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Systematics, Phylogenetics, and Biogeography of Early Mississippian Camerate Crinoids of the Nunn Member, Lake Valley Formation, in south-central New Mexico

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Systematics, Phylogenetics, and Biogeography of Early Mississippian Camerate Crinoids of the
Nunn Member, Lake Valley Formation, in south-central New Mexico

Elizabeth C. Rhenberg

Dissertation submitted to the Eberly College of Arts and Sciences
at West Virginia University
in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Geology

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Morgantown, West Virginia
2011

Keywords: Lake Valley Formation, Phylogenetics, Camerate Crinoids, Early Osagean
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ABSTRACT

Systematics, Phylogenetics, and Biogeography of Early Mississippian Camerate Crinoids of the Nunn Member, Lake Valley Formation, in south-central New Mexico

Elizabeth C. Rhenberg

The Lake Valley Formation has long been known for the crinoids that are abundant in the formation. The crinoids were noted in the first descriptions of the formations in the late 1800's, but there has never been a comprehensive study done on the crinoids and as a result there is no complete list of crinoids that existed in south-central New Mexico during the Early Mississippian. Although all subclasses of crinoids are found in the Nunn Member, it is the camerate crinoids that dominate the fauna and will be the focus of this study. Most of the specimens studied came from the Macurda collection from the University of Michigan. This collection was supplemented with specimens from the Laudon collection from the University of New Mexico and additional samples collected in the field. These collections provided more than 7000 specimens to be examined, with approximately 4500 of those being identifiable camerate crinoids.

The first chapter of this paper is a systematic review of the camerates. Sixty-one species are recorded from the Nunn Member, five of which are new species: *Blairocrinus macurdai*, *Iotacrinus novamexicana*, *Agaricocrinus alamogordoensis*, *Uperocrinus kuesi*, and *Collicrinus laudoni*. An updated list of camerates found in the Lake Valley allows for better understanding and easier comparison of crinoid faunas across North America during this time. Environmental preferences were also examined to see if there was a difference between the faunas found in the shallow water shelf and those found associated with Waulsortian mounds in deeper water.

The majority of the camerates found in the Lake Valley Formation are from the Family Actinocrinitidae. This family has been a source of much taxonomic confusion due to generic concepts not equally applied between Europe in North America. The second chapter of this paper objectively defines the actinocrinitids by discrete characters and reevaluates the generic assignments of North American species. A phylogenetic hypothesis is presented for the relationships of the Actinocrinitidae genera based on a parsimony-based analysis and plotted against stratigraphic ranges. Although groupings were revealed in this analysis, the Actinocrinitidae cannot be readily divided into subfamilies. Twenty-one genera of Actinocrinitidae are described, 17 of which are found in North America. A total of 125 species were evaluated of which 34 species and one open-nomenclature taxon are reassigned to different genera, and four species are designated as nomina dubia.

The third chapter evaluates the similarities of camerate genera in three coeval North American formations with the Lake Valley Formation. These formations are the lower Burlington Limestone of the Mississippi Valley, the Redwall Limestone of Arizona, and the Anchor Limestone of Nevada. These similarities are based on presence-absence data with the Jaccard Coefficient and with rarefaction curves. The lower Burlington and Lake Valley faunas are nearly equal in generic richness (35 and 31 respectively) and have a high similarity (0.61). The Redwall and Anchor limestones have approximately half the number of genera that the lower Burlington and Lake Valley formations have and are very dissimilar to each other (0.18).

The disparity in number of genera in the Redwall and Anchor limestones as compared to the lower Burlington and Lake Valley are likely taphonomic. The camerates of the Redwall are poorly preserved, likely due to early diagenesis of chert and dolomite. In the Anchor, the camerates were likely moved in debris flows from shallow water settings, diminishing their preservation potential. Because neither the Redwall nor the Anchor have significant numbers of unique genera and both have genera that are a subset of the lower Burlington fauna, the seas of North America were likely well connected during the Early Mississippian, allowing for the camerates to widely disperse. Rarefaction curves indicate that the Redwall and Anchor limestones have been incompletely sampled. Thus, poor preservation and limited sampling in these formations have produced an apparently endemic pattern for faunas that were originally cosmopolitan.

PREFACE – A Note on Organization

The following doctoral dissertation was completed in the form of three articles ready for submission to peer-reviewed journals. Because of this format, there is some repetition of general information and the figures and tables are found at the end of the each chapter.

The papers are treated as separate chapters. The first chapter is a systematic review of the camerates of the Nunn Member. The second chapter is a review of the genera within the Family Actinocrinitidae and a phylogenetic analysis of the family. The third chapter is a biogeographic comparison of camerate crinoids of the Nunn Member to three coeval formations: the lower Burlington of Iowa, the Redwall Limestone of Arizona, and the Anchor Limestone of Nevada.

ACKNOWLEDGMENTS

This research was supported by grants from the Eberly College of Arts and Sciences, the Department of Geology and Geography at West Virginia University, and the Shumaker Fund. Most of the material studied was collected by Dr. Brad Macurda during the 1960s and 70s while he was at the University of Michigan. I thank Dr. Macurda for providing his collection for my study. Dr. Barry Kues of the University of New Mexico provided helpful assistance in the field guiding us to various sites where the Lake Valley Formation outcrops in New Mexico and in allowing us to borrow from the Laudon collection. Dr. William Ausich of the Ohio State University provided a constructive review on the second chapter as well as helpful information throughout the writing of the first two chapters.

I would lastly like to thank Dr. Thomas Kammer, my Ph.D. adviser, for the help and advice that he provided throughout the identification of crinoids and the writing process. He made a significant contribution to this research with his seemingly endless knowledge on crinoids.

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Chapter 1:
Systematic review of camerate crinoids of the lower Mississippian Lake Valley Formation (Nunn
Member, Osagean), New Mexico

Elizabeth C. Rhenberg and Thomas W. Kammer

ABSTRACT

The Nunn Member (Early Osagean) of the Lake Valley Formation of New Mexico is known for its abundance of crinoids. Although the formation was first described in the late 1800's, there has not been a comprehensive study on its crinoids, and a complete list of the crinoid genera does not exist. All subclasses of crinoids occur in the Lake Valley, but the camerates are by far the dominant group. Study of the Macurda collection from the University of Michigan, the Laudon collection from the University of New Mexico, and what was personally collected in the field has provided more than 7000 specimens to be examined, 4500 of which were identifiable camerates. Sixty-one species of camerates have been recorded in the Nunn Member, including five new species: *Blairocrinus macurdai*, *Iotacrinus novamexicana*, *Agaricocrinus alamogordoensis*, *Uperocrinus kuesi*, and *Collicrinus laudoni*. These camerates share a high similarity with the lower Burlington Limestone of the Mississippi Valley. An update of the crinoid genera in the Lake Valley Formation allow for a better understanding and easier correlation of crinoid faunas across North American during the Early Mississippian. The majority of the camerates are in the western outcrops where the Nunn is thicker and the environment was shallower but several are found in association with the deep water Waulsortian mounds for which the Lake Valley Formation is famous. By using Jaccard Coefficient and Non-Metric Multidimensional Scaling, a difference in crinoid preferences for shallower or deeper water is demonstrated.

INTRODUCTION

The Lake Valley Formation occurs on either side of the Rio Grande Rift of southern New Mexico and consists of six members: Andrecito, Alamogordo, Nunn, Tierra Blanca, Arcente and Dona Ana (Laudon and Bowsher, 1949). The formation has a rich Early Mississippian fauna, especially crinoids, that are well preserved (Kues, 1986). However, despite their abundance, relatively little work has been published on the Lake Valley crinoids. The crinoids have only been mentioned in general faunal lists of the formation (Anonymous, 1881; Miller, S. A., 1881; Cope, 1882; Springer, 1884; Kues, 1986; 2008), as a part of larger studies on crinoids (Wachsmuth and Springer, 1897; Bowsher, 1955; Brower, 1965), or in microcrinoid studies (Strimple and Koenig, 1956; Lane, Sevastopulo, and Strimple, 1985). Information is so incomplete and outdated that several relatively abundant genera identified during this study are not listed from the Lake Valley Formation in Webster's (2003) Index.

The focus of this study will be the camerate crinoids. Although examples of all Paleozoic crinoid subclasses are in the Lake Valley, the camerates are the most abundant crinoids not only in generic richness, but also in number of specimens collected (>95%). Webster's (2003) Index only lists 14 genera and 25 species of camerates reported in previous literature. The camerates identified in this study have increased the number to 32 genera and 63 species, or 129% and 152%, respectively. The number of species described herein is much closer to the number that Kues (1986) reported (61 species), although he did not list those known species, nor does he specify how many fall into the different subclasses of crinoids. Kues (2008) mentioned that more than 100 species of crinoids have been reported, but only a third have been described and

illustrated. This study will focus on just the Nunn Member of the Lake Valley Formation.

Crinoids occur in all six members, but the Nunn Member holds the classic crinoid fauna (Laudon and Bowsher, 1949), representing the overwhelming majority of known specimens.

The crinoids that make up the bulk of the specimens studied are on loan from the University of Michigan. They were collected by Dr. Brad Macurda and his students while he worked at the University of Michigan in the 1960's and 1970's. The collection consists of more than 7,000 specimens of crinoids that were collected from more than 45 different sites in southern New Mexico (Fig. 1.1). Additional specimens from the Laudon collection are on loan from the University of New Mexico.

LOCALITY AND STRATIGRAPHY

The study area is located on either side of the Rio Grande Rift in southern New Mexico, near Lake Valley, NM in the western Black Range and Alamogordo, NM in the eastern Sacramento Mountains (Fig. 1.1, 1.2-3). Most of the collecting was done in the western part of the formation where the Nunn Member is thickest.

The Nunn Member is a highly fossiliferous, soft, blue-grey to greenish-grey nodular packstone to wackestone interbedded with shales and argillaceous limestones (Laudon and Bowsher, 1949; Jicha, 1954; Pray, 1951; Kues, 1986; Frank *et al.*, 1996; Brezinski, 2000). The exposures are best in the western extent of the Lake Valley Formation, becoming as thick as 60m near Santa Rita (Kues, 1986). In the Sacramento Mountains, the Nunn is thickest in the north (3m; Laudon and Bowsher, 1949), thinning southward until it eventually disappears (Lane, H. R., 1982; 1984). The difference in thickness is due to a change in paleogeographic setting. The

Nunn Member in the Sacramento Mountains represents biohermal flank beds, on to the well studied Waulsortian Mounds, and was deposited in deeper water along the shelf break (Brezinski, 2000). In the Black Range, the Nunn Member was deposited as a level bottom facies in a shelf environment.

Conodont biostratigraphy indicates correlation of the Lake Valley Formation to the Burlington Limestone in Iowa. H. R. Lane (1974) divided the Mississippian strata of New Mexico into 11 faunal units based on the conodonts. His correlations placed the Nunn Member as equivalent to the Fern Glen Formation and the lower part of the Burlington Limestone (Lane and Brenckle, 2001), which is conodont faunal unit 3 (Fig. 1.2).

FAUNAL ANALYSIS

One goal of this study is to determine if there were any differences between the crinoids on either side of the Rio Grande Rift. The crinoids to the east are associated with deeper-water Waulsortian Mounds. These mounds grew on the outer ramp, below wave base (Jeffery and Stanton, 1996). The crinoids to the west lived in a shallower shelf environment (Brezinski, 2000), similar to the Burlington Shelf. The difference in environments could be a cause for a difference in crinoid distribution (Fig. 1.3).

The localities were divided based on the information provided by Macurda and Laudon on their specimen labels and grouped so that localities near to each other in the same topographic feature were combined for analysis. By doing this, the number of localities was reduced to a manageable 18 as opposed to 54 (Macurda's 45 localities and 9 Laudon localities). These 18 localities account for 98% of the camerates studied. The other 2% have no locality information

(other than a statement that says they come from the Lake Valley Formation) or were found in the San Andres Mountains, which are difficult to access because they lie in the White Sands Missile Range where access is restricted by the U. S. military. Specimens from San Andres Mountains account for only 0.2% of the total amount.

Most of the localities (15) are in the western portion of the field area. All localities in Sierra County are technically part of the Black Range, but specific names are given where possible. Locality names are based on the Macurda or Laudon labels, but all localities were not given a site name. The two collecting localities that generated the largest number of specimens (M-15 and M-17) were not given a location name and thus remain as occurring in the Black Range. The undefined Black Range localities are between the P A Mountain localities and the Tierra Blanca Mountain localities (Fig. 1.4).

Several specimens from Laudon's collection were collected at Pryor Nunn Ranch, now known as Tierra Blanca Ranch. The ranch is located on Tierra Blanca Mountain, therefore all of those specimens are given the locality name of Tierra Blanca Mountain to prevent confusion for any future ranch name changes. Cook Range is located south of the Black Range in Luna County (Fig. 1.1).

Laudon's location of Wittenburg Ranch Windmill Section is unknown. There are no geographic coordinates on the labels, so it is unclear as to the location of the ranch. An internet search placed a Wittenburg Ranch near Separ, NM (Fig. 1.1) in Grant County, and according to Laudon and Bowsher (1949) the Lake Valley Formation does outcrop in that area. Therefore, Wittenburg Ranch has very tentatively been placed outside Separ, NM (Fig. 1.1). To confuse matters more, there are some specimens that have labels saying the Windmill Section is part of

the Pryor Nunn Ranch localities. There may have been a mistake in labeling, multiple Windmill Sections, or a single Windmill Section shared among two collecting sites. Though the exact location of Laudon's Wittenburg Ranch locality may not be known, it is certainly in the western portion of the study area.

The localities listed as being Indian Wells Canyon, Marble Canyon, and Grapevine Canyon are all in the eastern outcrops of the formation. These canyons are a feature of the Sacramento Mountains in Otero County (Fig. 1.4).

All locality information that is available for the collecting sites is listed in Appendices 1 and 2.

Presence-absence data were used with the Jaccard Coefficient for Non-Metric Multidimensional Scalding (MDS), using PAST software (Hammer *et al.*, 2001), to compare the two regions of the study area. Two of the localities (Berenda Canyon and Wilson Ranch) only had a single taxon each, which caused them to be outliers in the original plot. To expand the cluster of other localities, these two were dropped, taking the locality total down to 16, with 13 in the western portion of the study area. By discarding the two outliers, relationships among the main group of localities (Fig. 1.5) became more clear. The three eastern localities separate themselves from the western localities. This separation suggests that there was a difference, even if it was slight, between the crinoids in the shallower and deeper waters of the Lake Valley Formation.

The crinoids unique to the eastern localities make up a very small percentage of the total number of crinoids from the Lake Valley. The most abundant of these is *Abatocrinus clypeatus* (Hall, 1859) with four specimens. The genus *Abatocrinus* (*A. clypeatus* along with *A. aequalis*

(Hall, 1858)) only occurs in the deeper water setting. Most species unique to the east; *Cactocrinus multibrachiatus* (Hall, 1858), *Eutrochocrinus lovei* (Wachsmuth and Springer, 1881), *Agaricocrinus bullatus* Hall, 1858, *Agaricocrinus alamogordoensis* n sp., and *Oenochoacrinus cortina* (Miller and Gurley, 1894); are each known only by a single specimen. *Platycrinites burlingtonensis* (Owen and Shumard, 1850) is represented by three specimens. There are three specimens (*Uperocrinus* sp., *Dichocrinus* sp., and *Strimplecrinus* sp.) that are poorly preserved making it possible that these species may occur in other areas of the Lake Valley Formation. However, when these three specimens are removed from the data there is no significant difference in the MDS distribution of the localities.

Considering the large number of specimens collected and studied from the western part of the formation, it is likely that these few species from the east preferred a different habitat. The quieter waters may have been favored by these species, or they thrived better away from competition of the shallow water environment. Preservation of the crinoids is probably not an issue because the Indian Wells Canyon specimens are the most fragile of all collecting localities. With Indian Wells Canyon having the most fragile and yet the highest number of species unique to the east, it is doubtful that this is a taphonomic artifact where these species were just not preserved in the western region of the study area.

SYSTEMATIC PALEONTOLOGY

Terminology follows Ubaghs (1978). Materials examined are identified as follows: All M localities were collected by Dr. Macurda and his students in the 1960s and 1970s for the

University of Michigan. Indiana University specimens were part of the borrowed Macurda collection, collected by A. S. Horowitz and J. H. Johnson. These specimens will remain with the Macurda collection to be housed at the University of Michigan. A few USNM specimens were also part of the borrowed Macurda collection and will be returned to the United States National Museum of Natural History in Washington, D.C. once this study is complete. The USNM numbers associated with the genus *Nunnacrinus* are housed in the Springer Collection at the Smithsonian. Kues specimens were those collected by Dr. Barry Kues at the University of New Mexico that he was kind enough to allow to be studied and will be returned to him at the conclusion of this study. Laudon specimens are those collected by Dr. Lowell Laudon and are on loan from the University of New Mexico. Those specimens collected in the field by the authors in 2009 are labeled FC (for Field Collection) and will be sent with the Michigan samples. UMMP numbers are those from the University of Michigan that have been assigned to holotypes, paratypes, and all illustrated specimens.

The number of specimens associated with each locality number is indicated . Specimen numbers are represented after the number by (xN) where N is equal to the number of specimens.

Occurrence information includes the 18 localities used for the faunal analysis information as well as formation and state names for the species that occur outside of the Lake Valley Formation (Table 1.1). For more details on locality information, see Webster's Index (2003).

Synonymies (except where noted) are from Webster (2003).

Class CRINOIDEA Miller, 1821

Subclass CAMERATA Wachsmuth and Springer, 1885

Order DIPLOBATHRIDA Moore and Laudon, 1943

Suborder EUDIPLOBATHRINA Ubaghs, 1953

Superfamily RHODOCRINITACEA Roemer, 1855

Family RHODOCRINITIDAE Roemer, 1855

Genus RHODOCRINITES Miller, 1821

Type species.—*Rhodocrinites verus* Miller, 1821; by subsequent designation (Roemer, 1855).

Diagnosis.—Calyx low globe, sides nearly vertical or diverging upward, plates typically have stellate ornamentation; base flattened or concave; basals large; radials commonly smaller than basals, larger than primibrachials; one fixed secundibrachial, rarely more, in each ray; interrarial areas large, in contact with tegmen; CD interrarial wider than others; tegmen flat, composed of many small plates; anal tube short, eccentric.

RHODOCRINITES TUBERCULATUS (Wachsmuth and Springer, 1897)

Figure 1.7.1-1.7.2

Rhodocrinus tuberculatus WACHSMUTH AND SPRINGER, 1897, p. 232, pl. 13, figs. 3-4; MILLER, S. A., 1897, p. 752; WELLER, 1898, p. 528.

Rhodocrinites tuberculatus (Wachsmuth and Springer, 1897). BASSLER AND MOODEY, 1943, p. 665; MOORE AND LAUDON, 1944, p. 185, pl. 73, fig. 6; WEBSTER, 1973, p. 232; WEBSTER, 2003.

Diagnosis.—Basals smaller than radials; radials large with long tubercles directed obliquely downward; primibrachials large; tegmen plates large and irregularly arranged.

Material examined.—M-7(1966) (x1), M-17 (x1), M-80(1971) (x1), M-87 (x1), M-94 (x1), Kues1 (x1), Indiana University 10565 (x3), and USNM 6408 (x1).

Discussion.—*Rhodocrinites tuberculatus* is similar to another species reported from the Nunn Member, *R. barrisi divergens* (Hall, 1861a). The differences between the two species are that *R. tuberculatus* has larger radials than basals, and distinct nodes extend from the radials. The basals are larger and contain the large nodes in *R. barrisi divergens*. The best taxonomic reference for *R. tuberculatus* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon, Black Range undefined, Apache Hill, and North Hollow Creek.

Genus CRIBANOCRINUS Kirk, 1944

Type species.—*Rhodocrinus wortheni* Hall, 1858; by original designation.

Diagnosis.—Calyx medium globe to bowl-shaped, constricted at arm level; base flattened or depressed; basals and radials large compared to primibrachials; one or two fixed secundibrachials in each half-ray; interradial areas narrow and constricted at arm level; CD interray wider than regular interrays; tegmen small, convex, made up of small plates; anus small, either marginal or eccentric, may be protuberant.

CRIBANOCRINUS URCEOLATUS (Wachsmuth and Springer, 1897)

Figure 1.7.3-1.7.4

Rhodocrinus wortheni var. *urceolatus* WACHSMUTH AND SPRINGER, 1897, p. 221, pl. 12, figs. 8a-8b.

MILLER, S. A., 1897, p. 752; WELLER, 1898, p. 529.

Rhodocrinites wortheni urceolatus (Wachsmuth and Springer, 1897). BASSLER AND MOODEY, 1943, p. 666.

Cribanocrinus urceolatus (Wachsmuth and Springer, 1897). KIRK, 1944, p. 15; BROWER, 1970, p. 488, figs. 79C-79D, pl. 67, figs. 3-4; WEBSTER, 1973, p. 87; WEBSTER, 1977, p. 59; UBAGHS in Moore and Teichert, 1978, p. T425, fig. 233, nos. 3c-3d; WEBSTER, 1986, p. 106; WEBSTER, 2003.

Diagnosis.—Calyx urn-shaped; tegmen flat; anus subcentral, not protuberant

Material examined.—M-13 (x5), M-15 (x43), M-16 (x1), M-17 (x50), M-19 (x6), M-91 (x4), M-92 (x3), M-94 (x1), M-95 (x4), M-100 (x1), M-150 (x1), M-153 (x1), M-154 (x1), M-158 (x7), FC14 (x4), Indiana University 10565 (x28), USNM 6408 (x13), and an unknown locality (x2)

Discussion.—*Cribanocrinus urceolatus* is similar to the type species *C. wortheni* but is distinguished by being more globe-shaped than bowl-shaped and having a wider tegmen with fewer plates. The best taxonomic references for *C. urceolatus* are Wachsmuth and Springer (1897) and Brower (1970).

Occurrence.—Tierra Blanca Mountain, Black Range undefined, Rock Springs, Apache Hill, between North Percha Creek and Mineral Creek, North Hollow Creek, Percha Creek Fork, Percha Creek, and 0 (Zero) Bar 0 (Zero) Canyon; and Mooney Falls Member of Redwall Limestone, Arizona (Brower, 1970).

Genus GILBERTSOCRINUS Philips, 1839

Figure 1.7.5

Material examined.—FC1(x1)

Discussion.—*Gilbertsocrinus* is questionably assigned to one specimen. Only a partial tegmen is preserved, but the plates have the ornamentation and arrangement consistent with *Gilbertsocrinus*. There are also features that may be the bases of the tubular tegmen appendages for which the genus is known for.

Occurrence.—North Percha Creek.

Order MONOBATHRIDA Moore and Laudon, 1943

Suborder COMPSOCRININA Ubaghs, 1978

Superfamily PERIECHOCRINACEA Bronn, 1849

Family PERIECHOCRINIDAE Bronn, 1849

Genus ARYBALLOCRINUS Breimer, 1962

Type species.—*Actinocrinus (Megistocrinus) whitei* Hall, 1861; by original designation.

Diagnosis.—Calyx low to medium bowl, with thin plates; radials high; primibrachials, two, first about half size of radial and hexagonal, second smaller than first, pentagonal and axillary; median ray ridges present in some species; one or two secundibrachials fixed in calyx; interbrachials 1-3 in regular interray with three ranges, not depressed; CD interray very wide; tegmen low; anus eccentric.

ARYBALLOCRINUS WHITEI (Hall, 1861a)

Figure 1.7.8-1.7.9

Actinocrinus (Megistocrinus) whitei HALL, 1861a, p. 271 (part); HALL, 1861b, p. 271 (part); HALL, 1861c, p. 271 (part); SHUMARD, 1868, p. 350; HALL, 1872b, pl. 4, figs. 4-5 (non fig. 6).

Actinocrinus whitii HALL, 1861. MILLER, S. A., 1889, p. 220 (sic).

Megistocrinus (Saccocrinus) whitei (Hall, 1861). MEEK AND WORTHEN, 1873, p. 397, pl. 6, fig. 1.

Periechocrinus whitei (Hall, 1861). WACHSMUTH AND SPRINGER, 1881, p. 133 (307); WHITFIELD, 1893, p. 27, pl. 2, fig. 29.

Periechocrinus? whitei (Hall, 1861). WACHSMUTH AND SPRINGER, 1897, p. 530, pl. 2, fig. 21; pl. 46, figs. 1-3; pl. 51, figs. 9-10; GRABAU AND SHIMER, 1910, p. 537, fig. 1866.

Periechocrinites whitei (Hall, 1861). WELLER, 1898, p. 417; BASSLER AND MOODEY, 1943, p. 601; MOORE AND LAUDON, 1944, p. 189, pl. 75, fig. 14.

Aryballoocrinus whitei (Hall, 1861). BREIMER, 1962, p. 72; WEBSTER, 1973, p. 59; UBAGHS in Moore and Teichert, 1978, p. T443, fig. 252, no. 1; LANE AND DUBAR, 1983, p. 117, fig. 3, nos. J, P; WEBSTER, 1986, p. 68; WEBSTER, 1988, p. 40; WEBSTER, 2003.

Actinocrinus olliculus Hall, 1861. MILLER, S. A., 1889, p. 219.

Actinocrinus (Megistocrinus) olliculus HALL, 1861b, p. 2; WELLER, 1898, p. 417; BASSLER AND MOODEY, 1943, p. 601.

Megistocrinus olliculus (Hall, 1861). SHUMARD, 1868, p. 380.

Actinocrinus (Pradocrinus) amplus MEEK AND WORTHEN, 1861, p. 133; WELLER, 1898, p. 417; BASSLER AND MOODEY, 1943, p. 601.

Actinocrinus (Pradocrinus?) amplus Meek and Worthen, 1861. SHUMARD, 1868, p. 342.

Actinocrinus (Saccocrinus?) amplus Meek and Worthen, 1861. MEEK AND WORTHEN, 1868b, p. 470, Pl. 16, fig. 2; WELLER, 1898, p. 417.

Actinocrinus amplus Meek and Worthen, 1861. MILLER, S. A., 1889, p. 217; MILLER, S. A., 1897, p. 730.

Saccocrinus amplus (Meek and Worthen, 1861). MILLER, S. A., 1889, p. 278; MILLER, S. A., 1897, p. 752.

Saccocrinus christyi (Hall, 1863). MILLER, S. A., 1889, p. 278.

Diagnosis.—Calyx plates smooth without ridges along brachials.

Material examined.—M-7(1966) (x1), M-9 (x1), M-15 (x16), M-16 (x1), M-17 (x29), M-19 (x3), M-22 (x11), M-95 (x6), M-158 (x2), FC7 (x1), FC8 (x1), and Laudon 14,030 (x1).

Discussion.—The specimens of *Aryballocrinus whitei* are identical to those illustrated from the Burlington Limestone. This species is characterized by its lack of ornamentation, having smooth calyx plates where other members of the genus have some form of ridge across the plates. The best taxonomic reference for *A. whitei* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon, Black Range undefined, Rock Springs, Tierra Blanca Mountain, Percha Creek, North Percha Creek, and Wittenberg Ranch Windmill Section; plus Hampton Formation, and lower and upper Burlington Limestone, Iowa.

ARYBALLOCRINUS TENUIDISCUS (Hall, 1861b)

Figure 1.7.6-1.7.7

Actinocrinus? tenuidiscus HALL, 1861b, p. 14; SHUMARD, 1868, p. 348; MILLER, S. A., 1889, p. 220; WELLER, 1898, p. 417.

Periechocrinus tenuidiscus (Hall, 1861). WACHSMUTH AND SPRINGER, 1897, p. 520, pls. 46, fig. 4; 51, fig. 6; WELLER, 1898c, p. 417.

Periechocrinites tenuidiscus (Hall, 1861). BASSLER AND MOODEY, 1943, p. 601.

Aryballocrinus tenuidiscus (Hall, 1861). BREIMER, 1962, p. 73; WEBSTER, 1973, p. 59; WEBSTER, 2003.

Diagnosis.—Calyx plates ornamented with ill-defined ridges; ridges along brachials more prominent.

Material examined.—M-22 (x1) and M-87 (x1).

Discussion.—*Aryballocrinus tenuidiscus* is very similar to the Kinderhookian *A. sampsoni* (Miller and Gurley, 1896) but has a different plate arrangement in the CD interray.

Aryballocrinus tenuidiscus has three plates overlying the primanal, followed by two rows of five plates, whereas *A. sampsoni* has three plates following the primanal with five plates above that, but the outer plates of the third range extend up to the tegmen with several (up to ten) smaller plates between them. The best taxonomic reference for *Aryballocrinus tenuidiscus* is Wachsmuth and Springer (1897).

Occurrence.—Apache Hill and Rock Springs; lower Burlington Limestone, Iowa.

Family AMPHORACRINIDAE Bather, 1899

Genus AMPHORACRINUS Austin, 1848

Type species.—*Actinocrinus gilbertsoni* Miller in Phillips, 1836; by subsequent designation (Roemer, 1855).

Diagnosis.—Calyx low cone to low bowl; strong calyx lobation; basal circlet low, visible in lateral view; one or two fixed secundibrachials proximal to arm lobe, none in arm lobe; primanal followed by two or three plates; tegmen higher than calyx, medium to high inverted bowl in shape, lobed; five large orals, four forming semicircle around CD oral; anal tube eccentric,

oriented obliquely upward; no long distal tegmen spines, but short spines ranging to nodes may exist.

AMPHORACRINUS RUPINUS Webster and Lane, 1987

Figure 1.8.1-1.8.2

Amphoracrinus rupinus WEBSTER AND LANE, 1987, p. 10, fig. 5, nos. 3-7; WEBSTER, 1993, p. 24; WEBSTER, 2003; AUSICH AND KAMMER, 2008, p. 1142.

Diagnosis.—Calyx low bowl; primanal followed by three plates.

Material examined.—M-15, M-17 (x2), M-19 (x2), M-22, M-95, and an unknown locality.

Discussion.—The specimens examined are in varying states of preservation, with most lacking tegmens. However, there are enough characteristics to confidently assign these specimens to this species.

Occurrence.—Black Range, Rock Springs, and Tierra Blanca Mountain; and Anchor Limestone, Nevada.

Genus ANCALOCRINUS Webster and Lane, 1987

Type species.—*Actinocrinus spinobrachiatus* Hall, 1859; by original designation

Diagnosis.—Calyx flat cone, distinctly lobed; basal circlet low, not visible in lateral view; one fixed secundibrachial in calyx; primanal followed by two plates; tegmen much higher than calyx, low to medium bowl in shape, not lobed; five large orals, four forming semicircle around CD oral; anal tube eccentric, oriented obliquely upward; long distal tegmen spines.

ANCALOCRINUS SPINOBRACHIATUS (Hall, 1859)

Figure 1.8.3-1.8.4

Actinocrinus spinobrachiatus HALL, 1859, p. 6, fig. 6; SHUMARD, 1868, p. 348.

Amphoracrinus? spinobrachiatus (Hall, 1859). MEEK AND WORTHEN, 1873, p. 389, pl. 6, figs. 5a-5c; WACHSMUTH AND SPRINGER, 1897, p. 591, pl. 62, figs. 1-4.

Amphoracrinus spinobrachiatus (Hall, 1859). MILLER, S. A., 1889, p. 223; WELLER, 1898, p. 83; GRABAU AND SHIMER, 1910, p. 527, fig. 1854.

Ancalocrinus spinobrachiatus (Hall, 1859). WEBSTER AND LANE, 1987, p. 17, fig. 7, nos. 11-13; WEBSTER, 1993, p. 25; WEBSTER, 2003; AUSICH AND KAMMER, 2008, p. 1144, fig. 2, nos. 1-3, 5, 6.

Actinocrinus inflatus HALL, 1859, p. 20, unnumbered fig.; SHUMARD, 1868, p. 344.

Amphoracrinus inflatus (Hall, 1859). MILLER, S. A., 1889, p. 223; WHITFIELD, 1893, p. 22, pl. 2, figs. 10-11; MILLER, S. A., 1897, p. 734; WELLER, 1898, p. 83; BASSLER AND MOODEY, 1943, p. 300.

Diagnosis.—See genus description.

Material examined.—M-13 (x4), M-15 (x21), M-17 (x2), M-18 (x1), M-19 (x2), M-22 (x37), M-87 (x3), M-91 (x2), M-92 (x1), M-94 (x1), M-95 (x7), M-99 (x1), M-100 (x3), M-101 (x1), M-158 (x1), Indiana University 10565 (x8), and an unknown locality (x1).

Discussion.—*Ancalocrinus spinobrachiatus* has been described on either side of the Lake Valley Formation, both to the east in the Burlington Limestone and to the west in the Anchor Limestone. Its occurrence in the Nunn Member fills in a geographic gap between the

aforementioned formations. The best taxonomic reference for *A. spinobrachiatus* is Wachsmuth and Springer (1897).

Occurrence.—Tierra Blanca Mountain, Black Range, Rock Springs, Apache Hill, between North Percha Creek and Mineral Cree, North Hollow Creek, Percha Creek Fork, and Cooks Range; lower Burlington Limestone, Iowa; and Anchor Limestone, Nevada.

ANCALOCRINUS SP.

Figure 1.8.5-1.8.6

Material examined.—M-86.

Discussion.—This specimen does not have a complete tegmen, making a full comparison to *Ancalocrinus spinobrachiatus* impossible, but differs by having the basals visible in side view. This may be a variation of *A. spinobrachiatus*.

Occurrence.—Apache Hill.

Genus DISPLODOCRINUS Webster and Lane, 1987

Type species.—*Actinocrinus divergens* Hall, 1859; by original designation.

Diagnosis.—Calyx flat cone to flat bowl, strongly lobate; basal circlet flat, not visible in lateral view; fixed secundibrachial in arm lobe, none in calyx; primanal followed by three plates; tegmen higher than calyx, high cone to high inverted bowl in shape, not lobed; five large orals, four spinose orals forming semicircle around CD oral; anal tube eccentric, oriented obliquely upward; long distal tegmen spines.

DISPLODOCRINUS DIVERGENS (Hall, 1859)

Figure 1.8.7-1.8.8

Actinocrinus divergens HALL, 1859, p. 36; SHUMARD, 1868, p. 343.

Amphoracrinus divergens (Hall, 1859). MEEK AND WORTHEN, 1868a, p. 348; MEEK AND WORTHEN, 1873, p. 388, pl. 6, fig. 6; MILLER, S. A., 1889, p. 223; WHITFIELD, 1893, p. 21, pl. 2, figs. 12-13; KEYES, 1894, p. 166, pl. 22, fig. 4; WACHSMUTH AND SPRINGER, 1897, p. 588, pl. 62, figs. 5-10; WELLER, 1898, p. 82; GRABAU AND SHIMER, 1910, p. 527, fig. 1853; BASSLER AND MOODEY, 1943, p. 299; MOORE AND LAUDON, 1943, p. 139, pl. 10, fig. 13; MOORE AND LAUDON, 1944, p. 191, pl. 77, fig. 28; WEBSTER, 1973, p. 50.

Dispolodocrinus divergens (Hall, 1859). WEBSTER AND LANE, 1987, p. 25; WEBSTER, 1993, p. 52; WEBSTER, 2003; AUSICH AND KAMMER, 2008, p. 1146, fig. 3.1-3.7.

Amphoracrinus divergens var. *multiramosus* WACHSMUTH AND SPRINGER, 1897, p. 588; WELLER, 1898, p. 82; BASSLER AND MOODEY, 1943, p. 299.

Actinocrinus planobasalis HALL, 1859, p. 1; SHUMARD, 1868, p. 347; HALL, 1872b, pl. 4, figs. 10-11; MILLER, S. A., 1889, p. 219; WELLER, 1898, p. 82; BASSLER AND MOODEY, 1943, p. 299.

Amphoracrinus planobasalis (Hall, 1859). MEEK AND WORTHEN, 1868a, p. 348; MILLER, S. A., 1889, p. 223; MILLER, S. A., 1897, p. 734; BASSLER AND MOODEY, 1943, p. 299.

Actinocrinus quadrispinus WHITE, C. A., 1862 (adv. pub.); WHITE, C. A., 1865, p. 15; SHUMARD, 1868, p. 347; MILLER, S. A., 1889, p. 219; WELLER, 1898, p. 82; BASSLER AND MOODEY, 1943, p. 299; WEBSTER AND LANE, 1987, p. 25.

?*Actinocrinus quadrispinus* WHITE, 1862; WEBSTER AND LANE, 1987, p. 25; WEBSTER, 1993, p. 52.

Amphoracrinus quadrispinus (White, 1862). MILLER, S. A., 1889, p. 223; WACHSMUTH AND SPRINGER, 1889, pl. 18, fig. 13.

Diagnosis.—Calyx flat bowl; basals not visible in lateral view.

Material examined.—M-7 (1966) (x1), M-13 (x1), M-15 (x5), M-17 (x8), M-19 (x5), M-22 (x9), M-91 (x2), M-92 (x1), M-95 (x5), Kues1 (x1), Indiana University 10565 (x1), Unknown locality (x1), Laudon 13,567 (x1), and Laudon 13,905 (x2).

Discussion.—*Displodocrinus divergens* is different from the other two species of the genus, *D. nevadensis* (Webster and Lane, 1987) and *D. monticulus* Webster and Lane, 1987 by having a basal circlet that is not visible in lateral view. The basal circlet of *D. divergens* is flat and not projecting outward. The best taxonomic reference for *D. divergens* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon, Marble Canyon, Tierra Blanca Mountain, Black Range, Rock Springs, between North Percha Creek and Mineral Creek, Apache Hill, and Wittenberg Ranch Windmill Section; lower Burlington Limestone, Iowa; Anchor Limestone, Nevada; and Cuyahoga Formation, Ohio.

DISPLODOCRINUS NEVADENSIS (Webster and Lane, 1987)

Figure 1.8.9-1.8.10

Sunwaptacrinus nevadensis WEBSTER AND LANE, 1987, p. 22, fig. 7, nos. 1-5; WEBSTER, 1993, p. 114; WEBSTER, 2003.

Displodocrinus nevadensis (Webster and Lane, 1987). AUSICH AND KAMMER, 2008, p. 1146.

Diagnosis.—Calyx low bowl; basals visible in lateral view

Material examined.—M-17 (x1).

Discussion.—*Displodocrinus nevadensis* is similar to *D. monticulus* in that both have a low bowl-shaped calyx with basals visible in lateral view. However, the radials and primibrachials of *D. nevadensis* are much wider than high than those of *D. monticulus*.

Occurrence.—Black Range; and Anchor Limestone, Nevada.

Family ACTINOCRINITIDAE Austin and Austin, 1842

Subfamily ACTINOCRINITINAE Austin and Austin, 1842

Genus AACOCRINUS Bowsher, 1955

Type species.—*Aacocrinus nododorsatus* Bowsher, 1955; by original designation.

Diagnosis.—Calyx medium bowl to medium cone; basal circlet low; radial circlet high; one or two fixed secundibrachials; arms grouped; arm lobes short, extend laterally; interrays in contact with tegmen; no fixed interradians between half-rays; tegmen low arched, lower than calyx; anal tube eccentric; few, large tegmen plates; no tegmen spines; interradian regions of tegmen not depressed.

AACOCRINUS NODODORSATUS Bowsher, 1955

Figure 1.9.1-1.9.2

Aacocrinus nododorsatus BOWSHER, 1955, p. 5, pl. 1, figs. 2-3; figs. 1-2; BROWER, 1967, p. 685, pl. 76, figs. 12, 15-16; figs. 1, nos. A, D; 3, no. A; WEBSTER, 1973, p. 29; UBAGHS in Moore and Teichert, 1978, p. T169, Fig. 140, no. 4; BOWSHER in Moore and Teichert, 1978, p. T455, Fig. 262, no. 1; WEBSTER, 1986, p. 40; WEBSTER, 2003.

Diagnosis.—Calyx cone-shaped; two arm facets to each ray; interradial areas wide; tegmen plates few, large, nodose.

Material examined.—Indiana University 10565 (x1).

Discussion.—Although this is a species thus far known only from the Kinderhookian, the description of *Aacocrinus nododorsatus* best fits one of the specimens of *Aacocrinus* from the Nunn Member.

Occurrence.—Apache Hill; and Chouteau Limestone, Compton Limestone, Missouri.

AACOCRINUS ENIGMATICUS Webster and Lane, 1987

Figure 1.9.3-1.9.4

Aacocrinus enigmaticus WEBSTER AND LANE, 1987, p. 15, fig. 5, nos. 12-16; WEBSTER, 1993, p. 19; WEBSTER, 2003.

Diagnosis.—Calyx bowl-shaped; two arm facets to each ray; interradial areas not wide; tegmen plates many, small to medium, nodose.

Material examined.—Indiana University 10565 (x2).

Discussion.—Although *Aacocrinus* typically has large plates on the tegmen and *A. enigmaticus* has tegmen plates that are small to medium, the rest of the characters agree with the genus. Webster and Lane (1987, p. 15) discussed the differences between this species and the rest of the genus and why they place this species in this genus.

Occurrence.—Apache Hill; and Anchor Limestone, Nevada.

Genus BLAIROCRINUS Miller, 1891

Type species.—*Blairocrinus trijugis* Miller, 1891; by original designation.

Diagnosis.—Calyx low cone; basals low, form flattened disc; one fixed secundibrachial; arms grouped; arm lobes short, extend laterally; interrays in contact with tegmen; no fixed interradians between half-rays; tegmen higher than calyx; anal tube central; tegmen commonly composed of few large plates; proximal tegmen spines; interradian regions of tegmen not depressed.

BLAIROCRINUS MACURDAI n. sp.

Figure 1.9.5-1.9.6, Table 1.2

Diagnosis.—Arm lobes not protuberant; many medium-sized tegmen plates; tegmen plates spinose to nodose

Description.—Calyx small, low bowl. Arms moderately grouped. Calyx plates with multiple radiating ridges. Basal circlet 11 percent of calyx height. Basals small, three, equal in size. Radial circlet 40 percent of calyx height. Radials hexagonal, wider than high. Tegmen higher than calyx; conical. Tegmen composed of many medium to small spinose to nodose plates. Anal tube central to eccentric. Primal hexagonal, smaller than radials, followed by 2,3,2,2 plates. Interrays in contact with tegmen. First interradian hexagonal, followed by two plates. First primibrachial hexagonal, wider than high. Second primibrachial axillary, supporting two arm facets each.

Material examined.—UMMP 74065 (holotype); UMMP 74066, UMMP 740067 (paratypes); M-9 (x1), M-15 (x1), M-19 (x1), M-22 (x2), M-80(1971) (x1), M-92 (x1), M-94 (x1), M-95 (x3), M-101 (x1), M-158 (x1).

Discussion.—*Blairocrinus macurdai* n. sp. is most similar to *B. arrosus* Miller, 1892 (Table 1.3); however, the arm rays are not as protuberant as they are in *B. arrosus*. The ratio is determined by taking the measurements from center of the calyx to the edge of the interbrachial depression and from the center of the calyx to the edge of the ray. For *B. macurdai* this ratio is from 1.05 to 1.30, whereas in *B. arrosus* the ratio is 1.26 to 1.30 (Fig. 1.9). *Blairocrinus arrosus* has a much more constrained range than *B. macurdai*. There is only slight overlap between the two species, with *B. macurdai* generally having lower ratios and, therefore, having less protuberant arm rays.

Occurrence.—Indian Wells Canyon, Black Range undefined, Rock Springs, Apache Hill, North Hollow Creek, Tierra Blanca Mountain, Percha Creek, Percha Creek Fork, and Wilson's Ranch.

Etymology.—The trivial name recognizes Dr. Brad Macurda who collected most of the studied specimens during the 1960's and 1970's.

Genus IOTACRINUS Ausich and Sevastopulo, 2001

Type species.—*Actinocrinus dorsatus* de Koninck and LeHon, 1854; by original designation.

Diagnosis.—Calyx low bowl; basals low; one fixed secundibrachial; arms grouped; arm lobes medium in length, extend laterally; interrays in contact with tegmen; no fixed interradians between half-rays; calyx as high or higher than tegmen; anal tube eccentric; many medium-size tegmen plates; no tegmen spines; interradian regions of tegmen not depressed.

Discussion.— The occurrence of *Iotacrinus* in the Lake Valley Formation is the first recorded finding of *Iotacrinus* in North America. Other members of this genus are known only from Western Europe.

IOTACRINUS NOVAMEXICANA n. sp.

Figure 1.9.7-1.9.8, Table 1.4

Diagnosis.—Calyx low to medium bowl; tegmen as high or slightly higher than calyx.

Description.—Calyx small, low bowl. Arms strongly grouped, extended into short arm lobes. Calyx plates with multiple radiating ridges. Basals small, three, equal in size. Basal circlet accounts for 10 percent of calyx height. Radial circlet is 35 percent of calyx height. Radials hexagonal, wider than high. Tegmen as high or slightly higher than calyx, lobed, inflated. Tegmen plates are numerous, medium in size, smooth to slightly nodose. Anal tube eccentric. Primanal hexagonal, slightly narrower than radials, followed by 2,3 plate formula. Interrays in contact with tegmen. First interrarial hexagonal, followed by two plates. First primibrachial hexagonal, wider than high. Second primibrachial axillary, supporting one arm facet each. Arms and column not known.

Material examined.—UMMP 74068 (holotype); UMMP 74069, UMMP 74070 (paratypes); M-15 (x2), M-16 (x1), M-158 (x1), and Indiana University 10565 (x1).

Discussion.—*Iotacrinus novamexicana* shares characters of both actinocrinitids and amphoracrinidids. The calyx is undoubtedly of the actinocrinitid family based on shape, plates, and ornamentation, but the tegmen more closely resembles *Amphoracrinus* than any other known North American actinocrinitid. *Iotacrinus novamexicana* somewhat resembles the type species *I.*

dorsatus (Table 1.5), but the tegmen is much higher and more distinctly lobed, like the tegmens of *Amphoracrinus*.

One specimen has a higher calyx that is more conical than bowl shaped, but the other features remain constant to the species. Therefore, this specimen is considered to be a variation and not a separate species.

Occurrence.—Black Range undefined, Apache Hill, and Percha Creek.

Etymology.—The trivial name recognizes the state of New Mexico.

Genus STEGANOCRINUS Meek and Worthen, 1866

Type species.—*Actinocrinus pentagonus* Hall, 1858; by original designation.

Diagnosis.—Calyx medium cone; basal circlet low or high; radials high; primibrachial highest fixed brachial; arms grouped; interrays in contact with tegmen; fixed interbrachials between half-rays; tegmen flat to low arched to same height as calyx, composed of few, large plates; anal tube eccentric.

STEGANOCRINUS PENTAGONUS (Hall, 1858)

Figure 1.9.9-1.8.10

Actinocrinus pentagonus HALL, 1858, p. 577, pl. 10, figs. 6a-6b; SHUMARD, 1868, p. 346; MILLER, S. A., 1889, p. 219; WELLER, 1898, p. 600.

Steganoocrinus pentagonus (Hall, 1858). MEEK AND WORTHEN, 1866, p. 254; MEEK AND WORTHEN, 1868b, p. 474, pl. 16, fig. 8; MILLER, S. A., 1889, p. 282, fig. 430; KEYES, 1894, p. 195, pl. 24, fig. 9; WACHSMUTH AND SPRINGER, 1897, p. 579, pls. 4, fig. 12; 61, figs. 3a-4b; WELLER,

1898, p. 600; GRABAU AND SHIMER, 1910, p. 529; WILSON, H. E., 1916, p. 509, pl. 3, figs. 1-3; KIRK, 1943, p. 261, figs. 1-2; BASSLER AND MOODEY, 1943, p. 683; MOORE AND LAUDON, 1943, p. 139, pl. 10, fig. 12; MOORE AND LAUDON 1944, p. 193, pl. 77, fig. 6; LAUDON, 1948, pl. 3; SPRENG AND PARKS, 1953, p. 594, fig. 1, nos. f-h; BROWER, 1965, p. 776, pl. 91, figs. 1-15; pl. 92, figs. 1-37; fig. 1; BROWER, 1967, p. 683, pl. 76, fig. 9; BROWER, 1970, p. 494, pl. 64, figs. 6, 10, 13; fig. 80, nos. B-D; LAUDON, 1973, p. 29, fig. 5; HAUGH, 1973, p. 90, pl. 3, fig. 3; WEBSTER, 1973, p. 242; HAUGH, 1975b, p. 267, fig. 4, no. C; WEBSTER, 1977, p. 158; UBAGHS *in* Moore and Teichert, 1978a, p. T144, T179, T194, fig. 116, no. 3; fig. 151, no. 5; fig. 164, no. 3; BOWSER *in* Moore and Teichert, 1978, p. T455, fig. 263, no. 4; WEBSTER, 1986, p. 288; WEBSTER, 2003.

Actinocrinus araneolus MEEK AND WORTHEN, 1860, p. 387; SHUMARD, 1868, p. 342; MILLER, S. A., 1889, p. 217; WELLER, 1898, p. 599.

Steganocrinus araneolus (Meek and Worthen, 1860). MEEK AND WORTHEN, 1866a, p. 198, pl. 15, figs. 1a-1b; MILLER, S. A., 1889, p. 282; WACHSMUTH AND SPRINGER, 1897, p. 581, pl. 61, figs. 2a-2b; WELLER, 1898, p. 599; GRABAU AND SHIMER, 1910, p. 528; KIRK, 1943, p. 260, fig. 4; BASSLER AND MOODEY, 1943, p. 683; BROWER, 1965, p. 776; LAUDON, 1973, p. 29, fig. 5; WEBSTER, 1973, p. 242.

Steganocrinus arraneolus (Meek and Worthen, 1860) (sic). WEBSTER, 1977, p. 157.

Diagnosis.—Calyx medium cone and constricted above basals; plates strongly to weakly stellate, nodose or weakly tumid; basal circlet high; tegmen low arched.

Material examined.—M-5 (x2), M-6 (x6), M-7(1966) (x3), M-7(1972) (x3), M-9 (x1), M-13 (x32), M-15 (x323), M-16 (x6), M-17 (x267), M-18 (x5), M-19 (x52), M-21 (x2), M-22 (x90),

M-73 (x3), M-80 (x6), M-86 (x8), M-87 (x21), M-91 (x52), M-92 (x20), M-93 (x5), M-94 (x51), M-95 (x154), M-98 (x5), M-100 (x17), M-101 (x2), M-102 (x1), M-151 (x8), M-153 (x1), M-154 (x7), M-155 (x4), M-157 (x1), M-158 (x34), M-159 (x2), Barry2 (x1), FC2 (x2), FC9 (x2), Indiana University 10565 (x113), an unknown locality (x3), USNM 6408 (x1), USNM (x6), Laudon 14,031 (x6), Laudon 14,062 (x1), Laudon 13,918 (x15), Laudon 13,999 (x1), Laudon 14,022 (x10), and Laudon 13,567 (x2).

Discussion.—*Steganocrinus pentagonus* is the most abundant crinoid in the Nunn Member. The numerous specimens have the full range of variation found within the species. While most of the specimens are undoubtedly *S. pentagonus*, there are a handful of specimens that fall into the range of two other species: *S. altus* Brower, 1965 and *S. longus* Brower, 1965.

Brower (1965) stated that *Steganocrinus altus* is distinguished from *S. pentagonus* by having a more conical calyx, but all other aspects of *S. altus* are the same as *S. pentagonus*. The illustration of the paratype for *S. altus* (Brower, 1965, pl. 93, fig. 7) is identical to an illustrated *S. pentagonus* (Brower, 1965, pl. 92, fig. 29). Similarly, *S. longus* differs in shape of the calyx from *S. pentagonus*. The calyx of *S. longus* is more box-like and less cone-shape than *S. pentagonus*. Brower (1965) stated that *S. longus* also has calyx plates that are highly tumid as well as high ambulacral tracts. These two characteristics occur in *S. pentagonus* as well. It is possible that these two species are variations within the total range of *S. pentagonus*, but until further studies can be done, they will remain as separate species. The best taxonomic reference for *S. pentagonus* is Brower (1965).

Occurrence.—Indian Wells Canyon, Marble Canyon, San Andres Canyon, Trujillo Creek, Black Range undefined, Tierra Blanca Mountain, Rock Springs, Apache Hill, between North

Percha Creek and Mineral Creek, Percha Creek Fork, Percha Creek, North Percha Creek, 0 Bar 0 Canyon, Wittenberg Ranch Windmill Section, and Cooks Range; lower Burlington Limestone, Iowa; and Fern Glen Limestone, Missouri.

Subfamily CACTOCRINIAE Ubaghs, 1978

Genus CACTOCRINUS Wachsmuth and Springer, 1897

Type species.—*Actinocrinus proboscidualis* Hall, 1858; by original designation.

Diagnosis.—Calyx medium cone; basal circlet low; radials low; one fixed secundibrachial; arms not grouped; arm lobes absent; four to eight arms in each ray; interrays not in contact with tegmen; fixed interradians between half-rays present; tegmen and calyx approximately same height; anal tube central.

CACTOCRINUS PROBOSCIDIALIS (Hall, 1858)

Figure 1.11.1-1.11.2

Actinocrinus proboscidualis HALL, 1858, p. 584, pl. 10, fig. 13; HALL, 1859, pl. 3, fig. 2; SHUMARD, 1868, p. 347; MEEK AND WORTHEN, 1869, p. 440; MEEK AND WORTHEN, 1873, p. 328, pl. 9, figs. 7a-7c, 78a-8b; ZITTEL, 1880, p. 334, 369, figs. 229, 257, nos. a-d; MILLER, S. A., 1889, p. 219, fig. 234; NEUMAYR, 1889, p. 465, fig. 135; KEYES, 1890, pl. 8, fig. 2; STEINMANN AND DÖDERLEIN, 1890, p. 153, figs. 156, nos. B-C; 157, nos. B-C; KEYES, 1894, p. 185, pl. 20, fig. 2; pl. 24, fig. 1; LAHUSEN, 1895, p. 140, fig. 189, nos. a-c; ZITTEL, 1895, p. 119, 128, fig. 232, nos. A-C; fig. 246, nos. A-D; MILLER, S. A., 1897, p. 731; WELLER, 1898, p. 156; WACHSMUTH *in* Zittel, 1900, p. 124, 142, figs. 220, 232, 243, no. A; STEINMANN, 1903, p. 177, fig. 246, nos. B-C;

STEINMANN, 1907, p. 189, fig. 281, nos. B-C; BASSLER, 1938, p. 55; BASSLER AND MOODEY, 1943, p. 343.

Actinocrinus (Cactocrinus) proboscidialis HALL, 1858; STEINMANN, 1907, p. 189, fig. 267, nos. B-C.

Cactocrinus proboscidialis (Hall, 1858). WACHSMUTH AND SPRINGER, 1897, p. 601, pl. 5, fig. 10; pl. 58, figs. 3-7d; WELLER, 1898, p. 156; BATHER *in* Lankester, 1900, p. 129, fig. 44; GRABAU AND SHIMER, 1910, p. 526, figs. 1805, 1851; KIRK, 1911, pl. 5, figs. 4-5; SPRINGER *in* Zittel, 1913, p. 174, figs. 268, 280, 299-A; MOORE, 1939, p. 243, fig. 13, no. 2; BASSLER AND MOODEY, 1943, p. 343; MOORE AND LAUDON, 1944, p. 191, pl. 77, fig. 3; WEBSTER, 1973, p. 72; HAUGH, 1975a, p. 476, pl. 1, fig. 3; UBAGHS *in* Moore and Teichert, 1978, p. T154, T179, fig. 127, no. 1; fig. 152, no. 2; BOWSER *in* Moore and Teichert, 1978, p. T458, fig. 266, nos. 1a-1b; WOLF, 1979, p. 150, fig. 1, nos. g-h; WEBSTER, 1986, p. 83; WEBSTER, 2003.

Batocrinus proboscidialis (Hall, 1858). MILLER, S. A., 1897, p. 738.

Cactocrinus proboscidialis (Hall, 1858). SIEVERTS-DORECK, 1952, p. 424, fig. 2; UBAGHS, 1953, p. 739, fig. 22, no. e.

Actinocrinus quaternarius HALL, 1859, p. 22, unnumbered fig; SHUMARD, 1868, p. 347; WHITFIELD, 1881, p. 7, pl. 1, figs. 1-3; MILLER, S. A., 1889, p. 219; MILLER, S. A., 1897, p. 731; WELLER, 1898, p. 156; BASSLER AND MOODEY, 1943, p. 343.

Actinocrinus lagena HALL, 1861b, p. 13; SHUMARD, 1868, p. 345; MILLER, S. A., 1889, p. 218; WACHSMUTH AND SPRINGER, 1897, p. 453, pl. 35, fig. 4; Weller, 1898, p. 156; BASSLER AND MOODEY, 1943, p. 343.

Actinocrinus quaternarius var. *spinigerus* HALL, 1861b, p. 11; SHUMARD, 1868, p. 347; MILLER, S. A., 1889, p. 219; WELLER, 1898, p. 156; BASSLER AND MOODEY, 1943, p. 343.

Actinocrinus themis HALL, 1861b, p. 11; SHUMARD, 1868, p. 349; MILLER, S. A., 1889, p. 220; BASSLER AND MOODEY, 1943, p. 343.

Diagnosis.—Radials wider than long; first primibrachials larger than second; tegmen conical; tegmen about as high as calyx, plates large, spinous or nodose, separated by smaller, convex plates.

Material examined.—M-9 (x1), M-13 (x1), M-19 (x1), M-95 (x1), Laudon 13,998 (x1), and Laudon 13,578 (x2).

Discussion.—The specimens of *Cactocrinus proboscidualis* in the Nunn Member closely resemble those illustrated from the Burlington Limestone. Calyx plates have variation in ornamentation, ranging from being only slightly nodose to having distinct stellate ornamentation. The *C. proboscidualis* specimens from the Nunn Member fall between these two extremes. The best taxonomic reference for *C. proboscidualis* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon, Marble Canyon, Tierra Blanca Mountain, Black Range undefined, and Wittenberg Ranch Windmill Section; Chouteau Limestone, Missouri; and lower Burlington Limestone, Iowa.

CACTOCRINUS MULTIBRACHIATUS (Hall, 1858)

Figure 1.11.3-1.11.4

Actinocrinus multibrachiatus HALL, 1858, p. 580, pl. 10, fig. 10; fig. 85; SHUMARD, 1868, p. 346; MILLER, S. A., 1889, p. 219; WELLER, 1898, p. 155.

Cactocrinus multibrachiatus (Hall, 1858). WACHSMUTH AND SPRINGER, 1897, p. 617, pl. 56, figs. 6-7; pl. 58, fig. 8; WELLER, 1898, p. 155; BASSLER AND MOODEY, 1943, p. 342; MOORE AND LAUDON, 1943, p. 140, pl. 11, fig. 1; MOORE AND LAUDON, 1944, p. 191, pl. 77, fig. 2; WEBSTER, 1973, p. 71; BOWSHER *in* Moore and Teichert, 1978, p. T458, fig. 266, no. 1c; WEBSTER, 1986, p. 82; WEBSTER, 2003.

Actinocrinus multibrachiatus var. *echinatus* HALL, 1861b, p. 10; MILLER, S. A., 1889, p. 219; WELLER, 1898, p. 155; BASSLER AND MOODEY, 1943, p. 342.

Diagnosis.—Radials nearly as high as wide; second primibrachials larger than first; tegmen depressed conical; tegmen lower than calyx, plates largest near anal tube smallest near arm bases; nodose.

Material examined.—M-80(1971) (x1).

Discussion.—Although the tegmen is not complete on this specimen, it is evident from the angle of what is preserved that it is much lower than the calyx. The best taxonomic reference for *Cactocrinus multibrachiatus* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon; and lower Burlington Limestone, Iowa.

Genus CUSACRINUS Wachsmuth and Springer, 1897

Type species.—*Actinocrinus nodobrachiatus* Wachsmuth and Springer *in* Miller, 1889; by original designation.

Diagnosis.—Calyx steeply conical; basal circlet low; radials high; one fixed secundibrachial; arms weakly grouped; arm lobes absent; primanal slightly smaller than radials; interrays in

contact with tegmen; fixed interradians between half-rays present; tegmen low arched to conical; large plated; anal tube central to subcentral.

CUSACRINUS SOBRINUS (Miller and Gurley, 1896c) n. comb.

Figure 1.11.5-1.11.6

Actinocrinus sobrinus MILLER AND GURLEY, 1896c, p. 10, pl. 3, figs. 4-5; MILLER, S. A., 1897, p. 731; WELLER, 1898, p. 63.

Actinocrinites sobrinus (Miller and Gurley, 1896). BASSLER AND MOODEY, 1943, p. 274; WEBSTER, 2003.

Diagnosis.—Four arms per ray; tegmen depressed, convex, lacking spinose plates; anal tube small, subcentral.

Material examined.—Indiana University 10565 (x1), and an unknown locality (x1).

Discussion.—*Actinocrinites sobrinus* (Miller & Gurley, 1896c) is moved to the genus *Cusacrinus* for a lack of arm lobes, arms that are weakly grouped, and a tegmen that is lower than the calyx. It is conceivable that *A. spectabilis* (Miller & Gurley, 1896c) and *A. subscitulus* (Miller & Gurley, 1896c) can be synonymized into one species with *Cusacrinus sobrinus*, but until further investigations can be done, they will remain as separate species.

Occurrence.—Apache Hill; and Burlington Limestone, Iowa.

CUSACRINUS TENUISCUPTUS (McChesney, 1861)

Figure 1.11.7-1.11.8

Actinocrinus tenuisculptus MCCHESENEY, 1861, p. 15; MCCHESENEY, 1868, p. 11, pl. 5, figs. 1a-1b; unnumbered fig. p. 12; MILLER, S. A., 1889, p. 220; WACHSMUTH AND SPRINGER, 1897, p. 571, pl. 55, figs. 4a-4b; WELLER, 1898, p. 64.

Actinocrinites tenuisculptus (McChesney, 1861). BASSLER AND MOODEY, 1943, p. 275; LAUDON, 1973, p. 29, Fig. 5.

Cactocrinus tenuisculptus (McChesney, 1861). KIRK, 1943c, p. 346.

Cusacrinus tenuisculptus (McChesney, 1861). BOWSHER, 1955, p. 16; WEBSTER, 1973, p. 94; WEBSTER, 2003.

Diagnosis.—Six arms per ray; tegmen subpyramidal with spinose plates; anal tube large, central.

Material examined.—M-22 (x1), Indiana University 10565 (x1), and Laudon 14,920 (x1).

Discussion.—Two specimens of *Cusacrinus tenuisculptus* are known from the Nunn Member collections, and of the two, only one is well preserved. That specimen has only four arms per ray, which contradicts the descriptions of the species that say there are six arms per ray. However, illustrations by Wachsmuth and Springer (1897, pl. 55, figs. 4a-4b) indicate that the armless *C. tenuisculptus* appears to only have four arms per ray, whereas the armed specimen shows six. The inner arms bifurcate immediately after leaving the calyx, creating the six arms. If the arms break right at the calyx, then it appears that there are only four arms per ray.

It may be possible to synonymize *Actinocrinites plagosus* (Miller & Gurley, 1893) with *Cusacrinus tenuisculptus*. The single illustration and description of *A. plagosus* is reminiscent of the calyx of *C. tenuisculptus*. *A. plagosus* is also lacking a tegmen; and because both species

occur in the lower Burlington, it is plausible they are the same. But, more work will need to be done before that synonymy can be decided.

Occurrence.—Rock Springs, Apache Hill, and Tierra Blanca Mountain; Chouteau Limestone, Missouri; and Burlington Limestone, Iowa.

Genus NUNNACRINUS Bowsher, 1955

Type species.—*Nunnacrinus mammillatus* Bowsher, 1955; by original designation.

Diagnosis.—Calyx low to medium cone; basal circlet low; radials low; one fixed secundibrachial; arms weakly grouped; interrays in contact with tegmen; fixed interbrachials between half-rays; tegmen low to approximately as high as calyx; anal tube central.

NUNNACRINUS DALYANUS (Miller, 1881) n. comb.

Figure 1.11.9-1.11.10

Actinocrinus dalyanus MILLER, S. A., 1881, p. 309, pl. 7, figs. 1-1a; MILLER, S. A., 1889, p. 217; WELLER, 1898, p. 156.

Nunnacrinus dalyanus (Miller, 1881). BOWSHER, 1955, p. 18; WEBSTER, 2003.

Actinocrinus delayanus (Miller, 1881) (sic). BOWSHER, 1955, p. 18; WEBSTER, 1973, p. 182.

Nunnacrinus delayanus (Miller, 1881). BOWSHER, 1955, p. 18 (sic); WEBSTER, 1973, p. 182.

Nunnacrinus mammillatus BOWSHER, 1955, p. 19, pl. 3, figs. 6-7; pl. 6, figs. 2-3; fig. 3, nos. A-D;

WEBSTER, 1973, p. 182; BOWSHER in Moore and Teichert, 1978, p. T460, fig. 267, no. 2;

WEBSTER, 1986, p. 219; WEBSTER, 2003.

Diagnosis.—Calyx conical; tegmen as high as calyx, conical.

Material examined.—M-5 (x2), M-6 (x5), M-7(1966) (x5), M-9 (x2), M-13 (x12), M-15 (x136), M-16 (x7), M-17 (x119), M-18 (x2), M-19 (x37), M-21 (x3), M-22 (x40), M-73 (x2), M-80 (x2), M-86 (x6), M-87 (x15), M-91 (x17), M-92 (x13), M-93 (x2), M-94 (x5), M-95 (x73), M-97 (x2), M-99 (x1), M-100 (x8), M-102 (x2), M-151 (x1), M-154 (x1), M-155 (x3), M-158 (x40), M-159 (x2), FC11 (x1), Indiana University 10565 (x61), an unknown locality (x3), USNM 6431 (x1), Laudon 14,042 (x2), Laudon 14,041 (x1), Laudon 14,290 (x2), Laudon 14,022 (x1), Laudon 13,999 (x1), Laudon 13,559 (x1), Laudon 14,077 (x1), Laudon 13,998 (x10), Laudon 13,578 (x4), Laudon 14,028 (x7), and Laudon 13,817 (x2). USNM Specimens: S4622 (x1), S4621 (x1), S4623 (x1), S4619 (x4), S4618 (x10), 435908 (x1), 435904 (x1), 435907 (x1), 435905 (x1), 435906 (x1), 435912 (x1), 160619 (x1), 435910 (x1), 160618 (x1), 435911 (x1), 435923 (x1), 435903 (x1), 435898 (x1), 160604 (x1), 160617 (x1), 435909 (x1), 435895 (x1), 435899 (x1), 435897 (x1), 435900 (x1), 435901 (x1), 448071 (x1), 160602 (x1), 114695 (x1), S4620 (x4), S1218 (x3), 118032 (x1), 118028 (x5), 118030 (x2), 118026 (x2), 118027 (x1), 118029 (x1), and 118031 (x1).

Discussion.—Bowser (1955, p. 20) stated that *Nunnacrinus dalyanus* and *N. mammillatus* are readily separable from each other based on the number of plates that separate the rays (one plate and two plates respectively), different sizes, how conical the calyces and tegmens are, and how regular the size of the tegmen plates are. However, after comparing the 663 specimens in the Macurda and Laudon collections, as well as comparing the 61 in the Springer Room of the Smithsonian, it has been determined that the two species are the same. There is no set pattern for the interradial plates between the arm facets, with many having both single and double plates between the rays (Fig. 1.11), and the entire interradial area has a wide variety of plate

arrangements (Appendix 3). The other ways of supposed easy separation are likewise indistinguishable, showing the range of variability. The best taxonomic reference for *N. dalyanus* is Brower (1955).

The location of the type specimens is not known; and, therefore, a neotype has been established as UMMP 74074 (Fig. 1.10.9-1.10.10).

Occurrence.—Indian Wells Canyon, Marble Canyon, San Andres Canyon, Trujillo Creek, Tierra Blanca Mountain, Black Range undefined, Rock Springs, Apache Hill, between North Percha Creek and Mineral Creek, Percha Creek Fork, Percha Creek, North Hollow Creek, O Bar O Canyon, Cooks Range, and Wittenberg Ranch Windmill Section.

Genus TELEIOCRINUS Wachsmuth and Springer, 1881

Type species.—*Actinocrinus umbrosus* Hall, 1858; by original designation.

Diagnosis.—Calyx medium cone, plates nodose or stellate; basal circlet high; radial circlet high; one fixed secundibrachial; arms not grouped; arm lobes absent; interrays not in contact with tegmen; fixed interradians between half-rays present; tegmen lower than calyx; anal tube central.

TELEIOCRINUS UMBROSUS (Hall, 1858)

Figure 1.13.1-1.13.2

Actinocrinus umbrosus HALL, 1858, p. 590, pl. 11, figs. 3a-3b; fig. 89; SHUMARD, 1868, p. 349;

QUENSTEDT, 1876, p. 571, pl. 110, fig. 28; MILLER, S. A., 1889, p. 220; WELLER, 1898, p. 628.

Strotocrinus umbrosus (Hall, 1858). MEEK AND WORTHEN, 1873, p. 149 (323); MILLER, S. A., 1889, p. 284; WELLER, 1898, p. 628.

Teleiocrinus umbrosus (Hall, 1858). WACHSMUTH AND SPRINGER, 1881, p. 149 (323); KEYES, 1890, pl. 8, fig. 4; WACHSMUTH AND SPRINGER, 1897, p. 628, pl. 4, fig. 11; pl. 5, figs. 3-4; pl. 59, fig. 7; pl. 60, figs. 2a-2d; WELLER, 1898, p. 628; GRABAU AND SHIMER, 1910, p. 528, fig. 1855; WILSON, H. E., 1916, p. 508, pl. 1, figs. 1-6; VAN TUYL, 1925, p. 123, 131, pl. 4, fig. 11; BASSLER AND MOODEY, 1943, p. 707; MOORE AND LAUDON, 1943b, p. 140, pl. 11, fig. 5; MOORE AND LAUDON, 1944, p. 193, pl. 77, fig. 1; LAUDON, 1948, pl. 3 (part); SPRENG AND PARKS, 1953, p. 586, fig. 1, no. i; WEBSTER, 1973, p. 255; MACURDA, 1974, p. 829; BROWER, 1974b, p. 19, fig. 13, nos. 1-3; BURKE, 1975a, p. 483, pl. 1, fig. 10; pl. 2, fig. 11; pl. 3, fig. 10; WEBSTER, 1977, p. 167; UBAGHS in Moore and Teichert, 1978, p. T201, fig. 170, no. 2; BROWER in Moore and Teichert, 1978, p. T251, fig. 201, nos. 1-3; BOWSER in Moore and Teichert, 1978, p. T460, fig. 268, no. 1; WEBSTER, 1986, p. 301; WEBSTER, 2003.

Actinocrinites umbrosus (Hall, 1858). WELLER, 1898, p. 628.

Actinocrinites delicatus MEEK AND WORTHEN, 1870, p. 156; MEEK AND WORTHEN, 1873, p. 343, pl. 8, fig. 2; MEEK, 1874, p. 192; BASSLER AND MOODEY, 1943, p. 707.

Actinocrinus delicatus (Meek and Worthen, 1870). MEEK, 1874, p. 192; MILLER, S. A., 1889, p. 217; WELLER, 1898, p. 628.

Actinocrinus aeglops HALL, 1859, p. 5, unnumbered fig; WELLER, 1898, p. 628; BASSLER AND MOODEY, 1943, p. 707.

Teleiocrinus aeglops (Hall, 1859). WELLER, 1898, p. 628; BASSLER AND MOODEY, 1943, p. 707.

Teleiocrinus aegilops (Hall, 1859) (sic). SHUMARD, 1868, p. 341; MILLER, S. A., 1889, p. 217, 286.

Strotocrinus aegilops (Hall, 1859) (sic). MILLER, S. A., 1897, p. 753.

Teleocrinus aegilops (Hall, 1859) (sic). WHITFIELD, 1893, p. 21, pl. 2, figs. 27-28.

Actinocrinus rudis HALL, 1859a, p. 33; SHUMARD, 1868, p. 347; MILLER, S. A., 1889, p. 219;

WELLER, 1898, p. 628; BASSLER AND MOODEY, 1943, p. 707.

Teleiocrinus rudis (Hall, 1859). WACHSMUTH AND SPRINGER, 1881, p. 149 (323), pl. 19, fig. 11;

MILLER, S. A., 1889, p. 286; WACHSMUTH AND SPRINGER, 1897, p. 630, pl. 5, fig. 1; pl. 59, figs.

1-3; WELLER, 1898, p. 628; BASSLER AND MOODEY, 1943, p. 707; MOORE AND LAUDON, 1943b, p.

140, pl. 11, fig. 6; MOORE AND LAUDON, 1944, p. 193, pl. 77, fig. 11; LAUDON, 1948, pl. 3 (part);

WEBSTER, 1973, p. 255; MACURDA, 1974, p. 829; BURKE, 1975a, p. 483, pl. 1, fig. 5; pl. 5, fig.

9; HAUGH, 1975b, p. 269, fig. 5, no. 7; fig. 6, no. 6; fig. 7, no. D; WEBSTER, 1977, p. 167;

UBAGHS in Moore and Teichert, 1978, p. T195, fig. 164, no. 5; WEBSTER, 1986, p. 301.

Teleiocrinus rudis GOOD, 1968 (*non* Hall, 1858), pl. 1, fig. 7; WEBSTER, 1977, p. 167.

Actinocrinus clivosus HALL, 1861a, p. 274; HALL, 1861c, p. 274; SHUMARD, 1868, p. 350; MILLER,

S. A., 1889, p. 217; WELLER, 1898, p. 628; BASSLER AND MOODEY, 1943, p. 707.

Teleiocrinus clivosus (Hall, 1861). MILLER, S. A., 1889, p. 286.

Actinocrinus erodus Hall, 1861. WELLER, 1898, p. 628.

Actinocrinus (Calathocrinus) erodus HALL, 1861b, p. 12; SHUMARD, 1868, p. 344; MILLER, S. A.,

1889, p. 218; BASSLER, 1938, p. 56; BASSLER AND MOODEY, 1943, p. 707.

Teleiocrinus erodus (Hall, 1861). MILLER, S. A., 1889, p. 286.

Actinocrinus insculptus HALL, 1861. MILLER, S. A., 1889, p. 218; WELLER, 1898, p. 628.

Actinocrinus (Calathocrinus) insculptus HALL, 1861b, p. 12; SHUMARD, 1868, p. 344; BASSLER AND

MOODEY, 1943, p. 707.

Teleocrinus insculptus (Hall, 1861). MILLER, S. A., 1889, p. 286.

Diagnosis.—Calyx plates nodose.

Material examined.—Laudon 14,284 (x1).

Discussion.—The occurrence of *Teleocrinus umbrosus* in the Lake Valley Formation indicates the species originated earlier than once thought. It has previously been known from the upper Burlington Limestone but not the lower portion, which is correlative with the Nunn Member. The best taxonomic reference for *T. umbrosus* is Wachsmuth and Springer (1897).

Occurrence.—Tierra Blanca Mountain; and upper Burlington Limestone, Iowa.

Subfamily PHYSETOCRININAE Ubaghs, 1978

Genus PHYSETOCRINUS Meek and Worthen, 1869

Type species.—*Actinocrinus ventricosus* Hall, 1858; by subsequent designation (Wachsmuth and Springer, 1881).

Diagnosis.—Calyx medium-bowl to medium-cone shape; basal circlet high; radials large; tertibrachial to quartibrachial highest fixed brachials; arms grouped, lobed in early species, less so in later species; interrays in contact with tegmen; fixed intrabrachial between half-rays; tegmen lower than calyx; no anal tube; anal opening eccentric.

PHYSETOCRINUS COPEI (Miller, 1881)

Figure 1.13.5-1.13.6

Actinocrinus copei MILLER, S. A., 1881, p. 310, pl. 7, figs. 2-2b; WELLER, 1898, p. 426.

Physetocrinus copei (Miller, 1881). MILLER, S. A., 1889, p. 269, fig. 390; WACHSMUTH AND SPRINGER, 1897, p. 598, pl. 63, fig. 5; WELLER, 1898, p. 426; BASSLER AND MOODEY, 1943, p. 610; BROWER, 1970, p. 501, pl. 65, figs. 3-4; fig. 82, nos. A-B; WEBSTER, 1977, p. 135; WEBSTER, 2003.

Diagnosis.—Calyx conical, approximately equidimensional; basals with sutures slightly grooved; tegmen hemispherical, gently convex, not lobate; anal opening elevated slightly above tegmen.

Material examined.—M-5 (x1), M-6 (x7), M-13 (x6), M-15 (x225), M-16 (x5), M-17 (x149), M-18 (x3), M-19 (x30), M-21 (x2), M-22 (x107), M-80 (x3), M-86 (x1), M-87 (x9), M-89 (x1), M-91 (x37), M-92 (x8), M-94 (x14), M-95 (x62), M-98 (x1), M-99 (x3), M-100 (x1), (x6), M-101 (x2), M-102 (x2), M-151 (x3), M-152 (x1), M-154 (x1), M-155 (x2), M-158 (x36), M-159 (x1), FC3 (x3), FC6 (x4), Indiana University 10565 (x2), an unknown locality (x5), Laudon 14,061 (x1), Laudon 13,923 (x1), Laudon 13,803 (x10), Laudon 14,062 (x1), Laudon 14,065 (x1), Laudon 14,250 (x9), Laudon 13,619 (x4), Laudon 14,072 (x1), Laudon 14,059 (x1), and Laudon 14,042 (x2).

Discussion.—*Physetocrinus copei* is one of the most abundant crinoid species in the Nunn Member, second only to *Steganocrinus pentagonus* based on the collections studied. The number of specimens allow for studying the amount of variation within the species. The tegmen, especially, has a wide range of variation; ranging from slightly convex to rather inflated (Fig. 1.13). Specimens that have inflated tegmens have similarity to *P. majusculus* Webster and Lane, 1987 but do not have any other significant differences from *P. copei* and should remain as *P. copei*. It may well be that *P. majusculus* is a variation of *P. copei*, but until further investigations

can be made, the two will remain separate species. The best taxonomic reference for *P. copei* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon, Marble Canyon, Grapevine Canyon, Trujillo Creek, Tierra Blanca Mountain, Black Range undefined, Rock Springs, Apache Hill, between North Percha Creek and Mineral Creek, Percha Creek Fork, Percha Creek, North Percha Creek, North Hollow Creek, 0 Bar 0 Canyon, Wittenberg Ranch Windmill Section, and Cooks Range; and Thunder Springs Member or Mooney Falls Member of Redwall Limestone, Arizona.

PHYSETOCRINUS LOBATUS Wachsmuth and Springer, 1897

Figure 1.13.3-1.13.4

Physetocrinus lobatus WACHSMUTH AND SPRINGER, 1897, p. 599, pl. 63, figs. 8a-8b; MILLER, S. A., 1897, p. 749; WELLER, 1898, p. 427; BASSLER AND MOODEY, 1943, p. 610; MOORE AND LAUDON, 1944, p. 193, pl. 77, fig. 8; LAUDON, 1948, pl. 3; BOWSHER, 1954, p. 113, figs. 1-3; WEBSTER, 1973, p. 206; BROWER, 1970, p. 504, pl. 65, figs. 5-14; fig. 82, nos. C-K; WEBSTER, 1977, p. 135; WEBSTER, 2003.

Diagnosis.—Calyx conical with straight or slightly rounded sides, strongly necked base; basals with small notches at sutures; tegmen almost flat to gently convex, distinctly lobate; anal opening elevated slightly bulging, opens anteriorly.

Material examined.—M-6 (x2), M-13 (x2), M-15 (x76), M-16 (x1), M-17 (x105), M-18 (x1), M-19 (x22), M-22 (x17), M-86 (x1), M-87 (x10), M-89 (x2), M-91 (x5), M-92 (x5), M-93 (x3), M-94 (x12), M-95 (x29), M-98 (x1), M-100 (x3), M-151 (x7), M-154 (x1), M-158 (x4), M-159

(x1), FC5 (x1), FC15 (x2), Indiana University 10565 (x16), an unknown locality (x2), USNM 6409 (x1), USNM (x4), Laudon 13,999 (x1), and Laudon 13,803 (x1).

Discussion.—*Physetocrinus lobatus* differs from other members of the genus by having distinct lobes on the tegmen. Other species, such as *P. ornatus* (Hall, 1858) and *P. asper* (Meek and Worthen, 1870), have grooves at the arm openings, but these grooves do not extend across the whole of the tegmen. The lobes of *P. lobatus* are more deeply grooved and can be followed to the anal opening. The best taxonomic reference for *P. lobatus* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon, Marble Canyon, Tierra Blanca Mountain, Black Range undefined, Rock Springs, Apache Hill, between North Percha Creek and Mineral Creek, Percha Creek Fork, Percha Creek, North Percha Creek, 0 Bar 0 Canyon, North Hollow Creek, and Wittenberg Ranch Windmill Section; and Thunder Springs Member or Mooney Falls Member of Redwall Limestone, Arizona.

Superfamiy CARPOCRINACEA de Koninck and Le Hon, 1854

Family BATOCRINIDAE Wachsmuth and Springer, 1881

Genus ABATOCRINUS Lane, 1963

Type species.—*Actinocrinus turbinatus* Hall, 1858; by original designation.

Diagnosis.—Calyx high, sides straight or gently concave; basal and radial circlets high and prominent; interrays not in contact with tegmen; tegmen as high or lower than calyx; anal tube stout and central.

ABATOCRINUS AEQUALIS (Hall, 1858)

Figure 1.13.7-1.13.8

Actinocrinus aequalis HALL, 1858, p. 592, pl. 11, figs. 4a-4b; fig. 90; SHUMARD, 1868, p. 341;

MILLER, S. A., 1889, p. 217; WELLER, 1898, p. 123.

Actinocrinus (Batocrinus) aequalis (Hall, 1858). ROEMER, C. F., 1876, pl. 40, fig. 5; FRECH, 1902,

pl. 40, fig. 5; BASSLER AND MOODEY, 1943, p. 321.

Batocrinus aequalis (Hall, 1858). MILLER, S. A., 1889, p. 227; MILLER, S. A., 1897, p. 735;

WACHSMUTH AND SPRINGER, 1897, p. 371, pl. 28, figs. 5-6; WELLER, 1898, p. 123; SCHMIDT, H.,

1929, p. 83, pl. 20, fig. 13; BASSLER AND MOODEY, 1943, p. 321; LAUDON, 1973, p. 27, fig. 3;

WEBSTER, 1977, p. 47.

Abatocrinus aequalis (Hall, 1858). LANE, N. G., 1963, p. 696; WEBSTER, 1973, p. 30; WEBSTER,

2003; AUSICH AND KAMMER, 2010, p. 40.

Batocrinus aequabilis MILLER AND GURLEY, 1893, p. 25, pl. 5, figs. 13-15 (sic); BASSLER AND

MOODEY, 1943, p. 332.

Actinocrinus discoideus HALL, 1858, p. 594, Pl. 2, fig. 9.

Actinocrinus discoidues (Hall, 1858) (sic). SHUMARD, 1868, p. 343.

Batocrinus discoideus (Hall, 1858). MILLER, S. A., 1889, p. 227; WHITFIELD, 1893b, p. 14, pl. 1,

figs. 19-20; WELLER, 1898, p. 135; BASSLER AND MOODEY, 1943, p. 332.

Actinocrinus formosus HALL, 1859, p. 30, unnumbered fig; SHUMARD, 1868, p. 344; HALL, 1872c,

pl. 3-A, fig. 1; MILLER, S. A., 1889, p. 218; WELLER, 1898, p. 135; BASSLER AND MOODEY, 1943,

p. 332; LANE, N. G., 1963, p. 696; WEBSTER, 1973, p. 30.

Batocrinus formosus (Hall, 1859). MILLER, S. A., 1889, p. 228.

Actinocrinus subaequalis MCCHESNEY, 1861, p. 17; MCCHESNEY, 1865, pl. 5, figs. 7a-7b;

MCCHESNEY, 1868, p. 13, pl. 5, figs. 7a-7b; unnumbered fig. p. 14; SHUMARD, 1868, p. 348..

Batocrinus subaequalis (McChesney, 1861). MILLER, S. A., 1889, p. 228; WACHSMUTH AND

SPRINGER, 1897, p. 369, pl. 4, fig. 10; pl. 28, figs. 7-9; WELLER, 1898, p. 135; GRABAU AND

SHIMER, 1910, p. 541; BASSLER AND MOODEY, 1943, p. 332; MOORE AND LAUDON, 1943, p. 140,

pl. 11, fig. 10; MOORE AND LAUDON, 1944, p. 195, pl. 75, fig. 5; LAUDON, 1948, pl. 2; LAUDON,

1973b, p. 27, fig. 3; WEBSTER, 1973, p. 66; WEBSTER, 1977, p. 47.

Abatocrinus subaequalis (McChesney, 1861). ROSE, 1967, p. 24, pl. 17, fig. 6; WEBSTER, 1977, p.

47; WOLF, 1983, p. 170, pl. 23, fig. 3.

Actinocrinus doris HALL, 1861b, p. 15; SHUMARD, 1868, p. 343; MILLER, S. A., 1889, p. 218;

WELLER, 1898, p. 123; BASSLER AND MOODEY, 1943, p. 321.

Batocrinus doris (Hall, 1861). MILLER, S. A., 1889, p. 227.

Diagnosis.—Calyx same height as tegmen; both calyx and tegmen are medium cone-shaped.

Material examined.—Laudon 13,822 (x1) and Laudon 14,261 (x1).

Discussion.—*Abatocrinus aequalis* and *A. clypeatus* are associated with the deeper water sediments of the Nunn Member. This suggests this genus preferred the quieter waters associated with the Waulsortian mounds instead of the slightly more turbulent waters of the shallow shelf.

The best taxonomic reference for *A. aequalis* is Wachsmuth and Springer (1897).

Occurrence.—Marble Canyon; Chouteau Limestone, Missouri; and lower Burlington Limestone, Iowa.

ABATOCRINUS CLYPEATUS (Hall, 1859)

Figure 1.15.1-1.15.2

Actinocrinus clypeatus HALL, 1859, p. 12, unnumbered figure; SHUMARD, 1868, p. 343; HALL, 1872b, pl. 3, fig. 12; WEBSTER, 1973, p. 31.

Batocrinus clypeatus (Hall, 1859). MILLER, S. A., 1889, p. 227; WACHSMUTH AND SPRINGER, 1889, p. 342, pl. 18, fig. 5; WACHSMUTH AND SPRINGER, 1897, p. 380, pl. 27, figs. 8a-8e; WELLER, 1898, p. 125; GRABAU AND SHIMER, 1910, p. 541; BASSLER AND MOODEY, 1943, p. 323; LAUDON, 1973b, p. 27, figs. 3-4; HAUGH, 1975a, p. 484, pl. 5, fig. 5; HAUGH, 1975b, p. 267, fig. 5, no. 1; fig. 6, no. 7; WEBSTER, 1977, p. 47.

Abatocrinus clypeatus (Hall, 1859). LANE, N. G., 1963, p. 697; WEBSTER, 1973, p. 31; UBAGHS *in* Moore and Teichert, 1978, p. T214, fig. 184, no. 3; WEBSTER, 1986, p. 41; WEBSTER, 2003; AUSICH AND KAMMER, 2010, p. 40.

Actinocrinus inornatus HALL, 1859, p. 24; SHUMARD, 1868, p. 344.

Batocrinus inornatus (Hall, 1859). MILLER, S. A., 1889, p. 228; WHITFIELD, 1893, p. 15, pl. 2, figs. 1-3; WACHSMUTH AND SPRINGER, 1897, p. 380, pl. 5, fig. 17; WELLER, 1898, p. 125; BASSLER AND MOODEY, 1943, p. 323.

Actinocrinus papillatus HALL, 1859, p. 29, unnumbered figure; SHUMARD, 1868, p. 346; HALL, 1872c, pl. 3-A, figs. 10-11; MILLER, S. A., 1889, p. 219; WELLER, 1898, p. 125; BASSLER AND MOODEY, 1943, p. 323.

Batocrinus papillatus (Hall, 1859). MILLER, S. A., 1889, p. 228.

Batocrinus quasillus MEEK AND WORTHEN, 1868a, p. 351; MEEK AND WORTHEN, 1873, p. 367, pl. 5, figs. 2a-2b; MILLER, S. A., 1889, p. 228; WACHSMUTH AND SPRINGER, 1897, p. 372, pl. 28, figs.

4a-4b; WELLER, 1898, p. 132; BASSLER AND MOODEY, 1943, p. 329; LANE, 1963, p. 697;

WEBSTER, 1973, p. 31.

Batocrinus comparilis MILLER, S. A., 1892a, p. 675; MILLER, S. A., 1892b, p. 32, pl. 5, figs. 18-20; MILLER, S. A., 1894, p. 286, pl. 5, figs. 18-19; WELLER, 1898, p. 125.

Batocrinus aspratilis MILLER AND GURLEY, 1893, p. 21, pl. 5, figs. 4-6; MILLER, S. A., 1897, p. 735; WELLER, 1898, p. 125; BASSLER AND MOODEY, 1943, p. 323.

Diagnosis.—Calyx higher than tegmen; sides of calyx concave.

Material examined.—M-7 (1966) (x1) and Laudon 13,557 (x3).

Discussion.—Basals are not preserved in any of the specimens. The concave sides of the calyx make *Abatocrinus clypeatus* distinct from the similar species *A. turbinatus* (Hall, 1858), which has much straighter sides and less of an overhang at arm level. The best taxonomic reference for *A. clypeatus* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon and Marble Canyon; Chouteau Limestone, Missouri; and lower Burlington Limestone, Iowa.

Genus ERETMOCRINUS Lyon and Casseday, 1859

Type species.—*Eretmocrinus magnificus* Lyon and Casseday, 1859; by original designation.

Diagnosis.—Calyx low, broad; basals low, form projecting rim; interrays not in contact with tegmen; tegmen as high or higher than calyx, asymmetric and bulging, highest anteriorly, flattened posteriorly; anal tube short and curved in some species.

ERETMOCRINUS CORBULIS (Hall, 1861a)

Figure 1.15.3-1.15.4

Actinocrinus corbulis HALL, 1861a, p. 265; HALL, 1861b, p. 1; HALL, 1861c, p. 265; SHUMARD, 1868, p. 343.

Eretmocrinus corbulis (Hall, 1861). MILLER, S. A., 1889, p. 243; KEYES, 1894a, p. 175, pl. 23.

WACHSMUTH AND SPRINGER, 1897, p. 399, pl. 36, figs. 5-6; MILLER, S. A., 1897, p. 744; WELLER, 1898, p. 249; BASSLER AND MOODEY, 1943, p. 456; WEBSTER, 1977, p. 79; WEBSTER, 2003; AUSICH AND KAMMER, 2010, p. 43.

Eretmocrinus corbulus (Hall, 1861). LAUDON, 1973, p. 28, fig. 4.

Batocrinus corbulis (Hall, 1861). MILLER, S. A., 1897, p. 736.

Diagnosis.—Calyx medium globe, plates nodose; basals deeply notched at sutures; nodes on radials project downward.

Material examined.—Laudon 14,041 (x1).

Discussion.—The basal flange that is characteristic for the genus *Eretmocrinus* is not quite as distinct in *E. corbulis* as it is in other species. The basals do not project outward, but rather downward. The best taxonomic reference for *E. corbulis* is Wachsmuth and Springer (1897).

Occurrence.—Tierra Blanca Mountain; and lower Burlington Limestone, Iowa.

Genus EUTROCHOCRINUS Wachsmuth and Springer, 1897

Type species.—*Actinocrinus christyi* Shumard, 1855; by original designation.

Diagnosis.—Calyx narrow proximally, abruptly expanding above radials; interrays may or may not be in contact with tegmen; tegmen flat peripherally, rising centrally to form anal tube.

EUTROCHOCRINUS CHRYSTYI (Shumard, 1855)

Figure 1.15.5-1.15.6

Actinocrinus christyi SHUMARD, 1855, p. 191, pl. A, fig. 3; SHUMARD, 1868, p. 342; ?BIGSBY, 1868, p. 196; QUENSTEDT, 1876a, p. 742, pl. 17, fig. 17; QUENSTEDT, 1876b, p. 581, pl. 11-A, figs. 15-18; MILLER, S. A., 1889, p. 217.

Eutrochocrinus christyi (Shumard, 1855). WACHSMUTH AND SPRINGER, 1897, p. 409, pl. 3, fig. 21; pl. 4, figs. 7, 13, 16; pl. 5, fig. 10; pl. 29, fig. 6; pl. 32, figs. 1a-1c; WELLER, 1898, p. 270; GRABAU AND SHIMER, 1910, p. 542, fig. 1871; BASSLER AND MOODEY, 1943, p. 477; MOORE AND LAUDON, 1943, p. 141, pl. 12, fig. 11; MOORE AND LAUDON, 1944, p. 197, pl. 75, fig. 8; pl. 76, fig. 21; LAUDON, 1948, pl. 2. UBAGHS, 1953, p. 740, fig. 22, no. c; GOOD, 1968, pl. 1, fig. 4; LAUDON, 1973, p. 28, fig. 4; WEBSTER, 1973, p. 130; HAUGH, 1975a, p. 479, pls. 1, fig. 2; pl. 3, figs. 1, 4; pl. 5, fig. 8; UBAGHS in Moore and Teichert, 1978, p. T118, T201, fig. 90, no. 4; fig. 170, no. 6; fig. 171; LANE in Moore and Teichert, 1978, p. T469, fig. 276, no. 1; WOLF, 1979, p. 151, fig. 2, no. g. HAUGH AND BELL, 1980, p. 654, fig. 2, no. A; WEBSTER, 1986, p. 148; WEBSTER, 2003; AUSICH AND KAMMER, 2010, p. 43.

Actinocrinus cristii (Shumard, 1855) (sic). QUENSTEDT, 1867, p. 742, pl. 71, fig. 17.

Actinocrinites cristii (Shumard, 1855) (sic). QUENSTEDT, 1885, p. 956, pl. 77, fig. 4.

Batocrinus christyi (Shumard, 1855). MEEK AND WORTHEN, 1873, p. 367, pl. 5, fig. 4; MILLER, S. A., 1889, p. 227; WELLER, 1898, p. 270; BASSLER AND MOODEY, 1943, p. 477.

Eutrochocrinus christi (Shumard, 1855). MCLEAD, 1973, p. 244, pls. 1, fig. 3; 2, fig. 5.

Eutrochocrinus christyi var. *trochiscus* WACHSMUTH AND SPRINGER, 1897, p. 410, pl. 32, fig. 3; BASSLER AND MOODEY, 1943, p. 478.

Eutrochocrinus christyi trochiscus WACHSMUTH AND SPRINGER, 1897. WELLER, 1898, p. 270;

LAUDON, 1973, p. 28, figs. 1, 4; WEBSTER, 1977, p. 85.

Batocrinus altiusculus MILLER AND GURLEY, 1893, p. 20, pl. 5, figs. 1-3; MILLER, S. A., 1897, p. 735; WELLER, 1898, p. 270; BASSLER AND MOODEY, 1943, p. 477.

Batocrinus bisbrachiatus WHITFIELD, 1893, p. 13, pl. 2, figs. 4-5; MILLER, S. A., 1897, p. 735; WELLER, 1898, p. 270; BASSLER AND MOODEY, 1943, p. 478.

Actinocrinites sp. CHRISTY, 1848, pl. 1, figs. 1-2; WELLER, 1898, p. 270.

Diagnosis.—Arm openings continuous; interrays not in contact with tegmen.

Material examined.—M-6 (x1) and Laudon 13,806 (x1).

Discussion.—Wachsmuth and Springer (1897) stated that both *Eutrochocrinus christyi* and *E. lovei* (Wachsmuth and Springer, 1881) closely resemble each other and are difficult to separate unless arms are preserved or the arm openings are perfectly preserved. Neither of these qualifiers are the case for the Nunn specimens, but it appears the presence of a depression between rays may be a clue. The illustrations of Wachsmuth and Springer (1897, *E. christyi*: pl. 29, fig. 6 and pl. 32, figs. 1a-1c, 3; *E. lovei*: pl. 29, fig. 7 and pl. 32, figs. 2a-b) also indicate this slight difference between the two species. The best taxonomic reference for *Eutrochocrinus christyi* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon and Tierra Blanca Mountain; Chouteau Limestone, Missouri; Fern Glen Limestone and upper Burlington Limestone, Iowa; and St. Joe Formation, Arkansas.

EUTROCHOCRINUS LOVEI (Wachsmuth and Springer, 1881)

Figure 1.15.7-1.15.8

Batocrinus lovei WACHSMUTH AND SPRINGER, 1881, p. 168 (342).

Batocrinus lovii Wachsmuth and Springer, 1881 (sic). MILLER, S. A., 1889, p. 228.

Eutrochocrinus lovei (Wachsmuth and Springer, 1881). WACHSMUTH AND SPRINGER, 1897, p. 412, pl. 29, fig. 7; pl. 32, figs. 2a-2b; WELLER, 1898, p. 270; BASSLER AND MOODEY, 1943, p. 478; WEBSTER, 2003; AUSICH AND KAMMER, 2010, p. 43.

Diagnosis.—Arms grouped, separated by slight depression between rays; interrays in contact with tegmen.

Material examined.—Laudon, 13,569 (x1).

Discussion.—The occurrence of *Eutrochocrinus lovei* in the Nunn Member extends the range of the species to be older than once thought. The best taxonomic reference for *E. lovei* is Wachsmuth and Springer, (1897).

Occurrence.—Marble Canyon; and upper Burlington Limestone, Iowa.

Genus SIMATOCRINUS Ausich and Kammer, 2010

Type species.—*Batocrinus heteroclitus* Miller and Gurley, 1895; by original designation.

Diagnosis.—Calyx low cone or expanding with concave sides; basals low, truncate or narrow proximal expansion; radials low; interrays in contact with tegmen; rays lobate; tegmen as high or higher than calyx, flat to low cone- or inverted bowl-shaped; anal tube central and cylindrical.

SIMATOCRINUS SP.

Figure 1.15.9-1.15.10

Diagnosis.—Basals low, expand outward; arm facets face obliquely upward; arms weakly grouped.

Material examined.—M-17 (x1) and M-91 (x1).

Discussion.—Two specimens of *Simatocrinus* occur in the collections. Neither is well preserved. Individual plates of the calyx are not easy to discern, therefore assigning these two specimens to a species is difficult.

Occurrence.—Black Range and between North Percha Creek and Mineral Creek.

Genus UPEROOCRINUS Meek and Worthen, 1865

Type species.—*Actinocrinus pyriformis* Shumard, 1855; by original designation.

Diagnosis.—Calyx expanding with concave sides or low to medium cone; basal and radial circlets high and prominent; interrays in contact with tegmen; rays may be lobate; tegmen as high or lower than calyx, flat to low cone or low inverted bowl; anal tube central and cylindrical.

UPEROOCRINUS KUESIN. sp.

Figure 1.16.1-1.16.2, Table 1.6

Diagnosis.—Calyx plates nodose; tegmen lower than calyx.

Description.—Calyx expanding with concave sides. Arms moderately grouped. Calyx plates either nodose or smooth. Basal circlet is 16 percent of calyx height and composed of three large, equal plates that are trilobate. Radial circlet is 30% of the calyx height. Radials are hexagonal or heptagonal, wider than long, with a prominent node in the center. Tegmen low arched, slightly lobed between rays. Composed of many large, convex plates. Anal tube

eccentric. Primanal hexagonal; higher and narrow than radials. Primanal followed by 3,2,1 plates. Interrays in contact with tegmen. First interrarial hexagonal, large, and followed by 2 plates. First primibrachial hexagonal, wider than high. Second primibrachial axillary. Both have central node. First secundibrachial hexagonal, second axillary, both with central node. Each axillary secundibrachial supports two tertibrachials.

Material examined.—UMMP 70471 (holotype)

Discussion.—*Uperocrinus kuesi* appears to be a mixture of two previously known species of *Uperocrinus* (Table 1.7). In overall shape, *U. kuesi* resembles *U. hageri* (McChesney, 1861), however, the basals are much more pronounced in *U. kuesi*, and the calyx plates are nodose. *Uperocrinus marinus* (Miller and Gurley 1890) has the same calyx nodes as *U. kuesi*, but the anal tube is stouter. Though the full anal tube is not preserved on *U. kuesi*, the base of the tube is small and narrow, much like *U. hageri*.

Occurrence.—Berenda Canyon.

Etymology.—The trivial name recognizes Dr. Barry Kues, who was kind enough to share his expertise at the different Lake Valley Formation collecting sites.

UPEROOCRINUS SP.

Figure 1.16.3-1.16.4

Diagnosis.—Calyx plates smooth; tegmen slightly lobed, low inverted bowl; many large, smooth plates on tegmen; anal tube eccentric.

Material examined.—Laudon 13,553 (x1).

Discussion.—Basals and radials are not preserved, but this specimen appears to be most similar to *Uperocrinus pyriformis* (Shumard, 1855), which is what Laudon concluded.

Occurrence.—Marble Canyon.

Family COELOCRINIDAE Bather, 1899

Genus AGARICOCRINUS Hall, 1858

Type species.—*Agaricocrinus tuberosus* Hall, 1858; by subsequent designation (Miller and Gurley, 1897).

Diagnosis.—Calyx conical or hemispherical; basals flat or concave, basals and commonly radials not visible in side view; interrays in contact with tegmen; tegmen higher than calyx, conical or hemispherical; tegmen plates commonly large, tumid, or nodose; CD oral commonly large; anal opening on side of tegmen.

AGARICOCRINUS BULLATUS Hall, 1858

Figure 1.16.5-1.16.6

Agaricocrinus bullatus HALL, 1858, p. 662, pl. 9, figs. 11a-11b; SHUMARD, 1868, p. 351; MILLER, S. A., 1889, p. 220; WACHSMUTH AND SPRINGER, 1897, p. 489, pl. 41, figs. 2a-2d; WELLER, 1898, p. 68; GRABAU AND SHIMER, 1910, p. 534; BASSLER AND MOODEY, 1943, p. 285; EHLERS AND KESLING, 1963, p. 1030; MCLEAD, 1973, p. 244, pl. 1, fig. 6; WEBSTER, 1973, p. 41; WEBSTER, 1977, p. 32; WEBSTER, 2003.

Agaricocrinites bullatus (Hall, 1858). MOORE AND LAUDON, 1942, p. 74, fig. 4, no. c; MOORE AND LAUDON, 1943, p. 141, pl. 12, fig. 4; MOORE AND LAUDON, 1944, p. 195, pl. 76, fig. 14; WEBSTER, 1973, p. 41.

Agaricocrinus pentagonus HALL, 1859, p. 57, unnumbered figure; SHUMARD, 1868, p. 351; MILLER, S. A., 1889, p. 221; WHITFIELD, 1893, p. 25, pl. 2, figs. 17-18; KEYES, 1894, p. 167, pl. 22, fig. 9; MILLER, S. A., 1897, p. 732; WELLER, 1898, p. 68; BASSLER AND MOODEY, 1943, p. 285.

Diagnosis.—Calyx depressed pyramidal, pentangular below arm bases, deeply concave at bottom; tegmen high, hemispherical, much higher than calyx.

Material examined.—M-80(1971) (x1).

Discussion.—*Agaricocrinus bullatus* separates itself from the other species of *Agaricocrinus* in the Nunn Member by having a tegmen that is more boxy and much higher than the calyx. The best taxonomic reference for *A. bullatus* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon; lower and upper Burlington Limestone, Iowa; and Warsaw Limestone, Illinois.

AGARICOCRINUS PLANOCONVEXUS Hall, 1861a

Figure 1.17.1-1.17.2

Agaricocrinus (Amphoracrinus) planoconvexus HALL, 1861a, p. 280; HALL, 1861c, p. 280.

Agaricocrinus planoconvexus HALL, 1861b, p. 3; SHUMARD, 1868, p. 351; MILLER, S. A., 1889, p. 221; KEYES, 1894, p. 167, pl. 22, figs. 7a-7b; WACHSMUTH AND SPRINGER, 1897, p. 503, pl. 38, figs. 6a-6c; WELLER, 1898, p. 71; GRABAU AND SHIMER, 1910, p. 534; BASSLER AND MOODEY,

1943, p. 288; EHLERS AND KESLING, 1963, p. 1030; GOOD, 1968, pl. 1, fig. 3; LAUDON, 1973, p. 30, figs. 1-2; WEBSTER, 1973, p. 42; WEBSTER, 1977, p. 33; WEBSTER, 2003.

Agaricocrinites planoconvexus (Hall, 1861). MOORE AND LAUDON, 1943, p. 141, pl. 12, fig. 3; MOORE AND LAUDON, 1944, p. 195, pl. 76, fig. 13; LAUDON, 1948, pl. 2.

Agaricocrinus decornis ROWLEY AND HARE, 1891, p. 117, pl. 3, fig. 10; WELLER, 1898, p. 71; BASSLER AND MOODEY, 1943, p. 28.

Diagnosis.—Calyx distinctly pentangular, bottom wholly or partly excavated; tegmen low, hemispherical, higher than calyx.

Material examined.—M-13, M-15 (x39), M-16 (x3), M-17 (x41), M-19 (x2), M-22 (x10), M-80(1971) (x1), M-87 (x8), M-91 (x9), M-92 (x2), M-94 (x5), M-95 (x6), M-101 (x1), M-102 (x2), M-151 (x2), M-158 (x5), Kues1 (x4), Kues2 (x2), Indiana University 10565 (x5), an unknown locality (x1), USNM 6408 (x3), Laudon 13,997 (x1), Laudon 13,863 (x3), Laudon 13,986 (x4), and Laudon 13,552 (x1).

Discussion.—*Agaricocrinus planoconvexus* is the most abundant species of the genus in the Nunn Member and one of the most abundant species of camerates. The characteristic size range of the species is a calyx width between 9mm-15mm, but a few grew much larger, having a calyx width of 25mm. The best taxonomic reference for *A. planoconvexus* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon, Marble Canyon, Tierra Blanca Mountain, Black Range undefined, Rock Springs, Apache hill, between North Percha Creek and Mineral Creek, Percha Creek, North Hollow Creek, Wittenberg Ranch Windmill Section, and Cooks Range; Chouteau

Limestone, Missouri; lower and upper Burlington Limestone, Iowa; and Nada Member of the Borden Formation in Kentucky.

AGARICOCRINUS PYRAMIDATUS (Hall, 1858)

Figure 1.17.3-1.17.4

Actinocrinus pyramidatus HALL, 1858, p. 565; SHUMARD, 1868, p. 347.

Agaricocrinus pyramidatus (Hall, 1858). MILLER, S. A., 1889, p. 221; WHITFIELD, 1893, p. 23, pl. 2, figs. 23-25; WACHSMUTH AND SPRINGER, 1897, p. 512, pl. 38, figs. 4-5; WELLER, 1898, p. 72; GRABAU AND SHIMER, 1910, p. 534; BASSLER AND MOODEY, 1943, p. 288; EHLERS AND KESLING, 1963, p. 1031; WEBSTER, 1973, p. 42; WEBSTER, 2003.

Agaricocrinus (Amphoracrinus) corrugatus HALL, 1861a, p. 283; HALL, 1861c, p. 283; WELLER, 1898, p. 72; BASSLER AND MOODEY, 1943, p. 288.

Agaricocrinus corrugatus HALL, 1861b, p. 4; SHUMARD, 1868, p. 351; MILLER, S. A., 1889, p. 220; WACHSMUTH AND SPRINGER, 1897, p. 512; WELLER, 1898, p. 72; BASSLER AND MOODEY, 1943, p. 288.

Diagnosis.—Calyx flat; tegmen low, depressed pyramidal, higher than calyx.

Material examined.—Indiana University 10565 (x1).

Discussion.—The calyx of *Agaricocrinus pyramidatus* is unlike the previous two species of *Agaricocrinus*. Where *A. bullatus* and *A. planoconvexus* have flat calyces where the arm facets rest evenly on a horizontal plane, *A. pyramidatus* is slightly elevated by the radials so that the arm facets are not even with the horizontal. The best taxonomic reference for *A. pyramidatus* is Wachsmuth and Springer (1897).

Occurrence.—Apache Hill; and lower Burlington Limestone, Iowa.

AGARICOCRINUS ALAMOGORDOENSIS n. sp.

Figure 1.17.5-1.17.6, Table 1.8

Diagnosis.—Calyx low cone; tegmen high cone, same height as calyx.

Description.—Calyx small, low cone, convex. Basals small, three, equal, form a concavity, edges visible in side view. Radials medium, hexagonal, wider than high with prominent node in center. Tegmen higher than calyx. Composed of several medium convex to nodose plates. CD oral largest plate, spinose. Primanal hexagonal, higher and narrower than radials, followed by three rows of three plates before the anal opening, which is on the side of the tegmen. First primibrachial hexagonal, wider than high. Second primibrachial axillary, supporting secundibrachials, which support one arm facet apiece. Arms and column unknown.

Material examined.—UMMP 74072 (holotype).

Discussion.—This species is similar to *Agaricocrinus brevis* (Hall, 1858), but the anal area is significantly different (Table 1.9). The primanal of *A. brevis* is followed by 3, 4(5), then numerous smaller plates, whereas in this species the primanal is followed by 3, 3, 3. This species also lacks the well-defined groove at the sides of the anal area that *A. brevis* has.

The A and D rays of the holotype have slight variation from the other three rays, which are presumably the normal condition for *Agaricocrinus alamogordoensis*. The A ray only has one primibrachial, which is axillary as opposed to two as in the other rays. The D ray has three arm facets rather than two. The secundibrachial on the anal side is axillary, supporting two

tertibrachials, which in turn supports the arm facets. Opposite the anal side, there are two secundibrachials before the arm facet.

Occurrence.—Indian Wells Canyon.

Etymology.—The trivial name recognizes the city of Alamogordo, NM near where the holotype specimen was collected.

COELOCRINIDAE indet.

Discussion.—Three crinoids are poorly preserved and cannot be identified any further than family level. Two of the specimens were identified by Laudon as being *Dorycrinus unicornis* (Owen and Shumard, 1850) but neither specimens are whole and it impossible to be certain of this identification. The third specimen only has the anal area, illustrating the distinct anal plates, but this is insufficient for identification.

Material examined.—M-159 (x1), Laudon 14,088 (x1), and Laudon 13,551 (x1).

Occurrence.—Marble Canyon and Percha Creek.

Superfamily HEXACRINITACEA Wachsmuth and Springer, 1885

Family DICHOCRINIDAE Miller, 1889

Genus DICHOCRINUS Münster, 1839

Type species.—*Dichocrinus radiatus* Münster, 1839; by original designation.

Diagnosis.—Calyx high bowl-shaped, small; basals and radials high; tegmen lower than calyx, composed of numerous small plates; anal opening eccentric.

DICHOCRINUS CONUS Meek and Worthen, 1860

Figure 1.17.7-1.17.9

Dichocrinus conus MEEK AND WORTHEN, 1860, p. 381; MEEK AND WORTHEN, 1866a, p. 169, pl. 16, figs. 5a-5b; SHUMARD, 1868, p. 366; MILLER, S. A., 1889, p. 239; WACHSMUTH AND SPRINGER, 1897, p. 770, pl. 75, fig. 6; WELLER, 1898, p. 221; BASSLER AND MOODEY, 1943, p. 419; BROADHEAD, 1981, p. 107, pl. 7, figs. 1-3, 6, 12-13, 16; WEBSTER, 1988, p. 71; WEBSTER, 2003.

Dichocrinus scitulus HALL, 1861a, p. 289; HALL, 1861b, p. 4; HALL, 1861c, p. 289; SHUMARD, 1868, p. 366; HALL, 1872c, pl. 2-A, figs. 12-13; MILLER, S. A., 1889, p. 239; WACHSMUTH AND SPRINGER, 1897, p. 767, pl. 78, figs. 13a- 14; WELLER, 1898, p. 224; BASSLER AND MOODEY, 1943, p. 422; LAUDON, 1973, p. 32, fig. 7; WEBSTER, 1977, p. 70; WEBSTER, 2003.

Platycrinus elegans HALL, 1861a, p. 285; HALL, 1861b, p. 4; HALL, 1861c, p. 285; SHUMARD, 1868, p. 388; HALL, 1872a, pl. 2A, fig. 15; MILLER, S. A., 1889, p. 270; WHITFIELD, 1893, p. 3, fig. 1; MILLER, S. A., 1897, p. 750; WELLER, 1898, p. 438; BASSLER AND MOODEY, 1943, p. 619; WEBSTER, 2003.

Platycrinites elegans (Hall, 1861). BASSLER AND MOODEY, 1943, p. 619.

Diagnosis.—Calyx inornate, plates smooth; basal cup conical.

Material examined.—M-17 (x1), M-102 (x1), Indiana University 10565 (x1), Laudon 14,272 (x1), and Laudon 13,765 (x1).

Discussion.—Two species of *Dichocrinus* (*D. conus* and *D. scitulus*) as well as *Platycrinites elegans* were synonymized by Broadhead (1981), but this was not recognized by Webster (2003). The best taxonomic references for *D. conus* are Wachsmuth and Springer (1897) and Broadhead (1981).

Occurrence.—Black Range undefined, Apache Hill, Wittenberg Ranch Windmill Section, and Cooks Range; lower and upper Burlington Limestone, Iowa; and Boone Formation, Arkansas.

DICHOCRINUS SP.

Figure 1.17.10-1.17.11

Material examined.—M-7(1966) (x1).

Discussion.—This specimen is poorly preserved, with only the radials and anal plate. It is likely that it is *Dichocrinus conus*, but without a full calyx, it is not possible to confidently assign it to a species.

Occurrence.—Indian Wells Canyon.

GENUS STRIMPLECRINUS Broadhead, 1981

Type species.—*Dichocrinus plicatus* Hall, 1861; by original designation.

Diagnosis.—Calyx low to medium bowl, rarely conical; basals and radials high; tegmen lower than calyx, composed of many small plates.

Discussion.—*Strimplecrinus* is very similar to *Dichocrinus* with the calyx shape an important difference between the two genera. *Strimplecrinus* is more globose than *Dichocrinus*. Another difference may be that *Strimplecrinus* has an anal tube. However, the only known tegmen for *Strimplecrinus* is from the oldest known species. That feature may have been lost in later species, therefore it cannot be used as a distinguishing character until more tegmens are found.

STRIMPLECRINUS PISUM (Meek and Worthen, 1869)

Figure 1.18.1-1.18.2

Dichocrinus pisum MEEK AND WORTHEN, 1869, p. 69; MEEK AND WORTHEN, 1873, p. 441, pl. 3, fig. 2; MILLER, S. A., 1889, p. 239; WACHSMUTH AND SPRINGER, 1897, p. 763, pl. 76, fig. 5; pl. 77, fig. 10; WELLER, 1898, p. 224; BASSLER AND MOODEY, 1943, p. 422; LAUDON, 1973, p. 32, fig. 7. *Strimplecrinus pisum* (Meek and Worthen, 1869). BROADHEAD, 1981, p. 141, pl. 14, fig. 10; pl. 15, figs. 1-2, 6, 10, 22; BROADHEAD, 1985, p. 211, fig. 5, no. A; WEBSTER, 1988, p. 153; WEBSTER, 2003.

Dichocrinus prisus (Meek and Worthen, 1869) (sic). WEBSTER, 1977, p. 70.

Diagnosis.—Calyx short; basals broadly expanding, shallow; radial circlet vertical to slightly contracted to summit; plates plicate to striate.

Material examined.—M-15 (x2).

Discussion.—Neither specimen is perfectly preserved, but both has striations. The basals are broad and shallow, which separates them from *Strimplecrinus striatus* (Owen & Shumard, 1850). The basals also lack nodose striae, which separates it from *S. ovatus* (Owen & Shumard, 1850). One specimen preserves the striae very well. The other has been abraded but the ghosts of the striae can still be discerned on the plates. The best taxonomic references for *S. pisum* are Wachsmuth and Springer (1897) and Broadhead (1981).

Occurrence.—Black Range undefined; and lower Burlington Limestone, Iowa.

STRIMPLECRINUS SP.

Figure 1.18.3

Material examined.—M-9 (x1).

Discussion.—The specimen of this dichocrinid is crushed, but the width of the radial plates is indicative of *Strimplecrinus*. Placing this specimen in a species is difficult, as there appears to be no ornamentation. The only known *Strimplecrinus* species that are inornate are either from the Kinderhookian (*S. campto* (Laudon, 1933) and *S. inornatus* (Wachsmuth & Springer, 1890)) or the Chesterian (*S. superstes* (Wachsmuth & Springer, 1897)). Although it is conceivable that this species is a holdover from the Kinderhookian, with only one example, any definitive species assignment is impossible.

Occurrence.—Indian Wells Canyon.

Suborder GLYPTOCRINIA Moore, 1952

Superfamily PLATYCRINITACEA Austin and Austin, 1842

Family PLATYCRINITIDAE Austin and Austin, 1842

Genus PLATYCRINITES Miller, 1821

Type species.—*Platycrinites laevis* Miller, 1821; by subsequent designation (Meek & Worthen, 1865).

Diagnosis.—Calyx low to medium bowl; basal circlet high, visible in side view; radials lack laterally projecting neck at radial facet; five or ten arm openings; tegmen medium to low cone, as high or lower than calyx; few to numerous small- to medium-sized tegmen plates; tegmen plate size gradational from orals to margins; anal tube on top or upper margin of tegmen.

PLATYCRINITES S.S. BURLINGTONENSIS (Owen and Shumard, 1850)

Figure 1.18.4-1.18.5

- Platycrinus burlingtonensis* OWEN AND SHUMARD, 1850, p. 60, pl. 7, fig. 5; OWEN AND SHUMARD, 1852, p. 589, pl. 5A, fig. 5; SHUMARD, 1868, p. 387; MCCHESENEY, 1868, p. 4, pl. 4, fig. 3; WACHSMUTH AND SPRINGER, 1885, pl. 8, fig. 6; pl. 9, fig. 6; LESLEY, 1889, p. 686, fig. 1; WACHSMUTH AND SPRINGER, 1897, p. 653, pl. 69, figs. 3a-3l; WELLER, 1898, p. 435; GRABAU AND SHIMER, 1910, p. 518, fig. 1839; BREIMER, 1962, p. 139, fig. 32; WEBSTER, 1973, p. 211.
- Platycrinites burlingtonensis* (Owen and Shumard, 1850). MEEK AND WORTHEN, 1873, p. 452, pl. 3, figs. 6a-6c; BASSLER AND MOODEY, 1943, p. 617; MOORE AND LAUDON, 1944, p. 203, pl. 78, fig. 24; WEBSTER, 1973, p. 211; WEBSTER, 2003.
- Platycrinites s.s. burlingtonensis* (Owen and Shumard, 1850). AUSICH AND KAMMER, 2009, p. 702.
- Platycrinus exsertus* HALL, 1858, p. 549, unnumbered figure; SHUMARD, 1868, p. 388; MILLER, S. A., 1889, p. 270; BASSLER AND MOODEY, 1943, p. 617.
- Platycrinus exsertus* (Hall, 1858) (sic). WELLER, 1898, p. 435.
- Platycrinus nodobrachiatus* HALL, 1858, p. 542, unnumbered figure; HALL, 1861b, p. 17. SHUMARD, 1868, p. 388; MILLER, S. A., 1889, p. 271; WELLER, 1898, p. 435; BASSLER AND MOODEY, 1943, p. 617.
- Platycrinus nucleiformis* HALL, 1858, p. 540, unnumbered figure; SHUMARD, 1868, p. 388; MILLER, S. A., 1889, p. 271; WELLER, 1898, p. 435; BASSLER AND MOODEY, 1943, p. 617.
- Platycrinus inornatus* MCCHESENEY, 1861, p. 7; SHUMARD, 1868, p. 387; MILLER, S. A., 1889, p. 271; MILLER, S. A., 1897, p. 750; WELLER, 1898, p. 436; BASSLER AND MOODEY, 1943, p. 617.

Platycrinus lautus MILLER, S. A., 1891a, p. 17, pl. 2, figs. 3-4; MILLER, S. A., 1892a, p. 681;

WELLER, 1898, p. 436; BASSLER AND MOODEY, 1943, p. 617.

Diagnosis.—Calyx smooth; plate sutures not pronounced; arm facets large; tegmen low, few medium to large plates.

Material examined.—M-7 (x1), an unknown locality (x1), and Laudon 13,757 (x1).

Discussion.—*Platycrinites burlingtonensis* can be readily separated from the similar Nunn Member species *P. illinoisensis* by having plate sutures that are not well pronounced. The latter species has deep grooves where the calyx plates connect, whereas *P. burlingtonensis* is very smooth. The best taxonomic reference for *P. burlingtonensis* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon; and lower Burlington Limestone, Iowa.

PLATYCRINITES S.S. ILLINOISENSIS (Miller and Gurley, 1896a)

Figure 1.18.8-1.18.9

Platycrinus illinoisensis MILLER AND GURLEY, 1896a, p. 62, pl. 5, figs. 5-7; MILLER, S. A., 1897, p.

750; WELLER, 1898, p. 441.

Platycrinites illinoisensis (Miller and Gurley, 1896). BASSLER AND MOODEY, 1943, p. 622;

WEBSTER, 2003.

Platycrinites s.l. illinoisensis (Miller and Gurley, 1896); AUSICH AND KAMMER, 2009, p. 704.

Diagnosis.—Calyx smooth; plate sutures deeply beveled; arm facets large; tegmen low, few large plates.

Description.—Calyx flat bowl, plates smooth. Basal circlet flat, slight depression where column meets calyx. Radial circlet 80 percent of calyx height, plates smooth. Radial facets approximately 75 percent of distal radial width. Tegmen lower than calyx, low inverted bowl, composed of few large, nodose plates; orals largest with other tegmen plates slightly smaller. Primanal large. Column and arms are unknown.

Material examined.—M-86 (x1), M-176 (x1), Laudon 13,775 (x1), and Laudon 13, 787 (x1).

Discussion.—Ausich and Kammer (2009) assigned *Platycrinites illinoisensis* to *Platycrinites* sensu lato because of a lack of information on the tegmen. Miller and Gurley (1896a) described the holotype without any information on the tegmen. The specimens collected in the Nunn Member match the illustrations of the Burlington Limestone calyces perfectly and it is with confidence that these specimens are being placed into this species. With the addition of the tegmen which has an anal tube, this species can be removed from *Platycrinites* sensu lato and placed in *Platycrinites* sensu stricto following the convention of Ausich and Kammer (2009).

Occurrence.—Indian Wells Canyon, and Apache Hill; and Burlington Limestone, Iowa, Illinois.

PLATYCRINITES S.S. PARVINODUS (Hall, 1861b)

Figure 1.18.6-1.18.7

Platycrinus parvinodus HALL, 1861b, p. 17; SHUMARD, 1868, p. 389; MILLER, S. A., 1889, p. 271;

WACHSMUTH AND SPRINGER, 1897, p. 696, pl. 68, figs. 6a-6b; WELLER, 1898, p. 442.

Platycrinites parvinodus (Hall, 1861). BASSLER AND MOODEY, 1943, p. 624; WEBSTER, 2003.

Platycrinites s.l. *parvinodus* (Hall, 1861). AUSICH AND KAMMER, 2009, p. 704.

Diagnosis.—Calyx plates contain nodes that radiate from arm facet to either corner of radial; sutures indistinct; arm facets small; tegmen low to medium bowl, with few to numerous small to medium plates.

Description.—Calyx medium bowl, plates nodose. Basal circlet low with small nodes that cover the plates. Radial circlet approximately 70 percent of calyx height, covered in fine nodes that may form lines that radiate from the radial facet. Radial facet approximately 45 percent of the distal radial width. Tegmen lower than calyx; low to medium bowl with few to numerous smooth plates. Primanal large. Arms and column not known.

Material examined.—M-15 (x7), M-17 (x6), M-19 (x2), M-92 (x1), M-95 (x2), an unknown locality (x1), Laudon 13,727 (x1), Laudon 13,833 (x1), and Laudon 13,768 (x2).

Discussion.—Ausich and Kammer (2009) placed this species in *Platycrinites* sensu lato because only the calyx has been known for this species. The specimens collected in the Nunn Member match the only illustration of the calyx in Wachsmuth and Springer (1897, pl. 68, fig. 6a-6b), so it with confidence that this species is assigned to these specimens. With the addition of the tegmen and evidence of an anal tube, this species may be removed from *Platycrinites* s.l. and placed in *Platycrinities* s.s.

The specimens of *Platycrinites parvinodus* have a wide range of variation, although the overall characteristics remain the same. Some specimens have more nodes that cover all of the basals and radials instead of only distinct lines. The height of the tegmen varies as well; from being nearly flat to being one half the height of the calyx.

Occurrence.—Black Range undefined, North Hollow Creek, Tierra Blanca Mountain, and Wittenberg Ranch Windmill Section; and lower Burlington Limestone, Iowa.

PLATYCRINITES S.S. PECULIARIS (Wachsmuth and Springer, 1897)

Figure 1.18.10-1.18.11

Platycrinus peculiaris WACHSMUTH AND SPRINGER, 1897, p. 700, pl. 68, figs. 7a-7b; pl. 71, fig. 16;

MILLER, S. A., 1897, p. 750; WELLER, 1898, p. 443; BASSLER AND MOODEY, 1943, p. 624.

Platycrinites peculiaris (Wachsmuth and Springer, 1897). BASSLER AND MOODEY, 1943, p. 624;

HAUGH, 1978, p. 166, figs. 15, no. D; 17, no. G; WEBSTER, 1986, p. 255; WEBSTER, 2003.

Platycrinites s.s. peculiaris (Wachsmuth and Springer, 1897). AUSICH AND KAMMER, 2009, p. 702.

Diagnosis.—Calyx smooth; plate sutures not pronounced; arm facets small; tegmen $\frac{3}{4}$ height of calyx, with numerous small plates.

Material examined.—M-7 (x3), M-15 (x2), M-22 (x1), M-80(1971) (x1), M-86 (x3), M-95 (x1), FC16 (x1), Indiana University 10565 (x8), an unknown locality (x5), Laudon 13,765 (x1), Laudon 13,833 (x2), Laudon 13,825 (x1), Laudon 13,777 (x7), Laudon 13,794 (x1), Laudon 13,781 (x2), Laudon 13,755 (x1), Laudon 13,750 (x1), Laudon 13,838 (x2), Laudon 13,836 (x1), and Laudon 13,766 (x1).

Discussion.—This is the dominant species of *Platycrinites* in the Nunn Member based on the collections studied. The number of specimens includes a wide range of size differences from small (10.4 x 8.4 mm) to large (24.4 x 18.6 mm). In his collection, Laudon assigned at least three separate new species names (unpublished) to the different *P. peculiaris*, but the only difference between them is the size. The best taxonomic reference for *P. peculiaris* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon, Black Range undefined, Rock Springs, Apache Hill, North Hollow Creek, and Wittenberg Ranch Windmill Section.

PLATYCRINITES SP.

Figure 1.19.1-1.19.2

Diagnosis.—Calyx elongate, smooth; plate sutures not pronounced; arm facets large; tegmen low; plates smooth; orals nodose

Material examined.—M-15 (x1), and an unknown locality (x2).

Discussion.—Three specimens of *Platycrinites* look unlike any other found in the Nunn Member. It is believed that these three, of varying sizes, represent different ages for one species. The tegmen is the same for all three. The two smaller specimens have a calyx that is not quite as elongate as the larger one. More specimens need to be found before a trivial name can be placed on them.

Occurrence.—Black Range undefined.

Genus COLLICRINUS Ausich and Kammer, 2009

Type species.—*Collicrinus shumardi* Ausich and Kammer, 2009; by original designation.

Diagnosis.—Calyx flat to very low cone; basal circlet low, not visible in side view; radials lack laterally projecting neck at radial facet; five arm openings; tegmen low inverted bowl, lower, as high, or higher than calyx; few large-sized tegmen plates; tegmen plates not gradational from orals to margins; anal tube from upper margin or side of tegmen.

COLLICRINUS SHUMARDI Ausich and Kammer, 2009

Figure 1.19.3-1.19.4

Collicrinus shumardi AUSICH AND KAMMER, 2009, p. 712, figs. 3.4-3.6.

Platycrinus yandelli OWEN AND SHUMARD, 1850, p. 58, pl. 7, figs. 6a-6b; OWEN AND SHUMARD, 1852, p. 547, pl. 5a, figs. 6a-6b; SHUMARD, 1868, p. 390; WACHSMUTH AND SPRINGER, 1889, p. 342, pl. 18, fig. 8; MILLER, S. A., 1889, p. 272; LESLEY, 1889, p. 690, figs. 6a-6b; WACHSMUTH AND SPRINGER, 1897 (in part), p. 706, pl. 66, figs. 6a; pl. 68, figs. 3a-3c; WELLER, 1898, p. 448; BREIMER, 1962, p. 139, fig. 32.

Platycrinites yandelli (Owen and Shumard, 1850). BASSLER AND MOODEY, 1943, p. 629. WEBSTER, 1973, p. 215; WEBSTER, 2003.

Diagnosis.—Calyx plates nodose to short spinose; tegmen higher than calyx; anal tube on margin, projects upward.

Material examined.—M-15 (x2) and Indiana University 10565 (x1).

Discussion.—The Nunn Member specimens of *Collicrinus shumardi* are not well preserved. However, the preservation is well enough to confidently assign to this species. The calyx plates do not have coarse sculpturing, and the anal tube projects upward and not laterally, as with the other known member of this genus, *C. formosus* (Miller and Gurley, 1895b). The best taxonomic reference for *Collicrinus shumardi* is Ausich and Kammer (2009).

Occurrence.—Black Range undefined and Apache Hill; and lower Burlington Limestone, Iowa.

COLLICRINUS LAUDONI n. sp.

Figure 1.19.5-1.19.6, Table 1.10

Diagnosis.—Calyx plates smooth; tegmen lower than calyx; anal tube on margin, projects obliquely upward.

Description.—Aboral cup flat bowl, plates smooth. Basal circlet flat, visible in lateral view. Radial circlet 85 percent of calyx height. Radial plates five, as wide as high and smooth. Radial facet 80 percent width of distal radial width. Tegmen lower than calyx; low inverted bowl, composed of large nodose plates. Orals largest plates and other tegmen plates slightly smaller. Primanal large. Plates surrounding primanal indistinguishable, but anal tube starts immediately above primanal. Primibrachial large, axillary. Other aspects of arms and column unknown.

Material examined.—UMMP 74073 (holotype).

Discussion.—This species is similar to *Collicrinus formosus* (Miller and Gurley, 1895a), but differs in that the basals are not within a concavity, the calyx lacks plate ornamentation, and the anal tube opens along the margin of the tegmen, not on the side (Table 1.11). *Collicrinus laudoni* differs from *C. shumardi* by having basals that are visible in lateral view and smooth calyx plates.

Occurrence.—Apache Hill.

Etymology.—The trivial name recognizes Dr. Lowell Laudon, who did some of the first extensive studies on the Lake Valley Formation and who collected a portion of the crinoids used in this study.

Genus ELEGANTOCRINUS Ausich and Kammer, 2009

Type species.—*Platycrinus hemisphaericus* Meek and Worthen, 1865; by original designation.

Diagnosis.—Calyx low bowl to cone; basal circlet high, visible from side view; radials lack laterally projecting neck at radial facet; five or ten arm openings; tegmen medium to low inverted bowl, lower than calyx; numerous medium- to small-sized plates; plate size gradational from orals to margin; anal tube absent, anus on side of tegmen.

ELEGANTOCRINUS ANNOSUS (Miller, 1891a) n. comb.

Figure 1.19.9-1.19.10

Platycrinus annosus MILLER, S. A., 1891a, p. 14, pl. 1, fig. 12; MILLER, S. A., 1897, p. 750, fig. 1373; WELLER, 1898, p. 434; PECK AND KEYTE, 1938, p. 90, pl. 30, figs. 6-8; BASSLER AND MOODEY, 1943, p. 615.

Platycrinus anosus (Miller, 1891) (sic). MILLER, S. A., 1892a, p. 681.

Platycrinites annosus (Miller, 1891). BASSLER AND MOODEY, 1943, p. 615; WEBSTER, 2003.

Platycrinites s.l. *annosus* (Miller, 1891). AUSICH AND KAMMER, 2009, p. 704.

Diagnosis.—Calyx smooth, bowl-shaped; plate sutures not well pronounced; arm facets small.

Description.—Calyx low bowl, plates smooth. Basal circlet low, plates smooth, column facet small. Radial circlet approximately 70 percent of calyx height. Radial facets small, approximately 50 percent of distal radial width. Tegmen flat inverted bowl, many small nodose plates. Anal open on side of tegmen. Arms and column not known.

Material examined.—M-18 (x1).

Discussion.—Ausich and Kammer (2009) placed this species in *Platycrinites* sensu lato due to a lack of information on the tegmen. The specimen from the Nunn is identical to the illustrations of the calyx and as the specimen lacks evidence of an anal tube on the well-preserved tegmen, it is placed in the genus *Elegantocrinus*.

Occurrence.—Black Range undefined; and Chouteau Limestone, Missouri.

ELEGANTOCRINUS CANALICULATUS (Hall, 1858) n. comb.

Figure 1.19.7-1.19.8

Platycrinus canaliculatus HALL, 1858, p. 539; SHUMARD, 1868, p. 387; MILLER, S. A., 1889, p.

270; WACHSMUTH AND SPRINGER, 1897, p. 689, pl. 75, figs. 7a-7b; WELLER, 1898, p. 436.

Platycrinites canaliculatus (Hall, 1858). BASSLER AND MOODEY, 1943, p. 617; WEBSTER, 2003.

Platycrinites s.l. *canaliculatus* (Hall, 1858). AUSICH AND KAMMER, 2009, p. 704.

Diagnosis.—Calyx bowl shaped, plates contain large nodes; basals low; plate sutures well defined; arm facets large.

Description.—Calyx low bowl, plates with few nodes. Basal circlet flat, plates have a few nodes on them; slight depression where column attaches. Radial circlet approximately 85 percent of calyx height, plates with few nodes forming lines that radiate from radial facets. Radial facets approximately 50 percent of distal radial width. Tegmen low inverted bowl with large orals and smaller plates surrounding. Tegmen plates nodose. Anal opening is on side of the tegmen. Arms and column not known.

Material examined.—M-7 (x1), Laudon 13,824 (x1), and Laudon unknown no. (x1).

Discussion.—Ausich and Kammer (2009) placed the species in *Platycrinites* sensu lato due to a lack of information on the tegmen. The specimens from Nunn are identical to the illustrations of the calyx and as the specimen lacks evidence of an anal tube on the well-preserved tegmen, it is placed in the genus *Elegantocrinus*.

Occurrence.—Indian Wells Canyon and Tierra Blanca Mountain; and lower and upper Burlington Limestone, Iowa.

ELEGANTOCRINUS NODOSTRIATUS (Wachsmuth and Springer, 1897)

Figure 1.20.1-1.20.2

Platycrinus nodo-striatus WACHSMUTH AND SPRINGER, 1897, p. 698, pl. 66, figs. 5a-5b; pl. 70, figs. 3-4c.

Platycrinus nodostriatus (Wachsmuth and Springer, 1897). MILLER, S. A., 1897, p. 750; BASSLER AND MOODEY, 1943, p. 623; WELLER, 1898, p. 442.

Platycrinites nodostriatus (Wachsmuth and Springer, 1897). BASSLER AND MOODEY, 1943, p. 623; BROWER, 1970, p. 524, pl. 66, fig. 8; fig. 86, no. C; LAUDON, 1973, p. 31, fig. 6; WEBSTER, 1977, p. 138; WEBSTER, 2003.

Elegantocrinus nodostriatus (Wachsmuth and Springer, 1897). AUSICH AND KAMMER, 2009, p. 709.

Diagnosis.—Calyx bowl-shaped, plates contain very fine nodes; plate sutures not well pronounced; arm facets small.

Material examined.—Indiana University 10565 (x1).

Discussion.—*Elegantocrinus nodostriatus* is similar to *E. canaliculatus* in shape of the theca but differs in having much smaller nodes on the radials and having smaller arm facets. The best taxonomic reference for *E. nodostriatus* is Wachsmuth and Springer (1897).

Occurrence.—Apache Hill; upper Burlington Limestone, Iowa; and Thunder Springs Member or Mooney Falls Member of Redwall Limestone, Arizona.

ELEGANTOCRINUS PILEIFORMIS (Hall, 1858) n. comb.

Figure 1.20.5-1.20.6

Platycrinus pileiformis HALL, 1858, 529, pl. 8, figs. 3a-3c; fig. 5b; SHUMARD, 1868, p. 389;

MILLER, S. A., 1889, p. 271; KEYES, 1894, p. 198, pl. 25, fig. 5; WACHSMUTH AND SPRINGER, 1897, p. 656, pl. 69, fig. 5; pl. 70, figs. 13a-13b; WELLER, 1898, p. 443; STEINMANN, 1903, p. 175, fig. 230, nos. C-D; fig. 242, nos. C-D; STEINMANN, 1907, p. 195, fig. 277, no. C.

Platycrinites pileiformis (Hall, 1858). BASSLER AND MOODEY, 1943, p. 624; LAUDON, 1973b, p. 31, fig. 6; WEBSTER, 1977, p. 138; WEBSTER, 2003.

Platycrinites s.l. *pileiformis* (Hall, 1858). AUSICH AND KAMMER, 2009, p. 704.

Platycrinus carchesium MILLER, S. A., 1891a, p. 23, figs. 6-7; MILLER, S. A., 1892a, p. 681; WELLER, 1898, p. 443; BASSLER AND MOODEY, 1943, p. 624.

Diagnosis.—Calyx cone-shaped, plates smooth; plate sutures not well pronounced; arm facets large.

Description.—Calyx high bowl, plates smooth. Basals high, smooth plates. Radial circlet approximately 66 percent of the calyx height. Radial facets approximately 60 percent of the

distal radial width. Tegmen low inverted bowl with many medium, nodose plates. Anal opening on the side of the tegmen. Arms and column unknown.

Material examined.—M-15 (x1), M-17 (x2), M-86 (x1), Indiana University 10565 (x1), and Laudon 14,249 (x1).

Discussion.—Ausich and Kammer (2009) placed this species in *Platycrinites* sensu lato due to a lack of information on the tegmen. The specimens collected from the Nunn lack any evidence of an anal tube on the well-preserved tegmens and are therefore assigned to the genus *Elegantocrinus*. The upper Burlington species *Elegantocrinus halli* (Shumard, 1865) is similar to *E. pileiformis*, but the differences between the two species are in the length and number of arms, which the Nunn specimens are lacking. Because *E. pileiformis* is from the lower Burlington, it is the right age. Therefore, these specimens are placed in that species.

Occurrence.—Marble Canyon, Black Range undefined, and Apache Hill; Chouteau Limestone, Missouri; and lower Burlington Limestone, Iowa.

ELEGANTOCRINUS POCILLIFORMIS (Hall, 1858) n. comb.

Figure 1.20.3-1.20.4

Platycrinus pocilliformis HALL, 1858, p. 528, pl. 8, figs. 2a-2b; WACHSMUTH AND SPRINGER, 1897, p. 706, pl. 68, figs. 2a-2b; SHUMARD, 1868, p. 389; MILLER, S. A., 1889, p. 271; WELLER, 1898, p. 444; MOORE, 1939 p. 199, fig. 8, nos. 1a-1b.

Platycrinites pocilliformis (Hall, 1858). BASSLER AND MOODEY, 1943, p. 625; WEBSTER, 2003.

Platycrinites s.l. *pocilliformis* (Hall, 1858). AUSICH AND KAMMER, 2009.

Diagnosis.—Calyx bowl-shaped, plates contain small nodes; plates sutures moderately developed; arm facets small.

Description.—Calyx low bowl, plates smooth to slightly nodose. Basals low, flat. Radial circlet approximately 75 percent of the calyx height. Radial facets approximately 70 percent of the distal radial width. Tegmen low inverted bowl, with many small plates that are smooth and convex. Anal opening on side of tegmen. Arms and column unknown.

Material examined.—M-7 (x1), M-15 (x1), M-17 (x2), M-80 (x2), M-94 (x1), Laudon 13,778 (x2), Laudon 13,754 (x1), Laudon 13,779 (x1), Laudon 13,980 (x1), Laudon 13,769 (x4), and Laudon 13,855 (x1).

Discussion.— Ausich and Kammer (2009) placed this species in *Platycrinites* sensu lato due to a lack of information on the tegmen. The specimens from the Nunn are identical to the illustrations of the calyx and as the specimen lacks evidence of an anal tube on the well-preserved tegmen, it is placed in the genus *Elegantocrinus*.

Elegantocrinus pocilliformis is similar to *E. nodostriatus*, but the latter has much finer nodes that almost coalesce to form lines around the edges of the plates. The former's nodes, though relatively small, are not nearly as numerous and do not form a linear pattern.

Occurrence.— Indian Wells Canyon, Black Range undefined, North Hollow Creek, Hillsboro, and Tierra Blanca Mountain; and lower Burlington Limestone, Iowa.

ELEGANTOCRINUS SP. A

Figure 1.20.7-1.20.8

Diagnosis.—Calyx plates smooth; basals low; plate sutures moderately developed; arm facets small.

Material Examined.—M-17 (x1), M-87 (x1), and Laudon 14,030 (x1).

Discussion.—These three specimens appear to most closely resemble *Platycrinites peculiaris* with the noticeable exception that they lack an anal tube. They also have affinity to the Western European species *Elegantocrinus externus* (Wright, 1956). There is a possibility that these specimens are younger forms of *E. pileiformis*. The specimens are in varying states of preservation. One is crushed, one lacks a tegmen (though the anal opening is preserved), and the third, though whole, is degraded in such a way it is difficult to make out features. Because of this, no name will be placed on these specimens until better ones can be acquired.

Occurrence.—Black Range undefined, Apache Hill, and Wittenberg Ranch Windmill Section.

ELEGANTOCRINUS SP. B

Figure 1.20.9-1.20.10

Diagnosis.—Calyx plates nodose; basals low; plate sutures well developed; arm facets small to medium; tegmen $\frac{3}{4}$ the height of calyx.

Material Examined.—M-94 (x2).

Discussion.—Two specimens of *Elegantocrinus* have a higher tegmen than the others in the Nunn Member. The tegmen is about $\frac{3}{4}$ the height of the calyx and inflated compared to the other species of *Elegantocrinus*. The calyx most closely resembles that of *E. pocilliformis* in ornamentation and shape.

Occurrence.—North Hollow Creek.

Genus EUCLADOCRINUS Meek, 1872

Type species.—*Platycrinites (Eucladocrinus) montanaensis* Meek, 1872; by original designation.

Diagnosis.—Calyx low to medium bowl; basal circlet high (rarely low), visible in side view; radials lack laterally projecting neck at radial facet; five arm openings; arm trunks present; tegmen flat to medium inverted bowl, lower than calyx; many medium-sized tegmen plates; tegmen plate size not gradational from orals to margins; anal tube absent, anus on side of tegmen.

Discussion.—The occurrence of *Eucladocrinus* in the Nunn Member fills in the time gap of the genus being from the latest Kinderhookian (Time Unit 2) and the upper Burlington (Time Unit 4) (Ausich and Kammer, 2006, Table 1).

EUCLADOCRINUS PLEUROVIMENUS (White, 1862)

Figure 1.20.11

Platycrinus pleurovimenus WHITE, C. A., 1862, p. 17; SHUMARD, 1868, p. 389; MILLER, S. A., 1889, p. 271.

Eucladocrinus pleurovimenus (White, 1862). WELLER, 1898, p. 261; MOORE AND LAUDON, 1944, p. 205, pl. 78, fig. 28; LAUDON, 1973, p. 31, fig. 6; WEBSTER, 2003.

Platycrinus pleuroviminus (White, 1862) (sic). BASSLER AND MOODEY, 1943, p. 470.

Eucladocrinus pleuroviminus (White, 1862) (sic). MILLER, S. A., 1889, p. 244; WACHSMUTH AND SPRINGER, 1897, p. 724, pl. 73, fig. 4; pl. 74, fig. 1; BASSLER AND MOODEY, 1943, p. 470; UBAGHS, 1953, p. 743, fig. 102; WEBSTER, 1973, p. 127; LANE *in* Moore and Teichert, 1978, p. T515, fig. 317, no. 3; WEBSTER, 1986, p. 145; AUSICH AND KAMMER, 2009, p. 706.

Eucladocrinus pleurovimineus (White, 1862) (sic). MOORE AND LAUDON, 1943, p. 143, pl. 14, fig. 13; WEBSTER, 1977, p. 83.

Platycrinus discoideus HALL, 1858, p. 535, pl. 8, figs. 8a-8b (*non* OWEN AND SHUMARD, 1850); WELLER, 1898, p. 261; BASSLER AND MOODEY, 1943, p. 470.

Diagnosis.—Basal circlet low, flat, barely visible in side view; radial plates moderately spreading.

Material examined.—M-7 (x1), M-17 (x2), M-80 (x2), M-86 (x1), Indiana University 10565 (x2), and an unknown locality (x1).

Discussion.—The occurrence of *Eucladocrinus pleurovimenus* in the Nunn Member extends the range of the species, making it slightly older than known previously.

In trying to determine the species, *Eucladocrinus praenuntius* (Wachsmuth and Springer, 1878) was also considered as it supposedly closely resembles *E. pleurovimenus*. However, the single illustration of the species is only of the oral surface (Wachsmuth and Springer, 1897, Pl. 73, fig. 5). The original description is not accompanied by an illustration, although Webster (2003) noted that a plate does accompany a separate of the paper in the Springer Collection at the U. S. National Museum and that it is unknown whether that separate was widely published or not. It is possible that *E. praenuntius* is a junior synonym of *E. pleurovimenus* based on

description alone. The best taxonomic reference for *E. pleurovimenus* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon, Black Range undefined and Apache Hill; and upper Burlington Limestone, Iowa.

EUCLADOCRINUS SP.

Figure 1.20.12

Diagnosis.—Basal circlet low, swollen, visible in side view; radial plates very spreading.

Material examined.—Indiana University 10565 (x1) and Laudon 13,929 (x1).

Discussion.—Two specimens of *Eucladocrinus* are similar to *E. pleurovimenus* with a low basal circlet and spreading radials, but significant differences indicate it is a separate species. The basals on *E. pleurovimenus* are flat, making them relatively difficult to see in side view. Although low, the basals on *Eucladocrinus* sp. are swollen, making them visible in side view. The radials are also wider than those on *E. pleurovimenus*. These differences make it different from *E. pleurovimenus*, but other characters are needed to describe a new species.

Occurrence.—Apache Hill and Wittenberg Ranch Windmill Section.

Genus OENOCHOACRINUS Breimer, 1962

Type species.—*Oenochoacrinus princeps* Breimer, 1962; by original designation.

Diagnosis.—Calyx low to medium bowl, or expanding with concave sides; basal circlet high, visible in side view; radials lack laterally projecting neck at radial facet; ten arm openings; tegmen flat to low cone, lower than calyx; fifteen to few tegmen plates, ten small- or five

medium-sized plates and five large-sized plates; tegmen plate size not gradational from orals to margins; anal tube absent, anus on side of tegmen.

Discussion.—The tegmen of the Mississippian species of *Oenochocrinus* have more plates than the Devonian species. The tegmen of *O. limbus* and *O. cortina* both resemble the tegmen of *O. pileatus* (Breimer, 1962, fig. 30) except the medium-sized plates on the margin are now two small-sized plates. As this is the only difference, it is not necessary to erect a new genus.

OENOCHOACRINUS LIMBUS Webster and Lane, 1987

Figure 1.21.1-1.21.2

Oenochocrinus limbus WEBSTER AND LANE, 1987, p. 41, fig. 11, nos. 12-23; WEBSTER, 1993, p. 80; WEBSTER, 2003; AUSICH AND KAMMER, 2009, p. 707.

Diagnosis.—Calyx medium bowl; basal circlet high with flange; radial facets small.

Material examined.—M-80(1971) (x4), M-86 (x1), M-176, (x1) Indiana University 10565 (x7), an unknown locality (x3), Laudon 13,770 (x1), Laudon 13,759 (x1), Laudon 13,779 (x1), and Laudon 13,760 (x1).

Discussion.—Though the description of the genus lists at most ten plates in the tegmen, none of the *Oenochocrinus* from the Nunn Member has that few. Most of the specimens have fifteen plates: five large orals in the center of the tegmen surrounded by ten medium sized plates over the arm facets. This is the same pattern in the *O. limbus* illustrations in Webster and Lane (1987). A couple of specimens have 20 plates in the tegmen. The pattern is the same as the 15-

plated specimens, only with the addition of five small plates between the large orals and the medium plates.

Occurrence.—Indian Wells Canyon and Apache Hill; and Anchor Limestone, Nevada.

OENOCHOACRINUS CORTINA (Miller and Gurley, 1894) n. comb.

Figure 1.21.3-1.21.4

Platycrinus cortina MILLER AND GURLEY, 1894, p. 40, pl. 3, figs. 15-16; MILLER, S. A., 1897, p.

750; WELLER, 1898, p. 437; PECK AND KEYTE, 1938, p. 97, pl. 30, figs. 9-10.

Platycrinites cortina (Miller and Gurley, 1894). BASSLER AND MOODEY, 1943, p. 618; WEBSTER, 2003.

Platycrinites s.l. *cortina* (Miller and Gurley, 1894). AUSICH AND KAMMER, 2009, p. 704

Diagnosis.—Calyx expanding cone with concave sides; basals high, no flange; radial facets one-half size as radial.

Description.—Calyx expanding cone with smooth plates. Basals high, slightly constricted at distal end. Radial circlet approximately 55 percent of calyx height. Radial facet approximately 70 percent of distal radial width. Tegmen low inverted bowl with five large orals and ten smaller plates that are over the arm facets as with most of the *Oenochoacrinus limbus* specimens. Anal opening on the side of the tegmen. Arms and column not known.

Material examined.—Laudon 13,834 (x1).

Discussion.—Ausich and Kammer (2009) placed *Platycrinites cortina* in *Platycrinites* s.l. because of poor specimen preservation with only an incomplete tegmen. They noted that it most likely belongs to either *Oenochoacrinus* or *Pleurocrinus* but tegmen characteristics must be

known before it can be assigned to either. The single specimen in the Lake Valley collection has a calyx that greatly resembles the diagram of Peck and Keyte (1938, Pl. 30, fig. 9-10) with a tegmen that matches the 15-plated *Oenochoacrinus limbus* specimens also in the Nunn Member.

There is some confusion on the age of *Oenochoacrinus cortina* as it is reported in the literature as being from the Chouteau Limestone at Sedalia, Missouri, although it is most likely from the Burlington Limestone. Gahn and Kammer (2002, p. 127) address the issue of crinoids collected from Sedalia and their likely age.

Occurrence.—Indian Wells Canyon; and Chouteau Limestone, Missouri.

Genus PLEMNOCRINUS Kirk, 1946

Type species.—*Plemnocrinus beebei* Kirk, 1946; by original designation.

Diagnosis.—Calyx low to flat cone or bowl; basal circlet low, usually not visible in side view; radials have laterally projecting neck at radial facet; five arm openings; tegmen flat cone to inverted bowl, lower than calyx; many medium- to large-sized tegmen plates; tegmen plate size gradational from orals to abaxial margins; anal tube absent, anus on upper margin of tegmen.

PLEMNOCRINUS BULLATUS Kirk, 1946

Figure 1.21.5-1.21.6

Plemnocrinus bullatus KIRK, 1946, p. 437, pl. 65, fig. 1; WEBSTER, 1973, p. 218; WEBSTER, 2003;

AUSICH AND KAMMER, 2009, p. 707.

Diagnosis.—Calyx bowl shaped; basals protuberant, visible in lateral view; tegmen lower than calyx, plates nodose.

Material examined.—M-7 (x2), M-13 (x2), M-15 (x40), M-16 (x1), M-17 (x49), M-19 (x3), M-22 (x2), M-87 (x2), M-93 (x1), M-94 (x4), M-95 (x23), M-102 (x1), M-158 (x1), Indiana University 10565 (x7), an unknown locality (x6), and Laudon 14,029 (x3).

Discussion.—Kirk (1946) described the tegmen of *Plemnocrinus bullatus* as high and domed, but this disagrees with the specimens in the Springer Collection that Kirk mentions in his paper. The tegmens of *P. bullatus* are not high, but low, and do not exceed the height of the calyx.

Occurrence.—Indian Wells Canyon, Tierra Blanca Mountain, Black Range undefined, Apache Hill, Rocks Springs, North Hollow Creek, Percha Creek, Wittenberg Ranch Windmill Section, and Cooks Range; and Burlington Limestone, Iowa.

PLEMNOCRINUS HOMALUS Kirk, 1946

Figure 1.21.7-1.21.8

Plemnocrinus homalus KIRK, 1946, p. 439, pl. 66, figs. 1-6; WEBSTER, 1973, p. 218; WEBSTER, 2003; AUSICH AND KAMMER, 2009, p. 707

Diagnosis.—Calyx flat; basals not visible in lateral view; tegmen slightly higher than calyx, plates spinose.

Material examined.—M-6 (x1), M-7 (x9), M-9 (x3), M-13 (x4), M-15 (x112), M-16 (x4), M-17 (x95), M-18(x1), M-19 (x4), M-22 (x26), M-69 (x1), M-73 (x8), M-80(1971) (x6), M-91 (x6), M-92 (x3), M-94 (x5), M-95 (x26), M-100 (x1), M-151 (x2), M-158 (x8), M-176 (x6), Barry1 (x1), Indiana University 10565 (x14), an unknown locality (x12), USNM 6462 (x4), Laudon 13,923 (x7), Laudon 14,072 (x1), and Laudon 14,029 (x2).

Discussion.—The two species of *Plemnocrinus* that make up the majority of specimens in the genus in the Nunn Member (*P. bullatus* and *P. homalus*) may be two morphotypes of the same species. The tegmens are identical. The difference between the two species is the shape of the calyx, with *P. homalus* having a flat calyx and *P. bullatus* having a bowl shaped calyx. It could be a question of variation within one species. However, until further investigation can be done, the two will remain in separate species.

Occurrence.—Indian Wells Canyon, San Andres Canyon, Tierra Blanca Mountain, Black Range undefined, Rock Springs, Apache Hill, between North Percha Creek and Mineral Creek, Percha Creek Fork, Percha Creek, North Hollow Creek, and Wittenberg Ranch Windmill Section; and Burlington Limestone, Iowa.

PLEMNOCRINUS SUBSPINOSUS (Hall, 1858)

Figure 1.21.9-1.21.10

Platycrinus subspinosus HALL, 1858, p. 536, pl. 8, figs. 9-10; SHUMARD, 1868, p. 390; MILLER, S. A., 1889, p. 272; WACHSMUTH AND SPRINGER, 1897, p. 717, pl. 66, figs. 9a-9b; WELLER, 1898, p. 446; BATHER *in* Lankester, 1900, p. 158, fig. 71, no. 1; DELAGE AND HEROUARD, 1904, p. 382, fig. 462; GRABAU AND SHIMER, 1910, p. 519, fig. 1841; SPRINGER *in* Zittel, 1913, p. 199, fig. 300; WILSON, H. E., 1916, p. 509, pl. 2, fig. 6.

Platycrinites subspinosus (Hall, 1858). MEEK AND WORTHEN, 1873, p. 452, pl. 11, fig. 2; WELLER, 1898, p. 447; BASSLER AND MOODEY, 1943, p. 627.

Platycrinus (Pleurocrinus) subspinosus MEEK AND WORTHEN, 1866a, p. 173, pl. 15, fig. 6; BASSLER AND MOODEY, 1943, p. 627.

Plemnocrinus subspinosus (Hall, 1858). KIRK, 1946, p. 440; WEBSTER, 1973, p. 218, WEBSTER, 2003; AUSICH AND KAMMER, 2009, p. 707.

Diagnosis.—Calyx flat; basals not visible in lateral view; tegmen domed, much higher than calyx, plates nodose or spinose; ambulacral plates differentiated.

Material examined.—M-17 (x2) and Indiana University 10565 (x2).

Discussion.—A distinct gradation exists in the few specimens of *Plemnocrinus subspinosus* in the collections studied. The smallest specimen looks exactly like the one figured in Wachsmuth and Springer (1897, pl. 66, fig. 9b), whereas the largest only vaguely resembles it. The tegmen on the largest specimen is nearly three times higher than the calyx on the smallest specimen with a tegmen only 1.5 times higher. The sides of the tegmen are also nearly vertical in the largest specimen, whereas the tegmen sides of the smallest specimen is more convex. However, the two medium-sized specimens are intermediary between the others. The largest specimen of *Plemnocrinus subspinosus* resembles *Laticrinus oweni* Ausich and Kammer (2009) as figured in Wachsmuth and Springer (1897, pl. 66, figs. 10b-10c), except that *P. subspinosus* has a radial plate with a projecting neck, whereas *L. oweni* does not. The best taxonomic references for *P. subspinosus* are Wachsmuth and Springer (1897) and Kirk (1946).

Occurrence.—Black Range undefined and Apache Hill; and lower Burlington Limestone, Iowa.

Genus PLEUROCRINUS Austin and Austin, 1843

Type species.—*Pleurocrinus mucronatus* Austin in Austin and Austin, 1843; by original designation.

Diagnosis.—Calyx low bowl or expanding with concave sides; basal circle high, visible in side view; radials without laterally projecting neck at radial facet; five arm openings; tegmen flat inverted bowl, lower than calyx; five distinct large orals surrounded by few to relatively numerous small tegmen plates, small- and large-sized tegmen plates; tegmen plate size not gradational from orals to abaxial margins; anal tube absent, anus on upper margin of tegmen.

PLEUROCRINUS QUINQUENODUS (White, 1862)

Figure 1.21.11-1.21.12

Platycrinus quinquenodus WHITE, C. A., 1862 (adv. pub.); WHITE, C. A., 1865, p. 18; WACHSMUTH AND SPRINGER, 1897, p. 661, pl. 71, figs. 14a-14c; WELLER, 1898, p. 444; BASSLER AND MOODEY, 1943, p. 625.

Platycrinus quenquenodus (White, 1862) (sic). SHUMARD, 1868, p. 389; MILLER, S. A., 1889, p. 271.

Platycrinites quinquenodus (White, 1862). BASSLER AND MOODEY, 1943, p. 625; MOORE AND LAUDON, 1944, p. 203, pl. 78, fig. 19; GOOD, 1968, pl. 1, fig. 10; LAUDON, 1973, p. 31, fig. 6; WEBSTER, 1973, p. 213; WEBSTER, 1977, p. 139.

Pleurocrinus quinquenodus (White, 1892). WEBSTER, 2003; AUSICH AND KAMMER, 2009, p. 706.

Platycrinus plano-basalis ROWLEY AND HARE, 1891, p. 97, pl. 2, fig. 1; WELLER, 1898, p. 444.

Platycrinus planobasalis (ROWLEY AND HARE, 1891). MILLER, S. A., 1892a, p. 681; BASSLER AND MOODEY, 1943, p. 625.

Diagnosis.—Calyx low bowl; basals low.

Material examined.—M-9 (x1), M-15 (x1), M-17 (x1), M-86 (x1), Laudon 13,611 (x1), Laudon 13,763 (x1), and Laudon 13,785 (x1).

Discussion.—The discovery of *Pleurocrinus quiquenodus* in the Nunn Member extends the range of this species downward from the upper Burlington Limestone. The best taxonomic reference for *P. quiquenodus* is Wachsmuth and Springer (1897).

Occurrence.—Indian Wells Canyon, Marble Canyon, Black Range undefined, Tierra Blanca Mountain, and Apache Hill; and upper Burlington Limestone, Iowa.

PLEUROCINUS SP.

Figure 1.21.13-1.21.14

Diagnosis.—Calyx medium bowl; basals high

Material examined.—M-15 (x1) and M-17 (x3).

Discussion.—Although they are similar to the Western European species of *Pleurocrinus tuberculatus* (Miller, 1821), and *P. bellmanensis* (Wright, 1942) with a straight sided calyx, the Lake Valley specimens are so poorly preserved it is not possible to designate a new species. These specimens look nothing like either known North American species.

Occurrence.—Black Range undefined.

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TABLE 1.1.— Distribution of Lake Valley Formation crinoid species as they occur elsewhere according to Webster (2003). Kinderhookian formations include the Choteau Limestone and Compton Limestone in Missouri, the Hampton Formation in Iowa, and the Cuyahoga Formation of Ohio. Osagean formations include Fern Glenn Limestone in Missouri, Burlington Limestone (separated into lower and upper to distinguish what is equivalent to the Nunn Member (lower Burlington) and which is younger) in Iowa, lower Warsaw Formation in Illinois, Borden Formation in Kentucky, St. Joe Limestone and Boone Formation in Arkansas, Redwall Limestone in Arizona, and the Anchor Limestone in Nevada. Three species have only been reported in the Lake Valley Formation and are represented as such. Five species were specified as only being found in the Burlington Limestone with no indication as to whether it is the lower or the upper part; these are marked with xx.

	Kinderhookian				Osagean										LVF Only
	Choteau	Compton	Cuyahoga	Hampton	Fern Glen	L. Burl	U. Burl	Warsaw	Borden	Boone	St. Joe	Redwall	Anchor		
<i>Rhodocrinites tuberculatus</i>															X
<i>Cribanocrinus urceolatus</i>												X			
<i>Aryballocrinus whitei</i>				X		X	X								
<i>Aryballocrinus tenuidiscus</i>						X									
<i>Amphoracrinus rubinus</i>														X	
<i>Ancalocrinus spinobrachiatus</i>						X								X	
<i>Displodocrinus divergens</i>			X			X								X	
<i>Displodocrinus nevadensis</i>														X	
<i>Aacocrinus nododorsatus</i>	X	X													
<i>Aacocrinus enigmaticus</i>														X	
<i>Steganoocrinus pentagonus</i>					X	X									
<i>Cactocrinus proboscidalis</i>	X					X									
<i>Cactocrinus multibrachiatus</i>						X									
<i>Cusacrinus sobrinus</i>						xx	xx								
<i>Cusacrinus tenuisculptus</i>	X					xx	xx								
<i>Nunnacrinus dalyanus</i>															X
<i>Teliocrinus umbrosus</i>							X								
<i>Physetocrinus copei</i>												X			
<i>Physetocrinus lobatus</i>												X			
<i>Abatocrinus aequalis</i>	X					X									
<i>Abatocrinus clypeatus</i>	X					X									
<i>Eretmocrinus corbulis</i>						X									
<i>Eutrochocrinus christyi</i>	X				X		X				X				
<i>Eutrochocrinus lovei</i>							X								
<i>Agaricocrinus bullatus</i>						X	X	X							
<i>Agaricocrinus planoconvexus</i>	X					X	X		X						
<i>Agaricocrinus pyramidatus</i>						X									
<i>Dichocrinus conus</i>						X	X			X					

	Kinderhookian				Osagean									
	Choteau	Compton	Cuyahoga	Hampton	Fern Glen	L. Burl	U. Burl	Warsaw	Borden	Boone	St. Joe	Redwall	Anchor	LVF Only
<i>Strimplecrinus pisum</i>						X								
<i>Platycrinites burlingtonensis</i>						X								
<i>Platycrinites illinoisensis</i>						xx	xx							
<i>Platycrinites parvinodus</i>						X								
<i>Platycrinites peculiaris</i>														X
<i>Collicrinus shumardi</i>						X								
<i>Elegantocrinus annosus</i>	X													
<i>Elegantocrinus canaliculatus</i>						X	X							
<i>Elegantocrinus nodostriatus</i>							X					X		
<i>Elegantocrinus pileiformis</i>	X					X								
<i>Elegantocrinus pocilliformis</i>						X								
<i>Eucladocrinus pleuroviminus</i>							X							
<i>Oenochoacrinus limbus</i>													X	
<i>Oenochoacrinus cortina</i>	X													
<i>Pleurocrinus quiquenodus</i>						xx	xx							
<i>Plemnocrinus bullatus</i>						xx	xx							
<i>Plemnocrinus homalus</i>						X								
<i>Plemnocrinus subspinosus</i>							X							
Counts	10	1	1	1	2	27	16	1	1	1	1	4	6	3

TABLE 1.2.—Measurements of *Blairocrinus macurdai* n. sp. (in mm); holotype indicated by asterisk.

	Crown	Aboral Cup	Calyx (A-CD)	Basal		Radial		Primanal	
	H	H	W	H	W	H	W	H	W
UMMP 74065*	21.2	6.8	20.4	2.2	2.8	3.1	3.8	2.8	3.8
UMMP 74066	17.7	5.3	20.0	-	-	-	-	-	-
UMMP 74067	12.5	3.2	13.5	1.0	3.1	1.5	2.5	1.8	1.6

TABLE 1.3.— Comparison of diagnostic characters of *Blairocrinus macurdai* n. sp. with other known species of the genus.

	<i>B. trijugis</i>	<i>B. arrosus</i>	<i>B. protubertus</i>	<i>B. macurdai</i>
Calyx	low bowl	low bowl	low cone	low bowl
Basals	small, form flat horizontal disk	small, project slightly from column	small, barely visible in lateral view	small, visible in lateral view
Radials	large, nearly as wide as long; stellate	little wider than long; has transverse nodes	large; elongate nodes	wider than high; stellate
Primibrachials	1st quadrangular wider than long; 2nd larger than 1st	1st quadrangular, wider than long; 2nd axillary, larger than first	1st pentagonal or hexagonal; 2nd axillary, same size as first	1st hexagonal, wider than high; 2nd axillary, same size as first
Secundibrachials	one per half-ray	one per half-ray	one per half-ray	one per half-ray
Anal	Primanal smaller than radials; 1;2;2;2. Anal tube central, stout	Primanal as large as radials; 1;2;2. Anal tube central, stout	Primanal same size as radials; 1;2;3;3. Anal tube slightly eccentric, narrow	Primanal smaller than radial; 1;2;3;2;2. Anal tube central to slightly eccentric, stout
Tegmen	low inverted bowl; large spines on ambulacral plates, rest smooth	low to medium inverted bowl; plates nodose to spinose	flat or very low cone; plates low spines or smooth	medium cone; plates spinose to nodose

TABLE 1.4.—Measurements of *Iotacrinus novamexicana* n. sp. (in mm); holotype indicated by asterisk.

	Crown	Aboral Cup	Calyx (A-CD)	Basal		Radial		Primanal	
	H	H	W	H	W	H	W	H	W
UMMP 74068*	15.5	5.7	14.3	1.0	3.8	2.8	3.7	2.2	2.7
UMMP 74069	16.8	7.1	16.7	1.4	4.0	2.5	4.2	2.6	2.6
UMMP 74070	17.2	6.5	14.6	1.4	3.5	3.2	4.0	2.5	3.0

TABLE 1.5.—Comparison of diagnostic characters of *Iotacrinus novamexicana* n. sp. with other known species of the genus.

	<i>I. dorsatus</i>	<i>I. novamexicana</i>
Calyx	low bowl	low bowl
Basals	small, visible in lateral view	small, visible in lateral view
Radials	hexagonal or heptagonal, wider than high; stellate	hexagonal, wider than high; stellate
Primibrachials	1st wider than high; 2nd axillary, smaller than 1st	1st hexagonal, wider than high; 2nd axillary, slightly smaller than 1st
Secundibrachials	one per half-ray	one per half-ray
Anal	Primanal narrower than radials; 1;2;3 or 1;2;3;2. Anal tube eccentric, long	Primanal narrower than radials; 1;2;3. Anal tube eccentric, stout
Tegmen	flat to low bowl; approximately as high as calyx; plates nodose	medium to low inverted bowl; as high as or slightly higher than calyx; plates smooth to slightly nodose

TABLE 1.6.—Measurements of *Uperocrinus kuesi* n. sp. (in mm).

	Crown	Aboral Cup	Calyx (A-CD)	Basal		Radial		Primanal	
	H	H	W	H	W	H	W	H	W
UMMP 74071	29.4	14.8	28.0	4.5	9.0	5.7	8.2	8.6	7.1

TABLE 1.7.—Comparison of diagnostic characters of the most similar species to *Uperocrinus kuesi* n. sp. as well as the type species.

	<i>U. pyriformis</i>	<i>U. hageri</i>	<i>U. marinus</i>	<i>U. kuesi</i>
Calyx	medium cone	low cone to low bowl	medium cone	medium cone
Basals	wider than long	rounded at bottom	wider than high, sutures grooved, trilobate outline	wider than high, sutures grooved, trilobate outline
Radials	large, higher than wide, no ornamentation	higher than wide, no ornamentation	higher than wide, prominent node in center	wider than high, prominent node in center
Primibrachials	1st small, quadrangular; 2nd axillary, wider than 1st	1st quadrangular, wider than long; 2nd axillary, wider than 1st	1st quadrangular, wider than long; 2nd axillary, wider than 1st	1st hexagonal, wider than long; 2nd axillary, smaller than 1st; both have central node
Secundibrachials	one per half-ray, supports tertibrachs, which support arm facets	two per half-ray; support arm facets	two per half-ray; support arm facets	two per half-ray; supports arm facets; both with central node
Anal	Primanal as large as radials; 1;3;3;1-2. Anal tube long, central, heavy	Primanal little smaller than radials; 1;3;3;2;2. Anal tube eccentric, very narrow, short	Primanal higher and narrower than radials; 1;3;3;2;2. Anal tube long, heavy	Primanal higher and narrower than radials; 1;3;2;1. Anal tube eccentric, very narrow
Tegmen	medium cone; same height as to lower than calyx, slightly bulging; plates nodose	flat cone; lower than calyx; plates smooth	unknown	flat cone; lower than calyx; plates convex

TABLE 1.8.—Measurements of *Agaricocrinus alamogordoensis* n. sp. (in mm).

	Crown	Aboral Cup	Calyx (A-CD)	Basal		Radial		Primanal	
	H	H	W	H	W	H	W	H	W
UMMP 74072	17.5	6.1	15.7	2.0	4.0	3.2	4.8	3.9	3.4

TABLE 1.9.—Comparison of diagnostic characters of the most similar species to *Agaricocrinus alamogordoensis* n. sp. as well as the type species.

	<i>A. tuberosus</i>	<i>A. brevis</i>	<i>A. convexus</i>	<i>A. coreyi</i>	<i>A. fiscellus</i>	<i>A. alamogordoensis</i>
Calyx	depressed bowl	low bowl, convex	low cone, convex	low bowl, convex	low bowl, convex	low cone, convex
Basals	small, hidden by column	Small, form bottom of column depression	small, in depression, hidden by column	small, on level with radials	Shallow depression at center for column	Small, form concavity, edges visible in side view
Radials	as long as wide; no ornamentation	little longer than wide; ridges occupy upper end, convex lower part smooth	large, as long as wide; no ornamentation	large; wider than long; no ornamentation	Wider than long, upper part little nodose, but w/o ornamentation	wider than high, prominent node in center
Primibrachials	1st small, quadrangular; 2nd axillary, wider than 1st	1st small, quadrangular, convex sides. 2nd axillary shorter than 1st but wider	1st quadrangular, wider than long; 2nd axillary, wider than first	1st quadrangular, wider than long; 2nd axillary, smaller than 1st	1st quadrangular, wider than long; 2nd axillary, wider than 1st	1st hexagonal, wider than long; 2nd axillary, same width as 1st
Secundibrachials	one per half-ray	two per half-ray	two per half-ray	two per half-ray	two per half-ray	one per half-ray, supports one arm facet apiece
Anal	Primal anal higher and narrower than radials; 1;3;3. Anal opening directed laterally	Primal anal little narrower than radials. 1;3;4-5;many. Well defined grooves on sides of anal area. Anal opening directed laterally	Primal anal higher and narrower than radials; 1;3;4-5;many; shallow groove on sides. Anal opening directed obliquely upwards	Primal anal higher and narrower than radials; 1;1;1. No grooves. Anal opening directed obliquely upwards	As <i>A. brevis</i> but more bulging	Primal anal higher and narrower than radials. 1;3;3;3. No grooves. Anal opening directed laterally
Tegmen	much higher than calyx	same height as calyx	lower than calyx	Same height as calyx	lower than calyx	Same height as calyx

TABLE 1.10.—Measurements of *Collicrinus laudoni* n. sp. (in mm).

	Crown	Aboral Cup	Calyx (A-CD)	Basal		Radial	
	H	H	W	H	W	H	W
UMMP 74073	12.1	7.0	14.9	3.9	6.5	7.5	7.8

TABLE 1.11.—Comparison of diagnostic characters of *Collicrinus laudoni* n. sp. with other known species of the genus.

	<i>C. shumardi</i>	<i>C. formosus</i>	<i>C. laudoni</i>
Calyx	flat bowl	low bowl flat, within basal concavity, nodes visible in lateral view	flat bowl
Basals	flat, not visible in lateral view		flat, visible in lateral view
Radials	wider than high, circular to elongate nodes crudely aligned in rows	wider than high, nodose	as wide as high, smooth
Anal	Anal tube on margin of upper side of tegmen	Anal tube stout, side of tegmen, projects outward or obliquely upward	Anal tube eccentric, projects upward
Tegmen	low inverted bowl, higher than calyx; plates large w/ short spines	as high as calyx; plates few, very convex to nodose	low inverted bowl, lower than calyx; plate large and nodose

FIGURE 1.1.—Map of New Mexico showing the collecting sites for the Nunn Member. Most were collected by Dr. Brad Macurda.

Age	Formation	Member	Faunal Unit		Faunal Unit	Formation	Age
L. Osagean - E. Meramecian	Lake Valley	Doña Ana	7		7	Salem Ls	E. Meramecian
						Upper Warsaw Sh	
						L. Warsaw	
						Keokuk Ls	
					6		Osagean
Arcente		6		5	Burlington Limestone		
				4U			
Tierra Blanca		5		4L			
		4					
Nunn		3		3B	Fern Glen Ls		
Alamo-gordo				3A	Meppen Ls		
Andre-cito		2		2			

FIGURE 1.2.—Comparative stratigraphic column showing how the Lake Valley Formation and the Burlington Limestone correlate to each other using conodont faunal units proposed by Lane (1974) for the Lake Valley and Lane and Brenckle (2001) for the Burlington.

FIGURE 1.3.—Map showing the paleogeography of the area during the Early Osagean. The white markers indicate the main collecting localities (Sacramento Mountains to the east and Black Range to the west). The basin to the southeast of the Lake Valley Formation does not have a Mississippian name, but is where the Permian Delaware Basin forms.

FIGURE 1.4.—Map showing the grouped localities in the Black Range (see Fig. 1).

FIGURE 1.5.—Map showing the grouped localities in the Sacramento Mountains (see Fig. 1).

FIGURE 1.6.—Q-Mode MDS plot using Jaccard Coefficient showing the distribution of the 16 collecting localities (Berenda Canyon and Wilson Ranch excluded because they have one taxon each). A divide between the eastern localities and western localities is evident. Stress value = 0.13, which is a fair to good fit (Kruskal, 1964).

FIGURE 1.7.— Crinoids from the families Rhodocrinitidae (diplobathrid) and Periechocrinidae (monobathrid). 1,2, *Rhodocrinites tuberculatus* (Wachsmuth and Spinter 1897), x3.0: 1, A-ray lateral view; 2, CD interray lateral view. 3,4, *Cribanocrinus urceolatus* (Wachsmuth and Springer, 1897), x3.0: 3, A-ray lateral view; 4, CD interray lateral view. 5, *Gilbertsocrinus* sp., tegmen view, x1.5. 6,7, *Aryballocrinus tenuidiscus* (Hall, 1861), x2.0: 6, A-ray lateral view; 7, CD interray lateral view. 8,9, *Aryballocrinus whitei* (Hall, 1861), x1.5: 8, A-ray lateral view; 9, CD interray lateral view.

FIGURE 1.8.—Crinoids from the family Amphoracrinidae. 1,2, *Amphoracrinus rupinus* Webster and Lane, 1987, x1.5: 1, A-ray lateral view; 2, CD interray lateral view. 3,4, *Ancalocrinus spinobrachiatus* (Hall, 1859), x2.0: 3, A-ray lateral view; 4, CD interray lateral view. 5,6, *Ancalocrinus* sp, x3.0: 5, A-ray lateral view; 6, CD interray lateral view. 7,8 *Displodocrinus divergens* (Hall, 1859), x3.0: 7, CD interray lateral view; 8, A-ray lateral view. 9, 10, *Displodocrinus nevadensis* (Webster and Lane, 1987), x2.0: 9, CD interray lateral view; 10, A-ray lateral view.

FIGURE 1.9.—Crinoids from the family Actinocrinitidae, subfamily Actinocrinitinae. 1,2, *Aacocrinus nododorsatus* Bowsher, 1955, x3.0: 1, A-ray lateral view; 2, CD interray lateral view. 3,4, *Aacocrinus enigmaticus* Webster and Lane, 1987, x2.0: 3, A-ray lateral view; 4, CD interray lateral view. 5,6, *Blairocrinus macurdai* n. sp.; UMMP 74066; x2.0: 5, A-ray lateral view; 6, CD interray lateral view. 7,8 *Iotacrinus novamexicana* n. sp.; UMMP 74068; x3.0: 7, A-ray lateral view; 8, CD interray lateral view. 9, 10, *Steganocrinus pentagonus* (Hall, 1858), x2.0: 9, CD interray lateral view; 10, A-ray lateral view.

FIGURE 1.10.—Chart showing the ratio differences between the protuberance of arm rays between *Blairocrinus arrosus* and *B. macurdai* n. sp.

FIGURE 1.11.—Crinoids from the family Actinocrinitidae, subfamily Cactocrininae. 1,2, *Cactocrinus proboscidalis* (Hall, 1858), x2.0: 1, A-ray lateral view; 2, CD interray lateral view. 3,4, *Cactocrinus multibrachiatus* (Hall, 1858), x1.5: 3, A-ray lateral view; 4, CD interray lateral view. 5,6, *Cusacrinus sobrinus* (Miller and Gurley, 1896), x2.0: 5, A-ray lateral view; 6, CD interray lateral view. 7,8 *Cusacrinus tenuisculptus* (McChesney, 1861), x2.0: 7, A-ray lateral view; 8, CD interray lateral view. 9, 10, *Nunnacrinus dalyanus* (Miller, 1881), x1.5: 9, A-ray lateral view; 10, CD interray lateral view.

FIGURE 1.12.— Plots showing the interradial plate number that separates the rays on the 61 *Nunnacrinus* specimens (*N. dalyanus* n=23; *N. mammillatus* n=38) found in the Springer Room of the Smithsonian. Brower (1955) states that *N. dalyanus* only has one interradial plate between rays and *N. mammillatus* has two. Examination of the interradial plates shows that there is no set pattern and that most specimens have both single and double plates between rays and therefore making *N. mammillatus* a junior synonym of *N. dalyanus*. Zero plates in the interray indicate that those interrays were poorly preserved and the number of plates could not be counted. Specific information on the specimens from the Smithsonian can be found in Appendix 3.

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FIGURE 1.13.—Crinoids from the family Actinocrinitidae, subfamily Cactocrininae, subfamily Physetocrininae and family Batocrinidae. 1,2, *Teleocrinus umbrosus* (Hall, 1858), x1.5: 1, A-ray lateral view; 2, CD interray lateral view. 3,4, *Physetocrinus lobatus* Wachsmuth and Springer, 1897, x2.0: 3, CD interray lateral view; 4, A-ray lateral view. 5,6, *Physetocrinus copei* (Miller, 1881), x1.5: 5, CD interray lateral view; 6, A-ray lateral view. 7,8 *Abatocrinus aequalis* (Hall, 1858), x2.0: 7, A-ray lateral view; 8, CD interray lateral view.

FIGURE 1.14.—Width-height ratio of the tegmens of 37 specimens of *Phyetocrinus copei* from the undefined Black Range area (locality M-17) showing the variation of tegmen inflation as compared to the height of the crown.

FIGURE 1.15.—Crinoids from the family Batocrinidae. 1,2, *Abatocrinus clypeatus* (Hall, 1859), x3.0: 1, A-ray lateral view; 2, CD interray lateral view. 3,4, *Eretmocrinus corbulis* (Hall, 1861), x3.0: 3, A-ray lateral view; 4, CD interray lateral view. 5,6, *Eutrochocrinus christyi* (Shumard, 1855), x2.0: 5, CD interray lateral view; 6, A-ray lateral view. 7,8 *Eutrochocrinus lovei* (Wachsmuth and Springer, 1881), x2.0: 7, A-ray lateral view; 8, CD interray lateral view. 9, 10, *Simatocrinus* sp., x3.0: 9, A-ray lateral view; 10, CD interray lateral view.

FIGURE 1.16.—Crinoids from the families Batocrinidae and Coelocrinidae. 1,2, *Uperocrinus kuesi* n. sp.; UMMP 74071; x2.0: 1, A-ray lateral view; 2, CD interray lateral view. 3,4, *Uperocrinus* sp., x2.0: 3, A-ray lateral view; 4, CD interray lateral view. 5,6, *Agaricocrinus bullatus* Hall, 1858, x3.0: 5, A-ray lateral view; 6, CD interray lateral view.

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FIGURE 1.17.—Crinoids from the families Coelocrinidae and Dichocrinidae. 1,2, *Agaricocrinus planoconvexus* Hall, 1861, x3.0: 1, A-ray lateral view; 2, CD interray lateral view. 3,4, *Agaricocrinus pyramidatus* (Hall, 1858), x3.0: 3, A-ray lateral view; 4, CD interray lateral view. 5,6, *Agaricocrinus alamogordoensis* n. sp.; UMMP 74072; x3.0: 5, CD interray lateral view; 6, A-ray lateral view. 7-9, *Dichocrinus conus* Meek and Worthen, 1860, x3.0: 7, CD interray lateral view; 8, A-ray lateral view; 9, different specimen that shows the arms attached. 10,11, *Dichocrinus* sp., x2.0; 10, CD interray lateral view; 11, A-ray lateral view.

FIGURE 1.18.—Crinoids from the families Dichocrinidae and Platycrinidae. 1,2, *Srimplecrinus pisum* (Meek and Worthen, 1869), x3.0: 1, A-ray lateral view; 2, CD interray lateral view. 3, *Srimplecrinus* sp., x3.0. 4,5, *Platycrinites burlingtonensis* (Owen and Shumard, 1850), x3.0: 4, A-ray lateral view; 5, CD interray lateral view. 6,7, *Platycrinites parvinodus* (Hall, 1861), x2.0: 6, A-ray lateral view, 7, CD interray lateral view. 8,9, *Platycrinites illinosensis* (Miller and Gurley, 1896), x2.0: 8, A-ray lateral view; 9, CD interray lateral view. 10,11, *Platycrinites peculiaris* (Wachsmuth and Springer, 1897), x3.0: 10, A-ray lateral view; 11, CD interray lateral view.

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FIGURE 1.19.—Crinoids from the family Platycrinidae. 1,2, *Platycrinites* sp., x1.5: 1, A-ray lateral view; 2, CD interray lateral view. 3,4, *Collicrinus shumardi* Ausich and Kammer, 2009, x3.0: 3, A-ray lateral view; 4, CD interray lateral view. 5,6, *Collicrinus laudoni* n. sp.; UMMP 74073; x3.0: 5, A-ray lateral view; 6, CD interray lateral view. 7,8 *Elegantocrinus canaliculatus* (Hall, 1858), x3.0: 7, CD interray lateral view; 8, A-ray lateral view. 9, 10, *Elegantocrinus annosus* (Miller, 1891), x3.0: 9, CD interray lateral view; 10, A-ray lateral view.

FIGURE 1.20.—Crinoids from the family Platycrinitidae. 1,2, *Elegantocrinus nodostriatus* (Wachsmuth and Spinger, 1897), x3.0: 1, A-ray lateral view; 2, CD interray lateral view. 3,4, *Elegantocrinus pocilliformis* (Hall, 1858), x3.0: 3, CD interray lateral view; 4, A-ray lateral view. 5,6, *Elegantocrinus pileiformis* (Hall, 1858), x2.0: 5, A-ray lateral view; 6, CD interray lateral view. 7,8 *Elegantocrinus* sp. A, x2.0: 7, A-ray lateral view; 8, CD interray lateral view. 9, 10, *Elegantocrinus* sp. B, x1.5: 9, A-ray lateral view; 10, CD interray lateral view. 11, *Eucladocrinus pleuroviminus* (White, 1862), aboral view, x2.0. 12, *Eucladocrinus* sp., aboral view, x2.0.

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FIGURE 1.21.—Crinoids from the family Platycrinitidae. 1,2, *Oenochocrinus limbus* Webster and Lane, 1987, x3.0: 1, CD interray lateral view; 2, A-ray lateral view. 3,4, *Oenochocrinus cortina* (Miller and Gurley, 1894), x3.0: 3, A-ray lateral view; 4, CD interray lateral view. 5,6, *Plemnocrinus bullatus* Kirk, 1946, x2.0: 5, A-ray lateral view; 6, CD interray lateral view. 7,8 *Plemnocrinus homalus* Kirk, 1946, x2.0: 7, A-ray lateral view; 8, CD interray lateral view. 9, 10, *Plemnocrinus subpinosus* (Hall, 1858), x3.0: 9, A-ray lateral view; 10, CD interray lateral view. 11,12, *Pleurocrinus quiquenodus* (White, 1862), x2.0: 11, A-ray lateral view; 12, CD interray lateral view. 13,14 *Pleurocrinus* sp., x1.5: 13, CD interray lateral view; 14, A-ray lateral view.

Chapter 2:
Generic Concepts in the Actinocrinitidae Austin and Austin, 1842 and Evaluation of Generic
Assignments of North American Species

Elizabeth C. Rhenberg, William I. Ausich, and Thomas W. Kammer

ABSTRACT

The Actinocrinitidae was a significant contributor to the global biodiversity peak of crinoids that occurred during the Mississippian and is referred to as the “Age of Crinoids.” Although the actinocrinitids are a major component of the high diversity, they are also a source of much taxonomic confusion. Generic concepts were not applied equally between Europe and North America creating disparity in genus definition. In this contribution, the global genera are defined objectively by discrete characters, and the generic assignments of the North American species are reevaluated. A phylogenetic hypothesis is presented for the relationships of the Actinocrinitidae genera based on a parsimony-based analysis and plotted against stratigraphic ranges. Although groupings were revealed in this analysis, the Actinocrinitidae cannot be readily divided into subfamilies. Twenty-one genera are described, 17 of which are found in North America. A total of 125 species were evaluated of which 34 species and one open-nomenclature taxon are reassigned to different genera, and four species are designated as *nomina dubia*.

INTRODUCTION

The Actinocrinitidae is a very important family of Mississippian crinoids due to their considerable diversity and high abundance. Actinocrinitids encompass a large array of morphological disparity produced by the complex arrangements of their numerously plated

calyxes. Because there are innumerable specimens in many Mississippian faunas and because we suspect that hybridization was a complicating factor as demonstrated in *Eretmocrinus* (Ausich and Meyer, 1994) and suggested for the Batocrinidae (Ausich and Kammer, 2010), this is a complex group. Both Wachsmuth and Springer (1897) and Bowsher (1955) worked to clarify generic definitions among North American actinocrinitids, but many issues still remain. First and most significant among these problems is that the generic concept for *Actinocrinites*, as defined by *Actinocrinites triacontadactylus* Miller, 1821, was not applied consistently to North American faunas.

Ausich and Sevastopulo (2001) designated a neotype for *Actinocrinites triacontadactylus*; and with this definition re-established, Ausich and Sevastopulo (2001) and Ausich and Kammer (2006) made generic reassignments to all actinocrinitids from Ireland, England, and Wales. Species-level systematics has only been completed for Ivorian faunas (Ausich and Sevastopulo, 2001). A total of six actinocrinitid genera are now recognized from Ireland, England, and Wales.

The primary source of confusion for understanding the systematics of North American (and other) actinocrinitids is that genus-level diagnostic characters that define European actinocrinitids have been applied as species-level diagnostic characters among North American forms. For example, ray grouping and lobation helps to define European genera, but this currently is used to differentiate North American species of *Actinocrinites*. Unfortunately, the solution for this is reassignment of many well-known North American species of “*Actinocrinites*” to other genera. Although inconvenient, this situation is not surprising, because many nineteenth century “catch-all” genera have been subdivided into numerous new genera, such as *Cyathocrinites*, *Phanocrinus*, *Platycrinites*, and *Poteriocrinites*. Recognition of well-

defined genus concepts is a prerequisite for fully understanding the phylogeny, paleobiogeography, and evolutionary paleoecology of these crinoids.

This study is a continuation of the efforts to redefine the generic concepts of monobathrid camerates (Ausich and Kammer, 2008; Ausich and Kammer, 2009; Ausich and Kammer, 2010). Revising the camerates is an important step in compiling an accurate database to evaluate the evolutionary paleoecology of Mississippian crinoids, which will include an examination of the global, generic relationships between longevity, eurytopy, and evolutionary paleoecology of these crinoids (Ausich and Kammer, 2010). The camerates are of particular interest because they reached their peak diversity during the Tournaisian and are one of the most diverse groups of crinoids during this time (Kammer and Ausich, 2006; Sallan, *et al.*, 2011).

In this contribution, the goals are to define all Actinocrinitidae genera with objective characters and to assign all North American species to the correct genus. This study looked at 125 North American species and 34 species and one species left in open nomenclature were reassigned to different genera (Table 2.1) and four species were designated as nomina dubia. This is only a first step for a full understanding of the Actinocrinitidae, but it does allow for evaluation of regional and global patterns of generic longevity, eurytopy, and evolutionary paleoecology. Significant evaluation of species-level systematics remains to be completed but is far beyond the scope of this study.

SYSTEMATIC PALEONTOLOGY

Where possible, all species were characterized by original descriptions and illustrations, subsequent descriptions and illustration of type specimens, and examination of type specimens. Complete synonymies are not provided as they are published in Webster (2003). Terminology

follows Ubaghs (1978a) with modifications from Ausich et al. (1999) and open nomenclature that follows Matthews (1973).

Carboniferous stratigraphy follows Heckel and Glayton (2005). Table 2.2 shows the detailed chronostratigraphic scheme and correlations that are used in this paper which follow Ausich and Kammer (2008).

This study focuses on the genera and species that are found in North America. Genera that are found outside of North America are described so that their characters can be fit within the family, but more detail is not added. Sixty-seven species found outside North America are mentioned, but their assignments are not verified. If an obvious error in generic placement was seen, it is noted, but no further investigation was done.

CLASS CRINOIDEA Miller, 1821

Subclass CAMERATA Wachsmuth and Springer, 1885

Order MONOBATHRIDA Moore and Laudon, 1943

Suborder COMPSOCRININA Ubaghs, 1978b

Superfamily PERIECHOCRINACEA Bronn, 1849

Family ACTINOCRINITIDAE Austin and Austin, 1842

Discussion.—Bowsher and Ubaghs (1978) subdivided the Actinocrinitidae into four subfamilies: Actinocrinitinae Austin and Austin, 1842; Eumorphocrininae Ubaghs, 1978c; Cactocrininae Ubaghs, 1978d; and Physetocrininae Ubaghs, 1978e. A phylogenetic analysis was performed to investigate relationships between genera and to test if the previously named subfamilies represented actual clades. Phylogenetic relationships are inferred using parsimony-based character analysis of genera using PAUP ©4.0b10 (Swofford, 2001). The actinocrinitid

genera are defined using objective characters that define basic and distinctive characters found in of the calyx and tegmen. Seventeen characters with 68 character states were used to analyze the genera. These characters are unordered and unweighted; search methods were heuristic with random stepwise addition. Two trees were found under these conditions with a Rolf's consistency index (C.I.) of 0.56. The tree presented in this study (Fig. 2.1) is the one that places *Manillacrinus* in the clade with *Cactocrinus* as opposed to creating a polytomy with the clades containing *Cactocrinus* and *Actinocrinites*.

The outgroup used for this analysis are two genera from the Periechocrinidae Bronn, 1849 including *Periechocrinus* Morris, 1843, a Silurian and Devonian genus and *Megistocrinus* Owen and Shumard, 1852, a Devonian and Mississippian genus. Characters that are used for the outgroup genera are based on their type species, but the character states used for the Actinocrinitidae are based on all known species for each of the genera.

Only one subfamily defined by Ubaghs (1978b), the Actinocrinitinae, forms a clade in the phylogenetic analysis (Fig. 2.1) completed herein. The other three subfamilies are scattered throughout the tree. Thus, the subfamily classification of the *Treatise* (Ubaghs, 1978b) does not recognize monophyletic clades and should be abandoned.

Webster (2003) listed 21 genera in the family Actinocrinitidae; of these 21, five are not known in North America; one, *Ancalocrinus* Webster and Lane, 1987, was later included in the family Amphoracrinidae (Webster et al., 2004); and one, *Diatorocrinus* Wright, 1955, was synonymized into *Actinocrinites* (Ausich and Kammer, 2006). Ausich and Sevastopulo (2001) described two new genera of Actinocrinitidae, *Iotacrinus* and *Thinocrinus*, from Hook Head, Ireland. With these subtractions and additions, the present study recognizes 21 genera globally, with 17 recognized in North America.

Wachsmuth and Springer (1897) subdivided the actinocrinitids into three primary groups that included: 1) genera with an anal tube, calyx lobed, and interradians in contact with the tegmen; 2) genera with an anal tube, calyx not lobed, and interradians not in contact with the tegmen; and 3) genera without an anal tube. Although these three groups are a good general way to subdivide the family, they do not represent any phylogenetic relationship between genera. For example, *Physetocrinus* and *Strotocrinus* Meek and Worthen, 1866 are the only known actinocrinitid genera without an anal tube, yet *Strotocrinus* is more closely related to *Teleiocrinus* Wachsmuth and Springer, 1881 than it is to *Physetocrinus* (Fig. 2.1).

The genus-level diagnostic characters for genera within Actinocrinitidae are defined as follows: calyx shape, basal circlet height, number of fixed secundibrachials, highest brachitaxis in the vertical wall of the calyx, number of ranges in the regular interrays, regular interrays in contact with tegmen, posterior interray in contact with tegmen, number of plates above the primanal, presence or absence of fixed interbrachials between half-rays, arms grouped, arm lobes, length of arm lobes, tegmen height compared to calyx, tegmen plate sculpture, tegmen shape, tegmen interrays depressed, and position of anal tube (Table 2.3).

One of the most distinct characters that separates genera within the actinocrinitids is the presence or absence of arm lobes. Arm lobes are extensions of the theca (calyx and tegmen) away from the distal portion of the calyx, formed by fixed brachials proximally and tegmen plates distally. All actinocrinitids that have arm lobes have arms that are strongly grouped and interrays that are in contact with the tegmen. This was the condition that Bowsher and Ubaghs (1978) used to distinguish the subfamily Actinocrinitinae; the same genera form a single clade in the phylogenetic tree (Fig. 2.1). When the theca is complete, the distinction is obvious, but if the arm trunks are broken, it could be impossible to know for certain whether or not arm trunks

existed. Two other basic conditions exist among the actinocrinitids that lack arm trunks (i.e., where arms become free in a more-or-less circular pattern rather than being extended into arm lobes). Most actinocrinitids that lack arm lobes have arms that are either strongly or weakly grouped, allowing for the interrays to be in contact with the tegmen. In contrast, a few actinocrinitids have arm openings that are in continuous lateral contact, not allowing for interrays to connect with the tegmen. Examples of these conditions are as follows: *Actinocrinites* has long arm lobes, *Aacocrinus* has short arm lobes, *Eumorphocrinus* lacks arm lobes, but has a strong grouping of arm openings, *Nunnacrinus* lacks arm lobes and only has a slight grouping of arm openings, and *Cactocrinus* lacks arm lobes and all the arm facets are in lateral contact with one another.

Actinocrinitids that have arm lobes are *Aacocrinus*, *Abactinocrinus*, *Actinocrinites*, *Blairocrinus*, *Iotacrinus*, *Sampsonocrinus*, *Steganocrinus*, and *Thinocrinus*, and these genera form a distinct clade (Fig. 2.1). These crinoids can be distinguished based on the height of the basal circlet, length of arm lobes, number of plates in the vertical wall of the calyx, height of the tegmen, position of anal tube, and whether or not the tegmen is depressed in the interrays.

Actinocrinites was first described by Miller (1821) with the type species *Actinocrinites triacontadactylus* from the Chadian of England. Among the English and Irish actinocrinitids, *Actinocrinites* is distinct because it is the only one that has arm lobes and fixed brachials in the vertical wall of the calyx that is higher than the primitaxis (Ausich and Sevastopulo, 2001). The Irish, English, and Welsh actinocrinitid generic assignments were revised by Ausich and Sevastopulo (2001) and Ausich and Kammer (2006).

North American species of *Actinocrinites* need to be reassigned based on the characters that define the genus. Many of species that have traditionally been in *Actinocrinites* lack arm

lobes, only have primibrachials in the vertical calyx wall, or both. This is unfortunate due to how common *Actinocrinites* sensu lato is and that it is easily identifiable with isolated radial plates or basal circlets. The only *Actinocrinites* sensu stricto that remain in North America are *Actinocrinites grandissimus* Van Sant, 1965, *Actinocrinites jugosus* (Hall, 1859), *Actinocrinites lobatus* (Hall, 1859), *Actinocrinites magnificus* (Wachsmuth and Springer, 1897); *Actinocrinites monticuliferus* (Miller and Gurley, 1894), and *Actinocrinites spergenensis* (Miller and Gurley, 1896).

The three more common actinocrinitids of North America are *Aacocrinus* Bowsher, 1955, *Steganocrinus*, Meek and Worthen, 1866, and *Thinocrinus* Ausich and Sevastopulo, 2001. All have calyces that are either a medium cone or a medium bowl shaped. *Aacocrinus* has short length arm lobes, a tegmen that is lower in height than the calyx, and an anal tube that is eccentric. *Steganocrinus* and *Thinocrinus* are easy to distinguish when the specimens are complete because *Steganocrinus* has long arm trunks along which the biserial arms are borne, and *Thinocrinus* has normal biserial free arms that leave the calyx from a fixed brachial. Unfortunately, most specimens are not complete and have either some or all of the arm lobes broken. Arms versus arm trunks must then be inferred and other characters considered. *Thinocrinus* has a tegmen that is lower than the calyx, the interrays on the tegmen are depressed, and the anal tube is central, whereas *Steganocrinus* has a tegmen that is as high as the calyx, interrays on the tegmen are not depressed, and the anal tube is eccentric. However, the most telling characteristic that distinguishes *Steganocrinus* from *Thinocrinus* (and other actinocrinitids) is that the first primibrachial flares outward and the second primibrachial (primaxil) is directed almost horizontally. In contrast, *Thinocrinus* has the first primibrachial in the calyx wall and the outflaring into arms begins with the primaxil or on the primaxil facet.

The characters of where the primibrachial outflaring begins and the presence or absence of arm trunks are sufficient to diagnose most specimens between these two genera. Even though arm trunk preservation is extremely rare, it does not prevent the inference as to whether or not the trunk existed. In *Steganoocrinus* the arm trunks divide from five to ten at a distance away from the calyx wall, whereas in *Thinocrinus* and other actinocrinitids, the rays divide into ten or more arms very close to the body wall. Because of the difference, in typical preservation (distal rays damaged or broken) a single ray opening is preserved in *Steganoocrinus* and all other actinocrinitids preserve the ambulacral divisions either partially or completely.

Abactinoocrinus Laudon and Severson, 1953 and *Sampsonocrinus* Miller and Gurley, 1895 both have medium bowl shaped calyces and depressions in the tegmen inetrarrays. *Abactinoocrinus* is more closely related to *Thinocrinus* based on phylogenetic analysis, and although *Sampsonocrinus* shares many of the same characters with both *Abactinoocrinus* and *Thinocrinus*, it is separated by having an anal tube that is eccentric and not central.

Iotocrinus Ausich and Sevastopulo, 2001 is unique among the actinocrinitids with both arm lobes and a low bowl-shaped calyx. It is also one of only two of all the actinocrinitids to have a tegmen that can be higher than the calyx. *Blaiocrinus* Miller, 1891 is the only genus where all known species have a higher tegmen than the calyx. It can be readily distinguished from *Iotocrinus* by having a low-cone shaped calyx and a central anal tube.

No other actinocrinitids have arm lobes, and most of the others cluster together in a single clade. This clade, which consists of *Cactocrinus*, *Cusacrinus*, *Glaphyrocrinus*, *Ilmocrinus*, *Maligneocrinus*, *Manillacrinus*, *Nunnacrinus*, *Strotocrinus*, and *Teliocrinus*.

Cactocrinus Wachsmuth and Springer, 1897, *Ilmocrinus* Solov'yeva, 1984, *Strotocrinus* Meek and Worthen, 1866, and *Teliocrinus* Wachsmuth and Springer, 1881 are the only

actinocrinitids that have arm openings that are in continuous lateral contact, completely separating the tegmen from the calyx. *Teleocrinus* and *Strotocrinus* are distinguishable from the other two because they have a high number of ranges in the regular interrays (five or more), and the lack of an anal tube in *Strotocrinus* makes it the easiest to identify. The tegmen of *Ilmocrinus* is unknown, but the features of the calyx make it most similar to *Cactocrinus*, particularly in having only three ranges in the regular interrays, but it is separated from *Cactocrinus* in that the highest brachitaxis in the calyx wall is the tertibrachitaxis whereas in *Cactocrinus*, the highest brachitaxis is the secundibrachitaxis.

The other actinocrinitids in this clade have grouped arms. *Manillacrinus* Campbell and Bein, 1971 and *Glaphyocrinus* Lindley, 1988 have arms that are strongly grouped. *Glaphyocrinus* has two fixed secundibrachials and four ranges in the regular interrays, whereas *Manillacrinus* has only one fixed secundibrachial and three ranges in the regular interrays.

Nunnacrinus Bowsher, 1955, *Cusacrinus* Bowsher, 1955 and *Maligneocrinus* Laudon, Parks, and Spreng, 1952 have weakly grouped arms. *Cusacrinus* and *Nunnacrinus* are very similar to one another, but *Nunnacrinus* distinguishes itself within the clade by having the primibrachitaxis as the highest brachitaxis in the calyx; the highest brachitaxis in *Cusacrinus* is the secundibrachitaxis. *Maligneocrinus* is unique among the actinocrinitids in being the only one that has a globe-shaped calyx.

Eumorphocrinus Wright, 1955 and *Cytidocrinus* Kirk, 1944 are the most primitive of the actinocrinitids because they lack fixed intrabrachials between half-rays. This feature can occur in a few of the lobed forms, but most of the actinocrinitids lack it. The two genera are easily distinct from one another as *Eumorphocrinus* has smooth tegmen plates, two fixed secundibrachials, the tertibrachitaxis is highest in the calyx wall, and five or more ranges in the

regular interrays. In contrast, *Cytidocrinus* has spinose tegmen plates, no fixed secundibrachials, the primibrachitaxis is the highest in the calyx wall, and there are only four ranges in the regular interrays.

On the phylogenic diagram (Fig. 2) *Physetocrinus* Meek and Worthen, 1869 and *Dialutocrinus* Wright, 1955 are ladderized between *Eumorphocrinus*/*Cytidocrinus* and more advanced actinocrinitids. *Physetocrinus* is distinct in having weakly to strongly grouped arms with no anal tube. *Dialutocrinus* does not have any characters that are unique to the genus, but rather a conglomeration of characters that it shares with various groups. *Dialutocrinus* shares many characters with the clade that includes *Cactocrinus* including lack of arm lobes, the tertibrachitaxis being the highest brachitaxis in the vertical wall of the calyx, and having fixed interbrachials between half-rays. However, a medium bowl calyx shape is not common in the *Cactocrinus* clade and neither is having three ranges in the regular interrays. As a result, *Dialutocrinus* separates away from the other genera of actinocrinitids.

The Actinocrinitidae is a group that mostly existed within the Mississippian, although it originated during the Famennian and ranged through the Bashkirian. Geographically, the actinocrinitids are recognized in North America, Western Europe, North Africa, Russia, China, Japan, and Australia. There are also reports that this family from in the Permian of Indonesia and Australia, but more work needs to be done with the Permian taxa and it unknown exactly where they fit within the family, if at all. Clearly more work needs to be completed on the Actinocrinidae elsewhere the world.

Genus ACTINOCRINITES Miller, 1821

Type species.—*Actinocrinites triacontadactylus* Miller, 1821, by subsequent designation (Wachsmuth and Springer, 1881).

Other species.—European species include: *Actinocrinites aculeatus* Austin and Austin, 1842; *Actinocrinites alatus* Wright, 1955a; *Actinocrinites batheri* (Whidborne, 1896); *Actinocrinites caryocrinoides* (M'Coy, 1844); *Actinocrinites comptus* Wright, 1955a; *Actinocrinites constrictus* (M'Coy, 1844); *Actinocrinites coplowensis* Wright, 1955a; *Actinocrinites costus* (M'Coy, 1844); *Actinocrinites decadactylus* (Gilberston in Portlock, 1843); *Actinocrinites depressus* Wright, 1955a; *Actinocrinites elongates* Wright, 1955a; *Actinocrinites goldfussi* (Schmidt, 1930); *Actinocrinites granulatus* Goldfuss, 1831 *Actinocrinites intermedius* Wright, 1955a; *Actinocrinites laevis* Miller, 1821; *Actinocrinites moderatus* Wright, 1955a; *Actinocrinites nodosus* Wright, 1955a; *Actinocrinites parkinsoni* Wright, 1955a; *Actinocrinites pusillus* (M'Coy, 1844); *Actinocrinites rotundatus* Wright, 1955a; *Actinocrinites tenuis* (de Koninck and Le Hon, 1854); *Actinocrinites tenuistriatus* (Phillips, 1841); *Actinocrinites tricuspidatus* (de Koninck and Le Hon, 1854); *Actinocrinites tripus* Ehlers and Kesling, 1963; and *Actinocrinites vermiculatus* Wright, 1955a.

North American species include *Actinocrinites grandissimus* Van Sant, 1965; *Actinocrinites jugosus* (Hall, 1859); *Actinocrinites lobatus* (Hall, 1859); *Actinocrinites magnificus* (Wachsmuth and Springer, 1897); *Actinocrinites monticuliferus* (Miller and Gurley, 1894); *Actinocrinites spergenensis* (Miller and Gurley, 1896); and *Actinocrinites* sp. (Brower, 1970) [new combination].

Additionally, *Actinocrinites higuchisawensis* (Minato, 1951) and *Actinocrinites ohmoriensis* (Minato, 1951) have been described in Japan; ?*Actinocrinites polydactylus* Miller,

1821 from Australia; *Actinocrinites skourensis* (Termier and Termier, 1950) from Morocco; *Actinocrinites zhaoae* (Lane, *et al.*, 1997) from China; *Actinocrinites becharensis* Webster, *et al.*, 2004; and *Actinocrinites combinatus* Webster, *et al.*, 2004 from Algeria.

Diagnosis.—Calyx shape medium cone or high bowl; basal circlet high; one fixed secundibrachial; secundibrachitaxis or higher highest brachitaxis in vertical wall of calyx; three ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays present or absent; arms strongly grouped; arm lobes present and extend laterally; arm lobes long; tegmen lower than calyx; plates on tegmen nodose; tegmen shape low to high cone or low inverted bowl; tegmen interray not depressed; anal tube central.

Occurrence.—This genus occurs in the Osagean of Indiana, Illinois, Iowa, Tennessee, Kentucky, Missouri, Colorado, and Arizona as well as the Meramecian of Indiana in North America. It also occurs in the Famennian of England and China; the Tournasian of Scotland, Ireland, England, Belgium, and Japan; the Viséan of Germany, Morocco, and Belgium; and the Serpukhovian of Algeria.

Discussion.—Brower (1970) questionably assigned a specimen to the genus *Eumorphocrinus*, but the known characters of this specimen better fit the genus *Actinocrinites*. *Actinocrinites* sp. has a conical calyx, the half rays are separated by intrabrachials, and what is known of the tegmen indicates that it is a low cone. *Eumorphocrinus* does not have these characters, having a medium bowl shaped calyx, no fixed intrabrachials between half-rays, and a low inverted bowl shaped tegmen.

Actinocrinites marcoui Collignon, 1924 is considered a *nomen dubium* because the only illustration of it is a plate diagram. Although the plate diagram may be accurate, it does not

illustrate specimens of the species; and therefore, it cannot be compared to other species within the genus.

Several species of crinoids that were assigned to the genus *Actinocrinites* by Wanner (1924, 1937) from Timor and Australia are not included in the list above but are included in Webster (2003). These species may be a holdover of the actinocrinitids, but it is unlikely that they belong to this genus. There is still much work that needs to be done on them, but that is beyond the scope of this paper so they will not be included here.

Genus AACOCRINUS Bowsher, 1955

Type species.—*Aacocrinus nododorsatus* Bowsher, 1955, by original designation.

Other species.—North American species include *Aacocrinus boonensis* (Peck and Keyte, 1938); *Aacocrinus chouteauensis* (Miller, 1892); *Aacocrinus enigmaticus* Webster and Lane, 1897; *Aacocrinus protuberoarmatus* Brower, 1967; *Aacocrinus sampsoni* (Miller and Gurley, 1895); *Aacocrinus senectus* (Miller and Gurley, 1897); *Aacocrinus spinosulus* (Miller and Gurley, 1893); and *Aacocrinus tetradactylus* Brower, 1967.

Non-North American species include *Aacocrinus acylus* Webster and Jell, 1999 and *Aacocrinus algeriaensis* Webster *et al.*, 2004.

Diagnosis.—Calyx shape medium cone to medium bowl; basal circlet low; zero, one, or two fixed secundibrachials; primibrachitaxis or secundibrachitaxis highest brachitaxis in vertical wall of calyx; three ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays absent; arms strongly grouped; arm lobes present and extend laterally; arm lobes short; tegmen lower than calyx; plates

on tegmen nodose; tegmen shape flat cone or low inverted bowl; tegmen interray not depressed; anal tube eccentric

Occurrence.—This genus occurs in the Kinderhookian of Missouri and the Osagean of New Mexico and Nevada. It also occurs in the Tournaisian or Visean of Australia and the Bashkirian of Algeria.

Discussion.—*Aacocrinus* is a genus known mostly from North America, though *A. acylus* has been described in Australia (Webster and Jell, 1999) and *A. algeriaensis* has been described in Algeria (Webster *et al.*, 2004). Brower (1967) thoroughly described this genus, which will not be repeated here.

Aacocrinus triarmatus Brower, 1967 was named for two specimens that are poorly preserved. One specimen is very small (only 4 mm), a possible juvenile, and lacks a tegmen, and the other is a set of isolated arms. The conditions of these two specimens are too poor to confidently assign a new species to them and therefore *A. triarmatus* is designated as *nomen dubium*.

Genus ABACTINOCRINUS Laudon and Severson, 1953

Type species.—*Abactinocrinus rossei* Laudon and Severson, 1953, by original designation.

Other species.—*Abactinocrinus devonicus* Waters *et al.* 2003.

Diagnosis.—Calyx shape medium bowl; basal circlet low; one fixed secundibrachial; primibrachitaxis highest brachitaxis in vertical wall of calyx; three ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays absent; arms strongly grouped; arm lobes present and extend

laterally; arm lobes long; tegmen lower than calyx; plates on tegmen nodose; tegmen shape flat inverted bowl; tegmen interray depressed; anal tube central.

Occurrence.—This genus occurs in the Kinderhookian of Montana and the Famennian of China.

Discussion.—The discovery of *Abactinocrinus devonicus* in the Famennian of China makes this genus among the oldest of the actinocrinitids along with *Actinocrinites* (also found in the same Chinese rocks) and *Eumorphocrinus* from the Devonian of England. Brower (1967) thoroughly described this genus.

Genus BLAIROCRINUS Miller, 1891

Type species.—*Blairocrinus trijugis* Miller, 1891 by original designation.

Other species.—North American species include *Blairocrinus arrosus* Miller, 1892; *Blairocrinus macurdai* Rhenberg and Kammer, ms; *Blairocrinus protuberus* Lee *et al.*, 2005; and *Blairocrinus smalleyi* (Weller, 1909) [new combination].

Non-North American species include *Blairocrinus grafensis* Webster *et al.*, 2004.

Diagnosis.—Calyx shape low cone; basal circlet low; one fixed secundibrachial; primibrachitaxis highest brachitaxis in vertical wall of calyx; two ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays absent; arms strongly grouped; arm lobes present and extend laterally; arm lobes short; tegmen higher than calyx; plates on tegmen nodose, smooth, or with proximal spines; tegmen shape low to high cone or medium inverted bowl; tegmen interray not depressed; anal tube central.

Occurrence.—This genus occurs in the Kinderhookian of Missouri and the Osagean of Kentucky, Missouri, and New Mexico. It also occurs in the Bashkirian of Algeria.

Discussion.—*Blairocrinus* is the only actinocrinitid that has a tegmen that is higher than the calyx, which makes it easy to distinguish from the other actinocrinitids.

Physetocrinus smalleyi is reassigned to *Blairocrinus* based on the characters that match it to the latter genus. These characters are the tegmen is higher than the calyx and the arms are strongly grouped and occur in short arm lobes. In Weller's (1909) description, he stated that there was no anal tube, but his illustrations indicate that the beginning of one located centrally on the tegmen and broken off.

Blairocrinus arrosus is a species that is subject to much confusion. This confusion stems from S. A. Miller assigning two actinocrinitids with the species name “arrosus”: *Blairocrinus arrosus* Miller, 1892 and *Actinocrinites arrosus* Miller and Gurley, 1893. Without presenting a complete history of the confusion, Bassler and Moodey (1943) assigned the 1892 species to *Actinocrinites*, and they left the 1894 species in *Actinocrinites* with a note that said it probably belonged in *Cactocrinus*. Webster (2003) considered both species to be in *Cactocrinus* (with *B. arrosus* also considered in the genus *Aacocrinus*), and presumably, synonymous homonyms. However, *B. arrosus* was correctly assigned to *Blairocrinus* by Miller (1892), as regarded by Brower (1967) and Lee *et al.* (2005). *Actinocrinus arrosus* Miller and Gurley, 1893 was correctly assigned to *Cactocrinus*.

Genus CACTOCRINUS Wachsmuth and Springer, 1897

Type species.—*Actinocrinus proboscoidalis* Hall, 1858; by original designation.

Other species.—*Cactocrinus arrosus* (Miller and Gurley, 1893); *Cactocrinus bacatus* Wood, 1914; *Cactocrinus bischoffi* (Miller and Gurley, 1896c) [new combination]; *Cactocrinus clarus* (Hall, 1861a); *Cactocrinus extensus* Wachsmuth and Springer, 1897; *Cactocrinus fossatus* (Miller, 1892a); *Cactocrinus glans* (Hall, 1859a); *Cactocrinus hurdianus* (McChesney, 1861) [new combination]; *Cactocrinus imperator* (Laudon, 1933) [new combination]; *Cactocrinus lucina* (Hall, 1861b); *Cactocrinus magnidactylus* Laudon and Severson, 1953; *Cactocrinus multibrachiatus* (Hall, 1858); *Cactocrinus obesus* (Keyes, 1894c); *Cactocrinus opusculus* (Hall, 1859a); *Cactocrinus platybrachiatus* (Wood, 1914); *Cactocrinus sexarmatus* (Hall, 1859a); *Cactocrinus springeri* (Rowley, 1900a); and *Cactocrinus thalia* (Hall, 1861b).

Diagnosis.—Calyx shape medium cone; basal circlet low; one fixed secundibrachial; secundibrachitaxis highest brachitaxis in vertical wall of calyx; two or three ranges in regular interray; regular interray not in contact with tegmen; posterior interray not in contact with tegmen; fixed intrabrachials between half-rays present; arms not grouped; arm lobes absent; tegmen lower than or same height as calyx; plates on tegmen smooth or spinose; tegmen shape low to medium cone or low inverted bowl; tegmen interray depressed; anal tube central.

Occurrence.—This genus is known from the Kinderhookian of Missouri; the Osagean of Iowa, Missouri, Illinois, New Mexico, and Utah.

Discussion.—*Cusacrinus bischoffi*, *C. hurdianus*, and *C. imperator* are reassigned to *Cactocrinus* because the arms are not grouped and the arm facets are connected to each other not allowing the interrays to be in contact with the tegmen.

Cactocrinus excerptus (Hall, 1861a) has neither been illustrated nor have any type specimens been located for study. Until type specimens are found, *C. excerptus* is regarded a *nomen dubium*. *Cactocrinus fosteri* (McChesney, 1861) is also considered a *nomen dubium*.

This species name was assigned to a specimen that did not have a tegmen and the illustration is all that remains of the original type; the types were lost in the Chicago fire of 1871 (Wachsmuth and Springer, 1897).

Genus CUSACRINUS Bowsher, 1955

Type species.—*Actinocrinites nodobrachiatus* Wachsmuth and Springer in Miller, 1889; by original designation.

Other species.—*Cusacrinus arnoldi* (Wachsmuth and Springer in Miller, 1889); *Cusacrinus asperrimus* (Meek and Worthen, 1870); *Cusacrinus chloris* (Hall, 1861); *Cusacrinus coelatus* (Hall, 1858); *Cusacrinus daphne* (Hall, 1863b); *Cusacrinus denticulatus* (Wachsmuth and Springer, 1897); *Cusacrinus ectypus* (Meek and Worthen, 1870a); *Cusacrinus kuenzii* (Laudon *et al.*, 1952); *Cusacrinus limabrachiatus* (Hall, 1861a); *Cusacrinus longus* (Meek and Worthen, 1870); *Cusacrinus ornatissimus* (Wachsmuth and Springer in Miller, 1889); *Cusacrinus penicillus* (Meek and Worthen, 1870); *Cusacrinus sampsoni* (Miller and Gurley, 1896c) [new combination]; *Cusacrinus sobrinus* (Miller and Gurley, 1896c) [new combination]; *Cusacrinus spectabilis* (Miller and Gurley, 1896c) [new combination]; *Cusacrinus spinotentaculus* (Hall, 1859); *Cusacrinus subscitulus* (Miller and Gurley, 1896c) [new combination]; *Cusacrinus tenuisculptus* (McChesney, 1861); *Cusacrinus thetis* (Hall, 1861); *Cusacrinus tuberculosus* (Wachsmuth and Springer, 1897); *Cusacrinus viaticus* (White, 1874).

Diagnosis.—Calyx shape low to medium cone; basal circlet high or low; one fixed secundibrachial; secundibrachitaxis highest brachitaxis in vertical wall of calyx; four ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays present; arms weakly grouped; arm lobes absent;

tegmen lower than or same height as calyx; plates on tegmen smooth or spinose; tegmen shape flat cone, low to medium cone, or low inverted bowl; tegmen interray not depressed; anal tube central.

Occurrence.—This genus occurs in the Kinderhookian of Iowa, Ohio, Montana, Utah, and Alberta, Canada as well as the Osagean of Iowa, Missouri, New Mexico, and Nevada.

Discussion.—*Actinocrinites sobrinus*, *A. spectabilis*, and *A. subscitulus* are reassigned to *Cusacrinus* due to the lack of arm lobes, arms that are weakly grouped, correct number of ranges in the regular interrays, and the tegmen plate sculpture. It is possible that all three of these species are variations on one species. They all occur in the Burlington Limestone, and the differences between them appear to be minor. Miller and Gurley (1896c) even noted that they frequently found differences in the number of interradian plates among specimens of the same species, which is one of their distinguishing characters to separate *C. spectabilis* [new comb.] and *C. sobrinus* [new comb.]. The other determining character between the two species is that the regular interrays are not in contact with the tegmen.

Cusacrinus arnoldi and *C. ornatissimus* were synonymized with *C. nodobrachiatus* in Webster's Index (2003), however there is no explanation as to why these three species should be considered the same. All three species are distinguishable from each other and should remain separate. *Cusacrinus nodobrachiatus* has steep sided, medium-cone shaped calyx, low basals, and spinose plates on the tegmen. Whereas *C. arnoldi* has the medium-cone shaped calyx, the sides are not so steep, the basals are higher, and the tegmen plates are smooth. *Cusacrinus ornatissimus* has a low-cone shaped calyx, making it different than the previous two, low basals, and the tegmen is unknown.

Nunnacrinus sampsoni has been placed in *Cusacrinus* because the highest brachitaxis in the calyx is the secundibrachitaxis. The highest brachitaxis in *Nunnacrinus* is the primibrachitaxis.

Genus CYTIDOCRINUS Kirk, 1944

Type species.—*Actinocrinus sculptus* Hall, 1858 by original designation.

Diagnosis.—Calyx shape medium bowl; basal circlet high; zero fixed secundibrachials; primibrachitaxis highest brachitaxis in vertical wall of calyx; four ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays absent; arms strongly grouped; arm lobes absent; tegmen lower than calyx; plates on tegmen spinose; tegmen shape low inverted bowl; tegmen interray not depressed; anal tube central.

Occurrence.—This genus occurs in the Osagean of Missouri and Iowa; it has been reported in New Mexico, but this is not confirmed.

Discussion.—The genus *Cytidocrinus* is fully described by Kirk (1943a, p. 263).

Genus DIALUTOCRINUS Wright, 1955

Type species.—*Dialutocrinus milleri* Wright, 1955.

Other species.—European species include *Dialutocrinus aculeatus* (Austin and Austin, 1843); *Dialutocrinus austini* Ausich and Sevastopulo, 2001; *Dialutocrinus icosidactylus* (Portlock, 1843); *Dialutocrinus mcoyi* Ausich and Sevastopulo, 2001; *Dialutocrinus polydactylus* (Miller, 1821); and *Dialutocrinus tessellatus* (Phillips, 1836).

North American species include *Dialutocrinus? gracilis* (Wachsmuth and Springer, 1897) [new combination].

Diagnosis.—Calyx shape medium bowl; basal circlet high or low; one fixed secundibrachial; tertibrachitaxis highest brachitaxis in vertical wall of calyx; three ranges in regular interrays; regular interrays in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays present; arms strongly or weakly grouped; arm lobes absent; tegmen lower than calyx; plates on tegmen nodose; tegmen shape low cone or low inverted bowl; tegmen interray not depressed; anal tube central.

Occurrence.—This genus occurs in the Osagean of Iowa and the late Tournaisian of England, Ireland, Belgium, France, and Germany.

Discussion.—*Cusacrinus gracilis* is questionably reassigned to *Dialutocrinus* because the calyx shape is a bowl and not a cone. There are also only three ranges of plates in the regular interray, not four which is what it would be if it were a *Cusacrinus*. However, the secundibrachitaxis is the highest brachitaxis in the vertical wall, which does not fit the characters seen in *Dialutocrinus*. The tegmen is not known for *D. gracilis* [new comb.], but the calyx features best fit *Dialutocrinus*. The reassignment of *D. gracilis* brings *Dialutocrinus* to North America, whereas before it has only been known in western Europe.

Genus EUMORPHOCRINUS Wright, 1955

Type species.—*Eumorphocrinus erectus* Wright, 1955.

Other species.—*Eumorphocrinus elongates* Lindley, 1979; *Eumorphocrinus excelsus* Wright, 1955; and *Eumorphocrinus hibernicus* Wright, 1955. Devonian species includes *Eumorphocrinus porteri* (Whidborne, 1896).

Diagnosis.—Calyx shape medium bowl; basal circlet high; two fixed secundibrachials; tertibrachitaxis highest brachitaxis in vertical wall of calyx; five or more ranges in regular interrays; regular interrays in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays absent; arms strongly grouped; arm lobes absent; tegmen lower than calyx; plates on tegmen smooth; tegmen shape low inverted bowl; tegmen interray not depressed; anal tube central.

Occurrence.—Famennian of England; late Tournaisian, Visean of Scotland, Ireland, and New South Wales, Australia.

Genus GLAPHYROCRINUS Lindley, 1988

Type species.—*Glaphyrocrinus expansus* Lindley, 1988.

Other species.—*Glaphyrocrinus minutus* Lindley, 1988.

Diagnosis.—Calyx shape medium cone; basal circlet high; two fixed secundibrachials; secundibrachitaxis highest brachitaxis in vertical wall of calyx; four ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays present; arms strongly grouped; arm lobes absent; tegmen lower than calyx; few large sized tegmen plates; plates on tegmen nodose; tegmen shape low inverted bowl; tegmen interray not depressed; anal tube central.

Occurrence.—Visean of New South Wales, Australia.

Genus ILMOCRINUS Solov'yeva, 1984

Type species.—*Ilmocrinus dissymmetricus* Solov'yeva, 1984.

Diagnosis.—Calyx shape low to medium bowl; basal circlet low; one fixed secundibrachial; tertibrachitaxis highest brachitaxis in vertical wall of calyx; two ranges in regular interray; regular interray not in contact with tegmen; posterior interray not in contact with tegmen; fixed intrabrachials between half-rays present; arms not grouped; arm lobes absent; tegmen height unknown; tegmen plate size unknown; tegmen plate sculpture unknown; tegmen shape unknown; tegmen interray depression unknown; anal tube unknown.

Occurrence.—Late Visean, Serpukhovian, Russia

Genus IOTACRINUS Ausich and Sevastopulo, 2001

Type species.—*Actinocrinus dorsatus* (de Koninck and LeHon, 1854) by original designation.

Other species.—*Iotacrinus novamexicana* Rhenberg and Kammer, ms.

Diagnosis.—Calyx shape low bowl; basal circlet low; one fixed secundibrachial; tertibrachitaxis highest brachitaxis in vertical wall of calyx; three ranges in regular interrays; regular interrays in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays absent; arms strongly grouped; arm lobes present and extend laterally; arm lobes medium in length; tegmen lower or higher than calyx; many medium sized tegmen plates; plates of tegmen nodose; tegmen shape low inverted bowl; tegmen interray not depressed; anal tube eccentric.

Occurrence.—Nunn Member of the Lake Valley Formation (Early Osagean) of New Mexico; Tournaisian of Ireland and Belgium.

Discussion.—Until a recent review of the Lake Valley Formation crinoids, *Iotacrinus* was only known in the “Mountain Limestone” of Belgium and in the Hook Head Formation of

Ireland (Ausich and Sevastopulo, 2001). The North American species, *Iotacrinus novamexicana*, is similar to the European species but has a tegmen that is much higher and is more distinctly lobed.

Genus MALIGNEOCRINUS Laudon, Parks, and Spreng, 1952

Type species.—*Maligneocrinus medicinensis* Laudon, Parks, and Spreng, 1952.

Diagnosis.—Calyx shape medium globe; basal circlet low; one fixed secundibrachial; tertibrachitaxis highest brachitaxis in vertical wall of calyx; five or more ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-ray present; arms weakly grouped; arm lobes absent; tegmen lower than calyx; tegmen plate sculpture unknown; tegmen shape unknown; tegmen interray depression unknown; anal tube unknown.

Occurrence.—This genus occurs in the Kinderhookian of Alberta.

Discussion.—Although this genus is known only from partial crowns, the calyx shows the characteristics of actinocrinitids, making it a definite fit for this family. *Maligneocrinus* does not fit into other actinocrinitid genera due to its globe shaped calyx. It is the only known actinocrinitid with this particular calyx shape.

Genus MANILLACRINUS Campbell and Bein, 1971

Type species.—*Cactocrinus? brownei* Dun and Benson, 1920; by original designation.

Other species.—*Manillacrinus acanthus* Webster and Jell, 1999. Campbell and Bein (1971) also describe *Manillacrinus* sp.

Diagnosis.—Calyx shape medium cone; basal circlet high; one fixed secundibrachial; secundibrachitaxis highest brachitaxis in vertical wall of calyx; three ranges in regular intarray; regular intarray in contact with tegmen; posterior intarray in contact with tegmen; fixed intrabrachials between half-rays present; arms strongly grouped; arm lobes absent; tegmen lower than or same height as calyx; plates on tegmen nodose; tegmen shape medium cone; tegmen intarray not depressed; anal tube central.

Occurrence.—Tournaisian of New South Wales, Australia.

Discussion.—It should be noted that Bowsher (*in* Moore and Teichert, 1978, p. T458) erroneously refers to this genus as *Manillocrinus*.

Genus NUNNACRINUS Bowsher, 1955

Type species.—*Nunnacrinus mammillatus* Bowsher, 1955; by original designation.

Other species.—North American species include *Nunnacrinus dalyanus* (Miller, 1881); *Nunnacrinus eraticus* (Miller and Gurley, 1893) [new combination]; *Nunnacrinus foveatus* (Miller and Gurley, 1895); *Nunnacrinus jessieae* (Miller and Gurley, 1897); *Nunnacrinus locellus* (Hall, 1861); *Nunnacrinus ovatus* (Hall, 1861) [new combination]; *Nunnacrinus pallubrum* (Miller and Gurley, 1896b); *Nunnacrinus pettisensis* (Miller and Gurley, 1896c); *Nunnacrinus plagosus* (Miller and Gurley, 1893) [new combination]; *Nunnacrinus puteatus* (Rowley and Hare, 1891); *Nunnacrinus reticulatus* (Hall, 1861) [new combination]; and *Nunnacrinus rubra* (Weller, 1909).

European species include *Nunnacrinus armatus* (de Koninck and Le Hon, 1854); *Nunnacrinus deornatus* (de Koninck and Le Hon, 1854); *Nunnacrinus dorsatus* (de Koninck and Le Hon, 1854); and *Nunnacrinus stellaris* (de Koninck and Le Hon, 1854).

Diagnosis.—Calyx shape low to medium cone; basal circlet low; one fixed secundibrachial; primibrachitaxis highest brachitaxis in vertical wall of calyx; four ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays present; arms weakly grouped; arm lobes absent; tegmen lower than or same height as calyx; plates on tegmen nodose or spinose; tegmen shape medium cone or low inverted bowl; tegmen interray not depressed; anal tube central.

Occurrence.—This genus is known from the Kinderhookian of Missouri; the Osagean of Iowa, Missouri, and New Mexico; and the Tournaisian of Belgium.

Discussion.—When Bowsher (1955) named the genus *Nunnacrinus*, he designated the type species as being *N. mammillatus*. This species is known only to occur in the Nunn Member of the Lake Valley Formation. However, this species is the same as a species already named in the Lake Valley Formation, *N. dalyanus* (Miller, 1881). Bowsher (1955, p. 20) said that the two species are distinguishable from each other most readily by the number of plates that separate the rays: *N. mammillatus* having two plates that separate the rays and *N. dalyanus* having only one plate that separates the rays. This distinction is not valid as there is variation in plate number between rays in more than 700 *Nunnacrinus* specimens studied from the Lake Valley, including the types for *N. mammillatus* (Appendix 3). Most of the specimens have both single and double plates between the rays and not just one or the other. The other ways that Bowsher separated *N. mammillatus* and *N. dalyanus* also have great variation among the specimens studied. These characters include *N. mammillatus* being smaller in size, having less conical calyx and tegmen, weaker plate structure on the calyx, and great irregularity of size of tegmen plates. All of these features have the range of variability with one species of crinoid. Because of this, *N. mammillatus* is a junior synonym of *N. dalyanus*.

Actinocrinus erraticus and *A. plagosus* are reassigned to *Nunnacrinus* because the arms are weakly grouped, do not form lobes, and have the correct number of ranges in the interrays. Although the tegmen is not known for *N. plagosus* [new comb.], the calyx characters best fit *Nunnacrinus*.

Cactocrinus reticulatus and *C. reticulatus ovatus* are reassigned to *Nunnacrinus* because the interrays connect with the tegmen, which is not a character for *Cactocrinus*. Furthermore, *N. ovatus* [new comb.] is returned to a separate species and not a variation of *N. reticulatus* [new comb.]. Wachsmuth and Springer (1897) said that *N. ovatus* was a variation of *N. reticulatus* but the illustrations do not have enough similarities to be the same species. Both species have the medium-shaped cone, but *N. ovatus* has a more rounded overall shape, almost boarding on a bowl shaped calyx. *Nunnacrinus reticulatus* has a medium-cone shaped tegmen that is about the same height as the calyx with long spines on most of the tegmen plates, including the plates that form the base of the anal tube. *Nunnacrinus ovatus* has a low inverted bowl shaped calyx with short spines on a few of the tegmen plates; the spines do not appear to continue up the anal tube.

One problem *Nunnacrinus* is *N. jessieae*. In 1896, Miller and Gurley described several new camerate crinoids, and two were given the trivial name “jessieae”, *Actinocrinites jessieae* Miller and Gurley, 1896a and *Amphoracrinus jessieae* Miller and Gurley, 1896c. Webster (2003) synonymized both of these species as *N. jessieae*, although they are two very distinct species. Bowsher (1955) correctly placed *Actinocrinites jessieae* as *Nunnacrinus* and Ausich and Kammer (2008) considered *Amphoracrinus jessieae* to be a *nomen dubium*.

Bowsher (1955) placed four species from Europe into the genus *Nunnacrinus* (*N. armatus*, *N. deornatus*, *N. dorsatus*, and *N. stellaris*). These species, however, are unlikely to

belong to this genus, but will remain here as non-North American species are not within the scope of this study to verify.

Genus PHYSETOCRINUS Meek and Worthen, 1869

Type species.—*Actinocrinus ventricosus* Hall, 1858; by subsequent designation (Wachsmuth and Springer, 1881).

Other species.—North American species include *Physetocrinus asper* (Meek and Worthen, 1870); *Physetocrinus copei* (Miller, 1881); *Physetocrinus dilatatus* (Meek and Worthen, 1870); *Physetocrinus lobatus* Wachsmuth and Springer, 1897; *Physetocrinus majusculus* Webster and Lane, 1987; and *Physetocrinus ornatus* (Hall 1858).

European species include *Physetocrinus brightoni* Wright, 1955.

Diagnosis.—Calyx shape medium cone to medium bowl; basal circlet high; one fixed secundibrachial; secundibrachitaxis or tertibrachitaxis highest brachitaxis in vertical wall of calyx; four ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays present; arms strongly to weakly grouped; arm lobes absent; tegmen lower than calyx; plates on tegmen smooth; tegmen shape flat to low inverted bowl; tegmen interray not depressed; anal tube absent, opening eccentric

Occurrence.—This genus is known from the Kinderhookian of Iowa and Missouri, the Osagean of Iowa, Illinois Missouri, New Mexico, Arizona, and Nevada and the Tournaisian of Ireland.

Discussion.—*Physetocrinus* is mostly known from North America, although one species, *P. brightoni*, occurs in the Hook Head Formation of Ireland. This species is most similar to the North American species, *P. lobatus*, which is present in New Mexico and Arizona.

The species *Physetocrinus majusculus* is questionably kept as a separate species from *P. copei*. The main difference cited by Webster and Lane (1987) between the two species is that *P. majusculus* has a more highly inflated tegmen than *P. copei*. A study on *P. copei* from the Lake Valley Formation indicates that there is a wide variation of tegmen inflation in that species (fig. WWW in Rhenberg and Kammer, ms). Otherwise, the differences between the two species are minute. These differences include *P. majusculus* having a more conical calyx, a weak overhang at the base of the arms, fewer plates separating the ambulacral tracts between rays and half-rays, and more uniform tegmen plates. However, until a more detailed study on the species can be done, they will remain separate species.

Genus SAMPSONOCRINUS Miller and Gurley, 1895

Type species.—*Sampsonocrinus hemisphericus* Miller and Gurley, 1895

Other species.—North American species include *Sampsonocrinus? globosus* (Wachsmuth and Springer, 1897); and *Sampsonocrinus sedaliensis* (Miller and Gurley, 1895) [new combination].

Non-North American species include *Sampsonocrinus cannindahensis* Webster and Jell, 1999 and *Sampsonocrinus cheguigaensis* Webster *et al.*, 2004.

Diagnosis.—Calyx shape medium bowl; basal circlet low; fixed secundibrachial number unknown; primibrachitaxis highest brachitaxis in vertical wall of calyx; two ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays present; arms strongly grouped; arm lobes present and extend laterally; arm lobes short; tegmen lower than calyx; plates on tegmen nodose; tegmen shape flat to low inverted bowl; tegmen interrays depressed; anal tube eccentric.

Occurrence.—This genus occurs in the Kinderhookian of Missouri, the Visean of Queensland, Australia, and the Bashkirian of Algeria.

Discussion.—*Actinocrinus sedaliensis* is reassigned to the genus *Sampsonocrinus* because the characters better fit the latter genus. The species has a low basal circlet, two ranges in the regular interrays, and an eccentric anal tube.

The species *Sampsonocrinus? globosus* is a problematic species in that it does not conform to any known crinoid genus. Brower (1965, pg. 789) discusses this issue, suggesting it may be a new genus of actinocrinitid. As the species is known from a single specimen, he hesitated to name a new genus and concluded that it is most similar to *Sampsonocrinus* and questionably placed it within this genus. With no new information to add, we follow Brower's suggestion and leave *S. globosus* where it is.

Genus STEGANOCRINUS Meek and Worthen, 1866a

Type species.—*Actinocrinites pentagonus* Hall, 1858; by original designation.

Other species.—*Steganocrinus altus* Brower, 1965; *Steganocrinus? burlingtonensis* Brower, 1965; *Steganocrinus concinnus* (Shumard, 1855); *Steganocrinus elongatus* Kirk, 1943; *Steganocrinus longus* Brower, 1965; *Steganocrinus multistriatus* Brower, 1965; *Steganocrinus planus* Brower, 1965; *Steganocrinus robustus* Brower, 1965; and *Steganocrinus validus* (Meek and Worthen; 1860).

Diagnosis.—Calyx shape medium cone; basal circlet low; zero fixed secundibrachials; primibrachitaxis highest brachitaxis in vertical wall of calyx; two ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed interbrachials between half-rays present; arms strongly grouped; arm lobes present, long, and

extend laterally; tegmen lower than or same height as calyx; plates on tegmen nodose; tegmen shape flat- to low inverted bowl; tegmen interrays not depressed; anal tube eccentric.

Occurrence.—This genus is known from the Osagean of Iowa, Missouri, New Mexico, Nevada, and Arizona.

Discussion.—The species *Steganocrinus altus* and *S. longus* may be variations of *S. pentagonus*. The descriptions by Brower (1965) indicated that the tegmen features of all three species are the same, and that it is only minor differences in the calyx that separates them. The differences between *S. altus* and *S. pentagonus* is that *S. altus* has a more conical dorsal cup; however, when comparing *S. pentagonus* (plate 92, figure 29) and *S. altus* (plate 93, figure 7), it is difficult to tell the two apart. *Steganocrinus longus* differs from *S. pentagonus* by having low basals, highly tumid calyx plates, and very high ambulacral tracts. Geographically, *S. altus* and *S. longus* only occur in the Nunn Member of the Lake Valley Formation, which also indicates that they may be variations of *S. pentagonus*. As the individual review of the species is beyond the scope of this paper, they will remain separate species.

Steganocrinus planus Brower, 1965 is a species that is least like the others in the genus. The main difference being that all other species of *Steganocrinus* have few, large plates on the tegmen, but *S. planus* is covered with numerous smaller plates. Brower (1965) noted that the tegmen is very similar to *Abactinocrinus*, but all features of the calyx better fit with *Steganocrinus*. Therefore, we will follow Brower and retain *S. planus* within this genus.

Another species Brower (1965) described is *Steganocrinus burlingtonensis*. He stated the following similarity between *S. burlingtonensis* and *S. planus*: both have flat tegmens with small tegmen plates, but with calyx features that are most similar to the genus *Steganocrinus*. The feature that distinguishes *S. burlingtonensis* is the lack of an anal tube on the single known

specimen. Brower's description and illustrations indicate that the anal tube was never present, whereas *S. planus* exhibits evidence of an anal tube, although the tube had been broken off. The lack of an anal tube would remove *S. burlingtonensis* from this genus, but there is no currently known actinocrinitid genus to place it in. The two genera that do not have an anal tube also lack arm lobes, which this species has. As there is only one specimen of *S. burlingtonensis*, with no way of knowing what the variations of the species could be or even if it is not just an aberrant form of *S. planus*, a new genus will not be erected. Therefore, *Steganocrinus? burlingtonensis* will remain associated with this genus until more information becomes available.

GENUS STROTOCRINUS Meek and Worthen, 1866b

Type species.—*Actinocrinites perumbrosus* Hall, 1860; by subsequent designation (Meek and Worthen, 1866a).

Diagnosis.—Calyx shape medium cone flared distally; basal circlet low; one fixed secundibrachial; secundibrachitaxis or tertibrachitaxis highest brachitaxis in vertical wall of calyx; 10 or more ranges in regular interray; regular interray not in contact with tegmen; posterior interray not in contact with tegmen; fixed intrabrachials between half-rays present; arms not grouped; arm lobes absent; tegmen lower than calyx; plates on tegmen smooth; tegmen shape flat inverted bowl; tegmen interrays not depressed; anal tube absent, opening eccentric.

Occurrence.—This genus is known from the Osagean of Iowa and Missouri.

Discussion.—*Strotocrinus glyptus* (Hall, 1860), is the only recognized species in this genus. Macurda (1974) synonymized all reported members of the genus into *S. glyptus*, including *S. perumbrosus*; stating that *S. glyptus* is the valid name due to page priority. Ausich

and Kammer (1991) also discussed nomenclatural history of *S. glyptus* and therefore, it will not be repeated here.

Genus TELEIOCRINUS Wachsmuth and Springer, 1881

Type species.—*Actinocrinites umbrosus* Hall, 1858; by original designation.

Other species.—North American species include *Teleiocrinus adolescens* Wachsmuth and Springer, 1897; *Teleiocrinus blairi* (Miller and Gurley, 1895) [new combination]; *Teleiocrinus liratus* (Hall, 1859); *Teleiocrinus ornatus* (Miller and Gurley, 1896a) [new combination]; and *Teleiocrinus venustus* (Miller and Gurley, 1893) [new combination].

Russian species include *Teleiocrinus? sibiricus* Yakovlev in Yakovlev and Ivanov, 1956.

Diagnosis.—Calyx shape medium cone; basal circlet high; one fixed secundibrachial; tertibrachitaxis highest brachitaxis in vertical wall of calyx; five or more ranges in regular interray; regular interray may or may not be in contact with tegmen; posterior interray not in contact with tegmen; fixed intrabrachials between half-rays present; arms not grouped; arm lobes absent; tegmen lower than calyx; plates on tegmen nodose; tegmen shape flat cone; tegmen interrays not depressed; anal tube central.

Occurrence.—This genus occurs in the Kinderhookian of Missouri, the Osagean of Iowa, Missouri, Illinois, and New Mexico, and the Tournaisian of Russia.

Discussion.—*Strotocrinus blairi* and *S. ornatus* have been reassigned to *Teleiocrinus* because they have an anal tube, which *Strotocrinus* does not. *Strotocrinus venustus* is reassigned to *Teleiocrinus* based on characters of the calyx (the tegmen is unknown; and therefore, it is unknown whether an anal tube exists). The calyx of *T. venustus* lacks distal flaring and has fewer ranges in the interray than *Strotocrinus*. Macurda (1974) placed this species with

Cusacrinus ectypus (Meek and Worthen, 1870), but the original description (Miller and Gurley, 1893, p. 27) and illustration (pl. VI, fig. 1) show that it has at least 60 arm facets that separate the calyx from the tegmen, not allowing for the interrays to be in contact with the tegmen. This feature distinguishes this species from *Cusacrinus*, which has fewer arms and interrays that connect with the tegmen.

Genus THINOCRINUS Ausich and Sevastopulo, 2001

Type species.—*Sampsonocrinus westheadi* Wright, 1947, by original designation.

Other species.—European species include *Thinocrinus loricatus* (Schlotheim, 1820); 2001; *Thinocrinus smythi* Ausich and Sevastopulo, 2001; and *Thinocrinus wexfordensis* Ausich and Sevastopulo.

North American species include *Thinocrinus anchorensis* (Webster and Lane, 1987) [new combination]; *Thinocrinus benedicti* (Miller, 1892) [new combination]; *Thinocrinus blairi* (Miller and Gurley, 1897) [new combination]; *Thinocrinus botruosus* (Miller and Gurley, 1895) [new combination]; *Thinocrinus eximius* (Kirk, 1943) [new combination]; *Thinocrinus gibsoni* (Miller and Gurley, 1893) [new combination]; *Thinocrinus griffithi* (Wachsmuth and Springer, 1897) [new combination]; *Thinocrinus lowei* (Hall, 1858) [new combination]; *Thinocrinus multiradiatus* (Shumard, 1857) [new combination]; *Thinocrinus multiramosus altidorsatus* (Rowley, 1904) [new combination]; *Thinocrinus pernodosus* (Hall, 1858) [new combination]; *Thinocrinus probolos* (Ausich and Kammer, 1991) [new combination]; *Thinocrinus? sampsoni* (Miller and Gurley, 1896c) [new combination]; *Thinocrinus semimultiramosus* (Whitfield, 1900) [new combination]; *Thinocrinus scitulus* (Miller and Gurley, 1897) [new combination]; *Thinocrinus subpulchellus* (Miller and Gurley, 1896c) [new combination]; *Thinocrinus tripus*

(Ehlers and Kesling, 1963) [new combination]; and *Thinocrinus verrucosus* (Hall, 1858) [new combination].

Diagnosis.—Calyx shape medium cone to medium bowl; basal circlet high or low; one or two fixed secundibrachials; primibrachitaxis highest brachitaxis in vertical wall of calyx; three or four ranges in regular interray; regular interray in contact with tegmen; posterior interray in contact with tegmen; fixed intrabrachials between half-rays present or absent; arms strongly grouped; arm lobes present and extend laterally; arm lobes medium; tegmen lower than calyx; plates on tegmen nodose or smooth; tegmen shape flat to medium cone or low inverted bowl; tegmen interrays depressed; anal tube central.

Occurrence.—This genus occurs in the Osagean of Kentucky, Indiana, Missouri, Illinois, Iowa, and Nevada, as well as the Tournaisian of Scotland, Ireland, and England.

Discussion.—Most of the species reassignments to *Thinocrinus* are due to the redefinition of *Actinocrinites* (Ausich and Sevastopulo, 2001). Therefore, many of the species assigned to *Thinocrinus* were formerly in *Actinocrinites*. The exception is reassignment of *Physetocrinus sampsoni* to *Thinocrinus*.

The calyx characters of *Thinocrinus? sampsoni* [new comb.] are three ranges in the regular interray, fixed intrabrachials between the half-rays absent, and arm lobes present.

Physetocrinus has more ranges in the regular interrays, fixed interbrachials between half-rays, and the arms do not form lobes. The features that makes it similar to *Physetocrinus* is the lack of an anal tube on the tegmen. Only two genera of actinocrinitids are known to lack an anal tube (*Physetocrinus* and *Strotocrinus*), but the other features of the species do not fit either of those genera. In some ways, *Thinocrinus? sampsoni* is similar to *Steganocrinus? burlingtonensis* in that both have arm lobes and lack an anal tube. However, they lack other similarities. The calyx

shape, basal height, and interray ranges are all very different and it would not make sense to combine these into a single, new genus. Until more information can be found on this species, *Thinocrinus? sampsoni* will remain with this genus.

There is some confusion with the species *Actinocrinites scitulus*. Kirk (1943) said there is some question as to whether or not *Actinocrinites sharonensis* (Miller and Gurley, 1897) is a valid species, but listed it as being synonymous with *A. scitulus*. Brower (1955) stated that *A. sharonensis* should be a separate species, but listed *A. scitulus* in the synonymy list. On the same page, Brower listed *A. scitulus* as a separate species. Webster (2003) followed Brower's first synonymy list, naming *A. sharonensis* as the valid name in the index and *A. scitulus* as a junior synonym. It is the belief of the authors that both species are the same, just variations. Because *A. scitulus* has priority, the valid name for this species is *Thinocrinus scitulus* [new comb.].

Webster (2003) left *Steganocrinus griffithi* Miller and Gurley, 1897 as a separate species, even though Kirk, (1943) and Brower (1955) synonymized it with *Actinocrinites scitulus*.

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TABLE 2.1.—Listing of actinocrinitid species that have a revised generic assignment.

NEW GENERIC ASSIGNMENTS	
Previous assignment	Current assignment
<i>Actinocrinites anchorensis</i> Webster and Lane, 1987	<i>Thinocrinus anchorensis</i> (Webster and Lane, 1987)
<i>Actinocrinites benedicti</i> (Miller, 1892)	<i>Thinocrinus benedicti</i> (Miller, 1892)
<i>Actinocrinites blairi</i> (Miller and Gurley, 1897)	<i>Thinocrinus blairi</i> (Miller and Gurley, 1897)
<i>Actinocrinites botruosus</i> (Miller and Gurley, 1895)	<i>Thinocrinus botruosus</i> (Miller and Gurley, 1895)
<i>Actinocrinites erraticus</i> (Miller and Gurley, 1893)	<i>Nunnacrinus erraticus</i> (Miller and Gurley, 1893)
<i>Actinocrinites eximius</i> (Kirk, 1943)	<i>Thinocrinus eximius</i> (Kirk, 1943)
<i>Actinocrinites gibsoni</i> (Miller and Gurley, 1893)	<i>Thinocrinus gibsoni</i> (Miller and Gurley, 1893)
<i>Actinocrinites griffithi</i> (Wachsmuth and Springer, 1897)	<i>Thinocrinus griffithi</i> (Wachsmuth and Springer, 1897)
<i>Actinocrinites lowei</i> (Hall, 1858)	<i>Thinocrinus lowei</i> (Hall, 1858)
<i>Actinocrinites multiradiatus</i> (Shumard, 1857)	<i>Thinocrinus multiradiatus</i> (Shumard, 1857)
<i>Actinocrinites multiramosus altidorsatus</i> (Rowley, 1904)	<i>Thinocrinus multiramosus altidorsatus</i> (Rowley, 1904)
<i>Actinocrinites pernodosus</i> (Hall, 1858)	<i>Thinocrinus pernodosus</i> (Hall, 1858)
<i>Actinocrinites plagosus</i> (Miller and Gurley, 1893)	<i>Nunnacrinus plagosus</i> (Miller and Gurley, 1893)
<i>Actinocrinites probolos</i> Ausich and Kammer, 1991	<i>Thinocrinus probolos</i> (Ausich and Kammer, 1991)
<i>Actinocrinites scitulus</i> (Miller and Gurley, 1897)	<i>Thinocrinus scitulus</i> (Miller and Gurley, 1897)
<i>Actinocrinites semimultiramosus</i> (Whitfield, 1900)	<i>Thinocrinus semimultiramosus</i> (Whitfield, 1900)
<i>Actinocrinites sobrinus</i> (Miller and Gurley, 1896c)	<i>Cusacrinus sobrinus</i> (Miller and Gurley, 1896c)
<i>Actinocrinites spectabilis</i> (Miller and Gurley, 1896c)	<i>Cusacrinus spectabilis</i> (Miller and Gurley, 1896c)
<i>Actinocrinites subpulchellus</i> (Miller and Gurley, 1896c)	<i>Thinocrinus subpulchellus</i> (Miller and Gurley, 1896c)
<i>Actinocrinites subscitulus</i> (Miller and Gurley, 1896c)	<i>Cusacrinus subscitulus</i> (Miller and Gurley, 1896c)
<i>Actinocrinites tripus</i> Ehlers and Kesling, 1963	<i>Thinocrinus tripus</i> (Ehlers and Kesling, 1963)
<i>Actinocrinites verrucosus</i> (Hall, 1858)	<i>Thinocrinus verrucosus</i> (Hall, 1858)
<i>Cactocrinus reticulatus</i> (Hall, 1861)	<i>Nunnacrinus reticulatus</i> (Hall, 1861)
<i>Cactocrinus reticulatus ovatus</i> (Hall, 1861)	<i>Nunnacrinus ovatus</i> (Hall, 1861)
<i>Cusacrinus bischoffi</i> (Miller and Gurley, 1896c)	<i>Cactocrinus bischoffi</i> (Miller and Gurley, 1896c)
<i>Cusacrinus gracilis</i> (Wachsmuth and Springer, 1897)	<i>Dialutocrinus gracilis</i> (Wachsmuth and Springer, 1897)
<i>Cusacrinus hurdianus</i> (McChesney, 1861)	<i>Cactocrinus hurdianus</i> (McChesney, 1861)
<i>Cusacrinus imperator</i> (Laudon, 1933)	<i>Cactocrinus imperator</i> (Laudon, 1933)
<i>Eumorphocrinus</i> sp. Brower, 1970	<i>Actinocrinites</i> sp. (Brower, 1970)
<i>Nunnacrinus sampsoni</i> (Miller and Gurley, 1896c)	<i>Cusacrinus sampsoni</i> (Miller and Gurley, 1896c)
<i>Physetocrinus sampsoni</i> Miller and Gurley, 1896c	" <i>Thinocrinus</i> " <i>sampsoni</i> (Miller and Gurley, 1896c)
<i>Physetocrinus smalleyi</i> Weller, 1909	<i>Blairocrinus smalleyi</i> (Weller, 1909)
<i>Strotocrinus blairi</i> Miller and Gurley, 1895	<i>Teleiocrinus blairi</i> (Miller and Gurley, 1895)
<i>Strotocrinus ornatus</i> Miller and Gurley, 1896a	<i>Teleiocrinus ornatus</i> (Miller and Gurley, 1896a)
<i>Strotocrinus venustus</i> Miller and Gurley, 1893	<i>Teleiocrinus venustus</i> (Miller and Gurley, 1893)

TABLE 2.2.—Chronostratigraphic correlation of time units for North America and Europe
(from Ausich and Kammer, 2008).

Time Units	North American chronostratigraphic units	European chronostratigraphic units
11	Upper Chesterian	Arnsbergian (E2)
10	Middle Chesterian	Serpukhovian, Pendleian (E1)
9	Lower Chesterian	Visean, Brigantian (V3c)
8	Late Meramecian	Visean, Asbian (V3b)
7	Early Meramecian	Visean, Holkerian (V3a)
6	Late Osagean	Visean, Arundian (V1b, V2a)
5	Late Osagean	Visean, upper Chadian (V1a)
4	Middle Osagean	Tournaisian, lower Chadian (Tn3c)
3	Early Osagean	Tournaisian, Ivorian (Tn3a-Tn3c)
2	Late Kinderhookian	Tournaisian, late Hasterian (Tn2)
1	Early Kinderhookian	Tournaisian, early Hasterian (Tn1b)

TABLE 2.3.—Diagnostic characters of the calyx and tegmen of genera within Actinocrinitidae.

Genus	Calyx Shape	Basal Circlet	Number of Fixed Secundibrachials	Highest Brachial in Vertical Wall of Calyx Before Arm Lobes	Number of Ranges in Regular Interray	Regular Interrays in Contact with Tegmen	Posterior Interray in Contact with Tegmen	Fixed Intrabrachs Between Half-Rays	Arms Grouped
<i>Cactocrinus</i>	medium cone	low	1	Secundabrachitaxis	2, 3	no	no	present	not grouped
<i>Ilmocrinus</i>	medium bowl, low bowl	low	1	Tertibrachitaxis	2	no	no	present	not grouped
<i>Teleiocrinus</i>	medium cone	high	1	Tertibrachitaxis	5 or more	yes, no	no	present	not grouped
<i>Strotocrinus</i>	medium cone flared distally	high	1	Secundabrachitaxis, Tertibrachitaxis	10 or more	no	no	present	not grouped
<i>Maligneocrinus</i>	medium globe	low	1	Tertibrachitaxis	5 or more	yes	yes	present	weakly
<i>Cusacrinus</i>	medium cone, low cone	low, high	1	Secundabrachitaxis	4	yes	yes	present	weakly
<i>Nunnacrinus</i>	medium cone, low cone	low	1	Primibrachitaxis	4	yes	yes	present	weakly
<i>Glaphyocrinus</i>	medium cone	high	2	Secundabrachitaxis	4	yes	yes	present	strongly
<i>Manillacrinus</i>	medium cone	high	1	Secundabrachitaxis	3	yes	yes	present	strongly
<i>Thinocrinus</i>	medium cone, medium bowl	low, high	1, 2	Primibrachitaxis	3, 4	yes	yes	present, absent	strongly
<i>Abactinocrinus</i>	medium bowl	low	1	Primibrachitaxis	3	yes	yes	absent	strongly
<i>Iotacrinus</i>	low bowl	low	1	Primibrachitaxis	3	yes	yes	absent	strongly

Genus	Calyx Shape	Basal Circlet	Number of Fixed Secundibrachials	Highest Brachial in Vertical Wall of Calyx Before Arm Lobes	Number of Ranges in Regular Interray	Regular Interrays in Contact with Tegmen	Posterior Interray in Contact with Tegmen	Fixed Intrabrachs Between Half-Rays	Arms Grouped
<i>Aacocrinus</i>	medium cone, medium bowl	low	0, 1, 2	Primibrachitaxis, Secundabrachitaxis	3	yes	yes	absent	strongly
<i>Blairocrinus</i>	low cone	low	1	Primibrachitaxis	2	yes	yes	absent	strongly
<i>Sampsonocrinus</i>	medium bowl	low	unknown	Primibrachitaxis	2	yes	yes	present	strongly
<i>Steganocrinus</i>	medium cone	low	0	Primibrachitaxis	2	yes	yes	present	strongly
<i>Actinocrinites</i>	medium cone, high bowl	high	1	Secundabrachitaxis, Tertibrachitaxis, Quartibrachitaxis	3	yes	yes	present, absent	strongly
<i>Dialutocrinus</i>	medium bowl	low, high	1	Tertibrachitaxis	3	yes	yes	present	strongly, weakly
<i>Physetocrinus</i>	medium cone, medium bowl	high	1	Tertibrachitaxis, Quartibrachitaxis	5 or more	yes	yes	present	strongly, weakly
<i>Eumorphocrinus</i>	medium bowl	high	2	Tertibrachitaxis	5 or more	yes	yes	absent	strongly
<i>Cytidocrinus</i>	medium bowl	high	0	Primibrachitaxis	4	yes	yes	absent	strongly

Genus	Arm Lobes	Arm Lobe Length	Tegmen as High as Calyx	Tegmen Plate Sculpture	Tegmen Shape	Tegmen Interray Depressed	Anal Opening
<i>Cactocrinus</i>	absent	absent	lower, same	smooth, spinose	low cone, medium cone, low inverted bowl	no	tube present, central
<i>Ilmocrinus</i>	absent	absent	unknown	unknown	unknown	no	unknown
<i>Teleiocrinus</i>	absent	absent	lower	nodose	flat cone	no	tube present, central
<i>Strotocrinus</i>	absent	absent	lower	smooth	flat inverted bowl	no	tube absent, eccentric
<i>Maligneocrinus</i>	absent	absent	lower	unknown	unknown	no	unknown
<i>Cusacrinus</i>	absent	absent	lower, same	smooth, spinose	low cone, medium cone, flat cone, low inverted bowl	no	tube present, central
<i>Nunnacrinus</i>	absent	absent	lower, same	nodose, spinose	medium cone, low inverted bowl	no	tube present, central
<i>Glaphyrocristus</i>	absent	absent	lower	nodose	low inverted bowl	no	tube present, central
<i>Manillacristus</i>	absent	absent	lower, same	nodose	medium cone	no	tube present, central
<i>Thinocrinus</i>	present, extend laterally	medium	lower	nodose, smooth	medium cone, flat cone, flat inverted bowl, low inverted bowl	yes	tube present, central
<i>Abactinocrinus</i>	present, extend laterally	long	lower	nodose	flat inverted bowl	yes	tube present, central

Genus	Arm Lobes	Arm Lobe Length	Tegmen as High as Calyx	Tegmen Plate Sculpture	Tegmen Shape	Tegmen Interray Depressed	Anal Opening
<i>Iotacrinus</i>	present, extend laterally	medium	lower, higher	nodose	low inverted bowl	no	tube present, eccentric
<i>Aacocrinus</i>	present, extend laterally	short	lower	nodose	flat cone, low inverted bowl	no	tube present, eccentric
<i>Blairocrinus</i>	present, extend laterally	short	higher	nodose, smooth, proximal spines	low cone, medium cone, high cone, medium inverted bowl	no	tube present, central
<i>Sampsonocrinus</i>	present, extend laterally	short	lower	nodose	flat inverted bowl, low inverted bowl	yes	tube present, eccentric
<i>Steganoocrinus</i>	present, extend laterally	long	same	nodose	flat inverted bowl, low inverted bowl	no	tube present, eccentric
<i>Actinocrinites</i>	present, extend laterally	long	lower	nodose	low cone, flat cone, low inverted bowl	no	tube present, central
<i>Dialutocrinus</i>	absent	absent	lower	nodose	low cone, low inverted bowl	no	tube present, central
<i>Physetocrinus</i>	absent	absent	lower	smooth	flat inverted bowl, low inverted bowl	no	tube absent, eccentric
<i>Eumorphocrinus</i>	absent	absent	lower	smooth	low inverted bowl	no	tube present, central
<i>Cytidocrinus</i>	absent	absent	lower	spinose	low inverted bowl	no	tube present, central

Penn	Gzhel			
	Kasim			
	Mosco			
	Bash			
Miss	Serp	11 10		
	Vise	9 8 7 6 5		
		Tourn	4 3 2 1	
			Dev	Fame
				Frasn
	Givet			
	Eifel			
	Ems			
Prag				
Lochkov				
Sil	Pridoli			
	Ludlow			
	Wenlock			
	Llandov

FIGURE 2.1.—Phylogenetic analysis from PAUP© 4.0b10; 23 taxa, 17 characters, 68 character states, all characters were unordered and unweighted; search methods heuristic with random stepwise addition. Rolf's consistency index (C.I.) of 0.56. Thirty apomorphies are as follows: 1, two plates above primanal; 2, no fixed interbranchials between half-rays; 3, no fixed secundibrachials; 4, anal tube absent; 5, arms grouped, but arm lobes absent, tertibrachitaxis highest brachitaxis in vertical wall of calyx, calyx medium bowl, three ranges in regular interrays; 6, arm lobes present and extend laterally; 7, high basal circlet, secundibrachitaxis highest brachitaxis in vertical wall of calyx; 8, basal circlet low, anal tube eccentric; 9, arm lobes short in length; 10, tegmen interrays depressed; 11, no fixed interbranchials between half-rays; 12, tegmen higher than calyx; 13, three ranges in regular interrays; 14, arm lobes medium in length; 15, low bowl calyx; 16, anal tube central and tegmen interrays depressed; 17, arm lobes long in length; 18, arms not lobed; 19, four or more ranges in regular interrays; 20, two fixed secundibrachials; 21, arms not strongly grouped; 22, primibrachitaxis is highest brachitaxis in vertical wall of calyx; 23, secundibrachitaxis is highest brachitaxis in vertical wall of calyx; 24, tertibrachitaxis is highest brachitaxis in vertical wall of calyx; 25, globe shaped calyx; 26, arms not grouped, interrays not in contact with tegmen; 27, five or more ranges in regular interrays; 28, anal tube absent; 29, fewer than four ranges in regular interrays; 30, secundibrachitaxis is highest brachitaxis in vertical wall of calyx.

Chapter 3:
Did North American Mississippian Camerate Crinoids have an Endemic or Cosmopolitan
Biogeographic Distribution during the Early Osagean?

ABSTRACT

Early Mississippian seas over North America provided extensive habitat space for crinoids by extending across most of the continent. During this time, several formations were laid down that preserved a high number of camerate crinoids. By comparing the camerate crinoid faunas at the genus level from the lower Burlington Limestone (IA), the Lake Valley Formation (NM), the Redwall Limestone (AZ), and the Anchor Limestone (NV) differences and patterns can be discerned. Similarities were evaluated using a) presence-absence data with the Jaccard Coefficient, b) percentage of common genera, and c) with rarefaction curves.

The camerate crinoids in each of the formations are thought to mostly be from shallow water settings. The lower Burlington and Lake Valley faunas are nearly equal in generic richness (35 and 31 respectively) with a Jaccard similarity of 0.61 despite being separated by a large distance (1600km). Conversely, the Redwall and Anchor faunas have approximately half the number of genera of the lower Burlington and Lake Valley formations and are very dissimilar to one another (similarity of 0.18) despite being geographically close. This is the expected pattern for faunal endemism.

However, the differences in the number in genera of the Redwall and Anchor limestones as compared to the lower Burlington and Lake Valley are probably taphonomic. The camerates are poorly preserved in the Redwall, due to the early diagenesis that produced the chert and dolomite common in the formation. The Anchor camerates were presumably moved in debris flows from shallow water settings, diminishing the preservation potential of the crinoids. Because neither the Redwall nor the Anchor has a significant number of unique genera and all other genera are a

subset of the lower Burlington fauna, the seas of North America were probably well connected allowing for the camerate crinoids to widely disperse. Rarefaction curves comparing the Anchor, Redwall, and Lake Valley indicate that the differences in number of genera are likely due to incomplete sample sizes and not necessarily differences in environments. Thus, poor preservation and limited samples have produced an apparent pattern of faunal endemism in what may originally have been cosmopolitan faunas.

INTRODUCTION

North America was covered by extensive shallow seas during the early Mississippian (Fig. 3.1), and these shallow seas provided the prime environment for crinoids to thrive. The environment was ideal for the stenohaline crinoids because extensive reefs that restricted marine circulation during the Devonian were decimated in the Frasnian-Famennian mass extinction (Copper, 1994; Copper, 2002; Kammer and Ausich, 2006). With the reefs gone, carbonate ramps formed, allowing for normal marine conditions and salinities to expand across epicontinental seas providing crinoids increased habitat space. Another factor that allowed crinoids to prosper was the end-Devonian Hangenberg extinction event that removed many of the crinoids' fish predators from the system (Sallan, *et al.*, 2011). Without as many predators, crinoids diversified rapidly in the early Mississippian.

Of those formations laid down during this time in North America, the Burlington Limestone is the most studied. The significance of the Burlington is in part because it covers a large area. Including the overlying Keokuk Limestone, the exposure of outcrop is 74,000 km² with a combined thickness more than 50 m (Ausich, 1997). Burlington Limestone exposures extend over several states, not just at the type locality in Burlington, Iowa (Witzke and Bunker,

2002). The Burlington is also well known for the crinoids it contains (Wachsmuth and Springer, 1897; Gahn, 2002) with nearly 300 total species within all five major crinoid groups (camerates, primitive cladids, advanced cladids, disparids, and flexibles) throughout the formation (Gahn, 2002).

Although the Burlington is the most widespread and best studied, it is not the only formation with an abundance of early Osagean crinoids. The Lake Valley Formation of New Mexico, Redwall Limestone of Arizona, and Anchor Limestone of Nevada are three of the better studied formations of this time interval with crinoids. Examples of all five groups of crinoids are in both the Lake Valley and Anchor formations, but the Redwall has examples of only camerates, disparids, and advanced cladids. Despite having examples of each of the different groups in all but the Redwall, the camerates are the best represented in all four formations and, therefore, will be the focus of this study.

The Lake Valley, Redwall, and Anchor formations are geographically separated from the Burlington by large distances (the Lake Valley Formation is the closest to the Burlington Limestone at 1600 km) and the emergent Transcontinental Arch (Fig. 3.1). The camerates in these formations have extensive overlap in genera, especially comparing each of the three western formations to the Burlington. The questions are: how similar are the genera in these formations, and what are the underlying causes for the differences? By comparing these four formations, biogeographic patterns can be discerned that give a better idea of how interconnected the North American seas were during this time period.

The focus of this study will be on the camerates of the lower Burlington Limestone, the Nunn Member of the Lake Valley Formation, the Thunder Springs and Mooney Falls members of the Redwall Limestone, and the whole of the Anchor Limestone. These are the portions of the

formations that are coeval with one another (Fig. 3.2) and, in the case of the Redwall and Lake Valley formations, where the majority of the crinoids are found.

AGE RELATIONSHIPS OF FORMATIONS

The lower Burlington Limestone and the Nunn Member of the Lake Valley Formation are known to be of similar age based initially on the crinoids (Springer, 1884) and later by conodonts. Lane (1974) used conodonts to subdivide the Lake Valley Formation and correlate to the conodont time zones in the Mississippi Valley (Lane and Brenckle, 2001). Brezinski (2000, 2007) showed that the trilobite faunas were similar between the two formations as well.

The Thunder Springs Member and the lower part of the Mooney Falls Member are the only portions of the Redwall that have identifiable crinoids (McKee and Gutschick, 1969b; Brower, 1969), and the crinoids from these units correlate to the classic crinoid faunas of the Burlington and Lake Valley. Several coral species also correlate between the three formations (Sando, 1969).

The interpreted age of the Anchor Limestone has changed considerably since the 1930's (Webster and Lane, 1987, fig. 3). Webster and Lane (1987) assigned a late Kinderhookian/early Osagean age for the Anchor based on the crinoid and conodont fauna. However, Webster (1997) later found conodonts, specifically *Polygnathus communis carina*, in the basal units of the Anchor which indicate the entirety of the formation is within the Osagean.

Based on the crinoids, conodonts, trilobites, and corals, these four formations are shown to be coeval with each other (Fig. 3.2). All of the relevant parts of the formations were deposited during the early Osagean, or time unit 3 of Ausich and Kammer (2008).

DEPOSITIONAL ENVIRONMENTS OF THE FORMATIONS

Lower Burlington: Dolbee Creek and Haight Creek members.—The lower Burlington consists of the lower Dolbee Creek Member and the middle Haight Creek Member (Witzke and Bunker, 2002). The Dolbee Creek Member has a succession of stacked crinoidal packstones and grainstones. These beds may be graded and are interbedded with mudstones and wackestones. The interbeds are usually dolomitized. The Haight Creek Member is dominated by dolomite that may be cherty to very cherty. There is a middle layer of limestone similar to those found in the Dolbee Creek Member.

The lower part of the Burlington Limestone is thought to have been deposited entirely within the middle-shelf area (Witzke and Bunker, 2002). The middle-shelf is characterized by normal salinity, good circulation, and bottom conditions below normal wave base but above storm wave base (Wilson and Jordan, 1983). The Burlington is considered to be a good example of middle-shelf deposits (Witzke and Bunker, 2002). It is characterized by having slow average rates of subtidal sediment accumulation and being subjected to varying degrees of storm activity depending on the water depth. The lack of evidence for peritidal and mudflat/sabkha facies or exposure surfaces supports the hypothesis that the Burlington was deposited in subtidal environments. Episodic storm-current activity is thought to be the reason why graded to amalgamated bedforms of crinoidal packstone and grainstone were formed. The grainstones interbedded between these graded beds are formed by dolomitized or silicified mudstones. These mudstones are interpreted to have formed between storms when bottom conditions were quiet and currents were unable to winnow the muds.

Lake Valley Formation: Nunn Member.— The Nunn Member is a highly fossiliferous, soft, blue-grey to greenish-grey nodular carbonate packstone to wackestone interbedded with

shales and argillaceous limestones (Laudon and Bowsher, 1949; Jicha, 1954; Pray, 1951; Kues, 1986; Frank *et al.*, 1996; Brezinski, 2000).

Although the formation is typically associated with deep-water Waulsortian mounds in the Alamogordo Member, the deposition of most of the Lake Valley sediments took place on a shallow marine carbonate shelf known as the Lake Valley Shelf (Lane and De Keyser, 1980; Kues, 1986). The sediments are thickest to the north and wedge out southward into a lower-energy, most likely deep-water, sediment-starved basin (Kues, 1986; Batchel and Dorobek, 1998). The Nunn Member was laid down by a transgressive system (Batchel and Dorobek, 1998), and its thickness varies greatly throughout the extent of the Lake Valley Formation. This is due to the differences in paleogeographic setting (Brezinski, 2000). To the east in the Sacramento Mountains, the Nunn is a flank bed to the Waulsortian mounds (Lane, 1982). In the San Andres Mountains and farther west where most of the crinoids occur, the Nunn was probably deposited as a level bottom facies in a shelf environment (Brezinski, 2000).

Redwall Limestone: Thunder Springs and Mooney Falls members.—The packstone that constitutes the Redwall Limestone was deposited on what is known as the Redwall Shelf (Witzke and Bunker, 2002). The Thunder Springs Member consists of thin beds and elongate lenses of chert that alternate with thin beds of limestone or dolomite (McKee and Gutshick, 1969a). The dolomite is finely crystalline, and the limestone ranges from fine to very coarse. The grains of the limestone are composed of fossil fragments and peloids. The Mooney Falls Member consists of thick to very thick beds of packstone with zones of chert near the top of the member. The environment has been interpreted as having normal marine conditions, good circulation, and shallow to moderate depths.

The Thunder Springs Member is interpreted to have been laid down during a regression (McKee and Gutshick, 1969a). This is indicated by thin bedding thought to have formed by a shallow base level and consistent interruptions to sedimentation. This member has an abundant amount of chert that is likely due to early diagenesis because it is uniformly distributed across the region. The chert probably formed before the dolomite (also thought to be due to early diagenesis) because the external molds of fossils preserved in the chert have excellent preservation of detail, but details are very poorly preserved in the dolomite.

The Mooney Falls Member was laid down during a time of maximum transgression with few interruptions to sedimentation (McKee and Gutshick, 1969a). There was very little terrigenous sediment input in this member.

The crinoids in both of these members have a similar distribution pattern which may indicate that the environment for the two members was similar (Brower, 1969). The preservation of the crinoids in the Thunder Springs Member (within the chert) does make this speculation questionable because the environment in which the bedded chert was formed is not well understood (McKee and Gutshick, 1969b). However, it is probable that the crinoids preferred living along depositional topographic highs as their calyces have not been collected away from these highs (Brower, 1969). Sedimentation rates that buried the crinoids were presumably moderate to high when calyces are found within the formation, and very slow where only crinoidal debris is preserved.

Anchor Limestone.—Webster and Lane (1987) separated the Anchor into three sections; lower, middle, and upper. The lower section is composed of packstone to grainstone with a general increase in grain size upward. Chert beds and nodules are also present. The middle section is composed of wackestone to packstone that contain some chert nodules and

discontinuous thin bands of chert. The upper member is packstone to grainstone with graded beds and crossbedding.

The Anchor Limestone has evidence that it was deposited in a high-energy setting (Webster and Lane, 1987). Webster and Lane (1987) stated that the crinoids in the Anchor suggest a mix of two environments. The disparids and flexibles in the Anchor still have portions of their arms attached, which is indicative of burial near where they lived, at the base of a slope. The base of the slope environment is suggested because disparids dominate the base of the Borden Delta (Ausich *et al.*, 1979). The species of conodonts found in the Anchor also suggest a base of slope environment (Webster and Lane, 1987). The camerates lack arms and columns and are therefore likely to have been transported by debris flows. The camerates probably lived on a shallow platform and were transported to their burial sites. However, taphonomic studies on crinoids (Donovan, 1991; Ausich, 2001; Baumiller, 2008) show that the arms will be the first to disarticulate, even without transportation. The camerates may have been buried near where they lived, but they were exposed longer, allowing for the disarticulation of the arms. If this is the case, the depositional environment for the Anchor camerates is not the shallow shelf of the other formations, but rather the base of a slope.

CRINOID FAUNAS

The camerate crinoids are the focus of this study because they represent the majority of the crinoids in the four formations. This bias toward the camerates is undoubtedly due to the structure of the calyx, which has rigidly connected plates (Ubaghs, 1978, Ausich *et al.*, 1999), giving them higher preservation potential.

The information used to conduct this study came from both published and compiled crinoid lists for the formations. The lists of genera were determined from the following sources: for the Burlington, Gahn (2002); for the Lake Valley, Rhenberg and Kammer (ms); for the Redwall, Brower (1969); and for the Anchor, Webster and Lane (1987). These lists were updated using new generic concepts (Ausich and Kammer, 2008; 2009; 2010; Rhenberg, Ausich, and Kammer, ms). With the information given for the Lake Valley, Redwall, and Anchor formations, the number of specimens for each genus was also noted to determine those genera that were the most prominent or common in each formation (Fig. 3.3). The Burlington Limestone is not included in the counts because it is impractical to track down and count the thousands of crinoids that have been collected from that formation and are stored in major museum collections (e.g. Smithsonian Institution, Harvard University, etc.)

Table 3.1 lists the different camerate genera from the four formations. The Burlington Limestone has the most at 35 with five of those genera known exclusively within the Burlington (of the four formations in this study). The Nunn Member of the Lake Valley Formation has almost as many genera (31), with three that are unique to it. The Redwall and the Anchor have half the number of known genera (18 and 15 respectively), and they have one unique genus each. Only five genera occur in all four formations; these are *Stegancrinus*, *Physetocrinus*, *Agaricocrinus*, *Platycrinites*, and *Pleminocrinus*.

FAUNAL SIMILARITY

The degree of similarity between the faunas was evaluated using the Jaccard Coefficient along with non-metric multidimensional scaling (MDS) with PAST software (Hammer *et al.*,

2001; Table 3.2; Fig. 3.4). The Jaccard Coefficient emphasizes similarity by using the following formula:

$$J = \frac{a}{a+b+c}$$

Where a = number of shared genera, b = number of unique genera in one sample, and c = number of unique genera in the other sample. The Burlington and the Lake Valley formations are fairly similar at 0.61 similarity. Twenty-five genera occur in both formations (Table 3.3.1) despite being separated by a great distance (~1600 km). Conversely, the Redwall and Anchor limestones are located closest to each other (~200 km) but share very few similar genera (0.18 similarity). The only genera that the Redwall and Anchor share are the five genera present in all four formations. The MDS plots suggest that some genera are cosmopolitan plotting in the center of the R-mode MDS graph (Fig. 3.4.1), whereas others appear to be endemic plotting far from the center and characterizing individual formations (Fig. 3.4.1).

Also examined was similarity based on shared genera using the formula:

$$S = \frac{a}{N \text{ of smaller fauna}}$$

This formula calculates the percentage of genera in the smaller fauna that are shared with the larger fauna. This formula basically shows how similar two faunas are based on the genera available from the smaller fauna, ignoring the effect of missing genera. Thus, a smaller fauna that is a complete subset of a larger fauna would be 100% similar. Although the Redwall and the Anchor each have approximately half the number of genera than the Burlington, most of the genera in both are also in the Burlington. Sixteen of the 18 genera in the Redwall and 12 of the 15 in the Anchor are also in the Burlington Limestone giving them 89% and 80% shared genera,

respectively, with the Burlington. (Table 3.3.2). However, the Anchor and the Redwall appear to be relatively different subsets of the Burlington because the similarity between the Anchor and Redwall is only 33%.

Rarefaction curves were also created to allow for the comparison of the Lake Valley, Redwall, and Anchor formations (Fig. 3.5). Rarefaction is a resampling technique that allows for samples of different sizes to be compared (Raup, 1975; Foote, 1992; Kammer *et al.*, 1997). This is done by interpolating how many species there would be if the sample sizes were standardized (Raup, 1975). The standardization allows for samples of various sizes to be compared more directly. With the rarefaction method, the raw total number of taxa or specimens are not compared, but rather the diversity or abundance curves that are created (Sanders, 1968). Curves generated indicate whether or not the number of samples collected are sufficient (Gotelli and Colwell, 2001). If the numbers of samples are insufficient, rarefaction curves are steep indicating more taxa should be found with additional samples. With increasing sample size the curves should begin to flatten. When sampling is sufficient, an asymptote is reached. If curves of different length overlap, or plot closely together, the assumption is that the sampled populations are similar. If the curves are widely separated, no matter their lengths, then the underlying populations are probably different.

Though actual numbers of specimens are known for the western formations, the lower Burlington was modeled on the logarithmic decline of the genera of the Lake Valley Formation multiplied by ten (Fig. 3.5.3). This increase of an order of magnitude for the Burlington is certainly an underestimate of the number of specimens in known collections, but it gives a general idea of how the Burlington compares to the other formations and the asymptote is reached around 15,000 specimens.

DISCUSSION

An organism that exhibits cosmopolitanism is one that occurs globally or spans a large area such as an ocean basin, whereas an endemic organism is one that is restricted to certain areas or regions (Spellerberg and Sawyer, 2000). For this study, these terms reference only North America where cosmopolitanism refers to genera found across the Mississippian continent and endemic genera are those found only in a single formation. The only truly cosmopolitan genera in this study are *Steganoecrinus*, *Physetocrinus*, *Agaricocrinus*, *Platycrinites*, and *Plemnocrinus*, as they occur in all four formations across North America. This would indicate that these genera were less restricted in their habitat than other taxa; or they had a better ability to overcome any barriers between the formations by larval dispersal. The endemic genera (in terms of this study) would be those few that are found exclusively in one formation. The endemic taxa in the lower Burlington Limestone are *Megistocrinus*, *Cytidocrinus*, *Azygocrinus*, *Gongylocrinus*, and *Laticrinus*; the Lake Valley Formation has *Blairocrinus*, *Iotacrinus*, and *Eucladocrinus*; the Redwall Limestone has *Actinocrinites*; and the Anchor Limestone has *Tarantocrinus*. Of the mentioned endemic genera, *Megistocrinus*, *Actinocrinites*, *Blairocrinus*, *Cytidocrinus*, *Iotacrinus*, and *Eucladocrinus* are in other formations across the world; *Azygocrinus*, *Gongylocrinus*, and *Laticrinus* are only known in the Burlington Limestone and *Tarantocrinus* is only known from the Anchor Limestone. The endemic genera may have been restricted to particular environments or not have had the ability to move long distances or past barriers during their larval dispersal stage. All other genera are in more than one formation, with most being found in the lower Burlington.

The numbers of camerate genera in each of these four formations are distinctly different. The raw distribution of genera across North America would suggest a pattern more closely associated with endemism than cosmopolitanism. This is especially true if only the Redwall and Anchor limestones are taken into account as the only shared genera are the five known in all four formations. However, the genera in the Redwall and Anchor are not truly endemic as both share a number of genera with the lower Burlington Limestone. There is a high similarity between the shared genera of all formations to the lower Burlington. For example, of the 18 genera in the Redwall Limestone, 16 of those also occur in the lower Burlington Limestone, which equates to an 89% similarity (Table 3.3). Because such a high similarity exists between the lower Burlington and the western formations in terms of shared genera, endemism cannot be the true pattern for Osagean camerates. The high similarity and the high number of endemic genera make it conceivable that the Burlington was a center of evolutionary origin for the North American Osagean camerates. Because the Burlington Shelf covered such a large area that was ideal for crinoids, they may have started in that area and dispersed to the other formations during the early Osagean. But it may be just as likely that the extensive amount of Burlington Limestone that is preserved and weathers easily creates a “taphonomic window” that provides diverse and abundant specimens. Whatever the reason for the high numbers of Burlington taxa, the high similarity between shared genera contradicts the Jaccard Coefficient (Table 3.2), which considers overall similarity based on presence and absence of genera in each fauna, not just shared genera, and indicates that only the Lake Valley is similar to the lower Burlington. What might have caused the disparity in diversity?

It is unlikely that the reason for the difference is due to different environments as the camerates in all four formations were living on a shallow carbonate shelf. Distance may be a

reason for the disparity because the greater the distance between two areas, the more likely an organism will encounter barriers that need to be overcome (Mayr, 1970). However, distance is unlikely a reason for the difference because of the high similarity of shared genera between the camerates in the Burlington Limestone and those in the Redwall and Anchor limestones. This suggests that the most likely reasons for the differences in number of genera is either taphonomic in origin or due to uneven sample sizes.

The plates of crinoids are held together by ligaments known as “mutable collagenous tissues” or MCTs (Donovan, 1991; Baumiller, 2008). Once the MCTs decay, the plates begin to fall apart (Donovan, 1991). MCTs may decay quickly. Cain (1968) showed that an extant comatulid crinoid completely disarticulated within two days, even in an anaerobic and unagitated environment. However, not all MCTs will decay so quickly (Donovan, 1991). Some pluricolumnals (partially fragmented columns) were sturdy enough to produce tool marks, orient to the current, and survive downhill saltation with little fragmentation. Camerate crinoids have calyx plates that are strongly sutured (Ubaghs, 1978), making it more difficult for them to disarticulate. Disarticulation of crinoid plates could take between days to a couple of weeks, dependent on the conditions of the environment (agitation, presence of scavengers, temperature, etc.) where the crinoid died (Donovan, 1991; Ausich *et al.*, 1999). To preserve a complete crinoid, the crinoid must be buried rapidly and deep enough so that it is not re-excavated by currents or disrupted by scavengers (Ausich *et al.*, 1999).

As previously mentioned, the Redwall Limestone was subjected to early diagenesis from both chert and dolomite replacement (McKee and Gutshick, 1969a), which would not be conducive to the preservation of fossils. Diagenesis often has a destructive effect on fossils (Tucker, 1991) and poor preservation limits the ability to correctly identify the crinoids (Brower,

1969). The Anchor Limestone has a similar problem because the camerates may have been moved in debris flows from the shallow shelf environment (Webster and Lane, 1987). This movement would lower preservation potential of camerates as even the calyx became disarticulated.

Another issue that may be the cause of the disparity in diversity is the limited amount of sampling that has occurred for the western formations. The Burlington Limestone has been collected from for well over a century (Wachsmuth and Springer, 1897; Gahn, 2002) and the Lake Valley Formation has long been noted as having an abundance of crinoids (Kues, 1986) and recent work done by Rhenberg and Kammer (ms) identified more than 4,400 camerates (Fig. 3.3.1) out of more than 7,000 specimens collected by Brad Macurda. Neither the Redwall Limestone nor the Anchor Limestone have anywhere near that number of crinoids. Only one major study of the crinoids has been conducted for each of the Redwall and Anchor limestones. In the Redwall study (Brower, 1969), 245 specimens (Fig. 3.3.2) were collected, whereas in the Anchor study (Webster and Lane, 1987), only 88 (Fig. 3.3.3) were collected. These numbers reflect the limited exposures, poor preservation, and potential weathering of specimens from the rocks.

Rarefaction curves were created for these three formations using the PAST software with the numbers gathered from the different studies (Fig. 3.3.1-3). When all three curves are plotted together (Fig. 3.5.1) it becomes clear that the most likely cause for the differences in camerate genera is due to sampling issues. Neither the Redwall nor the Anchor limestones approach an asymptote as the Lake Valley Formation does, which indicates that the former formations require more sampling. Before the current study of the Lake Valley Formation (Rhenberg and Kammer, ms), only 16 genera were reported; with the addition of the 4500 specimens, the number of

genera nearly doubled. If more extensive sampling were completed for the Redwall and the Anchor, it is likely that the genus richness gaps would be filled and the formations would show much more similarity in camerate crinoids. When the Lake Valley numbers are removed from the rarefaction curve (Fig. 3.5.2), the same steep trend occurs and the Redwall curve does not begin to reach its asymptote, which indicates that if more specimens were collected, the diversity of the formation would most likely increase.

The inferred similarity between the formations indicates that all four formations were connected to each other during the Mississippian via marine currents that would allow for the dispersal of crinoid larvae. Localized environmental differences may have allowed for the unique genera to take hold in specific formations and not the others, but for the most part, the camerate crinoids of the Early Mississippian North American seas appear to have originally been cosmopolitan.

CONCLUSIONS

The differences in the numbers of camerate crinoid genera between the four major early Osagean formations of North America is most likely due to uneven sampling of these formations. Whereas the lower Burlington Limestone and the Nunn Member of the Lake Valley Formation have relatively well preserved crinoids that are easy to collect, the Redwall and Anchor limestones lack both good preservation and collectability. The early diagenesis which produced chert and dolomite in the Redwall and movement of crinoids by debris flows in the Anchor have made collecting identifiable crinoids difficult. If preservation and collectability were better for the Redwall and Anchor, it is likely that more of the genera in the Burlington and Lake Valley formations would also be found in the western formations. If more sampling were

to be done on the western formations, some of the gaps in genus richness might be filled. Thus, it may be inferred that an ostensible pattern of biogeographic endemism in early Osagean camerates, as illustrated by MDS using the Jaccard Coefficient, resulted from poor preservation of an originally widely dispersed cosmopolitan fauna.

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TABLE 3.1.—Generic list of the camerates found in the lower Burlington Limestone, Lake Valley Formation (Nunn Member), Redwall Limestone (Thunder Springs and Mooney Falls members), and Anchor Limestone.

Burlington	Lake Valley	Redwall	Anchor
Rhodocrinitidae			
	<i>Rhodocrinites</i>	<i>Rhodocrinites</i>	
<i>Cribanocrinus</i>	<i>Cribanocrinus</i>	<i>Cribanocrinus</i>	
<i>Gilbertsocrinus</i>	<i>Gilbertsocrinus</i>		
Periechocrinidae			
<i>Aryballocrinus</i>	<i>Aryballocrinus</i>		
<i>Megistocrinus</i>			
Amphoracrinidae			
	<i>Amphoracrinus</i>		<i>Amphoracrinus</i>
<i>Ancalocrinus</i>	<i>Ancalocrinus</i>		<i>Ancalocrinus</i>
<i>Dilatocrinus</i>			<i>Dilatocrinus</i>
<i>Displodocrinus</i>	<i>Displodocrinus</i>		<i>Displodocrinus</i>
Actinocrinitidae			
	<i>Actinocrinites</i>		
<i>Aacocrinus</i>	<i>Aacocrinus</i>		<i>Aacocrinus</i>
	<i>Blairocrinus</i>		
	<i>Iotacrinus</i>		
<i>Steganocrinus</i>	<i>Steganocrinus</i>	<i>Steganocrinus</i>	<i>Steganocrinus</i>
<i>Thinocrinus</i>			<i>Thinocrinus</i>
<i>Cytidocrinus</i>			
<i>Cactocrinus</i>	<i>Cactocrinus</i>	<i>Cactocrinus</i>	
<i>Cusacrinus</i>	<i>Cusacrinus</i>		<i>Cusacrinus</i>
<i>Nunnacrinus</i>	<i>Nunnacrinus</i>	<i>Nunnacrinus</i>	
<i>Teleiocrinus</i>	<i>Teleiocrinus</i>		
<i>Physetocrinus</i>	<i>Physetocrinus</i>	<i>Physetocrinus</i>	<i>Physetocrinus</i>
Batocrinidae			
<i>Abatocrinus</i>	<i>Abatocrinus</i>	<i>Abatocrinus</i>	
<i>Azygocrinus</i>			
<i>Eretmocrinus</i>	<i>Eretmocrinus</i>		<i>Eretmocrinus</i>
<i>Eutrochocrinus</i>	<i>Eutrochocrinus</i>		
<i>Gongylocrinus</i>			
<i>Macrocrinus</i>		<i>Macrocrinus</i>	
<i>Simatocrinus</i>	<i>Simatocrinus</i>		
<i>Uperocrinus</i>	<i>Uperocrinus</i>	<i>Uperocrinus</i>	
Coelocrinidae			
<i>Agaricocrinus</i>	<i>Agaricocrinus</i>	<i>Agaricocrinus</i>	<i>Agaricocrinus</i>
<i>Aorocrinus</i>		<i>Aorocrinus</i>	

<i>Dorycrinus</i>		<i>Dorycrinus</i>	
Unknown Family			
<i>Tarantocrinus</i>			
Dichocrinidae			
<i>Dichocrinus</i>	<i>Dichocrinus</i>	<i>Dichocrinus</i>	
<i>Strimplecrinus</i>	<i>Strimplecrinus</i>	<i>Strimplecrinus</i>	
Platycrinitidae			
<i>Platycrinites</i>	<i>Platycrinites</i>	<i>Platycrinites</i>	<i>Platycrinites</i>
<i>Collicrinus</i>	<i>Collicrinus</i>		
<i>Elegantocrinus</i>	<i>Elegantocrinus</i>		
	<i>Eucladocrinus</i>		
<i>Laticrinus</i>			
	<i>Oenochocrinus</i>		<i>Oenochocrinus</i>
<i>Plemnocrinus</i>	<i>Plemnocrinus</i>	<i>Plemnocrinus</i>	<i>Plemnocrinus</i>
<i>Pleurocrinus</i>	<i>Pleurocrinus</i>	<i>Pleurocrinus</i>	

TABLE 3.2.—Similarity matrix based on the Jaccard Coefficient (see text).

	Lake			
	Burlington	Valley	Redwall	Anchor
Burlington	1			
Lake Valley	0.68	1		
Redwall	0.43	0.41	1	
Anchor	0.32	0.32	0.18	1

TABLE 3.3.—Number of genera and similarity between the Burlington, Lake Valley, Redwall, and Anchor formations: 1) Actual counts of genera found in the formations with the number of similar genera between formations; 2) Percentage of common genera found between formations. Similarity based on shared genera, with number of shared genera divided by the total number in the smaller fauna.

	Burlington	Lake Valley	Redwall	Anchor	
Burlington	35				
Lake Valley	25	31			
Redwall	16	14	18		
Anchor	12	12	5	15	1

	Burlington	Lake Valley	Redwall	Anchor	
Burlington	100%				
Lake Valley	81%	100%			
Redwall	89%	78%	100%		
Anchor	80%	80%	33%	100%	2

FIGURE 3.1.—Paleogeographic reconstruction of North America in the early Mississippian (Blakey, 2007). Stars indicate location of the Burlington Limestone (BL) in Iowa, Lake Valley Formation (LVF) in New Mexico, Redwall Limestone (RL) in Arizona, and Anchor Limestone (AL) in Nevada.

Chronostratigraphic units	Time Units (Ausich and Kammer, 2006)	Mississippi Valley (Lane and Brenckle, 2001)	New Mexico (Lane, 1974)	Arizona (Sando, 1969)	Nevada (Webster and Lane, 1987)
Meramecian	7	Salem		Horseshoe Mesa Mb	
Osagean	6	U. Warsaw	Lake Valley Formation	Redwall Limestone	Bullion
	5	L. Warsaw			
	4	Keokuk			
	3	Upper Burlington			
		Lower Burlington	Arcente Mb.		
			Tierra Blanca Mb.		
			Nunn Mb.	Thunder Springs Mb.	Anchor
			Alamogordo Mb.		
			Andrecito Mb.	Whitemore Wash Mb. (upper)	

FIGURE 3.2.—Correlated stratigraphic columns of the Mississippi Valley, New Mexico, Arizona, and Nevada formations for the Osagean and early Meramecian.

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FIGURE 3.3.—Specimen counts for the Lake Valley, Redwall, and Anchor formations: 1) Nunn Member counts (Rhenberg and Kammer, ms), n=4457; 2) Thunder Springs and Mooney Falls member counts (Brower, 1969), n=245; 3) Anchor Limestone counts (Webster and Lane, 1987), n=88; 4) Percentages of camerates compared between the formations.

FIGURE 3.4.—Graphs based on the Jaccard Coefficient showing the similarity between the formations: 1) R-Mode MDS graph showing how camerate genera correlate to the formations. The genera unique to each formation are found at the farthest points away from the center in each quadrant; 2) Q-Mode MDS graph showing how the formations plot based on faunal similarity, or number of shared genera. The lower Burlington and Lake Valley formations plot closely to each other because of the greatest number of shared genera, whereas the Anchor and Redwall limestones plot on opposite ends.

FIGURE 3.5.—Rarefaction curves indicating that the low generic richness of the Anchor and Redwall is due to low sample sizes: 1) Curve comparing the Redwall and Anchor to the Lake Valley; 2) Curve showing just the Redwall and Anchor; 3) Curve showing the lower Burlington modeled after the logarithmic decline of genera in the Lake Valley multiplied by ten.

APPENDIX 1 – Locality information for collecting sites. M localities were collected by Dr. Macurda, Laudon numbers collected by Dr. Laudon, and FC localities were collected by the authors.

Year	Locality #	Locality Name
1970	M-153	0 Bar 0 Canyon
1970	M-154	0 Bar 0 Canyon
1970	M-155	0 Bar 0 Canyon
1970	M-149	Apache Hill
1970	M-150	Apache Hill
1970	M-152	Apache Hill
1965	M-86	Apache Hill
1965	M-87	Apache Hill
1965	M-89	Apache Hill
1966	M-15	Black Range
1966	M-16	Black Range
1966	M-17	Black Range
1966	M-18	Black Range
1969	M-18	Black Range
1966	M-19	Black Range
1972	M-7	Black Range
1971	M-91	btw North Percha & Mineral Creeks
1965	M-101	Cooks Range
1965	M-102	Cooks Range
1971	M-97	Cooks Range
1965	M-80	Deadman Canyon
1970	M-176	Indian Wells Canyon
1966	M-6	Indian Wells Canyon
1965	M-69	Indian Wells Canyon
1966	M-7	Indian Wells Canyon
1971	M-80	Indian Wells Canyon
1966	M-9	Indian Wells Canyon
1971	M-92	North Hollow Creek
1971	M-93	North Hollow Creek
1971	M-94	North Hollow Creek
1970	M-158	Percha Creek
1970	M-159	Percha Creek
1971	M-100	Percha Creek Fork
1971	M-101	Percha Creek Fork
1971	M-98	Percha Creek Fork
1971	M-99	Percha Creek Fork
1970	M-157	Rock Springs
1966	M-21	Rock Springs
1966	M-22	Rock Springs
1975	M-73	San Andres Canyon
1971	M-102	Santa Rita
1971	M-103	Santa Rita
1972	M-8	Santa Rita
1966	M-13	Tierra Blanca Mt.
1965	M-95	Tierra Blanca Mt.
1972	M-5	Trujillo Creek

Laudon #	Locality Name	Laudon #	Locality Name
13,579	Alamo Canyon	13,806	Pryor Nunn Ranch
13,752	Apache Hill	13,824	Pryor Nunn Ranch
13,779	Apache Hill	13,855	Pryor Nunn Ranch
13,817	Apache Hill	13,986	Pryor Nunn Ranch
13,863	Apache Hill	14,041	Pryor Nunn Ranch
14,272	Apache Hill	14,042	Pryor Nunn Ranch
14,052	Berenda Canyon	14,072	Pryor Nunn Ranch
14,061	Grapevine	14,284	Pryor Nunn Ranch
13,980	Hillsboro	14,290	Pryor Nunn Ranch
13,754	Indian Wells Canyon	13,743	San Andres Canyon
13,760	Indian Wells Canyon	13,750	Unknown
13,763	Indian Wells Canyon	13,755	Unknown
13,777	Indian Wells Canyon	13,757	Unknown
13,778	Indian Wells Canyon	13,766	Unknown
13,834	Indian Wells Canyon	13,769	Unknown
13,836	Indian Wells Canyon	13,775	Unknown
13,838	Indian Wells Canyon	13,781	Unknown
13,784	Lake Valley	13,785	Unknown
13,966	Lake Valley	no #	Unknown
13,509	Marble Canyon	13,765	Wittenberg Ranch Windmill Section
13,551	Marble Canyon	13,768	Wittenberg Ranch Windmill Section
13,552	Marble Canyon	13,803	Wittenberg Ranch Windmill Section
13,553	Marble Canyon	13,825	Wittenberg Ranch Windmill Section
13,557	Marble Canyon	13,833	Wittenberg Ranch Windmill Section
13,567	Marble Canyon	13,905	Wittenberg Ranch Windmill Section
13,569	Marble Canyon	13,918	Wittenberg Ranch Windmill Section
13,572	Marble Canyon	13,923	Wittenberg Ranch Windmill Section
13,578	Marble Canyon	13,929	Wittenberg Ranch Windmill Section
13,611	Marble Canyon	13,932	Wittenberg Ranch Windmill Section
13,619	Marble Canyon	13,964	Wittenberg Ranch Windmill Section
13,822	Marble Canyon	13,997	Wittenberg Ranch Windmill Section
14,028	Marble Canyon	13,998	Wittenberg Ranch Windmill Section
14,031	Marble Canyon	13,999	Wittenberg Ranch Windmill Section
14,077	Marble Canyon	14,006	Wittenberg Ranch Windmill Section
14,088	Marble Canyon	14,022	Wittenberg Ranch Windmill Section
14,249	Marble Canyon	14,025	Wittenberg Ranch Windmill Section
14,250	Marble Canyon	14,030	Wittenberg Ranch Windmill Section
14,260	Marble Canyon	14,059	Wittenberg Ranch Windmill Section
14,261	Marble Canyon	14,062	Wittenberg Ranch Windmill Section
13,727	Pryor Nunn Ranch	14,065	Wittenberg Ranch Windmill Section
13,763	Pryor Nunn Ranch		

Locality #	Locality Name
FC1	Apache Hill
FC2	Percha Creek Fork
FC3	North Percha Creek

APPENDIX 2 – Township and range information for the Macurda localities.

Year	Locality #	County	Quad	Locality Name	Township and Range
1965	M-69				West half of sec. 14, T16S, R10E
1965	M-80			Deadman Canyon	NW¼SE¼ sec. 3, T17S, R10E
1965	M-86		Lake Valley	Apache Hill	SE¼ sec. 16, T18S, R7W
1965	M-87		Lake Valley	Apache Hill	SE¼ sec. 16, T18S, R7W
1965	M-89		Lake Valley	Apache Hill	SE¼ sec. 16, T18S, R7W
1965	M-95	Sierra		Tierra Blanca Canyon	SW¼NW¼ sec. 10, T17S, R8W
1965	M-101	Luna	Lake Valley	Cooks	S½NW¼ & N½SW¼ of SW¼ sec. 13, T20S, R9W
1965	M-102			North Cooks	NW¼ sec. 13, T20S, R9W
1966	M-6	Otero			SE¼SW¼SW¼ sec. 11, T16S, R10E
1966	M-7	Otero		Indian Wells Canyon	SE¼SE¼SW¼ sec. 11, T16s, R10E
1966	M-9	Otero		Indian Wells Canyon	NW¼NW¼NW¼ sec. 1, T16S, R10E
1966	M-13	Sierra	Hillsboro	Tierra Blanca Canyon	SW¼NW¼ sec. 10, T17S, R8W
1966	M-15	Sierra	Hillsboro		NE¼NE¼NE¼NW¼ sec. 22, T17S, R8W
1966	M-16	Sierra	Hillsboro		SW¼NE¼NE¼NW¼ sec. 22, T17S, R8W
1966	M-17	Sierra	Hillsboro	PA Mountain	NW¼NW¼SW¼ sec. 26, T17S, R8W
1966	M-18	Sierra	Hillsboro	PA Canyon	C NW¼SE¼ sec. 26, T17S, R8W
1966	M-19	Sierra	Hillsboro	PA Mountain	C NE¼ sec. 34, T17S, R8W
1966	M-21	Sierra	Hillsboro	Rock Springs	SE¼SW¼NW¼ sec. 28, T16S, R8W
1966	M-22	Sierra	Hillsboro	Rock Springs	C N½NW¼ sec. 28, T16S, R8W
1969	M-18	Sierra	Hillsboro		NW¼SW¼SE¼NW¼ sec. 33, T16S, R8W
1970	M-149	Sierra	Lake Valley	Apache Hill	SW¼ & SE¼ of NW¼ sec. 21, T18S, R7W
1970	M-150	Sierra	Lake Valley	Apache Hill	C N½ line btw NW¼NE¼ & NE¼NW¼ of SW¼ sec. 21, T18S, R7W
1970	M-151	Sierra	Lake Valley	Apache Hill	C line btw NW¼ & NE¼ of NE¼SW¼ sec. 21, T18S, R7W
1970	M-152	Sierra	Lake Valley	Apache Hill	NE¼SE¼NE¼SW¼ sec. 21, T18S, R7W
1970	M-153	Sierra	Hillsboro	0 Bar 0 Canyon	C SW¼SW¼ sec. 35, T17S, R8W
1970	M-154	Sierra	Hillsboro	0 Bar 0 Canyon	C N½SW¼SW¼SW¼ sec. 35, T17S, R8W
1970	M-155	Sierra	Hillsboro	0 Bar 0 Canyon	NW¼SE¼SE¼SE¼ sec. 34, T17S, R8W
1970	M-157	Sierra	Hillsboro	Rock Springs	SE¼SE¼NW¼ sec. 28, T16S, R8W

Year	Locality #	County	Quad	Locality Name	Township and Range
1970	M-158	Sierra	Hillsboro		C NW $\frac{1}{4}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 14, T16S, R7W
1970	M-159	Sierra	Hillsboro	Percha Creek	C E $\frac{1}{2}$ NE $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 14, T16S, R7W
1970	M-176	Otero	Alamogordo	Indian Wells Canyon	C SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 11 to SW $\frac{1}{4}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 11, T16S, R10E
1971	M-80	Otero	Alamogordo	Indian Wells Canyon	SE $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 11 to SW $\frac{1}{4}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 11, T16S, R10E
1971	M-91	Sierra	Hillsboro	btw North Percha & Mineral Creeks	NW $\frac{1}{4}$ NE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 30, T15S, R8W SW $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ & C N $\frac{1}{4}$ line btw NE $\frac{1}{4}$ & NW $\frac{1}{4}$ of NE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 3, T18S, R8W
1971	M-92	Sierra	Hillsboro		C line btw SE $\frac{1}{4}$ NE $\frac{1}{4}$ & NE $\frac{1}{4}$ SE $\frac{1}{4}$ of SE $\frac{1}{4}$ sec. 3, T18S, R8W
1971	M-93	Sierra	Hillsboro		C E $\frac{1}{2}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 3, T18S, R8W
1971	M-94	Sierra	Hillsboro	North Hollow Creek	S $\frac{1}{2}$ NW $\frac{1}{4}$ of NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 24, T20S R9W
1971	M-97	Sierra	Lake Valley		NE $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 16, T16S, R8W
1971	M-98	Sierra	Hillsboro	Middle Percha Creek	NW $\frac{1}{4}$ NW $\frac{1}{4}$ SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 16, T16S, R8W
1971	M-99	Sierra	Hillsboro		SE $\frac{1}{4}$ thru SW $\frac{1}{4}$ of NE $\frac{1}{4}$ to NE $\frac{1}{4}$ SW $\frac{1}{4}$ of SE $\frac{1}{4}$ sec. 16, T16S, R8W
1971	M-101	Sierra	Hillsboro	South Percha Creek	SE $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 16, T16S, R8W
1971	M-102	Grant	Santa Rita		C E $\frac{1}{2}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 7, T17S, R11W
1971	M-103	Grant	Santa Rita		NW $\frac{1}{4}$ NW $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 7, T17S, R11W
1972	M-5	Sierra	Hillsboro		C line btw NE $\frac{1}{4}$ & NW $\frac{1}{4}$ sec. 26, T16S, R7W C line btw SW $\frac{1}{4}$ & SE $\frac{1}{4}$ of NW $\frac{1}{4}$ to NW $\frac{1}{2}$ NE $\frac{1}{4}$ SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 15, T17S, R8W
1972	M-7	Sierra	Hillsboro		SW $\frac{1}{4}$ NW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 6, T17S, R11W
1972	M-8	Grant	Santa Rita		CN $\frac{1}{2}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 18 and NW $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 17, T18S, R4E
1975	M-73	Dona Ana	Bear Peak	San Andres Canyon	

APPENDIX 3 – Interradial plate counts of all *Nunnacrinus dalyanus* studied, including the type specimens of *Nunnacrinus mammillatus* from the Smithsonian Institution.

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-005-1	1	1,2,1,2	-	-	-	-
M-006-2	1	1,2,1,2	1,2,1,1	-	-	-
M-006-2	2	1,2,1,1	1,2,1,1	1,2,3,2	1,2,1,1	1,2,1,?
M-006-2	4	1,2,1	1,2?,1?	1,2,1?,1	1,2,1,1	1,2,1,1
M-006-2	3	1,2,2,?	1,2,2,2	1,2,3?,1?,1?	1,2,2,1,2	1,2,2,1,?
M-007-11	1	-	-	-	-	-
M-007-12	1	-	-	1,2,?	-	-
M-007-16	1	1,2,2,1	-	-	-	-
M-009-2	2	-	1,1,1	1,2,1,1	-	-
M-009-2	1	-	-	-	-	-
M-013-05	4	-	-	1,2,3,1	1,2,1,1	1,2,1,1
M-013-05	1	1,2,2,2	1,2,2,2	1,2,2,2,2	1,2,?	1,2,2,?
M-013-05	2	1,2,2,?	1,2,2,?	1,2,3,2	1,2,?	1,2,?
M-013-05	3	1,1,2,2,2,1	1,2,?	1,2,2,3,1	1,2,1,2	1,2,2,1
M-013-11	3	1,2,?,1	1,2,2,?	1,2,2,1,2	1,2,1	1,2,?,1
M-013-11	2	-	1,2,2,?	1,2,3,2,1	1,2,?	1,2,2,2
M-013-11	1	-	-	-	-	-
M-013-13	1	1,2,2,1	1,2,?,1	1,3,3,1	1,2,?,1	1,2,2,1
M-013-13	2	1,2,2,1	1,2,2,1	1,2,2,1,1	-	1,2,?
M-013-13	3	-	-	-	-	-
M-015-10	1	-	1,2,?	1,2,2,1	1,2,2,1	-
M-015-10	2	1,2,?	1,2,2,1	1,2,2,1	1,2,2,1	1,2,?,1
M-015-10	3	1,2,2	1,2,?	1,2,2,1	-	1,2,2
M-015-10	5	1,2,2,1	1,2,1	1,2,2,1	1,2,1	1,2,?,1
M-015-10	8	1,2,2,1	1,2,?	1,2,3,?,2	1,2,?,1	1,2,?,1
M-015-10	4	1,2,?,1	1,2,2,2	1,2,3,2	1,2,2,2	1,2,2,2
M-015-10	6	1,2,2	1,2,2	1,2,?,3	1,2,2	1,2,2
M-015-10	7	1,2,2,2	1,2,2,2	1,2,3,1,2	1,2,2,2	1,2,2,2
M-015-10	9	1,2,2,1	-	-	-	1,2,?
M-015-15	1	1,2,2,1	1,2,2,1	1,2,?,?,3	1,2,?,1	1,2,?,1
M-015-15	2	1,2,2,1	1,2,2,1	1,2,?	-	1,2,2,?
M-015-15	3	-	-	-	-	-
M-015-15	4	-	-	-	-	-
M-015-15	5	-	-	-	-	-
M-015-33	1	1,2,?,1	1,2,2,1	1,2,3,1	1,2,2,1	1,2,?,1
M-015-33	2	1,2,2,1	1,2,2,1	1,2,2,?,1	1,2,2,1	1,2,2,1
M-015-33	3	1,2,2,1	1,2,2,?,2	1,2,3,?	1,2,2,1	-
M-015-33	4	1,2,2,1	1,2,?,1	1,2,?	-	1,2,?

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-015-33	5	1,2,2,?,1	1,2,2,1	1,2,?,1	1,2,2,1,1	-
M-015-33	6	1,2,1,1	1,2,2,1	1,2,1,1	1,2,1,1	1,2,2,1
M-015-33	7	-	1,2,1	1,2,1,1	1,2,1	-
M-015-33	8	1,2,1,1	1,2,1,1	-	-	1,2,1,1
M-015-33	10	1,2,?	1,2,?,1	1,2,?,1	1,2,1,1	-
M-015-33	9	1,2,?	1,2,?	1,2,?	-	-
M-015-33	11	-	-	-	-	-
M-015-33	12	-	-	-	-	-
M-015-33	13	-	-	-	-	-
M-015-33	14	-	-	-	-	-
M-015-45	4	1,2,?,1	1,2,?	1,2,2,1	1,2,1,1	1,2,2,1
M-015-45	6	1,2,?,1	1,2,?	1,2,3,?,1	-	-
M-015-45	16	1,2,2,1	1,2,2,2,1	1,2,3,?	1,2,2,2	1,2,2,2,1
M-015-45	1	1,2,2,2,1,1	1,2,2,2,1,1	1,2,3,3,2,1,2	1,2,2,2,1	1,2,2,2,1,1
M-015-45	8	-	-	1,2,3,?,2	1,2,2,2	-
M-015-45	9	-	-	1,2,3,2,2	1,2,2,2	1,2,2,2
M-015-45	2	1,2,?,1	1,2,?	-	-	-
M-015-45	3	-	-	-	-	-
M-015-45	5	1,2,2,1	-	-	-	-
M-015-45	7	-	-	-	-	-
M-015-45	10	-	-	-	-	-
M-015-45	11	1,2,2,1	-	-	-	-
M-015-45	12	-	-	-	-	-
M-015-45	13	-	-	-	-	-
M-015-45	14	-	-	-	-	-
M-015-45	15	-	-	-	-	-
M-015-45	17	1,2,?,2	-	-	-	-
M-015-54	1	-	1,2,2,?	1,2,?	1,2,2,1,1	1,2,2,1
M-015-54	2	1,2,2,?	-	1,3,?	1,2,2,1	1,2,2,1
M-015-62	1	1,2,?,1	-	1,3,3,2	1,2,?,1	1,2,2,1
M-015-62	2	1,2,2	1,2,?	1,2,2,?	-	-
M-015-80	1	1,2,?	1,2,?	1,2,2,2	1,2,2,1	1,2,2,?
M-015-80	2	1,2,2,1	1,2,2,1	1,2,3,2,2	1,2,2,1	1,2,2,1
M-015-80	4	1,2,2,?	1,2,1,1	1,2,?	-	1,2,2,1
M-015-80	14	-	1,2,1	1,2,1,1	-	-
M-015-80	9	-	1,2,2,2,1	1,2,?	-	1,2,2,1,2
M-015-80	11	1,2,2,2	1,2,2,1	1,2,2,?	1,2,2,2	1,2,2,2
M-015-80	3	-	-	1,2,3,?,?	1,2,?	-
M-015-80	5	1,2,2,2	-	-	-	-
M-015-80	6	-	-	-	-	-
M-015-80	7	1,2,2,1	1,2,1	-	-	-

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-015-80	8	-	-	-	-	-
M-015-80	10	1,2,?	1,2,?	1,2,?	-	1,2,?
M-015-80	12	-	1,2,2,?	1,2,?	-	-
M-015-80	13	-	-	-	-	-
M-015-80	15	-	-	-	-	-
M-015-81	1	1,2,2,1	1,2,2,?	1,2,3,3,2	1,2,2,1	1,2,2,2
M-015-81	2	-	-	1,2,?	1,2,2,1	1,2,?
M-015-81	3	1,2,?	1,2,?	1,2,?	1,2,?	1,2,?
M-015-82	1	1,2,2,1	1,2,2,1	1,2,3,2,?	1,2,2,1	1,2,2,1
M-015-82	3	1,2,2,1	1,2,2,1	1,2,3,2,3	1,2,1,1	1,2,2,1
M-015-82	4	1,2,2,1	1,2,2	-	1,2,1	1,2,1
M-015-82	5	1,2,1,1	1,2,2,?	1,2,?,1	-	1,2,2,2
M-015-82	6	1,2,2,1	1,2,2,1	1,2,3,1	1,2,2,1	1,2,2,1
M-015-82	2	1,2,2,2,1	1,2,2,1,1	1,2,?,1	1,2,2,1,1	1,2,2,1,1
M-015-82	7	1,2,2,1	1,2,?	-	-	-
M-015-83	1	1,2,?,2	1,2,2,1	1,2,2,2,1	1,2,?,1	1,2,?
M-015-83	3	1,2,1,1	1,2,2,1	1,2,3,2,1	1,2,2,1	1,2,2,1
M-015-83	4	1,2,?,1	1,2,?	1,2,?	1,2,?,2	-
M-015-83	5	1,2,2,2	1,2,2,1	1,2,3,3,1	1,2,?,1	1,2,?,
M-015-83	13	1,2,?	1,2,2,?	1,2,3,?	1,2,?,1	1,2,2,?
M-015-83	15	-	1,2,2,1	1,2,2,1	-	-
M-015-83	16	-	1,2,?	1,2,2,2,1	1,2,1	-
M-015-83	17	-	-	1,2,3,1	-	1,2,1,1
M-015-83	20	1,2,?	1,2,1	1,2,3,?	1,2,1,1	1,2,2,1
M-015-83	21	1,2,2,1,?	1,2,2,2,1	1,2,?	-	-
M-015-83	23	-	-	1,2,3,?	1,2,2,1	1,2,2,1,1
M-015-83	2	-	1,2,?	1,2,3,?,2	-	1,2,?
M-015-83	6	-	-	-	-	-
M-015-83	7	-	1,2,?,?,1	1,2,?	-	-
M-015-83	8	1,2,2,1	-	-	-	-
M-015-83	9	1,2,?	1,2,?	1,3,?	-	-
M-015-83	10	1,2,?,1	1,2,?,1	-	-	-
M-015-83	11	-	-	-	1,2,1,1	-
M-015-83	12	1,2,?,2	-	-	-	-
M-015-83	14	1,2,1	-	-	-	-
M-015-83	18	-	-	-	-	-
M-015-83	19	-	-	-	-	-
M-015-83	22	-	-	-	-	-
M-015-83	24	-	-	-	-	-
M-015-83	25	-	-	-	-	-
M-015-85	2	1,2,2	1,2,1	1,2,3,?	1,2,2	1,2,1

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-015-85	4	1,2,2,1	1,2,2,2	1,2,3,1,1	1,?,?,2	1,2,?
M-015-85	8	1,2,?	1,2,?	1,2,3,2,1	-	1,2,?,2
M-015-85	12	1,2,2,1	1,2,2,1	1,2,2,?,1	1,2,2,1	-
M-015-85	13	1,2,2,?	1,2,?	1,3,3,?	1,2,2,1	-
M-015-85	20	-	1,2,2,1	1,2,3,2,1	-	-
M-015-85	9	-	-	1,2,3,2,2	1,2,?,2	-
M-015-85	17	1,2,?,2	1,2,?	1,2,?	1,2,?,1	1,2,?,2
M-015-85	1	1,2,2,1	-	-	1,2,?	1,2,2,2
M-015-85	3	-	-	-	-	-
M-015-85	5	-	-	-	-	-
M-015-85	6	-	-	-	-	-
M-015-85	7	-	-	-	-	-
M-015-85	10	-	-	-	-	-
M-015-85	11	1,2,2,1	-	-	-	-
M-015-85	14	1,2,2,1,1	-	-	-	-
M-015-85	15	-	-	-	-	-
M-015-85	16	-	-	-	-	-
M-015-85	18	1,2,?,2	-	-	-	-
M-015-85	19	1,2,2,?	1,2,?,1	-	-	-
M-015-117	1	1,2,2,1	1,2,?,1	1,2,1,1	1,2,1	1,2,?,1
M-015-117	2	1,2,2,2	1,2,2,1	1,2,3,1,2	1,2,2,2	1,2,2,2
M-016-02	1	1,2,1,1	1,2,1,1	1,2,2,1,1	1,2,1,1	1,2,1,1
M-016-12	2	1,2,1	1,2,1	1,2,2,1,?	1,2,1	1,2,1
M-016-12	3	1,2,1,1	1,2,?	1,2,2?,1?	-	-
M-016-12	4	1,2,1	1,2,1	1,2,2,1	1,2,1	1,2,?
M-016-12	1	1,2,2,?	1,2,2,1	1,2,2,1	1,2,1,1	1,2,2,1
M-017-04	1	1,2,?,2	1,2,?	1,2,3,1,2	1,2,?	1,2,2,2
M-017-04	2	-	1,2,?	1,2,3,?	1,2,?	-
M-017-07	1	1,2,2,1	1,2,1,1	1,2,3,1	-	1,2,2,1
M-017-07	6	-	-	1,2,3,2	1,2,1	1,2,1,2
M-017-07	8	1,2,1	1,2,1	-	1,2,1	1,2,1
M-017-07	9	-	-	1,2,3,2,1	1,2,2,1	1,2,2,1
M-017-07	11	1,2,2,1	1,2,1,1	-	1,2,2,2	-
M-017-07	13	1,2,?	1,2,2,1	1,2,3,1,1	-	-
M-017-07	20	1,2,2,?	1,2,2,1	1,2,3,?	-	1,2,1,1
M-017-07	10	1,2,2,1	1,2,2,1	1,2,3,2,?	1,2,2,2,1	1,2,2,?,1
M-017-07	22	1,2,?	1,2,2	1,2,2,1,2	-	-
M-017-07	23	1,2,2,2,2	1,2,2,2	1,2,3,2,2	1,2,2,2,1	1,2,2,2,1
M-017-07	24	-	1,2,?,1	1,2,2,2,?	-	1,2,?,2
M-017-07	26	1,2,?,1	-	1,2,3,?	-	1,2,?,1
M-017-07	5	1,2,2	1,2,?	1,2,3,3	1,2,1,2	1,2,2

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-017-07	2	1,2,2,2	1,2,2,1	-	1,2,2,?	1,2,?
M-017-07	3	1,2,2,1	1,2,2,1	-	-	-
M-017-07	4	1,2,2,?,1	-	-	-	-
M-017-07	7	-	-	-	1,2,2	-
M-017-07	12	-	-	-	-	-
M-017-07	14	-	-	-	-	-
M-017-07	15	1,2,?,2	-	1,2,?	1,2,?	-
M-017-07	16	1,2,1	1,2,1	-	1,2,1	-
M-017-07	17	1,2,1,2	1,2,1,1	-	1,2,1,1	-
M-017-07	18	-	-	1,2,?	-	1,2,2,1
M-017-07	19	1,2,2,2,1	1,2,2,2,1	-	1,2,?	-
M-017-07	21	1,2,1	-	-	-	-
M-017-07	25	-	-	-	-	-
M-017-07	27	-	-	-	-	-
M-017-07	28	1,2,?,2	-	-	-	-
M-017-07	29	-	-	-	-	-
M-017-09	1	1,2,2,1	1,2,2,1	1,2,3,1,1	1,2,2,1	1,2,2,2
M-017-09	3	1,2,2,1	1,2,2,1	1,2,2,1	1,2,2,1	1,2,2,1
M-017-09	4	1,2,?	1,2,?	1,2,3,2,1	1,2,2,1	1,2,2,1
M-017-09	5	1,2,2,1	1,2,?	1,2,3,?,2	1,2,2,1	1,2,2,2,1
M-017-09	9	1,2,2,1	1,2,1,1	1,2,3,2	1,2,1	1,2,2,1
M-017-09	10	-	1,2,?	1,2,?	1,2,1	1,2,1
M-017-09	11	1,2,2,2	1,2,2,2	1,3,2,2	1,2,?,1	1,2,?
M-017-09	13	1,2,?,2	1,2,?	1,2,2,2,1	-	-
M-017-09	16	1,2,2,1	1,2,?	1,2,3,?	1,2,?,1	1,2,2,1
M-017-09	17	1,1,2,2	1,2,2,1	1,2,2,2,2	-	-
M-017-09	19	1,2,1	-	1,2,2,1	1,2,?	1,2,2
M-017-09	20	1,2,2,1	1,2,2,2	1,3,2,?	1,2,2,2	1,2,?
M-017-09	21	1,2,?	1,2,1,1	1,2,3,2	-	1,2,2
M-017-09	28	1,2,2,1	1,2,2,1	1,2,2,2,1	1,2,2,2	1,2,2,?
M-017-09	32	1,2,?	1,2,?,2	1,2,3,?	1,2,2	-
M-017-09	2	1,2,?,1	1,2,?	1,2,3,2,1	1,2,2,1,2	1,2,2,?,1
M-017-09	7	1,2,?,1	1,2,2,2	1,2,2,2	-	1,2,2,2
M-017-09	8	1,2,1,2	1,2,2	1,2,3,2,2	1,2,2,2	1,2,2,1
M-017-09	12	1,2,2,2	1,2,2,2	1,2,3,?	1,2,2	1,2,2
M-017-09	18	1,2,2,2	1,2,2,2	1,3,2,2	1,2,2,2	1,2,?
M-017-09	23	1,2,?	1,2,2,1	1,2,3,2	1,2,2	1,2,2,2
M-017-09	26	1,2,2,?	1,2,2,1	1,2,3,1,1	1,2,2,2	1,2,1,2
M-017-09	30	1,2,2,2	1,2,2,2	1,2,3,2,1	1,2,2,2	1,2,?
M-017-09	31	-	-	1,2,3,2	1,2,2,2	-
M-017-09	35	1,2,2,1,1	-	-	1,2,2,2	1,2,2,2

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-017-09	36	-	1,2,2,1	1,2,2,2,2	-	-
M-017-09	39	1,2,?	1,2,?	1,2,3,2	1,2,?	1,2,2,1
M-017-09	6	1,2,?	-	-	1,2,2,2,1	1,2,2,?
M-017-09	14	1,2,2,1	-	-	-	-
M-017-09	15	1,2,2,2	1,2,2,2	-	-	-
M-017-09	22	-	1,2,?	1,2,3,?	1,2,2	-
M-017-09	24	-	-	-	-	-
M-017-09	25	1,2,2,1	1,2,?	-	-	-
M-017-09	27	1,2,?	-	1,2,3,?	1,2,?	-
M-017-09	29	-	-	-	-	-
M-017-09	33	-	1,2,2,?	1,2,3,2	-	-
M-017-09	34	-	-	-	-	-
M-017-09	37	1,2,?	-	-	-	-
M-017-09	38	1,2,2,1	-	-	-	1,2,?
M-017-13	1	1,2,?,2	1,2,?	1,2,?	1,2,1,1	1,2,2,2
M-017-13	2	1,2,2,2	-	-	-	-
M-017-13	3	-	1,2,?	1,2,3,1	1,2,?	1,2,?
M-017-31	1	1,2,2,1	1,2,2,1	1,2,3,1,1	1,2,?	1,2,2,1
M-017-31	2	1,2,?,1	1,2,?	1,2,3,1	1,2,?,1	1,2,?
M-017-31	3	1,2,?	1,2,?	1,2,2,2,1	-	1,2,2,1
M-017-31	7	-	-	1,2,3,?	1,2,2,1	1,2,1,1
M-017-31	11	1,2,1,1	1,2,2,1	1,1,2,1,1	-	1,2,1
M-017-31	12	1,2,?,2	1,2,2,1	-	-	1,2,?,2
M-017-31	13	-	-	1,2,3,1,1	1,2,1,1	1,2,2,1
M-017-31	15	1,2,2,1	1,2,2,1	1,2,3,2,1	1,2,2,?	1,2,2,1
M-017-31	5	1,2,2,1	1,2,?	1,2,3,2,?	1,2,2,1	1,2,2,2
M-017-31	8	1,2,2,?	-	1,2,3,2	1,2,2,2	1,2,2,1
M-017-31	9	1,2,2,?,1	1,2,2,?,1	1,2,3,1,1	1,2,2,?,1	1,2,2,2,1
M-017-31	4	1,2,2,1	1,2,?	-	-	-
M-017-31	6	-	1,2,?	-	1,2,?	-
M-017-31	10	1,2,?,1	-	-	-	1,2,?
M-017-31	14	1,2,?	1,2,?	-	1,2,?	-
M-017-31	16	1,2,?,1	1,2,2,1	-	-	-
M-017-40	1	1,2,2,1	-	1,?	1,2,?,1	1,2,1,1
M-017-40	6	1,2,1,1	-	1,2,2,1	1,2,2,?	-
M-017-40	7	1,2,1	1,?,1	1,2,?	1,2,1	1,2,1
M-017-40	8	1,2,2,1	1,2,1	1,2,3,2,2	1,2,2,1	1,2,2,1
M-017-40	10	1,2,2,1	1,2,2,1	1,2,3,2,1	1,2,1,2	1,2,2,1
M-017-40	11	1,2,2,1	1,2,1,2	1,2,2,2	1,2,?	-
M-017-40	12	1,2,2,?	1,2,2,2	1,2,3,1,1	1,2,2,1	1,2,?
M-017-40	16	1,2,2,1	1,2,2,?	1,2,3,1	1,2,2,1	1,2,2,1

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-017-40	17	-	-	1,2,3,1	-	1,2,2,1
M-017-40	2	1,2,2,1	1,2,2,2	1,2,?,?,2	1,2,?,1	1,2,2,1,1
M-017-40	3	1,2,2,?,1	1,2,2,1,?	1,2,3,2,1	1,2,2,1	1,2,2,?,1
M-017-40	5	1,2,2,1	1,2,2,?	1,2,3,?	-	1,2,2,2,1
M-017-40	9	1,2,2,1	1,2,?,1	1,2,3,2,?	-	1,2,2,2,2
M-017-40	4	1,2,2,2	1,2,2,2	-	-	-
M-017-40	13	1,2,?	1,2,?	-	-	-
M-017-40	14	1,2,?	1,2,?,1	-	1,2,?,1	-
M-017-40	15	1,2,?,2	-	-	-	1,2,1,1
M-017-40	18	-	-	1,2,3,2,2	-	-
M-017-40	19	-	-	-	-	-
M-017-40	20	-	-	-	-	-
M-018-3	1	-	-	-	-	-
M-018-7	1	1,2,2,1,2	1,2,2,1	-	1,2,2,1	-
M-019-10	5	1,2,1,1	1,2,?	1,2,3,?	1,2,2,1	1,2,1,1
M-019-10	1	-	1,2,1,1	1,2,3,2,2	1,2,1,2	-
M-019-10	2	1,2,2,1	1,2,2,1	1,2,3,2,1	1,2,2,2	1,2,2,1
M-019-10	4	1,2,2,2	1,2,1,2	1,2,3,2,2	1,2,2,2	1,2,2,2
M-019-10	6	1,2,?,1	1,2,?	1,2,3,2,1	1,2,?	1,2,?
M-019-10	7	-	-	1,2,3,2,2	-	-
M-019-10	9	-	-	1,2,?	-	1,2,2,2
M-019-10	3	1,2,2,1	-	1,3,2,1	1,2,2,1	1,2,2,1
M-019-10	8	-	-	1,2,3,?	1,2,?,2	-
M-019-10	10	-	-	-	-	-
M-019-17	4	1,2,1,?	1,2,2,?,1	1,2,2,1,1	1,2,?	1,2,1,1
M-019-17	14	-	1,2,?,1	1,2,2,?,1	1,2,1,1	-
M-019-17	20	1,2,1	1,2,1	1,2,2,1,1	1,2,1	1,2,1
M-019-17	3	1,2,2,1	1,2,2,1	1,2,3,1,1	1,2,2,1,1	1,2,?
M-019-17	5	1,2,?,2	1,2,?,1	1,2,3,2,1	1,2,2,2	-
M-019-17	6	1,2,2,1,2	1,2,2,2,1	1,2,4,3,1	1,2,2,2,1	1,2,2,2,?
M-019-17	7	1,2,2,1	1,1?,1,1	1,2,3,2,2	1,2,?,2	1,2,1,1
M-019-17	9	1,2,2,1	1,2,1,?	1,2,3,?	1,2,2,1,2	1,2,2,2
M-019-17	10	1,2,2,2,1	1,2,2,1,2	1,2,3,2,1	1,2,2,1	1,2,2,2
M-019-17	11	1,2,2,2	1,2,2,2	1,2,3,1,1	1,2,2,2	1,2,2,1
M-019-17	12	1,2,2,2,1	1,2,2,?	1,2,3,3,1	1,2,2,2,1	1,2,2,2,2
M-019-17	15	1,2,2,2,1	1,2,2,2,1	1,2,3,2?,1	1,2,2,2,1	1,2,2,2,1
M-019-17	16	-	1,2,?	1,2,3,2,2	-	-
M-019-17	18	1,2,?	1,2,2,1	1,2,3,2,1	1,2,2,1	-
M-019-17	21	-	1,2,2,2	1,2,3,2,1	-	-
M-019-17	23	-	-	1,2,3,2,1	-	-
M-019-17	24	1,2,2	1,2,?	1,2,3,2,2	1,2,?	1,2,1

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-019-17	1	1,2,1,?	1,2,1,?	1,2,3,2,1	1,2,2,1	1,2,1,1
M-019-17	2	1,2,?,1	-	1,2,3,?	1,2,?	1,2,?,1
M-019-17	8	1,2,1,1	1,2,1,1	-	-	-
M-019-17	13	1,2,2,1	-	-	-	-
M-019-17	17	1,2,2,?	-	-	-	-
M-019-17	19	1,2,1,1	-	-	-	-
M-019-17	22	-	-	-	-	-
M-019-17	25	1,2,2	-	-	-	-
M-021-3	1	-	1,2,1	1,2,2	1,2,2	-
M-021-3	2	1,2,1	-	-	-	-
M-022-04	1	-	-	-	1,2,?	1,2,2,2
M-022-12	3	-	-	1,2,3,1	-	-
M-022-12	1	1,2,2,2	1,?	1,2,3,?	-	1,2,?,2
M-022-12	2	-	-	-	-	-
M-022-14	1	1,2,?,1	1,2,?,1	1,2,2,?	1,2,1,1	1,2,1,1
M-022-14	2	1,2,?	1,2,?	1,2,3,1	1,2,1,2	1,2,1,2
M-022-14	4	-	-	1,2,2,?	1,2,1,1	1,?,?,1
M-022-14	6	1,2,1,2	1,2,1,2	-	1,2,?	1,2,1,2
M-022-14	8	1,2,1,1	1,2,1,1	1,2,3,2,?	1,2,1,?	-
M-022-14	9	1,2,?	-	1,2,3,?,2	1,2,1,1	1,2,2,1
M-022-14	21	-	-	1,2,3,2	1,2,1,1	-
M-022-14	5	1,2,?	1,2,2,2,2	1,2,3,?	1,2,?	1,2,2,?
M-022-14	10	-	1,2,?,2	1,3,2,1	1,2,2,?,1	-
M-022-14	11	-	1,2,2,2	1,3,3,2,1	-	-
M-022-14	12	-	-	1,2,3,2,2	1,2,?	-
M-022-14	19	1,2,2,?	-	1,3,3,2,1	1,2,?	1,2,2,1
M-022-14	20	1,2,2,2	1,2,?	1,2,2,?	-	-
M-022-14	27	-	-	1,2,3,2,1	-	-
M-022-14	30	1,2,2,1	1,2,2,1	1,2,3,2,2	1,2,2	1,2,2,2
M-022-14	3	1,2,1	-	-	-	-
M-022-14	7	-	-	-	-	-
M-022-14	13	-	-	-	-	-
M-022-14	14	-	-	-	-	-
M-022-14	15	1,2,1	1,2,1	-	-	-
M-022-14	16	1,2,1,1	-	-	-	-
M-022-14	17	1,2,2	-	-	-	-
M-022-14	18	-	-	-	-	-
M-022-14	22	1,2,2,1	-	-	-	-
M-022-14	23	-	-	-	-	-
M-022-14	24	-	-	-	-	-
M-022-14	25	1,2,2,2	-	-	-	-

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-022-14	26	-	-	-	-	-
M-022-14	28	1,2,2,1	-	-	-	-
M-022-14	29	1,2,2,1	-	-	-	-
M-022-59	1	1,2,1,2	1,2,2,2	1,2,3,2	-	-
M-022-59	3	1,2,1,2	1,2,1,?	1,2,3,2,?	1,2,2,1	1,2,1,1
M-022-59	7	1,2,1	1,2,1	1,2,2,1	1,2,1	-
M-022-59	8	1,2,?	1,2,1,2	1,2,3,?,2	-	-
M-022-59	2	1,2,2,?	1,2,2,?	1,2,3,2,2,1	1,2,2,1	1,2,2,1
M-022-59	5	1,2,2,1	1,2,1,1	1,2,2,2,?	1,2,2,1	1,2,2,1
M-022-59	4	1,2,2,1	1,2,1,1	-	-	-
M-022-59	6	1,2,2,1	1,2,2,1	-	-	-
M-080-8	1	1,2,2,1	1,2,1,1	1,2,2,2,1	1,2,2,1	1,2,2,1
M-086-3	1	1,2,2	1,2,?	1,2,1,2	1,2,2	1,2,2
M-086-5	1	1,2,2,1	-	-	-	-
M-086-5	2	-	1,2,1,1	-	-	-
M-086-5	3	1,2,?	1,2,?,1	1,2,3,?	1,2,?	-
M-087-09	1	1,2,2,?	1,2,?,2	1,2,?	1,2,?,2	1,2,2,1
M-087-12	13	1,2,1,1	1,2,1,1	1,3,?	1,2,2,1	-
M-087-12	14	1,2,2,1	1,2,2,2,1	1,2,2,1,1	1,2,2,2	1,2,2,1,1
M-087-12	1	1,2,2,1	1,2,2,?	1,2,2,?,1	1,2,2,1	1,2,?
M-087-12	2	1,2,?,2	1,2,?,2	-	1,2,2,2	-
M-087-12	3	1,2,2,1	1,2,2,1	1,2,?	1,2,1	1,2,2,1
M-087-12	7	1,2,2,2,1	1,2,2,2,2	1,2,3,2,2	1,2,2,1	1,2,2,1
M-087-12	8	1,2,?,1	1,2,1,1	1,2,3,3	1,2,2,2	-
M-087-12	4	1,2,2,2	-	-	-	-
M-087-12	5	-	-	1,2,?	-	-
M-087-12	6	1,2,2,2,2	-	-	-	-
M-087-12	9	-	-	-	-	-
M-087-12	10	-	-	-	-	-
M-087-12	11	1,2,1	-	-	-	-
M-087-12	12	-	-	1,2,?	-	-
M-091-1	1	1,2,2,1	-	1,2,3,?,1	1,2,1,2	1,2,2,1
M-091-1	2	-	1,2,?	1,2,3,?,1	-	-
M-091-7	1	1,2,2,2	1,2,2,1	1,2,3,1,1	1,2,2,1	1,2,?,2
M-091-7	2	1,2,1,1	1,2,?,1	-	1,2,2,1	-
M-091-9	3	1,2,2,1	1,2,2,1	1,2,?	1,2,?	1,2,2,1
M-091-9	4	-	1,2,2,1	1,2,?	-	-
M-091-9	5	-	1,2,1	1,2,3,2,3	-	-
M-091-9	9	-	1,2,?	1,2,3,1	1,2,2	-
M-091-9	6	1,2,2,2	1,2,2,1,2	1,2,3,2,1	1,2,?	1,2,2,2
M-091-9	8	1,2,2,?	1,2,2,2,1	1,2,3,2,2	1,2,2,?,1	-

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-091-9	1	1,2,2,1	-	-	-	-
M-091-9	2	1,2,2,1	-	-	-	-
M-091-9	7	1,2,?,3	-	-	-	-
M-091-9	10	-	-	1,2,2,2,1	-	-
M-091-9	11	1,2,?,2	-	-	-	-
M-092-1	5	-	1,2,1,1	1,2,?,?,1	-	-
M-092-1	1	1,2,?,1	1,2,?,1	1,2,3,2,1	1,2,?,1	1,2,?
M-092-1	2	1,2,1,?	1,2,2,1	1,2,2,2,2	1,2,2,1	1,2,?
M-092-1	3	1,2,2,2,2	1,2,2,?,2	1,2,3,2,2	1,2,?	1,2,?,2
M-092-1	4	-	-	-	-	-
M-092-2	5	1,2,?	1,2,?	1,2,3,2,2	1,2,2,1	1,2,1
M-092-2	6	1,2,2,1	1,2,1,1	1,2,3,2,?	1,2,2,1	1,2,2,1
M-092-2	1	1,1,1	1,?	1,2,3,1	1,?	1,?
M-092-2	2	1,2,?	1,2,2,?	1,4,3,2	1,2,1	1,2,2,2
M-092-2	3	1,2,2,?,1	-	-	-	-
M-092-2	4	-	-	-	-	-
M-092-2	7	-	-	-	-	-
M-093-3	1	1,2,2,1	1,2,?,2	-	-	1,2,2,1
M-094-07	1	1,2,2,1	1,2,2,2	1,2,?	1,2,?,1	-
M-094-10	1	1,2,2,2	1,2,?	1,2,3,2,2	1,2,?,1	-
M-094-10	2	-	-	-	1,2,?	1,2,?
M-094-11	2	1,2,2,1	1,2,2,1	1,2,2,2,1	1,2,?,1	1,2,?,1
M-094-11	1	1,2,2,1,2	1,2,2,?,2	1,2,3,?,2	-	1,2,2,?
M-095-01	1	-	-	-	-	-
M-095-01	2	-	-	-	-	-
M-095-07	3	-	1,2,2,1	1,2,?	1,2,?,1	1,2,2,2
M-095-07	4	1,2,2,2	1,2,1,1	1,2,3,2,1	1,2,1,1	1,2,2,2
M-095-07	6	1,2,2,1	1,2,1,1	1,2,3,?,1	1,2,2,1	1,2,2,1
M-095-07	2	1,2,?,1	1,2,1,1	1,2,?	1,2,?,1	1,2,?,1
M-095-07	1	-	-	-	-	-
M-095-07	5	1,2,1,1	1,2,1,1	-	-	-
M-095-07	7	-	-	-	-	-
M-095-10	4	1,2,2,1	-	1,2,3,1,1	-	-
M-095-10	5	1,2,1	-	1,2,?	1,2,2	1,2,1,1
M-095-10	10	-	1,2,?,?,1	1,2,2,1	-	1,2,?,1
M-095-10	1	1,2,?,1	1,2,?,2	1,2,3,2,1	-	-
M-095-10	2	-	1,2,2,2	1,2,3,2,1	1,2,2,2	1,2,2,2
M-095-10	3	1,2,2,2,2	1,2,2,2,2	1,2,3,3,2	-	1,2,2,2,1
M-095-10	6	-	-	-	-	-
M-095-10	7	-	-	1,2,2,?,1	-	-
M-095-10	8	-	-	-	-	-

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-095-10	9	-	-	-	-	-
M-095-11	1	1,2,2,2,?	-	1,2,?	1,2,?	1,2,2,1
M-095-16	1	-	-	-	-	-
M-095-19	1	1,2,?,1	1,2,?	1,3,2,?	1,2,2,1	1,2,2,1
M-095-19	2	1,2,2,1	-	1,2,?	1,2,?,1	1,2,2,1
M-095-19	3	1,2,1,1	-	1,2,3,2,1	-	1,2,?
M-095-19	4	-	-	-	-	-
M-095-19	5	-	-	-	-	-
M-095-20	1	1,2,1,1	1,2,1,1	1,2,2,2	1,2,1,1	1,2,2,1
M-095-29	1	1,2,2,1	1,2,1,1	1,2,2,1	1,2,1	1,2,1
M-095-29	2	1,2,2,1	1,2,1	1,2,2,1	1,2,2,1	1,2,2,1
M-095-29	3	1,2,2,1	1,2,2,1	1,2,3,2,1	1,2,?	1,2,2,1
M-095-29	4	1,2,?	1,2,?	1,2,2,1	1,2,?,1	1,2,?,1
M-095-29	5	1,2,?	1,2,?	1,2,?,1	1,2,?,1	1,2,?
M-095-29	6	1,2,2,1	1,2,?	1,2,3,2	1,2,2,1	1,2,?
M-095-29	7	1,2,2,1	1,2,2,1	1,2,3,?	1,2,2,1	1,2,2,1
M-095-29	8	1,2,1,?	1,2,1,2	1,2,3,?,2	1,2,1,1	1,2,2,1
M-095-29	10	1,2,2,1	1,2,?,1	1,2,3,?	1,2,?,1	1,2,?,1
M-095-29	12	1,2,2,2	1,2,?	1,2,2,2,2	1,2,?	1,2,?,2
M-095-29	19	1,2,2,1	1,2,2,1	1,2,3,2,1	1,2,2,1	1,2,2,1
M-095-29	20	1,2,?,1	1,2,?,2	1,2,3,?	-	1,2,?
M-095-29	21	1,2,1,2	1,2,1,1	1,2,3,1	1,2,2,1	1,2,1,1
M-095-29	22	1,2,2,1	1,2,1,1	1,2,2,1,1	-	-
M-095-29	23	1,2,1,1	1,2,1,1	1,2,3,?	1,2,2,1	1,2,2,1
M-095-29	24	1,2,?,1	1,2,2,2	1,2,?	1,2,?,2	1,2,?,1
M-095-29	25	1,2,2,1	1,2,2,1	1,2,3,1	1,2,2,1	1,2,2,1
M-095-29	26	-	-	1,2,3,2,1	1,2,2,2	1,2,?
M-095-29	27	1,2,2,1	1,2,2,1	1,2,?	-	-
M-095-29	28	1,2,2	1,2,1	1,2,4,2,?	1,2,2	1,2,1
M-095-29	30	-	1,2,2,1	1,2,3,2,1	-	-
M-095-29	31	1,2,2,1	-	1,2,3,2,1	-	1,2,?
M-095-29	32	-	1,2,2,?	1,2,3,2,1	1,2,2,1	1,2,2,1
M-095-29	11	1,2,2,2	1,2,2,1	1,2,3,2	1,2,2,2	1,2,?,1
M-095-29	15	1,2,?	-	1,2,3,2,1	1,2,2,1	-
M-095-29	17	1,2,2,?	1,2,2,1,1	1,3,4,2,1	-	-
M-095-29	9	-	-	-	-	-
M-095-29	13	-	-	-	1,2,?,1	1,2,1,1
M-095-29	14	-	1,2,?,1	1,2,?	-	-
M-095-29	16	-	-	-	-	-
M-095-29	18	-	-	-	-	-
M-095-29	29	-	-	-	-	-

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-095-29	33	1,2,2,1	-	-	-	-
M-095-29	34	-	-	-	-	-
M-097-1	1	-	-	-	-	-
M-099-1	1	-	1,2,2,1	1,2,3,?,1	1,2,?	1,2,?
M-100-1	1	1,2,?,1	-	-	-	-
M-100-2	1	1,2,2,2	1,2,?,2	1,2,2,1	1,2,?,2	1,2,?
M-100-2	2	1,2,2,1	1,2,2,1	1,2,3,2,2	1,2,?,1	1,2,2,1
M-100-2	3	-	-	-	-	-
M-100-2	4	-	-	-	-	-
M-102-1	2	1,2,2,2,1	1,2,2,1,?	1,3,3,1,1	1,2,2,1	1,2,2,1,1
M-102-1	1	1,2,?,1	-	-	-	-
M-151-1	1	1,2,?	1,2,2,2	1,2,?	1,2,2,2	1,2,?,2
M-154-1	1	1,2,2,1,1	1,2,?	1,2,3,?	-	1,2,2,1
M-154-1	2	-	-	-	-	-
M-155-1	2	1,2,2,1	1,2,2,1	1,2,3,2,1	1,2,?,1	1,2,?,1
M-155-1	3	1,2,?,1	-	1,2,3,?,1	-	1,2,?
M-155-1	1	1,2,?,2	1,2,2,1	-	1,2,2,1	-
M-158-02	1	-	-	-	-	-
M-158-02	2	-	-	-	-	-
M-158-05	1	1,2,1,1	1,2,1	1,2,2,1	1,2,1,1	1,2,1,1
M-158-05	2	1,2,?	1,2,1,1	1,2,?	1,2,?,1	1,2,?,1
M-158-05	3	1,2,2,1	1,2,?	1,2,3,1,2	1,2,1,?	1,2,1,1
M-158-05	5	-	-	1,2,2,?	1,2,1,1	1,2,?
M-158-05	4	1,2,?	1,2,?	1,2,3,?	-	1,2,?
M-158-06	2	1,2,2,?	1,2,?	1,3,?	1,2,2,1	1,2,2,2
M-158-06	1	-	-	-	-	-
M-158-07	1	1,2,2,2	-	-	-	-
M-158-08	1	1,2,2,1	1,2,?	1,2,3,1,1	1,2,?,1	1,2,2,1
M-158-08	4	1,2,1	-	1,2,?,1	-	-
M-158-08	7	1,2,?	1,2,1	1,2,3,?	-	-
M-158-08	9	-	1,2,2,1	1,2,2,?	-	-
M-158-08	2	1,2,?	1,2,?	1,2,?	-	-
M-158-08	3	-	-	-	-	-
M-158-08	5	-	-	-	-	-
M-158-08	6	1,2,2,2	-	-	-	-
M-158-08	8	-	-	-	-	-
M-158-08	10	1,2,2,2	1,2,?	1,2,3,?	-	-
M-158-12	1	1,2,2,1	1,2,?,1	1,2,?	-	1,2,?,2
M-158-12	4	1,2,2,1	1,2,2,1,1	1,2,3,2,1	1,2,2,1	1,2,2,1
M-158-12	7	-	1,2,2,2	1,2,2,1,1	1,2,2,2	-
M-158-12	2	-	1,2,2,2	1,2,3,2,1	1,2,2,2	-

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
M-158-12	3	1,2,?,2	1,2,2,1	1,2,2,2	1,2,2,2	1,2,2,2
M-158-12	5	1,2,2,2,1	1,2,2,2,1	1,1,2,3,2,1	1,2,2,2,1	1,2,2,2,1
M-158-12	6	1,2,?,1	-	1,2,3,2,2	1,2,2,2	1,2,?,2
M-158-12	8	1,2,?,2	1,2,?,2	1,2,?,?,2	1,2,?	1,2,?
M-158-12	10	1,2,2,2	1,2,?	1,2,3,2,2	1,2,2,2	1,2,2,2
M-158-12	9	1,2,2,?,1	1,2,2,1,1	-	-	-
M-158-14	2	-	-	1,2,3,1	1,2,?,1	-
M-158-14	3	1,2,?	1,2,2,?	1,2,3,1,1	1,2,2,1	1,2,2,1
M-158-14	5	1,2,1	1,2,1	1,2,2,1	-	-
M-158-14	1	1,2,2,2	1,2,2,2	1,2,4,?	-	1,2,2,2
M-158-14	4	-	-	-	-	-
M-158-14	6	-	-	-	-	-
M-158-15	1	1,2,2,2,2	1,2,2,2,1	1,2,3,2,1	1,2,2,2,2	1,2,2,2,2
M-159-2	1	-	1,2,?	1,2,2,?,2	1,2,2,2	1,2,2,2
FC-11	1	-	-	1,2,3,?,1	-	-
InUni-04	1	1,2,2,1	1,2,2,?	1,2,3,2	1,2,1,1	1,2,2,1
InUni-04	4	-	1,2,2,1	1,2,2,1	1,2,?	1,2,2,1
InUni-04	6	-	-	1,2,3,1	1,2,1	-
InUni-04	3	1,2,1	1,2,?	1,2,3,2	1,2,1	1,2,1
InUni-04	2	-	-	-	-	-
InUni-04	5	-	-	-	-	-
InUni-04	7	-	-	-	-	-
InUni-04	8	-	-	-	-	-
InUni-09	1	-	-	-	-	-
InUni-13	2	1,2,1,1	1,2,2,1	1,2,3,2,?	-	1,2,?,1
InUni-13	3	1,2,2,1	1,2,2,1	1,2,3,1	1,2,2,1	1,2,2,1
InUni-13	7	1,2,2	1,2,2,1	1,2,2,2,1	-	1,2,?
InUni-13	1	1,2,2	1,2,1	1,3,2	1,2,2	1,2,2
InUni-13	5	1,2,1	1,2,1	1,2,1,1	1,2,1	1,2,1
InUni-13	4	-	-	-	-	-
InUni-13	6	-	-	-	-	-
InUni-21	1	1,2,2,2	1,2,3,?	-	-	-
InUni-23	2	1,2,2,?	1,2,?	1,2,3,2,?	-	1,2,?
InUni-23	1	1,2,?	1,2,1,1	-	-	-
InUni-30	1	-	-	1,2,2,?	1,2,2,1	-
InUni-30	2	1,2,?,1	1,2,2,1	1,3,2,?	-	-
InUni-30	3	1,2,?,2	1,2,2,2	1,2,3,1	-	1,2,?
InUni-30	4	1,2,2,2	-	1,2,3,1,1	1,2,2,1	1,2,2,?
InUni-30	5	1,2,2,2	1,2,2,2	1,2,2,?,1	-	-
InUni-32	1	1,2,2,1	1,2,2,1	1,2,3,3,1,1	1,2,2,1,1	1,2,2,1,1
InUni-36	2	1,2,2,1	1,2,2,1	1,2,2,1,1	1,2,2,1	1,2,2,1

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
InUni-36	3	1,2,2,?,1	1,2,2,?,1	1,2,3,2,?,1	1,2,2,?	1,2,2,?,1
InUni-36	4	1,2,?	1,2,?	1,2,3,2,1	1,2,2,1	1,2,2,?,1
InUni-36	5	1,2,?	1,2,?	1,2,3,2	-	1,2,?
InUni-36	6	1,2,2,1	1,2,2,1	1,2,3,2,1	1,2,2,1	1,2,2,1
InUni-36	7	-	1,2,2,1	1,2,?,?,1	-	-
InUni-36	8	1,2,2,1	-	1,2,3,?,1	1,2,2,1	1,2,2,1
InUni-36	9	-	1,2,2,1	1,2,3,2,2	1,2,2,2,1	-
InUni-36	10	-	-	1,2,3,?	1,2,?	1,2,?,2
InUni-36	11	-	1,2,2,?,1	1,2,3,2,1	1,2,2,2,2	1,2,2,2,1
InUni-36	1	1,2,1,1	-	-	-	-
InUni-37	1	1,2,1	1,2,1	1,2,?,1	1,?,1	1,3,1
InUni-37	2	1,2,?,1	1,2,?	1,2,3,1	1,2,2,1	1,2,2,1
InUni-38	1	1,2,1,1	1,2,1	1,2,1,1	1,2,1	1,2,?,1
InUni-42	1	1,2,?	-	1,2,3,1	1,2,2,1	1,2,1,1
InUni-42	2	-	1,?,?,2	1,2,2,1	-	-
InUni-42	5	1,2,2,1	1,2,2,2	1,2,3,?,2	1,2,2,1	1,2,2,1
InUni-42	6	1,2,2,1	1,2,2,1	1,2,3,?	1,2,2,1	1,2,2,1
InUni-42	8	1,2,?	1,2,1	1,2,3,2,1	1,2,2,1	1,2,1
InUni-42	3	-	-	1,2,3,2,	-	-
InUni-42	4	-	-	1,2,3,2,?	1,2,2,1	-
InUni-42	7	-	-	1,3,3,?	1,2,?,1	-
InUni-42	9	-	-	-	-	-
InUni-42	10	1,2,?	1,2,?	1,2,?	1,2,?,1	1,2,2,?,1
InUni-42	11	1,2,?,1	1,2,?	1,2,2,2,1	-	-
InUni-43	2	1,2,?,1	-	1,2,?	1,2,2,1	1,2,?
InUni-43	3	1,2,?	1,2,?	1,2,3,1	1,2,?	1,2,?
InUni-43	5	1,2,2	1,2,?	1,2,?	-	1,2,2
InUni-43	7	1,2,2,2	1,2,?,1	1,2,3,?	1,2,2,1	1,2,?
InUni-43	8	1,2,?,?,1	1,2,?	1,2,3,1	-	1,2,2,1
InUni-43	4	1,2,2,2	1,2,2,2	1,2,3,2,2	1,2,2,?	1,2,2,2
InUni-43	1	1,2,?	1,2,?	1,2,?	1,2,?	1,2,?
InUni-43	6	-	-	-	-	-
L-13,559	1	1,2,?	1,2,1,1	1,3,2,2,1	1,2,?	1,2,1,1
L-13,578	2	1,2	-	1,2,1,1	-	1,2,1
L-13,578	1	-	-	-	-	-
L-13,578	3	1,2,2,1	1,2,1,1	-	-	-
L-13,578	4	-	-	-	-	-
L-13,578	5	1,2,?	1,2,2,?	-	1,2,2,?	1,2,2,?
L-13,578	6	-	-	-	-	-
L-13,803	1	1,2,2,1	-	-	-	-
L-13,803	2	-	-	-	-	-

Locality	Specimen #	A-B	B-C	C-D	D-E	E-A
L-13,998	1	1,2,?	-	-	-	1,2,2,2
L-13,998	2	1,2,?	1,2,?	1,2,?,?,1	-	1,2,?
L-13,998	3	-	1,2,?	1,2,?,?,1	-	1,2,2,1
L-13,998	4	-	-	1,2,3,?	-	-
L-13,998	5	-	-	-	-	-
L-13,998	6	-	1,2,2,?	1,3,?	-	-
L-13,998	7	-	-	-	-	-
L-13,998	8	-	-	-	-	-
L-13,998	9	-	-	-	-	-
L-13,998	10	-	-	-	-	-
L-14,022	1	1,2,2,1	-	-	-	-
L-14,028	1	1,2,?,1	-	1,2,?	1,2,1,1	1,2,?,1
L-14,028	2	1,2,2,1	-	1,2,3,?	1,2,2,1	1,2,2,2
L-14,028	3	1,2,?	1,2,2,?	1,2,?	1,2,?	1,2,?
L-14,028	5	1,2,?,1	-	1,2,3,2,?	1,2,?,1	1,2,?
L-14,028	6	1,2,?	1,2,2	-	1,2,?,2	1,2,1
L-14,028	4	-	-	1,2,3,2,1	-	-
L-14,028	7	-	-	-	-	-
L-14,077	1	1,2,?	1,2,?	1,2,3,?	1,2,?	1,2,?
Unk-1	1	-	-	-	-	-
Unk-3	1	1,2,?	1,2,?	1,2,3,2,2	1,2,?	1,2,?
Unk-3	2	1,2,2,2,2	-	-	-	-
USNM-2	1	1,2,?,1	1,2,?,1	-	-	-

Smith. #	Specimen #	A-B	B-C	D-E	E-A	Anal	Species
S4622	1	1,2,2,2	1,2,2,2	1,2,2,2	1,2,2,2	1,2,3,?,2	mammillatus
S4621	1	1,2,2,2	1,2,2,1	1,2,2,1	1,2,2,2	1,2,2,2,1	mammillatus
S4623	1	1,2,2,?	1,1,1,1	1,2,2,1	1,2,2,1	1,3,2,1	mammillatus
S4619	1	1,2,2,1	-	1,2,2,1	1,2,2,1	1,2,2,1	mammillatus
S4619	2	1,2,2,1	1,2,2,1	1,2,2,1	1,2,2,1	1,2,3,2,1	mammillatus
S4619	3	1,2,2	1,2,2,2	1,2,2,2	1,2,2,2	1,2,?,1	mammillatus
S4619	4	-	-	-	-	1,2,2,?	mammillatus
S4618	1	1,2,2,2,1	-	1,2,2,1	1,2,2,2	1,2,?	mammillatus
S4618	2	1,2,2,2	1,2,2,1	1,2,2,2	1,2,?	1,2,3,2,2	mammillatus
S4618	3	-	1,2,?,1	1,2,?,1	1,2,?	1,2,1,1	mammillatus
S4618	4	-	-	-	-	1,2,?	mammillatus
S4618	5	1,2,2	1,2,?	1,2,2	1,2,2	1,2,2,2	mammillatus
S4618	6	1,2,2,1	1,2,?,1	1,2,2,1	1,2,2,1	1,2,2,?	mammillatus
S4618	7	1,2,2,1	1,2,1	1,2,1,1	1,2,2,?	1,2,2,2	mammillatus
S4618	8	-	-	-	-	-	mammillatus
S4618	9	1,2,2,1,1	1,2,2,1	1,2,2,2,1	-	1,2,3,2,2	mammillatus
S4618	10	1,2,?,1	1,2,1,2	-	-	1,2,2,2	mammillatus
435908	1	1,2,2,2	1,2,2,2	1,2,2,2	1,2,2,2	1,2,3,2	dalyanus
435904	1	1,2,2,1	1,2,2,1	1,2,2,1	1,2,2,1	1,2,2,1	dalyanus
435907	1	1,2,2,1	1,2,2,1,2	1,2,2,2,1	1,2,2,2,1	1,2,3,2,1	dalyanus
435905	1	1,2,2	1,2,1	1,2,1	1,2,1	1,2,2,?	dalyanus
435906	1	1,2,1	1,2,?	1,2,1	1,2,2,1	1,2,1,1	dalyanus
435912	1	1,2,2,2	1,2,2,?	1,2,2,2,1	1,2,2,2,2	1,2,3,3,2	dalyanus
160619	1	1,2,2,2,2	1,2,2,2,1	1,2,2,2,1	1,2,2,2	1,2,2,2,1	dalyanus
435910	1	1,2,2,2	1,2,2,2	1,2,2,2	1,2,2,2	1,2,3,2,2	dalyanus
160618	1	1,2,2,1	1,2,2	1,2,2,1	1,2,2,1	1,2,3,2,2	dalyanus
435911	1	1,2,1	1,2,1,1	1,2,2	1,2,1,2	1,2,3,2,2	dalyanus
435923	1	1,2,1	1,2,1	1,2,1	1,2,1	1,2,3,2	dalyanus
435903	1	-	1,2,2,2	1,2,1,2	-	1,2,2,2	dalyanus
435898	1	1,2,1	1,2,1	1,2,1	1,2,2,2	1,2,2,1	dalyanus
160604	1	1,2,1	1,2,1	1,2,1	-	1,2,2,1	dalyanus
160617	1	1,2,2,1	1,2,2,1	1,2,2,2	1,2,2,2,1	1,2,2,2,1	dalyanus
435909	1	1,2,2,1	1,2,2,1	1,2,2,1	1,2,2,1	1,2,3,1,1	dalyanus
435895	1	1,2,1,1	1,2,1	-	1,2,1	1,2,2,1	dalyanus
435899	1	-	-	-	-	-	dalyanus
435897	1	1,2,2,?	1,2,1,2	1,2,1,1	1,2,2,2	1,2,3,1	dalyanus
435900	1	1,2,2,2	1,2,1	1,2,2,1	1,2,1,1	1,2,3,2,1	dalyanus
435901	1	1,2,2,2,1	1,2,2,2,1	1,2,2,2,1	1,2,2,2,1	1,2,3,3,2	dalyanus
448071	1	1,2,3,1,?	1,2,3,2,?	1,2,2,1,1	1,2,2,1	1,2,4,5,2	dalyanus
160602	1	1,2,2,1	1,2,2,2	1,2,2,1	1,2,?	1,2,2,1,1	dalyanus
114695	1	1,2,1,2	1,2,2,2	1,2,2,2	1,2,2,2	1,2,3,2,2	mammillatus

Smith. #	Specimen #	A-B	B-C	D-E	E-A	Anal	Species
S4620	1	1,2,2,2	1,2,1,2	1,2,2,2	1,2,2,1	1,2,3,2,2	mammillatus
S4620	2	1,2,2,1	1,2,2,1,2	1,2,2,1,1	1,2,2,2	1,2,2,3,2	mammillatus
S4620	3	1,2,2	1,2,2,2	1,2,2,2	1,2,2,2	1,2,3,2,2	mammillatus
S4620	4	1,2,2,1	1,2,2,2	-	1,2,2,1	1,2,3,1,1	mammillatus
S1218	1	1,2,2,1	1,2,2,2	1,2,2,2	1,2,2,2	1,2,2,2,2	mammillatus
S1218	2	1,2,2,2,2	1,2,2,2,2	1,2,2,2,2	1,2,2,2,2	1,2,3,3,3,3	mammillatus
S1218	3	1,2,2,2,1	1,2,1,2,1	1,2,2,2,1	1,2,2,2,1	1,2,4,?	mammillatus
118032	1	1,2,2,1	1,2,2,1	1,2,2,1	1,2,2,2	1,2,3,2,2	mammillatus
118028	1	2,2,2,1	1,2,2,2	1,2,2	1,2,1	1,2,2,2,1	mammillatus
118028	2	1,2,2,1	1,2,2,1	1,2,2,1	1,2,2,1	1,2,2,1,1	mammillatus
118028	3	1,2,2,1	1,2,2,1	1,2,1,1	1,2,2,1	1,2,3,1,2	mammillatus
118028	4	1,2,1,1	1,2,2,1	1,2,2,1	1,2,2,1	1,2,3,1	mammillatus
118028	5	1,2,2,2	1,2,2,2	1,2,2,2	1,2,2,2	1,2,3,2	mammillatus
118030	1	1,2,2,2	1,2,2,2	1,2,2,2	1,2,2,2	1,3,2,2	mammillatus
118030	2	1,2,2,1	1,2,1,2	1,2,2,2	1,2,2,2	1,2,3,2,1	mammillatus
118026	1	1,2,2,2	1,2,2,1,2	1,2,2,1	1,2,2,2	1,2,3,2,2	mammillatus
118026	2	1,2,2,2	1,2,2,?	-	-	-	mammillatus
118027	1	1,2,2,2	1,2,2,2	1,2,2,2	1,2,2,?	1,2,2,2	mammillatus
118029	1	1,2,2,1	1,2,?	1,2,?	1,2,2,2,1	1,2,2,2,2	mammillatus
118031	1	1,2,2	1,2,2,2	1,2,2	1,1,2	1,2,3,2	mammillatus

APPENDIX 4 - Characters for phylogenetic analysis

A, Calyx shape: 0, medium cone; 1, medium bowl; 2, high bowl; 3, low cone; 4, low bowl; 5, medium globe; 6, medium cone flared distally; 7, high cone.

B, Basal circlet: 0, low; 1, high.

C, Number of fixed secundibrachials: 0, zero; 1, one; 2, two.

D, Highest brachitaxis in vertical wall of calyx: 0, primibrachitaxis; 1, secundabrachitaxis; 2, tertibrachitaxis; 3, quartibrachitaxis.

E, Number of ranges in regular interrays: 0, two; 1, three; 2, four; 3, five or more; 4, ten or more.

F, Regular interrays in contact with tegmen: 0, yes; 1, no.

G, Posterior interray in contact with tegmen: 0, yes; 1, no.

H, Number of plates above primanal: 0, three; 1, two.

I, Fixed interbrachials between half-rays: 0, present; 1, absent.

J, Arms grouped: 0, strongly; 1, no; 2, weakly.

K, Arm lobes: 0, present and extend laterally; 1, absent.

L, Arm lobe length: 0, absent; 1, long; 2, short; 3, medium.

M, Tegmen height vs. calyx: 0, lower; 1, higher; 2, same.

N, Tegmen plate sculpture: 0, nodose; 1, smooth; 2, spinose; 3, proximal spines.

O, Tegmen shape: 0, low cone; 1, medium cone; 2, high cone; 3, flat cone; 4, flat inverted bowl; 5, low inverted bowl; 6, medium inverted bowl.

P, Tegmen interray depressed: 0, no; 1, yes.

Q, Anal opening: 0, tube present and central; 1, tube present and eccentric; 2, tube absent and eccentric.

APPENDIX 5– Character chart for phylogenetic analysis

Genus	Character																
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
<i>Periechocrinus</i>	7	1	2	2	3	0	0	0	0	0	1	0	0	1	4	0	1
<i>Megistocrinus</i>	1	0	2	2	3	0	0	0	0	2	1	0	0	(0,1)	4	0	1
<i>Eumorphocrinus</i>	1	1	2	2	3	0	0	1	1	0	1	0	0	1	5	0	0
<i>Cytidocrinus</i>	1	1	0	0	2	0	0	1	1	0	1	0	0	2	5	0	0
<i>Physetocrinus</i>	(0,1)	1	1	(2,3)	3	0	0	1	0	(0,2)	1	0	0	1	(4,5)	0	2
<i>Dialutocrinus</i>	1	(0,1)	1	2	1	0	0	1	0	(0,2)	1	0	0	0	(0,5)	0	0
<i>Thinocrinus</i>	(0,1)	(0,1)	(1,2)	0	(1,2)	0	0	1	(0,1)	0	0	3	0	(0,1)	(1,3,4,5)	1	0
<i>Abactinocrinus</i>	1	0	1	0	1	0	0	1	1	0	0	1	0	0	4	1	0
<i>Iotocrinus</i>	4	0	1	0	1	0	0	1	1	0	0	3	(0,1)	0	5	0	1
<i>Aacocrinus</i>	(0,1)	0	(0,1,2)	(0,1)	1	0	0	1	1	0	0	2	0	0	(3,5)	0	1
<i>Blairocrinus</i>	3	0	1	0	0	0	0	1	1	0	0	2	1	(0,1,3)	(0,1,2,6)	0	0
<i>Sampsonocrinus</i>	1	0	?	0	0	0	0	1	0	0	0	2	0	0	(4,5)	1	1
<i>Steganocrinus</i>	0	0	0	0	0	0	0	1	0	0	0	1	2	0	(4,5)	0	1
<i>Actinocrinites</i>	(0,2)	1	1	(1,2,3)	1	0	0	1	(0,1)	0	0	1	0	0	(0,3,5)	0	0
<i>Cactocrinus</i>	0	0	1	1	(0,1)	1	1	1	0	1	1	0	(0,2)	(1,2)	(0,1,5)	0	0
<i>Ilmocrinus</i>	(1,4)	0	1	2	0	1	1	1	0	1	1	0	?	?	?	0	?
<i>Teliocrinus</i>	0	1	1	2	3	(0,1)	1	1	0	1	1	0	0	0	3	0	0
<i>Strotocrinus</i>	6	1	1	(1,2)	4	1	1	1	0	1	1	0	0	1	4	0	2
<i>Maligneocrinus</i>	5	0	1	2	3	0	0	1	0	2	1	0	0	?	?	0	?
<i>Cusacrinus</i>	(0,3)	(0,1)	1	1	2	0	0	1	0	2	1	0	(0,2)	(1,2)	(0,1,3,5)	0	0
<i>Nunnacrinus</i>	(0,3)	0	1	0	2	0	0	1	0	2	1	0	(0,2)	(0,2)	(1,5)	0	0
<i>Glaphyrocrinus</i>	0	1	2	1	2	0	0	1	0	0	1	0	0	0	5	0	0
<i>Manillacrinus</i>	0	1	1	1	1	0	0	1	0	0	1	0	(0,2)	0	1	0	0

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Work Experience	<p>Lecturer, Department of Geology, Appalachian State University <ul style="list-style-type: none"> • Historical Lecture • Historical Lab • Enviromental Lab </p> <p>Teaching Assistant, Department of Geology and Geography, West Virginia University. <ul style="list-style-type: none"> • Taught Paleontology Lab • Taught Earth History Introductory Lab • Head TA for Earth History Lab • Taught Geology 101 in large lecture setting (300+ students) </p> <p>Teaching Assistant, Department of Geology, Kent State University <ul style="list-style-type: none"> • Helped teach Paleontology Lab • Taught Earth History Introductory Lab </p> <p>Introduction to Physical Geology Lab Instructor, University of Tennessee, Martin</p> <p>Supplemental Instructor Introduction to Physical Geology, University of Tennessee, Martin</p> <p>Workship student at the Department of Geology, Geography, and Physics, University of Tennessee, Martin</p>	<p><i>2011-2012</i></p> <p><i>2007-2011</i></p> <p><i>2005-2007</i></p> <p><i>2005</i></p> <p><i>2005</i></p> <p><i>2001-2004</i></p>

Presentations and Abstracts

- Rhenberg, Elizabeth C., Thomas W. Kammer. *Low Endemism of Early Osagean (Mississippian) Camerate Crinoids in North America*. Meeting: Geological Society of America, Denver, Colorado, United States, October 31-November 3, 2010.
- Rhenberg, Elizabeth C., Thomas W. Kammer. *Systematic Review of Crinoid Genera from the Early Mississippian Lake Valley Formation (Nunn Member) of South-Central New Mexico*. Meeting: Geological Society of America, Portland, Oregon, United States, October 17-23, 2009.
- Rhenberg, Elizabeth C., D. Jade Simon, Lewis A. Cook, Magdalena K. Gill, William I. Ausich, and Thomas W. Kammer. *Comparison of Early Mississippian Crinoid Generic Diversity Patterns Between the Lake Valley Formation of New Mexico and the Burlington Limestone Of Iowa*. Meeting: Geological Society of America, Houston, TX, United States, October 5-9, 2008
- Gill, Magdalena K., D. Jade Simon, Elizabeth C. Rhenberg, Lewis A. Cook, William I. Ausich, and Thomas W. Kammer. *Crinoid Biodiversity in the Lower Mississippian Lake Valley Formation, New Mexico*. Meeting: Geological Society of America, Houston, TX, United States, October 5-9, 2008
- Rhenberg, Elizabeth and Michael Gibson. *Preliminary Field Research of Stromatolites in Laguna Bacalar, Mexico*. Meeting: Tennessee Academy of Science 114th annual meeting, Columbia, TN, United States, November 18-19, 2004.
- Gibson, Michael, and Elizabeth Rhenberg. *An Exercise in Forensic Paleontology: Establishing the Authenticity of the "Kirkland Dinosaur Eggs."* Meeting: Tennessee Academy of Science 114th annual meeting, Columbia, TN, United States, November 18-19, 2004.
- Beasley, Ryan, Adam Hames, Michael Latham, Mark McKee, Elizabeth Rhenberg, Chris Seifert, Yuko Takashita, Mary M. Ulderich, Jane Whitnel, and Michael Gibson. *Comparative Taphonomy of Scyphocrinites loboliths from two west-central Tennessee Localities*, Journal of the Tennessee Academy of Science, 78 (1), p. 28, 2003. Meeting: Tennessee Academy of Science 112th annual meeting, Johnson City, TN, United States, November 15, 2002.

Professional Affiliations and Offices

Sigma Gamma Epsilon	2002-2011
• Upsilon Chapter (2008-2011)	
• Gamma Zeta Chapter	
○ President (2006-2007)	
• Eta Alpha Chapter	
○ President (2003-2005)	
○ Secretary (2002-2003)	
Geological Society of America	2006-2011
Paleontological Society	2008-2011
American Association of Petroleum Geologists	2008-2010