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Early Pennsylvanian Crinoids from the South-Central Wasatch Mountains of Central Utah*

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ABSTRACT.—The lower Pennsylvanian part of the Oquirrh Formation within Sections 27, 33, and 34, T. 5 S., R. 3 E., Utah County, Utah, contains a diverse crinoid fauna. Specimens occur in a rhythmic sequence composed of alternating limestone and shaly limestone. Articulated specimens are found on the upper surface of mounds composed of limestone buried by the more shaly strata.

Three species of *Hypselocrinus* Kirk, *H. defendus* n. sp., *H.* (?) *cavus* n. sp., and *H.* (?) *superus* n. sp.; two species of *Cymbiocrinus* Strimple, *C. anatonus* n. sp. and *C. secundus* n. sp; two species of *Delocrinus* Miller and Gurley, *D.* cf. *D. mathert* Moore and Plummer, *D.* aff. *D. subhemisphericus* Moore and Plummer; a species of *Aesiocrinus*, *A. secundus* n. sp; a species of *Globocrinus* n. genus, *G. bulbus* n. sp.; a species of *Synarmocrinus* Lane, *S. depressus* n. sp.; and one species of *Phanocrinus* Kirk, *P. vadosus* n. sp. are described and figured. Twenty-two specimens have been found representing eleven species.

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INTRODUCTION

Purpose

The study is undertaken as a systematic paleontologic description of the Crinoidea found in the Morrowan Oquirrh strata along the Provo River in eastern Utah County, Utah. Pennsylvanian crinoid studies west of the Rocky Mountains are very limited. This study will aid in filling this information gap.

Location

Crinoidea crowns and dorsal cups described in the study were collected from three sites in the Bridal Veil Falls Member of the Oquirrh Formation where it is exposed along the walls of Provo Canyon, in eastern Utah County, Utah. All three localities are within two miles of each other in the Bridal Veil Falls quadrangle (Text-fig. 1).

Locality one occurs along the Bridal Veil Falls Trail, near Bridal Veil Falls, in the northeast corner of SE$\frac{1}{4}$, Section 33, T. 5 S., R. 3 E. This site yielded two float specimens of *Hypselocrinus secundus* n.sp. Locality two is 100 yards south of the Flume Aqueduct intake, south across Provo River opposite Slide Canyon in the NW$\frac{1}{4}$, Section 34, T. 5 S., R. 3 E. The only articulated specimen of *Delocrinus* aff. *D. subhemisphericus* Moore and Plummer was collected as float from the base of a small ledge exposed at this locality. Locality three occurs on the ridge west of Slide Canyon, northwest across the river from locality two, at the southeast corner of SE$\frac{1}{4}$, Section 27, T. 5 S., R. 3 E. All of the specimens considered in this study except those listed above were collected at this locality.

Previous Work

The Oquirrh Formation was named by Gilluly (1932) from outcrops twenty miles northwest of Provo, Utah, in the Oquirrh Mountains. Previously, Spurr (1894) had designated the sequence as the Upper Intercalated Series.

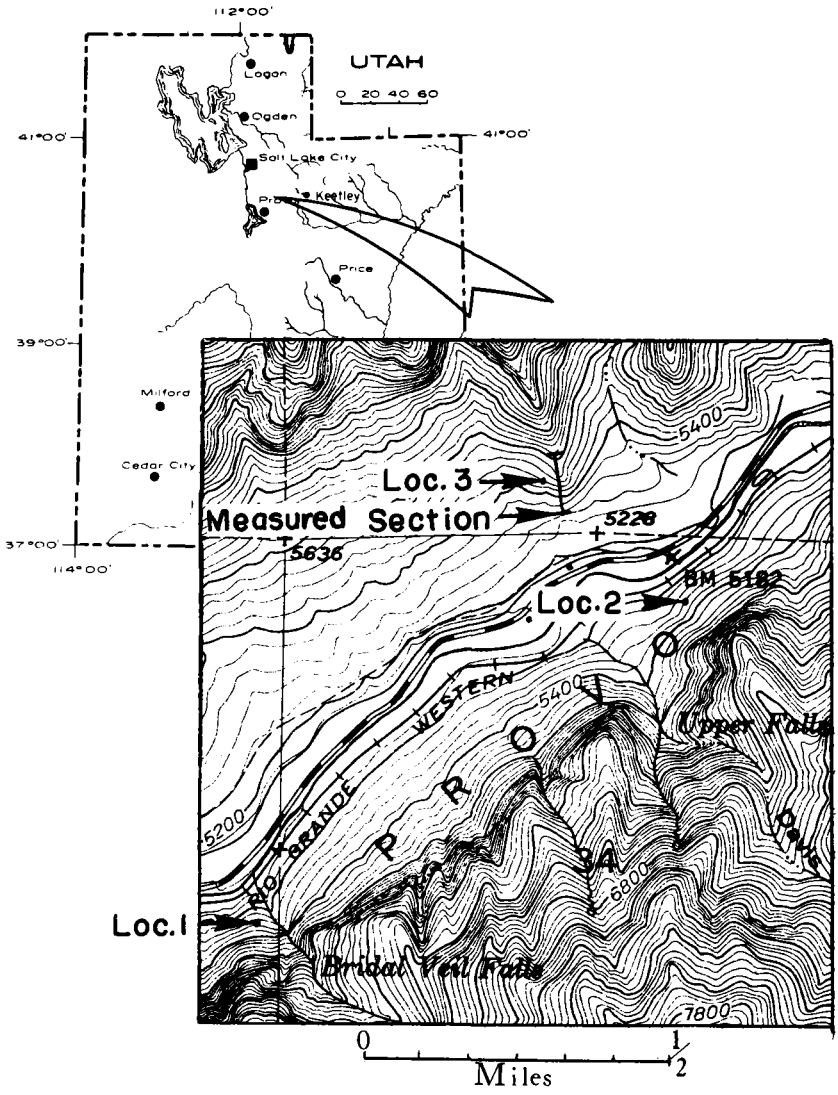
Bissell (1936) was first to use the Oquirrh Formation for the Pennsylvanian sequence found in the south-central Wasatch Mountains of central Utah. Franson (1950) studied and described the stratigraphy of the lower 1,360 feet of the Oquirrh Formation near Bridal Veil Falls in Provo Canyon, eastern Utah County, Utah. Although Morrowan faunal elements such as brachiopods (Murphy, 1954) and trilobites (Chamberlain, ms.) have been described from strata near the area considered by this study, the Crinoidea have been neglected. Literature relevant to the study is composed mainly of papers describing midcontinent forms, studies such as those by Mather (1915), Miller and Gurley (1890), Moore (1939), Moore and Laudon (1943, 1944), Moore and Plummer (1937, 1940), Strimple (1940a, 1940b, 1948, 1949, 1951), and many others. A paper by Lane (1964) on crinoids from Nevada was also of value in the present study.

ACKNOWLEDGMENTS

For assistance given during this study the author extends acknowledgment to the following members of the Brigham Young University Geology Department for their advice and guidance: Dr. J. Keith Rigby, thesis chairman; Dr. Harold Bissell; and Dr. Morris S. Petersen. Mr. William Ratcliffe of Provo, Utah,

and the staff and students of Brigham Young University collected several of the specimens. Miss Mary Ellen Howell typed the final draft.

The author is deeply appreciative of his wife Linda for her help in the preparation of this thesis.



TEXT-FIGURE 1.—Index map showing collecting localities and the site of the measured section. Locality one is near Bridal Veil Falls in Sec. 33. Locality two in Sec. 34, locality three in Sec. 27, and the measured section in Sec. 34, are near Slide Canyon—all in T. 5 S., R. 3 E.

TECHNIQUES

The only section measured was at locality three. It extends from the base of the Bridal Veil Falls Member, at the base of the Oquirrh Formation, to 280 feet above the base. The section begins at the southeast corner of SE¼, Section 27, T. 5 S., R. 3 E. All specimens found *in situ* are referred to this section.

Various specimens were removed from the matrix sufficiently to observe and measure all pertinent characteristics. This was accomplished with dental tools and an Airbrasive unit, a miniature sand blaster. Some specimens were left partly imbedded in the rock matrix, but others were completely removed.

STRATIGRAPHY

The crinoid-bearing sequence occurs in the lower part of the Bridal Veil Falls Member (Baker and Crittenden, 1961) of the Oquirrh Formation. The member is of Morrowan age and occurs just above the Mississippian-Pennsylvanian Manning Canyon Shale. The Oquirrh Formation is some 26,000 feet thick and ranges from Morrowan to Wolfcampian in age. Only approximately the lower 1,000 feet is Morrowan.

Strata within the section measured on the ridge west of Slide Canyon are rhythmic and consist of alternating thick-bedded limestone and thin-bedded shaly limestones. The articulated crinoids occur on the top surface of limestone mounds just below thin, muddy, limestone partings.

Although articulated crinoid specimens are rare in lower Oquirrh strata, disarticulated ossicles are common and form an important part of some of the thick-bedded limestones.

CONCLUSIONS

Although the present fauna is considerably removed from the localities of other Morrowan faunas, close taxonomic relationship above the specific level with other similar age faunas is notable.

Moore (1952) concluded and demonstrated that most species described prior to 1952 from Morrowan strata belong to the order Cladoidea. A similar relationship is also noted in the present study, for all forms in these Utah collections belong to this same order. Crinoidea from the Pennsylvanian Cordilleran Geosyncline, when adequately collected and described, will be generically very similar to the abundant crinoid faunas collected from the midcontinent area. In contrast to this, only about one third of the species described prior to 1952 (Moore, 1952) belong to genera also occurring in the Eurasiatic area.

TABLE 1
Abbreviations and Symbols Used in This Paper

Character		Character	
Infrabasal plate	IB	Right tube plate	rt
Infrabasal plates	IBB	Brachial ossicle	Br
Basal plate	B	Brachial ossicles	Brr
Basal plates	BB	Left	l
Radial plate	R	Right	r
Radial plates	RR	Anterior	a
Radianal plate	RA	Posterior	p
Anal x	x		

SYSTEMATIC PALEONTOLOGY

Family AMPELOCRINIDAE Kirk, 1942

Genus *AESIOCRINUS* Miller and Gurley, 1890

The low, bowl-like dorsal cup consists of 5 IBB, 5 BB, 5 RR, and 1 anal plate. It has 2 IBrr in each ray with the $IBrr_2$ auxiliary. The arms may or may not divide above the $IBrr_2$, and they are uniserial, pinnulate, and branch isotomously.

Aesiocrinus secundus n. sp.

Plate 1. figs. 1-3

Description.—The holotype and only known specimen, BYU 1483, consists of a complete crown except for the proximal ends of the arms and some portions of the BB. The dorsal cup is 0.47 times as high as wide and has the shape of a low, truncated bowl which flairs outward from a flattened, slightly centrally depressed base. The pinnulate arms are oriented laterally and branch once isotomously on the $IBrr_2$. They are preserved to $IIBrr_{11}$ on some rays of the present specimen. Cup sutures are slightly impressed and all cup plates lack ornamentation.

Small IBB occur in the depressed portion of the dorsal cup base. They are diamond-shaped and slightly higher than wide. They are not visible when the cup is viewed from the side. The cicatrix is not preserved.

BB are slightly convex horizontally and rather highly convex vertically. The proximal half of the circlet forms part of the cup side, and the other half of this plate series curves inward to form part of the cup base. All of the BB are hexagonal, except the pB which is heptagonal. BB are smaller than the RR.

RR are pentagonal and the widest part of the dorsal cup occurs at the scalloped summit of this circlet. The plates are 0.47 times as high as wide and form most of the dorsal cup side.

The anal plate is rectangular and has two facets for the reception of tube plates on its distal margin. It extends above the dorsal cup summit and bends inward toward the cup's center.

$IBrr_2$ are auxiliary and give rise to ten isotomously branched pinnulate, uniserial arms. The other Brr are rectangular in side view. The arms taper distally rather quickly, suggesting relatively short arms.

TABLE 2

Measurements of the holotype of *Aesiocrinus secundus* n. sp.

Character	mm.
Maximum width of dorsal cup (a to p)	23.2
Maximum width of dorsal cup (Perpend. to a-p)	26.8
Height of dorsal cup	11.8
Height of IBB	4.5
Width of IBB	4.2
Height of BB	8.5
Width of BB	10.1
Length of interbasal sutures	4.3
Height of RR	9 2
Width of RR	14.8
Length of interradial sutures	5.8
Height of anal	6.3
Width of anal	5.9

Discussion.—*Aesiocrinus secundus* n. sp. is differentiated from other species of this genus by its shallow basal invagination. The exception to this is *A. luxuris* Strimple (1951, p. 288-289, Pl. 5, figs. 7-10). *A luxuris* Strimple is differentiated from *A. secundus* n. sp. by having one instead of two tube plates resting distally on the RA.

Occurrence.—The specimen was found as float on the west side of Slide Canyon in eastern Utah County, Utah, and probably came from the Morrowan Bridal Veil Falls

Member of the Oquirrh Formation judging from the position where the specimen was found. Careful examination of this area suggests that *Aesiocrinus secundus* n. sp. originated from within a crinoid-rich sequence found between 210 and 275 feet from the base of the Bridal Veil Falls Member. These crinoid-rich strata are immediately above the spot where this specimen was found. Beds above the sequence between 210 feet and 275 feet have been removed by erosion. The above combination of factors suggest that this specimen, as well as many others described in this study, originated from the crinoid-rich series of beds between 210 feet and 275 feet in the measured section at this locality.

Type specimen.—Holotype, BYU 1483.

Genus *CYMBIOCRINUS* Kirk, 1944

The low, basin-shaped dorsal cup has an invaginated base which contains all of the IBB and the distal ends of the BB. RR are larger than the BB and in most species a single anal truncates the pB. $IBrr_2$ are auxiliary and give rise to 10 uniserial pinnulate arms. The IIBr may be cuneate in shape and typically all the cup plates are convex.

Cymbiocrinus anatonus n. sp.

Plate 1, figs. 4-6

Description.—The holotype and only known specimen, BYU 1484, consists of an incomplete crown with the arms missing above $IBrr_1$. Dorsal cup is 0.41 times as high as wide and has a low, bowl-like shape with the extreme tips of the BB and all of the IBB participating in formation of a basal invagination. Shape of dorsal cup is very similar to that of *Delocrinus*. Arms branch isotomously on the auxiliary $IBrr_2$ and are uniserial with quadrate-shaped brachials. Cup sutures are moderately impressed and dorsal cup is ornamented only by very fine granulations.

Diamond-shaped IBB form a major portion of the moderately deep basal invagination. Cicatrix is not preserved.

BB are about as high as wide and are hexagonal except for the pB which is heptagonal. The proximal one third of the BB forms part of the sides of the dorsal cup while the distal two thirds of the circlet bends inward to form the dorsal cup base. Distal tips of the BB bend upward and participate in formation of the basal invagination.

Pentagonal RR form most of the side of the dorsal cup and are 0.58 times as high as wide. The widest portion of the cup occurs at their summit. Length of interradial and interbasal sutures is about equal even though the RR are larger plates.

The single, pentagonal anal, the RA, has two unequal facets on its distal end for articulation with two tube plates. About one third of it extends above the dorsal cup and bends inward slightly.

Isotomously branched arms divide on the auxiliary $IBrr_2$ and are scandently oriented. They are missing above $IIBrr_1$ on the present specimen. This is probably a ten-armed species, but one cannot be certain until a complete specimen is found. Brr are rectangular in side view and are wider than high.

TABLE 3

Measurements of the holotype of *Cymbiocrinus anatonus* n. sp.

Character	mm.
Height of dorsal cup	6.9
Average width of dorsal cup	16.8
Height of IBB	2.1
Width of IBB	1.8
Height of BB	5.4
Width of BB	5.5
Length of interbasal sutures	3.4
Height of RR	5.3
Width of RR	9.2
Length of interradial sutures	3.5
Height of anal	4.6
Width of anal	4.1

Discussion.—*Cymbiocrinus anatonus* n. sp. is differentiated from other species of the genus by its ornamentation. The surface of the dorsal cup is covered with fine granulations while other species in *Cymbiocrinus* are smooth.

Previously the most recent species of *Cymbiocrinus* were described from Chester rocks. *C. anatonus* n. sp. extends the range of the genus to the Morrowan portion of the Pennsylvanian.

Occurrence.—The specimen was found as float at 195 feet in the measured section on the ridge west of Slide Canyon. Judging from the position where it was found, it probably came from crinoid-rich strata between 210 feet and 275 feet in the measured section. This would suggest that it came from within the Morrowan Bridal Veil Falls Member of the Oquirrh Formation.

Type specimen.—Holotype, BYU 1484.

Cymbiocrinus cuneatus n. sp.

Plate 1, figs. 7-9

Description.—The holotype and only known specimen, BYU 1485, consists of a partial crown with a complete dorsal cup and arms preserved to IIBrr$_5$. The low, unornamented, bowl-shaped cup is 0.35 times as high as wide and has a moderate basal invagination. Sides flair outward, and sutures are impressed. Widest diameter of the cup occurs at the top of RR circlet.

Diamond-shaped IBB form most of the basal invagination, and are 1.4 times as high as wide. Cicatrix is not preserved.

BB are about as high as wide and are hexagonal except for the pB which is heptagonal. The seventh suture is produced by the pB being truncated by the RA. About one third of the height of the BB participates in forming the dorsal cup side, one third in the cup's base, and the remaining one third in forming the basal invagination.

Pentagonal RR form most of the side of the moderately flairing dorsal cup. They are larger than the BB and are uniform in size, except for the lpR and rpR which are smaller.

The single anal, the RA, is roughly rectangular and is widest at its summit and does not protrude above the top of the dorsal cup. It has two sutures on its distal end for articulation with the tube plates. The anal series above the dorsal cup is preserved on the inside of the cup. Evidently they fell into it during deposition and were preserved. The anal series consists of two plates articulating with the RA, then two smaller plates above the first two, then one larger plate above the second set, and finally a single, small pointed plate at the summit of the anal series.

There are two IBrr per ray and the IBrr$_2$ are auxiliary. The IBrr$_2$ give rise to ten horizontal, uniserial, isotomously branched arms which have cuneate-shaped Brr.

The proximal columnals are round.

TABLE 4

Measurements of the holotype of *Cymbiocrinus cuneatus* n. sp.

Character	mm.
Height of dorsal cup	8.1
Average width of dorsal cup	23.3
Height of IBB	4.9
Width of IBB	3.5
Height of BB	7.0
Width of BB	7.1
Length of interbasal sutures	2.9
Height of RR	7.7
Width of RR	12.4
Length of interradial sutures	4.3
Height of anal	5.7
Width of anal	6.4

Discussion.—*Cymbiocrinus cuneatus* is differentiated by the horizontal orientation of its arms. Other species in the genus have scandently oriented arms and are much smaller.

C. gravis Strimple (1951, p. 196, Pl. 4, figs. 4-6) is closest in size to this species. It, however, has pentagonal proximal columnals rather than round proximal columnals, and its IIBrr are less cuneate.

Occurrence.—The specimen was found as float approximately 180 feet above the base of the measured section, on the west side of Slide Canyon in Provo Canyon. Judging from the position where the specimen was found, it probably came from crinoid-rich strata between 210 feet and 275 feet in the section.

Type specimen.—Holotype, BYU 1485.

GLOBOCRINUS n. gen.

Globocrinus has 5 RR, 5 BB, and 5 IBB. However, IBB are fused into a solid disk which is plainly visible from the side. The $IBrr_2$ are auxiliary and support ten isotomously branched, uniserial arms to at least $IIBrr_5$. Arms are missing on the specimens of the type species above this position. The single anal plate extends above the summit of the dorsal cup. Dorsal cup has a globous shape with its summit somewhat constricted. Its maximum diameter occurs through the upper part of the BB.

Cup shape and plate combinations are similar to *Polusocrinus* (Strimple, 1961) except that IBB are fused into one plate and are considerably larger. Also, adults are stemless.

Type species.—*Globocrinus bulbus* n. sp.

Globocrinus bulbus n. sp.

Plate 2, figs. 1-6

Description.—The holotype, BYU 1488, consists of a complete crown except for the distal ends of the arms. Dorsal cup has a globous shape and is 0.82 times higher than wide in the holotype and 0.72 times as high as wide in the paratype. All cup plates are tumid and have deeply impressed sutures. Surfaces of cup plates are covered with fine granulations except for the depressed portions along sutures.

IBB are fused and are plainly visible from the side. On the holotype, the fused disk is staroid while the paratype has a pseudopentagonal-shaped disk. The thick circlet lacks a cicatrix, a structure which would certainly be obvious if present on such well preserved specimens.

BB are slightly wider than high and are hexagonal except for the pB which is heptagonal. BB form a major part of the side of the dorsal cup. Greatest cup diameter is through the distal end of the B circlet.

RR are 0.63 times as high as wide on the holotype and 0.55 times as high as wide on the paratype. They are much smaller than the BB. They have long radial-basal sutures and rather short interradial sutures.

TABLE 5

Measurements of the holotype of *Globocrinus bulbus* n. sp.

Character	BYU 1488 Holotype mm.	BYU 1489 Paratype mm.
Height of dorsal cup	24.2	21.3
Width of dorsal cup (a to p)	28.7	30.5
Width of dorsal cup (perp to a-p)	30.3	31.9
Width of IBB (approximate)	17.3	17.1
Height of BB	14.0	16.6
Width of BB	14.5	16.8
Length of interbasal sutures	8.1	9.5
Height of RR	8.5	8.6
Width of RR	13.4	14.7
Length of interradial sutures	3.0	2.8
Height of RA	7.4	....
Width of RA	7.2	8.1
Height of pB	12.8	13.5

The single anal truncates the pB. Laterally it is in contact with the lpR and rpR. The distal end of the medium-sized anal extends above the summit of the dorsal cup. It has five facets with two on the distal end for reception of tube plates.

Ten uniserial arms are produced by a single isotomous division on the IBrr$_2$. Arms are missing beyond the IIBrr$_5$; they could also have a division in this missing distal portion. Brr are twice as wide as high and are rectangular when viewed from the side. Arms are oriented scandently in death position.

Discussion.—The stemless holotype and paratype are judged as varieties of the same species. However, as additional specimens are found, these differences may prove to have specific value.

Occurrence.—This specimen was collected as float on the west side of Slide Canyon, Sec. 27, T: 5 S., R. 3 E., where the ridge ends on the north side of Provo Canyon. The specimen probably originated from 210 feet to 275 feet in the measured section, judging from the position where the specimens were found. This crinoid-rich series of beds is in the Morrowan Bridal Veil Falls Member of the Oquirrh Formation. This is the type species of the genus.

Type specimens.—Holotype, BYU 1488, Paratype, BYU 1489.

Family CROMYOCRINIDAE Jaekel, 1918
Genus *SYNARMOCRINUS* Lane, 1964

The large, low dorsal cup of this genus consists of 5 IBB, 5 BB, 5 RR, and 2 anals. Surfaces of RR, BB, and anals are covered with pustule-like nodes. Ten uniserial arms branch isotomously on IBrr$_1$.

Synarmocrinus depressus n. sp.
Plate 2, figs. 7-9

Description.—The dorsal cup is large, approximately one half as high as wide, and it has a low globous shape with a broad, flattened, slightly impressed base. The widest portion of it occurs near the summit of the basal circlet. All sutures are deeply impressed.

Diamond-shaped IBB are slightly higher than wide. The IBB circlet occurs in a shallow basal depression Cicatrix is round.

Hexagonal BB form most of the side of the cup. They are considerably more convex vertically than horizontally; their distal ends bend inward to form part of the flattened cup base Interbasal sutures are more than twice as long as interradial sutures. The lpB is reduced in width and other BB are approximately 0.9 times as high as wide.

Only one R is preserved and it is 0.8 times as high as wide. It has a shallow, rather broad vertical depression in the medial portion of the plate. RR are considerably smaller than BB; the diameter of the dorsal cup is somewhat less at the summit of the RR than through the upper portion of the BB.

Anals are missing, but sutures of the RA on the pB and rpB indicate that the position of this plate is the same as in the genus *Synarmocrinus*.

TABLE 6

Measurements of the holotype of *Synarmocrinus depressus* n. sp.

Character	mm
Height of dorsal cup (approximate)	23.0
Width of dorsal cup (approximate)	46.0
Height of IBB	9.4
Width of IBB	9.0
Width of IBB circlet	18.8
Length of inter-infrabasal sutures	8.8
Height of BB	22.6
Width of BB	25.8
Length of interbasal sutures	15.2
Height of RR	16.7
Width of RR	21.6
Length of interradial sutures	8.6

Entire surface of the dorsal cup is ornamented with large pustule-like nodes which often become confluent. A V-shaped pattern of nodes is developed parallel to proximal sutures of the RR and BB. A series of ridges produced by confluent nodes is present vertical to and entering into depressed sutures around each cup plate except for the IBB and distal margin of the RR.

Discussion.—The holotype and only known specimen, BYU 1490, consists of an incomplete dorsal cup. IBB and BB are preserved, but four RR and both anals are missing. Nevertheless, complete IBB and BB circlets, plus the single R and positioning of the RA suture on the pB and rpB, gives sufficient information to differentiate the specimen taxonomically.

This new species is differentiated from other species of this genus by the shape of its R. *Synarmocrinus brachiatus* Lane (1964, p. 678-680, Pl. 112, figs. 14-15) and *S. fundundus* Strimple (1966, p. 8-12, Pl. 2, figs. 1-4) have evenly convex RR horizontally. In *S. depressus* n. sp. a distinct vertically aligned depression occurs in the central portion of the R plate. This depression extends from the distal to the proximal margins.

Occurrence.—The holotype was found as float on the west side of Slide Canyon. Also, one basal plate of the species was found *in situ* in the measured section at 223 feet above the base of the Morrowan Bridal Veil Falls Member of the Oquirrh Formation on the west side of Slide Canyon in Provo Canyon, Utah County, Utah. Judging from the position where the basal plate was found, it seems most likely that the holotype also came from the Bridal Veil Falls Member of the Oquirrh Formation.

Type specimen.—Holotype, BYU 1490.

Family ERISOCRINIDAE Miller, 1889

Genus *DELOCRINUS* Miller and Gurley, 1890

The dorsal cup of the genus has a low, bowl-like shape with a basal invagination which is made of the IBB and part of the BB. There are 5 IBB, 5 BB, 5 RR, and 1 anal in the dorsal cup. The ten biserial, isotomously branched, pinnulate arms are auxiliary on the $IBrr_1$. The proximal one fourth to one third of the arms may have cuneate Brr.

Delocrinus cf. *D. matheri* Moore and Plummer, 1937

Plate 3, figs. 1-3

Delocrinus matheri Moore and Plummer, 1937, Denison Univ. Sci. Lab., Bull., v. 38, no. 2, p. 289-291, pl. 14, figs. 7a-d.

Description.—The dorsal cup has a low, bowl-like shape with a moderately deep basal invagination. Sutures are shallowly to moderately impressed, and pits occur at the junction between the plates. The columnal covers most of the IBB circlet which occurs entirely in the basal invagination. Surface of the dorsal cup and the $IBrr_1$ are covered with a shagreen of fine granulations which usually become confluent to form a series of winding valleys and ridges.

Small diamond-shaped IBB contained in the basal invagination are almost entirely covered by the round, proximal columnal and were not measured.

BB are hexagonal except for the pB which is heptagonal. They have a tumid appearance and their upper half forms part of the dorsal cup side. The lower part of the BB circlet curves inward to form part of the base, and then curves upward to form part of the basal invagination. These plates are longer than wide and are tightly convex vertically.

RR are 0.61 times as high as wide and form most of the side of the cup. They are pentagonal and flare gradually outward to a point near their summit where they curve inward sharply.

The anal x is 1.7 times as high as wide. One third of it extends above the dorsal cup summit where it bends sharply inward.

Arms are composed of cuneate and biserial Brr. The proximal one fourth of the arms has cuneate Brr while the distal three fourths has biserial Brr. The arms maintain their width to about one half their length and then gradually taper to their distal ends. There is one pinnule per Br which produces a row of pinnules on each side of the arms in the biserially arranged portion.

The round column is composed of nodals, internodals, and infranodals with the nodals having the widest diameter.

Discussion.—This species is differentiated from all other species of *Delocrinus* by its ornamentation consisting of a shagreen of granulations which often become confluent to form fine winding valleys and ridges. *D. matheri* Moore and Plummer (1937) has a lower dorsal cup; its RR have a lower height/width ratio. The difference in the shape of the RR and the dorsal cup may or may not have specific value.

TABLE 7

Measurements of figured specimen of *Delocrinus* cf. *D. matheri* Moore and Plummer

Character	Figured Specimen, BYU 1493 mm	Figured Specimen, BYU 1494 mm
Length of crown	48.0	43.0
Height of dorsal cup	7.0	6.4
Width of dorsal cup	16.7	15.4
Height of BB (curved surface)	8.8	7.0
Width of BB (curved surface)	7.0	6.0
Length of interbasal sutures	3.7	3.1
Height of RR	6.6	5.5
Width of RR	10.8	8.5
Length of interradial sutures	2.7	2.2
Height of anal x	5.2	....
Width of anal x	3.0	....

Three specimens of the species are in the collection. All were found as float on a single limestone slab. Figured specimen, BYU 1493, is a complete crown except for some fragments broken from the arms and the left posterior side of the dorsal cup. Figured specimen, BYU 1494, is a complete crown except for missing fragments on the posterior side of the dorsal cup. The third specimen is partially disarticulated and the distal ends of the arms are missing.

Occurrence.—The specimens were found as float on the west side of Slide Canyon in Provo Canyon, Utah. Judging from the position where the float block was found, it probably came from fossiliferous strata located between 210 feet and 275 feet in the measured section. This unit is part of the Morrowan Bridal Veil Falls Member of the Oquirrh Formation.

Figured specimens.—Figured specimen, BYU 1493, figured specimen, BYU 1494.

Delocrinus aff. *D. subhemisphericus* Moore and Plummer, 1940

Plate 3, figs. 4-6

Delocrinus subhemisphericus Moore and Plummer, 1940, Univ. Texas Bull., no. 3945, p. 258-261, Pl. 11, fig. 4.

Description.—The only specimen of this form in the collections, BYU 1495, consists of a partially disarticulated dorsal cup along with 3 $IBrr_1$, each of which possesses a single, long spine. It has a low, bowl-like shape with a basal invagination and is free of ornamentation. Cup sutures are slightly impressed.

IBB are missing.

BB are hexagonal and slightly wider than high. The proximal one half of the BB forms part of the side of the dorsal cup, while the distal part of the basal plates curve inward and then slightly upward into the basal invagination. Although the specimen has an anal plate, the pB is not truncated by it. BB are mildly convex horizontally and strongly convex vertically.

RR are pentagonal and 0.61 times as high as wide. They form most of the cup side and are equally convex horizontally and vertically.

The single pentagonal anal extends above the dorsal cup summit. That portion of the anal x entending above the RR circlet does not bend toward the center of the dorsal cup.

$IBrr_1$ are auxiliary and each possesses a single long, slender, pointed spine. The height/width ratio of these plates, including the spine, is 1.95. Arms above $IBrr_1$ are missing.

TABLE 8

Measurements of figured specimen of *Delocrinus* aff. *D. subhemisphericus* Moore and Plummer

Character	mm
Height of dorsal cup (est.)	5.1
Width of dorsal cup (est.)	11.8
Height of BB	4.0
Width of BB	4.5
Length of interbasal sutures	1.9
Height of RR	4.3
Width of RR	7.0
Length of interradial sutures	2.3
Length of $raIBr_1$	12.7
Maximum width of $raIBr_1$ at dorsal cup summit	6.5

Discussion.—*Delocrinus* aff. *D. subhemisphericus* is very similar to Missourian *D. subhemisphericus* except for its $IBrr_1$ spines which are more slender and its anal x which does not truncate the pB. These features seem sufficient to place this specimen in a new species, but formal definition will be postponed until more complete specimens are found.

Occurrence.—The specimen was found as float at the base of a small outcrop south of the Provo River, 100 yards south of the power plant water intake, one mile up Provo Canyon from the Upper Falls. The occurrence suggests that the specimen came from beds equivalent to the lower 30 feet of the measured section west of Slide Canyon. Appearance of the IBr_1 plates are distinctive. They are common as isolated plates in the fossiliferous strata between 25 feet and 55 feet in the measured section.

Figured specimen.—Figured specimen, BYU 1495.

Genus *PHANOCRINUS* Kirk, 1937

The crown has a basally invaginated, low, bowl-shaped dorsal cup with 5 IBB, 5BB, 5RR, and 3 anals. The genus has cup plates which are somewhat tumid and ten uniserial, pinnulate arms which branch isotomously on $IBrr_1$.

Phanocrinus vadosus n. sp.

Plate 1, figs. 10-12

Description.—Dorsal cup of this species has a low, bowl-like shape with a shallow basal invagination. Although IBB are missing in the holotype, a second, poorly preserved paratype shows the invagination. Sutures are deeply impressed; the tumid plates are free of ornamentation except for the raR and laR which have small grooves radiating from a round depression near the center of these plates. Function of this structure is unknown.

IBB are detached and missing from the holotype.

BB are as wide as high and are hexagonal except for the lpB and rpB which are heptagonal. About four fifths of this circlet forms part of the side of the dorsal cup, and the remaining distal one fifth bends inward to form part of the cup base. Interbasal and interradial sutures are about equal in length.

Pentagonal RR are 0.60 times as high as wide, and the cup is constricted at its summit.

Two of the three tumid anals, the rt and the anal x, extend above the summit of the dorsal cup and rest on the distal end of the RA. The RA has contact with both the pB and rpB.

The species has ten uniserial, pinnulate, scandently oriented arms which branch once isotomously on the $IBrr_1$. Brr are slightly cuneate and each alternating Br bears a pinnule.

Discussion.—*Phanocrinus vadosus* n. sp. is differentiated from all other species of the genus by it shallow basal invagination. In other species of this genus at least one fourth

TABLE 9
Measurements of the holotype of *Phanocrinus vadosus* n. sp.

Character	mm
Length of crown	34.1
Height of dorsal cup	5.7
Width of dorsal cup	11.3
Height of BB	3.9
Width of BB	3.9
Length of interbasal sutures	2.5
Height of RR	3.2
Width of RR	5.3
Length of interradial sutures	2.2

of the BB participates in the invagination while in this species only the distal tips of the basal circlet flex inward and upward to participate with the IBB in the formation of the basal depression. This species is also characterized by highly tumid cup plates and slightly cuneate Brr. Grooves radiating from the depressions on the raR and laR may or may not have specific value. All other species of this genus are restricted to Late Mississippian Chesterian rocks. This, coupled with the shallow basal invagination, suggests that the species may not be a true *Phanocrinus,* but the species is placed here for it seems to fit best in this genus.

Occurrence.—The two known specimens were found as float on the west side of Slide Canyon in Provo Canyon on the same block as *Delocrinus* cf. *D. matheri* Moore and Plummer (1937, p. 289-291, Pl. 14, figs. 7a-d). The float block probably came from the Morrowan Bridal Veil Falls Member of the Oquirrh Formation judging from the position where the float block was found.

Type specimens.—Holotype, BYU 1486, paratype, BYU 1487. Paratype, BYU 1487, is figured only as a basal view.

Family SCYTALOCRINIDAE Moore and Loudon, 1943

Genus *HYPSELOCRINUS* Kirk, 1942

Hypselocrinus has a steeply conical cup with long pinnulate, uniserial arms. Arms divide once isotomously on $IBrr_1$. However, in some species the anterior ray may remain undivided. The genus has 5 IBB, 5 BB, 5 RR, and 3 anal plates consisting of the RA, the anal x, and the rt.

Hypselocrinus defendus n. sp.

Plate 3, figs. 7-15

Description.—The dorsal cup has a steeply conical shape and is 0.88 times as high as wide on BYU 1497, a paratype. Although this specimen is poorly preserved, it is the only specimen with a complete dorsal cup. Sutures are not impressed except for the interradial sutures. Surface of the cup is ornamented with fine granulations.

The only complete IBB circlet is preserved on a paratype, BYU 1497. IBB are pentagonal when viewed from the side and are 1.25 times as high as wide. Cicatrix is round and approximately 3 mm in diameter.

BB of the holotype are hexagonal, except for the pB and the rpB which are heptagonal and are 1.17 times as high as wide.

RR are pentagonal and are 0.56 times as high as wide. Interradial sutures are shallowly impressed.

The three anals—the RA, anal x, and rt—occur in the flattened to slightly concave interray on the posterior of the dorsal cup. Distal ends of anal x and rt extend above the summit of the dorsal cup, while the larger RA has contact with the rpB and pB.

Arms are best preserved on BYU 1499, a paratype. They are long and slender and branch once isotomously on $IBrr_1$. The ten pinnulate arms have uniserial brachials. This species has developed a rather interesting feature in that both sides of the ten arms are flattened along their full extent. Therefore, when the arms were brought together, the flattened sides fitted tightly against each other—perhaps as a defensive mechanism developed to protect the pinnules and tegmen from predators.

Discussion.—Hypselocrinus is represented in the collection by several incomplete crowns. The holotype, BYU 1496, lacks the distal two thirds of the arms and the distal portion of the IBB. BYU 1497, a paratype, is complete except for the distal two thirds of the arms, and BYU 1499, a second paratype, is missing the left side of the dorsal cup.

Hypselocrinus defendus n. sp. is differentiated from other species of the genus by its ornamentation and arm structure. The only species which resembles it closely is *H. arcanus* (Miller and Gurley) (1890, p. 29, Pl. 5, fig. 4). *H. arcanus,* however, has much shorter arms and lacks the fine granules on the dorsal cup surface.

TABLE 10

Measurements of the holotype and paratypes of *Hypselocrinus defendus* n. sp.

Character	Holotype BYU 1496 mm	Paratype BYU 1497 mm	Paratype BYU 1499 mm
Approx. length of crown	....	....	58.0
Height of dorsal cup	17.9	22.8	....
Approx. width of dorsal cup	21.1	26.0	10.7
Height of IBB	....	7.3	....
Width of IBB	5.5	5.6	....
Height of BB	9.7	10.4	4.6
Width of BB	8.3	9.0	5.4
Length of interbasal sutures	5.4	5.6	2.6
Height of RR	7.5	8.5	4.9
Width of RR	7.5	13.8	7.4
Length of interradial sutures	5.4	5.1	3.0

Occurrence.—All five known specimens of the species probably came from the Morrowan Bridal Veil Falls Member of the Oquirrh Formation in Provo Canyon. The holotype, BYU 1496, and a specimen, BYU 1498, were found as float on the Bridal Veil Falls Trail near Bridal Veil Falls. Paratypes, BYU 1497 and BYU 1499, were found on the west side of Slide Canyon, a tributary to Provo Canyon. A fifth crushed specimen of this species was found in place, 275 feet above the base of the measured section. Finding the crushed specimen *in situ,* places this species in the Morrowan Bridal Veil Falls Member of the Oquirrh Formation.

Type specimens.—Holotype, BYU 1496; paratypes, BYU 1497, 1498, and 1499.

Hypselocrinus (?) *superus* n.sp.

Plate 2, figs. 10-12

Description.—Hypselocrinus(?) *superus* n. sp. is described from a single, well-preserved dorsal cup which has a moderately steep conical shape and is 0.79 times as high as wide. All cup plates are equally steeply inclined except for the flattened anal area on the posterior side of the dorsal cup. The rt and anal x extend above the summit of the RR circlet. Cup sutures are slightly impressed. All cup plates are ornamented with fine granules which often become confluent to form winding valleys and ridges.

IBB are higher than wide and hexagonal except for the pB which is octagonal due to its truncation by the RA.

BB are hexagonal except for the pB which is octagonal; they are higher than wide. Interbasal sutures are about as long as interradial sutures.

RR are 0.61 times as high as wide and are pentagonal except for the rpR which is heptagonal and lpR which is hexagonal. The RR circlet has a scalloped distal margin which curves inward slightly.

The three anals—the RA, rt, and anal x—occur in a vertical position over the pB. The RA is pseudotriangular and is about as wide as high. It has contact with the pB proximally and the rpR laterally. Distally, it has contact with the rt and the anal x. The rt and anal x rest on the Ra between the lpR and the rpR. Their distal ends extend above the summit of the dorsal cup and curve inward.

Discussion.—Morphology of the cup prompts tentative placement of this species in the genus *Hypselocrinus,* at least until more complete specimens are found. *H*(?) *superus* n. sp. is differentiated from other species of *Hypselocrinus* by the shape of its IBB and by the position of the RA. The following species of the genus are sufficiently similar to *H.*(?) *superus* n. sp. to warrant discussion. *H. hoveyi* (Worthen) (1875, p. 516, Pl. 29, fig. 6); *H. defendus* n. sp. (this paper, Pl. 3, figs. 7-15) and *H. arcanus* (Miller

TABLE 11

Measurements of the holotype of *Hypselocrinus*(?) *superus* n. sp.

Character	mm
Height of dorsal cup	14.0
Width of dorsal cup	17.7
Height of IBB	3.4
Width of IBB	3.8
Length of interinfrabasal suture	2.2
Width of cicatrix	3.6
Height of BB	7.6
Width of BB	6.6
Length of interbasal sutures	4.1
Height of RR	6.3
Width of RR	10.3
Length of interradial sutures	4.7

and Gurley) (1890, p. 29, Pl. 5, fig. 4) have IBB which are higher than wide, while *H*(?) *superus* n. sp. has IBB wider than high. *H. sansabensis* (Moore and Plummer) (1937, p. 247-250, Pl. 14, figs. 9a-b) and *H.*(?) *cavus* n. sp. (this paper, Pl. 2, figs. 13-15) are differentiated by the position of the RA. In the above species the RA is situated between the pB and rpB; in *H.*(?) *superus* n. sp., it is directly above the pB and has no contact with the rpB.

Occurrence.—The holotype of *Hypselocrinus superus* n. sp. was found as float on the west side of Slide Canyon. Judging from the position where the specimen was found, it probably originated from the upper crinoid-bearing strata in the Morrowan Bridal Veil Falls Member of the Oquirrh Formation.

Type specimen.—Holotype, BYU 1491.

Hypselocrinus (?) *cavus* n. sp.

Plate 2, figs. 13-15

Description.—The holotype consists of a complete dorsal cup which is 0.77 times as high as wide. It has a moderately steep conical shape with the RR circlet being more steeply inclined than the BB and IBB circlets. The anal series in the posterior interray is in a shallow depression below the surface of the RR. Cup plates are smooth; sutures are not impressed.

IBB are wider than high and are pentagonal when viewed from the side. The cicatrix is round, impressed into the distal ends of the IBB circlet, and pierced by a star-shaped lumen.

BB are wider than high and are smaller than the RR. They are hexagonal, except for the lpB and rpB which are heptagonal. The rpB is larger than the rest of the BB.

RR are 0.65 times as high as wide and are pentagonal. Interradial sutures are about 1.5 times as long as interbasal sutures. Summit of dorsal cup has a scalloped appearance in side view.

Anal plates extend from the proximal end of the left posterior interbasal suture to above summit of RR. The three plates present are the RA, rt, and anal x. Distal ends of the rt and anal x bend inward toward the center of dorsal cup. The RA has contact with the pB and rpB proximally and the rt, anal x, and rpR distally. The anal x and rt rest on the RA and occur between the lpR and rpR. About one fourth of the rt and one half of the anal x extend above the summit of the dorsal cup.

Arms are missing.

TABLE 12
Measurements of the holotype of *Hypselocrinus(?) cavus* n. sp.

Character	mm
Height of dorsal cup	13.8
Width of dorsal cup	17.8
Height of IBB	3.6
Width of IBB	4.8
Length of interinfrabasal sutures	2.7
Width of cicatrix	3.6
Height of BB	6.9
Width of BB	7.5
Length of interbasal sutures	3.0
Height of RR	6.5
Width of RR	10.0
Length of interradial sutures	4.8

Discussion.—Hypselocrinus(?) cavus n. sp. is differentiated from other species of the genus by the shape of the IBB and BB and by the nature of the cicatrix. The following species of *Hypselocrinus* are similar and warrant discussion. *H. defendus* n. sp. (this paper, Pl. 3, figs. 7-15), *H.(?) superus* n. sp. (this paper, Pl. 2, figs. 10-12), *H. hoveyi* (Worthen) (1875, p. 516, Pl. 29, fig. 6), *H. sansabensis* (Moore and Plummer) (1937, p. 247-250, Pl. 14, figs. 2a-b), and *H. arcanus* (Miller and Gurley) (1890, p. 29, Pl. 5, fig. 4). All of the above have BB which are as high as wide or higher than wide. *H.(?) cavus* n. sp., however, has BB which are wider than high. Because of the importance of the arms in morphologic differentiation of this genus from other genera, *H.(?) cavus* n. sp. is placed with reservation in *Hypselocrinus* until more complete specimens are found.

Occurrence.—The holotype and only known specimen was found *in situ* at 270 feet in the measured section on the west side of Slide Canyon in Provo Canyon, Utah, in the Morrowan Bridal Veil Falls Member of the Oquirrh Formation.

Type specimen.—Holotype, BYU 1492.

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Explanation of Plate 1

All figures X 1

AESIOCRINUS SECUNDUS n. sp., *CYMBIOCRINUS ANATONUS* n. sp., *C. CUNEATUS*, n.sp., and *PHANOCRINUS*(?) *VADOSUS* n. sp.

Figs. 1-3.—*Aesiocrinus secundus* n. sp., holotype, BYU 1483. *1.* posterior view. *2.* anterior view. *3.* basal view.

Figs. 4-6.—*Cymbiocrinus anatonus* n. sp., holotype, BYU 1484. *4.* posterior view. *5.* anterior view. *6.* basal view.

Figs. 7-9.—*Cymbiocrinus cuneatus* n. sp., holotype, BYU 1485. 7. posterior view. *8.* anterior view. *9.* basal view.

Figs. 10-11.—*Phanocrinus*(?) *vadosus* n. sp., holotype, BYU 1486. *10.* posterior view. *11.* anterior view.

Fig. 12.—*Phanocrinus*(?) *vadosus* n. sp., paratype, BYU 1487. *12.* basal view.

Explanation of Plate 2

All figures X 1

GLOBOCRINUS BULBUS n. sp., *SYNARMOCRINUS DEPRESSUS* n. sp., *HYPSELOCRINUS*(?) *SUPERUS* n. sp., and *H.*(?) *CAVUS* n. sp.

Figs. 1-3.—*Globocrinus bulbus* n. sp., holotype, BYU 1488. *1.* posterior view. *2.* anterior view. *3.* basal view.

Figs. 4-6.—*Globocrinus bulbus* n. sp., paratype, BYU 1489. *4.* posterior view. *5.* anterior view. *6.* basal view.

Figs. 7-9.—*Synarmocrinus depressus* n. sp., holotype, BYU 1490. 7. basal view. *8.* radial plate. *9.* anterior view.

Figs. 10-12.—*Hypselocrinus*(?) *superus* n. sp., holotype, BYU 1491. *10.* posterior view. *11.* anterior view. *12.* basal view.

Figs. 13-15.—*Hypselocrinus*(?) *cavus* n. sp., holotype, BYU 1492. *13.* posterior view. *14.* anterior view. *15.* basal view.

Explanation of Plate 3

All figures X 1

DELOCRINUS cf. *D. MATHERI* MOORE AND PLUMMER, *D.* aff. *D. SUBHEMISPHERICUS* MOORE AND PLUMMER and *HYPSELOCRINUS DEFENDUS* n. sp.

Figs. 1-3.—*Delocrinus* cf. *D. matheri* Moore and Plummer. *1.* left posterior view of figured specimen BYU 1493. *2.* right posterior view of figured specimen BYU 1494. *3.* basal view of figured specimen BYU 1493.

Figs. 4-6.—*Delocrinus* aff. *D. subhemisphericus* Moore and Plummer, figured specimen BYU 1495. *4.* posterior view. *5.* left posterior view. *6.* isolated primabrachial one showing spine.

Figs. 7-9.—*Hypselocrinus defendus* n. sp., holotype BYU 1496. 7. posterior view. *8.* anterior view. *9.* basal view.

Figs. 10-11.—*Hypselocrinus defendus* n. sp., paratype, BYU 1497. *10.* right posterior view. *11.* basal view.

Figs. 12-13.—*Hypselocrinus defendus* n. sp., paratype, BYU 1498. *12.* posterior view. *13.* anterior view.

Figs. 14-15.—*Hypselocrinus defendus* n. sp., paratype, BYU 1499. *14.* posterior view. *15.* left posterior view showing the long arms of the species.

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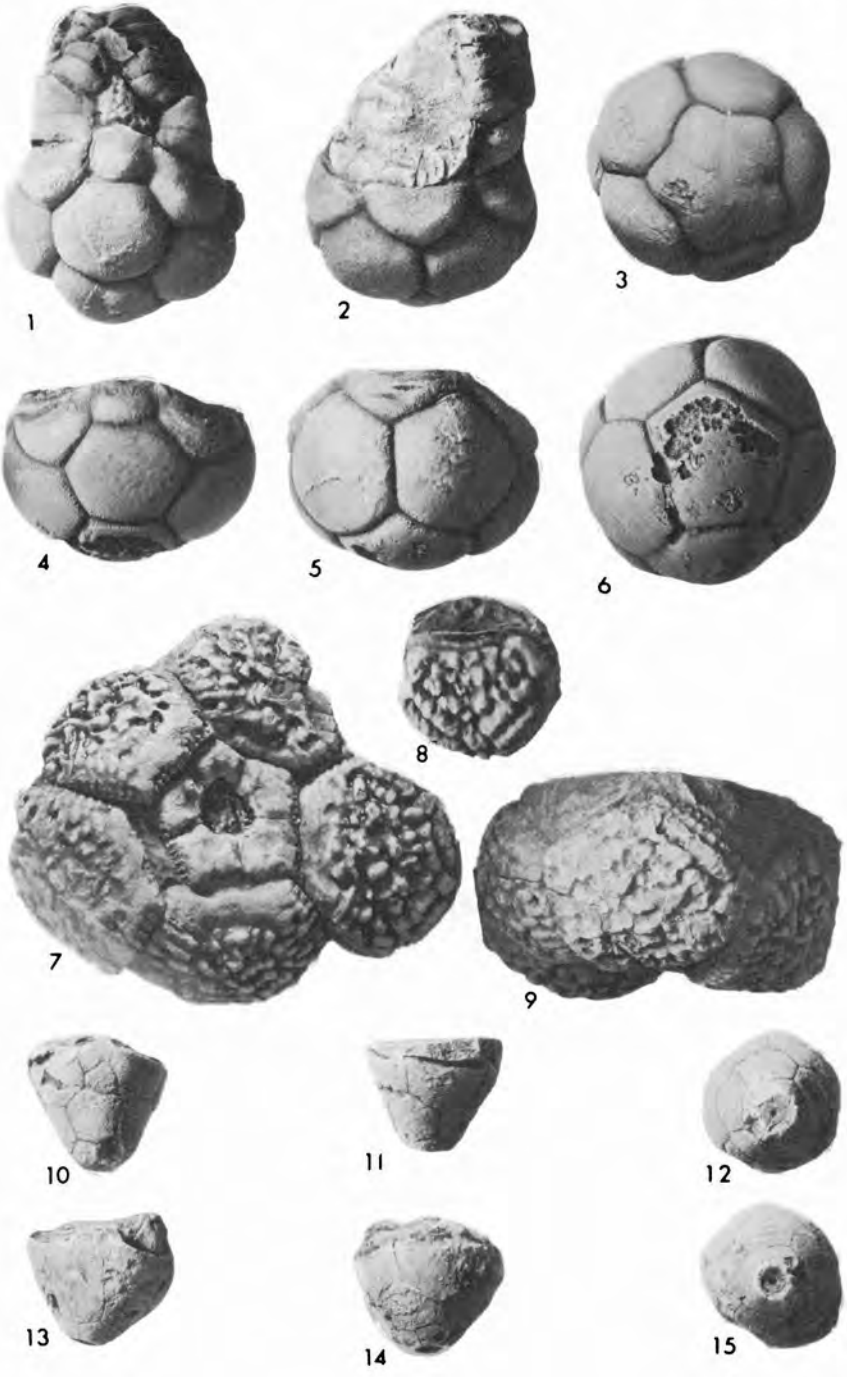
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