located in the tropical climatic zone directly south of the equator (Ziegler et al., 1979). Paleocurrent determinations of sole marks, rippled beds, and crossbeds in the Cuyahoga Formation indicate that shoreline lay to the east and southeast of the Cuyahoga valley area. Basal units of the Cuyahoga Formation are represented by transgressive anerobic to dyserobic black shale facies of the Sunbury and Orangeville Shale Members. Deposition proceeding the Orangeville indicates gradually regressive conditions, characterized by periodic pulses of dense sediment laden currents. Improved circulation became supportive to the establishment of a diverse benthic fauna. As progradation continued the paleoenvironment progressively changed from a dyserobic-aerobic open shelf and prodelta environment to shallower aerobic delta front and delta platform environments. Coarse clastics of the Rittman and Black Hand Members are examples of aerobic delta front and platform facies. In central Ohio, Bork and Malcuit (1979, p. 1093) determined shale of the Cuyahoga Formation to be comparable with the Bellerophon community of Bowen et al. (1974), a molluscan rich community representative of a nearshore zone adjacent to a prograding clastic lobe. Alternatively, Kammer (1982, p. 174) argued that this molluscan rich fauna does not require proximity to shoreline, but may represent an instance of environmental stress caused by dyserobic bottom conditions which likely persisted below normal wave base during quieter intervals of sedimentation.

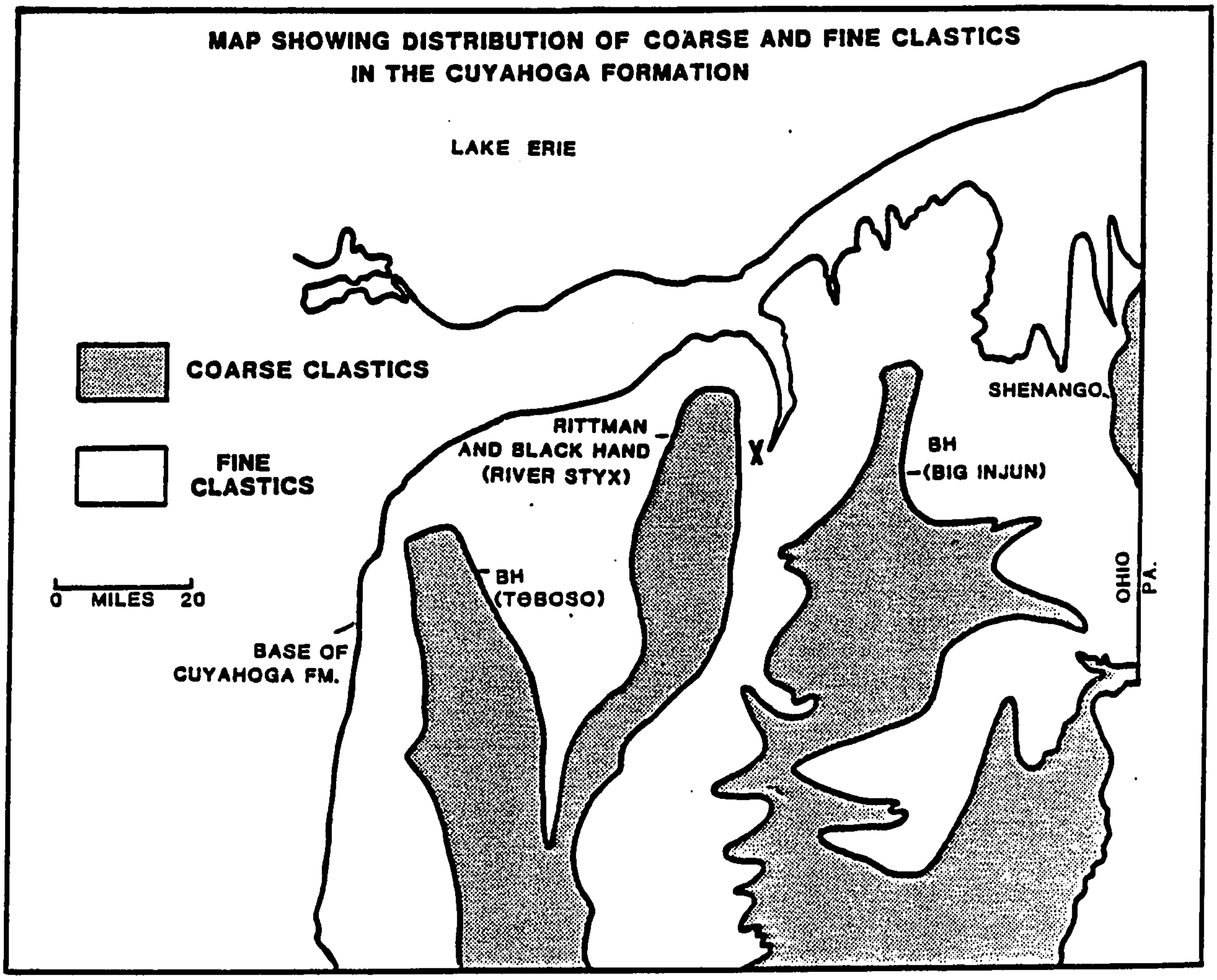
Ettensohn (1985, p. 71) suggests that the Catskill Delta developed in a warm setting ideal for thermohaline density stratification where warm, light, oxygen-rich surface water was found above denser, more saline bottom water. This zone of changing temperature and salinity gradients is better known as the pycnocline. Ettensohn (1985, p. 66, fig. 1) placed the pycnocline boundary between the prodelta and delta front environments. A similar thermohaline density stratification may also have been present during stages of the Waverly-Borden Delta complex.

According to Woodrow (1985, p. 61) the pycnocline formed an effective process boundary whereby sediments above it were moved by wave-related traction processes, and by turbidity currents below it. Alternatively, a model for a sedimentological process boundary need not envoke density stratification. Rather, the seaward return of storm surges such as those envisioned by Hayes (1967) and Swift and others (1971) may also have been responsible for the generation of turbidity currents. Dependent upon a region's supply of coarse clastics and a storm's intensity and epicenter, a continuum of storm generated sedimentological sequences may develop (Dott and Bourgeois, 1982, p. 678, fig. 24). The crinoid community near Richfield, Ohio flourished on an upper prodeltaic, or distal bar facies in tropical waters above storm wave base within the Ohio Mississippian marine embayment (Text Fig. 10).

Text Figure 9. Lower Mississippian stratigraphic units in northern Ohio and their inferred depositional environments. Vertical dimensions of the units are not drawn to scale (adapted from Osgood and Szmuc, 1972).


FORMATION
MEMBER
DEPOSITIONAL ENVIRONMENT
LOGAN
BEREA
REDISTRIBUTED DELTAIC SAND-SHEET
CUYAHOGA
BLACK HAND
DELTAIC BAR-FINGER
WOOSTER
PRODELTAIC
ARMSTRONG
PRODELTAIC AND SHALLOW OFFSHORE MARINE
RITTMAN
DELTAIC BAR-FINGER
MEADVILLE
PRODELTAIC AND SHALLOW OFFSHORE MARINE
"STRONGSVILLE BEDS"
STAGNANT SHALLOW SEA
SHARPSVILLE
SHALLOW OFFSHORE MARINE
ORANGEVILLE
SHALLOW OFFSHORE MARINE
SUNBURY
STAGNANT SHALLOW SEA
BEREA
DELTAIC AND NON-MARINE CHANNEL
CONGLOMERATE
GRAY SHALE
SILTSTONE AND GRAY SHALE
SANDSTONE
BLACK SHALE
ZOOPHYCOS IN SILTSTONE
VERTICAL LINGULA

Text Figure 10. Map showing the distribution of coarse and fine clastics of the Cuyahoga Formation in north-eastern Ohio (adapted from Ver Steeg, 1947 (in Szmuc, 1970)). Point 'X' marks approximate location of the Richfield fossil site.


MAP SHOWING DISTRIBUTION OF COARSE AND FINE CLASTICS
IN THE CUYAHOGA FORMATION
LAKE ERIE
COARSE CLASTICS
FINE
CLASTICS
0 MILES 20
RITTMAN
AND BLACK HAND
(RIVER STYX)
X
BH
(BIG INJUN)
SHENANGO
BH
(TOBOSO)
BASE OF
CUYAHOGA FM.
OHIO
PA.

LITHOLOGY

Shales range from medium light bluish gray (5B-5/1) to medium dark gray (N4) in color due to slight compositional variations in the silt fraction and organic content. Parting is poor to moderate and shales typically produce a blocky to splintery fracture upon splitting. Discoidal or elliptical claystone concretions and small claystone pebbles, interpreted as representing current-reworked bodies of cohesive clays, occur locally in some of the shale units. The smaller claystone pebbles typically are less than 2 cm in diameter, whereas, larger discoidal and elliptical concretions generally average between 8-15 cm along their elongate axis. Concretions show outer weathering rims that range from yellowish brown, or buff, to dark reddish gray in color. Both fossiliferous and nonfossiliferous shale units are present along section. Fossiliferous shales show a tendency to be softer and less silty than their counterparts.

Siltstones are divided into four separate lithosomes based upon composition, grain size, and to a lesser degree color:

1) Faintly laminated, or massive sandy siltstones ranging light olive gray (5Y-6/1), yellowish gray (5Y-7/2), yellowish brown (10YR-4/2-6/2, 6/4), or medium light bluish gray (5B-6/1) in color, and typically showing thin slabby bedding (e.g, units 25, 28, 30, 33).
2) Fine parallel and low cross-laminated, medium light bluish gray (5B-6/1) to light olive gray (5Y-6/1) siltstones

occurring as thin discontinuous beds intercalated within shale horizon (*e.g.*, units 4, 6, 13, 15, 17), or as laterally more continuous, moderately thick individual beds (e.g., units 26, 27, and 32). Fossil content is typically poor, or absent.

3) Bioturbated medium light bluish gray (5B-6/1) and medium light to dark gray (N3-N8) siltstones (*e.g.*, units 8, 16, and 23).

4) Calcisiltites and sideritic siltstones ranging in color from medium light bluish gray (5B-6/1), gray (N3-N6), and black (N1) in diagenetically less altered regions, and light grayish red (10R-5/2), pale to dark yellowish brown (10YR-6/2, 6/4-4/2), and brownish gray (5YR-5/1) in well cemented iron-rich (siderite and pyrite) zones. Calcisiltite and sideritic siltstone beds are relatively thin (avg. 0.4 - 0.8 ft. thick), lateral discontinuous, and show sharp upper and lower contacts. Top surfaces may be rippled, or show irregular and wavy bedding; whereas, bottom surfaces frequently show fine groove and prod markings (units 14, 16, 31, and 29).

Examples of lithologies found along the measured section are illustrated in Text Figure 11. Detailed description of individual units is provided in Appendix I.

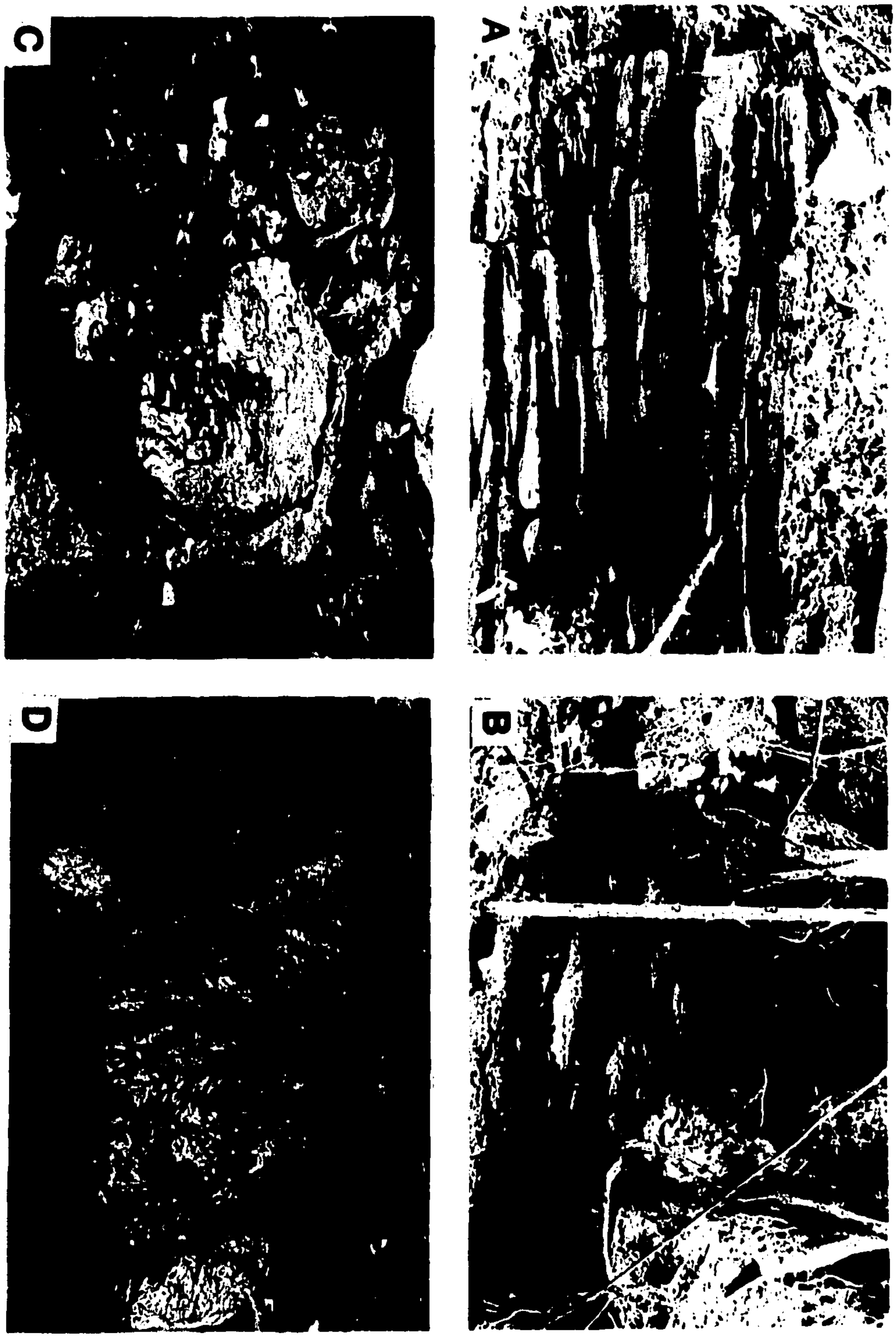
Text Figure 11. Rock units along measured section.

A. Unit 29. Intercalated siltstone-shale sequence with a clastic ratio of about 2:1.

B. Unit 31. Intercalated siltstone-shale sequence with shale more abundant than siltstone. Siltstone beds are thin, laterally discontinuous.

C. Unit 16. Irregular top surface of sideritic siltstone bed.

D. Unit 16. Bioturbated base of sideritic siltstone bed. Note: hypichnial grooves of *Paleophycus* and/or *Planolites*.


A
B
C
D

SEDIMENTARY STRUCTURES

Sedimentary structures provide important information about the overall environment of deposition. Inorganic structures include irregular wavy bedding, oscillation ripple marks, current ripple marks, and interference ripple marks along the top of the bed, and load casts, brush and prod marks, and rare flute casts along the base, or sole of beds. Organically derived structures, i.e., trace fossils, are treated separately in the following section.

Oscillation ripple marks are found on thin intercalated siltstone beds in shale dominated unit 15, and on sandy siltstone beds of unit 30. A symmetrically rippled surface in unit 15 shows a wave amplitude of 1.0 cm and wave length of 11.5 cm (sample RSF-2). In unit 30 three symmetrically rippled beds show the respective measurements: 1) a = 0.7 cm, α = 11.0 cm, trend N5°W; 2) a = 0.8 cm, α = 9.0 cm, trend N80° W; and 3) a = 0.5 cm, α = 6.5 cm, trend N55°W. Additional symmetrically rippled surfaces undoubtedly occur along section, but were not exposed along the creek surface. A more complete representation of symmetrically rippled beds in the Upper Meadville can be found along rock units directly below Ledge Lake Park of Hinkley reservation in northern Medina County (West Richfield Quad., T4N, R13W; 61,530 m N and 39,200 m E). At this location measurement of 12 symmetrically rippled beds (Appendix 3) reveals an average amplitude of 0.6 cm, wave length 8.0 cm, and crestline trends centered around N40°W and N20°E.

In a larger regional analysis of Northern Ohio Szmuc (1970, p. 53) found crestline trends for rippled beds in the Cuyahoga formation to average 30-35 degrees east or west of north. Osgood and Szmuc (1972, p. 14) interpreted the occurrence of oscillation ripple marks in the Meadville as evidence of deposition above wave base. However, in this analysis a distinction between normal wave base and storm wave base is important. The Richfield site was periodically transversed by turbidity currents, a zone suggesting deposition below normal wave base. Presence of some symmetrically rippled beds is believed to indicate that deposition was above 'maximum' storm wave base.

Current ripple marks occur along the top surface of the crinoid-bearing siltstones of unit 31 (Text Fig. 12). Vertical sections through the lens reveal a "coarse-tail" bioclastic layer formed by a high concentration flow from suspension, which grades upward into a fine laminated layer that is capped by low angle cross laminations and some convolute laminations (Pettijohn, 1957; Middleton, 1967). The composite unit is interpreted as representing the A, B, and C intervals of Bouma's (1962) idealized turbidity current flow deposit. Convolute bedding coexisting alongside current rippled surfaces is interpreted as related to the partial liquefaction and dewatering of sediments (Middleton and Hampton, 1973). Alternatively, crinoid-bearing units show a resemblance to what was termed micro-hummocky lens by Dott and Bourgeois (1979; 1982, p. 678). These micro-hummocky lens may be nearly indistinguishable from proximal turbidites. However, as both types may be sotrm-generated a lengthy analysis of bedform is not deemed necessary. The crinoid-bearing beds of unit 31 are believed to have been storm-generated, and as such may be termed a tempestite.

Interference ripple marks are found near the base of unit 32 and also at the Ledge Lake Park section in Medina County. Interference ripple patterns result when wave or currents of different direction, and possibly different length, imprint their record simultaneously, or at separate time on the underlying sediment (Reineck and Singh, 1980).

Text Figure 12. Top surface of crinoid-bearing siltstone bed of Unit 31.

A. View of convoluted surface.

B. Current rippled bed with convolute structures. Current ripples along lower center of photo show an average crestline trend of N30°E.

A

B

SOLE MARKS

Inspection of the base of the crinoid-bearing layer in Unit 31 reveals a nearly flat, rather unimpressive surface. Flute casts, the basal feature of Bouma's (1962) A unit of a classic turbidite sequence are conspicuously absent. Within the measured section flute casts were only observed on a single bed in unit 28 (Text. Fig. 2). In a larger regional analysis of the Cuyahoga Formation in northern Ohio, Szmuc (1970, p. 51) writes: "Flute casts are rare in northern Ohio and virtually restricted to a single bed near the top of the Sharpsville Member at Cuyahoga Falls." This absence of flute casts may reflect the cohesive properties of the underlying muds, or erosive power of the turbidite (Potter et al., 1980, p. 29-30). Lundegard, Samuels, and Pryor (1985, p. 113-114) found base-truncated Bouma sequences in siltstone beds of the Brallier Formation (U. Devonian) to be indicative of low velocity turbidites. Apparently, these turbidites were unchanneled and followed a gentle paleoslope gradient perpendicular to the basin axis.

Fine groove casts, prod marks, and localized load casts are found along the base of Unit 31. Load casts represent deformation features resulting from unequal loading and liquefaction along the mid-silt interface, their occurrence suggests rapid deposition of the silts over a "hydroplastic" mud layer (Reineck and Singh, 1980, p. 85). Groove marks tend to be sharp, of low relief, and limited lateral expression (commonly less than 10 cm). The delicate thread-like nature of these grooves suggest that crinoid derived material likely formed a large, or major portion of the inscribing agents. A particularly well striated bed of the crinoid-bearing horizon shows a unimodal trend averaging approximately N45°E (UCGM 46236). Paleocurrent determinations of crinoid columns, crowns, and miscellaneous elongate fragments (wood and mud intraclasts) within the excavated unit show a remarkably close correspondence to groove marks with the major axis following a NE-SW trend centered between 40-60 degrees east of north (Text Fig. 7).

TRACE FOSSILS [teminology after: Seilacher, 1964; Martinsson, 1965]

A single specimen of Zoophycos (Massalongo) was found in float along exposures of siltstone beds of Unit 15 (UCGM 46220; Text Fig. 13, Fig. 4). The small size and drainage of the creek indicates that the fossil could not have been transported far from its point of origin. An exact horizon could not be located. Osgood and Szmuc (1972, p. 5-16) described the occurrence of Zoophycos from the Cuyahoga Formation of northeastern Ohio. Population density was found to be greatest in the Strongsville Member, where entire bedding plane surfaces are covered with this trace. The authors interpreted Zoophycos as having lived in shallow offshore marine environments of intermediate water depth above wave base. Evidence in support of this conclusion consists of: a) the in-situ occurrence of Lingula melie (Hall) with Zoophycos, b) abundant land-derived plant debris in the Strongsville Member, c) lenticular bedding and oscillation ripple marks, and d) a regional "stratigraphic position between deltaic and delta derived sediments."

A shallow offshore interpretation for Zoophycos contrasts with the views of Seilacher (1964; 1967) and Ekdale (1967) who regarded this trace as indicative of deep water, below wave base. However, Hallam (1975) stated that Zoophycos may be found over a wide bathymetric range in regions of the sea floor not strongly disturbed by waves, currents, or other forms of bioturbation.

U-shaped burrows attributable to Arenicolites (Salter) were found in Unit 16 (Text. Fig. 13, fig. 5). Its appearance marks the first recorded account of this ichnogenus in the Cuyahoga Formation of northeastern Ohio. Description of UCGM 46221 follows:

Arenicolites sp. Salter, 1957, p. 204

Description - Small, vertical to oblique U-shaped tubes without spreiten. Tubes cylindrical to pod-shaped in cross-section, showing flared funnel-shaped apertures and possible slight lateral migration in one limb. Burrow diameter 3.0-10.0 mm, depth 22.0 mm, and horizontal distance between apertures 46.0 mm. Burrow infilled with dark gray mudstone.

Interpretation

Arenicolites is believed to represent the U-shaped dwelling tubes of a suspension, or partial surface deposit feeding invertebrate, possibly a worm (Eager et al., 1985, p. 131). Arenicolites has been found in intertidal (Legg, 1985; Corbo, 1979; Miller, 1979), lacustrine (Bromley and Asgaard, 1979) and tidal delta slope environments (Legg, 1985). Appearance of the ichnogenus suggests environments of shallow to intermediate water depth, those of aerobic bottom conditions. The ichnogenus Helminthoida (Schafhault) occurs as an endichnial trace in Unit 23 (Text Fig. 13, fig. 1). Previous description of its occurrence in the Cuyahoga Formation of northeastern Ohio is unknown. Helminthoida is a common trace in the Borden Group of northeastern Kentucky (Chaplin, 1980) and west central Indiana (Lane, 1973). Description of UCGM 4622 follows:

Helminthoida sp. Schafhault, 1851

Description - Small, irregular trace with tightly coiled loops and simple linear trails. Burrow width 0.4-2.0 mm, average 1.0 mm. Dark mud infilled burrows stand out in marked contrast to lighter gray siltstone matrix.

Interpretation

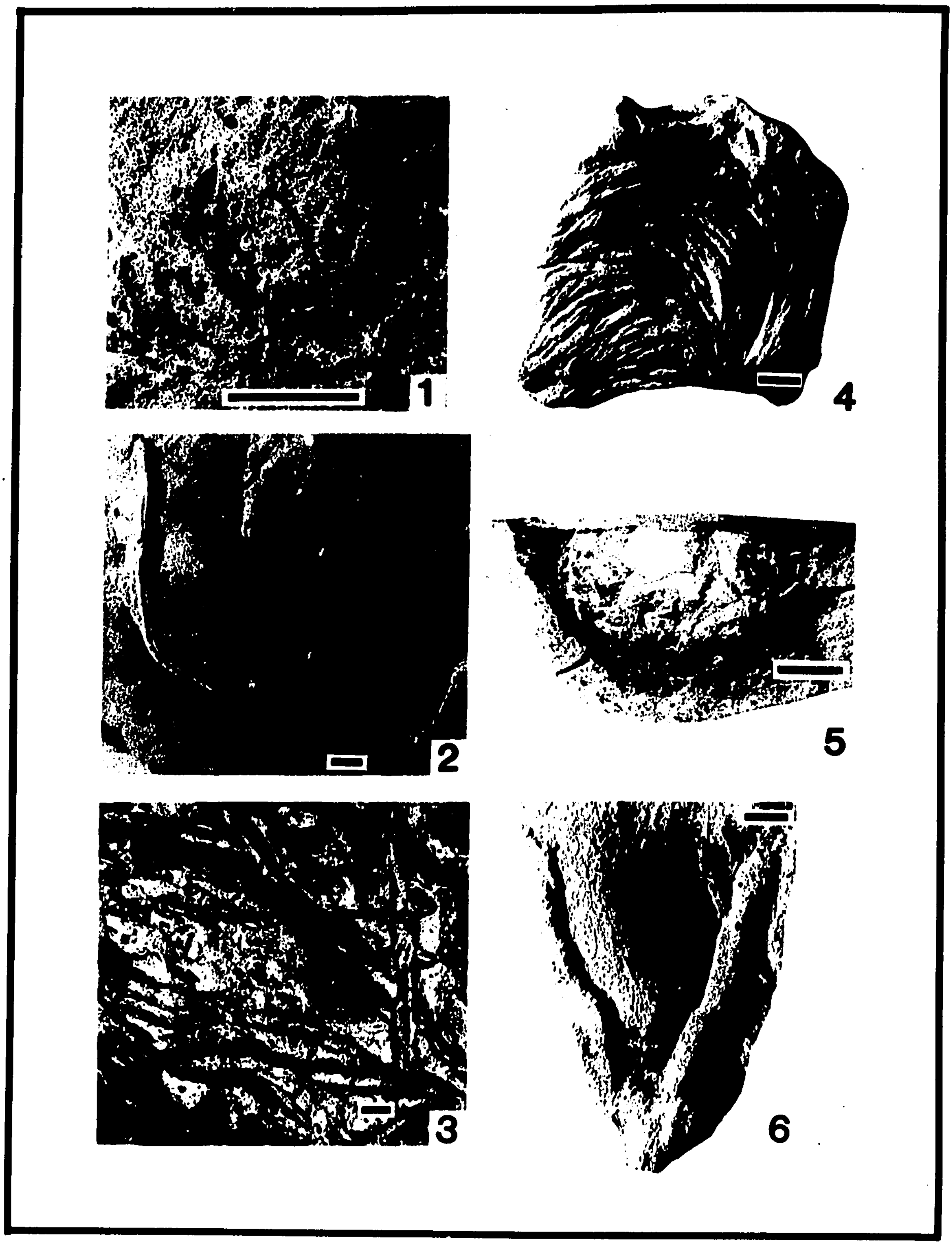
Helminthoida is believed to represent the internal grazing traces of a polychaete "worm" (Hantzschel, 1975, p. 70). Miller and Knox (1985, p. 84-85) described similar traces from the Fentress Formation of Tennessee as belonging to the ichnogenus Helminthopsis. However, I consider Helminthoida to be the correct designation. Helminthopsis is typically a larger and more open trace.

Horizontal burrows are the most common trace fossil found along the measured section (Text Fig. 13, figs. 1, 3, and 6). They are found as positive and negative hyporeliefs, negative epireliefs, and endichnial traces (Units, 8, 15, 16, 17, 18, 20, and 31). Unbranched, mud-infilled burrows are assigned to Planolites, regarded as representing the feeding burrows of an infaunal deposit feeding worm (Hantzschel, 1975; Eager et al., 1985, p. 143). Whereas, the branched horizontal burrows found along siltstone-shale interfaces are assigned to Paleophycus. Paleophycus is believed to represent crawling or feeding traces of a worm, or worm-like organism (Eager et al., 1985, p. 141).

Currently, numerous trace fossils in the Meadville Member and other lithologic units in the Cuyahoga Formation remain undescribed. A more intensive search will undoubtedly uncover additional forms. In a rather brief collecting field trip below Ledge Lake Park in Medina County (West Richfield Quad., T4N, R13W; 61,530 m N and 39,200 m E) I observed vertical dwelling or escape (?) burrows, and the ichnogenus Didymanlichnus (Young, 1972).

Text Figure 13. Trace Fossils of the Upper Meadville member.

1. Helminthoida Schafault, 1851. Small endichnial burrows occurring in Unit 23.
2. Didymanlichnus Young, 1972. Epichnial bilobate ridge on oscillation rippled bed at the Ledge Lake Park section in Medina county.
3. Paleophycus Hall, 1847. Epichnial grooves in shale at the Ledge Lake Park section in Medina county.
4. Zoophycos Massalongo, 1855. Specimen found loose in float along exposures of Unit 25.
5. Arenicolites Salter, 1857. U-shape burrow found in Unit 16.
6. Paleophycus Hall, 1847. Hypichnial ridge on siltstone bed in Unit 31.



TAPHONOMY

Preservation of three complete crinoids, including column and distal cirri rooted into the surrounding matrix, is taken as direct evidence that crinoids were living at the site prior to burial. The majority of specimens show evidence of moderate disassociation and local transport. Crinoid crowns typically are separated from most or all of their attached column. Arms in the crown assumed a tear-shaped survival posture which protected them from mechanical damage and sealed off vunerable ambulacral feeding surfaces (Haugh, 1978). Dis-associated columns range from single ossicles to sections greater than 20 cm in length. Conditions allowing some crinoids to escape dismem-berment remains unknown, however, complete preservation may have resulted from local "sheltering" phenomena, or early entombment.

The final burial event must have been rapid. Crinoids showing preservation of fine delicate features such as pinnules and cirri imply live burial, or burial within a few hours after death on the sea floor. Studies of modern crinoids have shown that crinoids decay rapidly and become disarticulated shortly (5-10 days) after death (Meyer, 1971; Liddell, 1975). Potentially, the bioclastic portion consisting of single ossicle remains may largely represent normal mortality accumulations. Crinoid ossicles formed a pavement which aided in stabilization of the substrate surface.

The majority of crinoids show burial positions parallel to bedding. A smaller percentage were buried at oblique angles, with arms collapsed above or below the calyx. Oblique burial positions were most frequently encountered in the crinoid Amphoracrinus viminalis (Hall), possibly due to the shape of its wide box-like theca. A flume study testing the hydrodynamic behavior of various crinoid crown shapes and their subsequent burial positions may prove interesting. Currently, none is known to this author.

Crinoids were subject to varying degrees of diagenetic compression. Factors controlling the amount of calyx deformation includes: 1) composition of the surrounding matrix, 2) precipitation of sideritic cements and pyrite, and 3) mechanical strength of the calyx.

The crinoid-bearing layers of Unit 31 show a variety of heterogenous lithotypes ranging from a predominance of shale and/or carbonaceous plant debris to a relatively "clean" siltstone. Specimen compression was found to largely correlate with the amount of enclosed shale and/or carbonaceous material; i.e., high percentages in the siltstone matrix result in a greater degree of specimen compression. Mud and organic substrates are known to undergo large water losses during compaction (Zangerl and Richardson, 1963, p. 176).

Crinoids in well cemented sideritic siltstones and those replaced by pyrite were found to be less compressed than others. An excellent example of this phenomenon is furnished by a speciment of Cusacrinus daphne (Hall) (UCGM 46104; Plate 3, figs. 1-2) which perfectly preserves the crinoid's original three dimensional form. Specimens of Cusacrinus daphne (Hall) are normally crushed. Precipitation of siderite and pyrite occurred shortly after burial and was initiated under anaeorbic conditions, most likely produced by the decomposition of organic matter.

The mechanical durability of a crinoid calyx to compression is related to: a) size or open volume of the calyx, b) plate thickness and ornament, and c) individual size and arrangement of plates in the calyx. Crinoids with large volumetric calices and relatively thin plates such as Cusacrinus daphne (Hall) indicate the worst record of preservation. Conversely, crinoids with small calices and relatively thick plates such as Acrocrinus helice (Hall), Ascetocrinus subcarinatus (Hall), and Forbesiocrinus communis (Hall), typically show less compression.

Crinoid skeletal material ranges from stark white to deep reddish brown in color. These variations are thought to be related to diagenetically produced pigmentation by small amounts of siderite and pyrite within the crinoid's stereomic microstructure. It is somewhat puzzling, however, that different species within the same given area will generally show a "preferred color", e.g., the genera Cusacrinus and Platycrinites are typically white, whereas, Ascetocrinus, Acrocrinus, and Amphoracrinus are almost always some shade of brown to reddish brown. Perhaps these interspecific variations are due to genetic related variations in the porosity of the stereomic microstructure. An exact cause remains unknown.

Major replacement of crinoid skeletal material by pyrite was not common in the Richfield material. Generally replacement is not complete, e.g., in specimens UCGM 46139 and 46104 the calyx is pyritized, but arms a short distance distally become calcitic.

Apparently, only regions closest to decaying visera of the tegmen maintained optimal bacterial growth and proper Eh-pH conditions for the precipitation of pyrite.

Crinoids in shales and impure siltstone lithologies frequently show some damage due to groundwater solution. This was especially true for exposures directly adjacent to the creek. In some instances only a mold of the crinoid remained.

AGE

In a regional analysis of northeastern Ohio, Szmuc (1957; 1970) determined invertebrate faunas of the Cuyahoga Formation to range from late Kinderhook to early Osage in age. Driscoll (1965; 1973 (In Lane)) considered bivalves of the Waverly Group to be Osagian, closely correlating with the Marshall Sandstone in Michigan. But, Manger (1971) considered amminoid faunas from the Cuyahoga and Logan Formations to be late Kinderhook, equivalent to the Northview Shale and Chouteau of Missouri, and Rockford Limestone of Indiana.

The Richfield crinoid fauna show affinity with crinoid faunas ranging from late Kinderhook (Chouteau) to early Osage (Burlington) in age (Table 1). Nonendemic genera most indicative of age include: *Cusacrinus* (Bowsher), *Paracosmetocrinus* (Strimple), *Logocrinus* (Goldring), *Amphoracrinus* (Austin), and *Aorocrinus* (Wachsmuth and Springer). Crinoids typical of the Keokuk are conspicuously absent. Springer (1920, p. 248) considered the Richfield fauna as decidedly Pre-Keokuk:

> "Among Camerates, Hall's "*Actinocrinus*" *viminalis* is an *Amphoracrinus* and his *A*. *daphne* is a *Cactocrinus* (=*Cusacrinus* (Bowsher, 1955)) two genera which do not pass beyond the Lower Burlington. *A*. *helice* is an *Aorocrinus* a genus which begins in the Devonian and ends in the Upper Burlington. Not a single species, or type, of the entire crinoid fauna resembles in the slightest degree those characteristics of the Keokuk."

In this study, the closest age equivalent of the Richfield fauna is suggested to exist with the Wassonville Limestone of Legrande, Iowa and the Banff and Lodgepole Formations of the Western Interior.

TABLE 1. AGE CORRELATION

CORRELATION OF THE WAVERLY CRINOID GENERA	KINDERHOOK						OSAGE					
	CHOUTEAU LS.	WASSONVILLE LS.	GILMORE CITY FM.	LODGEPOLE LS.	BANFF FM.	REDWALL LS.	FERN GLEN LS.	LAKE VALLEY LS.	BURLINGTON LS.	NEW PROVIDENCE	FORT PAYNE LS.	EDWARDSVILLE FM.
	CHOUTEAU						F.G.	BURLINGTON		KEOKUK		
<u>CAMERATES</u>												
AOROCRINUS	X	X	X	X	X			X	X			
CUSACRINUS		X	X	X	X				X			
AMPHORACRINUS								X	X	X		
PLATYCRINITES	X	X	X	X	X	X	X	X	X	X	X	X
<u>INADUNATES</u>												
PARACOSMETOCRINUS		X	X	X								
COSMETOCRINUS		X			X				X			
LINOCRINUS			X	X	X				X			
HISTOCRINUS					X				X			X
PACHYLOCRINUS		X			X				X			X
LOGOCRINUS				X	X							
ASCETOCRINUS		*		*	*				X			
ACYLOCRINUS		*		*			X		X			
CYATHOCRINITES	X	X		X	X				X			X
GONIOCRINUS		X	X	X	X							X
<u>FLEXIBLES</u>												
FORBESIOCRINUS					X				X	X	X	
TAXOCRINUS		X							X			X
DACTYLOCRINUS												

SOURCE: BASSLER AND MOODEY (1943), WEBSTER (1973; 1977), AND OTHERS. * CLOSELY RELATED FORM

RANK ABUNDANCE

Monobathrid camerates dominated the crinoid community with 172 specimens distributed among four genera and seven species (Text Fig. 14). The crinoids Aorocrinus helice (Hall) and Cusacrinus daphne (Hall) show the greatest rank abundance, being two and three times (respectively) more abundant than the next most abundant camerate Amphoracrinus viminalis (Hall). The genus Platycrinites (Miller) shows the lowest abundance among camerates with only 14 specimens distributed between 4 species. Diplobathrid camerates are conspicuously absent.

Inadunate crinoids rank second in overall abundance and first in species diversity. Of the ten genera represented nine are cladid poteriocrine inadunates. The remaining genus Cyathocrinites (Miller) is a member of the suborder Cyathocrinina (Bather). No disparid inadunates were found. Among inadunate species Paracosmetocrinus richfieldensis (Worthen) dominates with 12 specimens, and is closely followed by Linocrinus merope (Hall) with 11 specimens. Overall, dominance patterns among inadunates remains somewhat tentative due to the low number of individuals in each species. Additional collection may more firmly establish these patterns.

Flexible crinoids ranked third in both numerical abundance and species diversity. Forbesiocrinus communis (Hall) was the most abundant form represented.

The Richfield crinoid fauna provides important information of crinoid community structure within a clastic-siltstone depositional setting during late Kinderhook to early Burlington(?) time. Crinoid communities located along the western flank of the continental basin occupied bioclastic-carbonate settings. Record of community structure during this time is missing from the east-central region of the Illinois basin of the Borden Group in Indiana and northern Kentucky due to starved basin conditions (Lineback, 1969). The Richfield crinoid fauna may be best described as a monobathrid camerate community. However, the greater species diversity of poteriocrine inadunates may indicate that monobathrid camerates were in the process of losing dominance in the crinoid community. Subsequent crinoid communities of the U.S. continental interior in fine clastic siltstone and sandstone depositional settings were dominated by poteriocrine inadunates (Ausich and Lane (in press)).

Ausich and Lane (in press) divided Lower Mississippian (Osage-Meramecian) crinoid communities of the U.S. continental interior into three separate groups: 1) Poteriocrine inadunate community, 2) Monobathrid-disparid community, and 3) Equitable diversity community. The distribution and composition of these communities was found to reflect substrate type. The monobathrid-disparid community occupied a bioclastic setting, the poteriocrine inadunate community a siltstone and fine sandstone setting, and the equitable diversity community a mudstone setting. Substrate provides information concerning the overall current regime of the depositional setting, and thus, indirectly influenced the abundance and type of food available for that community. Competition between taxonomic groups for food resources, or changes in the composition of those resources are suggested to account for the variation in dominance between crinoid communities.

In a comparison of crinoid community structure, Lower Mississippian strata of the Banff and Lodgepole Formations reveal crinoid diversity to be highest among monobathrid camerates, and second highest among poteriocrine inadunates (Laudon _et al_., 1952; 1953) (Text Fig. 15). Information concerning crinoid numerical abundance was not published. Crinoid communities of the Banff and Lodgepole Formations inhabited fine clastic and bioclastic-carbonate environmental settings.

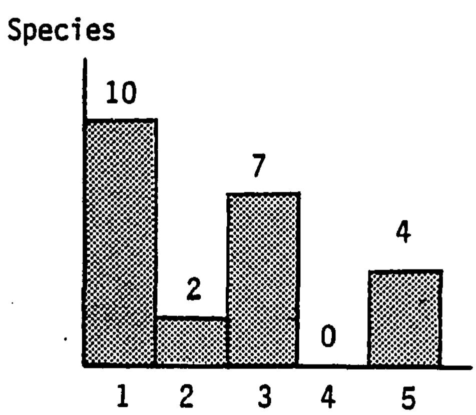
TEXT FIGURE 14. NUMERICAL RELATIONSHIPS AMONG CRINOIDS AT RICHFIELD

A. RANK ABUNDANCE BY SPECIES

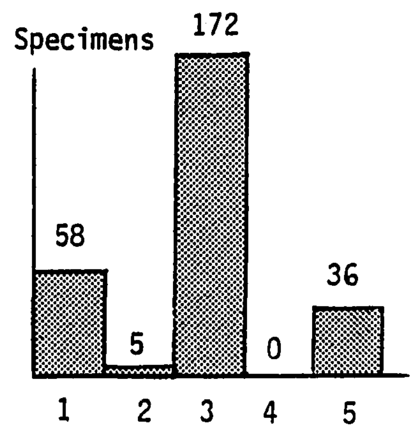
1) AOROCRINUS HELICE	86
2) CUSACRINUS DAPHNE	51
3) FORBESIOCRINUS COMMUNIS	26
4) AMPHORACRINUS VIMINALIS	21
5) PARACOSMETOCRINUS RICHFIELDENSIS	12
6) LINOCRINUS MEROPE	11
7) PLATYCRINITES CONTRITUS	8
8) HISTOCRINUS AEGINA	7
9) PACHYLOCRINUS SUBTORTUOSUS	7
10) LOGOCRINUS MARTINI	5
11) ASCETOCRINUS SUBCARINATUS	5
12) DACTYLOCRINUS TARDUS	5
13) ACYLOCRINUS LYRIOPE	4
14) COSMETOCRINUS CRINEUS	4
15) TAXOCRINUS COMMUNIS	4
16) CYATHOCRINITES EXERTUS	4
17) PLATYCRINITES GRAPHICUS	4
18) PARACOSMETOCRINUS CORYCIA	2
19) GONIOCRINUS SCELETUS	1
20) CYATHOCRINITES SIMPLEX	1
21) TAXOCRINUS KELLOGI	1
22) PLATYCRINITES LODENSIS	1
23) PLATYCRINITES BURKI	1

TOTAL =271

B. GROUP DIVERSITY

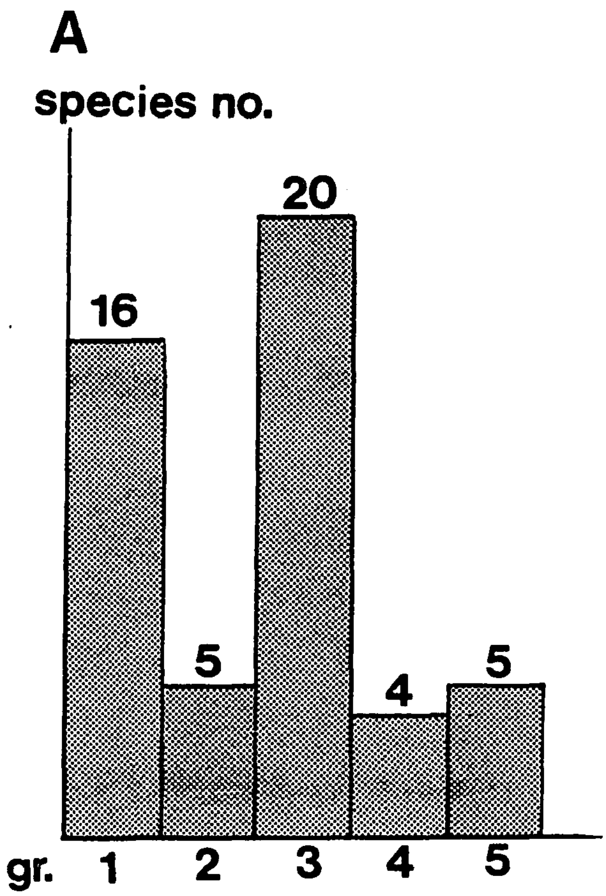


C. GROUP ABUNDANCE



KEY: GROUPS 1) POTERIOCRINE INADUNATES
2) OTHER INADUANATES
3) MONOBATHRID CAMERATES
4) DIPLOBATHRID CAMERATES
5) FLEXIBLES

TEXT FIGURE 15 GROUP DIVERSITY IN CRINOIDS FROM THE A) BANFF AND B) LODGEPOLE FORMATIONS



KEY: GROUP
1) POTERIOCRINE INADUNATES
2) OTHER INADUNATES
3) MONOBATHRID CAMERATES
4) DIPLOBATHRID CAMERATES
5) FLEXIBLES

* Species lists compiled after Laudon and Severson(1952) and Laudon, Parks, and Spreng (1953).

PALEOECOLOGY

In the presence of gentle to moderate currents modern comatulids and stalked isocrinoids feed by the formation of planar, or parabolic filtration fans directed into the prevailing currents. In quiet waters crinoids have been observed to form horizontal collecting bowls (Magnus, 1967; Meyer, 1973). However, most modern crinoid species will take advantage of even gentle currents for feeding, and therefore, may be considered rheophilic, or "current seeking".

Brett (1984, p. 97; after Lane and Breimer, 1974) divided modes of feeding among Silurian crinoid faunas into six categories: 1) rheophilic filtration fan (full and limited mucous net), 2) ciliary filtration pump, 3) tube feet ciliary, 4) raptorial, 5) rheophobic collecting baffle, and 6) epidermal feeding. Two categories 1) rheophilic filtrating fan, and 2) raptorial, are recognized in the Richfield crinoid fauna.

Crinoids forming rheophilic filtration fans are divided into two groups: 1) pinnulate camerates and inadunates with a "close mesh" filtration fan: Aorocrinus helice (Hall), Cusacrinus daphne (Hall) Amphoracrinus viminalis (Hall), Platycrinites lodensis (Hall and Whitfield), Platycrinites contritus (Hall), Platycrinites graphicus (Hall), Platycrinites burki (sp. nov.), Histocrinus aegina (Hall), Ascetocrinus subcarinatus (Hall), Paracosmetocrinus richfieldensis (Worthen), Paracosmetocrinus corycia (Hall), Cosmetocrinus crineus (Hall), Pachylocrinus subtortuosus (Hall), Acylocrinus lyriope (Hall), and Linocrinus merope (Hall), and 2) nonpinnulate and ramulate inadunates with more "open-mesh" filtration fans: Goniocrinus sceletus (sp. nov.), Logocrinus martini (sp. nov.), Cyathocrinites exertus (sp. nov.), and Cyathocrinites simplex (sp. nov.). Adaptations which allowed "open-mesh" crinoids to form effective filtration baffles include: a) isotomous and heterotomous arm branching, and b) possible (?) large tube feet to "fill in the gaps" (Brett, 1984, p. 98).

Flexible crinoids are regarded raptorial feeders (Lane and Breimer, 1974; Brett, 1984). These crinoids show nonpinnulate arms with relatively wide ambulacral grooves, and flexible unions between arm brachials. Flexible crinoids were probably incapable of forming effective filtration fans. Food particles were captured directly along arm rami. Many flexibles show tightly coiled arm tips, which suggests prey may have been actively seized. Flexible crinoids described for the Waverly include: Taxocrinus communis (Springer), Taxocrinus kellogi (Hall), Forbesiocrinus communis (Hall), and Dactylocrinus tardus (Hall).

Fenestrata bryozoans, brachiopods, bivalves, glass sponges, and other invertebrates are abundantly represented at the Richfield site. A comprehensive analysis of the entire invertebrate fauna was not possible at this time. Biovolumetric analysis of invertebrate taxa was initiated, but could not be completed due to the time consuming nature of the project. Qualitative observations indicate that shales contain fewer crinoids and a larger percentage of fenestrate bryozoans and productid brachiopods than adjacent siltstone units. Conversely, siltstones show a greater percentage of crinoids, gastropods, and bivalves. Ecologic segregation based upon substrate is suggested. Additional factors which may be involved include competition between species, and the developmental stage of community succession. Crinoids possibly represent an opportunistic group which settled and quickly flourished upon episodically deposited influxes of silt and very fine sand within a more stabilized bryozoan-brachiopod mud-dominated environmental setting. Time duration of the crinoid community may have been short, not unlike predictions made by Kesling and LeVasseur (1971) for the brittle star community of Strataster ohioensis (Kesling and LeVasseur). The brittle star community was interpreted as having survived approximately 30 years.

The abundance of both low and high level suspension feeders implies the existence of a rich suspended food supply carried by currents along the sea floor. Furthermore, the specific presence of fenestrate bryozoans and open-mesh rheophilic inaduanate crinoids suggests that these currents were gentle to moderate. The food supply likely consisted of phytoplankton, clay-size particles of organic debris, and dissolved organic matter. Abundant carbonaceous plant debris is found locally and could have formed a food source in itself, or more likely formed an indirect food source by a microbiota which feed on its decaying tissue.

Thin sections of well cemented sideritic siltstones show small spherical-shaped bodies with a dark opaque nucleus. These bodies are inferred to be fecal pellets, which abundantly occur at the fossil site. Fecal pellets may have "washed in", or have been produced locally.

Subclass CAMERATA Wachsmuth and Springer, 1885

Order MONOBATHRIDA Moore and Laudon, 1943

Suborder COMPSOCRININA Ubaghs, 1978

Superfamily CARPOCRINACEA de Konick and Le Hon, 1854

Family COELOCRINIDAE Bather, 1899

Genus AOROCRINUS Wachsmuth and Springer, 1897

DIAGNOSIS

A coelocrinid with small to medium, subconical, or bowl shaped cup. Basals three, each alike, low in lateral view. Radials five, large. Primibrachs two. First primibrach quadrangular, wider than high; second primibrach axillary, pentagonal. Secundibrachs two, three, or four in each ray. Interprimibrachs two or three. Primanal large, followed by two, or three plates. Anal opening through tegmen, tube absent. Arms two, three, or four in each ray. Brachials frequently spinose. Column round, showing well developed arrangement of nodes and internodes; heteromorphic.

DISCUSSION

Moore and Laudon (1943, p. 93) assigned Aorocrinus to their family Desmidocrinidae, a group believed to have evolved from an unknown form somewhere between the genus Compsocrinus (Miller) of the Tanocrinidae, and the genus Periechocrinus (Morris) of the Periechocrinidae. Recently, Ubaghs _et_ _al_. (1978, p. 462-473) combined members of the Desmidocrinidae (nom. null) and Batocrinidae within the Superfamily Carpocrinacea, a group composed of the families Carpocrinidae, Batocrinidae, and Coelocrinidae.

The genus _Aorocrinus_ is of significant importance in the phylogeny between family members of the Carpocrinacea. Ubaghs (1978, p. 289) writes:

> "....the Carpodcrinidae contain genera which seem well fitted to represent the source from which the Coelocrinidae could be derived. _Desmidocrinus_, for instance, combines primitive features, such as uniserial free arms, interbrachials connected with interambulcrals, a median series of extra plates in the CD interray, and a variable number of free arms, with typical carpocrinacean characters. Between _Desmidocrinus_ and the oldest known coelocrinid _Aorocrinus_, there is not a wide morphological gap. In its turn, _Aorocrinus_ does not seem to be very far from the less advanced batocrinids."

Aorocrinus _helice_ (Hall)

Actinocrinus _helice_ Hall 1864, p. 53; 1863, preliminary notice.

Hall and Whitfield 1875, p. 163; Pl. 11, figs. 5-8.

Aorocrinus _helice_ Wachsmuth and Springer 1897, p. 481; Pl. 45, figs. 1, 5.

Actinocrinus _helice_ var. _eris_ Hall 1864, p. 53; 1863, preliminary notice.

Hall and Whitfield 1875, p. 164; Pl. 11, Figs. 9, 10.

Tables 2-5; Text Figures 16-19; Plate 1, figs. 1-8; Plate 2, figs. 1-7; Plate 5, fig. 3.

DIAGNOSIS

A species of Aorocrinus with compact crown. Dorsal cup rapidly expanding, wider than high, subturbinate to bowl shaped. Ornament of dorsal cup variable; plates broadly convex and without ridges, or strongly nodose and with well defined network of radiating ridges. Arms twelve to eighteen, moderately thick, biserial. Column round.

DESCRIPTION

Dorsal cup - small to medium size, rapidly expanding, wider than high, subturbinate to bowl shaped. Basals three, each alike, low in lateral view, forming slightly projecting rim margin at base of cup. Radials five, large, wider than high. Primibrachs two. Secundibrachs two, three, or four in each ray. Primanal large, inserted between C and D ray radials, but narrower, and taller than radials. Primanal followed by three plates, each alike, or with lateral pairs somewhat narrower than central plate. Interprimibrachs three in each interray. Cup ornament variable; plates broadly convex and without ridges, or nodose, with ridges radiating between plates. Description of ornament which follows pertains to specimens with well developed ridge markings.

Basals -three, hexagonal, subequal, wider than high; H:W ratio 0.27-0.44, avg. 0.35 (Table 2, n=17). Each basal with subround ridge or flange at its proximal base; ridge protrudes slightly over column and extends nearly full width of plate. Swelling at lateral extremities and center found in some specimens.

Radials - five, large, wider than high; H:W ratio 0.45-0.76, avg. 0.65 (Table 2, n=20). Plates of two types: 1) hexagonal in A, C and D rays, and 2) heptagonal in B and E rays. Proximal lateral margins slightly more elongate than distal lateral margins. Ornament consists of broad, protuberant central boss with six or seven ridges which radiate toward plate margins; corners depressed in ovate, or subtriangular shaped pits.

First Primibrachs - five, quadrangular, relatively small, approximately twice as wide as high; H:W ratio 0.30-0.71, avg. 0.52 (Table 2, n=20). Plate nodose, with axial ridge expanded barrel-like at plate center. Slender secondary ridges radiate to interprimibrachs or anal X along lateral margins of central node. Plate corners depressed in pits.

Second Primibrachs - five, pentagonal, axillary, about twice as wide as high; H:W ratio 0.30-0.60, avg. 0.49 (table 2, n=20). Plate surface nodose, with distally expanding, bifurcated axial ridge.

Secundibrachs and Tertibrachs - number variable, dependent upon ray position and specimen. Primaxil followed by four to six "fixed" brachial plates in each ray. A ray giving rise to two arms, B and E ray most frequently giving rise to three arms, and C and D rays most frequently giving rise to four arms (Text Fig. 16).

Anal X (Primanal) - heptagonal, height and width subequal, higher and narrower than radials; H:W ratio 0.93-1.32, avg. 1.06 (Table 2, n=16). Ornament consisting of protuberant central node, and seven short ridges which radiate toward plate margins; corners depressed in ovate to subtriangular shaped pits.

X_2 - three, hexagonal, each alike, or with outer lateral pair slightly narrower than central plate. Average plate height greater than width; H:W ratio 0.90-1.35, avg. 1.12 (Table 2, n=12).

First Interprimibrachs - one in each non-posterior interray, large, height and width subequal; H:W ratio 0.84-1.37, avg. 1.08 (Table 2, n=20). Shape of plate variable, typically octagonal, but shows range from hexagonal to decagonal. Ornament consists of protuberant central node with eight ridges that radiate toward plate margins; corners depressed in subtringular shaped pits.

Second Interprimibrachs - two in each non-posterior interray, small, quadrangular or pentagonal, higher than wide. Ornament consists of medial ridge, lateral margins depressed in pits.

Arms - twelve to eighteen, most common number sixteen, with A ray showing two arms, B and E rays three arms, and C and D rays four arms (Text Fig. 16). Arms moderately thick, expanding somewhat above proximal base, but becoming tapered near apex. Distal arm tips generally hidden, arms closely appressed and incurved near summit. Free arms biserial, except for the initial two to four cuneate brachials. Brachials showing transverse ridge, or broken line of nodes. Ridge ornament weak to absent near proximal base, but progressively more prominent toward summit. Pinnules strong, relatively elongate.

Tegmen - unknown for specimens collected in this study. However, Wachsmuth and Springer (1897, p. 481) note: "summit crowned with elongate node, or short spine" (Pl. 1, fig. 5).

Column - round, composed of alternating thick and thin ossicles. Noditaxis showing three orders of internodes. Columnal indices given in Table 3. Complete, or nearly complete column ranging 9.5 to 16.1 cm for specimens UCGM 46077-B, 46077-E, and 46082-A, respectively. Distal radix rooted with long, slender cirri. Lumen round.

Table 2. Measurements of <u>Aorocrinus</u> <u>helice</u> (mm)

SP. #		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BB	H	1.3	1.2	1.1	1.0	0.6	0.5	0.6	1.0	-	0.8	-	0.9	0.7	0.8	-	1.1	0.6	0.7	0.6	0.7
	W	3.2	2.8	2.8	2.9	1.5	1.4	2.1	2.4	-	1.9	-	3.1	2.6	2.0	-	2.9	1.8	2.3	1.8	2.2
RR	H	2.4	2.3	2.0	2.0	1.1	1.3	1.3	1.7	2.2	1.6	1.1	1.0	1.3	1.1	1.8	1.9	1.7	1.0	1.2	1.6
	W	3.8	3.9	3.3	3.4	1.7	2.4	2.0	2.8	3.5	2.4	3.2	3.3	3.4	2.8	2.6	2.5	2.9	2.7	2.7	2.4
IBR_1	H	1.7	1.6	1.0	0.9	0.3	0.8	0.5	0.9	1.3	0.7	1.5	1.3	1.3	1.3	0.9	1.1	1.1	1.1	1.9	0.8
	W	2.4	2.6	2.5	2.2	1.1	1.4	1.3	2.1	1.5	1.5	2.1	2.3	2.2	1.8	1.6	1.8	2.0	1.9	1.9	1.6
IAx	H	1.7	1.6	1.1	1.3	0.4	0.9	0.7	2.0	2.4	0.9	1.3	1.4	1.2	1.2	1.1	1.3	1.2	1.2	1.2	0.8
	W	2.7	2.8	2.8	2.4	1.2	1.8	1.5	2.2	3.0	2.1	2.5	2.8	2.8	2.0	2.0	2.2	2.3	2.0	2.1	1.6
iBR_1	H	3.3	3.1	2.8	2.8	1.1	1.5	1.5	2.0	2.7	2.1	2.6	2.7	2.1	2.1	2.4	2.6	2.3	2.0	2.2	1.7
	W	3.1	3.2	2.6	2.5	0.8	1.6	1.5	2.1	2.2	1.5	2.5	2.8	2.1	2.0	2.0	2.5	2.2	2.1	2.0	1.2
X_1	H	-	-	2.9	3.4	1.3	2.2	2.2	2.6	3.4	2.3	2.8	3.3	3.1	2.2	-	2.5	2.5	2.9	-	2.3
	W	-	-	2.9	3.2	1.0	2.2	1.9	2.6	3.2	2.3	2.8	3.3	3.2	2.4	-	2.2	2.4	2.4	-	2.0
X	H	-	-	2.4	2.5	-	1.8	-	2.4	2.8	1.8	-	-	2.4	-	1.9	1.6	2.3	2.0	-	1.8
	W	-	-	2.0	2.4	-	1.5	-	2.2	2.1	1.8	-	-	2.2	-	2.0	1.5	1.8	1.8	-	1,6
CUP	H	9.1	7.6	6.4	6.5	6.0	4.0	5.3	5.3	6.7	4.2	6.7	8.5	6.5	5.5	6.8	7.8	5.3	5.3	5.6	4.5
base	W	4.7	5.1	4.5	4.6	2.4	2.1	2.1	3.1	1.3	3.4	1.3	4.5	3.6	2.5	-	4.1	3.8	2.8	3.4	2.2
max.	W	15.5	14.4	11.7	17.0	5.0	8.5	9.9	10.5	12.8	9.7	16.1	14.3	13.0	14.2	13.4	11.8	13.0	10.8	11.5	9.4
ARM L		31.2	30.3	25.2	27.4	10.3	20.2	17.4	17.2	27.2	19.3	26.6	30.0	-	26.0	24.3	22.0	22.3	25.6	24.0	19.7

Museum number (chronological order): UCGM-46055, 46056, 46057, 46058, 46059, 46060, 46061-A, 46062, 46063, 46064-A, 46065, 46066, 46067, 46068, 46069, 46070, 46071, 46072, 46073, and 46074.

Table 3. Columnal measurements in Aorocrinus helice

Specimen UCGM	46073	46077-E	46082-A	46083	46084-A
INi	-	83.9	78.4	78.7	78.2
Ni	-	16.1	21.6	21.2	21.8
KHi	-	28.8	23.8	25.9	31.7
Li	12.4				
Ei	27.6				
Ci	60.0				

Columnal ratios and measurements after Moore, Jeffords, and Miller (1968, p. 21-24). Indices used in this study are:

1) Columnal height index (KHi)

Ratio of columnal (K) height (H) to its diameter (KD) x 100

KHI = KH/KD x 100

*For columnals with other than circular outlines, width is considered the sum of the short radius (KRx) and long radius (KRy)

KHi = KH/(KRx = KRy) x 100

2) Luminal index (Li)

Ratio of total width (diameter) of lumen to that of columnal articulum x 100. Depending on shapes of lumen and articulum mean diameter may need to be determined.

3) Nodal index (Ni)

Ratio of height of nodal (N) to total height of noditaxis (NT) containing it x 100.

Ni = NH/NTH x 100

4) Internodal index (INi)

Ratio of total height of internode IN to noditaxis NT containing it x 100

INi = INH/NTH x 100

Table 3 (Continued)

5) Columnal shape index (KSi)

Ratio of minimum columnal radius to maximum radius x 100

$$KSi = KRx/KRy \times 100$$

6) Crenularial index (Ci)

Ratio of total width of crenularium to columnal articular facet

$$Ci = CW/AW \times 100$$

7) Epifacet index (Ei)

Ratio of total width of epifacet to columnal articular facet

$$Ei = EW/AW \times 100$$

DISCUSSION

Variation

Arm number, interbrachial plate geometry, and surface ornament were found to exhibit morphologic variation.

Arm number in Aorocrinus helice (Hall) ranges from twelve to eighteen, with sixteen the most common number. A plot showing the typical arrangement of arms in respective ray positions is given in Text Fig. 16. Results of this plot verify Hall and Whitfield's (1875, p. 163) original observations:

> "A constant feature of this species, so far as observed, is the existence of two arms in the anterior ray, and four in each of the postero-lateral rays, while in the antero-lateral divisions there may be two, three, or four arms in one or both rays."

Hall and Whitfield (1875, p. 164) recognized a variety known as eris, which generally corresponds with A. helice but differs in showing plates that are not strongly nodose, and having three arms in each of the postero-lateral rays (C and D rays). The variant eris is rare in the collected material, only two among forty-seven specimens were found to show three arms in both C and D rays, and also show non-nodose plate ornament (Pl. 1, fig. 7-8). Neither arm number nor plate ornament are judged as sufficiently stable criteria to recognize eris as a separate species. Wachsmuth and Springer (1897) correctly diagnosed this form to be a synonym of Aorocrinus helice (Hall). Perhaps, the rarity of specimens showing low arm number may indicate that natural selection favored individuals with higher arm number. Brower (1974, p. 38) found Giradeau camerates with lower food gathering ratios, defined as the total length of the food gathering system (i.e., (avg. pinnule length x number of pinnule bearing brachials) + (length of all free arms)), to show higher mortality rates and rarely reach adulthood.

The first interbrachial plates are bordered by eight, nine, or ten plates. Shape ranges from hexagonal to decagonal. This variation in plate geometry results from the variable number of bordering secundibrachs, and the frequent combination of two or more borders into a "common" edge. In specimens UCGM 46056, 46057, and 46071 the first interbrachial of the EA interray is heptagonal because of the common margin phenomenon. Whereas, the number of bordering secundibrachs in the anterior (A) ray of specimen UCGM 46055 produce the nine-sided geometry of the AB interbrachial (Text Fig. 17). Similar edge related factors control the shape of the second interbrachial plates which ranges from quadrangular to pentagonal.

Perhaps the single most common feature to show variation is plate ornament. Dorsal cup ornament in Aorocrinus helice (Hall) ranges from specimens showing broadly convex plates without ridge development, to those with strongly nodose plates with a radiating network of ridges. Intraspecific genetic influences can account for a portion of the observed variation, however, much is undoubtedly due to the factors of ontogeny, preservation, and preparation of specimens.

Arm Regeneration

Four specimens of *Aorocrinus helice* (Hall) show arm regeneration. Both reproductive and augmentative types are represented (see Ubaghs, 1978, p. 143-144). Augmentative arm regeneration can be distinguished from reproductive regeneration in showing signs of arm damage. In the reproductive type arms are simply smaller with respect to adjacent ones. Augmentative regeneration is found in the distal third of the right-lateral arm in the A-ray of specimen UCGM 46057, and in the left central arm in the D ray of specimen UCGM 46081-B (Plate 2, figs. 2, 3, and 6). Reproductive regeneration occurs in the two right-lateral arms of the C ray in specimen UCGM 46081-B, and possibly in the five adjacent arms in the B and C rays of specimen UCGM 46089 (Plate 2, figs. 1, 5).

Phylogeny

Aorocrinus helice (Hall) belongs to a closely related group which includes *Aorocrinus douglassi* (Miller and Gurley) from the Lodgepole Formation, *Aorocrinus radiatus* (Wachsmuth and Springer) from the Wassonville Limestone, and an unnamed species of *Aorocrinus* (Laudon, Parks, and Spreng) from the Banff Formation. A feature separating this group from all others within the genus *Aorocrinus* is the development of stellate ridge ornament. *Aorocrinus helice* (Hall) can be distinguished from other species in this group in showing an average of sixteen arms, a range intermediate to *Aorocrinus radiatus* (Wachsmuth and Springer) with 12-14 arms and *Aorocrinus douglassi* (Miller and Gurley) with 18-20 arms (Laudon and Beane, 1937, p. 246; Laudon and Severson, 1953, p. 527).

Allometry

It is well documented that organisms may change their proportions during growth. Huxley (1924, p. 895) proposed a formula, best known as the allometric equation, which mathematically determined the relative magnitude of these changes:

Equation 1

$$Y = bX\alpha$$

where, Y and X are the independent variables of measurement, α the geometric growth rate, and b a constant which is equal to the value of Y where X equals unity. Derivation for the allometric equation may be found in Simpson *et al*., 1960, p. 396-399. Growth of an organism is isometric if body proportions are maintained throughout the growth interval. As such, the geometric growth rate (α) is equal to unity if X and Y measurements are one dimensional. Growth which departs from isometric is said to be allometric.

Seven well preserved specimens of *A*. *helice* (Hall), representing three size categories, were chosen for growth analysis (Table 4). Specimens are presumed to range from late juvenile to mature adult (Text Fig. 18; Plate 1, figs. 1-3). All calculations for the allometric equations were made with a HP-25 (Hewlett-Packard) programmable calculator. Growth ratio values (α) were determined by plotting independent plate measurements (Y value) against the cumulative measure of that dimension (*i.e.*, height or width) of all plates in the individual (X value). Ratios were tabulated and an overall growth value determined.

For calculations involving arm length and free brachial number arm measurements were plotted against calyx size, defined as the height from the proximal base of the basal plate to the apex of the primaxil.

Results

Negative allometric growth was recorded for basal plate height and width. Radial and primanal plates showed a similar negative increase in height, but width was more nearly isometric. Basals, radials, and primanal are generally considered the first plates formed in the dorsal cup, and therefore, showed their greatest growth during early stages of development prior to that represented in this growth series. Allometry of basals, radials, and primanal was proportionally less than that of more distal still developing elements.

The first and second primibach showed positive allometry in plate height, and a nearly isometric increase in plate width. Along the lateral margins of these plates the interprimibrachs show a nearly isometric increase in plate height, and a strongly positive allometric increase in plate width. As consequence of the strong positive allometry of interbrachial plate width arm groups are effectively spread apart and the cup widens during development.

The right-lateral second primibrach (primaxil) in the B ray of specimen UCGM 46059 appears to have grown by intercalation between the first primibrach and first secundibrach of that ray. Previous descriptions of growth by intercalation in camerates is limited to the interbrachial plates. However, intercalation of plates into the ray axis is not unknown for crinoids. Warn (1973, p. 10-18) described intercalation of brachial plates in the inadunate Heterocrinus tenuis. Warn's figure 2 d-f is similar to the shape and orientation found in the B ray primaxial of specimen UCGM 46059.

The secundiaxial showed negative allometric growth. The smallest specimen (UCGM 46059) shows a secundiaxil that is twice the height of either primibrachs (Plate 1, fig. 1; Text Fig. 18, fig. A). Conversely, in the largest individuals of the growth series (specimens UCGM 46055 and 46056) the secundiaxil is nearly equal, or slightly shorter than the primibrachs. Apparently, early growth of the secundiaxil was well advanced prior to the stage where primibrachs show their greatest size modification. This variation likely had its origin in the manner to which growth occurred. Primibrachs likely remained fixed within the dorsal cup throughout development, but secundibrachs were free during early stages of their development.

Both arm length and free brachial number shows a nearly isometric relationship to calyx size. These values, however, are considered to be somewhat under represented as arms are infolded or incomplete near their distal tips.

Young specimens of Aorocrinus helice (Hall) show flat or slightly convex plates with fine granulose surface ornament (Plate 1, figs. 1, 2). As growth proceeds plates become increasingly more nodose. Nodosity is first and most strongly developed along plates of the ray axis. Fully developed ornament is only known for mature adults (Text Fig. 19).

An excellent review on the ontogeny of camerate crinoids is provided by Brower (1973; 1974; and 1978). Brower (1974, p. 14-15) recognized five developmental types based upon the number and arrangement of fixed brachials, interbrachials, and arms (Table 5). These categories provide a framework which may be applied to the observations of this study.

Aorocrinus helice (Hall) was found to show affinity to both Brower's patelliocrinid and actinocrinid camerate groups. As in the patelliocrinids, radial plates showed a size dominance over the primibrachs throughout the measured growth interval. A relationship of A. helice (Hall) to the actinocrinid group is suggested by its tendency to incorporate axilliary plates within the dorsal cup. Brower (1974, p. 19) noted that scarcity of intersecundibrachs, intertertibrachs, and higher orders of interbrachial plates showed a direct correlation with the larger number of axilliaries found in the cup.

Table 4. Allometric analysis in Aorocrinus helice (Hall)
(plate measurements in mm)

SPECIMEN		1	2	3	4	5	6	7	K	(a)
BB	H	0.6	0.7	0.8	0.6	1.1	1.2	1.3	0.79	0.18
	W	1.5	2.0	1.6	2.1	2.8	2.8	3.2	0.75	0.35
RR	H	1.1	1.1	1.3	1.3	2.0	2.3	2.4	0.82	0.31
	W	1.7	1.6	2.1	2.0	3.3	3.9	3.8	1.03	0.19
IBr_1	J	0.4	0.5	0.6	0.5	1.0	1.6	1.7	1.44	0.05
	W	1.1	1.1	1.4	1.3	2.5	2.6	2.4	1.07	0.12
IAx	H	0.4	0.6	0.7	0.7	1.1	1.6	1.7	1.28	0.07
	W	1.2	1.3	1.7	1.5	1.8	2.8	2.7	1.02	0.15
IIAx	H	0.8	0.9	1.0	0.7	1.2	1.3	1.8	0.73	0.25
	W	1.2	1.2	1.4	1.5	2.2	2.3	2.5	0.86	0.20
iBr_1	H	1.1	1.3	1.9	0.8	2.8	3.1	3.3	1.08	0.24
	W	0.8	1.4	1.5	1.1	2.6	3.2	3.1	1.35	0.06
X	H	-	1.6	-	2.2	2.9	-	-	0.88	0.33
	W	-	1.6	-	1.9	2.9	-	-	0.93	0.19
ARM L		10.3	10.2	17.3	17.3	25.2	30.3	31.2	1.05	4.19
Br. no.		33	38	60	58	86	92	88	0.91	16.85
Cumul. height	H	4.4	5.1	6.4	5.3	9.2	11.1	12.2		
width	W	7.5	8.6	9.7	9.9	16.2	17.6	17.7		

Key

K - Allometric Value

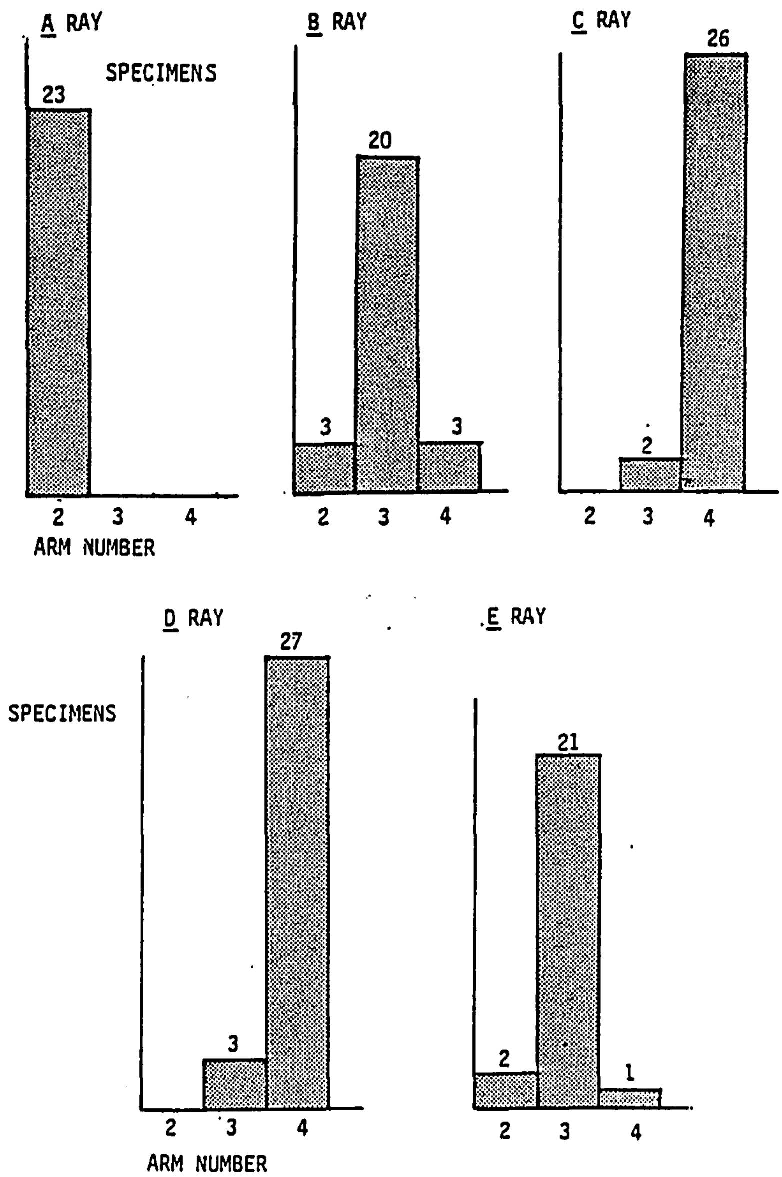
(a) - Graphic intercept

Museum numbers in numerical order:
UCGM 46059, 46077-F, 46096, 46061-A, 46056, 46055

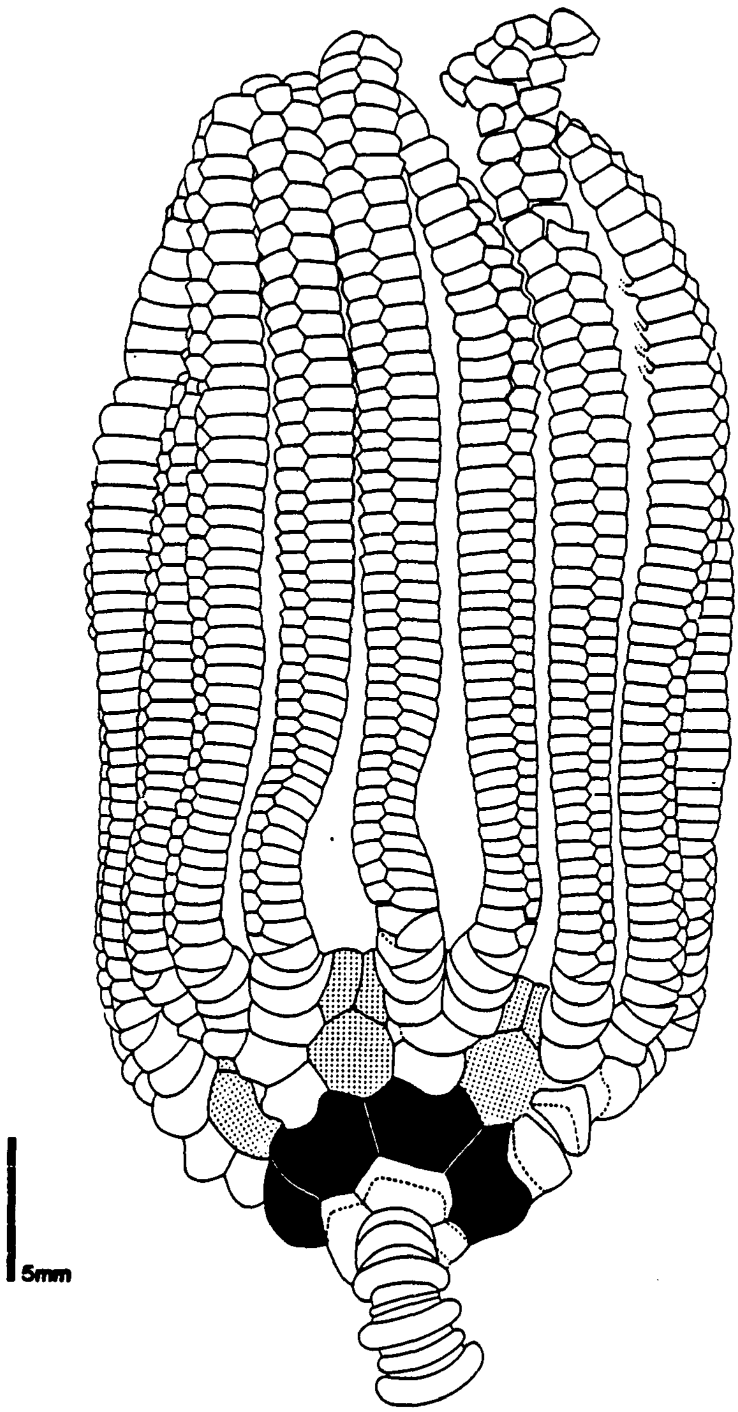
Table 5. Ontogeny in Camerates (Adapted after Brower (1974, p. 14-21))

CALYX TYPE	FEATURES	FAMILIES	ONTOGENY
XENOCRINID	Many fixed brachials Interbrachials small and irregular	Reteocrinidae, Xenocrinidae, some Tanaocrinidae	High rate of brachial fixation. Interbrachs remain small. Rays progressively spread apart by intercalation of interbrachs. Development, except for interbrachials similar to the glyptocrinids.
GLYPTOCRINID	Many fixed brachials Interbrachials large and regular Few arms in each ray	Glyptocrinidae, Scyphocrinitidae, Melocrinitidae, most Archaeocrinidae, some Rhodocrinitidae, Tanaocrinidae	High rate of brachial fixation. Radial plate initially larger than primibrachs, but size differences equalize during development. Calyx shows rapid distal extension. More rapid growth in the ray axis results in a lobate shape tegmen. Arms spread apart by incorporation of intersecundibrachs and intertibrachs.
ACTINOCRINID	Many fixed brachials Interbrachials large and regular Numerous arms in each ray	Most Actinocrinitidae, Batocrinidae, some Periechocrinidae, a few Rhodocrinitidae	Moderately high rate of brachial fixation. Axillary plates spread arms apart in each ray. Few intersecundibrachs, intertibrachs related to the large number of axillary plates.
PATELLIOCRINID	Few fixed brachials Interbrachials large and regular Two primibrachs in each ray	Gazacrinidae Desmidocrinidae, Coelocrinidae, Eucalyptocrinitidae, Patelliocrinidae, some Dimerocrinitidae, a few Hapalocrinidae	Low rate of brachial fixation. Radials remain in the largest plate in ray axis. Arms become separated by wide interrays.
PLATYCRINID	Few fixed brachials Interbrachials few and regular Primibrachs small Few to numerous arms in each ray	Nyctocrinidae, Dichocrinidae, some Hapalocrinidae, Platycrinitidae, Hexacrinitidae	Brachials generally not fixed. Growth of primibrachs minimal; plate size shows negative allometry relative to cup plates. Advanced members lose first primibrach and upon primaxil. Primaxil may change shape from pentagonal to trigonal.

Text Figure 16. Histograms showing frequency of arms in respective ray positions for 47 specimens of <u>Aorocrinus helice</u> (Hall) (abscissa number of specimens; ordinate number of arms in ray).



Text Figure 17. *Aorocrinus helice* (Hall). Camera lucida drawings of UCGM 46055, *A* ray view. Explanation: radials black; interprimibrachs dot stippled.


5mm

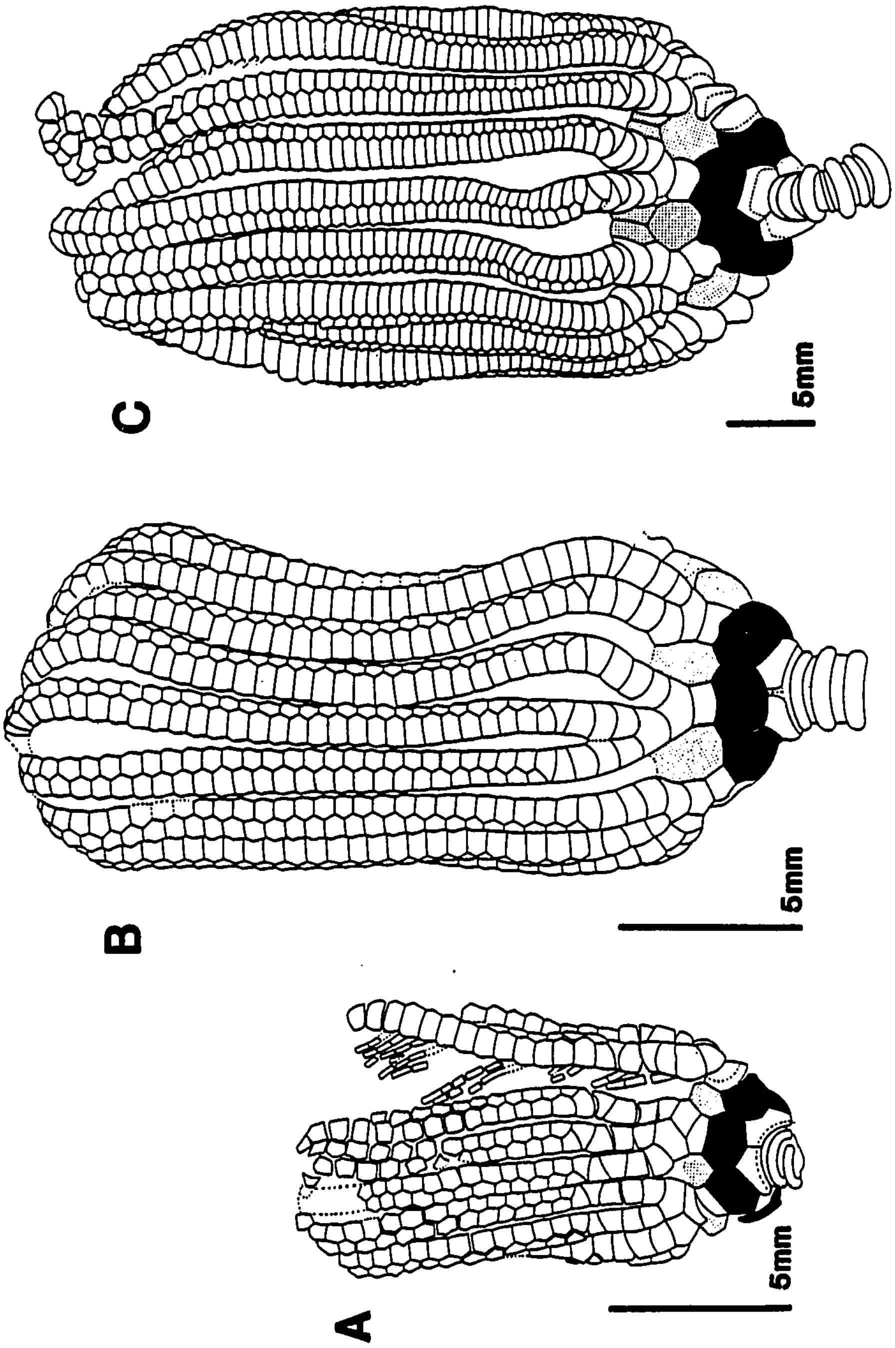
Text Figure 18 A-C. Growth sequence in <u>Aorocrinus</u> <u>helice</u> (Hall). Camera lucida drawing of three specimens.

A) Hypotype UCGM 46059; juvenile centered on B ray (Plate 1, fig. 1).

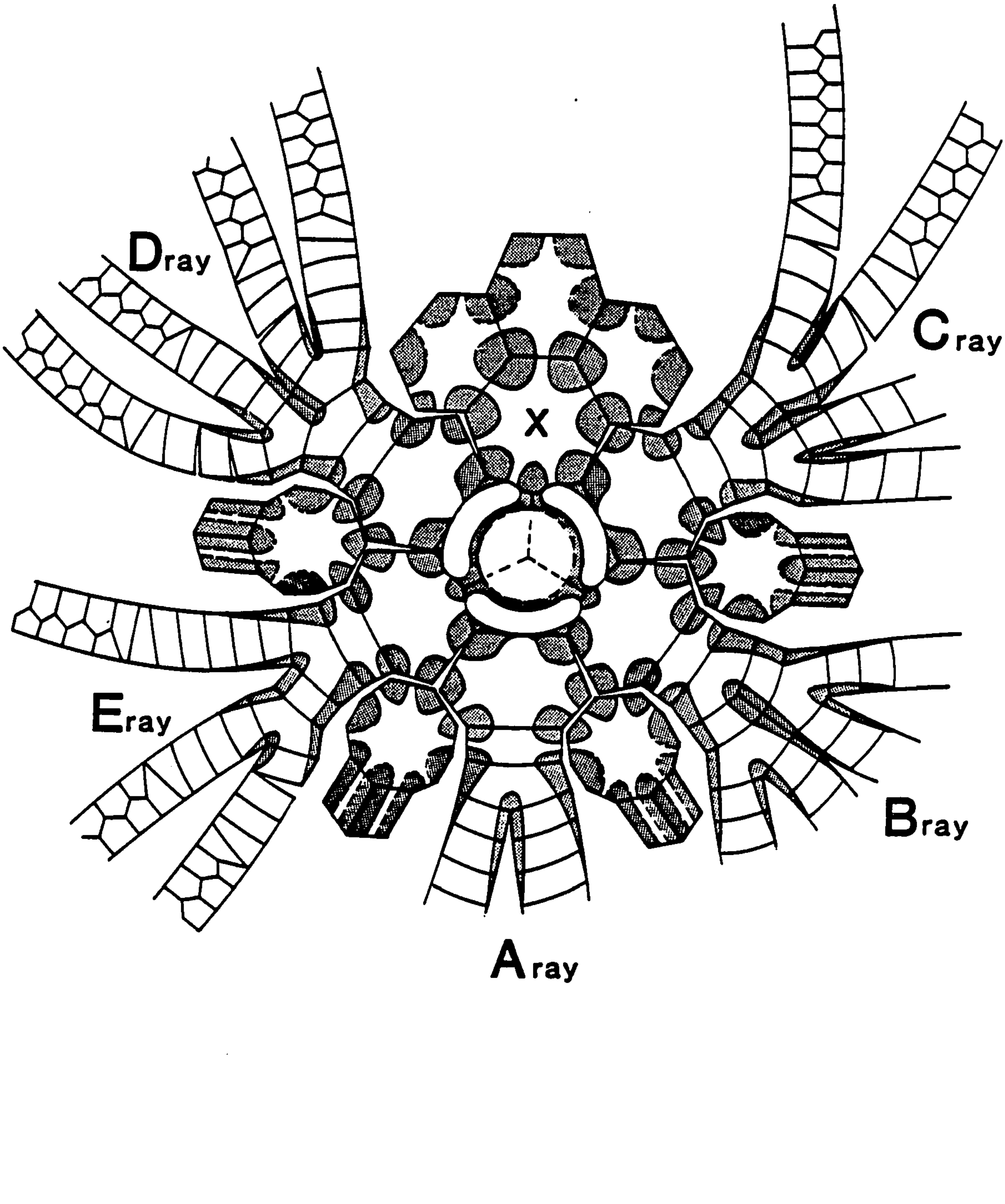
B) Hypotype UCGM 46061-D; immature adult centered on B ray (Plate 1, fig. 2)

C) Hypotype UCGM 46055; mature adult centered on A ray (Plate 1, fig. 3).

Explanation: radials black; interprimibrachs dot stippled.


A
5mm
B
5mm
C
5mm

Text Figure 19. Plate diagram of Aorocrinus helice (Hall). Plate arrangement based on UCGM 46062 (Plate 1, fig. 6). Information concerning surface ornament supplemented by additional well preserved specimens. Explanation: depressed areas dot stippled; X indicates primanal.


Dray
Cray
X
Eray
Bray
Aray

Superfamily PERIECHOCRINACEA Bronn, 1849

Family ACTINOCRINITIDAE Austin and Austin, 1842

Subfamily CACTOCRININAE Ubaghs, 1978

DIAGNOSIS

Fixed brachials weakly grouped, or not grouped (except in some species of Dialutocrinus). Rays typically not protuberant. Plates of tegmen undifferentiated. Anal tube present.

Genus CUSACRINUS Bowsher, 1955

DIAGNOSIS

An actinocrinid with moderate to steeply conical dorsal cup. Tegmen low, moderately arched or conical, with tall, slender anal tube rising from center. Rays not protuberant, or only slightly protuberant. Interbrachials numerous, connecting with plates of the tegmen. Basals three, wider than high, forming relatively wide base for column attachment. Radials large. Two primibrachs in each ray. One secundibrach in each half-ray. Tertibrachs simple, or axillary. Arms biserial, five to eight in each ray, weakly grouped. Pinnules long, slender, closely appressed, with short, overlapping spines. Column robust, composed of alternating series of nodals and internodals.

DISCUSSION

The genus _Cusacrinus_ (Bowsher) is most closely related to the genus _Actinocrinites_ (Miller). Bowsher (1955, p. 10) distinguished genera by their degree of ray axis protuberance (i.e., pentalobate vs. circular outline):

> "Although both _Actinocrinites_ and _Cusacrinus_ have grouped arms and a similar ray pattern, _Cusacrinus_ lacks the more or less protuberant ray at the base of the arms which characterizes most species of _Actinocrinites_. Primitive species of _Actinocrinites_ are similar to some cusacrinids and it is not always easy to make generic assignment of such forms. The difference between the two groups is accentuated though time by divergent trends, and advanced forms of _Actinocrinites_ can be recognized readily as distinct from _Cusacrinus_."

Within the subfamily Cactocrininae, genera can be differentiated by arm number, presence of arm branching, and whether interbrachial plates show connection with plates of the tegmen. The genus _Cusacrinus_ (Bowsher) can be distinguished from other members of the subfamily Cactocrininae (i.e., _Cactocrinus_ (Wachsmuth and Springer), _Nunnacrinus_ (Bowsher), _Teliocrinus_ (Wachsmuth and Springer), and _Dialutocrinus_ (Wright)) in showing both interbrachials which connect with plates of the tegmen, and five to eight, unbranched arms per ray.

Cusacrinus daphne Hall, 1863

Actinocrinus daphne	Hall, 1864, p. 52; Preliminary notice 1863, p. 3. Hall and Whitfield, 1875, p. 162; Pl. 11, fig. 11. Miller, 1889, p. 217. Wachsmuth and Springer, 1881, p. 143 (317). Wachsmuth and Springer, 1897, p. 574; Pl. 56, fig. 1.
Actinocrinites daphne	Bassler and Moodey, 1943, p. 269.
Cusacrinus daphne	Bowsher, 1955, p. 12.

Tables 6-8; Text Figures 20, 21; Plate 3, figs. 1-9; Plate 4, figs. 1, 2, and 7.

DIAGNOSIS

Species of Cusacrinus with elongate crown. Dorsal cup subturbinate to conical. Arms twenty-five to thirty, with each ray showing five or six arms. Other features same as in genus.

DESCRIPTION

Dorsal Cup - subturbinate to conical, with only slight axial ridge protuberance at arm level. Basals moderately large, wider than high. Radials large. Primibrachs two in each ray. Secundibrachs axillary, two in each ray. First tertibrach either axillary or simple; axillary plate found along the inner distal margin of one or both secundibrachs, whereas, outer margin supports a simple plate. Interprimibrachs showing connection with plates of the tegmen. One itersecundibrach inserted between inner pair of tertibrachs. CD interray wider than others. Anal X large. Second tier of anals (X_2) with two plates, each alike. Third tier of anals (X_3) with three, or more rarely four plates.

Basals - three, hexagonal, moderately large, wider than high; H:W ratio 0.47-0.54 in large mature specimens (UCGM 46103, 46106-A, 46108, and 46110) and H:W ratio 0.29-0.48 in smaller, less mature specimens (UCGM 46105-B, 46107, 46109, 46111, and 46112-A). Each basal with horizontal ridge or flange along its lower proximal border, and three vertical ridges, one which is central, and two along the plate's proximal lateral margins. Area between ridges depressed in shallow pits.

Radials five, hexagonal or heptagonal, large, wider than high; H:W ratio 0.76-0.89, avg. 0.83 in mature specimens, and H:W ratio 0.66-0.81, avg. 0.71 in smaller, less mature specimens (sample set same as for basals). Plates of two separate types: 1) A, C, and D rays hexagonal, resting upon the truncate distal margins of basals, 2) B and E rays heptagonal, with proximal margins acuminate, resting upon distal sloping shoulders of laterally adjacent basals. Ridge ornament radiating outward from plate center toward median position along the plate margins; corners depressed in triangular to subtriangular shape pits.

First Primibrachs - hexagonal, medium size, wider than high; H:W ratio 0.68 in mature specimens (UCGM 46103, 46106-A, 46108, 46113-A), and H:W ratio 0.43-0.95, avg. 0.53 in smaller, less mature specimens (UCGM

46105-A, 46105-B, 46107, and 46109). Ornament of two ridges perpendicularly bisecting plate; corners depressed in shallow pits.

Second Primibrachs - medium size, axillary, wider than high; H:W ratio 0.75 avg. in mature specimens (UCGM 46103, 46106-A, 46108, 46110, and 46113-A) and H:W ratio 0.57-0.98, avg. 0.71 in smaller, less mature specimens (UCGM 46105-A, 46105-B, 46107, 46109, and 46112-A). Ornament consisting of bifurcating axial ridge.

Secundibrachs - two in each ray, axillary, wider than high. Each plate supporting a simple or axillary tertibrach along its inner distal margin, and a simple tertibrach along its outer distal margin.

Tertibrachs - number variable, simple and axillary plates found in each ray; wider than high.

First Interprimibrachs - one in each ray, hexagonal, width and height subequal. Proximal margins acuminate between radials. Ornament consisting of six ridges which radiate from plate center; corners depressed in shallow pits.

Second Interprimibrachs - two in each ray, hexagonal, subequal, wider than high; H:W ratio 0.53-0.99, avg. 0.72 (UCGM 46103, 46105-A, 46107, 46109, and 46113-A). Ornament obscure and poorly known.

Third Interprimibrachs - two, or more typically three in each ray; shape variable, ranging from quadrangular to hexagonal (Text Figure 21). Variation found in plate shape reflecting the more irregular geometry of plates found in the tegmen. This suggests that interbrachials were incorporated from the tegmen early in ontogeny.

Intersecundibrachs - one, inserted between distal lateral margins of the first tertibrachs (Text Figure 20). Plate incorporated late in ontogeny; thus, interray plate not found in every specimen or ray position.

Axal X - large, hexagonal, height and width variable. In mature specimens (UCGM 46106-A, 46108, and 46113-A) plate higher than wide, H:W ratio, 1.15-1.69; whereas, smaller, less mature specimens (UCGM 46105-A, and 46107) plate slightly wider than high, H:W ratio 0.93-0.99. The greater plate height in large specimens may reflect a response of the crinoid to provide firm support for plates of the long conical tegmen. Ornament of six ridges radiates outward from plate center toward margins; corners depressed in triangular to subtriangular shape pits.

X_2 - two, each alike, hexagonal, width and height about equal. Ornament similar to Anal X.

X_3 - three, or four, size and shape variable. Specimen UCGM 46107 (Text Figure 20) showing hexagonal and quadrangular plates; specimen UCGM 46108 (Text Figure 21) with a small pentagonal plate bordered by two large hexagonal plates.

Tegmen - conical, with long, slender, anal tube (projecting from center); known only in specimen UCGM 46108. Anal tube deflected toward C ray (Text Figure 21). Plates irregularly polygonal.

Arms - twenty-five to thirty, with five or six arms in each ray; long, rising four to five times the height of dorsal cup. Distal arm tips nonpinnulate, recurved over the terminal series of pinnules. Brachials biserial, except in the first three to five nonaxillary plates. Each plate slightly rounded, or flattened along its aboral edge, and may show shallow longitudinal groove along axis between opposite facing brachials.

Pinnules inserted obliquely, with distal margin aborally (outwardly) protuberant and proximal margin adorally (inwardly) recessed. Pinnules long, slender, directed upward at an acute angle averaging 30 degrees (UCGM 46104, 46106-A, 46110, and 46111), and held together as cohesive paddle-like units resembling a feather. First pinnular short, expanded trumpet-like at base. Remaining pinnulars slightly longer, and showing a single short spine along the distal margin, which overlaps the adjacent pinnular found directly above (Pl. 4, fig. 7).

Arm regeneration found along a distal arm tip in specimen UCGM 46106 (Pl. 4, fig. 2).

Column - subround to elliptical, composed of alternating series of thick and thin ossicles; heteromorphic. Columnal indices in specimens UCGM 46112-A and 46118 (region between the fourth and seventh noditaxis) given in Table 6. Immature specimen UCGM 46120 with relatively complete column measuring 95.2 mm (Pl. 3, fig. 8).

Material - Holotype NYSM 6115; hypotypes -UCGM 46103, 46104, 46105-A, 46105-B, 46106-A, 46107, 46108, 46109, 46110, 46111, 46112-A, 46112-B, 46113-A, 46114, 46115, 46116, 46118, 46119-A, 46119-B, 46120, 46121-A, and 46122-46129.

Table 6. Columnal Indices in Cusacrinus daphne (Hall)

Specimen UCGM		46112-A	46118
Index	Ni	10.0	16.5
	KHi	11.3	10.7
Column L. (mm)		11.3	60.0

Ni - Nodal index

INi - Internodal index

KHi - Columnal height index for nodal (ni)

Table 7. Size measurements - <u>Cusacrinus daphne</u> Hall (mm)

Spec. no.		1	3	4	5	6	7	8	9	10	11	13	18
Plate													
BB	H	2.56	1.15	1.10	3.60	1.05	2.45	1.60	1.72	2.34	1.04	1.74	3.0
	W	5.30	3.07	2.85	7.03	3.65	4.53	4.50	3.67	5.78	2.15	--	5.1
RR	H	5.10	2.23	2.32	6.60	2.94	3.52	3.56	3.18	4.36	1.90	3.88	4.1
	W	5.40	3.40	3.33	7.40*	3.78	4.20	4.92	3.78	5.38	2.90	3.74	4.0*
IBr	H	2.54	1.30	1.20	4.40	2.03	1.94	1.80	1.66	2.97	1.23	2.14	2.6
	W	3.67	2.56	2.80	4.62	2.96	3.32	3.20	--	4.70*	--	3.52	3.9
IAx	H	2.42	1.55	1.66	2.76	1.95	2.12	2.10	1.80	--	1.25	2.24	2.9
	W	3.40	2.30	2.37	3.84	2.94	2.80	3.00	2.98	--	2.20	3.17	4.0
IIAx	H	2.00	1.24	1.50	3.26	1.37	1.64	1.44	1.47	--	1.20	2.00	-
	W	2.92	2.30	2.25	4.53	2.30	2.30	2.12	1.80	--	1.90	2.70	-
IIIAx	H	1.44	1.54	1.40	2.24	1.48	1.30	1.35	--	--	1.35	--	-
	W	1.88	1.92	1.75	2.50	2.04	1.70	2.20	--	--	1.55	--	-
iBr_1	H	3.46	2.22	2.14	--	2.75	2.96	2.72	2.70	4.20	1.30	3.62	4.2
	W	3.25	2.53	2.30	--	2.61	2.05	2.92	2.72	4.13	1.20	3.02	3.8
iBr_2	H	2.68	1.30	--	--	1.70	1.70	1.55	--	--	--	2.25	-
	W	2.72	2.00	--	--	2.10	2.20	2.04	--	--	--	2.48	-
iBr_3	H	1.30	--	--	--	--	1.04	--	--	--	--	--	-
	W	2.30	--	--	--	--	1.23	--	--	--	--	--	-
X_1	H	--	2.15	--	6.84	2.87	4.14	--	--	--	--	4.36	-
	W	--	2.30	--	5.92	2.90	2.46	--	--	--	--	3.80	-
X_2	H	--	1.50	--	4.86	2.14	2.13	--	--	--	--	2.55	-
	W	--	2.34	--	4.65	2.30	2.92	--	--	--	--	3.30	-
X_3	H	--	1.55	--	--	1.84	2.10	--	--	--	--	--	-
	W	--	1.47	--	--	1.76	2.27	--	--	--	--	--	-
Cup H		11.6	6.8	--	16.6	8.4	10.0	10.25	7.9	10.0	4.0	10.0	18.5
Arm L		49.0	29.2	--	78.3	29.4	49.3	--	36.1	--	22.0	43.7	61.0

Spec. no.	2	12	14	15	16	17
Cup H	8.1	7.7	--	13.1	--	12.5
Arm L	35.8	34.9	26.7	52.0	29.0	72.0

*Specimen 18 - Holotype NYSM 6115

<u>Museum numbers</u> (numerical order): <u>UCGM</u> - 46103, 46104, 46105A, 46105B, 46106A, 46107, 46108, 46109, 46110, 46111, 46112A, 46112B, 46113A, 46114 46115, 46116, 46117, and NYSM 6115 (Holotype)

DISCUSSION

Arms

The longitudinal groove occurring along the aboral edge of the arms of some specimens may have resulted from diagenetic compression or mechanical shear. However, an alternative explanation is that a depression developed during ontogeny to improve spacing between adjacent pinnule sets and increase width of the food groove.

An interesting feature in Cusacrinus daphne (Hall) is the series of overlapping spines that hold pinnules together as cohesive paddle-like units. This feature is also known in the closely related genus Cactocrinus (Wachsmuth and Springer). Apparently, pinnules were held at a relatively constant angular relationship to the arm axis and movement in a vertical mode was restricted. Deviations from this mode may have resulted in a loss of structural stability for the arm-paddle. Conversely, the combined lateral flexure of pinnules into a bowl-like curvature probably improved feeding efficiency due to the turbulent eddies and hydraulic lift resulting from arm paddles held in this configuration.

Gastropod association

The association between crinoids and gastropods has been long and well documented (see Bowsher, 1955). Some early authors believed gastropods to be carnivorous and preditory upon crinoids (Austin and Austin 1843-1849, and Billings 1870). But this view was later abandoned in favor of a commensal relationship, whereby the gastropod fed on the crinoid's feces. Gastropods are typically positioned directly over the crinoid's anal vent. Evidence suggesting that this relationship was long term is seen by the growth modifications of the gastropod's aperture margin, which directly match surface irregularities found on the crinoid's ventral surface. For a complete discussion see Bowsher (1955b, p. 1-11).

The gastropod Platyceras is found directly over the tegmen of specimens UCGM 46111, 46116, 46124, an 46129-(slide). This occurrence is somewhat unusual because specimens of Platyceras are not typically associated with crinoids showing a long anal tube. Lane (1978, p. 345-346) comments:

> "Platyceratids are most commonly found on crinoids that have a solid tegmen with firmly fused plates on which the anal opening is flush with the surrounding surface of the tegmen. A few specimens are known from camerate crinoids with a long anal tube, like Actinocrinites, but in these instances the tube is typically broken or the distal end is plugged with small plates and a secondary anal opening was resorbed through the tegmenal plates."

The specimens with gastropod attachment show no evidence of a broken anal tube. Platyceras completely covers the tegmen up to the base of the arms in these individuals. The relatively small size of these crinoids presented no problems for gastropod attachment. However, this may not have been the case with larger individuals where the size of the anal tube most certainly exceeded the size of the gastropod. It is conceivable that the long term positioning of the gastropod over the tegmen stunted development of the anal tube. However, this hypothesis is impossible to verify given the present suite of specimens. Large specimens with Platyceras attachment were not found.

Ontogeny

Crown heights in Cusacrinus daphne (Hall) range from 26.0 to 94.9 mm. To determine the magnitude of size modifications allometric analysis was performed on six specimens (Table 8). Methods employed are similar to those used for Aorocrinus helice (Hall). However, because plate information was not complete in all specimens analysis was performed in three steps.

STEP 1 - Ray axis analysis included all individuals in the sample set (UCGM 46103, 46105-A, 46107, 46108, and 46112-A). Allometric values were determined by plotting independent plate measurements against the cumulative measurement of plates found in the ray axis (BB + RR + IBr + IAx + IIAx + IIIAx).

STEP 2 - Interbrachial and anal plate analysis includes the first two orders of these plates in specimens UCGM 46103, 46105-A, 46106-A, 46107 and 46108. Allometric values were determined by plotting an independent plate measurement against the cumulative measurement of plates found in the ray axis, plus measurement of that plate.

STEP 3 - Arm analysis was made by plotting the maximum number of free brachials and arm length against the cumulative height of plates in the ray axis.

The greatest increase of plate height occurred in the basals. Increase in basal plate width was also positive, but secondary to its increase in height. The large values observed for basals may reflect conditions of rapid growth occurring in the column. Smaller positive increases occurred in radials and the first primibrachs. Values of height exceeded those of width.

In general, axillary plates grew at a substantially slower rate than plates which were more proximal in the cup. Primaxil and secundiaxil height values were slightly negative, but that of the tertiaxil was strongly negative. Plate width in all three axillaries was strongly negative, but that of the tertiaxil was most strongly negative. In specimens UCGM 46103, 46105-B, 46106-A, 46108, and 46109, modifications in plate height showed a progressive decrease from primaxil toward tertiaxil. Throughout the recorded growth interval height of the primaxil remained dominant over that of the secundibrach. Conversely, the tertiaxil of specimen UCGM 46105-A, smallest individual of the sample set, actually exceeded the height of both primaxil and secundiaxil. Apparently, early fixation of the primaxil and secundiaxil into the cup allowed the "free" tertiaxil to be taller during earlier stages of ontogeny. A similar relationship occurred between the primaxil and secundiaxil of <u>Aorocrinus</u> <u>helice</u> (Hall).

The Anal X showed an equivalent allometric value in plate height to that of the radials. Its value in plate width, however, was more strongly positive. Anal X_2 and Anal X_3 show similar allometric values in plate height, but plate width was considerably greater in the Anal X.

The first interprimibrachs show relatively similar negative values for both plate width and height. Allometric values in the second interprimibrachs are more strongly positive. Increase in plate height of the second interprimibrachs was exceptionally strong.

Brachial number and arm length show a nearly isometric relationship to "size", defined as the cumulative height of plates in the ray axis, excluding that of the tertiaxial.

Comparison of allometric values between *Aorocrinus helice* (Hall) and *Cusacrinus daphne* (Hall) is given in Table 8. In summary, the dorsal cup of *A. helice* (Hall) was allometrically modified during ontogeny from truncate conical to bowl-shaped, while the dorsal cup of *C. daphne* (Hall) underwent the opposite modification from bowl-shaped to conical.

Table 8. An allometric comparison between Aorocrinus helice (Hall) and Cusacrinus daphne (Hall)

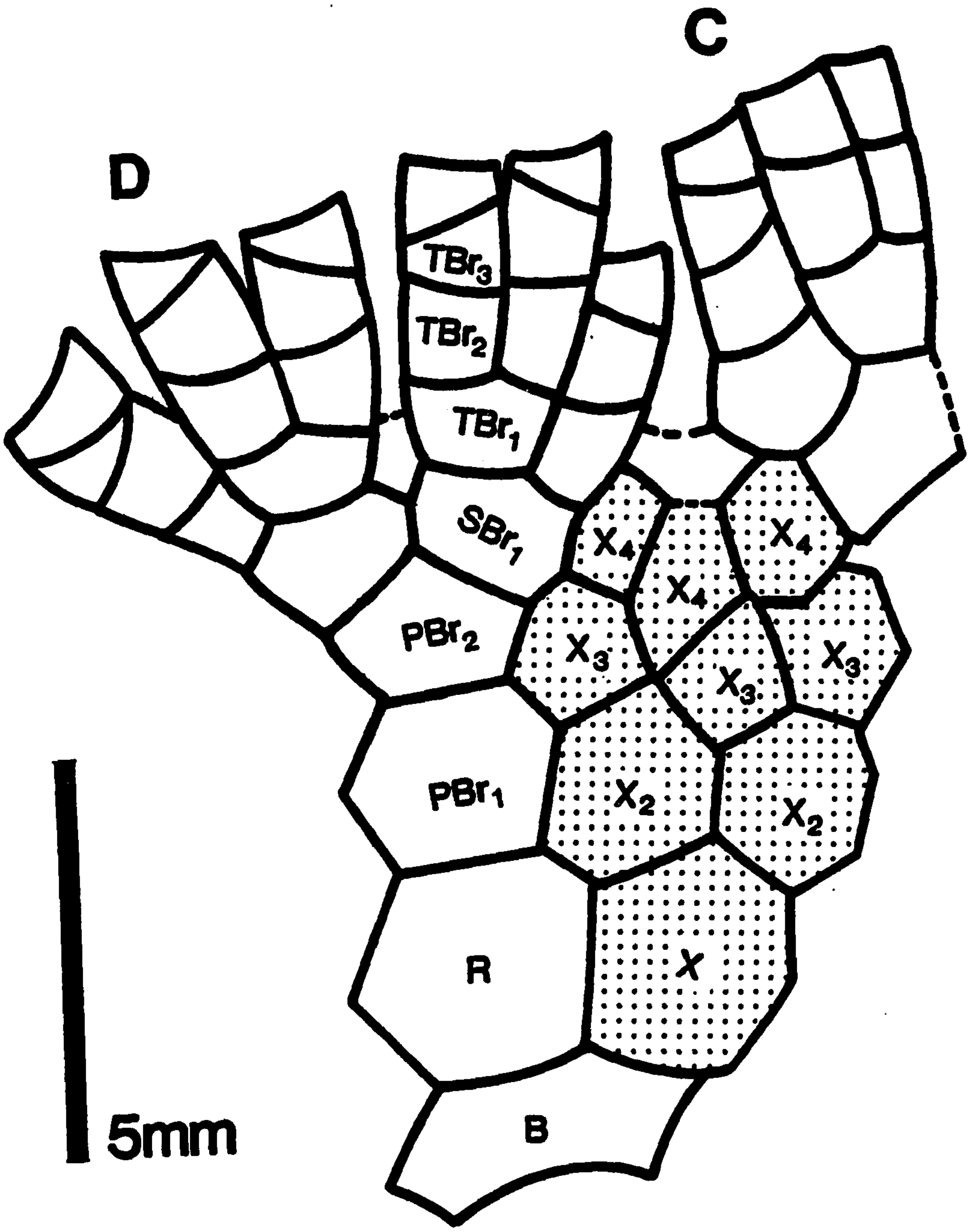
	Cusacrinus daphne				Aorocrinus helice			
	K_h	(a)	K_w	(a)	K_h	(a)	K_w	(a)
BB	1.27	0.07	1.16	0.14	0.79	0.18	0.75	0.35
RR	1.13	0.19	0.92	0.29	0.82	0.31	1.03	0.19
IBr	1.16	0.11	0.83	0.28	1.44	0.05	1.07	0.12
IAx	0.95	0.19	0.58	0.54	1.28	0.07	1.02	0.15
IIAx	0.94	0.16	0.79	0.26	0.73	0.25	0.86	0.20
IIIAx	0.37	0.61	0.66	0.30	--	--	--	--
iBr_1	0.84	0.29	0.76	0.28	1.08	0.24	1.35	0.06
iBr_2	1.22	0.07	0.86	0.16	--	--	--	--
Anal X	1.13	0.15	1.33	0.05	0.88	0.22	0.93	0.19
X_1	1.14	0.11	1.06	0.11	--	--	--	--

	Cusacrinus daphne		Aorocrinus helice	
	K	(a)	K	(a)
Brachial no. vs. Size	1.03	10.57	0.96	16.66
Arm length vs. Size	1.01	3.44	1.11	4.12

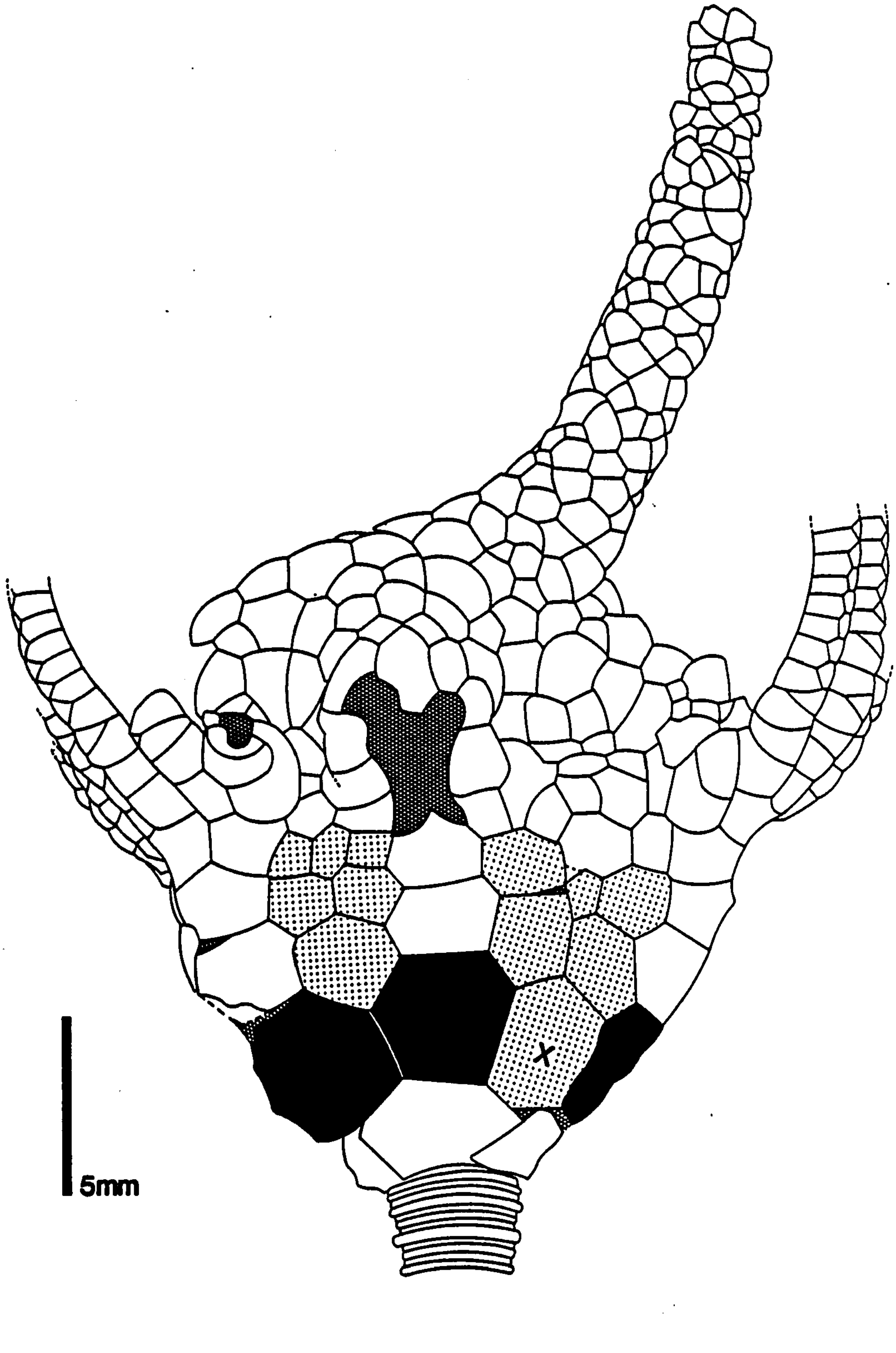
KEY: K = allometric value; h = height, w = width

(a) = graphic intercept

Text Figure 20. Cusacrinus daphne Hall. Plate diagram of CD interray and D ray in specimen UCGM 46107. Explanation: anal plates dot stippled.


C
D
TBr3
TBr2
TBr1
SBr1
PBr2
PBr1
R
B
X4
X4
X4
X3
X3
X3
X2
X2
X
5mm

Text Figure 21. Cusacrinus daphne Hall. Camera lucida drawing of specimen UCGM 46108; D ray view (Pl. 3, fig. 3). Tegmen with long, slender anal tube deflected toward C ray. Explanation: radials black; interbrachials and anals dot stipped; void spaces cross hatched; 'X' indicates Anal X.


x
5mm

Family AMPHORACRINIDAE Bather, 1899

DIAGNOSIS

Ubaghs (1978, p. 450) writes:

"Fixed secundibrachs one or two in each half-ray; fixed tertibrachs absent or present; interprimibrachs few, connected with tegmen; primanal typically hexagonal and followed by two plates, rarely heptagonal and followed by three plates; calycal plates generally with granulo-vermicular ornament. Tegmen usually high in relation to calyx; and tube moderately developed. Proximal region of arms horizontal or projecteding downward."

Genus AMPHORACRINUS Austin, 1848

DIAGNOSIS

Same as for family.

DISCUSSION

Moore and Laudon (1943, p. 92-93) interpreted the Amphoracrinidae as a specialized offshoot of the Periechocrinitidae, or as transitional between the Periechocrinitidae and the Actinocrinitidae. The actinocrinids show two plates following the primanal, whereas, the periechocrinids show three plates. Amphoracrinids have two, or more rarely three plates following the primanal.

An advanced feature not typically found in either the Periechocrinitidae or Actinocrinitidae, but common in the Amphoracrinidae and the somewhat more advanced family Paragaricocrinidae, is development of a quadrangular first primibrach. Within the Amphoracrinidae the genera Ectocrinus (Wright) and Pimlicocrinus (Wright) show a low, quadrangular first primibrach. The genus Amphoracrinus (Austin) is somewhat more variable in the shape of the first primibrach; Breimer (1962, p. 79) comments:

> "Some American Amphoracrinus species have low quadrangular first primibrachs as well, but this cannot be thought typical for Amphoracrinus as a whole. The neotype of Amphoracrinus gilbertsoni has five, or six sided first primibrachs, not well defined in form. This is often seen among Amphoracrinus species."

Amphoracrinus (Austin) is typically known as a European genus. Wright (1955, p. 193-204) described ten species from the British Isles. All British species show two plates following the primanal. Information concerning arm structure is missing.

Wachsmuth and Springer (1897, p. 586-592) recognized three species from North America, Amphoracrinus viminalis (Hall), Amphoracrinus divergens (Hall), and Amphoracrinus spinobrachiatus (Wachsmuth and Springer). All North American forms show two plates following the primanal, but also occasionally show three plates in the species, A. viminalis (Hall) and A. divergens (Hall). Arms originate from two to four main rami which remain simple, or branch dichotomously three to five times.

Amphoracrinus viminalis (Hall) appears to represent a rather specialized evolutionary offshoot of the Devonian periechocrinid genus Megistocrinus (Owen and Shumard). The arm structure of A. viminalis (Hall) is essentially that of Arballocrinus (Breimer), another specialized Megistocrinus offshoot, but the dorsal cup in Arballocrinus is taller, plates thinner, and the first primibrach hexagonal. Perhaps somewhat closer Sunwaptacrinus brazeauensis (Laudon, Parks, and Spreng) shows a quadrangular first primibrach, and wide bowl shaped calyx, but can be readily distinguished from A. viminalis (Hall) by arms which divide from four main rami in each ray, a tall conical tegmen, and three X_2 anals.

Amphoracrinus viminalis Hall, 1863

Actinocrinus viminalis Hall, 1864, p. 54; 1863 preliminary notice.
Hall and Whitfield, 1875, p. 165; Pl. II, figs. 12-14.

Amphoracrinus viminalis Wachsmuth and Springer, 1881, p. 155.
Wachsmuth and Springer, 1897, p. 590-591.
Bassler and Moodey, 1943, p. 300.

Tables 9-10; Text Figures 22-26; Plate 6, fig. 1-3; Plate 5, figs. 1, 2, and 4.

DIAGNOSIS

A species of Amphoracrinus with a low, bowl-shaped cup; plates thick, with incised sutures, and covered with fine nodes and vermicular ornament. Basal circlet composed of three equal plates. Radials five, large, wider than high. Primanal narrower and taller than radials, followed by two, or more rarely three X_2 anal plates. Rays projecting markedly outward beyond the first, or second primibrach. Arms biserial; ten at cup rim, becoming free above the second secundibrach, then branching heterotomously up to four times in each half-ray.

DESCRIPTION

Dorsal Cup - low bowl-shaped, about twice as wide as high; H:W ratio 0.33-0.54 avg. 0.46 (n=8; Table 10). Plates moderately thick, incised along suture margins, with small nodes and vermicular ornament. Basals three, equal, truncate at their proximal margin and forming slightly protuberant base. Radials five, largest plate in cup; circlet interrupted by primanal in CD interray. Primanal slightly higher and narrower than radials; followed by two, or more rarely three X_2 anals. Interprimibrachs large, rows of 1, 2, 3 plates in each of the nonposterior interrays. Primibrachs two in each ray. Rays projecting markedly beyond the first, or second primibrach. Arms free beyond the second secundibrachs (Text Figures 22 and 23).

Basals - three, equal, pentagonal or hexagonal in side view, with sutures in B, CD, and E ray positions. Basals slightly less than one-half size of radials, and about one third as high as wide; H:W ratio 0.25-0.33, avg. 0.29 (n=9; Table 10). Each basal truncate along its proximal base, forming slightly protuberant rim margin over column.

Radials - five, largest plate in dorsal cup; hexagonal in A, C, and D rays, and heptagonal in B and E rays. Each plate wider than high, H:W ratio 0.56-0.70, avg. 0.65 (n=9; Table 10). Proximal margins of heptagonal radials forming broad, low, barely visible V-shape insertion between basals. Vermiculate-nodose ornament well developed.

First Primibrachs - five, quadrangular, wider than high; H:W ratio 0.39-0.50, avg. 0.45 (n=9; Table 10). Plates convex, coarsely granulose, or showing traces of vermiculate-nodose ornament. Lateral margins subparallel, or slightly expanding toward second primibrach.

Second Primibrachs - five, pentagonal, axillary, about twice as wide as high; H:W ratio 0.45-0.48, avg. 0.46 (n=9; Table 10). Distal articular faces exposed in specimen UCGM 46134, slightly concave, curved hornlike around the ambulacral groove (Text Figure 24 A-B; Plate 5, fig. 1).

First Secundibrachs - two in each ray, quadrangular or obscurely pentagonal, wider than high, strongly convex. Each pair of secundibrachs fused along their inner lateral margins.

Second Secundibrachs - two in each ray, cunetae, wider than high, convex. Each pair of secundibrachs, as with first secundibrachs, united along their inner lateral margins.

First Interprimibrachs - four, large, exceeded in size only by radials and primanal, height and width nearly equal; H:W ratio 0.88-1.27, avg. 1.05 (n=9; Table 10). Lateral margins slightly expanding. Proximal and distal margins acuminate.

Second Interprimibrachs - eight; two in each nonposterior interray. Plate asymmetrical, hexagonal, height and width subequal; H:W ratio 0.67-1.19, avg. 1.02 (n=7; Table 10). Outer lateral margins of second interbrachs bordered by primaxil (PBr_2) and first secundibrach (SBr_1).

Third Interprimibrachs - twelve; three in each nonposterior interray. Plate hexagonal, height and width subequal; H:W ratio 0.67-1.19, avg. 1.02 (n=5; Table 10). Outer pair of plates bordered by first secundibrachs, but mostly forming portion of tegmen.

Primanal (Anal X) - large, slightly taller and narrower than radials, hexagonal, height and width subequal; H:W ratio 0.97-1.19, avg. 1.09 (n=6; Table 6). Proximal margins forming low, nearly truncate, acuminate insertion with basals. Lateral margins expanding distally. Distal margin acuminate.

X_2 - two, or more rarely three plates, hexagonal, slightly smaller than Anal X, height and width subequal; H:W ratio 0.93-1.10, avg. 1.04 (n=4; Table 10). Primanal followed by two plates in specimens UCGM 46135 and 46082-D, and by three plates in specimen UCGM 46093-B (Text Figure 15). Right lateral X_2 anal of specimen UCGM 46093-B smaller than other two anals, thus, plate may have been inserted from above by X_3 tier of anals.

X_3 - three, hexagonal, smaller than X_2 anals.

Tegmen - known from specimen UCGM 46134 (Text Figure 24 A-B; Pl. 5, fig. 1); conical, gently lobate, with short central spine on large, domed CD oral. Plates showing fine vermiculate ornament. Ambulacral plates relatively small, in paired arrangements easily distinguished near proximal arm base, but less clearly marked from adjacent interambulacrals above. Interambulacrals somewhat larger than ambulacrals, moderately convex, and slightly depressed within interrays. Orals large, hemisperically domed, with vermiculate ornament, reminiscent of brain coral. Orals of DE, EA, AB, and BC interrays nearly equal; CD oral larger than others, broadly conical, with short spinose process at its central apex, elongate in the direction of the D ray. Posterior margins of CD oral bordered by four (Text Figure 24-B) plates, not clearly differentiated as orals. Anal vent or tube not visible in figured specimen UCGM 46134.

Arms - robust, approximately five to six and one-half times the height of the dorsal cup, directed laterally outward near proximal base, and tapering distally. Ten arms at cup rim, then branching up to four times in each half ray. First arm division regular, occurring a short distance from the cupalong the fifth to tenth double row of brachials. Remaining arm divisions irregular; each half-ray remaining simple, or dividing up to three times (Text Figure 26). Specimen UCGM 46135 shows a particularly unusual arm division in the second left-lateral division of the D ray, where three rather than two arm branches originate from the same region.

Second to fourth secundibrach cuneate. Above, brachials biserial. Brachials exhibit low, angular, transverse ridge at their pinnular junction, which tapers out away from junction, about one-fourth to one-third plate width. Brachial-pinnular ridge ensures well developed articular union.

Pinnules long, slender. Pinnulars show keel along aboral surface; adoral surface with slit-like indentation of ambulacral groove. Transverse view triangular to pentagonal. First pinnular shorter than those which follow, expanded trumpet-like toward proximal base.

Column - round to slightly elliptical, composed of alternating series of thin and thick ossicles; heteromorphic. Noditaxis showing three orders. Lumen small, quinquelobate. Columnal indices for regions near proximal base given in Table 9.

Material: Holotype NYSM 6117; Hypotypes UCGM 46130, 46131, 46132, 46133, 46134, 46135, 46093-B, 46082-D, 46136-A, 46137, 46138, 46139, 46140, 46141, and 46142.

Table 9. Columnal Indices in Amphoracrinus viminalis (Hall)

Specimen UCGM	Ni	INi	KHi	Li	KSi
46130	24.3	75.7	14.5	--	68.3
46093-B	23.1	76.9	14.4	--	70.2
46082-D	--	--	--	13.8	88.0

Table 10. Plate measurements in <u>Amphoracrinus</u> <u>viminalis</u> Hall (mm)

Specimen		1	2	3	4	5	6	7	8	9*
BB	H	1.3	1.2	1.2	1.2	0.8	1.2	1.3	1.3	1.5
	W	4.5	4.0	5.0	4.7	3.2	4.0	3.9	3.9	4.8
RR	H	2.8	3.0	3.5	3.1	2.5	3.1	2.8	3.1	3.1
	W	4.3	4.3	5.3	4.5	3.6	5.1	4.3	5.0	5.5
IBr	H	1.7	1.5	2.1	1.9	1.3	2.0	1.7	2.0	1.1
	W	4.1	3.2	4.4	4.2	3.3	4.0	4.1	4.3	2.2
IAx	H	1.9	1.8	1.9	1.9	1.7	1.9	1.9	1.8	2.1
	W	4.1	2.8	3.2	3.0	2.8	3.1	3.0	3.0	3.4
IBr_1	H	3.4	3.3	3.8	3.8	2.8	3.7	3.3	3.4	3.5
	W	3.8	2.7	3.8	3.7	2.3	3.7	2.6	3.7	4.0
IBr_2	H	2.8	2.3	3.2	-	2.0	-	2.4	2.8	2.0
	W	2.4	2.3	2.7	-	1.9	-	2.3	2.8	3.0
IBr_3	H	2.1	-	2.7	-	2.0	3.6	2.0	-	-
	W	2.1	-	2.7	-	2.0	2.4	1.7	-	-
X	H	-	-	4.2	4.0	3.2	3.3	3.7	3.6	-
	W	-	-	3.7	3.8	2.7	3.4	3.4	3.5	-
X_2	H	-	-	-	3.3	2.3	2.8	-	3.4	-
	W	-	-	-	3.0	2.1	3.0	-	3.3	-
Cup	H	7.2	7.8	8.4	7.2	5.5	8.3	6.7	7.7	-
	W	15.3	17.0	18.5	21.9	12.3	17.2	12.4	16.2	-
ARM	L	35.0	45.0	38.3	44.0	34.0	46.0	34.0	-	-

Museum numbers (numerical order): UCGM 46130, 46131, 46132, 46133, 46134, 46135, 46093-B, 46082-D, and NYSM 6117

*Holotype NYSM 6117

DISCUSSION

At first very little information was known concerning the anal series of plates of this species. Hall and Whitfield (1875, p. 165) wrote: "The first anal is smaller than the first radial, and above they have not been determined." A more complete description was given by Wachsmuth and Springer (1897, p. 591). They found two or three plates to follow the primanal. However, the condition where three anals follow the anal X may be abnormal. Wachsmuth and Springer (1897, p. 587) comment:

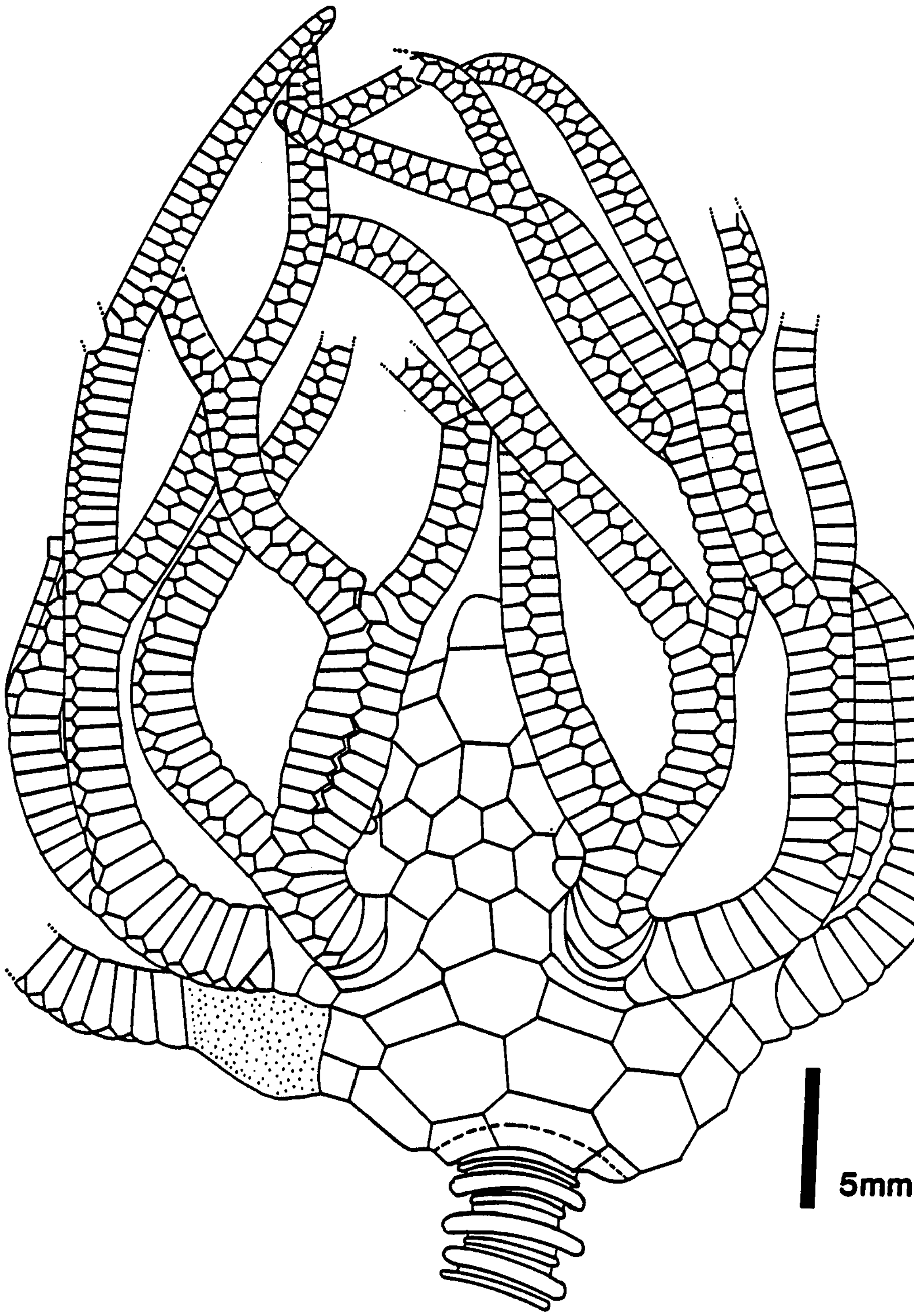
> "To understand the case correctly, it is important to note that the middle plate over the anal, when it does occur, is comparatively small and cuneate, often barely touching the anal plate; and we think it not improbable that it really represents a plate of the second row."

Of the material collected in this study specimen UCGM 46093-B shows three X anal. However, in this example the right lateral rather than the center plate was found to be smaller than the others. Text Figure 26 shows the anal series of plates found in three specimens of Amphoracrinus viminalis (Hall).

In North America Amphoracrinus ranges from Upper Kinderhook to Lower Osage (Burlington). A. divergens (Hall) and A. spinobrachiatus (Wachsmuth and Springer) are found in the Burlington Limestone of Iowa and the Lake Valley Formation of New Mexico. Amphoracrinus viminalis (Hall) is apparently the most primitive member of this group, and can be readily distinguished from the other species in having a dorsal cup not hidden by arms in lateral view, arms bifurcating from two main rami in each ray, and only a single spinose plate in the tegmen.

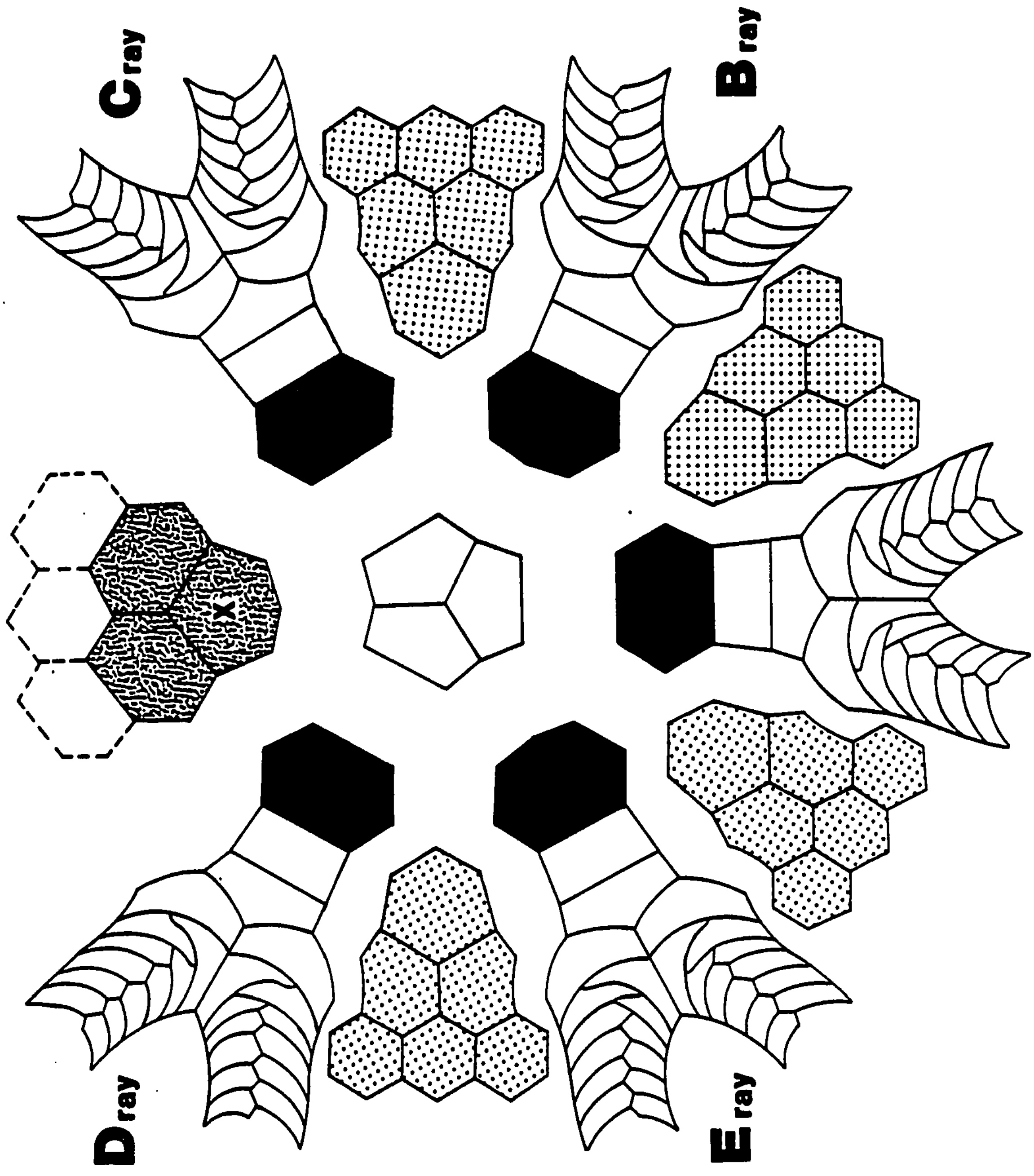
Text Figure 22. Amphoracrinus viminalis (Hall). Camera lucida drawing of Hypotype UCGM 46130; AB interray view (Pl. fig. 2). Note arms projecting outward close to their proximal base.

Explanation: stippled area along C ray indicating bryozoan encrustation.


5mm

Text Figure 23. Amphoracrinus viminalis (Hall). Plate diagram of dorsal cup, based upon Hypotypes: UCGM 46132 and UCGM 46135.

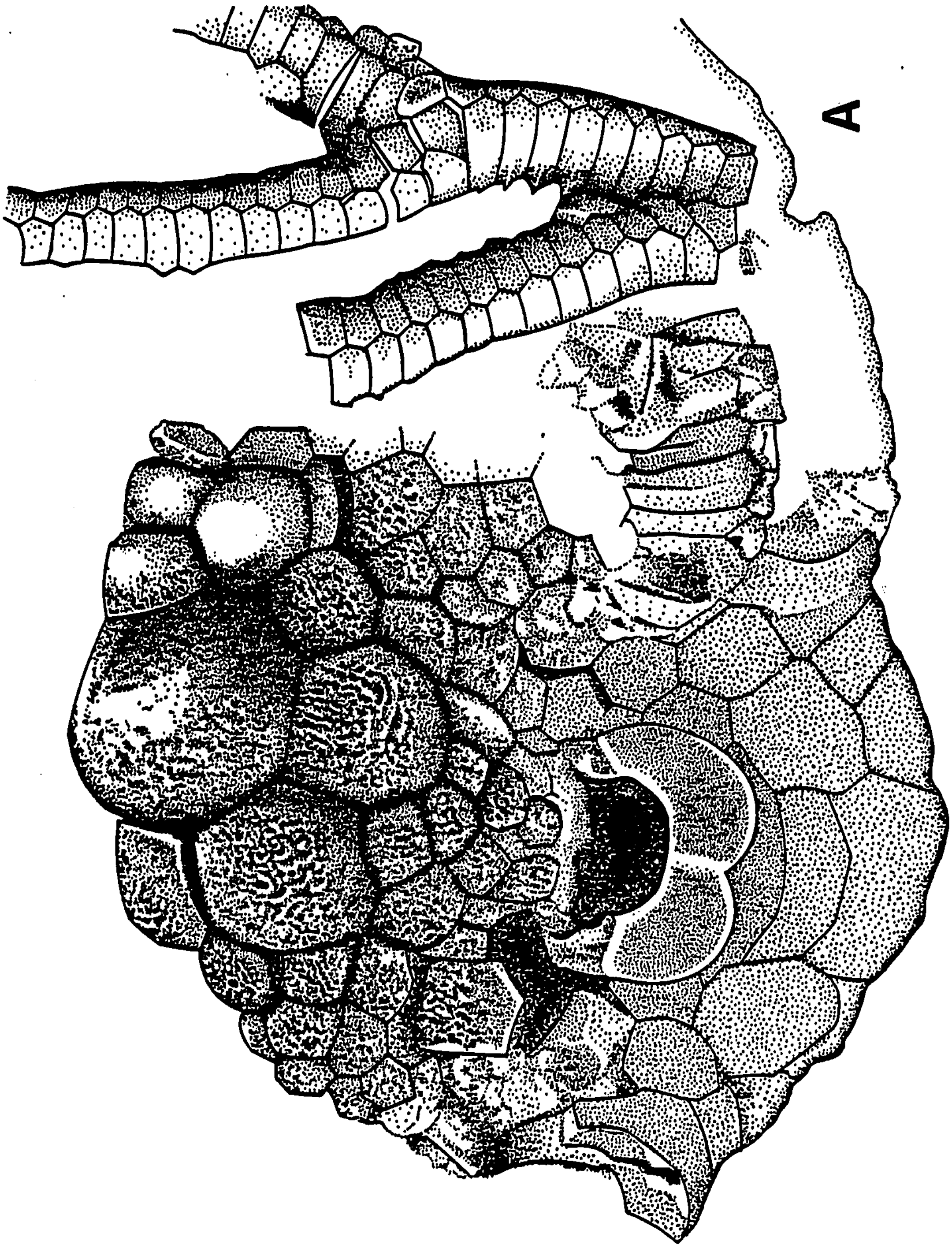
Explanation: radials black; interprimibrachs dot stippled; anals wrinkle stipped; X- indicates primanal.


A ray
B ray
C ray
D ray
E ray
X

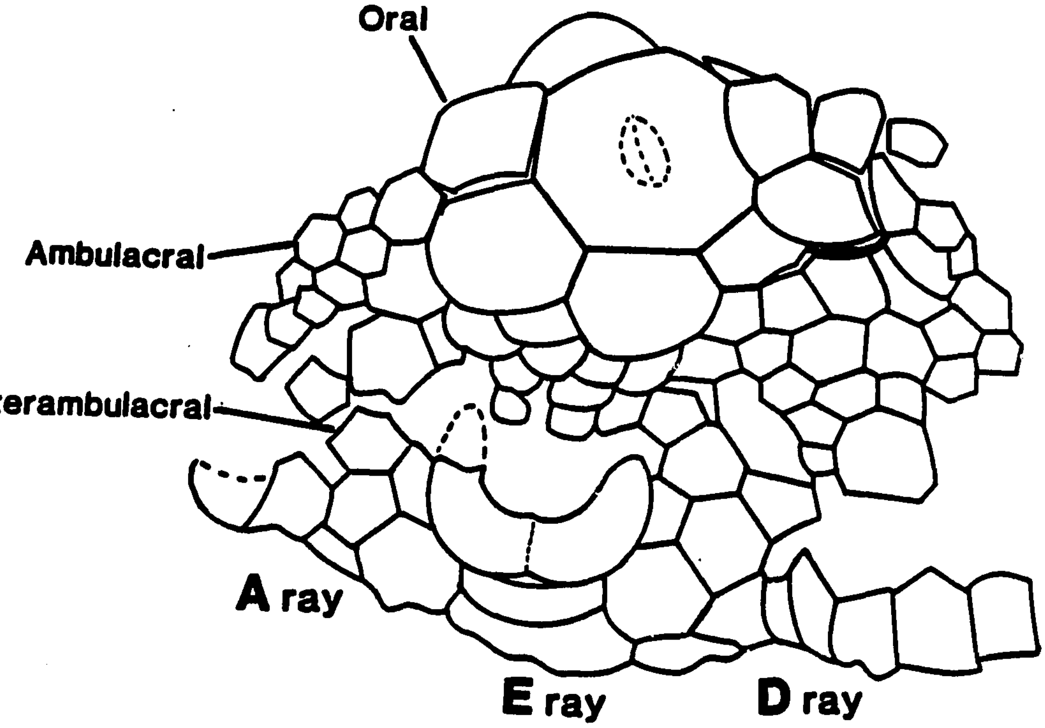
Text Figure 24 A–B. Amphoracrinus viminalis (Hall). Dorsal cup and tegmen in Hypotype UCGM 46134; E ray view.

A) Stippled drawing from photograph (Pl. 5, fig. 1).

B) Camera lucida drawing of same specimen after additional cleaning along posterior side. Orientation bringing two additional plates along CD oral into view.



A



B

Text Figure 25. Amphoracrinus viminalis (Hall). Camera lucida drawings of anal plates in three specimens.

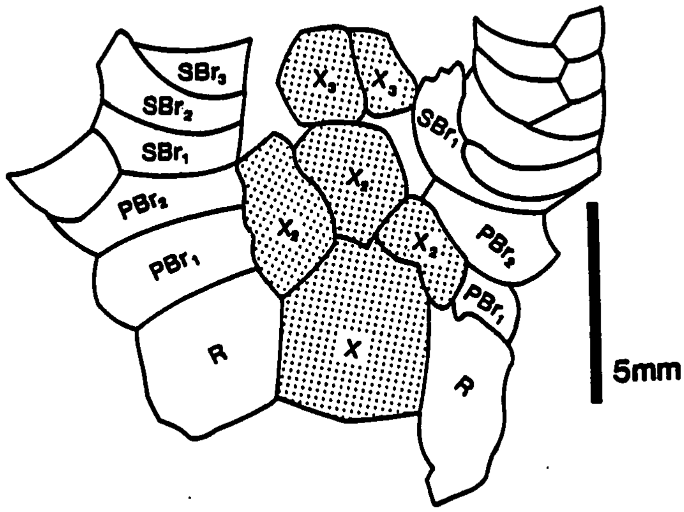
A) Hypotype UCGM 46093-B showing three X anals.

B) Hypotype UCGM 46082-D showing two X anals.

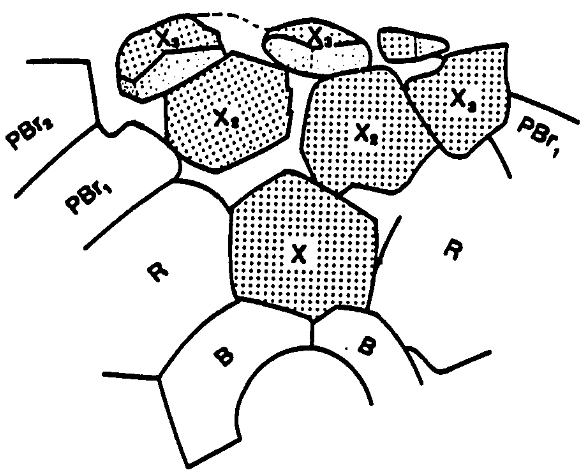
C) Hypotype UCGM 46135 showing normal arrangement of anals.

Explanation: Anals dot stippled.

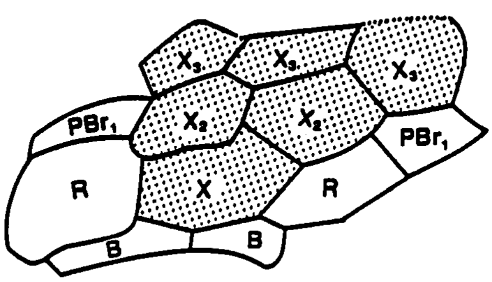
A


SBr3
SBr2
SBr1
X3
X3
SBr1
PBr2
X2
X2
X2
PBr1
PBr2
PBr1
R
X
R
5mm

B


X3
X3
PBr2
X2
X2
X2
PBr1
PBr1
R
X
R
B
B

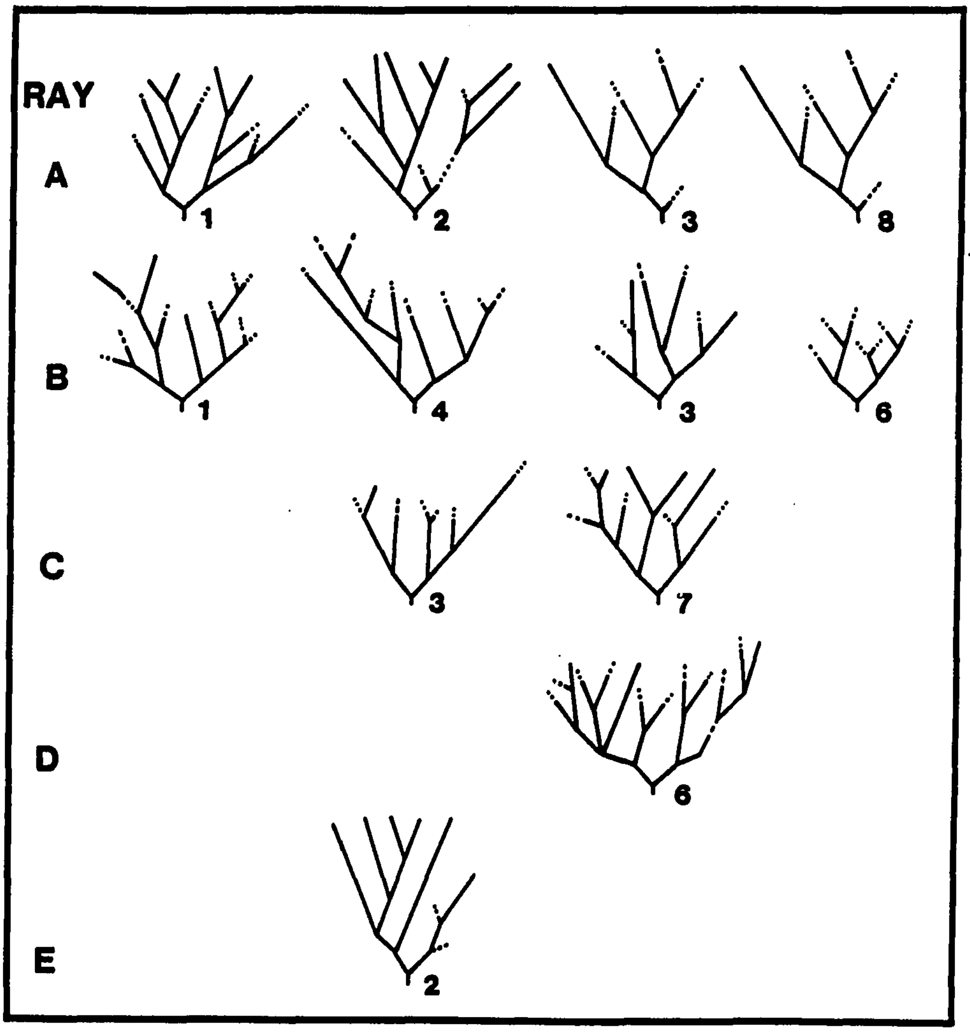
C


X3
X3
X3
PBr1
X2
X2
PBr1
R
X
R
B
B

Text Figure 26. Arm branching patterns in Amphoracrinus viminalis (Hall). Note unusual division in D ray of specimen no. 6.

Explanation: specimen numbers correspond to museum numbers (Numerical order): UCGM-46130, 46131, 46132, 46133, 46093-B, and 46082-D.

Arm Branching in *Amphoracrinus viminalis*



Suborder GLYPTOCRINACEA Moore, 1952

Superfamily PLATYCRINITACEA Austin and Austin, 1842

Family PLATYCRINITIDAE Austin and Austin, 1842

Genus PLATYCRINITES Miller, 1821

DIAGNOSIS

Dorsal cup bowl or box-shaped. Basal three, unequal; two plates large, each alike; remaining plate small, found in EA interray position. Basal circlet may show fusion. Radials five, large, subquadrangular. Anal X small, incorporated into tegmen. Tegmen composed of a few large plates or many small ones; flat or pyramidal. Orals distinct. Anal opening excentric, tube may be developed. Arms biserial, except in proximal-most series of plates. Arms branching heterotomous, one to five times. Primibrachs one, or rarely two. Proximal brachials similar to free arm plates, but fixed to tegmen by one to three interradials. Pinnulate. Column round close to proximal and distal bases, but becoming elliptical and helically twisted throughout most of its length. Column showing synarthrial articulation, with fulcral ridge running parallel to elongate axis. Lumen small, round.

DISCUSSION

Moore and Laudon (1943, p. 89-90 and 100) considered the platycrinids to be the end product of evolution which descended from the Thallocrinidae, a family which in turn descended from the Patelliocrinidae. Throughout the lineage basal plates show an unequal tripartite symmetry. Whereas, elements of the ray axis show perfect to nearly perfect pentamerous symmetry. In platycrinids there is a tendency toward simplification of the dorsal cup with exclusion of all brachials, and all but a single interbrachial from the dorsal cup. This condition is essentially equivalent to that found among inadunates. Moore and Laudon (1943, p. 90) considered the platycrinids to be the most highly evolved group within the Monobathrida.

Features not well understood in the evolution of the platycrinid lineage are those changes which occurred in the development of the tegmen. Thallocrinids have a tegmen composed of only a few large plates, whereas, platycrinids may show tegmens composed of either a few large plates, or many small ones. This led Laudon (1967, p. 1496) to suggest that platycrinids followed divergent evolutionary trends. Platycrinids with multi-plated tegmens such as Platycrinites symmetricus (Wachsmuth and Springer) and Platycrinites bozemanensis (Miller and Gurley) may have evolved from the Devonian genera Cordylocrinus (Angelin) or Cyttarocrinus (Goldring).

Platycrinites lodensis Hall and Whitfield, 1875

Platycrinus lodensis Hall and Whitfield, 1875, p. 168; Pl. 2, fig. 3. Wachsmuth and Springer, 1881, p. 72 (246). Wachsmuth and Springer, 1897, p. 666; Pl. 71, fig. 6.

Platycrinites lodensis Bassler and Moodey, 1943, p. 623.

Table 11; Text Figures 27 and 28; Plate 4, fig. 6.

DIAGNOSIS

A species of Platycrinites with stout, compact crown. Dorsal cup large, bowl-shaped. Arms sixteen; four in each ray, strong, relatively compact. Primibrachs one, axillary, low, subtrigonal. Secundibrachs four or five in each ray. Lateral margins of secundibrachs joined in fixed symplectical unions between half-rays. Arms free beyond the second tertibrach.

DESCRIPTION

Dorsal Cup - bowl-shaped, wider than high. Basals three, unequal; EA interray basal smaller than others. Basal circlet low, distally expanding, saucer-shaped. Radials five, large, subquadrangular, with facet relatively wide and deep. Primibrachs one in each ray, axillary, subtrigonal, wider than high. Anal plate unknown. Plates thick, smooth to finely granulose.

Basals - three, pentagonal in lateral view, unequal. Basal of EA interray smaller than others, height and width subequal. Large basals two, each alike, wider than high; H:W ratio 0.42 (n=1; Table 11).

Radials - five, large, subquadrangular, shovel-shaped, wider than high; H:W ratio 0.72 (n=1; Table 11). Distal margin excavated with wide, deep facet for reception of primibrach; facet about one-fourth plate height and two thirds plate width. Lateral shoulders on either side of facet forming low, V-shaped interradial notches.

Arms - sixteen; four in each ray, strong, short. Cup height to arm length ratio 0.39 (n=1; Table 11). Brachials with distinctly serrated margins; articulation symplectical (Text Fig. 28). Primibrachs one in each ray, axillary, subtrigonal, wider than high; H:W ratio 0.32 (n=1, Table 11). Secundibrachs four or five in each ray. Inner lateral margins of first and second(?) secundibrach joined together in rigid symplectical union (Text. Fig. 28-A). Secundiaxil pentagonal, wider than high; H:W ratio 0.48 (n=1; Table 11). First tertibrachs in each half-ray joined together along their inner lateral margins in rigid symplectical unions, but lateral margins between half-rays free (Text Fig. 28-B). First to fifth tertibrach uniserial, cuneate. Above, arms biserial, with approximately 60 (plus) brachials in each arm. Pinnules not visible in examined specimen UCGM 46143.

Tegmen and Column unknown in specimen UCGM 46143.

Material: P. lodensis (Hall and Whitfield) is represented by a single specimen from Richfield, Ohio (specimen UCGM 46143). The Holotype is listed as originating from Lodi, Ohio.

Table 11. Plate measurements in Platycrinites lodensis Hall and Whitfield (mm)

Measurements in Hypotype UCGM 46143

	BB	RR	IAX	IIAX	Cup	Arm L
H	3.6	7.2	1.8	1.8	5.10	17.7
W	8.5	10.0	5.6	3.8	--	--

DISCUSSION

Platycrinites lodensis (Hall and Whitfield) appears closely related to the group of platycrinids represented by P. bozemanensis (Miller and Gurley) and P. symmetricus (Wachsmuth and Springer). Each of these crinoids is represented by a broad dorsal cup, trigonal-shaped primaxil, and stout arms. P. lodensis (Hall and Whitfield) can be distinguished from the others in showing fused lateral unions between the proximal secundibrachs, and four arms in each ray. Distinction between P. symmetricus and P. bozemanensis is primarily based upon features contained within the tegmen. Laudon (1967, p. 1496) found features of the tegmen important for the identification of species of Platycrinites:

> "Because the cup structure of Platycrinites remained fundamentally very much the same throughout its evolutionary history and because the tegmen appears to be the last part of the crinoid to become modified, species can be much more easily delineated by a detailed analysis of the adult tegmen structure. Many of the smooth-plated forms from the Burlington Limestone of the Upper Mississippian Valley area are so much alike that they probably will never be separated satisfactorily except by a detailed analysis of the structure of the tegmen."

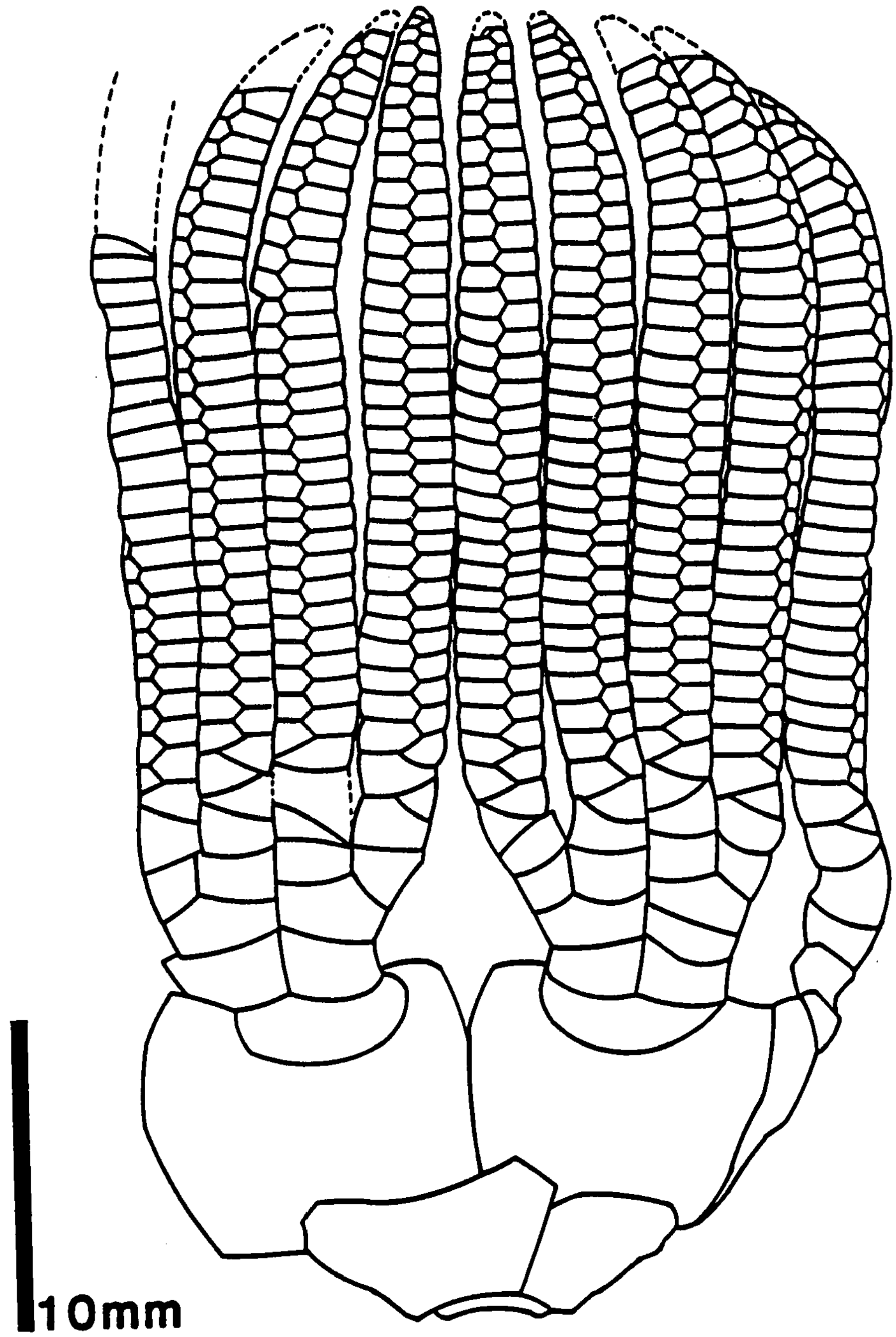
The tegmen in Platycrinites lodensis was not available for morphologic comparison.

Platycrinites lodensis (Hall and Whitfield) shows close relationship to Platycrinites chouteauensis (Miller). Both species show a similar bowl-shaped cup, wide radials, radial facet extending 2/3 plate width, trigonal primaxil, and secundibrachs which are suturally connected (Branson 1938, p. 94-95; Pl. 30, fig. 14). P. lodensis can be distinguished from P. chouteauensis by its taller basals.

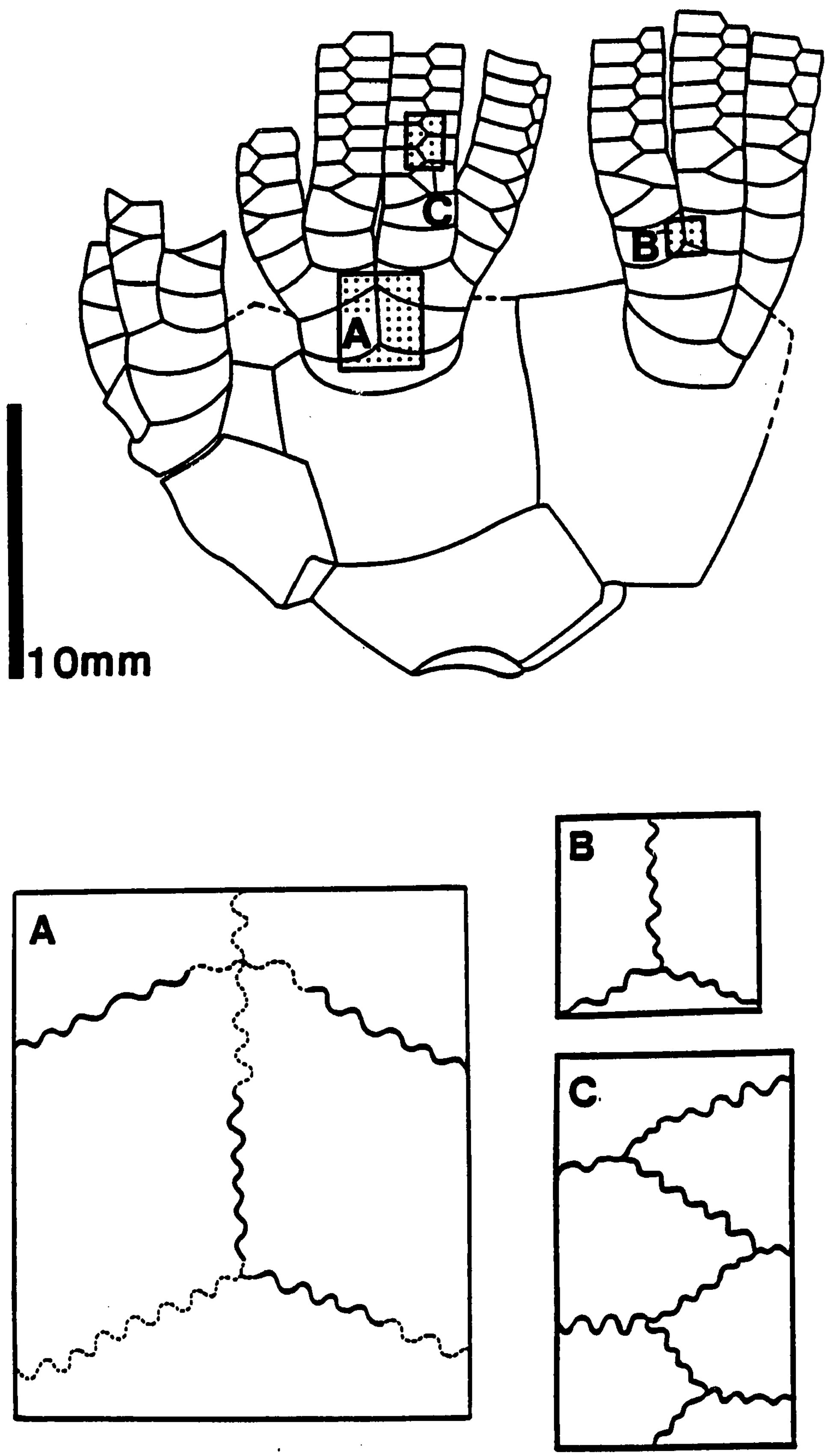
Although the ontogeny in Platycrinites lodensis is not known, it is reasonable to believe that it followed the same pattern as described by Laudon (1967, p. 1492-1495) for the crinoid P. bozenanensis. The most prominent changes which occurred during the development of that platycrinid were those of arm structure. Arm bachials showed a progressive modification from uniserial wedge-shaped (cuneate) to biserial during ontogeny. And, the axillary first primibrach showed a shape modification from pentagonal to trigonal.

Platycrinites lodensis is easily distinguished from P. contritus (Hall) and P. burki (sp. nov.) by its broad dorsal cup, thick arms, trigonal first primibrach, and laterally fused secundibrachs.

Text Figure 27. Platycrinites lodensis Hall and Whitfield. Camera lucida drawing of Hypotype UCGM 46143; AE interray view (Pl. 4, fig. 6). Note extra secundibrach in right-lateral branch of the E ray.


10mm

Text Figure 28. Platycrinites lodensis Hall and Whitfield. Camera lucida drawing of Hypotype UCGM 46143; D ray view. Boxed areas A-C are magnified to show symplectical sutures between arm brachials. Symplectical articulation along the inner lateral margins of the first secundibrachs and first tertibrachs indicates that the proximal portion of the arms were largely immobile. These proximal brachials functioned as a kind of extension to the dorsal cup.


A
C
B
10mm
A
B
C

Platycrinites contritus Hall, 1863

Platycrinus contritus Hall, 1864, p. 54; 1863, p. 5 Preliminary notice. Hall and Whitfield, 1875, p. 166; Pl. 11, fig. 4. Wachsmuth and Springer, 1881, p. 71 (245). Wachsmuth and Springer, 1897, p. 667; Pl. 71, fig. 8.

Platycrinites contritus Bassler and Moodey, 1943, p. 618. Brower, 1969, p. 523

Table 12 and 13; Text Figure 29; Plate 4, fig. 4; Plate 7, fig. 1, 4, 5, and 6.

DIAGNOSIS

A species of Platycrinites with moderately tall crown. Dorsal cup turbinate. Basals moderately tall, with truncate rim margin projecting over column. Radials large, subquadrangular; facet narrow, not extending more than one-half plate width. Arms biserial, slender, four to six in each ray. Column round close to proximal base, then bedoming elliptical and helically twisted away from base.

DESCRIPTION

Dorsal Cup - moderately tall, turbinate, wider than high, or subequal. Basals moderately tall, with truncate rim margin surrounding column. Radials five, large, subquadrangular; facet slightly less than 1/2 plate width. Primaxil small, pentagonal.

Basals - three, unequal; AE interray basal smaller than others. Two basals large, subequal, wider than high; H:W ratio 0.45-0.62, avg. 0.51 (n=4; Table 12). Sutures between plates poorly exposed and may be fused. Each plate with flat to slightly concave base, which forms rim margin surrounding column.

Radials - five, large, subquadrangular, shovel-shaped, wider than high; H:W ratio 0.56-0.93, avg. 0.75 (n=5; Table 12). Plate's lateral margins slightly expanding distally, but about parallel in younger, less mature specimens (Text. Figure 29). Distal margin excavated with concavity for reception of first primibrach; facet not extending more than one-half plate width. Lateral shoulders on either side of facet subhorizontal, slightly sloping, and forming low interradial notches. Basal/Radial plate height ratio: 0.45 (Holotype NYSM 6134).

Anal X - small, pentagonal, mostly wider than high; H:W ratio 0.39-1.06, avg. 0.68 (n=3; Table 12).

Arms - moderately slender, with four, five, or rarely six in each ray. Primibrachs one in each ray. pentagonal, axillary, wider than high; H:W ratio 0.48-0.75, avg. 0.63 (n=5; Table 12). Secundibrachs two in each half-ray. First secundibrach regular, height and width subequal. Second secundibrach axillary, wider than high; H:W ratio 0.75-0.93, avg. 0.85 (n=4; Table 12). First tertibrach simple. Second tertibrach axillary, small, higher than wide; H:W ratio 1.06 (n=1; Table 12). Four to six cuneate brachials follow the last axillary division in each arm. Above, arms biserial. Articulation between brachials symplectical. Pinnules long and slender.

Column - round close to proximal base, then becoming elliptical and helical away from base.

Tegmen - unknown.

Table 12. Plate measurements in Platycrinites contritus Hall (mm.)

UCGM		46145	46146	46149-A	46150	46151-A	6134*
BB	H	3.60	3.25	0.90	--	--	2.50
	W	5.70	6.85	2.00	--	--	5.50
RR	H	6.90	6.60	2.25	--	5.10	4.60
	W	7.40	8.60	2.90	--	7.00	8.20
IAx	H	1.80	2.20	1.50	--	2.00	1.90
	W	3.10	3.20	2.00	--	3.00	4.00
IIAx	H	1.90	1.80	1.55	--	1.95	--
	W	2.30	2.40	1.65	--	2.20	--
IIIAx	H	--	--	--	--	1.70	--
	W	--	--	--	--	1.60	--
Anal X	H	1.50	2.20	--	--	1.70	--
	W	3.80	3.65	--	--	1.60	--
Cup	H	--	--	5.10	9.70	--	9.60
Arm L.		--	--	17.7	36.8	--	21.1

*NYSM 6134 Holotype

Table 13. Allometric Analysis of *Platycrinites contritus* (Hall)

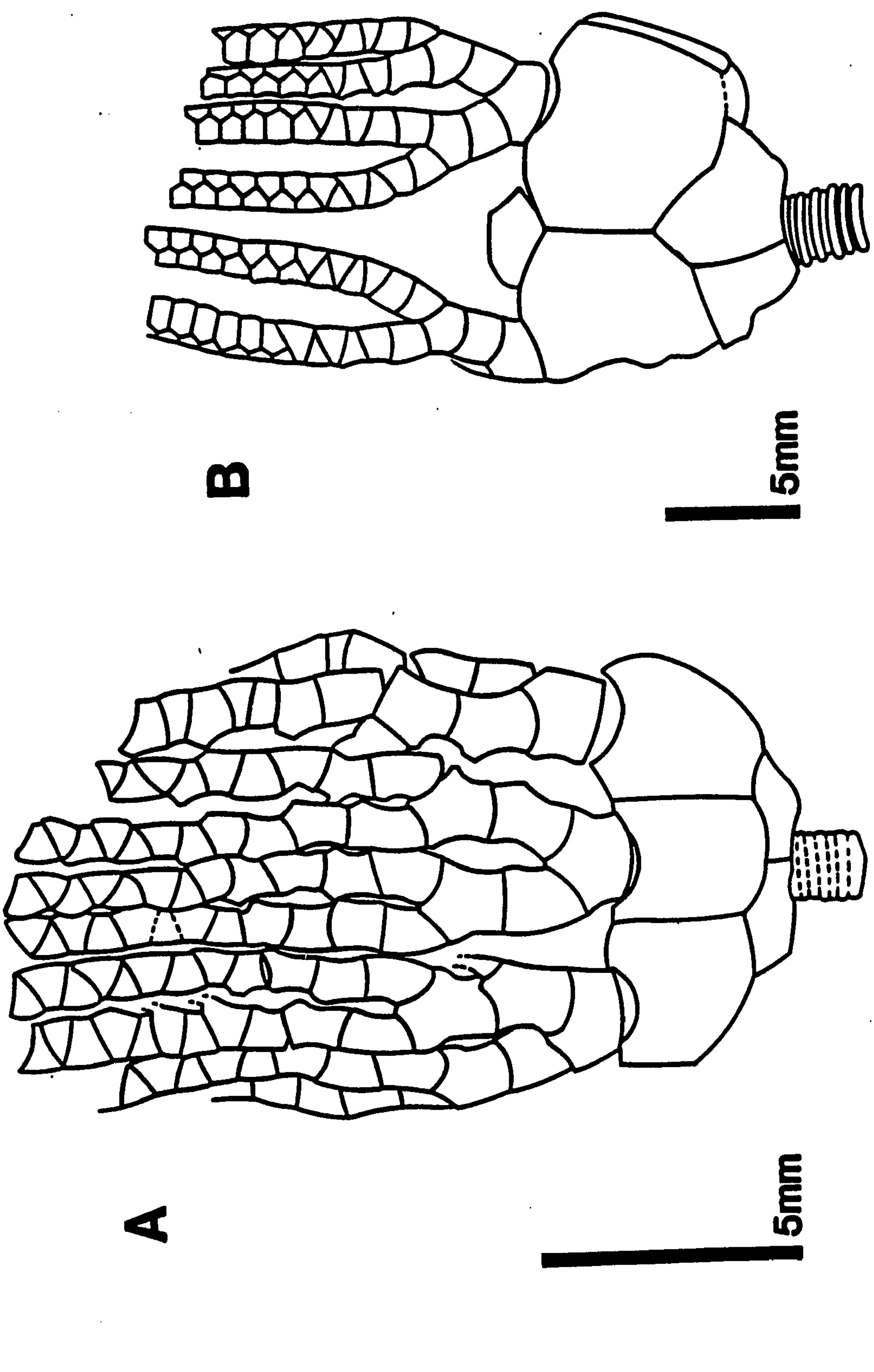
PLATE		ALLOMETRIC VALUE	GRAPHIC INTECEPT
BASALS	H	1.64	.05
	W	1.38	.11
RADIALS	H	1.18	.27
	W	1.17	.24
PRIMAXIL	H	0.30	.80
	W	0.51	.63
SECUNDIAXIL	H	0.21	1.07
	W	0.45	.57

*Methods used in allometric analysis similar to those employed for *A. helice* and *C. daphne*. Specimens of sample set taken from Table 12.

Text Figure 29. Ontogeny in Platycrinites contritus (Hall).

A) Hypotype UCGM 46149-A; young immature specimen showing cuneate arm brachials, wide radial facet, and low basal circlet (Plate 4, fig. 4).

B) Hypotype UCGM 46146; CD interray view. Mature specimen showing large radials, medium basals, narrow radial facet, slender arms with biserial brachials developed distally, and anal X plate (Plate 7, fig. 4).


B
5mm
A
5mm

DISCUSSION

Hall and Whitfield (1875, p. 166-167) described Platycrinites contritus (Hall) as showing four arms in the three anterior rays (A, B, and E) and five in the two posterior rays (C and D). However, Wachsmuth and Springer (1897, p. 667) indicate that ray position was incorrectly determined: "....if the position of the small basal is correctly figured, the five arms do not occur in the posterior, but in the anterior rays." Specimens examined in this study show four, five, or six arms in each ray. Ray positions were difficult or impossible to determine in most instances because of obscurely marked suture margins between plates of the basal circlet.

Playtcrinites contritus (Hall) is described from the Redwall Limestone of northern Arizona. Brower (1969, p. 523) notes:

> "Platycrinites contritus is a poorly known species and is represented only by the holotype from the Waverly Group of Ohio and two specimens from the Redwall Limestone. Although the Redwall specimens differ from the holotype in lacing the weak BB rim or flange, the three specimens are very similar in other dorsal cup constants."

Ontogeny

Allometric analysis was performed on five speciments of P. contritus (UCGM 46145, 46146, 46149-A, 46151-A, and NYSM 6134). Results of the analysis are given in Table 13. Basal plates showed the greatest positive allometry of all plates measured. The increase in plate height exceeded that of plate width, however, the value of width is considered somewhat tenuous because of the difficulty encountered in detecting suture margins. Radials showed a less positive allometric value than basals. Values in plate height were about equal to those of plate width. The wide gap of allometric values between basals and radials illustrate the potential danger of using basal/radial height ratios as a method for distinguishing species of Platycrinites. Stages of ontogeny may not always be clearly distinguishable.

The most obvious example of nonuniform development occurred in the arms, with both primaxil and secundiaxil showing a strongly negative allometric response. The increase in plate width exceeded plate height by 1.7 times in the primaxil, and by 2.1 times in the secundiaxil. Negative allometric values in arm plates indicate that growth of these plates was already well established by the time the smallest specimens are represented. Early rapid development in arm structure must have been important to the crinoid's survival, as selective pressures acting upon immature individuals were undoubtedly great. Allometric growth of the axillaries in Platycrinites contritus (Hall) closely agree with Brower's (1974, p. 32, 25; fig. 14) findings for platycrinids.

Platycrinites graphicus Hall, 1863

Platycrinus graphicus Hall, 1864, p. 55; preliminary notice 1863.
Hall and Whitfield, 1875, p. 166; Pl. 11, fig. 2.

Platycrinus graphicus Wachsmuth and Springer, 1881, p. 72 (246).
Wachsmuth and Springer, 1897, p. 672; Pl. 7, fig. 7.

Platycrinites graphicus Bassler and Moodey, 1943, p. 621.

Platycrinus richfieldensis Hall and Whitfield, 1875, p. 167; p. 2, fig. 1.

Table 14; Plate 7, figs. 2, 3, 7, and 8.

DIAGNOSIS

A species of Platycrinites with moderately tall, delicate crown. Dorsal cup box-shaped. Basals low, rapidly expanding, forming relatively wide cup base. Radials large, subquadranglar; facet narrow, not extending more than one-half plate width. Arms slender, four, or more rarely five in each ray. Brachials quadrangular to cuneate in proximal series, then biserial. Pinnulate. Column proxistele round, mesistele elliptical and helically coiled, and distestele round. Radix base.

DESCRIPTION

Dorsal Cup - wide, box-shaped. Basals low, rapidly expanding and forming wide cup-base. Radials large, subquadrangular; facet small, less than one-half plate width. Primaxil small, pentagonal. Anal X small, wider than high.

Basals - three, unequal; two plates large, each alike, wider than high; plate found in EA interray small, width and height subequal. Basal H:W ratio 0.41-0.71, avg. 0.57 (n=4; Table 14). Each plate with narrow rim margin surrounding column.

Radials - five, large, subquadrangular, wider than high; H:W ratio 0.66-0.93, avg. 0.77 (n=6; Table 14). Distal margin excavated with concavity for reception of axillary first primibrach; facet not extending more than one-half plate width. Lateral shoulders on either side of facet subhorizontal, sloping slightly, and forming low interradial notches.

Anal X - small, pentagonal, higher than wide; H:W ratio 1.07 (n=1; Table 14).

Arms - slender, four, or more rarely five in each ray. Primibrachs one in each ray, pentagonal, axillary, wider than high; H:W ratio 0.45-0.97, avg. 0.65 (n=6; Table 14). Secundibrachs two in each half-ray, except in UCGM 46147-A where right-lateral ray shows primaxil followed by simple brachials in one branch, and axillary in other (Pl. 7, fig. 8). Secundiaxil width and height subequal; H:W ratio 0.82-1.20, avg. 0.96

(n=5; Table 14). Tertiaxil height and width subequal; H:W ratio 1.01.07, avg. 1.04 (n=2; Table 14). Brachials transitional from cuneate to biserial above the last axillary division in each ray. Articulation sympletical. Pinnules long and slender.

Column - relatively complete in specimen UCGM 46147-A; length 14.5 cm. Proxistele round, rapidly becoming elliptical. Mesistele elliptical and helically coiled. Distestele round, with cirri forming radix hold-fast. Cirrus segments round, short, with protuberant rim margins, which resemble a Roman column.

Tegmen - unknown.

Table 14. Plate measurements in <u>Platycrinites</u> <u>graphicus</u> Hall (mm.)

PLATE		UCGM 46147-A	46148	46136-C	46151-B	46077-G	6135*
BB	H	2.80	3.25	2.40	2.00	1.70	6.50
	W	6.80	5.10	4.80	--	--	9.10
RR	H	4.30	5.40	4.30	3.55	4.90	6.80
	W	5.20	5.80	5.70	5.40	6.70	9.40
IAx	H	1.40	1.24	1.75	1.50	1.60	1.80
	W	2.10	2.40	1.80	2.10	3.00	4.00
IIAx	H	1.70	1.70	1.80	1.70	1.80	--
	W	1.90	2.00	1.50	1.65	2.20	--
IIIAx	H	2.00	--	--	1.60	--	--
	W	2.00	--	--	1.50	--	--
ANAL	H	--	--	--	1.60	--	--
	W	--	--	--	1.50	--	--
CUP	H	7.10	--	--	--	8.70	13.6
ARM L.		31.3	--	--	--	--	49.5

*HOLOTYPE NYSM 6135

DISCUSSION

Previous description of Platycrinites graphicus (Hall) was based upon a suite of relatively poorly preserved specimens. Wachsmuth and Springer (1897, p. 672) remark:

> "The known specimens of this species (P. graphicus) are badly crushed and it is impossible to give the form and proportion of the calyx, but probably the dorsal cup was moderately short and rounded at the base. The plates are thin and without ornament."

The majority of specimens of P. graphicus collected in this study show similar preservation. However, a few specimens do provide indication of the true form of the calyx, i.e., decidedly box-shaped (Plate 7, figs. 3 and 8).

Platycrinites graphicus (Hall) closely resembles P. contritus (Hall) of the same fauna, but can be distinguished by its more delicate slender arms, less protuberant basal rim margin, and box-shaped calyx.

Platycrinites burki sp. nov.

Table 15; Plate 4, figs. 3 and 5.

ETYMOLOGY

The specific name is in honor of Dr. John J. Burke, crinoid worker and former curator for the Cleveland Museum of Natural History, Cleveland, Ohio.

DIAGNOSIS

A species of Platycrinites with tall crown. Dorsal cup bowl-shaped, slightly higher than wide, with protuberant saucer-like basal plate rim margin. Arms six in each ray, long, slender.

DESCRIPTION

Dorsal Cup - somewhat compressed in Holotype UCGM 46144; tall, bowl-shaped, higher than wide. Basals three, showing fused lateral unions (ankylosis), with protuberant saucer-like rim or flange at proximal base. Radials five, large, subquadrangular, shovel-shaped. Primibrachs one in each ray, axillary, pentagonal, wider than high. Ornament consisting of very fine, subparallel to wavy, labyrinthine ridges. Plates moderately thick.

Basals - three, showing fused lateral unions, with protuberant saucer-liker rim or flange at proximal base. Columnal facet slightly concave. Ornament consisting of very fine, subparallel to wavy, labyrinthine ridges.

Radials - five, large, outwardly convex, subquadrangular, shovel-shaped, wider than high; H:W ratio 0.88 (Holotype; Table 15). Plate's lateral margins slightly expanding distally. Distal margins with moderately wide, concave depression for reception of axillary first primibrach. Lateral shoulders to either side of distal facet slightly sloping, forming interradial notches. Ornament consisting of very fine, subparallel to wavy, labyrinthine ridges. Ridges vertical along median axis of plate, but bending toward the horizontal away from this region; greatest curvature occurring adjacent to arm facets. Orientation of ornament closely following plate's convexity.

Arms - six in each ray, slender, 2.69 times the height of the dorsal cup (Holotype; Table 15). Articulation symplectical. Primibrachs one in each ray, pentagonal to subtrigonal, axillary, wider than high; H:W ratio 0.34 (Holotype; Table 15). Secundibrachs two in each half-ray; first secundibrach axillary, wider than high, H:W ratio 0.76. Above, inner lateral pair of arms in each ray divide on the second tertibrach, whereas outer pair remains undivided. Four to six cuneate brachials follow the last axillary division in each ray. Above, arms biserial. Pinnules long and slender. First pinnular expanded trumpet-like at its proximal base.

Tegmen and Column - unknown.

Material: Hototype UCGM 46144 and Paratype UCGM 46061-G.

Table 15. Plate measurements in Platycrinites burki sp. nov. (mm).

Measurements in Holotype UCGM 46144

Plate	BB	RR	IAX	IIAX	IIIAX	Cup	Arm L.
H	3.25	8.20	1.50	1.90	1.70	19.2	51.6
W	*8.60	9.30	4.40	2.50	2.10	--	--

*Best estimate

DISCUSSION

The Holotype UCGM 46144 was collected at a locality near Lodi, Ohio in float along a tributary of the Black River, south of Hwy 224 and approximately 200 feet east of Pawnee road (Lodi Quadrangle, Harrisville Township, T1N, R16W; 9,400 m. E and 41,450 m. N). Platycrinites burki (sp. nov.) is believed to be represented at the Richfield fossil site by Hypotype UCGM 46061-G, an incomplete specimen showing only a portion of dorsal cup and arms (Pl. 4, fig. 5).

Platycrinites burki can be distinguished from P. contritus (Hall) and P. graphicus (Hall) by its larger overall size, protruding saucer-like basal rim, and six arms in each ray. It also differs from P. lodensis (Hall) in lacking that species thick arms and laterally fused secundibrachs

Platycrinites burki resembles P. pratteni (Worthen) from the Lower Burlington Limestone in showing a similar protuberant saucer-like basal disk. However, Platycrinites pratteni (Worthen) can be easily distinguished from P. burki by its taller radials and more numerous arms (10-12) in each ray.

Subclass INADUNATA Wachsmuth and Springer, 1885

Order CLADIDA Moore and Laudon, 1943

Suborder CYATHOCRININA Bather, 1899

Superfamily CYATHOCRINITACEA Bassler, 1938

Family CYATHOCRINITIDAE Bassler, 1938

Genus CYATHOCRINITES Miller, 1921

DIAGNOSIS

A cyathocrinid with stout, or moderately tall, ovoid crown. Dorsal cup bowl or globe-shaped. Infrabasals five, small to medium, often barely visible in lateral view. Basals moderately large. Radials large, subquadrangular; facet augustary to peneplenary, horseshoe-shaped. Anal X alone in cup; anal sac stout, cylindrical, and confined to posterior CD interray. Posterior anal may be a madreporite. Arms uniserial; branching two or more times, with first division on primibrachs 1-7. Column round or pentagonal.

Cyathocrinites exertus sp. nov.

Tables 16 and 17; Text Figure 30 and 31; Plate 8, figs. 1-4.

ETYMOLOGY

The specific name is derived from the Latin exertus - in reference to the protuberant character of ridge ornament in the dorsal cup.

DIAGNOSIS

A diminutive species of Cyathocrinites with slender, moderately tall, ovoid crown. Dorsal cup small, bowl-shaped; plates showing strong ridge ornament. Infrabasals five, small. Basals five, medium. Radials five, moderately large; facet augustary, horseshoe-shaped, declivate. Anal X alone in cup; anal sac stout, subsylindrical, and confined to CD interray. Arms uniserial, heterotomous, branching two or more times. Brachial plates mildly angulated along aboral side. Column round, heteromorphic.

DESCRIPTION

Dorsal Cup - small, wider than high, bowl-shaped. Infrabasals small. Basals medium size. Radials moderately large; facet augustary, horseshoe-shaped, and declivate. Anal X alone in cup; anal sac stout subcylindrical, truncate at terminal apex, and confined to CD interray.

Infrabasals - five, small, barely visible in side view, pentagonal, wider than high; H:W ratio 0.41-0.50, avg. 0.46 (n=2; Table 16). Plate ornament unknown.

Basals - five, moderately large, pentagonal to obscurely hexagonal, higher than wide; H:W ratio 0.59-1.0, avg. 0.84 (n=4; Table 16). Plate's proximal margins subhorizontal, with very low acuminate insertion between infrabasals. Lateral margins expanding upward, about 25 degrees along each edge. Dorsal margins acuminate toward radials, with apical angle slightly greater than 90 degrees (Holotype UCGM 46158). Ornament stellate; six strong ridges radiate from plate center toward median positions along plate margins, while corner interareas with deeply incised triangular to subtriangular shape pits.

Radials - five, hexagonal, largest plate in cup , about twice as wide as high; H:W ratio 0.38-0.74, avg. 0.50 (n=4; Table 16). Plate's proximal margins broadly acuminate. Lateral margins distally expanding about 15 degrees along each edge. Distal margin excavated with narrow, declivate, horseshoe-shaped facet; facet about one-half to two-thirds plate width. Lateral shoulders on either side of radial facet gently sloping, forming distinct interradial notches. Ornament consisting of four strong ridges; two ridges radiate toward basals along proximal margins, and two ridges subhorizontal, adjoining adjacent radials. Corner interareas depressed in moderately deep pits.

Anals - one in cup.

Anal X - moderately large, hexagonal, wider than high; H:W ratio 0.81 (Paratype UCGM 46061-H; Table 16). Plate resting upon truncate distal margin of CD basal.

Anal Sac - stout, subcylindrical, restricted to CD interray, and truncate along distal apex. Anal sac protruding somewhat from inner ventral surface; protuberance exaggerated in Paratype UCGM 46157, but more true to form in Paratype UCGM 46061 (Text Figure 30 A-C).

Arms - slender, uniserial, branching up to five times in each ray, heterotomous. Primibrachs one to three in each ray, plate height variable. First primibrach wider than high, shorter than other primibrachs.

Primaxil slightly wider than high, or subequal; H:W ratio 0.58-1.29, avg. 0.91 (n=4; Table 16). Distal apex of primaxil and other axillaries with moderately wide gap between adjacent articular facets; gap creates U-shaped branching pattern in arms. Secundibrachs two or three, except in E ray of Paratype UCGM 46157, where normal secundibrach is followed by small wedge-shaped plate, and two laterally adjacent plates (Text Figure 30). This plate arrangement may represent an unsuccessful attempt at arm division. Secundiaxil slightly wider than high, or subequal; H:W ratio 0.65-1.27, avg. 0.94 (n=4; Table 16). Tertiaxil slightly higher than wide, or equal; H:W ratio 1.0-1.31, avg. 1.15 (n=2; Table 16). Brachials slightly angulated along their aboral edge. Nonpinnulate.

Column - round, composed of alternating thick and thin ossicles; heteromorphic. Columnal indices given in Table 17.

Material - Holotype UCGM 46158; Paratypes UCGM 46156, 46157, 46061-H

Table 16. Plate measurements in Cyathocrinites exertus sp. nov. (mm)

		IBB		BB		RR		ANAL		IAx		IIAx		IIIAx	
SPECIMEN #	RAY	H	W	H	W	H	W	H	W	H	W	H	W	H	W
UCGM 46156	D	-	-	1.6	2.2	1.3	2.6	-	-	1.3	1.6	1.3	1.2	-	-
	E	-	-	-	-	1.1	2.9	-	-	1.9	1.7	1.7	1.6	-	-
46157	A	-	-	-	-	-	-	-	-	1.6	1.6	1.7	1.8		
	B	-	-	2.3	2.8	1.6	3.6	-	-	2.1	2.2	-	-	-	-
	C	-	-	-	-	1.6	3.2	-	-	1.5	2.2	1.6	1.7	-	-
	D	-	-	2.3	2.6	1.5	3.7	-	-	1.6	1.9	1.7	1.8	-	-
	E	0.7	1.7	2.2	2.6	1.7	3.8	-	-	1.4	2.4	1.6	1.9	-	-
46061-H	C	-	-	1.6	2.7	2.0	2.7	1.7	2.1	1.5	1.8	1.4	2.0	1.7	1.3
	D	-	-	-	-	-	-	-	-	2.1	1.8	-	-	-	-
46158	Ce	-	-	1.9	2.2	-	-	-	-	-	-	-	-	-	-
	L	-	-	2.0	2.0	1.6	3.0	-	-	2.2	1.7	1.9	1.5	1.4	1.4
	R	0.6	1.2	2.1	2.1	1.5	2.8	-	-	1.7	2.2	1.1	1.7	-	-

Table 17. Columnal indices in Cyathocrinites exertus sp. nov.

SPECIMEN NO.	46157	46061-H
NODAL INDEX	27.3	36.4
INTERNODAL	72.7	63.6
COLUMNAL HEIGHT INDEX		
A) NODAL	22.5	33.3
B) INTERNODAL	21.2	20.0
DISTANCE FROM BASE (NODITAXIS NO.)	3	5 or 7?

DISCUSSION

Cup ornament in Cyathocrinites exertus (sp. nov). is best preserved in Holotype UCGM 46158 from the Pawnee Road-Blck River locality (see: P. burki section). Stellate ornament of C. exertus (sp. nov.) largely resembles that found in Pachylocrinus subtortuosus (Hall) from the same formation, but is easily distinguished from the latter species by its smaller, bowl-shaped cup, single anal plate in cup, narrow horseshoe-shaped radial facet, and nonpinnulate, uniserial arms. Cyathocrinites simplex (sp. nov.) from the same formation lacks stellate ornament.

Cyathocrinites asperimus (Springer) from the New Providence Formation resembles C. exertus (sp. nov.) in showing radials with four large, strong ridges which radiate from the facet rim, but is easily distinguished by its larger and wider facets. The radial facets of the new species more closely resemble those of Cyathocrinites astralus.(Kammer) from the New Providence Formation. However, Cyathocrinites astrulus (Kammer) lacks the same strong radial plate ornament and shows a more complex system of ridges and nodes on its basal plates.

An unnamed species of Cyathocrinites (Laudon, Parks, and Spreng) with stellate ornament occurs in the Banff Formation of Alberta, Canada, but it is impossible to accurately determine its relationship to the new species at this time. Laudon, Parks and Spreng (1952, p. 547) note: "specimens are too fragmentary to warrant assignment of a specific name."

Text Figure 30. Cyathocrinites exertus sp. nov.

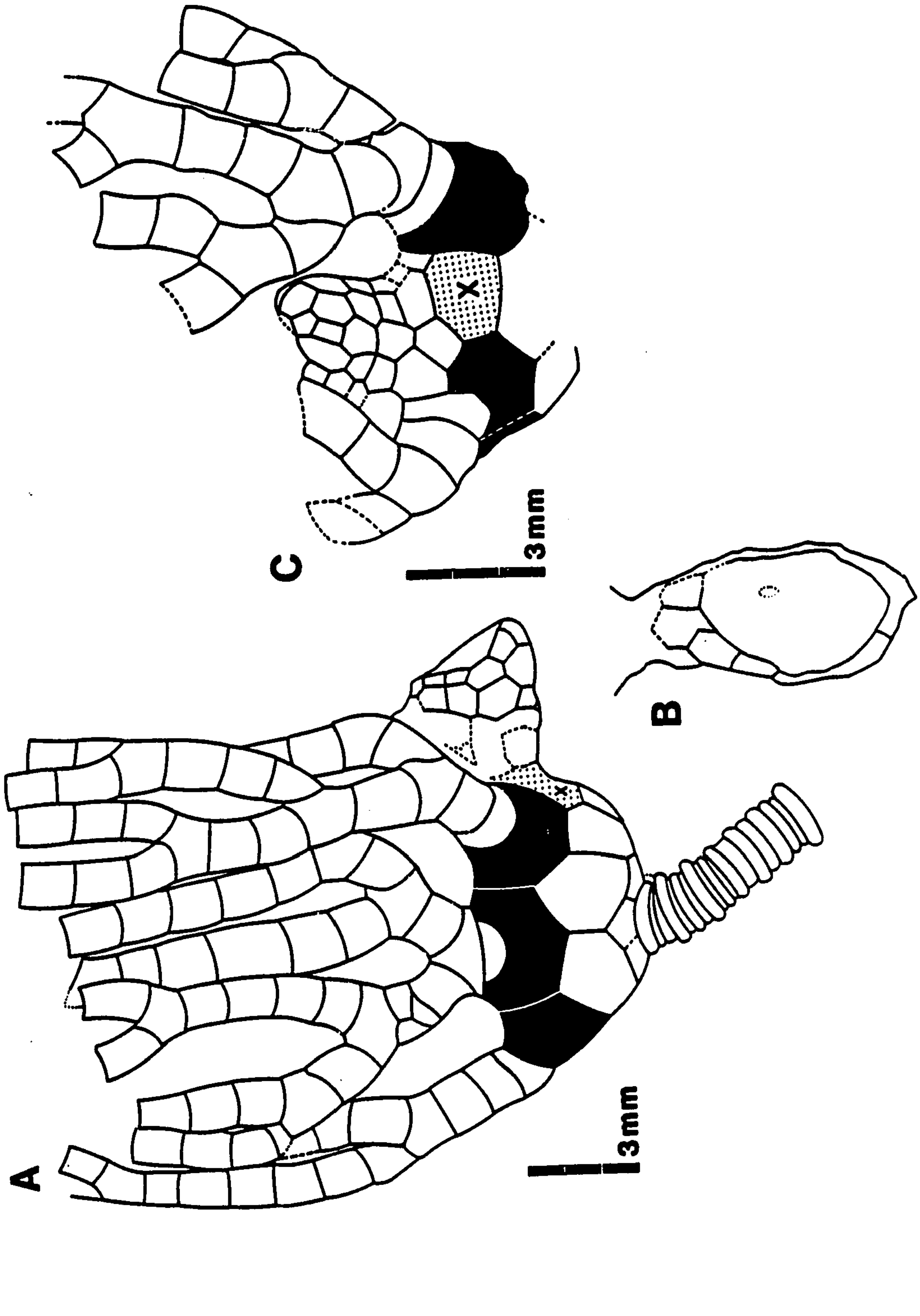
Camera lucida drawings of two individuals showing characteristics of anal sac.

A) Paratype UCGM 46157; E ray view. Proturbant anal sac. Proximal lateral edges of second primibrach of E ray resting directly on radial. Left lateral half-ray of E ray shows aberrant brachials (Plate 8, fig. 3).

B) Paratype UCGM 46157; adoral view of anal sac shown in Fig. A. Magnification X 2.0 with respect to figure A.

C) Paratype UCGM 46061-H; CD interray view showing Anal X plate.

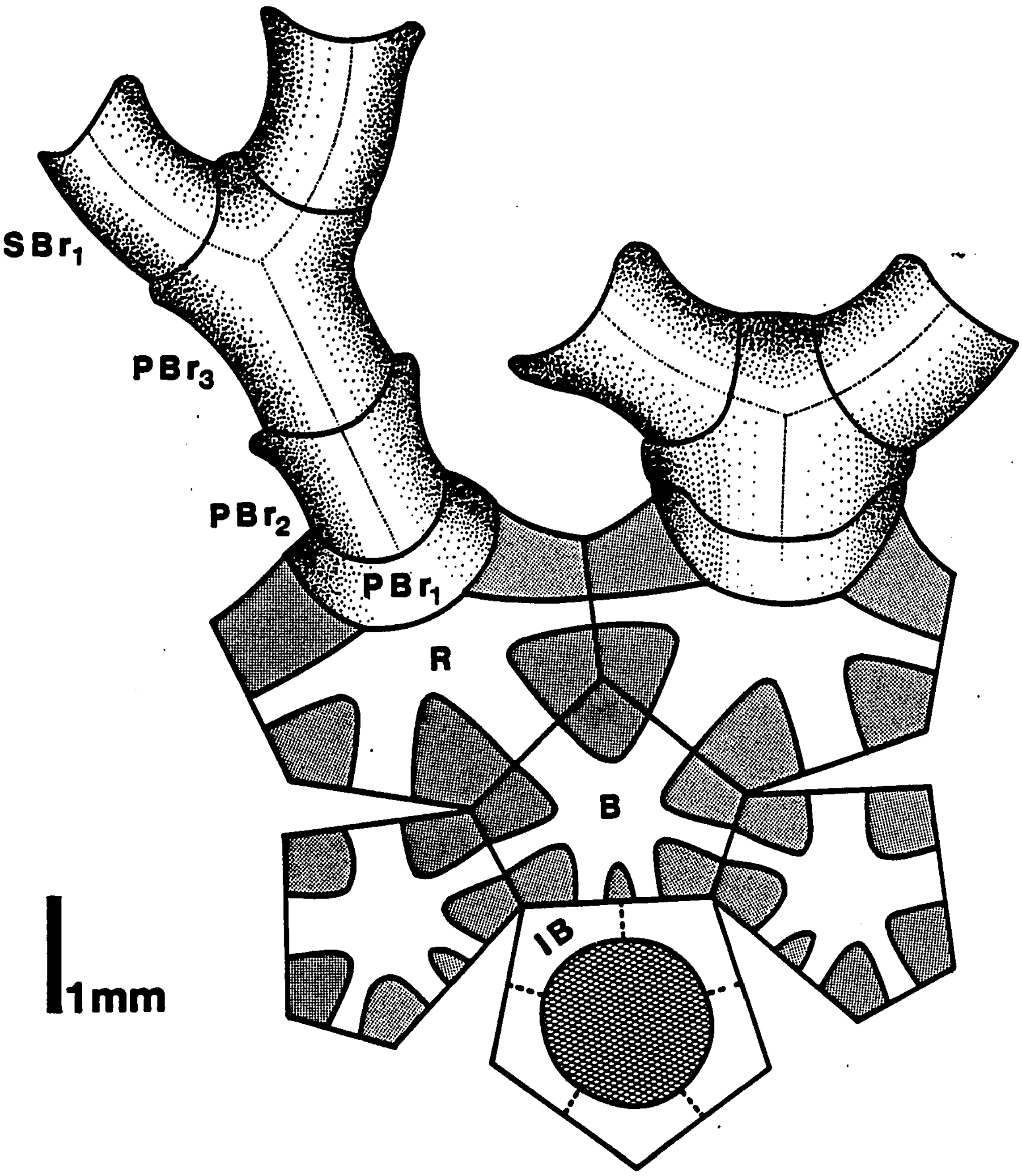
Explanation: radials black; anal X stippled.


A
3mm
B
C
3mm
x
x

Text Figure 31. Cyathocrinites exertus sp. nov.

Plate diagram of Holotype UCGM 46158; ray position uncertain (Pl. 8, fig. 1 and 2).

Explanation: crest of angulated ridge indicated by fine line; depressed areas stippled; cicatrix cross hatched.


SBr1
PBr3
PBr2
PBr1
R
B
IB
1mm

Cyathocrinites simplex sp. nov.

Table 18; Plate 8, figs. 7 and 8.

ETYNOLOGY

The specific name is in reference to the smooth plates of the cup.

DIAGNOSIS

A species of Cyathocrinites with slender, moderately tall crown. Dorsal cup small to moderately large (?). Plates smooth, with fine granulose surface ornament. Infrabasals five, small. Basals five, moderately large. Radials five, largest plate in cup; facet narrow (augustary), horseshoe-shaped, declivate. Anal X alone in cup; anal sac stout, confined to CD interray. Arms uniserial, branching up to three times, heterotomous. Brachials rounded along their aboral side. Nonpinnulate.

Column unknown.

DESCRIPTION

Dorsal Cup - compressed; small to moderately large, bowl-shaped, height and width subequal. Infrabasal small, incomplete. Basals and radials moderately large. Radial facet narrow (augustary), horseshoe-shaped, and declivate. Anal X alone in cup. Plates with fine granulose surface ornament.

Infrabasals - five (one known in Holotype), pentagonal; incomplete.

Basals - five (three known in Holotype), hexagonal, height and width equal; H:W ratio 1.0 (Holotype; Table 18).

Radials - five (three exposed in Holotype), hexagonal, wider than high; H:W 0.61 (Holotype; Table 18). Radial facet about two-thirds plate width, horseshoe-shaped, and declivate. Plate lateral shoulders on either side of facet steeply sloping, form distinct interradial notches.

Anals - poorly known in Holotype UCGM 46159; anal X alone in cup. Anal sac apparently stout, confined to CD interray (Plate 8, fig. 7).

Arms - slender, uniserial, branching up to three times, heterotomous. Primibrachs three or four, irregular in height. First primibrach invariably shortest primibrach in series. Primaxil wider than high, or subequal. Secundibrachs two or three, irregular in height. Secundiaxil height and width subequal. U-shaped form in arm branching resulting from moderately wide gap between articular facets at distal apex of axillary brachials. Each brachial round on its aboral side, subround or elliptical. Nonpinnulate.

Column - unknown.

Material - Holotype UCGM 46159; Paratype UCGM 46160.

Table 18. Plate measurements in Cyathocrinites simplex sp. nov. Holotype UCGM 46159 (mm)

	IBB		BB		RR		IAx		IIAx		IIIAx	
POSITION	H	W	H	W	H	W	H	W	H	W	H	W
D RAY	0.9	-	2.6	2.6	1.8	2.9	1.8	1.8	1.3	1.7	1.2	1.3
E RAY	-	-	-	-	1.7	2.8	1.5	1.9	2.0	1.7	1.2	1.1

DISCUSSION

Cyathocrinites simplex (sp. nov.) is a poorly known species represented only by Holotype UCGM 46159 and Paratype UCGM 46160. Cyathocrinites simplex (sp. nov.) can be distinguished from C. exertus (sp. nov.) from the same formation by its lack of stellate ornament and rounded brachials.

Suborder POTERIOCRININA Jaekel, 1918

DISCUSSION

The transition from the more primitive suborder Dendrocrinina (Bather) to the suborder Poteriocrinina (Jaekel) is indicated by development of muscular articulation and pinnulation (Lane 1978, p. 296-297). However, this distinction cannot be considered absolute as examples of overlap are found between both suborders, particularly between members of the family Mastigocrinidae (Jaekel) (suborder Dendrocrinina) and the family Rhenocrinidae (Jaekel) (suborder Poteriocrinina). Two matigocrinid genera, Dichenocrinus (Jaekel) and Quantoxocrinus (Webby) are pinnulate. Alternatively, ramules are developed in the rhenocrinid genera Rhenocrinus (Jaekel) and Charcentocrinus (Goldring). An even greater sense of overlap may be indicated in the development of muscular articulation.

Lane (1978, p. 297) suggests that development of muscular articulation did not closely follow phyletic history, but appeared after the development of pinnules. Muscular articulation may have developed in a sequence whereby it first appeared along the pinnule joint, spread to the main arm axis, and finally developed at the proximal base of the arm along the radial facet. However, little is known about the actual sequence due to the lack of information concerning surface details of the articular facets.

Superfamily RHENOCRINACEA Jaekel, 1918

Family RHENOCRINIDAE Jaekel, 1918

DIAGNOSIS

Cladid (dycyclic) inadunate crinoids with tall crown. Cup small, conical or subturbinate. Radial facets peneplanary, with slightly arcuate outer margin. Anal sac large, elongate; anal sac of some forms has an enlarged verticall row of plates on its posterior side. Arms uniserial, slender, pinnulate or more rarely ramulate, branching isotomously one or several times. Column round or pentagonal.

Genus GONIOCRINUS Miller and Gurley, 1890

DIAGNOSIS

A rhenocrinid with tall, slender, or moderately expanding crown. Cup small, truncate cone-shaped; plates outwardly convex, with sutures and corners depressed in pits. Infrabasals upflared, forming prominent portion of lateral wall. Basals and radials medium in size, never much larger than primibrachs. Radial facet peneplenary, declivate, slightly arcuate. Two anals in cup; radianal quadrangular; anal X pentagonal, supporting prominent longitudinal row of anals, which closely resemble arm brachials. Arms uniserial, strong, with main ramus branching on the third or fouth primibrach. Primibrachs show laterally projecting lobes.

Arms ramulate or pinnulate. Column pentalobate to pentagonal, heteromorphic. Cirri given off all along length of column.

DISCUSSION

Goniocrinus (Miller and Gurley) is placed in the family Rhenocrinidae (Jaekel) with the following amendment to family diagnosis: dorsal cup with two or three anal plates; arms ramulate or pinnulate. Moore and Lane (1978, p. 623) placed Goniocrinus in the family Mastigocrinidae (Jaekel). However, unlike the majority of genera in that family Goniocrinus shows an enlarged longitudinal row of anal plates. The occurrence of this feature led Laudon (1937, p. 254) to suggest taxonomic affinity with the family Rhenocrinidae:

> "the type and structure of the anal tube in Inadunate crinoids is always highly diagnostic. The long tube with the median row of plates is sufficiently different from other groups in Inadunate crinoids to place the form in the Glossocrinidae (=Rhenocrinidae). The only modification which has been necessary to produce the Goniocrinus structure is a slight shifting of the radial plate over against the anal plate thereby enclosing the radianal within the calyx."

The (Giventian) genus Kophinocrinus (Goldring) strongly resembles and maybe directly ancestral to Goniocrinus (Miller and Gurley), but can be distinguished by the presence of hypertrophied infrabasals. Goniocrinus ranges from the Lower Devonian (Emsian-Germany) to Middle Devonian (Eifelian/Givetian) before reappearing in the Mississippian. "Botryocrinus" bellensis is a Goniocrinus as are several other undescribed species that range from the Onondaga Limestone and Dock Street Clay

(George McIntosh 1985, personal communication). Mississippian (Kinderhook-Osage) species of Goniocrinus are found at the Wassonville Limestone (Iowa), Gilmore City Formation (Iowa), Cuyahoga Formation (Ohio), Lodgepole Formation (Montana), Banff Formation (Alberta), and Edwardsville Formation (Indiana).

Goniocrinus *sceletus* sp. nov.

Table 19; Text Figures 32 and 33; Plate 8, figs. 5 and 6.

ETYMOLOGY

The scientific name is derived from the latin *sceletus* meaning skeleton.

DIAGNOSIS

A species of *Goniocrinus* with moderately tall crown. Dorsal cup small, widely expanding, truncate cone-shaped; plates outwardly convex or nodose, with corners and suture margins depressed in moderately deep pits. Infrabasals and basals medium in size, subequal. Radials large, flaring toward distal margin; facet arcuate, peneplanary, and declivate. Two anals in cup; anal sac long, with row of brachial-like anals rising to almost distal tip of arms. Arms uniserial, moderately stout, with main ramus dividing on the third priumibrach in the E ray, and on the fourth primibrach in all others. Ramulate. Column proximally pentalobate, and distally pentagonal; heteromorphic. Cirri given off at regular points all along the column.

DESCRIPTION

Dorsal Cup - small, widely expanding, conical, wider than high; H:W ratio 0.48 (Table 19; Holotype). Infrabasals visible in side view, medium size, strongly nodose, resembling over-sized columnal. Basals similar to infrabasals in size. Radials largest plate in cup; facet gaping, declivate, peneplanary, with arcuate outer margin. Broad ridge ornament radiates between basal and radial plates; interridge areas depressed in shallow to moderately deep pits. Two anals in cup.

Infrabasals - five, pentagonal, small to medium size, wider than high; H:W ratio 0.66-0.81, avg. 0.74 (Table 19; Holotype). Plates clearly visible in lateral view, strongly nodose or protuberant, and forming rounded collar over base of column. Plate's proximal margins sinuous or wavelike, each plate forming approximately one and one-half wave cycles. Lateral margins corresponding to lobate positions of the column. Distal margins ventrally acuminate to basals; apical angle obtuse, about 110 degrees. Apex depressed into subtriangular pit which includes lateral margins of basals and proximal corner of radials.

Basals - five, hexagonal, slightly larger than infrabasals. Plate height and width variable; AE and AB interrays wider than high, H:W ratio 0.83 and 0.77, respectively (Table 19; Holotype); DE interray equal; BC and CD interrays higher than wide, H:W ratio 1.20 and 1.36, respectively (Table 19; Holotype). Plate's lateral margins short. Consequently, radials and infrabasals occur in close proximity to one another. Surface ornament in basals damaged, especially in AE and BC interrays. Fortunately, ornament well preserved in AB interray (Pl. 8, fig. 5); broad ridges descending from laterally adjacent radials coalesce as wide v-shaped ridge ornament. Distal apex depressed into small, moderately deep, subtriangular pit. Lateral margins and the majority of proximal margin depressed into slightly larger pits. Proximal apex confluent and merging with rimlike collar of infrabasal circlet.

Radials -five, approximately pentagonal (heptagonal with distal sloping margins included), largest plate in dorsal cup, nearly twice as large as basals, considerably wider than high; H:W ratio 0.50-0.79, avg. 0.67 (Table 19; Holotype). Plates moderately thick, strongly convex, flaring outward toward distal margin. Radial facet peneplanary, about 2/3 to 3/4 plate width, declivate, with suture gaping; facet platform flat to slightly concave, broadly U-shaped, showing faint trace of adoral groove. To either side of radial facet lateral shoulders gently sloping; interays mildly notched, except where anal X abuts C and D ray radials. Ridge ornament connects adjacent radials and anal X, radiates toward basals, and coalesces and flattens along distal facet margin (Text Figure 32).

Anals - two in cup.

RA - (Radianal) quadrangular, about size of basals, height and width equal. Plate resting equally upon BC and CD interray basals, adjoining C ray radial along its distal right-lateral margin, and anal X along its distal left-lateral margin. Due to compression the leading right proximal margin of radianal is partly hidden beneath the BC basal. Ornament unknown.

X - pentagonal, large, rising above level of radials, higher than wide; H:W ratio 1.50 (Table 19; Holotype). Plate convex, becoming markedly cylindrical distally.

X_2 - quadrangular, higher than wide; H:W ratio 1.45 (Table 19; Holotype). Plate cylindrical, resembling brachials but slightly taller and narrower.

Anal tube - long, rising almost to distal tip of arms. Holotype UCGM 46161 showing only large posterior row of anals, lateral series of anals unknown. Anals of upper (distal) series above the primaxil relatively short, flattened, and obscurely hexagonal. A slight twisting or coiling is suggested along the length of the anal tube. Pustulate ornament preserved in some plates of distal series.

Arms - uniserial, about nine times the height of the dorsal cup, branching one time on the third primibrach in the E ray, and on the fourth primibrach in all other ray positions. Each primibrach narrower at its proximal margin than distal margin, with laterally expanding, protuberant lobes. Lobes become progressively less pronounced distally, then disappear about midlength along the arms. Brachials with small, U-shaped groove along proximal margin; groove provided space for connective tissue, and may indicate muscular articulation. Ramules poorly known. Right-lateral ramus of B ray suggests ramules are given off on alternating sides of every third or fouth brachial. Ramule-like fragments between primibrachs of AB interray may actually represent remnants of small, nonposterior series of anal plates.

Column - incomplete; represented by two separated sections in Holotype UCGM 46161. Column pentalobate close to cup, then becoming pentagonal distally. Column heteromorphic, noditaxis composed of two or three orders. Nodal indices for most distal noditaxis of column section attached to cup, Ni 38.7 and INi 61.3. Columnal epifacet narrow, rounded along margins. Articulation symplectical. Articulum shows large pentastellate areola, moderately wide crenularium, and pentagonal (?) lumen (Text Figure 33-A). Cirri found at regular intervals along ray positions throughout entire length of column. Individual cirri more numerous near cup, and frequently directed toward cup. No more than one cirri for each cirrinodal was observed. Apparently, cirri alternate their ray postions between successive cirrinodals, but exact pattern could not be determined. Cirrus segments round and short close to their proximal base, then becoming more elongate, and uniformly subequal in size away from base.

Table 19. Plate measurements in Goniocrinus sceletus sp nov. (mm)

RAY POSITION		A(AB)	B(BC)	C(CD)	D(DE)	E(EA)
IBB	H	0.9	0.8	0.9	0.9	0.8
	W	1.2	1.2	1.2	1.1	1.2
BB	H	1.0	1.2	1.5	1.3	1.0
	W	1.3	1.0*	1.1	1.3	1.2
RR	H	1.1	1.1	1.4	1.5	1.3
	W	2.0	2.2	1.8	1.9	1.8
IBr_1	H	1.2	1.2	1.3	1.3	1.6
	W	1.6	1.7	1.4	1.8	1.4

Anals	RA	X_1	X_2	X_3
	H 1.2	H 1.8	H 1.6	H 1.8
	W 1.2	W 1.2	W 1.1	W 1.1

Dorsal Cup	H 2.5	Arm Length (max.) (B ray)
	W 5.2	22.3

*measurement incomplete due to preservation

Holotype: UCGM 46161

DISCUSSION

Goniocrinus sceletus (sp. nov.) most nearly resembles Goniocrinus scultilus (Miller and Gurley) from the Wassonville Limestone (Iowa), but differs in having arms which divide mostly on the fourth rather than the third primibrach, a more cone-shaped cup, and fewer cirri. Goniocrinus maximus (Laudon) is a larger species with more numerous ramules. Goniocrinus angulatus (Laudon, Parks, and Spreng) can be distinguished from G. sceletus (sp. nov.) in having angulated brachials. Goniocrinus harrsi (Miller) has narrower radial facets.

Cirri in Goniocrinus sceletus (sp. nov.) are directed in a proximal direction toward the crown. The maximum recorded length of cirri in the holotype is 18.8 mm. At this length it may have been possible for cirri near the dorsal cup to envelope the crown. As such, the crown could have been provided a form of protective concealment. Example of this type of concealment is documented for members of the Silurian-Devonian family Myelodactylidae, and also the Mississippian genus Camptocrinus (Ubaghs 1978, p. 87, figs. 57 and 62(3)).

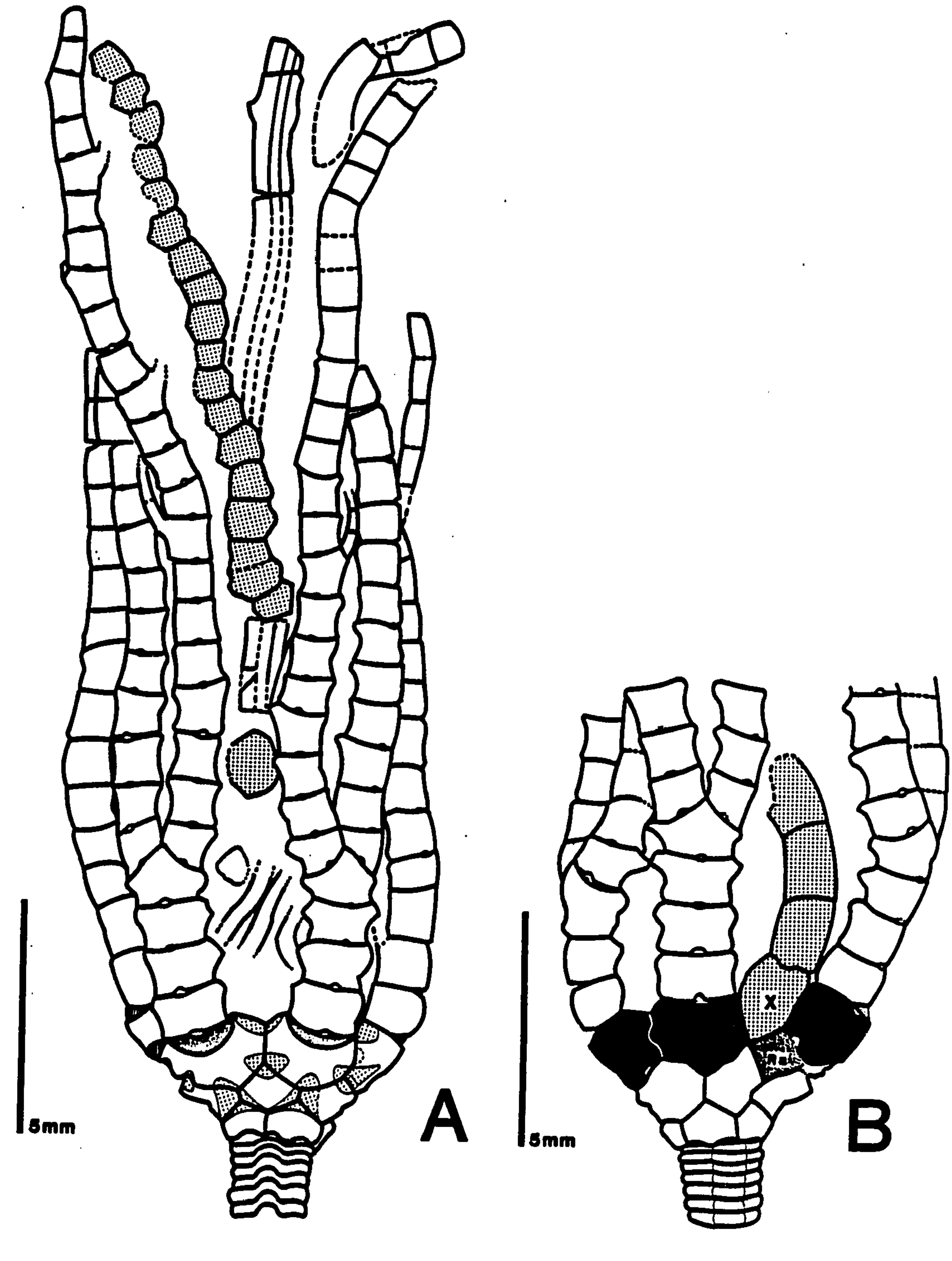
Cirri were commonly utilized as substrate anchors. These anchors were especially well suited in environments with soft sediment substrates of mud, silt and fine sand. In addition to substrate, cirri may have attached to the associated fauna, such as fenestrate bryozoans. A fenestrate bryozoan-crinoid coupling could have been particularly beneficial, as it may have provided a feeding advantage, and camouflaged concealment for the crinoid. Macurda and Meyer (1974) observed that modern isocrinids attach themselves to the substrate, other organisms, and objects on the substrate by means of grasping cirri. An attached individual need not have remained attached to a particular host or substrate, but could reattach following voluntary or involuntary dislodgement.

Text Figure 32. Goniocrinus sceletus sp. nov. Camera lucida drawings of Holotype UCGM 46161 (Pl. 8, figs. 5 and 6).

A) AB interray view. Note fossae along arm brachials. Ramules given off every third and fourth brachial along portion of right-lateral ramus of B ray.

B) D ray view, showing radianal plate (Ra) and anal X (X).

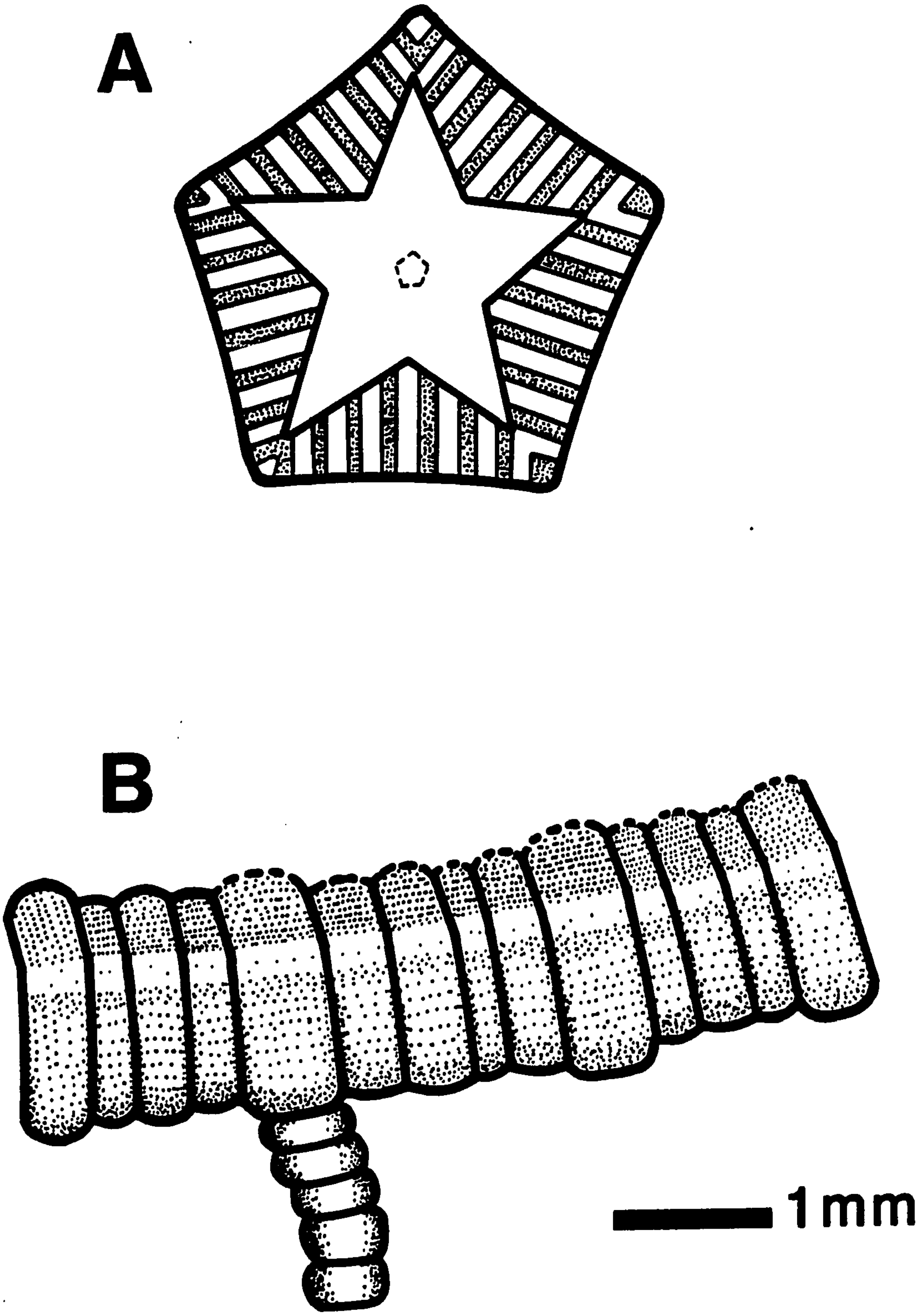
Explanation: radials black; radianal wrinkle stippled; anal plates and cup ornament in Figure A dot stippled.


5mm
A
x
5mm
B

Text Figure 33. Goniocrinus sceletus sp. nov. Diagrammatic representation of column in Holotype UCGM 46161.

A) Transverse view of articular facet in distal columnal showing crenularium, large star-shaped areola, and pentagonal (?) lumen.

B) Side view of column section showing alternating nodal and internodal columnals. Cirri round.


A
B
1mm

Family SCYTALOCRINIDAE Moore and Laudon, 1943

DIAGNOSIS

Cladid inadunate crinoids with slender, moderately tall, or tall crown. Dorsal cup bowl-shaped, or conical. Radial facet peneplenary to plenary, shallow, with transverse ridge and fossae. Three anals in cup; anal sac long and slender. Arms uniserial, or exceptionally biserial; typically branching once on the first to third primibrach, but may show numerous arm divisions. Pinnulate, or more rarely ramulate. Column round or pentagonal.

Genus LOGOCRINUS Goldring, 1923

DIAGNOSIS

A small scytalocrinid with moderately tall, slender crown. Dorsal cup narrow, conical to bell-shaped. Infrabasals small to medium, pentagonal, upflared and visible in side view. Basals medium, hexagonal or heptagonal. Radials moderately large, pentagonal, may be flared outward toward facet margin; facet plenary, slightly arcuate, relatively shallow. Three anals in cup; radianal pentagonal. Arms uniserial, branching once on the second, third, or fourth primibrach. Ramulate, or exceptionally pinnulate. Column round, but may be subpentagonal close to proximal base.

Logocrinus martini sp. nov.

Tables 20 and 21; Text Figure 34; Plate 9, figs. 1-4.

ETYMOLOGY

The specific name is named in honor of Mr. J. Martin, landowner of the crinoid-bearing locality examined in this study.

DIAGNOSIS

A species of *Logocrinus* with tall, slender crown. Dorsal cup tall, truncate conical. Infrabasals moderately large, forming about one-third cup height. Basals largest plate in cup, hexagonal in AB, DE, and EA interrays, and heptagonal in BC and CD interrays. Radials moderately large, pentagonal; facet slightly arcuate, shallow, plenary, and gaping. Three anals in cup; radianal pentagonal. Arms uniserial, ten, branching once on the third or fourth primibrach. Column round.

DESCRIPTION

Dorsal Cup - tall, narrow, truncate conical; confluent with tapering proximal columnals. Infrabasals five, pentagonal, tall, forming about one-third of cup height. Basals large, hexagonal in AB, DE, and EA interrays, and heptagonal in BC and CD interrays. Radials moderately large, pentagonal; facets slightly arcuate, shallow, plenary, and gaping.

Three anals in normal advanced position. Radianal large, pentagonal. Anal X slightly smaller than radianal, hexagonal. Anal X rising above level of radial facet, resting upon truncate distal margin of radianal. Plates smooth to finely granulose.

Infrabasals - five, pentagonal, tall, forming about one-third of dorsal cup; infrabasal/cup height ratio 0.33-0.42, avg. 0.38 (Table 20, n=5). Each plate higher than wide; H:W ratio 1.13-1.86, avg. 1.40 (Table 20, n=5). Proximal margin horizontally truncate. Lateral margins expanding distally. Distal margin acuminate, with apical angle slightly obtuse.

Basals - five, hexagonal in AB, DE, and EA interrays, and heptagonal in BC and CD interrays. Basals largest plate in cup. Each plate higher than wide: H:W ratio 1.15-1.70, avg. 1.36 (Table 20, n=5). Basals in BC and CD interrays slightly wider than others.

Radials - five, pentagonal, moderately large, similar in overall size to infrabasals. Each plate higher than wide; H:W ratio 0.52-0.83, avg. 0.69 (Table 20, n=5). Radial facet plenary, slightly arcuate, shallow, and gaping; articular surface with central fossae and adoral ridge. Posterior C ray radial slightly smaller than others due to lateral convergence with radianal.

Anal Series - three plates in cup. Radianal (RA) - pentagonal, relatively large, only slightly smaller than C ray radial, higher than wide; H:W ratio 1.20 (Table 20, UCGM 46164). Plate acuminate, inserted between BC and CD basals. Proximal margins subequal. Lateral margins also about equal, but slightly longer and distally tapered. Distal margin short, truncate.

X - hexagonal, smaller than radianal, higher than wide; H:W ratio 1.06 (Table 20, UCGM 46164). About one-third of plate rising above level of D ray radial.

X_2 - hexagonal, higher than wide; H:W ratio 1.07 (Table 20, UCGM 46164). Contact with C ray radial occurs along plate's proximal right-lateral margin.

Anal tube - incomplete.

Arms - uniserial, ten, long, slender, branching once on the third or fourth primibrach. First primibrach slightly larger than those which follow, trapezoidal, wider than high; H:W ratio 0.72 (Table 20, UCGM 46165). Second primibrach quadrangular, wider than high; H:W ratio 0.72 (Table 20, UCGM 46165). Third primibrach typically axillary, height and width subequal; H:W ratio 0.89 (Table 20, UCGM 46165). Proximal five to eight brachials quadrangular in outline (excluding axillary). Above, brachials cuneate. Ramulate. Paratype UCGM 46162 shows ramules given off on every fourth brachial (Pl. 9, fig. 3).

Column - round, composed of subequal ossicles. Proximal columnals tapered trumpet-like and expanded toward base. Distal portions of column unknown.

Material: Holotype UCGM 46165; Paratypes UCGM 46162, 46163, 46164, and 46166.

Table 20. Plate measurements in Logocrinus martini sp. nov. (mm)

UCGM		46162			46163					46164					46165**			46166		
		L	C	R	A	B	C	D	E	A	B	C	D	E	L	C	R	L	C	R
IBB	H	2.3	2.6	2.5	-	2.6	2.4	2.4	2.3	2.6	2.6	2.7	2.5	2.5	2.6	2.7	2.6	-	-	1.9
	W	-	1.7	1.5	-	1.9	1.8	1.8	1.8	1.3	1.1*	1.6	1.6	1.4	0.7*	2.4	1.7*	-	-	1.5
BB	H	3.1	3.0	-	3.5	3.2	3.3	3.4	3.2	3.4	3.5	3.6	3.5	3.4	3.2	3.3	3.2	-	2.7	-
	W	2.1	2.2	-	2.3	2.6	2.2*	2.4	2.4	2.0	2.0	2.3*	2.6	1.3*	2.6	2.6	1.0*	-	2.3	-
RR	H	1.8	-	1.8	1.9	1.9	1.4*	2.2	1.9	1.7	1.5	1.5	1.9	1.6	1.7	1.8	2.0	1.6	-	1.7
	W	2.6	-	2.4	2.1*	2.9	2.7	2.7	3.0	2.5	2.2	2.3	2.5	2.4	2.5	2.8	3.0	2.2	-	2.5
IBr_1	H	-	-	-	-	-	-	-	-	-	-	-	-	-	1.7	1.8	1.8	-	-	-
	W	-	-	-	-	-	-	-	-	-	-	-	-	-	2.3	2.6	2.5	-	-	-
IBr_2	H	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1	1.2	1.3	-	-	-
	W	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5	1.7	1.8	-	-	-
IBr_3	H	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5	1.6	1.8	-	-	-
	W	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8	1.9	1.8	-	-	-
ANALS																				
RA	H						2.2					2.4								
	W						1.5					2.0								
X	H											1.8								
	W											1.7								
X_2	H											1.5								
	W											1.4								
Cup	H		6.0				6.7					7.1				6.5			5.8	
	W_b		2.4				2.2					2.1				3.4			2.6	
	W_m		6.8				7.0					7.3				8.0			6.7	
Arm L.			-				-					-				37.8			28.0 (min.)	

* Incomplete because of exposure or compression
**Holotype

DISCUSSION

A close phyletic relationship is indicated between the scytalocrinid genera Logocrinus (Goldring), Bridgerocrinus (Laudon and Severson), and Hypselocrinus (Kirk). In each the dorsal cup is steeply conical, or slightly bell-shaped. Three anals are found in the cup; radianal is pentagonal. The column is transversely round, but may be pentagonal close to the cup. Genera are primarily differentiated by features of the primibrachial series, and ramulate to pinnulate condition. In a sequence from the genus Logocrinus to Hypselocrinus there is a reduction in the number of primibrachs, increase in the number of secondary arm appendages (ramulate to pinnulate), and ultimately an increase in the number of main arm divisions of some rays (Table 21). Development of pinnules and additional arm divisions indicates increased utilization of filter space, an advanced evolutionary trend toward improved feeding efficiency among inadunates.

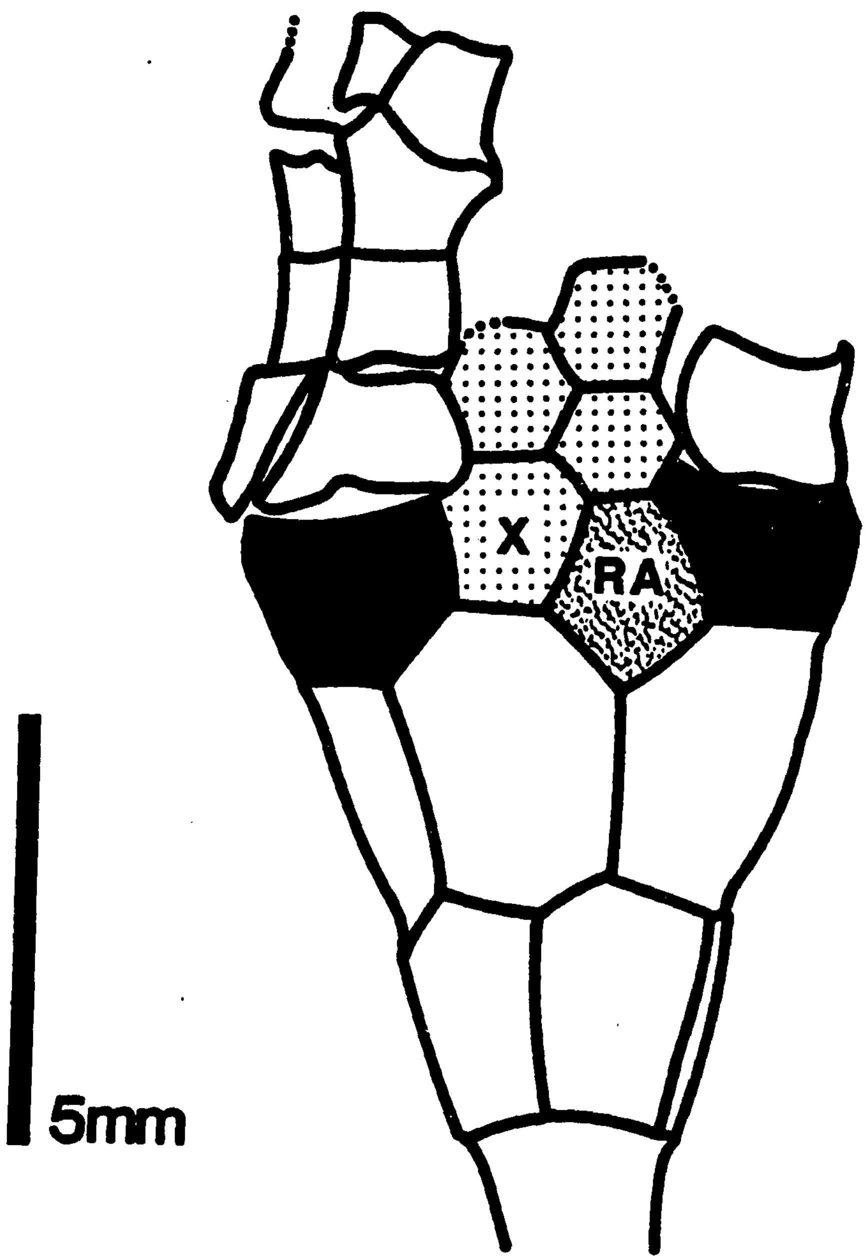
The genus Cradeocrinus (Goldring) strongly resembles Logocrinus (Goldring) in general appearance, but can be distinguished by its U-shaped radial facets, and quadrangular brachials. All Mississippian species currently assigned to the genus Cradeocrinus are more properly transferred to the genus Logocrinus (George McIntosh 1985, personal communication). Species of Logocrinus range from Middle Devonian (Eifelian) to Early Mississippian (Kinderhook) age strata.

Table 21. Distinguishing Features in three Scytalocrinid genera: Logocrinus, Bridgerocrinus, and Hypselocrinus

GENUS	LOGOCRINUS	BRIDGEROCRINUS	HYPSELOCRINUS
AUTHOR/ TYPE	Goldring 1923:438 *L. genticulatus*	Laudon & Severson 1953:518 *B. fairyensis*	Kirk 1940: 326 *H. hoveyi*
PRIMIBRACH NO.	2, 3 or 4	1, 2 or 3	1 or 2
RADIAL FACET/ PRIMIBRACHS	Radial facet plenary, shallow, and gaping. First primibrach trapezoidal.	Radial facet plenary, shallow, and slightly gaping. First primibrach elongate, moderately tapered.	Radial facet plenary, shallow, not gaping. First primibrach may be elongate.
SECONDARY ARMS	Ramulate-Pinnulate	Pinnulate	Pinnulate
ADDITIONAL ARM DIVISIONS IN SOME RAYS	No	No	Yes

Text Figure 34. Logocrinus martini sp. nov. Camera lucida drawing of Paratype UCGM 46164; CD interray view (Pl. 9, fig. 4).

Explanation: radials black; radianal (RA) wrinkle stippled; anals dot stippled.


X
RA
5mm

Genus HISTOCRINUS Kirk, 1940

DIAGNOSIS

Crown moderately tall, cylindrical, and somewhat open due non-appressed arms. Doral cup moderately large, subturbinate to truncate conical; plates smooth, or strongly ornate with ridge ornament. Infrabasals small, visible in side view. Basals and radials medium sized. Radial facet moderately arcuate, peneplenary, and not gaping. Three anals in cup; radianal pentagonal; anal X large, rising above level of radial summits; right tube plate (RT) smaller than anal X, rising well above radial summits. Anal sac cylindrical, slightly expanding, and distally reflexed. Arms nine or ten, relatively stout, uniserial, branching on the second primbrach in all rays except the anterior (A ray), which may be atomous. Pinnules strong, comb-like, standing stiffly outward from arms. Column round, but may be pentagonal close to proximal base (cup); heteromorphic.

DISCUSSION

The genotype Histocrinis coreyi (Worthen) is described as showing plates of the cup "thin, smooth, or with faint radial plications" and the column as "circular in section and made up of prominent nodals and internodals" (Kirk, 1940, p. 327-328). Histocrinus aegina (Hall) has a dorsal cup with strong ridge ornament, and a column which is pentagonal close to its proximal base. Amendment to generic diagnosis includes recognition of these features.

Histocrinus (Kirk) and Decadocrinus (Wachsmuth and Springer) are closely related genera. Both were formerly placed within the Scytalocrinidae, but are currently placed within separate families (Moore, Strimple, and Lane 1978-Treatise). The genus Histocrinus differs from Decadocrinus in having a taller, subturbinate to conical cup, infrabasals clearly visible in side view, an atomous A ray (exception - H. kivjuvenis (Meek and Worthen)), and peneplenary radial facets.

Histocrinus (Kirk) is a narrowly defined genus, ranging from the Lower Mississippian (Upper Kinderhook to Osage) Cuyahoga Formation to the Middle Mississippian (Osage) Edwardsville Formation of Indiana. Two species H. coreyi (Worthen) and H. graphicus (Miller and Gurley) are described from crinoid beds at Crawfordsville, Indiana (Van Sant and Lane 1964, p. 93-94). Histocrinus juvenis (Meek and Worthen) is found in the Lower Burlington Limestone of Iowa. Histocrinus aegina (Hall) the newly recognized species of the genus, is only known from the Cuyahoga Formation of northeastern Ohio.

Histocrinus aegina Hall, 1863 (n. comb.)

Poteriocrinus (Scaphiocrinus) aegina	Hall, 1864, p. 57; 1863 preliminary notice
	Hall and Whitfield, 1875, p. 174; Pl. 12, figs. 11-12.
Poteriocrinus (Decadocrinus) aegina	Wachsmuth and Springer, 1880, p. 119 (342)
Decadocrinus aegina	Bassler and Moodey, 1943, p. 405

Tables 22 and 23; Text Figure 35; Plate 10, figs. 6-9.

DIAGNOSIS

An ornate species of Histocrinus. Plates of dorsal cup with prominent ridges bisecting margins, and corners depressed in triangular to subtriangular pits. Column pentagonal close to cup, but becoming round distally. Other features same as in genus.

DESCRIPTION

Dorsal Cup - medium size, subturbinate to truncate conical, about twice as wide as high. Infrabasals small, visible in side view. Basals largest plates in cup, with AB, DE, and EA basals hexagonal, and BC and

CD basals heptagonal. Radials large, protuberant toward distal margin, showing semicylindrical facet platform at summit; facet peneplenary, occupying about two-thirds width of plate, declivate, and not gaping. Facet articular platform outlined with narrow rim margin, with V-shaped notch on adoral side, and transverse ridge separating inner and outer fossae (UCGM 46169; A ray view). Three anals in cup; radianal pentagonal, large; anal X large, rising above radial summits; right tube plate (RT) rising well above level of radial summits. Plates smooth to mildly fluted in Syntypes NYSM 6121 and 6122, but distinctly marked with strong stellate ridge network in Hypotypes UCGM 46169 and 46168.

Infrabasals - five, small, pentagonal, wider than high; H:W ratio 0.42-0.82, avg. 0.58 (Table 23, n=5). Proximal margin truncate at columnal facet. Distal margins crossed by medial ridge; plate apex forming plart of triangular pit. Infrabasal-infrabasal suture mildly indented (UCGM 46169; Pl. 10, fig. 7).

Basals - five, largest plate in cup, height and width subequal; H:W ratio 0.88-1.47, avg. 1.02 (Table 23, n=6). Plates hexagonal in AB, DE, and EA interrays; heptagonal in BC and CD interrays. Plates ornate with strong ridge ornament which radiates outward from elevated center and medially bisects plate margins; corners depressed in moderately deep triangular to subtriangular pits. Proximal set of ridges close-set, appearing as single double-crested, spear-shaped wedge (UCGM 46169; Pl. 10, fig. 7).

Radials - five, large, wider than high; H:W ratio 0.40-0.80, avg. 0.62 (Table 23, n=6). Plates heptagonal in A, B, and E rays; hexagonal in C and D rays. Radials protuberant toward distal margin, forming prominent semicylindrical facet platform at summit; facet peneplenary, occupying about two-thirds plate width, declivate, and not gaping. Interradial notches distinct. Facet platform with narrow rim margin along aboral side, V-shaped indentation along adoral side, and with medial transverse ridge between inner and outer fossae (UCGM 46169; A ray view). Moderately thick, semicyclindrical, ridge ornament bisecting plate's lateral and ventral margins; corners depressed in triangular to subtriangular pits. Strong ridges merging with semicylindrical facet platform give appearance of low cut tree stump.

Anals - three in cup. Radianal (RA) - large, pentagonal, higher than wide; H:W ratio 1.19-1.22, avg. 1.21 (Table 23, n=3). Plate resting about equal upon BC and CD basals, bordering C ray radial and anal X along lateral margins, and supporting first right tube plate (RT) directly above. Stellate ridge ornament weaker than that found on basals and radials. Anal X-large, hexagonal, about size of radianal, higher than wide; H:W ratio 0.96-1.28, avg. 1.17 (Table 23, n=3). Approximately one-third to one-half of plate rising above level of radials. Stellate ornament. Right Tube Plate (RT) - smaller than radianal and anal X, hexagonal. Proximal one-third to one-half of plate within cup, remainder rising above radial summits. Stellate ornament. Anal tube - unknown.

Arms - nine, uniserial, stout, not rising more than about 7 times height of dorsal cup; branching once on the second primibrach in each ray, except anterior (A ray) which is atomous. First primibrach quadrangular, wider than high; H:W ratio 0.86-1.35, avg. 0.66 (Table 23, n=6). Second primibrach slightly larger than first primibrach, axillary (except in A ray where first and second primibrachs are similar), wider than high; H:W ratio 0.86-1.35, avg. 1.14 (Table 23, n=6). Hypotype UCGM 46169 exposing left-lateral distal facet of primaxil in B ray; articulum with gently declivate, aboral fossae, and planate, adoral fossae. Area between adoral and aboral fossae crossed by transverse fulcral ridge which is disrupted midlength by V-shaped ambulacral indentation along adoral edge. Brachials short, weakly cuneate above second primibrach. Arm pathways mildly sinuous. Pinnules short, transversely cylindrical, heavy comb-like, standing stiffly outward from main arm axis (Text Figure 35; Pl. 10, figs. 7-9).

Column - composed of alternating series of thick and thin ossicles; heteromorphic. Three orders in noditaxis. Column pentagonal close to proximal base, but becoming round distally away from cup. Articulation symplectical. Lumen small, pentalobate or circular(?). Columnal indices given in Table 22.

Material: Syntypes - NYSM 6122 and 6121; Hypotypes UCGM 46167, 46168, 46169, 46170-A, 46171, and 46172.

Table 22. Columnal Indices in <u>Histocrinus</u> <u>aegina</u> (Hall)

Specimen	Measurement (mm)		Index
NYSM 6121	Height of Noditaxis	2.6	Ni 76.9
	Nodal height	0.6	INi 23.1
	Nodal width	2.5	KHi 24.0
UCGM 46169	Diameter of Articulum	0.5	
	Diameter of Lumen	2.5	Li 20.0

Table 23. Plate Measurements in *Histocrinus aegina* Hall (mm)

SPECIMEN		46167 H	46167 W	46168 H	46168 W	46169 H	46169 W	46170-A H	46170-A W	6122* H	6122* W	6121* H	6121* W
IBB	A	-	-	-	-	0.9	1.9	-	-	0.5	1.2	-	-
	B	-	-	-	-	-	-	-	-	0.6	1.3	-	-
	C	-	-	1.2	1.8	1.0	1.9	-	-	-	-	1.1	1.9
	D	-	-	1.4	1.7	0.9	1.7	1.8	2.6	-	-	1.1	2.1
	E	-	-	-	-	1.0	1.7	2.0	2.7	-	-	0.9	1.7
BB	AB	2.1	2.2	-	-	2.9	3.2	-	-	2.5	1.7	-	-
	BC	-	-	3.5	3.6	3.0	3.2	-	-	2.5	2.3	-	-
	CD	-	-	-	-	2.9	3.2	-	-	2.6	2.7	3.2	3.4
	DE	2.1	2.3	3.6	2.9	3.2	3.1	1.9	1.9	-	-	3.0	2.7
	EA	-	-	3.4	3.1	2.8	3.2	1.9	2.0	-	-	-	-
RR	A	-	-	-	-	1.7	4.3	-	-	2.0	3.0	-	-
	B	-	-	2.0	3.3	2.0	4.4	-	-	2.1	3.0	-	-
	C	-	-	1.8	3.4	1.9	4.0	1.7	2.5	1.9	2.9	-	-
	D	2.0	2.5	2.0	-	2.2	4.2	1.8	2.6	-	-	2.4	3.4
	E	1.9	2.6	2.1	3.3	2.1	4.3	1.3	1.6	-	-	-	-
IBr_1	A	-	-	-	-	-	-	-	-	1.1	1.9	-	-
	B	-	-	1.5	2.1	1.5	2.6	-	-	1.1	2.0	-	-
	C	-	-	1.5	2.0	1.7	2.5	-	-	1.2	2.1	-	-
	D	1.3	1.8	1.6	2.1	1.5	2.6	1.3	1.6	-	-	1.5	2.9
	E	1.9	2.2	1.6	2.4	-	-	1.4	2.0	-	-	1.3	2.8
IAX	A	-	-	-	-	-	-	-	-	2.7	2.0	-	-
or	B	-	-	2.9	2.8	2.9	2.4	-	-	2.7	2.3	-	-
IBr_2	C	-	-	3.0	2.8	2.9	3.1	-	-	3.1	2.5	-	-
	D	3.0	2.5	3.3	2.8	-	-	2.8	2.1	-	-	3.3	3.1
	E	2.6	2.7	3.0	2.6	-	-	2.6	2.5	-	-	3.2	2.9
RA		-	-	2.9	2.4	2.8	2.3	-	-	-	-	2.5	2.1
X		-	-	2.3	1.8	2.9	2.3	-	-	-	-	2.4	2.5
CUP H/W		4.1	8.2	6.2	7.7	5.0	10.1	3.3	6.8	4.4	8.2	5.9	11.2
ARM L.		25.5		26.0		32.7		-		29.6(B)		38.0(E)	

Explanation: Infrabasals not visible in specimen UCGM 46170-A; measurement underlined refers to specimen UCGM 46171.

* - syntypes.

DISCUSSION

Hall and Whitfield's (1875, Pl. XII, fig. 12) illustration of syntype NYSM 6122 is incorrect. Their figure shows two arms rising from the axillary second primibrach in the far right ray. However, examination of the syntype reveals that brachials of the far right arm branch continue toward the radial base of another ray position hidden on the concealed side. The exposed ray on the right side is atomous, which corresponds to the A ray. The atomous A ray is more clearly represented in Hypotype UCGM 46168 (Text Figure 35; Pl. 10, fig. 8).

Histocrinus aegina (Hall) differs from the other known species of the genus in showing a subconical cup with strong stellate ridge ornament, and weakly cuneate brachials. H. juvenis (Meek and Worthen) from the Lower Burlington Limestone with its dichotomous A ray, and more strongly cuneate brachials indicates taxonomic convergence with the genus Decadocrinus. Weakly cuneate brachials, and a peneplenary radial facet suggest that Decadocrinus brazeauensis (Laudon, Parks, and Spreng) from the Lower Mississippian (Kinderhook) Banff Formation of Alberta, Canada may be a Histocrinus.

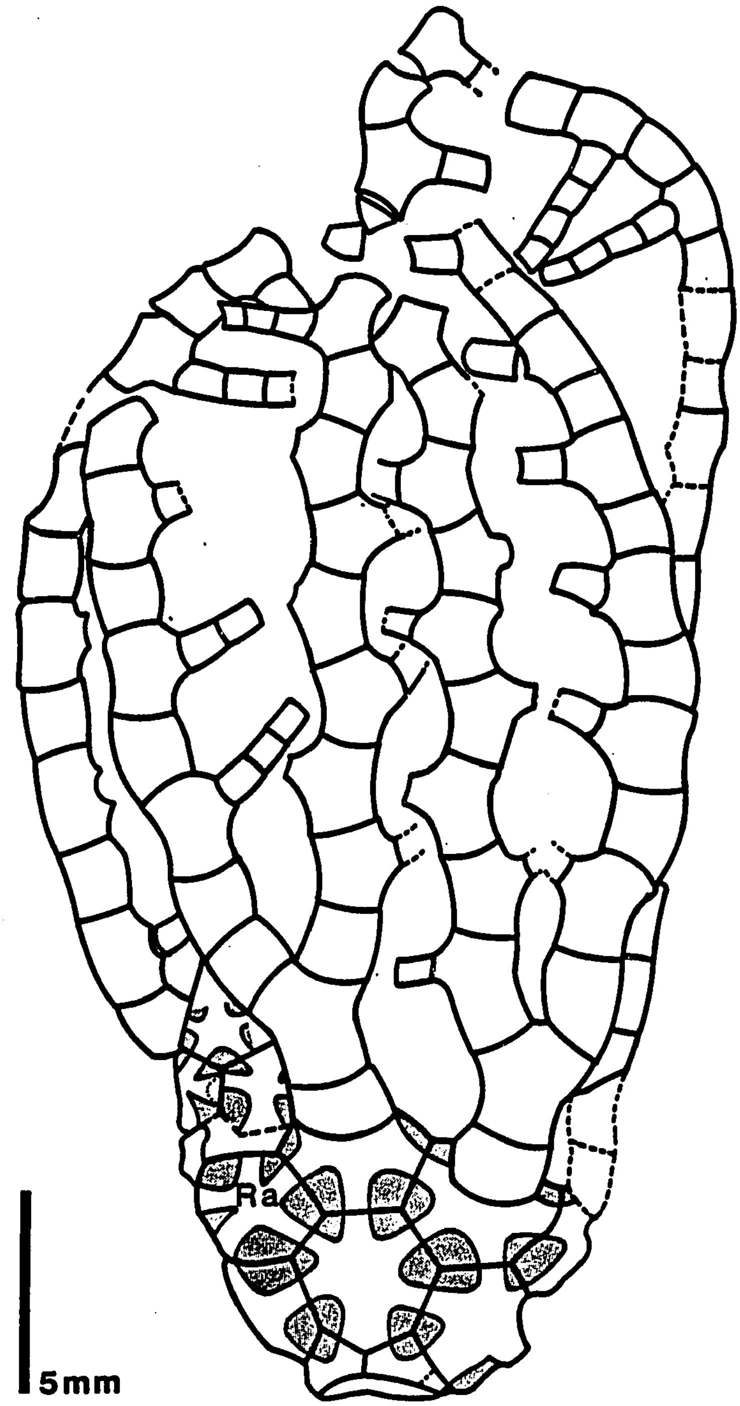
Text Figure 35. Histocrinus aegina Hall (n. comb.)

Camera lucida drawing of Hypotype UCGM 46168;

C ray view (Plate 10, fig. 8).

Explanation: depressed areas dot stippled;

radianal - RA.


Ra
5mm

Family APHELECRINIDAE Strimple, 1967

DIAGNOSIS

Cladid inadunate crinoids with slender, cyclindrical crowns. Dorsal cup small to medium, conical to slightly subturbinate. Infrabasals five, mostly upflared, visible in side view. Basals and radials medium sized. Three anals in cup; anal sac slender, moderately to strongly reflexed. Arms uniserial, branching on the first primibrach in all rays, except in an early genus (Paracosmetocrinus (Strimple)) which shows division above the first primibrach in the A ray. Arms with one, or two additional divisions. Column round, but may be pentagonal in proximal section.

Genus ASCETOCRINUS Kirk, 1940

Crown tall, slender. Dorsal cup small, compact, truncate conical; with small pits at plate angles. Infrabasals five, small, barely visible in side view. Basals and radials medium sized. Radial facet plenary, and slightly gaping. Three anals in cup; radianal pentagonal; anal X hexagonal, rising above radial summits; first right tube plate (RT_1) hexagonal, rising well above radial summits. Anal sac slender, relatively short, extending about one-half the height of the arms, and distally reflexed. Arms long, slender, branching on the first primibrach in all rays, then one or two additional times above. Brachials strongly cuneate, with prominent lateral projections for support of pinnules.

Pinnules long, slender. Column round, but may be pentagonal in proximal section; heteromorphic.

DISCUSSION

The genus Ascetocrinus (Kirk) is transferred to the family Aphelecrinidae (Strimple). Moore and Laudon (1943, p. 55) placed Ascetocrinus in their family Cercidocrinidae. However, features of the slender crown, conical dorsal cup, and slender, reflexed anal sac suggest that the genus is more appropriately assigned to the family Aphelecrinidae. Ascetocrinus subcarinatus (Hall) the newly recognized form, differs from other members of the genus in having isotomous arm divisions, a primitive feature suggesting the groups close affinity with the blothrocrinids. Arm divisions in the two other known species of the genus, A. rusticellus (White) and A. scoparius (Hall) are endotomous above the first primibrach. Ascetocrinus ranges from Lower Mississippian (Upper Kinderhook) to Upper Mississippian (Chester) of North America.

Ascetocrinus (Kirk) most nearly resembles Cosmetocrinus (Kirk), but can be distinguished by its proportionally smaller infrabasals, and pits at plate angles.

Ascetocrinus subcarinatus Hall, 1863 (n. comb.)

Scaphiocrinus subcarinatus Hall, 1864, p. 58; 1863 preliminary notice Hall and Whitfield, 1875, p. 176; Pl. 12, figs. 13, 14.

Poteriocrinus (Scaphiocrinus) subcarinatus Wachsmuth and Springer 1879, p. 113 (336).

Pachylocrinus subcarinatus Bassler and Moodey, 1943, p. 584.

Table 24; Text Figure 36; Plate 11, figs. 1-4

DIAGNOSIS

A strongly ornate species of Ascetocrinus. Crown slender, not widely expanding. Dorsal cup low, wider than high, truncate conical; ridge ornament well developed between basals and radials, plate corners depressed in pits. Arms uniserial, long, branching on the first primibrach in all rays, then one or two more times above. First primibrach exceptionally tall, similar in height to dorsal cup. Brachials strongly cuneate, with well developed median ridge and lateral processes for pinnules. Arm pathways markedly sinuous. Pinnulate. Column round, composed of alternating thick and thin ossicles.

DESCRIPTION

Dorsal Cup - small, truncate conical, with lateral edges inclined about 60-65 degrees to base, approximately twice as wide as high; H:W ratio 0.38-0.54, avg. 0.47 (Table 24, n=4). Infrabasals small, triangular to pentagonal in lateral view. Basals medium sized, higher than wide, hexagonal or heptagonal. Radials moderately large, wider than high, pentagonal; facet extending full width of plate, slightly declivate, and gaping. Three anals in cup; radianal large, hexagonal(?); anal X, and right tube plate (RT) moderately large, hexagonal, rising well above radial summits. Ornament consisting of short, stout ridges which radiate between plates; lateral margins and corners depressed in pits.

Infrabasals - five, small, triangular to pentagonal in lateral view, wider than high; H:W ratio 0.54-0.73, avg. 0.64 (Table 24, n=4). Proximal margin may be inwardly indented midlength, and show protuberant lobes along IB-IB junctions. Distal margins deeply acuminate between basals. Plate surfaces mildly nodose.

Basals - five, moderately large, hexagonal in AB, CD, DE, and EA interrays, heptagonal in BC interray, higher than wide; H:W ratio 1.05-1.46, avg. 1.23 (Table 24, n=4). Each distal margin bisected by short, rotund ridge; ridges centrally coalesced to form cordate to lozenge-shaped node. Lateral margins depressed in narrow lanceolate to spatulate pits. Plate's distal apex depressed in subtriangular pit.

Radials - five, moderately large, pentagonal, about twice as wide as high; H:W ratio 0.50-0.67, avg. 0.58 (Table 24, n=4). Plate distally outflaring, with thick distal rim. Stout ridges radiate toward basals. Proximal corners depressed in pits. Radial facet arcuate, extending full width of plate, declivate, and gaping.

Anals - three in cup. Radianal (RA) - moderately large, hexagonal(?), higher than wide; H:W ratio 1.31 (Table 24, n=1). Plate resting unequally upon BC and CD interrray basals, with about twice the area of contact along the CD interray basal. Ridge ornament hexagonal-stellate. Anal X - moderately large, hexagonal, higher than wide; H:W ratio 1.70 (Table 24, n=1). Ridge ornament incomplete. Anal X in Hypotype UCGM 46173 shows three ridges on the plate's right-lateral side; left-lateral side concealed by first primibrach of D ray. First Tube Plate (RT_1) - moderately large, hexagonal, higher than wide; H:W ratio 2.12 (Table 24, n=1). Ridge ornament incomplete; Hypotype UCGM 46173 shows four ridges (Text Figure 36; Pl. 11, fig. 3). Both anal X and RT_1 rising well above radial summits. Anal Sac - unknown from given suite of specimens.

Arms - uniserial, long, slender; branching on the first primibrach in each ray, then once or twice above. Initial two subdivisions invariably isotomous; third division irregular, branching on either one or both sides in each half-ray. First primibrach exceptionally tall, similar in height to dorsal cup; higher than wide, H:W ratio 1.04-1.90, avg. 1.31 (Table 24, n=4). Secundibrachs six to fourteen. Tertibrachs ten or more. Brachials angulated with median aboral ridge, strongly cuneate, and flared outward along their elongate edge with barb-like lateral process for reception of pinnules. Pinnules slender, closely appressed to main arm axis.

Column - round, composed of alternating thick and thin ossicles. Two or three order in noditaxis. Suture margins crenulate; articulation sympletical.

Material: Syntypes NYSM 6139 and 6140; Hypotypes UCGM 46173 and 46147-B.

DISCUSSION

Ascetocrinus subcarinatus (Hall) can be distinguished from Cosmetocrinus crineus (Hall) from the same formation by its smaller, ornate dorsal cup, exceptionally tall first primibrachs, and angulated cuneate brachials. A. subcarinatus (Hall) differs from the other members of its genus, A. rusticellus (White) and A. scoparius (Hall), by its tall, angulated first primibrachs, and isotomous arm divisions.

Table 24. Plate Measurements in Ascetocrinus subcarinatus Hall (mm)

SPECIMEN		46173		46147-B		6140*		6139*	
		H	W	H	W	H	W	H	W
IBB	A	0.7	1.0	0.8	1.1	-	-	0.7	1.3
	B	0.8	1.3	0.8	1.1	-	-	0.8	1.4
	C	0.8	1.3	-	-	-	-	-	-
	D	0.8	1.3	-	-	0.9	1.3	-	-
	E	0.8	1.3	-	-	0.8	1.4	-	-
BB	AB	1.9	1.6	1.7	1.3	-	-	2.1	1.8
	BC	2.1	1.8	1.6	1.4	-	-	2.1	2.0
	CD	2.0	1.4	-	-	2.0	1.6	-	-
	DE	2.1	1.5	-	-	1.8	1.7	-	-
	EA	1.9	1.3	1.6	1.3	1.7	1.5*	-	-
RR	A	1.4	2.1	1.3	2.2	-	-	1.5	2.7
	B	1.5	2.5	1.2	1.8	-	-	1.3	2.8
	C	1.5	2.5	-	-	-	-	-	-
	D	1.5	2.5	-	-	1.4	2.4	-	-
	E	1.5	2.6	-	-	1.6	2.6	-	-
IBr_1	A	4.0	2.1	2.8	2.2	-	-	4.1	2.8
	B	2.9	2.4	2.5	1.8	-	-	3.2	2.9
	C	3.5	2.5	-	-	-	-	-	-
	D	3.4	2.5	-	-	3.2	2.6	-	-
	E	2.9	2.7	-	-	2.6	2.5	-	-
ANALS	RA	1.7	1.3	-	-	-	-	-	-
	X_1	1.7	1.0	-	-	-	-	-	-
	X_2	1.7	0.8	-	-	-	-	-	-
CUP		3.3	6.1	2.4	6.3	3.3	6.6	3.4	7.4
ARM L.		-		35.7 (A)		28.2 (D)		37.4 (A)	

*Syntypes NYSM (New York State Museum);
* also indicating incomplete measurement.

Text Figure 36. <u>Ascetocrinus</u> <u>subcarinatus</u> Hall (n. comb.)

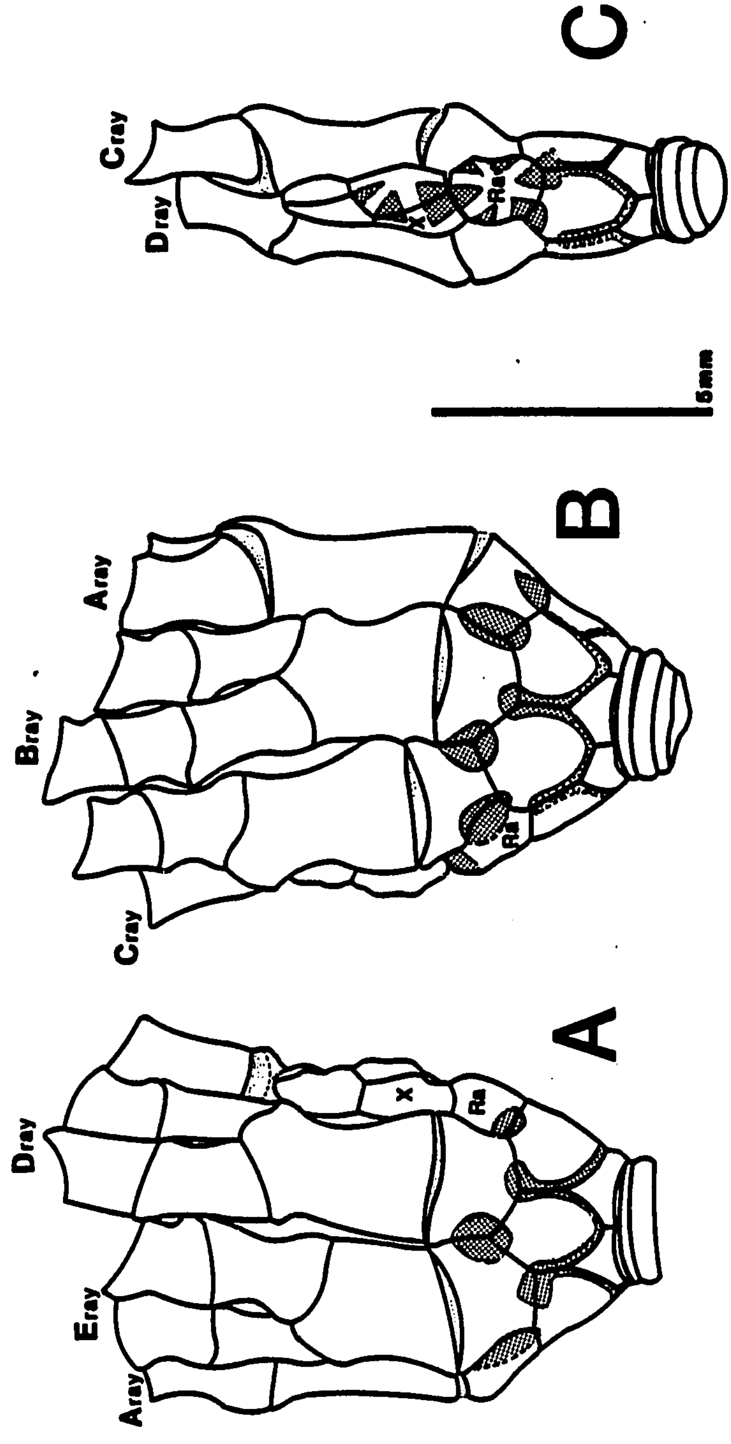
Camera lucida drawings of Hypotype UCGM 46173;

A) DE interray view (Pl. 11, fig. 3)

B) B ray view

C) CD interray view. Note lateral compression.

Explanation: depressed areas dot stippled; radianal - (Ra); anal X - (X).


A
Dray
Eray
Aray
X
Ra
B
Aray
Bray
Cray
Ra
C
Cray
Dray
X
Ra
5mm

Genus PARACOSMETOCRINUS Strimple, 1967

DIAGNOSIS

An aphelecrinid of diminutive size. Dorsal cup low bowl-shaped to subconical. Infrabasals small, barely visible in side view. Basals and radials moderately large. Radial facet shallow, plenary, and gaping. Arms slender; dividing on the first primibrach in all rays, except the anterior. A ray dividing once above the first primibrach. Other ray positions showing one or two additional divisions above the first primibrach. Column round, heteromorphic.

DISCUSSION

Strimple (1967, p. 81-85) established the family Aphelecrinidae with introduction of the genus Paracosmetocrinus. The genus was proposed to include forms essentially identical to Cosmetocrinus (Kirk), except for the A ray which divides above the first primibrach. Other variation noted in this study indicate that Cosmetocrinus is typically a larger form, and shows more strongly arcuate, deeper radial facets. Strimple (1967) listed the following species: Paracosmetocrinus strakai (Strimple), P. madisonensis (Laudon and Severson), P. cirrifer (Laudon), and P. crawfordsvillensis (Miller and Gurley). However, according to Van Sant and Lane (1964, p. 95) P. crawfordsvillensis = Hypselocrinus indianaensis (Meek and Worthen). Hypselocrinus indianensis (Meek and Worthen) clearly differs from the other species assigned to Paracosmetocrinus in showing two primibrchs in some rays, an undivided (atomous) A ray, and lacking arm divisions beyond the first. Paracosmetocrinus richfieldensis (Worthen) and P. corycia (Hall) represent new combinations.

Paracosmetocrinus (Kirk) is a narrowly defined Lower Mississippian (Upper Kinderhook-Lower Osage) genus described from the Wassonville Limestone (Iowa), Gilmore City Formation (Iowa), Lodgepole Formation (Montana), and Cuyahoga Formation (Ohio).

Aphelecrinus (kirk) most nearly resembles Paracosmetocrinus (Strimple), but differs in having arms divide on the first primibrach in all rays.

Paracosmetocrinus richfieldensis Worthen, 1881

Poteriocrinus richfieldensis Worthen 1882, p. 15; 1883, p. 285, Pl. 30, fig. 5.

Woodocrinus richfieldensis Wachsmuth and Springer 1886, p. 242 (166).

Cosmetocrinus richfieldensis Kirk 1941, p. 88.

Bassler and Moodey 1943, p. 374.

Aphelecrinus richfieldensis Laudon and Severson 1953, p. 521.

Cosmetocrinus richfieldensis Van Sant and Lane 1964, p. 94.

Aphelecrinus richfieldensis Strimple 1967, p. 81.

Table 15; Text Figure 37; Plate 10, figs. 1-5, 10-11.

DIAGNOSIS

A species of Paracosmetocrinus with subconical to bowl-shaped cup. Radial facet plenary, and gaping. Arms uniserial, slender, dividing on the first primibrach in all rays except the anterior; A ray dividing once on the seventh to eleventh primibrach. Others rays showing one additional division about midlength along the arms.

DESCRIPTION

Dorsal Cup - subconical to bowl-shaped, wider than high; H:W ratio 0.28-0.41, avg. 0.35 (Table 25, n=8). Plates smooth. Infrabasals small, pentagonal, barely visible in side view. Basals medium size; hexagonal in DE, EA, and AB interrays, and heptagonal in BC and CD interrays. Radials largest plate in dorsal cup, pentagonal, wider than high; facet gently arcuate, plenary, declivate, and gaping. Three anals in cup.

Infrabasals - five, pentagonal, small, barely visible in side view, wider than high; H:W ratio 0.50-0.66, avg. 0.57 (Table 25, n=5). Plates moderately upflared, and subhorizontal at proximal base.

Basals - five, medium size; hexagonal in AB, DE, and AE interrays, and heptagonal in BC and CD interrays. Each plate wider than high; H:W ratio 0.60-1.0, avg. 0.81 (Table 15, n=8). Basal of CD interray larger than others. Plate's proximal margins acuminate, with obtuse apical angle about 150-160 degrees. Lateral margins short, distally expanding. Distal margins acuminate between radials, apical angle about 90 degrees.

Radials - five, largest plate in dorsal cup, pentagonal, approximately twice as wide as high; H:W ratio 0.44-0.70, avg. 0.56 (Table 15, n=8). Radial facets shallow, gently arcuate, declivate, and gaping.

Anals - three in cup. Radianal - pentagonal, smaller than basals, wider than high; H:W ratio 1.0-1.50, avg. 1.25 (Table 25, n=6). Plate resting unequally on BC and CD basals, with approximately twice the area of contact occurring along the CD basal. Aberrant radianal in specimen UCGM 46178 quadrangular, lacking truncate distal margin for support of first right tube plate (RT_1) (Text Figure 37-B). Radianal absent in specimen UCGM 46180; anal X alone in cup (Text Figure 37-D).

Anal X - hexagonal, rising above radials, slightly wider than high; H:W ratio (0.86-1.33, avg. 1.08 (Table 25, n=6). Plate resting upon truncate distal margin of CD basal, except in aberrant specimen UCGM

46136-B, where truncate distal margin is absent; CD basal hexagonal (Text Figure 37-A). Right Tube Plate (RT_1) - hexagonal, rising well above radials, height and width subequal; H:W ratio 0.78-1.10, avg. 0.96 (Table 25, n=5). Plate resting upon truncate distal margin of radianal; contacts C ray radial along its proximal right-lateral margin. Anal Tube - slender; known only from its proximal series of hexagonal plates; distal portions concealed by arms.

Arms - eighteen, moderately long, slender; dividing on the first primibrach in all rays, except the anterior (A ray) which shows division on the seventh to eleventh primibrach. Other ray positions with one additional division about midlength along the arms. First primibrach exceptionally tall, frequently taller than height of dorsal cup; H:W ratio 0.87-2.20, avg. 1.44 (Table 25, n=8). Height of first primibrach variable between rays; in specimens UCGM 46176, 46177, and 46179 the B and E rays subequal in height, slightly shorter than C and D rays, which are also subequal in height. A ray corresponding to either B and E rays, or C and D rays in height (Table 25). Brachials cuneate, slightly angulated along aboral edge, showing distal lateral process along elongate edge for reception of pinnule branch. Pinnules slender.

Column - round, composed of alternating series of thick and thin ossicles. Two orders in noditaxis. Average nodal ratio for three successive noditaxes beginning 0.95 mm away from cup: Ni 30.9, INi 69.1 (Hypotype UCGN 46175-A).

Material - ten specimens - Hypotypes: UCGM 46174, 46136-B, 46152-B, 46175-A, 46176, 46177, 46178, 46179, 46180, and 46181.

Table 25. Plate measurements of *Paracosmetocrinus richfieldensis* Worthen (mm)

UCGM #		46174		46136-B		46152-B		46175-A		46176		46177		46178		46179	
		H	W	H	W	H	W	H	W	H	W	H	W	H	W	H	W
IBB	A							0.4	0.7	0.5	1.0						
	B																
	C									0.5	0.9					0.4	0.6
	D			0.5	0.8					0.4	0.8	0.5	1.0			0.4	0.7
	E																
BB	AB					1.3	1.7			1.0	1.3	1.2	1.7			1.2	1.5
	BC	1.2	2.0							1.0	1.3	1.4	1.6	1.3	1.6	1.3	1.3
	CD			1.5	1.6					1.3	1.5	1.8	1.9	1.7	1.7	1.4	1.5
	DE									1.1	1.2	1.4	1.4	1.3	1.8	1.3	1.3
	EA					1.3	1.5	1.0	1.4	1.0	1.3	1.3	1.6	1.2	1.3*	1.2	1.4
RR	A					1.6	2.3	1.0	1.0	1.1	1.6	1.2	2.3	1.2	2.2	1.1	1.9
	B					1.7	2.5			1.2	1.9	1.1	2.5	1.1	2.4	1.0	2.2
	C	1.2	2.4							1.1	1.8	1.3	2.2			1.1	1.9
	D			1.2	2.1					1.1	2.0	1.3	2.6	1.3	2.3	1.1	2.3
	E							0.9	2.1	1.1	1.9	1.3	2.3	1.2	2.0	1.1	2.0
IAx	A					1.8	2.0	1.3	1.5	3.3	1.5	3.3	2.2	3.1	2.0	3.0	1.8
	B	3.3	2.3			3.3	2.4	2.2	-	2.9	1.8	3.3	2.4	2.6	2.0	2.5	2.1
	C	3.6	2.3	2.5	1.6*					3.4	1.7	3.8	2.1			3.1	1.9
	D			2.6	1.9					3.1	2.0	3.6	2.5			3.0	2.2
	E			3.2	2.0	2.4	2.1	2.5	1.8	3.3	2.3	2.7	1.6	2.6	1.9		
ANALS																	
	RA	1.5	1.3	1.3	1.3					1.2	0.9	1.6	1.2	1.5	1.0	1.3	1.1
	X_1	1.4	1.1	1.2	0.9					0.8	1.0	1.2	1.1	1.2	1.4	1.1	1.0
	X_2	1.2	1.1	1.1	1.0					0.7	0.9	1.1	1.2			0.8	0.9
	X_3	1.5	1.1							0.7	1.0	1.0	1.1	1.2	1.0	0.9	0.9
DORSAL CUP		2.4	6.4	1.5	5.4	1.5	6.7	1.7	4.9	1.9	5.3	2.1	6.3	1.9	5.4	1.4	5.9
ARM L.										20.8_e		28.4_e		29.5_b		22.4_a	

KEY: * Indicates that plate measurement was incomplete due to compression or exposure. Letter subscripts indicate ray positions — arm length measurements.

DISCUSSION

The pattern of height a variation in the first primibrach of *Paracosmetocrinus richfieldensis* (Worthen) may be a consequence of ontogeny. Growth of the first primibrach is closely linked to that of its proximal neighbor the radials. Early developmental trends of radial plates in cladid inadunates is best known in the Lower Permian crinoid *Cranocrinus prastans* (Arendt). Arendt (1970) observed that the C ray radial was first to appear, followed by the almost simultaneous appearance of B, D, and E ray radials. The A ray radial appeared last. Development of the radial facets followed a similar pattern, with the facet of the C ray developing first, followed by a facet on the D ray, and then facets on B and E rays. The A ray facet was last to appear. If *P. richfieldensis* (Worthen) followed a similar pattern of development it may be possible to explain why the B and E ray first primibrachs are shorter than C and D ray first primibrachs (Table 25).

Morphologic variation between rays is also likely to be indicative of larger phylogenetic trends followed by echinoderms. These variations may be interpreted as indirect evidence of triradiality in crinoids. A hypothetical crinoid ancestor possessed three rays, the A, C, and D rays. Pentamerous symmetry evolved later, as the C and D rays bifurcated to form the B and E rays.

Hypotype UCGM 46180 is nearly identical to other specimens of *P. richfieldensis* (Worthen), but differs in showing arms divide on the first primibrach in all rays, and a single anal in the cup. Consequently, it may be an immature specimen of Acylocrinus lyriope (Hall). Unfortunately, distal features of the arms are not known. Hypotype UCGM 46180 is tentatively assigned to P. richfieldensis (Worthen).

Paracosmetocrinus richfieldensis (Worthen) most nearly resembles P. madisonensis (Laudon and Severson) from the Banff Formation of Alberta, Canada in having seven primibrach in the anterior ray, but differs in being somewhat more delicate in form, and showing less strongly cuneate brachials. P. straikai (Strimple) from the Wassonville Limestone (Iowa), and P. cirrifer (Laudon) from the Gilmore City Formation (Iowa) differ in showing four, and three primibrachs, respectively in the anterior ray.

Text Figure 37. Paracosmetocrinus richfieldensis Worthen (n. comb.) Camera lucida drawings of four specimens showing plates of CD interray.

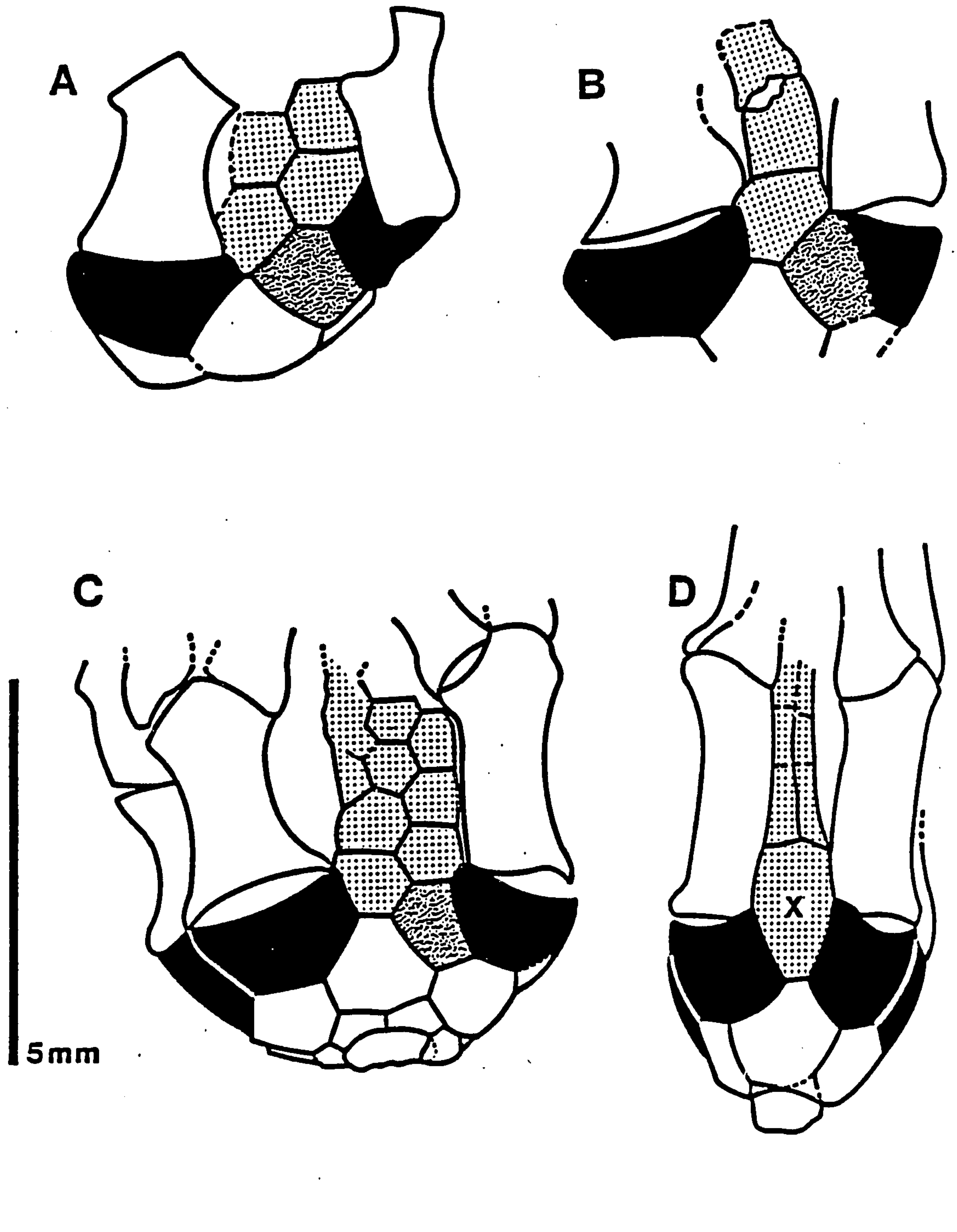
A) Hypotype UCGM 46136-B; abberant specimen with CD basal showing acuminate distal margins.

B) Hypotype UCGM 46178; aberrant speciment with two anal plates in cup. Right tube plate (RT) absent. Radianal quadrangular.

C) Hypotype UCGM 46177; speciment showing normal arrangement of anals in cup.

D) Hypotype UCGM 46180; abberant specimen showing anal X alone in cup. Anal X followed by double row of laterally compressed plates.

Explanation: radials black; radianal wrinkle stippled; anal plates dot stippled.


A
B
C
D
X
5mm

Paracosmetocrinus corycia Hall, 1863 (n. comb.)

Poteriocrinus corycia Hall, 1864, p. 57; 1863 preliminary notice. Hall and Whitfield, 1875, p. 173; Pl. 12, fig. 9.

Poteriocrinus (Scaphiocrinus) corycea Wachsmuth and Springer, 1879, p. 112 (335).

Pachylocrinus corycia Bassler and Moodey, 1943, p. 380.

Poteriocrinus pleias Hall, 1864, p. 57; 1863 preliminary notice. Hall and Whitfield, 1875, p. 175, Pl. 12, fig. 8.

Poteriocrinus (Decadocrinus) pleias Wachsmuth and Springer, 1880, p. 119 (341).

Hypselocrinus pleias Kirk, 1940, p. 217.

Hypselocrinus pleias Bassler and Moodey, 1943, p. 510.

Table 26; Plate 12, figures 6 and 7.

DIAGNOSIS

A species of Paracosmetocrinus with small, truncate conical cup. Infrabasals small, upflared, clearly visible in side view. Basals and radials medium size. Radial facet plenary. Arms slender. A ray showing one division on the fifth primibrach. Other rays dividing on the first primibrach, and showing up to two additional divisions above. Column round.

DESCRIPTION

Dorsal Cup - small, wider than high, truncate conical; H:W ratio 0.59-0.63, avg. 0.61 (Table 26, n=2). Infrabasals small, upflared, clearly visible in side view. Basals and radials medium size. Radial facet plenary. Three anals in cup. Plates smooth to finely granulose.

Infrabasals - five, small, pentagonal, forming about one-fourth height of dorsal cup, wider than high; H:W ratio 0.64-0.71, avg. 0.67 (Table 26, n=2).

Basals - five, medium size, hexagonal in DE, EA, and AB interrays, heptagonal in BC and CD interrays, height and width subequal; H:W ratio 0.95-1.0, avg. 0.98 (Table 26, n=2). CD basal slightly larger than others.

Radials - five, medium size, pentagonal, shovel-shaped, wider than high; H:W ratio 0.54-0.65, avg. 0.60 (Table 26, n=2). Facets plenary, slightly declivate.

Anals - three in cup. Radianal (RA) - pentagonal, moderately large, height and width about equal; H:W ratio 1.06 (Table 26, n=1). Plate resting unequally upon BC and CD interray basals, with greater contact occurring along the CD basal. Anal X - poorly exposed in Paratype NYSM 6124; hexagonal(?), rising above radial summits. Right Tube Plate (RT_1) - hexagonal, height and width equal; H:W ratio 1.0 (Table 26, n=1). Plate rising well above radial summits, about one-half in cup. Anal Tube - unknown.

Arms - incomplete; dividing on the first primibrach in E, C, and D rays, and on the fifth primibrach in the A ray. Condition of B ray unknown. First primibrach of E, C, and D rays slightly higher than wide; H:W ratio 1.05 (Table 26, n=2). First primibrach of A ray taller than other rays, higher than wide; H:W ratio 1.70 (Table 26, n=1). The E ray of Holotype NYSM 6138 showing second division on the tenth secundibrachs of both half-rays, and third division on the twelfth tertibrach of the far left-lateral quarter-ray. Brachials strongly cuneate. Pinnules unknown.

Column - incomplete; 17.0 mm in Paratype NYSM 6124. Column subpentagonal close to the cup, then becoming round distally. Ossicles alternatively thick and thin close to cup, but becoming more uniform in thickness distally away from cup.

Material - Holotype NYSM 6138, Paratype NYSM 6124.

Table 26. Plate Measurements in Paracosmetocrinus corycia Hall (mm)

SPECIMEN		NYSM 6138			NYSM 6124	
Ray		A(AB)	D(DE)	E(EA)	C(CD)	D(DE)
IBB	H	0.9	1.0	1.0	0.9	0.9
	W	1.4	1.4	1.5	1.3	1.4
BB	H	1.9	-	2.0	2.1	1.9
	W	2.0	-	2.0	2.2	1.9
RR	H	1.3	-	1.4	1.4	1.3
	W	2.4	-	2.3	-	2.0
IBr_1	H	3.4	-	2.3	2.3	-
	W	2.0	-	2.2	2.2	-
RA	H				1.7	
	W				1.6	
X	H				1.8	
	W				-	
RT_1	H				1.7	
	W				1.7	
CUP	H	3.5			3.9	
	W	5.6			6.6	

DISCUSSION

Paracosmetocrinus corycia (Hall) is rare, only known from two rather incomplete specimens, Holotype NYSM 6138 and Paratype NYSM 6124. Hall's (1864, p. 57) Poteriocrinus pleias is judged to represent a specimen of Paracosmetocrinus corycia (Hall) and is herein placed in synonmy. It has a similar shaped dorsal cup, moderately large first primibrachs, and strongly cuneate brachials.

Paracosmetocrinus corycia (Hall) can be easily distinguished from P. richfieldensis (Worthen) from the same formation by its more conical cup, larger upflared infrabasals, five primibrachs in the anterior ray, and presence of three arm divisions in at least one ray. It is the presence of the third arm division which suggests that this species is closely convergent upon the genus Cosmetocrinus, differing only by the nature of the arm division in the anterior ray. The genus Cosmetocrinus divides on the first primibrach in all rays. Collection of additional material may eventually disclose the full range of morphologic fetures of this rather poorly known species.

Genus COSMETOCRINUS Kirk, 1941

DIAGNOSIS

An aphelecrinid with high, subcylindrical crown. Dorsal cup conical to subturbinate. Plates smooth. Infrabasals medium size, upfalred and clearly visible in side view. Basals forming largest plate in cup. Radials moderately large; facet slightly cresentric, plenary, declivate, and gaping. Three anals in cup; anal sac long, slender. Arms long, slender, dividing up to three times in each ray. First division on the first primibrach in all rays. Second division isotomous, approximately one-third to one-half the height of the arms. Final division irregular; arms remain simple, or dividing on either inner or outer pair of rami. Brachials cuneate. Column round.

DISCUSSION

Aphelecrinus (Kirk) most nearly resembles Cosmetocrinus (Kirk), but differs in lacking the irregular third arm division in some rays. In Aphelecrinus (Kirk) arms divide on the first primibrach in all rays, then once more approximately one-third to one-half the height of the arms.

Upon re-evaluation of the genus Cosmetocrinus (Kirk) Strimple (1967, p. 81) removed all previously described species, except the genotype Cosmetocrinus gracilis (Kirk) and Cosmetocrinus crineus (Hall) from the genus. Cosmetocrinus (Kirk) occurs in the Cuyahoga Formation of northeastern Ohio, and the Upper Borden of Indian Creek, Montgomery Co., Indiana.

Cosmetocrinus crineus Hall, 1863

Poteriocrinus crineus Hall, 1864, p. 56; 1863 preliminary notice. Hall and Whitfield, 1875, p. 172; Pl. XII, figs. 6 and 7.

Poteriocrinus (Scaphiocrinus) crineus Wachsmuth and Springer, 1880, p. 112(335).

Cosmetocrinus crineus Kirk, 1941, p. 87. Bassler and Moodey, 1943, p. 373. Van Sant and Lane, 1964, p. 94.

Aphelecrinus crineus Strimple, 1967, p. 81.

Table 27; Plate 9, figs. 5 and 6.

DIAGNOSIS

Same as in genus.

DESCRIPTION

Dorsal Cup - moderately large, wider than high, truncate conical to subturbinate. Infrabasals medium size, upflared, forming prominent portion of cup. Basals largest plate in cup. Radials moderately large; facet plenary, slightly crecentric, declivate, and gaping. Three anals in cup; radianal pentagonal; anal X hexagonal, rising above radial summits; RT hexagonal, rising well above radial summits. Plates smooth, or finely granulose.

Infrabasals - five, pentagonal, medium size, wider than high; H:W ratio 0.49-0.79, avg. 0.59 (Table 27, n=2). Plates upflared, forming prominent portion of dorsal cup.

Basals - five, hexagonal in AB, DE, and EA interrays, and heptagonal in BC and CD interrays. Basals forming largest plate in dorsal cup, plate height and width subequal; H:W ratio 0.84-1.18, avg. 1.01 (Table 17, n=2).

Radials - five, pentagonal, shovel-shaped, wider than high; H:W ratio 0.59-0.76, avg. 0.65 (Table 27, n=2). Plate convex, with recessed lateral margins, and outflaring distal margin. Radial facet plenary, slightly cresentric, declivate, and gaping.

Anals - three in cup. Radianal (RA) - pentagonal, higher than wide; H:W ratio 1.12 (Table 27, Holotype NYSM 6137). Plate resting unequally on BC and CD basals, with greater contact occurring along the CD basal. Anal X - hexagonal, smaller than radianal, higher than wide; H:W ratio 1.07 (Table 27, Holotype NYSM 6137). Plate resting upon truncate distal margin of CD basal, rising above radial summits. Right Tube Plate (RT) - hexagonal, only slightly smaller than anal X, height and width equal; H:W ratio 1.0 (Table 27, Holotype NYSM 6137). Plate rising well above radial summits.

Arms - slender, approximately eight times the height of the dorsal cup. Arms dividing on the first primibrach in all rays; first primibrach axillary, similar to size of radials, slightly constricted along mid-section, height and width about equal; H:W ratio 0.77-1.29, avg. 0.91 (Table 27, n=2). Second arm division isotomous, occurring on the eighth to twelfth secundibrach in each ray. Final division irregular, with rami remaining simple or dividing on the twelfth to eighteenth tertibrach along either inner or outer pair of rami in each ray. Brachials cuneate. Pinnulate.

Column - composed of thin subequal ossicles; pentagonal to pentalobate directly below cup, then becoming round distally.

Material: Holotype NYSM 6137, Hypotypes UCGM 46182, and 46106-B.

Table 27. Plate Measurements in Cosmetocrinus crineus Hall (mm)

SPECIMEN		NYSM 6137					UCGM 46182	
RAY		A	B	C	D	E	CENTER	RIGHT
IBB	H	-	-	2.6	-	2.6	1.8	-
	W	-	-	5.8	-	3.3	3.6	-
BB	H	-	-	-	6.0	5.3	-	4.3
	W	-	-	-	5.1	6.3	-	4.3
RR	H	-	3.5	3.5	3.5	4.3	3.2	2.8
	W	-	5.9	5.9	5.9	6.4	4.2	4.1
IBr_1	H	4.1	3.7	3.7	3.5	-	3.4	3.6
	W	4.6	4.7	4.8	4.5	-	3.7	2.8
ANALS		RA	X_1		X_2			
		H 5.5	H 4.6		H 4.4			
		W 4.9	W 4.3		W 4.4			
Cup	H	10.4					7.6	
	W	16.3					-	
Arm L.		42.6 (D ray)					61.4 (Left ray)	

DISCUSSION

Cosmetocrinus crineus (Hall) is nearly identical to the genotype C. gracilis (Kirk) from the U. Borden of Indian Creek, Montgomery Co., Indiana. Species differ only slightly in the placement and arrangement of arm divisions. According to Kirk (1941, p. 87), the second arm division in C. gracilis (kirk) takes place on the first secundibrach in the C ray, and on the sixth to tenth secundibrach in other rays. In C. crineus (Hall) the second arm division ranges from the eighth to twelfth secundibrach. Similar minor variations occur in the final arm division of both species.

Superfamily LOPHOCRINACEA Bather, 1899

Family PACHYLOCRINIDAE Kirk, 1941

DIAGNOSIS

Cladid inadunate crinoids with tall, subcylindrical crown. Dorsal cup low, truncate bowl-shaped, infrabasals small, subhorizontal or downflared, not visible in side view. Basals moderately large. Radials medium size to large; facet peneplenary or plenary, bearing transverse ridge and ligamental pits. Three anals in cup; anal sac slender. Arms uniserial, branching two or more times. First division occurring on the first or second primibrach of each ray. Pinnulate. Column round, or obscurely subpentagonal.

Genus PACHYLOCRINUS Wachsmuth and Springer 1880

A pachylocrinid with tall, subcylindrical crown. Dorsal cup low, truncate bowl-shaped. Infrabasals small, subhorizontal or downflared at proximal base, not visible in side view. Basals large. Radials moderately large; facet wide, pleneplenary with small interradial notches, or plenary. Three anals in cup; anal sac tall, slender, subcylindrical. Arms uniserial, dividing on the second primibrach, then two or more times above. Brachials cuneate. Pinnulate. Column round or obscurely subpentagonal.

DISCUSSION

Throughout the course of its existence Pachylocrinus (Wachsmuth and Springer) has literally served as a waste-basket for various unrelated forms. Van Sant and Lane (1964, p. 87) recognized the primary cause of this confusion as an over-emphasis of arm structure:

> "Subsequent arm structure became emphasized so that almost any upper Paleozoic inadunates with 2 or 3 anals in the dorsal cup and arms branching dichotomously 2 or more times was referred to the genus. As a result a large number of unrelated species were included in Pachylocrinus and Abrotocrinus, which was defined as a Pachylocrinus with a pentagonal stem."

Pachylocrinus can be distinguished by its truncate bowl-shaped cup, infrabasals not visible in side view, arms which divide on the second primibrach in each ray, and round or obscurely subpentagonal column. Major credit for subdivision of Pachylocrinus must go to Edwin Kirk who recognized numerous valid genera by the shape of the dorsal cup, number of primibrachs in each ray, features of the anal sac, and column. The following are Kirk's (1940-41) subdivisions of the genera Pachylocrinus and Abrotocrinus: Cydrocrinus, Pelecocrinus, Dinotocrinus, Hylodecrinus, Ascetocrinus, and Cosmetocrinus. Among these, the genus Hylodecrinus most nearly resembles Pachylocrinus, but has a more compact crown, and pentagonal to pentastellate column.

The genotype P. aequalis (Wachsmuth and Springer) from the Borden of Crawfordsville, Indiana has radial facets which do not extend the full width of that plate. However, this feature cannot be considered as universally characteristic of the genus (e.g., P. subtortuosus (Hall)).

Amendment to generic diagnosis (above) includes recognition that radial facets range from peneplenary to plenary.

Pachylocrinus subtortuosus Hall, 1863 (n. comb.)

Scaphiocrinus subtortuosus Hall, 1864, p. 58; 1863 preliminary notice
Hall and Whitfield, 1875, p. 177; Pl. 12, figs. 15 and 16.

Poteriocrinus (Decadocrinus) subtortuosus Wachsmuth and Springer, 1880, p. 120.

Decadocrinus subtortuosus Bassler and Moodey, 1943, p. 408.

Table 28; Text Figure 38; Plate 11, figs. 5 and 6.

DIAGNOSIS

A species of Pachylocrinus with tall, subcylindrical crown. Dorsal cup low, truncate bowl-shaped; plates moderately thick, with ridge ornament. Infrabasals small, subhorizontal or downflared, not visible in side view. Basals and radials large. Radial facet plenary, arcuate, declivate, and gaping slightly. Three anals in cup; anal sac long, slender, composed of rows of moderately large, hexagonal plates. Arms tall, moderately thick; dividing on the second primibrach in each ray, then up to three additional times above. Brachials cuneate, angulated along their aboral edge. Column round, heteromorphic.

DESCRIPTION

Dorsal Cup - low, truncate bowl-shaped, wider than high; H:W ratio

0.46-0.54, avg. 0.50 (Table 28, n=3). Plates moderately thick with ridge ornament. Infrabasals small, subhorizontal or downflared, not visible in side view. Basals large, protuberant with X-shaped ridge ornament. Radials large, wider than high, facet arcuate, plenary, declivate, and gaping slightly. Three anals in cup.

Infrabasals - five, subhorizontal or downflared at base of cup, not visible in side view.

Basals - five, hexagonal, large, height and width subequal; H:W ratio 1.03-1.11, avg. 1.08 (Table 28, n=3). Plates moderately thick, protuberant, with X-shaped ridge ornament radiating outward from plate center; ridges straight or bowed gently outward. Pits between ridges relatively deep. BC interray basal of Hypotype UCGM 46183, and unknown interray basal of Holotype NYSM 6125 with one additional ridge radiating toward lateral margin (Text Figure 38; Pl. 11, figs. 5 and 6).

Radials - five, pentagonal, large, about one and one-half to two times as wide as high; H:W ratio 0.48-0.77, avg. 0.63 (Table 28, n=3). Plate strongly convex, almost hemicylindrical. Facet arcuate, plenary, declivate, and gaping slightly. Each plate with distal ridge along facet margin, and two ridges which form inverted V radiating toward proximal margins; ridges straight or bowed gently outward. Pits between ridges relatively deep.

Anals - three in cup. Radianal (RA) - large, pentagonal, higher than wide; H:W ratio 1.24 (Table 18, n=1). Plate resting subequally upon distal sloping margins of BC and CD interray basals. Ornament pentagonal stellate; ridges radiating outward from plate center toward medial positions along plate margins. Pits between ridges relatively deep. Anal X slightly smaller than radianal, hexagonal(?), rising above radial summits, height and width subequal; H:W ratio 1.08 (Table 28, n=1). Plate's left lateral margins not visible in Hypotype 45183; four ridges radiate outward from plate center (Text Fig. 38). Right Tube Plate (RT_1) - large, hexagonal(?), rising well above radial summits, height and width subequal; H:W ratio 1.08 (Table 28, n=1). Ornament hexagonal stellate, with ridges radiating outward from plate center toward medial positions along plate margins; corners depressed in moderately deep pits. Anal Tube - long, slender, composed of moderately large, hexagonal plates which are arranged in vertical rows. Ornament hexagonal stellate, with ridges radiating outward from plate center toward medial positions along plate margins; corners depressed in moderately deep pits. Medial vertical ridge thicker than lateral ridges.

Arms - long, moderately thick, approximately 12-13 times the height of the dorsal cup. First primibrach low, quadrangular, two to three times as wide as high; H:W ratio 0.35-0.52, avg. 044 (Table 28, n=3). Second primibrach axillary, wider than high; H:W ratio 0.61-0.70, avg. 0.65 (Table 28, n=3). Arms dividing up to four times in each ray. Lower two subdivisions invariably isotomous, with first division on the second primibrach, and second division on the tenth to fifteenth secundibrach. Final subdivisions more irregular, with rami remaining simple, or dividing endotomously one or two times. Arm pathways markedly sinuous. Brachials moderate to strongly cuneate, angulated along their aboral edge with distal barb-like lateral process for reception of pinnule.

Pinnules long, slender, angulated along their aboral edge.

Column - round, composed of alternating thick and thin ossicles; heteromorphic. Articulation symplectical.

Material: Holotype NYSM 6125; Hypotypes UCGM 46183, 46184, 46185, 46186, and 46194-B.

Table 28. Plate Measurements in Pachylocrinus subtortuosus Hall (mm)

SPECIMEN		UCGM 46183			UCGM 46184			NYSM 6125	
RAY		B(BC)	C(CD)	D(DE)	C	L	L	C(LC)	R(RC)
BB	H	3.1	3.1	3.0	3.7	3.7	-	2.1	2.2
	W	2.8*	3.0	2.7*	3.4	3.4		2.0*	2.6
RR	H	-	2.7	2.7	2.6	2.2	1.5	1.8	1.9
	W	-	3.5*	4.0	4.3	4.6	2.9	3.1	3.6
IBr	H	-	1.5	1.8	1.3	1.5	1.3	1.3	1.1
	W	-	3.0*	3.4	3.4	3.7	2.5	2.9	2.9
IAx	H	-	2.1	2.1	2.2	2.3	2.0	2.0	2.3
	W	-	3.0*	3.4	3.4	3.7	2.8	2.7	2.6
ANALS									
RA	H	3.1							
	W	2.5							
X	H	2.6							
	W	2.4							
X_2	H	2.8							
	W	2.6							
X_3	H	2.4							
	W	2.3							
Dorsal Cup	H	6.0			6.5			3.6	
	W	11.2			14.2			9.6	
Arm L.		77.6 (D ray)			79.3 (L ray)			-	

Key: *designates plate measurement is incomplete due to view of exposure or compression.

DISCUSSION

Arms in Holotype NYSM 6125 are incomplete (Pl. 11, fig. 5); Hall and Whitfield's (1875, p. 177) description is as follows:

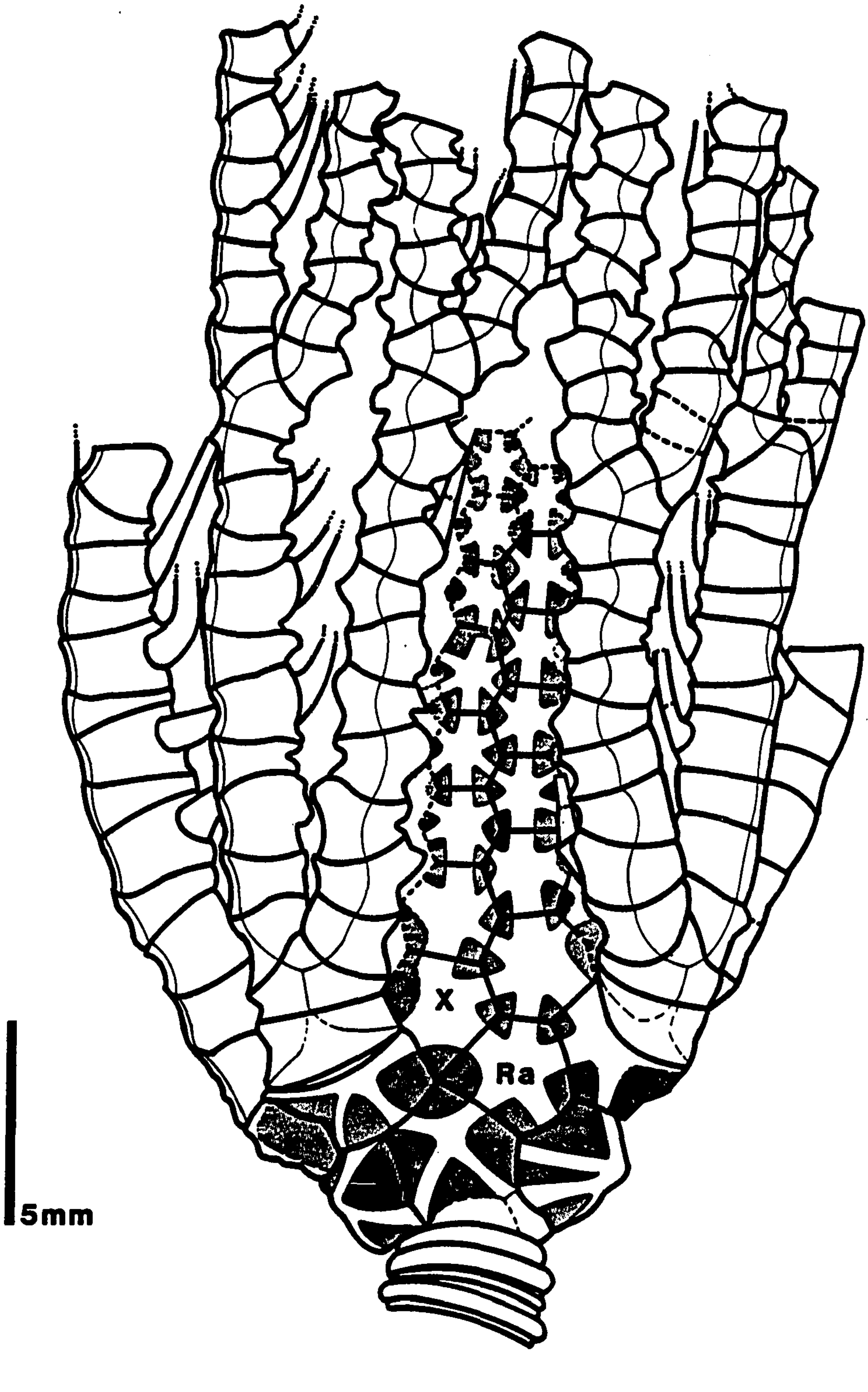
> "....the third radial plates very short, and supporting two arms, which bifurcate on the ninth and twelfth plates from their origin. No other bifurcation of the arms have been determined."

Additional information obtained from Hypotype UCGM 46183 indicates that arms divide up to four times in each ray. The lower two subdivisions are invariably isotomous, showing division on the second primibrach and tenth to fifteenth secundibrach, respectively. Final subdivisions tend to be more irregular, with rami remaining simple, or showing one or two endotomous arm divisions. Similar irregularities in arm braching are found in the type species of the genus, Pachylocrinus aequalis (Hall). Van Sant and Lane (1964, p. 88) note:

> "Unlike many inadunate species, the arms of Pachylocrinus aequalis exhibit considerable variation in patterns of branching. These seemingly can occur on any ray and range from endotomous to uniform dichotomous branches."

Pachylocrinus subtortuosus (Hall) is distinguished from P. aequalis (Hall) from the Borden at Crawfordsville, Indiana by its proportionally taller crown, fewer arm divisions, and strongly angulated brachials. P. Subtortuosus (Hall) most nearly resembles P. Gibsoni (White) but differs in being a larger, more strongly ornate species.

Text Figure 38. Pachylocrinus subtortuosus Hall (n. comb.)
Camera lucida drawing of Hypotype UCGM 46183;
CD interray view (Plate 11, fig. 6).
Explanation: depressed regions dot stippled;
radianal (Ra); anal X (X); fine lines donate
medial aboral ridge ornament.


X
Ra
5mm

Superfamily ERISOCRINACEA Wachsmuth and Springer, 1886

Family GRAPHIOCRINIDAE Wachsmuth and Springer, 1886

Genus ACYLOCRINUS Kirk, 1947

DIAGNOSIS

Cladid inadunate with slender, tall crown. Dorsal cup bowl-shaped, with depressed basal pit; plates smooth or finely granulose. Infrabasals small, not visible in side view. Basals moderately large. Radials large, wider than high; facet plenary, convex, and gaping. One anal in cup, rising above radial summits, distally lunate in section; anal sac long and slender. Arms ten, slender, long, dividing on the first primibrach in all rays. Brachials cuneate. Pinnulate. Column round; heteromorphic.

DISCUSSION

Acylocrinus (Kirk, 1947) and Holcocrinus (Kirk, 1945) are closely related. Kirk originally placed both genera in the family Graphiocrinidae (Wachsmuth and Springer). Later, Moore and Strimple (1978, p. 686 - Treatise) transferred Acylocrinus to the family Decadocriniadae (Bather). I have chosen to retain Kirk's original assignment. Both genera have a turbinate to bowl-shaped cup, arms dividing on the first primibrach in each ray, and a single anal in the cup. Genera are differentiated by features of cup, infrabasals, arms, and column. Kirk (1947, p. 294) remarks:

> "Acylocrinus, with the IBB concealed in the basal pit, readily distinguishes the genus from all the other known related genera.... In Holcocrinus the rami are relatively much longer and more slender. The turbinate doral cup, IBB visible in lateral view, and pentagonal column of Holcocrinus readily distinguish the genus."

Acylocrinus is known from Lower Mississippian strata of the Cuyahoga Formation of Ohio, Burlington Limestone of Iowa, and Fern Glen Formation of Missouri.

Acylocrinus lyriope Hall, 1863 (n. comb.)

Poteriocrinus (Scaphiocrinus) lyriope Hall, 1864, p. 58; 1863 preliminary notice. Hall and Whitfield, 1875, p. 175; Pl. 12, fig. 10.

Poteriocrinus (Decadocrinus) lyriope Wachsmuth and Springer, 1880, p. 119 (341)

Decadocrinus lyriope Bassler and Moodey, 1943, p. 407

Table 29; Text Figure 39; Plate 23, figs. 8 and 9.

DIAGNOSIS

A species of *Acylocrinus* with moderately tall, slender, subcylindrical crown. Dorsal cup low, bowl-shaped, sharply incurved and depressed at base. One anal in cup. Arms ten, dividing on the first primibrach in all rays. Brachials moderately elongate, cuneate. Column round, tapered at proximal base.

DESCRIPTION

Dorsal Cup - best preserved in Hypotype UCGM 46187; Holotype NYSM 6123 compressed. In Hypotype UCGM 46187 dorsal cup low, bowl-shaped, sharply incurved and depressed at base, wider than high; H:W ratio 0.39 (Table 29, n=1). Infrabasals small, within basal depression, not visible from side view. Basals moderately large. Radials large; facet plenary, gently arcuate, and gaping. One anal in cup; anal X large, rising above radial summits. Plates finely granulose.

Infrabasals - five, small, pentagonal, wider than high; H:W ratio 0.63-0.71 (Table 29, n=1). In Holotype NYSM 6123 plates upflared and visible from side view, but this condition is considered aberrant due to the compression of the dorsal cup. A more representative view is seen in Hypotype UCGM 46187, where infrabasals are hidden within a concavity at the base of the cup (Pl. 12, fig. 9).

Basals - five, moderately large, hexagonal; height and width subequal, except in CD basal. H:W ratio of CD basal 0.63 (Hypotype UCGM 46187); H:W ratio in nonposterior interrays 0.92 and 1.0 (Table 19, n=2). Basal circlet widely expanding, and sharply incurved along proximal margin.

Radials - five, largest plate in dorsal cup, pentagonal, wider than high; H:W ratio 0.48-0.68, avg. 0.58 (Table 29, n=1). Proximal margins broadly acuminate. Lateral margins slightly expanding toward distal facet. Radial facet plenary, declivate, and gaping. Articular surface of facet marked with transverse ridge separating inner and outer fossae; ridge disrupted adorally by small, narrow, central depression. Aboral rim convex; adoral rim linear. Outer fossae slightly declivate, whereas, inner fossae subhorizontal.

Anals - one in cup. Anal X alone in cup, large, rising above radial summits, slightly higher than wide; H:W ratio 1.12 (Table 29, n=1). Plate resting upon sloped distal right margin of CD basal. Anal Tube - only known from proximal series of plates in Hypotype UCGM 46187;

slender, subcylindrical, restricted to region of posterior interray.

Arms - ten or twelve, moderately slender, long, and rather closely appressed. Arms dividing once on the first primibrach. In Holotype NYSM 6123 one additional division taking place on the tenth secundibrach of one ray (Pl. 12, fig. 8). First primibrach axillary, tall, widest at its proximal base, medially constricted; H:W ratio 0.86-1.66, avg. 0.95 (Table 29, n=2). Height of first secundibrach about equal to first primibrach. Above, secundibrachs progressively decreasing in height. Brachials slightly cuneate, moderately elongate, distally projecting on alternate lateral sides for reception of pinnules; pinnular facet adorally shifted toward interior. Pinnules moderately slender.

Column - round. Proxistele short, tapering distally, cone-shaped, composed of thin ossicles with crenulate sutures. Mestistele about three to four times as long as proxistele, composed of alternating thick and thin ossicles of similar diameter. Dististele with ossicles becoming more uniformly thick, subequal. Columnal indices not recorded.

Material: Holotype NYSM 6123; Hypotypes - UCGM 46187, 46188, 46189.

Table 29. Plate Measurements in Acylocrinus lyriope Hall (mm)

SPECIMEN		UCGM 46187		NYSM 6123	
RAY		(CD)D	(DE)E	R	L
IBB	H	-	-	1.2	1.2
	W	-	-	1.7	1.9
BB	H	2.7	2.4	2.5	2.4
	W	4.3	2.6	2.2*	2.4
RR	H	2.3	2.8	1.9	1.7
	W	4.8	4.1*	2.8	2.9
IAX	H	3.9	3.9	4.5	3.0
	W	4.5	4.0*	2.7	2.6
ANAL (X)	H	2.9	-	-	-
	W	2.6	-	-	-
CUP	H	2.2	-	4.7	-
	W	5.7	-	8.6	-
ARM	L.	29.4			40.3

Key - * measurement incomplete due to exposure, or compression

DISCUSSION

Holotype NYSM 6123 differs from the other specimens of Acylocrinus lyriope (Hall) in showing an additional arm division on the tenth secundibrach of one ray (Pl. 12, fig. 8). Current definition of family and genus indicate that this feature is probably aberrant. Unfortunately, very few specimens were available to test the limits of morphologic variation.

A striking feature in holotype NYSM 6123 is exposure of infrabasals from side view. This feature is believed to have been diagentically produced; plates of the dorsal cup are compressed and a slight separation occurs between column and cup. An alternative explanation is that infrabasals become concealed during late stages of ontogeny. Potentially, as an individual matured infrabasals showed less expansion than more "distal" elements within the cup. This unequal expansion led to infrabasals becoming concealed within a concavity at the base of the cup. Evidence suggesting that holotype NYSM 6123 may be less mature than hypotype UCGM 46187 is noted by the size of the radials. Radial plates in hypotype UCGM 46187 are slightly higher and considerably wider than radials in the holotype.

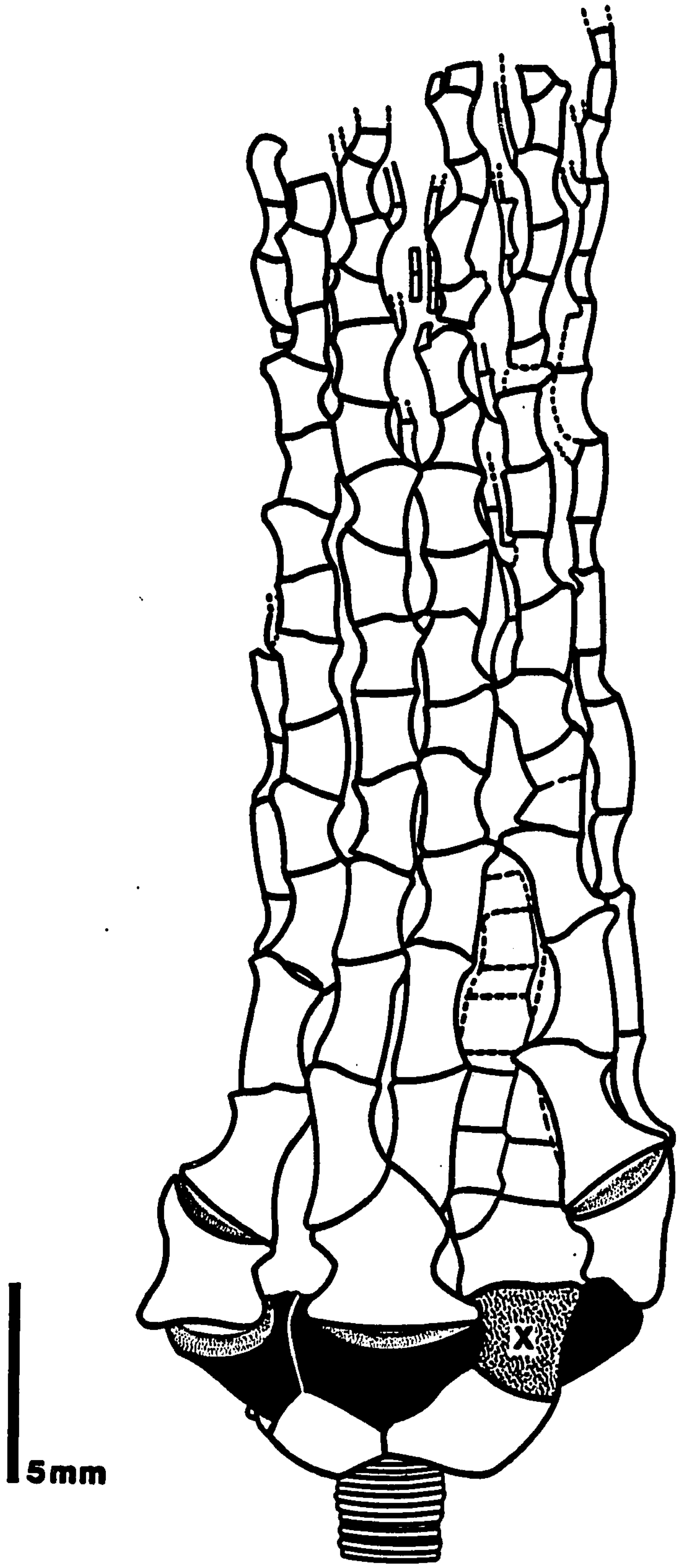
Acylocrinus lyriope (Hall) differs from A. tumidus (Meek and Worthen) (genotype*) from the Burlington Limestone of Iowa in having much more elongate and less strongly cuneate brachials.

Text Figure 39. Acylocrinus lyriope Hall (n. comb)

Camera lucida drawing of Hypotype UCGM 46187;

D ray view (Plate 12, fig. 9).

Explanation: radials black; anal X wrinkle stippled (X).


X
5mm

Superfamily ZEACRINITACEA Bassler and Moodey, 1943

Family ZEACRINITIDAE Bassler and Moodey, 1943

Genus LINOCRINUS Kirk, 1938

DIAGNOSIS

Crown relatively broad, subcylindrical. Dorsal cup somewhat flattened, low bowl or saucer-shaped, with basal concavity. Plates typically rugose. Infrabasals small, concealed from lateral view. Basals moderately large, forming portion of flattened or concave base. Radials moderately large; facet plenary, convex, with suture gaping. Three anals in cup; anal sac large, planispirally coiled in distal portion, with anal opening about mid-length along the anterior side. Arms uniserial, composed of quadrangular to cuneate brachials, endotomous, dividing two or more times above their primary division. Arms first dividing on the first primibrach in all rays, except the anterior, which divides on the third to sixth primibrach. Column round, heteromorphic.

DISCUSSION

Kirk (1938, p. 160-170) subdivided Zeacrinites (Troost) establishing five new genera, Adinocrinus, Alcimocrinus, Ceridocrinus, Eratocrinus and Linocrinus. Two of these genera, Adinocrinus and Cercidocrinus were later transferred to the Adionocrinidae (Strimple, 1961) and the

Ceridocrinidae (Moore and Laudon, 1943), respectively. The genus Linocrinus shows the closest relationship to the Richfield specimens.

Kirk (1938, p. 169) compared Linocrinus (Kirk) with Decadocrinus (Wachsmuth and Springer) and Pachylocrinus (Wachsmuth and Springer):

> " An endotomous Decadocrinus with a few minor changes would give Linocrinus, just as a Decadocrinus with two isotomous divisions above the main dichotom is essentially Pachylocrinus."

Laudon and Severson (1953, p. 577) similarly acknowledged this resemblance, but felt that Decadocrinus was only distantly related. Rather, affinity to Dinotocrinus (Kirk), Pachylocrinus (Wachsmuth and Springer), and Abrotocrinus (Miller and Gurley) was suggested. Among these, Abrotocrinus with its shallow cup, single primibrach, gaping radial facet, and multiple arm branching was thought to be most closely related to Linocrinus.

The genotype, Linocrinus wachsmuthi (Kirk) is an Upper Mississippian Chesterian form showing rugose plates, a sharply keeled first primibrach, and three to five primibrachs in the anterior radius. Both Chesterian species, L. wachsmuthi (Kirk) and L. arboreus (Worthen) have a low saucer-shaped cup which includes infrabasals and basals as part of a concave depression, and radials subhorizontal in part with the basal (or tangential) plane of the cup. This arrangement is in direct opposition to the Lower Mississippian forms of the genus, L. asper (Meek and Worthen), L. faculensis (Laudon, Parks, and Spreng), and L. wilsallensis (Laudon and Severson), where the cup is subturbinate to bowl-shaped, and basal and radial plates are exposed along the outer-lateral sides of the cup. Typically, only the proximal portions of the basal plates are included in the concave depression at the base of the cup. Divergence of characters suggests that these Lower Mississippian forms of Linocrinus should perhaps be split to a separate genus. Alternatively, intraspecific variation in cup structure may be a normal evolutionary progression within the genus. Presently, no attempt is made to change the current nomenclature. The Richfield specimens are closely aligned with Lower Mississippian forms currently assigned to the genus Linocrinus.

Linocrinus merope Hall, 1863 (n. comb.)

Zeacrinus merope	Hall, 1864, p. 60; 1863 preliminary notice. Hall and Whitfield, 1875, p. 178; Pl. 12, fig. 18.
Poteriocrinus (Pachylocrinus) merope	Wachsmuth and Springer, 1879, p. 339 (116).
Woodocrinus merope	Wachsmuth and Springer, 1886, p. 166. Weller, 1898, p. 640.
Zeacrinus merope	Sutton and Hagan, 1939, p. 94.
Zeacrinites merope	Bassler and Moodey, 1943, p. 718.
Zeacrinus paternus	Hall, 1864, p. 59; 1863 preliminary notice. Hall and Whitfield, 1875, p. 177; Pl. 12, fig. 17.
Poteriocrinus (Pachylocrinus) paternus	Wachsmuth and Springer, 1879, p. 339 (116).
Woodocrinus paternus	Wachsmuth and Springer, 1886, p. 166. Weller, 1898, p. 640.
Zeacrinus paternus	Sutton and Hagan, 1939, p. 94.
Zeacrinites paternus	Bassler and Moodey, 1943, p. 718.

Tables 30 and 31; Text Figure 40 and 41; Plate 12, figs. 1-5.

DIAGNOSIS

A species of Linocrinus with moderately tall, slightly expanded, subcylindrical crown. Dorsal cup low, bowl-shaped; plates thick, covered with coarse pustulose ornament. Infrabasals small, hidden from side view by concave depression at base of cup. Basals and radials moderately large. Radial facet plenary, convex, and gaping. Three anals in cup. Arms uniserial; dividing on the first primibrach in all rays, except the anterior which divides on the third to sixth primibrach. Above, arms showing two or three endotomous divisions. Brachials quadrangular. Column round, heteromorphic.

DESCRIPTION

Dorsal Cup - subturbinate to low, bowl-shaped; H:W ratio 0.33-0.39, avg. 0.37 (Table 30, n=7). Plates thick, covered with pustulose ridge and node ornament. Infrabasals small, not visible in side view (mature specimens), found in concave depression at base of cup. Basals moderately large, forming lowest circlet of plate in side view, and curved inward along their proximal margins. Radials moderately large; facet plenary, declivate, convex, and gaping. Three anals in cup.

Infrabasals - five, small, not visible in side view (mature specimens), found in concave depression at base of cup. Infrabasals in immature specimens subhorizontal at base of cup (Text Figure 40-B).

Basals - five, moderately large, hexagonal or heptagonal, slightly wider than high; H:W ratio 0.61-1.10, avg. 0.84 (Table 30, n=7). CD interray basal heptagonal, supporting anal X on its truncate distal margin. Proximal-most margins of basals curved invward. Basals moderate to strongly convex, with suture margins between plates recessed. Ornament consisting of network of pustulose ridges and nodes.

Radials - five, moderately large, pentagonal, about twice as wide as high; H:W ratio 0.41-0.68, avg. 0.50 (Table 30, n=7). Radials strongly convex, moderately flared outward toward distal margin, with sutures between plates recessed. Radial facet plenary, declivate, convex, and gaping. Ornament consisting of radiating network of pustulose ridges and nodes which medially coalesce to form an inverted V that points toward the first primibrach.

Anals - three in cup. CD interray moderately wide, similar to width of radial plate. Radianal (RA) - small to medium size, pentagonal, higher than wide, resting unequally upon BC and CD interray basals, with approximately twice the area of contact occurring along the CD basal. Anal X - similar to radianal in size, hexagonal, higher than wide, rising well above radial summits in immature specimens and equal to radial summits in mature adults (Text Figure 40). Right Tube Plate (RT_1) - hexagonal(?), slightly higher than wide, with about two-thirds rising above radial summits. Anal Tube - unknown.

Arms - moderately long, robust; dividing on the first primibrach in all rays, except the anterior which divides on the third to sixth primibrach. Above, arms showing two or three endotomous divisions. First primibrach large, slightly higher than wide, or subequal; H:W ratio 0.78-1.36, avg. 0,97 (Table 30, n=7). Plate covered with pustulose-nodose ornament along proximal semicircular boss, median ridge, and distal rim margins. To either side of median ridge lateral interareas depressed in relatively smooth, concave fossae. Secundibrach 6-14. First secundibrach with median ridge and traces of pustulose ornament, slightly higher than succeeding secundibrachs. Tertibrachs 7-14. First tertibrach similar to first secundibrach, i.e., slightly higher than those which follow. Quintibrachs 8 -16. Brachials quadrangular, with slightly outflared distal facets distinctly separating successive plates. Pinnules longitudinally angulated along their aboral edge.

Column - round, composed of alternating thick and thin ossicles. Noditaxis containing three orders of internodes. Columnal indices for noditaxis 6.0 mm distal to cup in Holotype NYSM 6132; Ni 24.1, INi 75.9, NHi 18.4 (Ni-nodal index; INi - internodal index; NHi - nodal height index). Columnal epifacets angulated.

Material: Holotype NYSM 6132; Paratype NYSM 6133; Hypotypes UCGM 46190, 46191, 46192, 46193, 46194-A, 46195, and 46196.

Table 30. Plate measurements in Linocrinus merope Hall (mm)

SPECIMEN		46190		46191		46192		46193		46194-A		6132**		6133	
plate		H	W	H	W	H	W	H	W	H	W	H	W	H	W
IBB	C	-	-	-	-	-	-	-	-	0.7	1.0	-	-	-	-
	D	-	-	-	-	-	-	-	-	0.6	1.0	-	-	-	-
	E	-	-	-	-	-	-	-	-	0.9	0.9	-	-	-	-
BB	AB	1.8	2.6	2.6	2.0*	-	-	2.1	2.1	1.3	2.1	1.7	1.8	1.5	2.2
	BC	2.0	2.6	2.7	3.1	1.8	1.8	2.0	2.4	1.5	2.0	1.6	2.2	-	-
	CD	-	-	2.7	2.8	1.8	2.1	2.2	2.0	2.0	2.1	1.9	1.5*	1.5	2.0
	DE	-	-	-	-	1.6	1.7	1.7	2.2	2.0	2.1	-	-	-	-
	EA	-	-	2.5	3.0	-	-	1.9	2.0	-	-	-	-	-	-
RR	A	-	-	2.4	4.6	-	-	1.9	2.8	1.5	2.8	-	-	1.3	-
	B	1.7	3.7	2.6	3.8	-	-	1.9	3.5	1.6	2.5	1.5	3.3	1.5	3.2
	C	-	-	2.0	4.8	1.4	2.9	1.5	3.4	1.4	1.4*	1.3	3.1	-	-
	D	-	-	2.5	4.3	1.4	3.0	1.7	2.8	1.5	2.9	-	-	-	-
	E	-	-	1.9	4.6	-	-	1.9	3.6	1.7	2.5	-	-	-	-
IBr	A	-	-	3.7	4.7	-	-	2.8	3.1	3.4	2.5	-	-	3.2	3.1
	B	3.0	3.7	4.2	3.7	-	-	3.0	3.4	2.9	2.9	2.7	3.0	2.8	3.4
	C	-	-	4.0	4.5	3.3	2.9	2.5	3.2	3.2	1.7*	3.0	3.1	3.0	2.9
	D	-	-	4.1	4.0	2.9	2.9	3.0	2.6	3.3	2.8	-	-	-	-
	E	-	-	3.9	4.6	-	-	2.9	3.9	2.9	2.0*	-	-	-	-
CUP		3.0	8.4	4.2	12.6	1.4	3.8	3.7	9.8	2.8	7.3	3.0	7.8	2.5	6.4
ARM L.		33.2		38.6		25.0		34.4		25.7		28.0		29.2	

KEY *designates measurement is incomplete due to view of exposure, or compression.

**denotes Holotype

DISCUSSION

Halls's Linocrinus paternus (NYSM 6133) is recognized as an immature somewhat distorted specimen of L. merope (Hall), and is herein considered a synonym. It primarily differs from the holotype of L. merope (NYSM 6132) in showing six, rather than three primibrachs in the anterior ray. I consider this feature within the limits of species variation; hypotype UCGM 46194-A shows five primibrachs in the anterior ray (Table 41). Additional features which differ, such as the specimen's slightly lower, bowl-shaped cup, and lack of pustulose-nodose ornament is largely a consequence of its oblique orientation on the slab with the cup partly hidden underneath its forward-facing arms, and immature condition. Hypotypes UCGM 46194-A and 46192 are similar to L. paternus (Paratype NYSM 6133) in their lower, bowl-shaped cup, and lack of pustulose-nodose ornament. Apparently, ornament developed late in ontogeny.

Linocrinus merope (Hall) most nearly resembles L. faculensis (Laudon, Parks, and Spreng) from the Banff Formtion of Alberta, Canada with its strongly keeled brachials, but differs in its pattern of cup ornament. In L. faculensis the dorsal cup has: "plates with sharp keel ridges, corners depressed". Development of pustulose-nodose ornament is not indicated (Laudon, Parks, and Spreng 1952, p. 55-56; Pl. 65, fig. 16 and Pl. 69, fig. 6).

Table 31. Variation of brachial number in <u>Linocrinus</u> <u>merope</u> Hall

Ray		L	A	R	L	B	R	L	C	R	L	D	R	L	E	R
Specimen no.																
UCGM 46190	P		3			1			1			-			-	
	S	10		-	8		10	7		8						
	T	12		-	10		10	-		10	-		-	-		-
	Q	-		-	-		-	-		-	-		-	-		-
UCGM 46191	P		3			1			-			-			-	
	S	8		14	-		6	-		-	-		-	6		6
	T	-		-	-		10	-		-	-		-	8		8
	Q	-		-	-		16	-		-	-		-	9		14
UCGM 46192	P		-			-			1			1			-	
	S							6		6*	6		6	-		-
	T	-		-	-		-	-		-	-		-	-		-
	Q	-		-	-		-	-		-	-		-	-		-
UCGM 46193	P		3			1			2			1			1	
	S	10		10	8		8	6		8	6		-	6		6
	T	-		-	8		7	8		8	8		-	10		8
	Q	-		-	-		-	12		-	-		-	10		10
UCGM 46194-A	P		5			1			1			1			1	
	S	-		-	-		6	6		-	6		6	6		6
	T	-		-	-		-	-		-	-		-	-		-
	Q	-		-	-		-	-		-	-		-	-		-
NYSM 6132	P		-			1			1			-			-	
	S	-		-	6		8	6		6	-		-	-		-
	T	-		-	10		10	10		10	-		-	-		-
	Q	-		-	-		-	-		-	-		-	-		-
NYSM 6133	P		6			1			-			-			-	
	S	12		10	-		-	-		-	-		-	-		-
	T	-		-	8		*5+	-		-	-		-	-		-
	Q	-		-	12		-	-		-	-		-	-		-

P - Primibrachs
S - Secundibrachs
T - Tertibrachs
Q - Quatribrachs

L - Left
R - Right

* - incomplete or uncertain

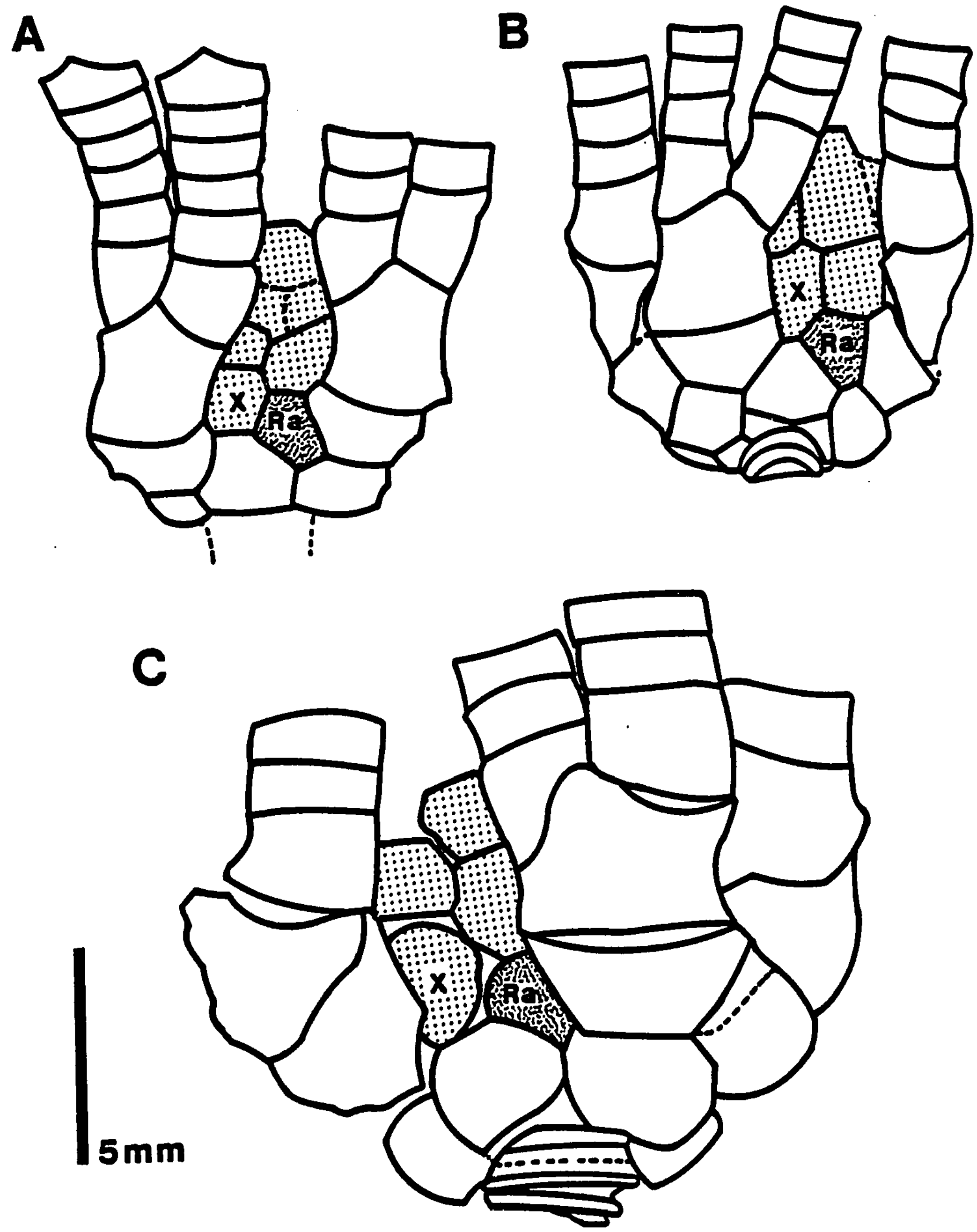
Text Figure 40. Linocrinus merope Hall. Cameras lucida drawings of three specimens showing CD interray.

A) Hypotype UCGM 46194-A; immature adult.

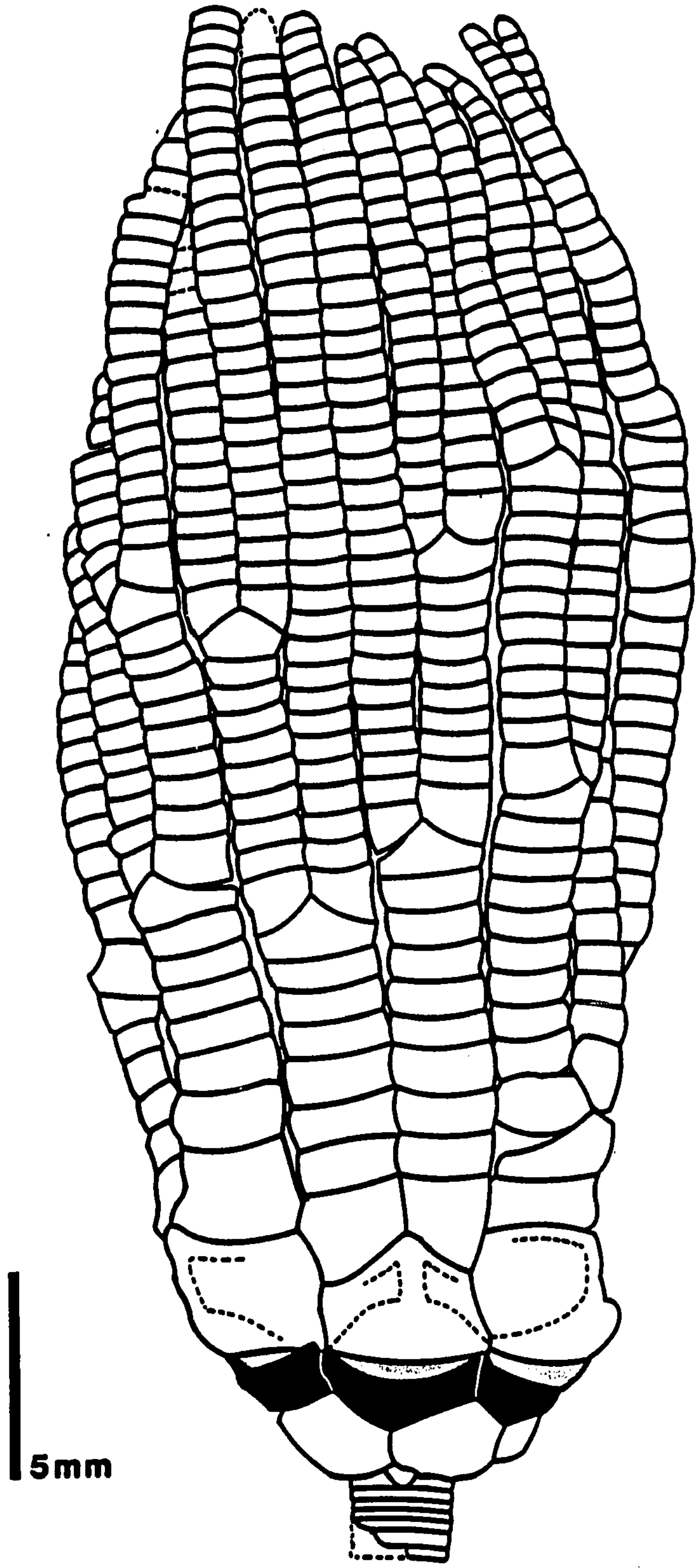
B) Hypotype UCGM 46192; immature adult. Note infrabasals visible in side view.

C) Hypotype UCGM 46191; mature adult (Pl. 12, fig. 4). Note descent of anal X into the cup, proportions of radianal and anal X in relation to basal and radial plates (diagrams A-C). Anals showing negative allometry.

Explanation: radianal (Ra) wrinkle stippled; anal X (X) and successive anals dot stippled.


A
B
X
Ra
C
5mm

Text Figure 41. <u>Linocrinus</u> <u>merope</u> Hall. Camera lucida drawing of Hypotype UCGM 46190; B ray view (Plate 12, fig. 3). Note endotomous arm branching, quadrangular brachials. Explanation: radials black; dashed line outlining nodose ornament of "keeled" first primibrach.


5mm

Subclass FLEXIBILIA Zittel, 1895

Analysis of flexible crinoids occurring at the excavated site could not be completed at this time. However, a list of fossil synonyms, and illustration of the holotypes and some additional specimens are provided for future reference (Plate 13, figs. 1-9).

Order TAXOCRINIDA Springer, 1913

Superfamily TAXOCRINACEA Angelin, 1878

Family TAXOCRINIDAE Angelin, 1878

Genus TAXOCRINUS Phillips, 1843

Taxocrinus communis Hall, 1863

Forbesiocrinus communis Hall, 1864, p. 55; preliminary notice 1863 p. 6. Hall and Whitfield, 1875, p. 169; Pl. 12, fig. 3.

Taxocrinus communis Meek and Worthen, 1865, p. 14-141; 1866, p.170. Wachsmuth and Springer, 1879, Pt. 1, 387; Pl. 52, figs. 1-4. Bassler and Moodey, 1943, p. 702.

Plate 13, figs. 2 and 3.

Taxocrinus kellogi Hall, 1863

Forbesiocrinus kellogi Hall, 1864, p. 56; preliminary notice 1863,

Forbesiocrinus kellogi	Hall, 1864, p. 56; preliminary notice 1863, p. 7. Hall and Whitfield, 1875, p. 171; Pl. 12, fig. 1.
Taxocrinus kellogi	Meek and Worthen, 1865, p. 140; 1866, p. 270 Wachsmuth and Springer, 1879, p.t 1, p. 49 (272). Springer, 1920, p. 388; Pl. 52, figs. 5a-c. Bassler and Moodey, 1943, p. 703.

Plate 13, fig. 4.

Order SAGENOCRINIDA Springer, 1913

Superfamily SAGENOCRINITACEA Roemer, 1854

Family SAGENOCRINITIDAE Roemer, 1854

Genus FORBESIOCRINUS De Koninck and Le Hon, 1854

Forbesiocrinus communis Hall, 1863

Forbesiocrinus communis	Hall, 1864, p. 55; preliminary notice 1863, p. 6. Hall and Whitfield, 1875, p. 169; Pl. 12, figs. 4 and 5 (not fig. 3 = _Taxocrinus communis_).
Taxocrinus communis	Meek and Worthen, 1865, p. 140. Wachsmuth and Springer, 1879, pt. 1, p. 48 (271).
Forbesiocrinus communis	Springer, 1920, p. 245-246; Pl. 20, figs 4-8 Bassler and Moodey, 1943, p. 479.

Plate 13, figs. 1, 5, and 9.

Family DACTYLOCRINIDAE Bather, 1899

Genus DACTYLOCRINUS Quenstedt, 1876

Dactylocrinus tardus Hall, 1863

Forbesiocrinus lobatus var. tardus Hall, 1864, p. 56; preliminary notice 1863, p. 7.

Forbesiocrinus tardus Hall and Whitfield, 1875, p. 170; Pl. 12, fig. 2.

Taxocrinus lobatus var. tardus Wachsmuth and Springer, 1879, pt. 1, p. 49.

Dactylocrinus tardus Springer, 1920, p. 307, 313; Pl. 41, fig. 11 Bassler and Moodey, 1943, p. 404.

Plate 13, figs. 7 and 8.

CONCLUSIONS

1) Analysis of camerate and indunate crinoid groups from the Meadville Member of the Cuyahoga Formation in northeastern Ohio reveal the occurrence of five species new to science: *Cyathocrinites exertus*, *Cyathocrinites simplex*, *Goniocrinus sceletus*, *Logocrinus martini*, and *Platycrinites burki*.

2) Six new combinations of genera are recongized: *Histocrinus aegina* (Hall), *Ascetocrinus subcarinatus* (Hall), *Paracosmetocrinus richfieldensis* (Worthen), *Paracosmetocrinus corycia* (Hall), *Pachylocrinus subtortuosus* (Hall), and *Linocrinus merope* (Hall).

3) Two inadunate species, *Hypselocrinus pleias* (Hall) and *Linocrinus paternus* (Hall) are herein considered synonyms: *Hypselocrinus pleias* (Hall) = *Paracosmetocrinus corycia* (Hall), and *Linocrinus paternus* (Hall) = *Linocrinus merope* (Hall).

4) Allometric analysis of three camerate species, *Aorocrinus helice* (Hall), *Cusacrinus daphne* (Hall), and *Platycrinites contritus* (Hall) showing ontogenetic varitaion reveal:

   a) developmental patterns to be largely consistent with Brower's (1974) findings for Patelliocrinid, Actinocrinid, and Platycrinid crinoid groups (Table 5);

   b) the combined influence of individual plate modifications in

Aorocrinus helice (Hall) resulted in the dorsal cup developing from conical to bowl-shaped;

c) in direct opposition, the combined influence of individual plate modifications in Cusacrinus daphne (Hall) resulted in the dorsal cup developing from bowl to conical-shaped;

d) in Platycrinites contritus (Hall) marked differences in allometry between basal and radial plates illustrate the inherent weakness of using basal/radial height ratios as a method for distinguishing species of Platycrinites;

e) all three camerate species show a strongly negative allometric response in growth for their final or "free" axillaries.

5) The crinoid community near Richfield, Ohio was numerically dominated by monobathrid camerates, and most diverse among poteriocrine inadunates. The greater divesity among inadunates forecasts subsequent evolutionary trends within crinoid communities of the Illinois basin during the Keokuk (Osage) and later Palerozoic, where poteriocrine inadunates became the dominant element in coarser clastic environmental settings.

6) Crinoids found at the site near Richfield, Ohio can be divided into two categories based upon their mode of feeding. Camerates and pinnulate and non-pinnulate inadunates were rheophilic (current-seeking), forming parabolic and planar filtration fans directed into the prevailing currents. Flexible crinoids were raptorial, capable of direct

food capture.

7) Composition of the Waverly crinoid fauna correlates closely with Lower Mississippian crinoid faunas from the Lodgepole and Banff Formations of the Western Interior, and the Wassonville Limestone (Hampton Fm.) and the Lower Burlington Limestone of the Mississippi Valley region, which would indicate that it is late Kinderhookian to early Osagian in age. Nonendemic genera most indicative of a pre-Keokuk age include the camerates, Aorocrinus, Cusacrinus, and Amphoracrinus, and the inadunates, Logocrinus and Paracosmetocrinus.

8) The crinoid community flourished on an upper prodeltaic, or distal bar facies, in warm, well-oxygenated, tropical waters of intermediate depth above storm wave base within the Ohio Mississippian marine embayment. The local paleoenvironment was subject to periodic, often rapid changes in sedimentation, and localized anoxic conditions produced by the decomposition of organic matter. The well-preserved crinoid biocoenose is thought to have resulted from the catastrophic burial of organisms by a small-scale or low velocity turbidity flow which may have been storm generated.

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PLATE 1 <u>AOROCRINUS</u> <u>HELICE</u> (HALL)

Growth Sequence in *Aorocrinus helice* (Hall) Text Figs. 1-3.

1) Hypotype UCGM 46059, B ray view of immature juvenile. Primaxil of B ray showing evidence of growth by intercalation. Magnification X 2.3

2) Hypotype UCGM 46061-D, B ray view of young adult. Note: expansion of interbrachial plates; early development of nodose ornament. Magnification X 2.3

3) Hypotype UCGM 46055, A ray view of adult. Magnification X 2.3

4) Hypotype UCGM 46098, B ray view of ornate individual from Lodi, Ohio. Magnification X 2.0

5) Wachsmuth and Springer's (1897) figured specimen showing tegmen with elongate spine (Pl. XLV, Fig. 5). Magnification approx. X 2.0

6) Hypotype 46062, Aboral view of individual upon which plate diagram was primarily based. Magnification X 2.0

7) Syntype NYSM 6118, D ray view. Hall's variety 'eris'. Magnification X 2.0

8) Hypotype UCGM 46063, B ray view of variety known as 'eris'. Magnification X 2.0

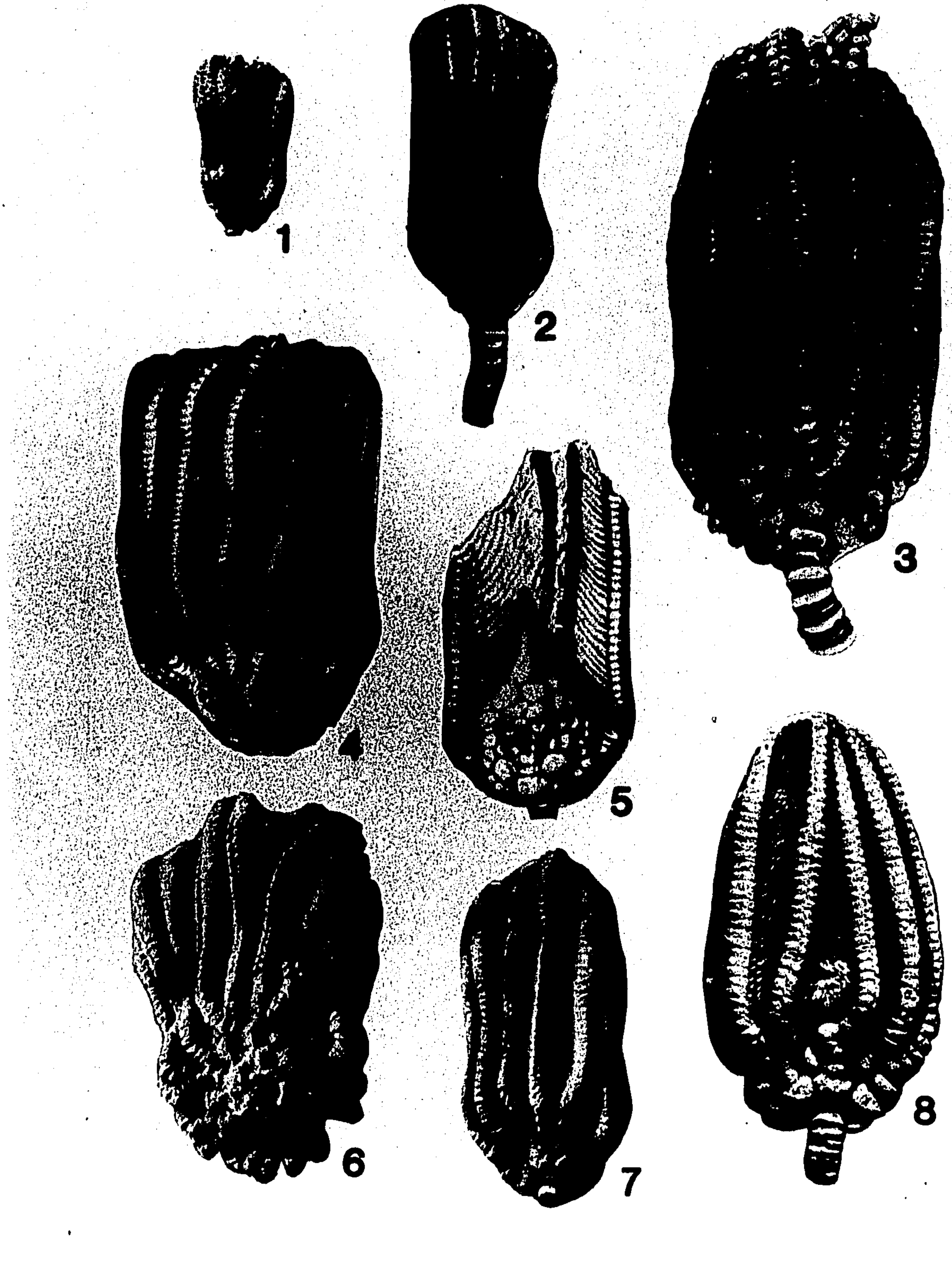
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PLATE 2 AOROCRINUS HELICE (HALL) - ARM FEATURES

1) Hypotype UCGM 46089, C ray view. Possible (?) reproductive arm regeneration. Note smaller size of arms in foreground. Magnification X 2.0

2) Hypotype UCGM 46081-B, CD interray view. Augmentative arm regeneration. Magnification X 2.0

3) Hypotype UCGM 46081-B, close view of arm showing arm regeneration in figure 2. Magnification X 6.0

4) Hypotype UCGM 46058, examination of arm brachials. Note the progressive development of nodes and ridges distally along arms. Magnification X 4.0

5) Hypotype UCGM 46081-B, C ray view. Reproductive arm regeneration. Magnification X 2.0

6) Hypotype UCGM 46057, A ray view. Augmentative arm regeneration. Magnification X 2.0

7) Syntype NYSM 6119, C ray view. Note "mushroomed" appearance produced by distal infolding of arms. Magnification X 2.0

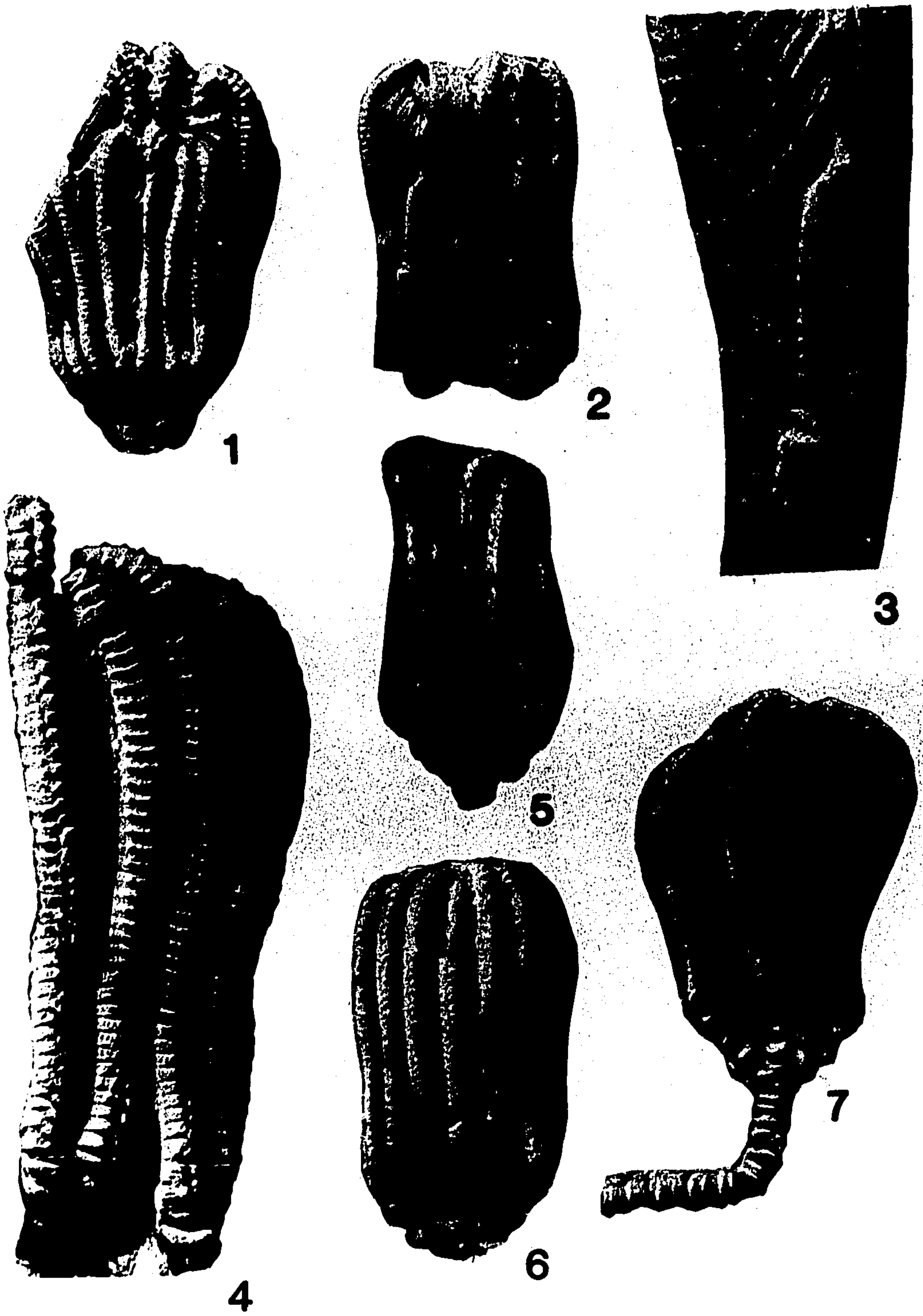
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PLATE 3 CUSACRINUS DAPHNE (HALL)

1) Hypotype UCGM 46104, D ray view of pyritized specimen. Although calyx was replaced by pyrite, arms remained calcitic. Magnification X 1.5

2) Aboral view of above specimen. Note three dimensional form of calyx, a rare occurrence in this species. Magnification X 1.5

3) Hypotype UCGM 46108, D ray view of specimen with deflected anal tube. Magnification X 2.0

4) Hypotype UCGM 46111, specimen with Platyceras (gastropod) attachment directly over tegmen. Magnification X 1.5

5) Hypotype UCGM 46116, small specimen with Platyceras (gastropod) attachment. Magnification X 2.0

6) Hypotype UCGM 46105-A, immature specimen used in growth series analysis. Magnification X 2.0

7) Holotype NYSM 6115. Magnification X 1.0

8) Hypotype UCGM 46120, nearly complete, immature specimen with very diminutive calyx and slender arms. Constrast this with figures 1 and 2 of Plate 4. Magnification X 1.0

9) Hypotype UCGM 46121, young adult showing distinctive features of heteromorphic column. Magnification X 1.0

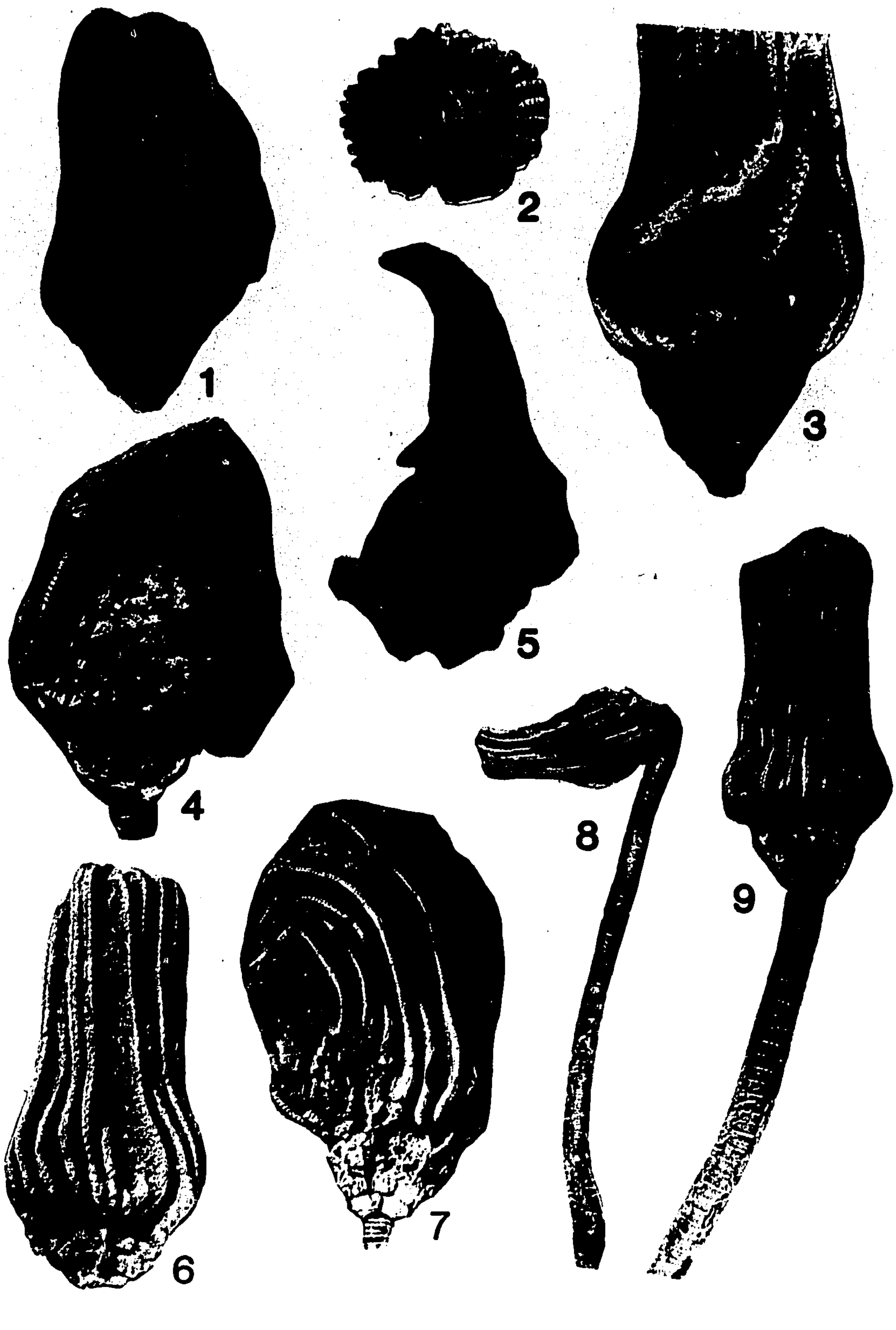
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PLATE 4 CAMERATES

1) Cusacrinus daphne (Hall); Hypotype UCGM 46103, B ray view. Magnification X 1.5

2) Cusacrinus daphne (Hall); Hypotype UCGM 46106. Magnification X 1.0

3) Platycrinites burki (sp. nov.); Holotype UCGM 46144, D ray view (right). Magnification 1.5

4) Platycrinites contritus (Hall); Hypotype UCGM 46149, immature specimen showing cuneate arm brachials and low basal circlet. Smallest individual measured for growth analysis. Magnification X 3.0

5) Platycrinites burki (sp. nov.); Paratype UCGM 46061-G, incomplete specimen. Magnification X 1.5

6) Platycrinites lodensis (Hall and Whitfield); Hypotype UCGM 46143, A ray view (right). Magnification X 1.5

7) Cusacrinus daphne (Hall); Hypotype UCGM 46106, arm details. Magnification X 4.0


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PLATE 5 CAMERATES

1) Amphoracrinus viminalis (Hall); Hypotype UCGM 46134, E ray view of specimen showing tegmen. Note domed orals, large CD oral with short spine, and vermiculate ornament. Magnification X 4.0

2) Amphoracrinus viminalis (Hall); Hypotype UCGM 46137, prior to removal of fractured rock - (see fig. 4). Magnification X 1.5

3) Aorocrinus helice (Hall); Hypotype UCGM 46082-A, E ray view of individual complete with crown, column, and distal radix holdfast. Magnification X 1.0

4) Amphoracrinus viminalis (Hall); Hypotype UCGM 46137, after rock fragment removed. Ventral surface shows Platyceras resting directly over tegmen. Magnification X 1.5

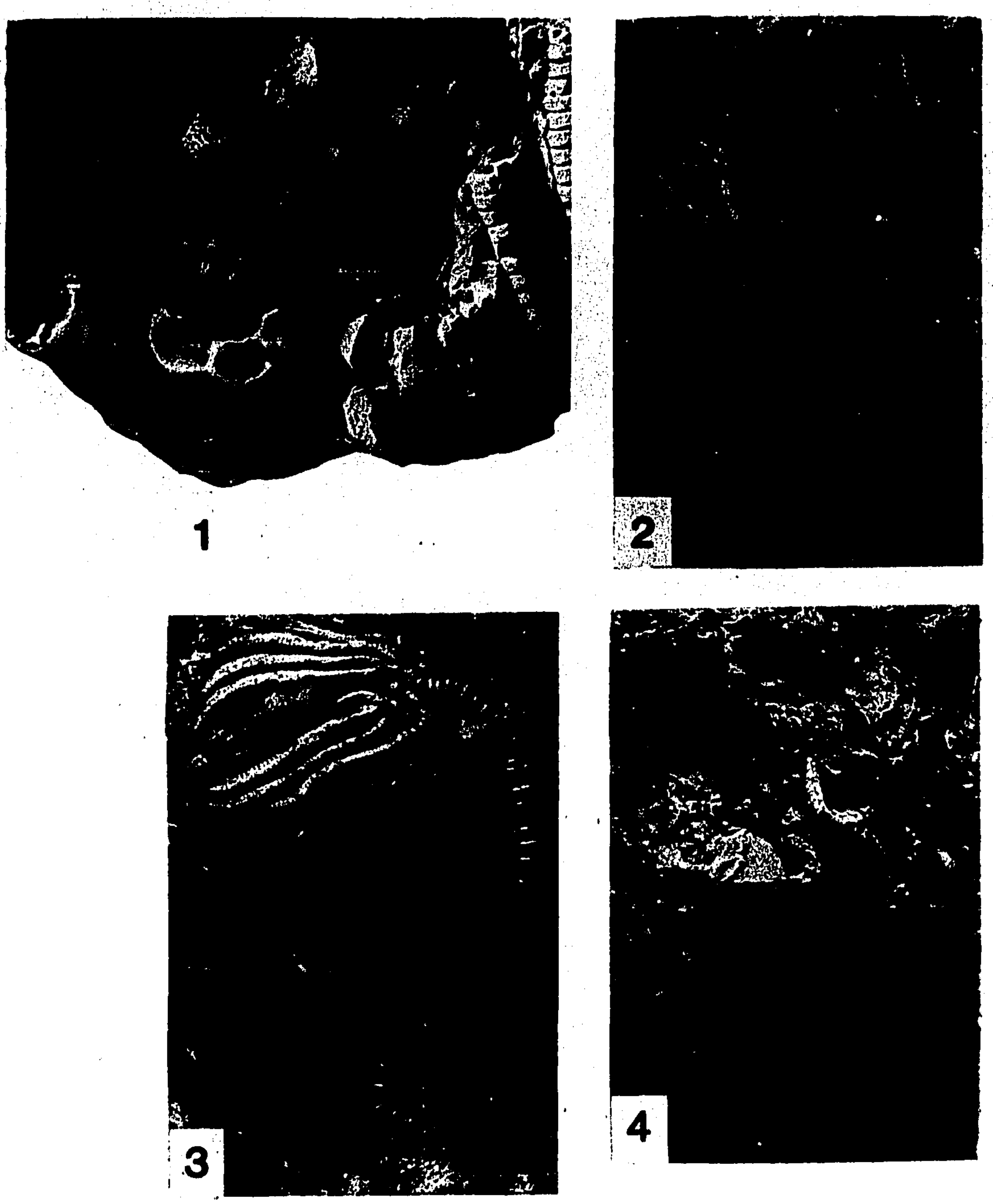
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PLATE 6 AMPHORACRINUS VIMINALIS (HALL)

1) Hypotype UCGM 46131, A ray view. Platyceras lying along distal arm tips, gastropod may have been dislodged from crinoid during burial event. Magnification X 1.5
2) Hypotype UCGM 46130, EA interray view. Magnification X 1.5
3) Hypotype UCGM 46132, A ray view of individual with moderate arm damage, but otherwise well preserved. Note quadranglar PBr , outward directed arm bases, and vermiculate ornament. Magnification X 2.0

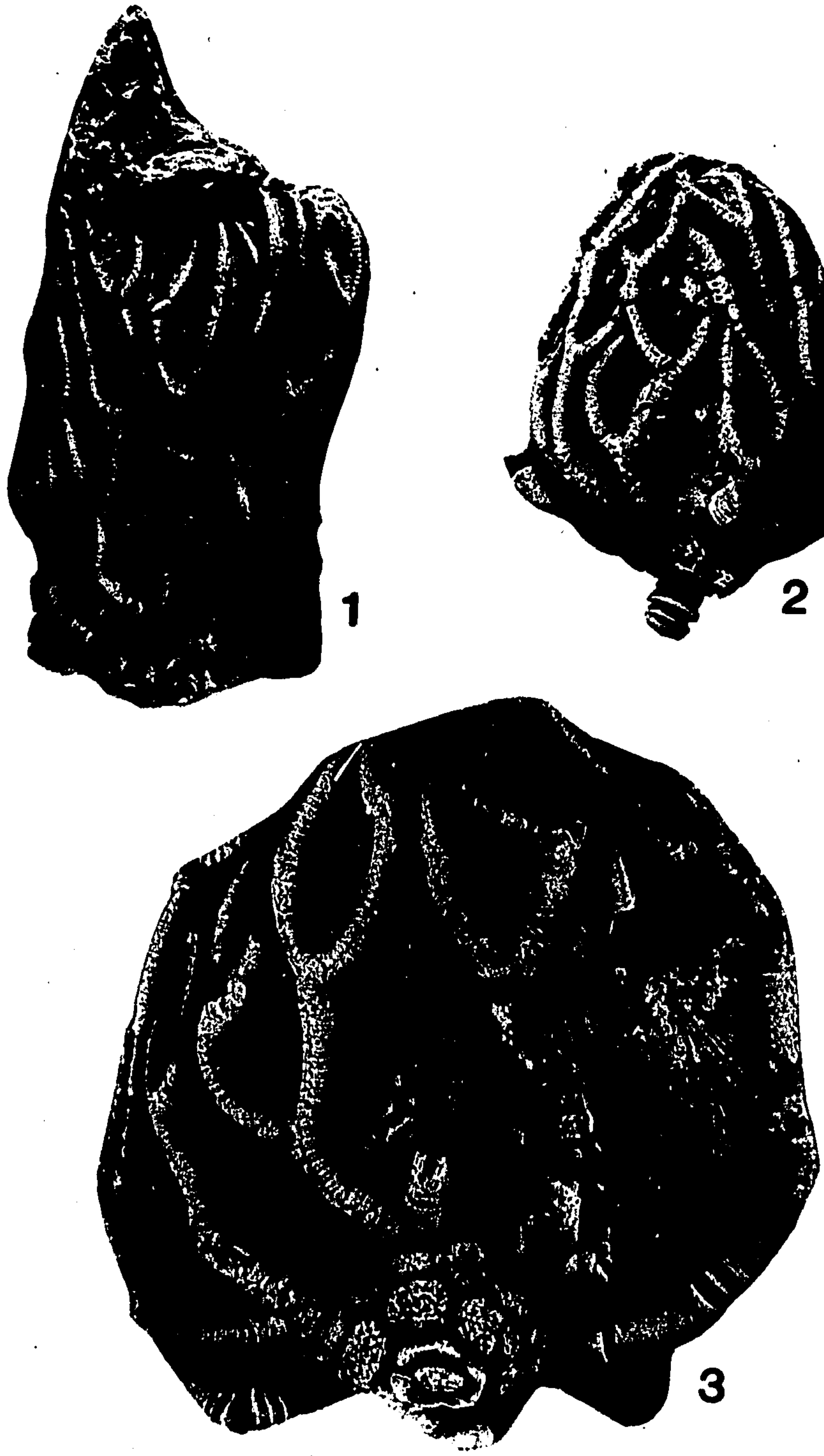
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PLATE 7 PLATYCRINITES

1) *Platycrinites contritus* (Hall); Holotype NYSM 6134. Magnification X 1.25

2) *Platycrinites graphicus* (Hall); Holotype NYSM 6135. Magnification X 1.0

3) *Platycrinites graphicus* (Hall); Hypotype UCGM 46136-C, BC interray (?) view. Magnification X 1.5

4) *Platycrinites contritus* (Hall); Hypotype UCGM 46146, CD interray view. Magnification X 1.15

5) *Platycrinites contritus* (Hall); Hypotype UCGM 46152-A, CD interray view. Magnification X 1.25

6) *Platycrinites contritus* (Hall); Hypotype UCGM 46145, showing features characteristic of the species, i.e., cup shaped calyx, moderately robust arms, and well developed flange over column base. Magnification X 1.5

7) *Platycrinites graphicus* (Hall); Hypotype UCGM 46147-A, radix holdfast of column. Magnification X 4.0

8) *Platycrinites graphicus* (Hall); Hypotype UCGM 46147-A, relatively complete individual showing crown, column, and distal radix (see fig. 7). Magnification X 1.0

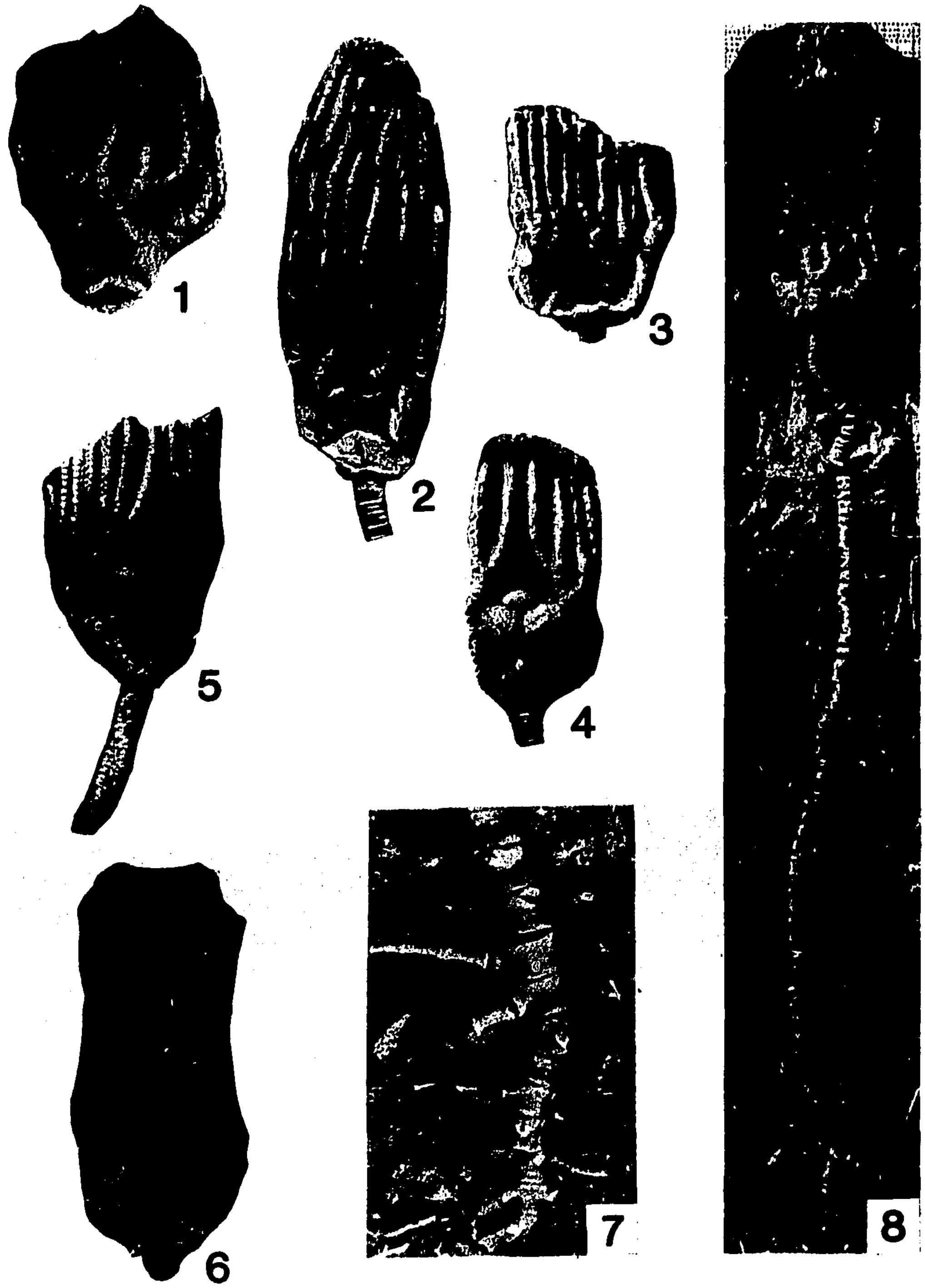
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PLATE 8 INADUNATES

CYATHOCRINITES EXERTUS (SP. NOV.) - FIGURES 1-4

1) Holotype UCGM 46158, showing ornate fatures characteristic of species. Magnification X 3.0

2) Same as above, enlarged view of dorsal cup. Magnification X 6.0

3) Paratype UCGM 46157, E ray view. Note protuberant anal sac. Magnification X 2.0

4) Paratype UCGM 46156, DE interray view. Magnification X 2.5

GONIOCRINUS SCELETUS (SP NOV.) - FIGURES 5-6

5) Holotype UCGM 46161, AB interray view. Anal series extend to distal arm tip adjacent to B ray. Helical coiling of anals suggested. Magnification X 4.0

6) Same as above, AB interray view showing column and cirri. Magnification X 2.0

CYATHOCRINITES SIMPLEX (SP. NOV.) - FIGURES 7-8

7) Holotype UCGM 46159, D ray view. Magnification X 2.0

8) Paratype UCGM 46160, incomplete specimen from Lodi, Ohio. Note lack of ridge development in cup and arms. Magnification X 2.0

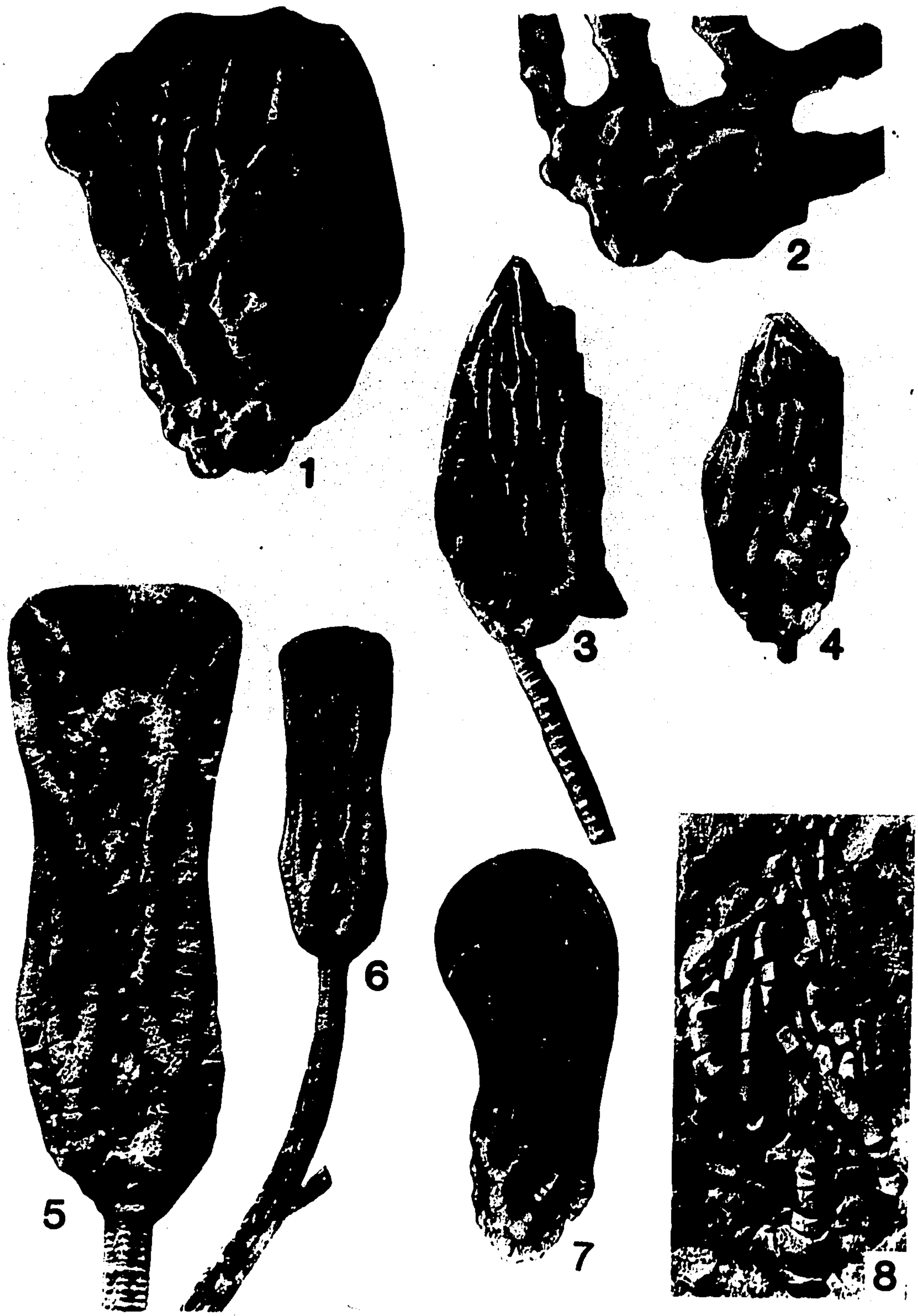
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PLATE 9 INADUNATES

LOGOCRINUS MARTINI (SP NOV.) - FIGURES 1-4

1) Paratype UCGM 46166. Magnification X 2.0

2) Holotype UCGM 46165, showing trapezoidal first and second primibrachs, and traces of long slender anal sac. Magnification X 2.0

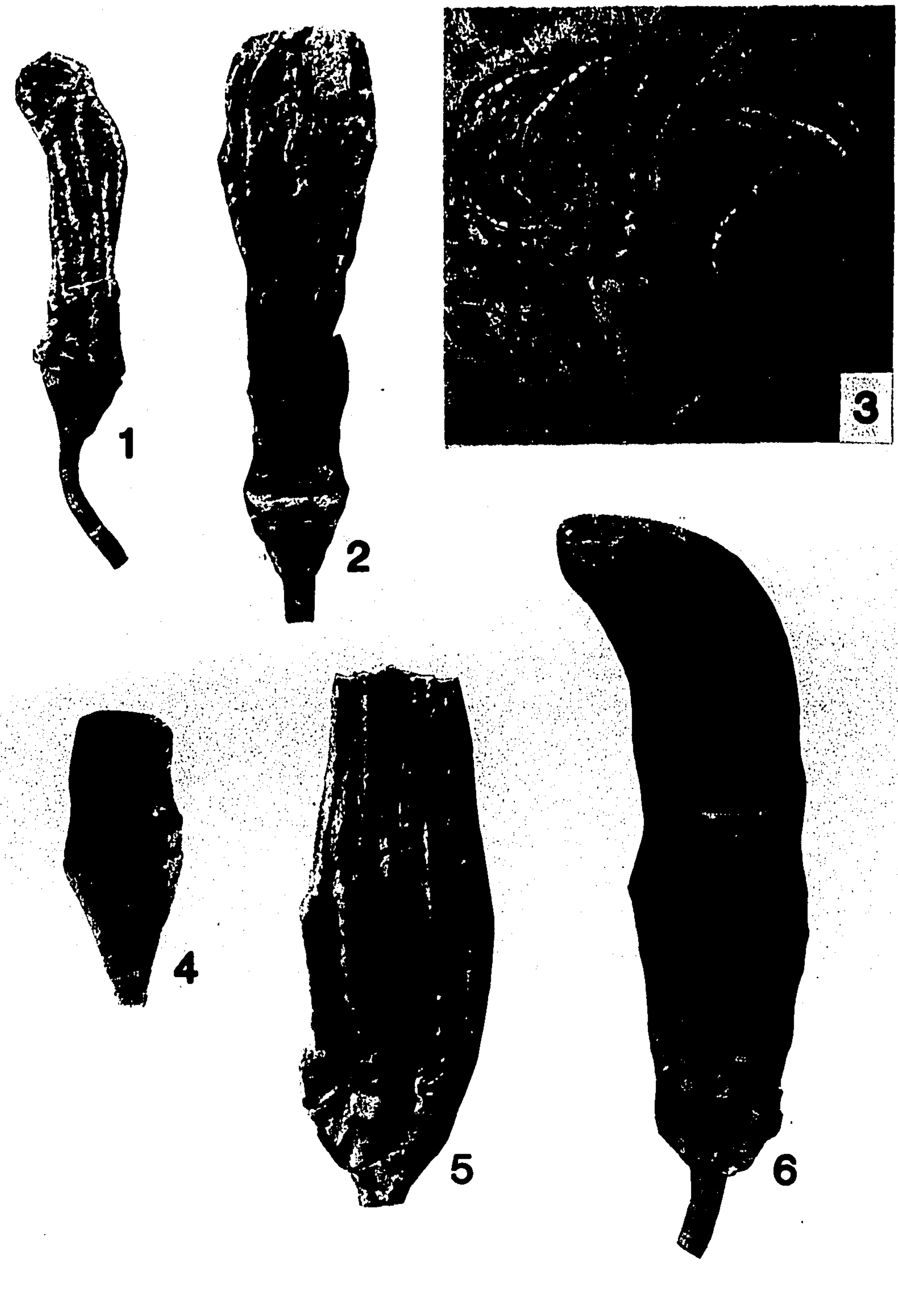
3) Paratype UCGM 46162. Magnification X 2.0

4) Paratype UCGM 46164, CD interray view. Magnification X 2.5

COSMETOCRINUS CRINEUS (HALL) - FIGURES 5-6

5) Holotype NYSM 6137, E ray view. Magnification X 1.5

6) Hypotype UCGM 46182. Magnification X 1.5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10 INADUNATES

PARACOSMETOCRINUS RICHFIELDENSIS (WORTHEN) FIGURES 1-5 *10-11

1) Hypotype UCGM 46176, A ray view. Note mid-length arm divisions and atomous A ray. Magnification X 2.5

2) Hypotype UCGM 46178, A ray view. Magnification X 2.5

3) Hypotype UCGM 46175-A, A ray view. Note bowl shape cup. Magnification X 2.5

4) Hypotype UCGM 46177, A ray view of specimen showing nodule of pyrite along arms. Magnification X 2.5

5) Hypotype UCGM 46179, A ray view. Magnification X 2.5

HISTOCRINUS AEGINA (HALL) FIGURES 6-9

6) Syntype NYSM 6121, D ray view. Magnification X 2.0

7) Hypotype UCGM 46169, C ray view. Note stellate plate ornament and comblike pinnules standing stifly outward from arms. Magnification X 2.0

8) Hypotype UCGM 46168, C ray view (see Text figure). Magnification X 2.0

9) Syntype NYSM 6122, B ray view. Magnification X 2.0

*———

10) Hypotype UCGM 46176, CD interray view. Magnification X 5.0

11) Hypotype UCGM 46179, CD interray view. Magnification X 5.0


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PLATE 11 INADUNATES

ASCETOCRINUS SUBCARINATUS (HALL) FIGURES 1-4

1) Hypotype UCGM 46147-B; note angulate arm brachials and flutted dorsal cup plates. Anal sac spines occur along distal portion of arm damaged region. Magnification X 2.0
2) Syntype NYSM 6139. Magnification X 2.0
3) Hypotype UCGM 46173, DE interray view. Infrabasals clearly visible in side view, PBr_1 tall, and doral cup plated flutted. Magnification X 3.0
4) Syntype NYSM 6140, showing ornate features of cup and arms. Magnification X 2.0

PACHYLOCRINUS SUBTORTUOSUS (HALL) FIGURES 5-6

5) Holotype NYSM 6125, incomplete specimen not showing additional arm divisions above PBr . Magnification X 1.5
6) Hypotype UCGM 46183, CD interray view. Magnification X 1.5


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PLATE 12 INADUNATES

<u>LINOCRINUS</u> <u>MEROPE</u> (HALL)

1) Hypotype UCGM 46191, A ray view. Magnification X 2.0

2) Paratype NYSM 6133, E ray (?) view. Synonym - <u>L</u>. <u>paternus</u> (Hall) = <u>Linocrinus</u> <u>merope</u> (Hall). Magnification X 1.75

3) Hypotype UCGM 46190, B ray view (Text Figure). Magnification X 1.75

4) Hypotype UCGM 46191, CD interray view showing details of cup ornament. Magnification X 2.25

5) Holotype NYSM 6132, C ray view. Magnification X 1.75

<u>PARACOSMETOCRINUS</u> <u>CORYCIA</u> (HALL)

6) Paratype NYSM 6124, CD interray view. Synonym <u>Hypselocrinus</u> <u>pleias</u> (Hall) = <u>Paracosmetocrinus</u> <u>corycia</u> (Hall). Magnification X 2.5

7) Holotype NYSM 6138, A ray view. Magnification X 2.5

<u>ACYLOCRINUS</u> <u>LYRIOPE</u> (HALL)

8) Holotype NYSM 6123. Magnification X 1.5

9) Hypotype UCGM 46187, D ray view showing single anal in cup and basal depression concealing infrabasals. Magnification X 2.0

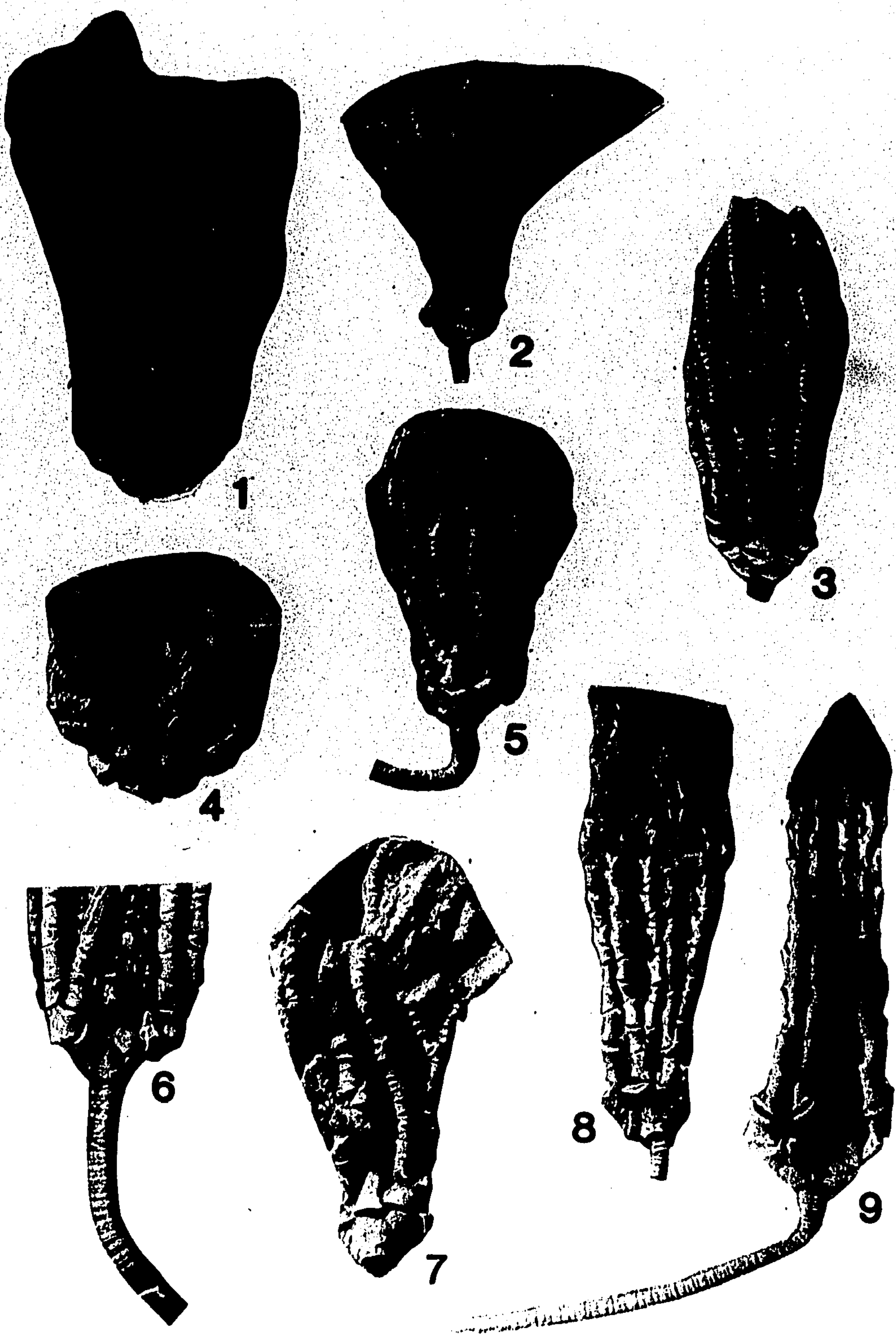
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PLATE 13 FLEXIBLES

1) Forbesiocrinus communis (Hall); Hypotype UCGM 46206, magnification X 1.5

2) Taxocrinus communis (Springer); Holotype NYSM 6141, magnification X 1.5

3) Taxocrinus communis (Springer); Hypotype UCGM 46219, magnification X 1.5

4) Taxocrinus kellogi (Hall); Holotype NYSM 6144, magnification X 1.5

5) Forbesiocrinus communis (Hall); Syntype NYSM 6142, magnification X 1.25

6) Dactylocrinus tardus (Hall); Holotype NYSM 6145, magnification X 1.5

7) Dactylocrinus tardus (Hall); Hypotype UCGM 46204, immature specimen. Magnification X 3.0

8) Dactylocrinus tardus (Hall); Hypotype UCGM 46200, magnification X 1.5

9) Forbesiocrinus communis (Hall); Syntype NYSM 6143, magnification X 1.5


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APPENDIX I

Measured section along a tributary creek of Furnace Run located in the N ½ of Richfield township: T4N, R12W; 66, 250 m. N and 46.300 m. E (unit 31). Measurement begins at 993 feet elevation (point "A", Fig. 1) directly SW of the intersection of Brush road and State Route 21.

UNIT		FEET	METERS
33	Sandy siltstone, medium light bluish gray (5B-6/1) to pale yellowish brown (10 YR-6/2), with fine parallel laminations. Sharp contacts (sample no. R5-25, 26).	3.7	1.13
32	Siltstone intercalated with thin shale beds. Siltstone, medium light bluish gray (5B-6/1) or pale to dark yellowish brown (10YR-6/2 to 10YR 4/2), with fine parallel and low cross laminations. Shale, medium light gray to dark gray (N6-N4), containing ellipsoidal claystone concretions. Unit fossiliferous along lower one-third. Abundant plate debris. Pyrite (sample nos. RS-22, 24).	6.3	1.92
31	Shale with lenticular siltstone. Siltstone, medium light bluish gray (5B-6/1), pale to dark yellowish brown (10YR-6/2 to 4/2), and light grayish red (10R-5/2) [color dependent upon localized influences of cementation], laterally discontinuous, with sharp lower and upper contacts. Shale, medium light gray to dark gray (N6-N4), with some ellipsoidal claystone concretions. Shale most abundant near base of unit, and decreases upward. Diverse marine fauna occurring in both shales and siltstone, i.e., brachiopods, pelecypods, crinoids, fenestrate bryozoans, sponges, conularids, fish and cephalopods. Abundant plant debris. Pyrite.	5.6	1.71
30	Sandy siltstone, pale yellowish brown (10YR-6/4) to dark yellowish brown (10YR-4/1), with barely visible fine parallel laminations, claystone concretions. Oscillation ripple marks. Fenestrate bryozoans. (Sample nos. RS-20, 21).	3.6	1.10
29	Siltstone intercalated with thin shale beds; clastic ratio of silt/shale about 2:1. Siltstone, medium light bluish gray (5B-6/1) to light olive gray (5Y-6/1), with fine parallel	4.4	1.34

UNIT		FEET	METERS
	and low cross laminations. Shale, medium light to dark gray (N6-N4), with some ellipsoidal claystone concretions. Fossiliferous, containing brachiopods: Cupularostum, Torynifer (?), Ericiatia, and Unispirifer; fenestrate bryozoan: Fenestella, and other fossils. (Sample nos. RS-17, 18, 19).		
28	Sandy siltstone, light olive gray (5Y-7/1-6/1), with faint, barely visible, fine parallel laminations. Fluted bed near small waterfall. Sharp upper and lower contacts.	4.1	1.25
27	Shale, medium light to dark gray (N6-N4), silty, finely micaceous. Unit forms abutment of bridge. (Sample nos. RS-14, 15).	1.6	0.49
26	Siltstone, medium light bluish gray (5B-6/1), with fine, regular, parallel laminations. Parting 'flaggy'. Fossiliferous, locally containing brachiopods and pelecypods. (Sample no. RS-13).	2.3	0.70
25	Sandy siltstone, yellowish gray (5Y-7/2), with fine parallel and cross laminations in part, or massive. Ichnofossil Zoophycos collected loose in float. Brachiopods: Unispirifer, Athyris, and Ericiatia. (Sample no. RS-12).	7.5	2.29
24	Covered interval.	2.6	0.79
23	Siltstone, medium light gray to dark gray (N6-N3), bioturbated, but with fine parallel laminations in part. Endichnial ichnofossil Helminthoida. Bivalve: Grammysia. (Sample no. RS-11, RSF-4).	0.8	0.24
22	Shale with thin intercalated siltstone beds. Siltstone medium light bluish gray (5B-6/1), laterally discontinuous. Shale, medium light gray to medium dark gray (N6-N4). Fenestrate bryozoan: Fenestella; brachiopod: Ericiatia.	1.2	0.37
21	Siltstone, pale yellowish brown (10YR-6/2), medium brownish gray (5YR-5/1), and medium gray (N4). Bedding irregular. Fossiliferous, containing crinoid columns and brachiopods; columnals on upper surface exhibit bimodal fabric (Appendix II). (Sample no. RS-10).	0.4	0.12

UNIT		FEET	METERS
20	Shale, medium light bluish gray (5B-6/1), finely micaceous, silty. Fenestrate bryozoan: Fenestella; ichnofossil Planolites and/or Paleophycus. (Sample no. RS-9).	0.4	0.12
19	Covered interval.	7.8	2.38
18	Siltstone, medium gray to medium dark gray (N5-N4), massive, with irregular-wavy bedding. Ichnofossil Paleophycus(?) on lower surface. Unit poorly exposed.	0.5	0.15
17	Shale intercalated with thin siltstone beds. Siltstone, medium light bluish gray (5B-6/1), with fine parallel laminations, and irregular shale partings; laterally discontinuous. Shale, medium light to dark gray (N6-N), silty, finely micaceous, with ellipsoidal sideritic claystone concretions. Ichnofossil Planolites and/or Paleophycus. (Sample no. RS-8).	1.5	0.46
16	Siltstone with ironstone horizons. Siltstone, medium light bluish gray (5B-6/1), with fine parallel and low cross laminations. Bedding locally bioturbated; ichnofossils Arenicolites, Planolites and/or Paleophycus. Ironstone, medium brownish gray (5YR-5/1 to 4/1), massive. Invertebrates include: unknown bivalve genera, and gastropod Straparollus(?). (Sample nos. RSF-3, RS-7).	0.4	0.12
15	Shale, intercalated with thin siltstone beds. Siltstone, medium light bluish gray (5B-6/1), with fine cross laminations, laterally discontinuous. Oscillation ripple marks. Ichnofossil: Planolites. Shale medium light gray to dark gray (N6-N4). (Sample no. RS-6).	1.1	0.34
14	Siltstone with ironstone horizons. Siltstone, light bluish gray (5B-5/1) to dark gray (N3), with fine parallel laminations. Ironstone, dark yellowish brown (10YR-4/2) to lgith brownish gray (5YR-6/2), with small black (N1) pyritic flecks. Crinoidal debris. (Sample nos. RS-5, 6).	0.4	0.12
13	Shale intercalated with thin siltstone beds. Siltstone, medium light bluish gray (5B-6/1), miceaceous. Shale, medium light to dark gray (N6-N4).	3.0	0.91

UNIT		FEET	METERS
12	Siltstone, light olive gray (5Y-6/1), micaceous, with fine parallel laminations.	0.3	0.09
11	Covered interval	8.9	2.71
10	Shale, medium light bluish gray (5B-6/1), finely micaceous. Poor exposure.	1.1	0.34
9	Covered interval.	2.0	0.61
8	Siltstone, medium to dark gray (N5-N3), with irregular layers and pods of light to medium light gray (N8-N6). Bioturbated. Ichnofossil *Paleophycus* and/or *Planolites*. Invertebrates include pelecypod *Edmondia* and brachiopod *Unispirifer*. Unit together with underlying shale forms small one foot waterfall. (Samples RS-3, RSF-1).	0.6	0.18
7	Shale, medium light bluish gray (5B-6/1), with small (2 cm<) claystone pebbles.	1.0	0.30
6	Siltstone, medium light bluish gray (5B-6/1), with fine subjparallel shale partings in upper one-third of bed. Lower portion faintly laminated. (Sample RS-2).	0.3	0.09
5	Shale, medium light bluish gray (5B-6/1) to medium gray (N5), silty, with small (2 cm<) claystone pebbles.	0.5	0.15
4	Siltstone, medium light bluish gray (5B-6/1), with irregular shale partings in lower half; upper half faintly laminated. (Sample RS-1).	0.3	0.09
3	Covered interval.	4.6	1.40
2	Shale, medium light bluish gray (5B-6/1) to medium gray (N5), weathered. Unit poorly exposed.	3.1	0.94
1	Covered interval.	10.5	3.20
	TOTAL THICKNESS MEASURED =	92.4 feet	28.15 meters

APPENDIX II. Orientation of crinoid columns in unit 21

1) N45°W	6) N20°E
2) N70°W	7) N21°E
3) N35°W	8) N10°E
4) N25°W	9) N18°E
5) N10°W	10) N35°E

APPENDIX III. Orientation of rippled surfaces on siltstone beds below Ledge Lake Park, Hinkley reservation, Medina County [T4N, R13W - 61,530 m.N and 39,200 m.E].

1) N30°W, λ = 11.0 cm, a = 1.0 cm
2) N60°W, λ = 9.0 cm, a = 0.5 cm
3) N80°W, λ = 7.5 cm, a = 0.7 cm
4) N55°W, λ = 8.0 cm, a = 0.5 cm
5) N35°W, λ = 6.5 cm, a = 0.5 cm
6) N35°W, λ = 6.0 cm, a = 0.4 cm
7) N40°E, λ = 6.0 cm, a = 0.4 cm
8) N40°W, λ = 6.0 cm, a = 0.4 cm
9) N 5°E, λ = 11.0 cm, a = 0.8 cm
10) N10°W, λ = 7.5 cm, a = 0.5 cm
11) N10°E, λ = 10.0 cm, a = 0.9 cm