

The First Pennsylvanian Batocrinid and Other New Echinoderms from the Minturn Formation of Central Colorado

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ABSTRACT

Middle Pennsylvanian (latest Atokan) strata in the Minturn Formation of north-central Colorado have yielded new specimens of echinoderms, which have not been previously described from the area. *Eretmocrinus sawdoi*, new species, is the first batocrinid known from the Pennsylvanian. The Batocrinidae (a family of camerate crinoids) were previously thought to have become extinct during the Mississippian. A probable codiacrinid and an unidentified, upflared, infrabasal circling are additions to the Minturn crinoid fauna. These specimens show that the crinoid fauna is more diverse than previously thought. New specimens of *Ulocrinus rockymontanus* Strimple and Moore, 1973, *Aglaocrinus magnus* (Strimple, 1949), and the columnal taxon *Pentaridica pentagonalis* Moore and Jeffords, 1968, provide new morphological information. Additional specimens of echinoid plates and spines have also been recovered from the Minturn Formation. They are assigned to *Archaeocidaris ourayensis* Girty, 1903, *Archaeocidaris triplex* White, 1881, and *Archaeocidaris cratis* White, 1876. These specimens come from three thin marine intervals that are overlain and underlain by coarse fluvial and marginal marine deposits. They were recovered from shale and limestone beds that interfinger with sandstone and shale beds. Thus, the echinoderms were living in areas that experienced frequent influxes of siliciclastic detritus.

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INTRODUCTION

The Pennsylvanian Minturn Formation is well known for its fossil crinoids, and the area around the village of McCoy in north-central Colorado (Fig. 1) has produced an exceptional number of specimens, including several new species. Crinoid collections from the McCoy area are housed at the U. S. National Museum, the Denver Museum of Nature and Science, the University of Colorado, the University of Nebraska, and the University of Iowa. These collections have been the subject of papers by Strimple and Moore (1973), Webster and Houck (1998) and Itano and Bateman (2001).

Additional collection of the Minturn Formation in the McCoy area has yielded new specimens of crinoids and echinoids, including a crinoid belonging to the family

Batocrinidae that was previously thought to have become extinct in the Mississippian Period. The other specimens provide additional information about the morphology and classification of Pennsylvanian crinoids and echinoids, as well as information about the diversity of echinoderms in the McCoy area. The purpose of this paper is to describe the specimens, to report on their stratigraphic and depositional setting, and to discuss their paleontologic significance.

STRATIGRAPHIC AND DEPOSITIONAL SETTING

During the Pennsylvanian Period, Colorado was the site of several elongate, fault-bounded uplifts and basins trending roughly NNW-SSE (Mallory, 1972; DeVoto, 1980). The

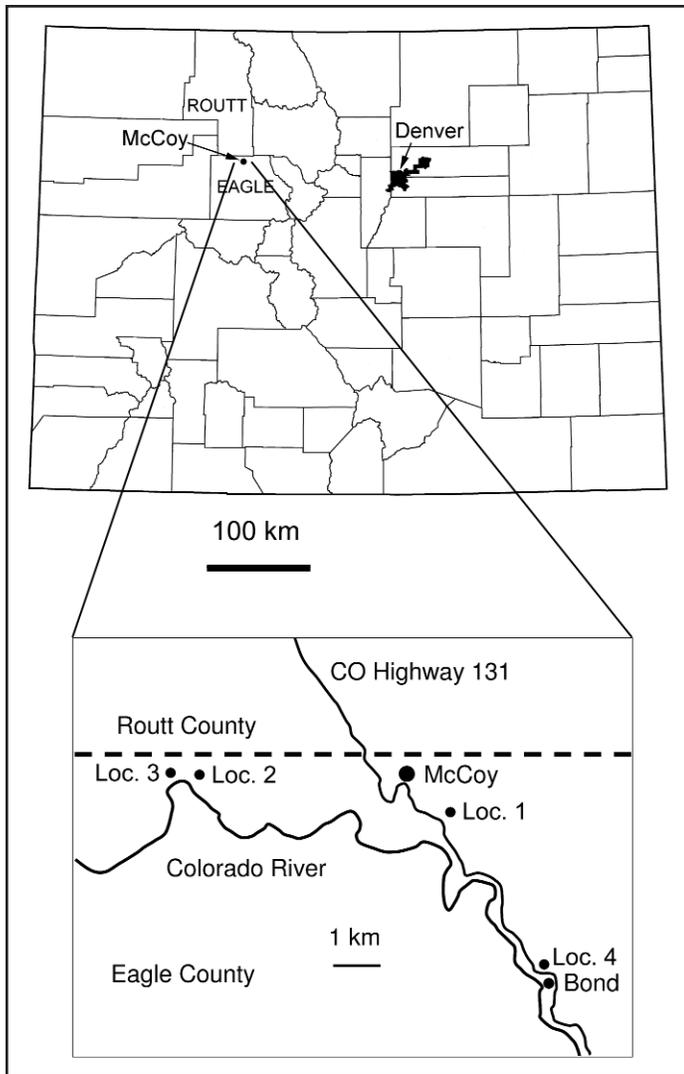


Figure 1. Map of Colorado showing the town of McCoy and Eagle and Routt counties, and enlarged view of the McCoy area, showing fossil localities, labeled Loc. 1, 2, 3, 4.

McCoy area was situated on the eastern margin of the Central Colorado Basin, adjacent to the Ancestral Front Range uplift. The basin subsided rapidly during the Pennsylvanian, accumulating as much as 3050 m of sediment in places (DeVoto, 1980). In the McCoy area the Minturn Formation is about 615 m thick and is composed of a variety of siliclastic and carbonate rocks, including conglomerate, sandstone, siltstone, shale, and limestone.

Sea level changes affected sedimentary deposition as the Minturn Formation accumulated, and the shoreline migrated through the area repeatedly to produce cyclic sequences equivalent to the Midcontinent cyclothems (Stevens, 1958; Houck, 1993, 1997). Sedimentary deposits represented in the Minturn Formation include nonmarine braided fluvial deposits, marginal marine delta and barrier

deposits, and shallow marine limestone and shale (Walker and Harms, 1991; Houck, 1993, 1997). Crinoids and echinoids are most commonly found in the thin intervals of marine limestone and shale in the middle portion of the formation.

Chronic and Stevens (1958) divided the Minturn Formation into 19 units that are traceable around the field area. Some of these units were later subdivided by Houck (1993), e.g., units 3a, 3b, and 3c (Fig. 2). Fusulinids found in units 3-9 yielded Atokan (units 3-4) and Desmoinesian (units 5-9) ages (Stevens, 1958; Houck, 1993, 1997; Webster and Houck, 1998). Specimens described in this paper come from three different stratigraphic horizons (Fig. 2). Fusulinids and other foraminifera recovered from unit 3b were identified by Charles Ross (Ross, 1993, pers. comm.) as *Fusulinella leyi*, *Beedeina* cf. *B. lucasensis*, *Endothyra* sp., *Bradyina* sp., and *Fusulinella* sp. They were assigned to the biozone of *Fusulinella famula*, *F. iowensis*, and *F. leyi* (Ross and Ross, 1987), which is latest Atokan in age. Stevens (1958) recovered fusulinids from unit 3a (his unit 3), which he identified as *F. leyi* and *Fusulina* (*Beedeina*) *rockymontana*. He correlated this unit with the Resolution Limestone Member of the Minturn Formation in the type area. Unit 3a is probably also in the biozone of *F. famula*, *F. iowensis*, and *F. leyi*. The third horizon is an unnamed horizon in unit 2 and has not yet been zoned.

The depositional settings of all four localities are very similar. A cross-section through Locality 2 (Fig. 3) illustrates the main lithologic features of the crinoid-bearing interval in unit 3b. This marine interval is underlain by fluvial channel deposits of light pink, trough cross-bedded, arkosic conglomerate. These are enclosed in overbank deposits of reddish-purple siltstone. The fluvial deposits are overlain by barrier deposits of planar-bedded and planar cross-bedded coarse sandstone and conglomerate. These rocks contain sparse marginal marine fossils, such as bellerophonid gastropods and orbiculoid brachiopods. The lower part of the marine interval consists of purple shale with nodules and lenses of gray limestone. Fossils found in the shale include short segments of crinoid stems, articulated crinoid cups, and spiriferid and productid brachiopods.

As one continues up the section, the amount of shale decreases, and limestone becomes more abundant. Most of the limestone beds are fossiliferous wackestone and packstone (Dunham, 1962), but there are also some lenses of crinoidal grainstone near the top of the limestone beds. Fossils found in the limestone include those found in the shale, as well as echinoid plates and spines, sponges, horn corals, fenestrate bryozoa, and gastropods. The bedded limestone is overlain by purple shale and siltstone. A few nodules and discontinuous beds of limestone are present in the lower part of the shale and siltstone beds. However, these disappear upward in the section and are replaced by fluvial channel deposits. These shale and siltstone beds are

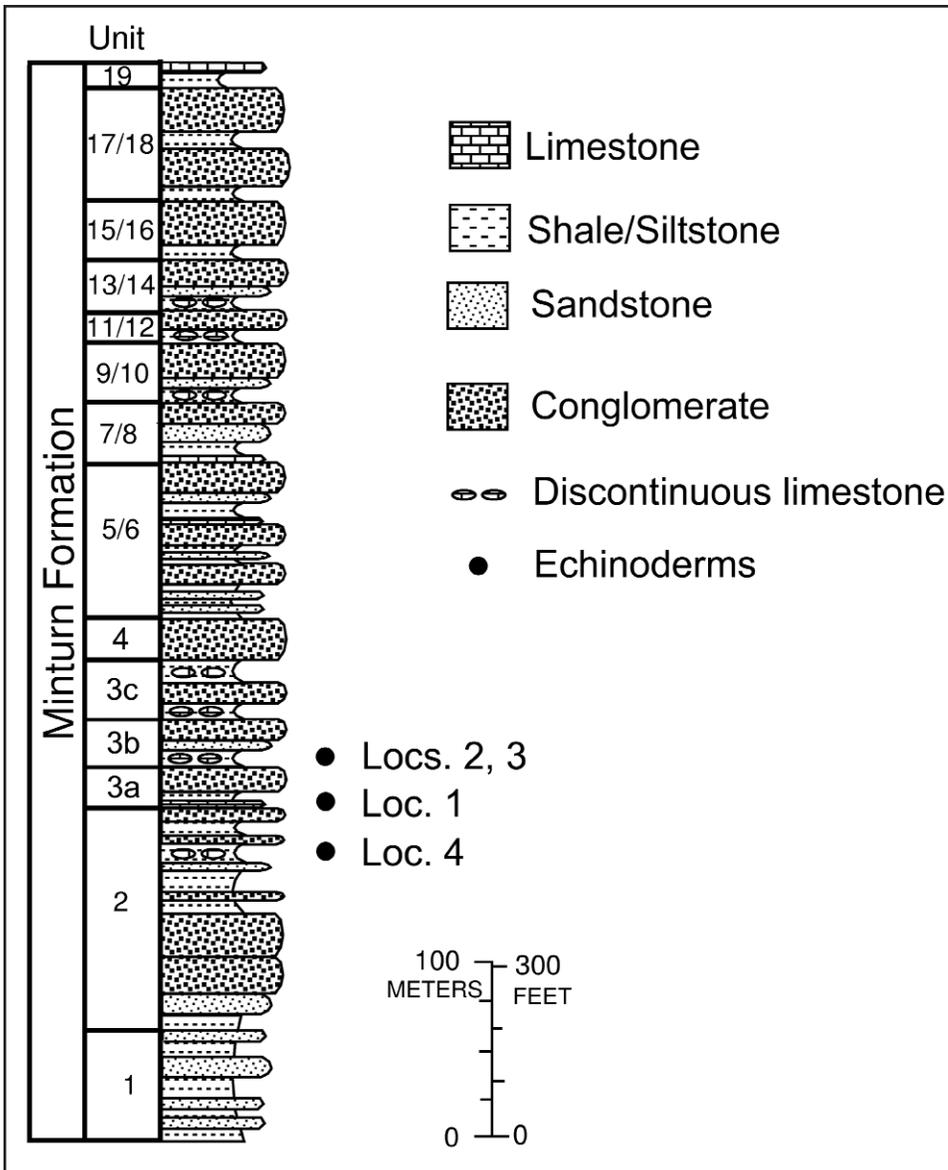


Figure 2. Generalized stratigraphic section of the Minturn Formation at McCoy, Colorado. The numbered units were defined by Chronic and Stevens (1958). Horizons and locality numbers of the fossils described in this study are marked by dots.

thus interpreted as representing progradation of the shore-line into an area that was formerly marine.

The marine interval also shows lateral facies variations. Some areas have much more shale (as opposed to limestone) than others. In these areas, the shale persists higher in the section. The shaly areas have the greatest abundance of crinoid debris and are especially noticeable between sections X and Y at Locality 2 (Fig. 3). From section X, the limestone-rich facies of the marine interval continues westward to Locality 3, where it again becomes shaly and crinoid debris again becomes abundant. Thus, outcrop relations at these localities show that siliciclastic sediment continued to enter the area during marine deposition. Gilbert delta lobes are present in coeval sections located approximately 1.5 km to the northeast (Houck,

1993), and these deltas may have supplied the sediment to the area around Localities 2 and 3.

Fossil echinoderms reported from Localities 2 and 3 by Webster and Houck (1998), Itano and Bateman (2001), and in this paper are listed in Table 1. *Synarmocrinus*, *Ulocrinus*, and *Aglaocrinus* were found in place, in the shaly facies, at section Y (Fig. 3). The other specimens were found lying loose on the surface, so it is not possible to know with certainty which facies or bed they came from within the marine interval.

Because the crinoids and one of the *Archaeocidaris ourayensis* specimens are partially articulated, it is unlikely that they were transported any great distance. Thus, they probably lived in this muddy environment. The crinoids all belong to the cladid family Cromyocrinidae. Several

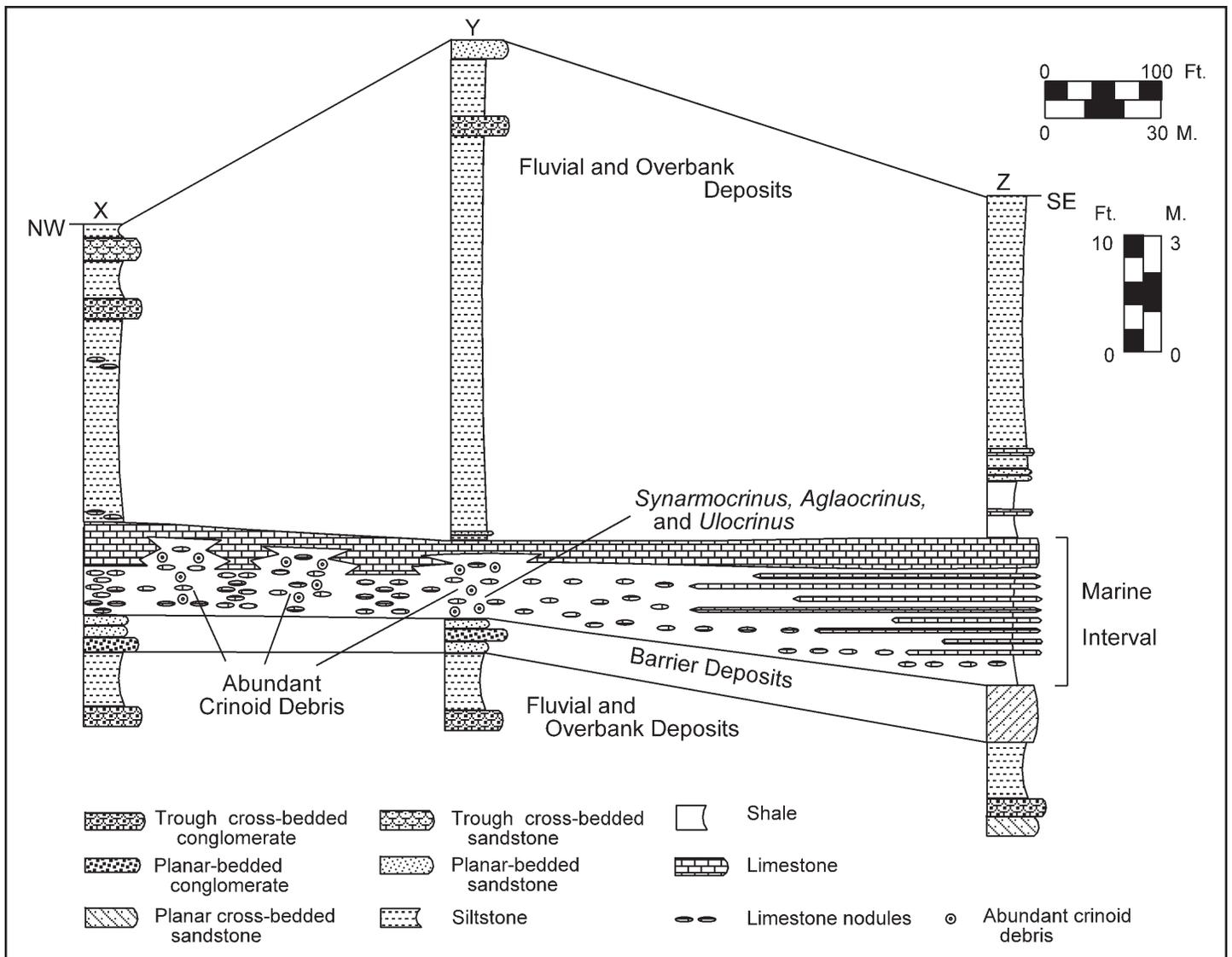


Figure 3. Northwest-southeast cross-section through Locality 2. Sedimentary deposits above and below the marine interval are shown, as are facies changes within the marine interval. Abundant crinoid debris and partially articulated cromyocrinids are most common between sections X and Y.

authors have noted that Pennsylvanian and Permian cromyocrinids tend to occur in nearshore areas with significant siliciclastic influx (Webster and Lane, 1970; Webster, 1981; Pabian et al., 1989; Webster and Houck, 1998). The preferential occurrence of cromyocrinids in and near shaly areas at Localities 2 and 3 further supports this interpretation and implies that these crinoids may have been adapted to these muddy environments.

The echinoderms at Locality 1 came from a different stratigraphic horizon, but the depositional setting is very similar to that of Localities 2 and 3. The marine interval is underlain by distributary channel deposits of tan, trough cross-bedded, conglomeratic sandstone, which are enclosed in dark gray, coaly shale and siltstone. The base

of the marine interval is marked by gray shale with lenses and nodules of gray limestone. As one continues upward in the section, the amount of shale decreases, and limestone becomes more abundant. The lower limestone beds are wackestone and packstone, but grainstones consisting mostly of broken echinoderm fragments are common in the upper limestone beds. The bedded limestone beds are overlain by siltstone and sandstone beds containing marginal marine and terrestrial trace fossils, again representing progradation of a shoreline into a formerly marine area.

At Locality 1, both the lower shaly facies and the upper limestone-rich facies contain abundant echinoderm debris. The shaly facies contains crinoid stems and infrabasal cir-clets, productid brachiopods, and nautiloid cephalopods.

Table 1
Echinoderm Taxa Found at Localities 1,2 and 3

Echinoderm Taxa	Loc. 1	Loc. 2	Loc. 3
Crinoids			
<i>Eretmocrinus sawdoi</i>	X		
Codiocrinid?	X		
Unidentified cladid	X		X
<i>Dicromyocrinus beldenensis</i>		X	
<i>Goleocrinus?</i> sp.		X	
<i>Synarmocrinus cobbani</i>		X	
<i>Ulocrinus rockymontanus</i>		X	
<i>Aglaocrinus magnus</i>		X	
<i>Pentaridica pentagonalis</i>	X		X
Echinoids			
<i>Archaeocidaris triplex</i>	X		X
<i>Archaeocidaris ourayensis</i>		X	X

Crinoid stems up to 2.5 cm in diameter are present, and stems of all sizes are commonly encrusted with bryozoa. In addition to the aforementioned taxa, the limestone-rich facies also contains horn corals, fenestrate and ramose bryozoa, sponges, gastropods, and additional varieties of brachiopods.

Fossil echinoderms reported from Locality 1 are listed in Table 1. *Eretmocrinus sawdoi* and the codiocrinid were found on top of a limestone slab in float. *Eretmocrinus sawdoi* is articulated and nearly complete, including much of the stem, and the codiocrinid is preserved as a partially articulated cup. Exceptional preservation indicates that they underwent little or no transport. The lower portion of the slab consists of grainstone with coarse to very coarse sand-sized pieces of broken echinoderm debris. The upper portion is packstone, which contains the specimens, as well as many articulated crinoid stem pieces and a few pieces of fenestrate bryozoa up to 1 cm in diameter. Though the exact horizon of the slab is not known, its lithology matches best with some of the thinner beds in

the limestone-rich marine facies. The other specimens were also found in float at the outcrop, and their exact position in the bedding is not known.

Locality 1 also shows evidence of siliciclastic influx during deposition of the marine interval. Nearly continuous exposure of the marine interval is present along a ridge for about 100 m. In the middle of the ridge, a lens of coarse, arkosic sandstone interfingers with the limestone beds. In this area, some siliciclastic grains were deposited within the limestone beds. About 40 m to the northwest of Locality 1, the limestone beds interfinger with shale.

Eretmocrinus is a camerate crinoid belonging to the family Batocrinidae. Batocrinids are known from the Mississippian Burlington Limestone of the Illinois Basin, where they occur in abundance in grainstones that were deposited under the influence of waves or currents. They are thought to have utilized currents as they fed by straining water with a dense, fan-shaped network of arms (Breimer and Lane, 1978; Clarkson, 1993). The discovery of a nearly complete *Eretmocrinus* in a slab of grainstone suggests that *Eretmocrinus* still occupied a high-energy environment in the Pennsylvanian. However, the environments of the Burlington Limestone and the Minturn Formation differed considerably in the amount of siliciclastic sediment entering the area during deposition, with the Minturn Formation showing evidence of both sand and mud influx in close proximity to the spot where the *Eretmocrinus* and codiocrinid were living.

Locality 4 is a small outcrop of an unnamed marine interval in unit 2. It consists mostly of gray shale with a few thin beds of limestone and is both overlain and underlain by fluvial and marginal marine sandstone and conglomerate. An echinoid spine, *Archaeocidaris cratis*, was found there. Thus, Locality 4 also shows evidence for siliciclastic influx during deposition of the marine interval.

Taken together, all four localities show direct outcrop evidence of siliciclastic influx during deposition of the marine intervals, as well as before and after development of fully marine conditions. As was noted in Webster and Houck (1998), this depositional setting is very different from the stable platform settings of the Midcontinent, where many previous studies of Pennsylvanian crinoids have been carried out. An outcrop containing coarse sandstone and conglomerate is not a place where one would normally look for fossil echinoderms, so their presence in the intermontane basin deposits of the Ancestral Rockies may be underreported.

The crinoid and echinoid taxa found at these localities had adapted to live successfully in a siliciclastic-rich environment and in proximity to actively prograding deltas. It is interesting to note that five of the nine echinoderm species found at these localities appear to be endemic to the Central Colorado Basin, and the other four species were first reported from adjacent Ancestral Rockies basins

in Colorado, Utah, New Mexico, and Oklahoma. From their root stocks in the tectonically quiet Mississippian Mid-continent, they evidently adapted to the gritty conditions of life in an active orogenic belt.

FAUNAL SIGNIFICANCE

The Minturn fauna was considered to be of low diversity when compared to Pennsylvanian faunas of the Mid-continent (Webster and Houck, 1998). Furthermore, Webster and Houck (1998) pointed out the dominance of the cromyocrinids in the Minturn faunas. Continued collecting of the Minturn has demonstrated that the cromyocrinids are indeed the dominant family in the faunas. The new taxa described herein, however, show that the Minturn faunas are more diverse than previously thought, but still significantly less diverse than many Pennsylvanian faunas of Kansas and Oklahoma. The presence of a batocrinid and a probable codiacrinid are especially important additions to the faunas. Also, the additional echinoids and crinoid columnals described below add to the overall echinoderm diversity in the faunas.

Batocrinids were a diverse, widely spread group of crinoids in the Kinderhookian and Osagean of North America, and except for two Devonian reports, one in Germany (Opitz, 1932), the other in China (Lane, et al., 1997), are unknown in the rest of the world. Only three species have been reported in the Chesterian, and the family was considered to have become extinct during the Chesterian. There are 10 batocrinid genera and 155 species recognized, with their acme in the late Kinderhookian and Osagean (Webster, 2003). Most of these species lived in the extensive carbonate banks of the Illinois Basin with a few species reported from the carbonate banks and ramps of New Mexico, Nevada, Montana, and the Canadian Rockies. Thus the discovery of *Eretmocrinus sawdoi* n. sp. in the intermontane basin setting of central Colorado in the late Atokan extends the range of the genus and family upward into the Pennsylvanian and suggests *Eretmocrinus* adapted to a significantly different environment before becoming extinct.

Eretmocrinus is an example of a "Lazarus taxon," that is, a fossil taxon that disappears from the fossil record for an extended period, and then reappears (Wignall and Benton, 1999). Most species of *Eretmocrinus* are from the early Osagean Burlington Limestone of Iowa and Missouri. The latest occurrence of *Eretmocrinus* reported previously is from the Meramecian Somerset Shale Member of the Salem Limestone in Kentucky (Feldman, 1989). The age gap between this occurrence and the late Atokan is approximately 25 to 30 million years. Traditional explanations for the Lazarus effect are the inadequacy of the fossil record (that is, a lack of well-preserved fossil assemblages from the outage period) or the temporary migration of the taxon

from its original range to small areas, called refugia, where their fossils are unlikely to be discovered. Wignall and Benton (1999) proposed a third explanation, that the temporary disappearance from the fossil record accurately reflects a relative decrease in abundance of the taxon. Though actually present, the Lazarus taxon is so rare during the outage period that it is unlikely to be found as a fossil. If it recovers after a time, then it reappears in the fossil record. In the case of *Eretmocrinus*, the fact that many North American crinoid assemblages are known from the outage period makes it somewhat unlikely that a poor fossil record could be the sole explanation for the Lazarus effect. It is not possible to say whether migration to refugia or low abundance during the outage period is responsible for the Lazarus effect. With only a single Pennsylvanian specimen known, it is not even possible to tell whether the abundance actually increased in the late Atokan or whether this was simply a lucky find.

Evidence that a fossil taxon can be present in an assemblage but be so rare as nearly to escape detection is provided by an example from the Minturn Formation crinoid assemblage. Despite fairly extensive collecting, the camerate crinoid genus *Platycrinites* is currently known only from a single columnal, assigned to *Platyplateium* cf. *texanum* (Webster and Houck, 1998). *Platyplateium* is the name applied to isolated stems of *Platycrinites*. If not for the fact that the columnal is so distinctive, *Platycrinites* would likely have escaped notice entirely. *Platycrinites* is nearly a Lazarus taxon. It is very common in the Mississippian, and it is common in the Permian in certain geographic areas, such as Timor. It is not common from the Pennsylvanian as summarized by Bowsher and Strimple (1986).

Codiacrinids are mostly very small individuals, often less than one centimeter in diameter and sometimes less than two millimeters in diameter in the adult stage. They are easily overlooked in the field and are probably more widespread than recognized. The disarticulated specimen questionably assigned to the codiacrinids herein was not recognized until the specimen of *Eretmocrinus sawdoi* was being cleaned for description. Codiacrinids are reported from the Middle Silurian, but are most common in the Devonian to Permian. They are generally found in shallow shelf carbonate and marl environments, but in the Permian of Western Australia they are found in arenaceous marls and limestones and in volcanoclastics in Timor.

Crinoid columnals are common in the carbonates of the Minturn Formation. Pluricolumnals are less common but present in moderate abundance. Most columnals and pluricolumnals are solution pressure pitted, fragmented, and crushed. Webster and Houck (1998) expanded the information on two taxa, *Blothronagma cinctutum* and *Floricyclus angustimargo*, previously reported by Moore and Jeffords (1968) from the Minturn. Furthermore, Webster and Houck (1998) suggested that these were probably the

stems of two of the described cromyocrinids, based on associated, but not articulated, columnals and cups. Webster and Houck (1998) also described *Cyclocaudex* sp. and *Platyplateium* cf. *texanum*. The latter was the first report of a camerate crinoid from the Minturn. Additional morphologic information modifies the description of *Pentariidica* and *P. pentagonalis* originally described by Moore and Jeffords (1968) from the Minturn Formation. The increasing knowledge of the Minturn columnals increases the value for correlation within the intermontane basins and with Midcontinent faunas.

The echinoid spines reported by Webster and Houck (1998) and herein along with earlier reports by Girty (1903), among others, show some diversity. This suggests they may be of value for correlation within the intermontane basins and the Cordillera of the western U. S. However, it will require additional study for verification.

SYSTEMATIC PALEONTOLOGY

Specimens are repositied in the Denver Museum of Nature and Science and bear repository numbers preceded by DMNH. Detailed locality information is available at the repository. Localities are shown in Figure 1. Locality 1 lies within unit 3a (Resolution Member) of Houck (1997) (see Figure 2). Localities 2 and 3 lie within unit 3b. Locality 4 is in unit 2. Units 2, 3a, and 3b are late Atokan in age. Locality 1 is in Sec. 5, T2S, R83W; Locality 2 is in Sec. 2, T2S, R84W; Locality 3 is in Sec. 3, T2S, R84W; Locality 4 is in Sec. 16, T2S R83W.

Class CRINOIDEA Miller, 1821

Subclass CAMERATA Wachsmuth and Springer, 1885

Family BATOCRINIDAE Wachsmuth and Springer, 1881

Genus ERETMOCRINUS Lyon and Casseday, 1859

ERETMOCRINUS SAWDOI new species

Figures 4, 5.1-5.2

Etymology. — Named for Jordan Sawdo, who found the specimen.

Diagnosis. — An *Eretmocrinus* distinguished by the combination of granular ornament on all cup and tegmen plates, except small plates bordering ambulacral openings, and coarse nodes on first interprimibrachials and on the three secundibrachials where they form linear ray ridges.

Description. — Specimen crushed on bedding plane with calyx crushed inward and stem broken 1.7 cm below cup with 11.4 cm of proximal stem in direct association. Theca large, 50.9 mm long (crushed), 47 mm wide (crushed), turbinate with extended anal tube; all thecal plates, except small plates bordering ambulacral openings, bear medium granular ornament, becoming finer on tegmen plates than on subtegmenal plates. Coarse rounded

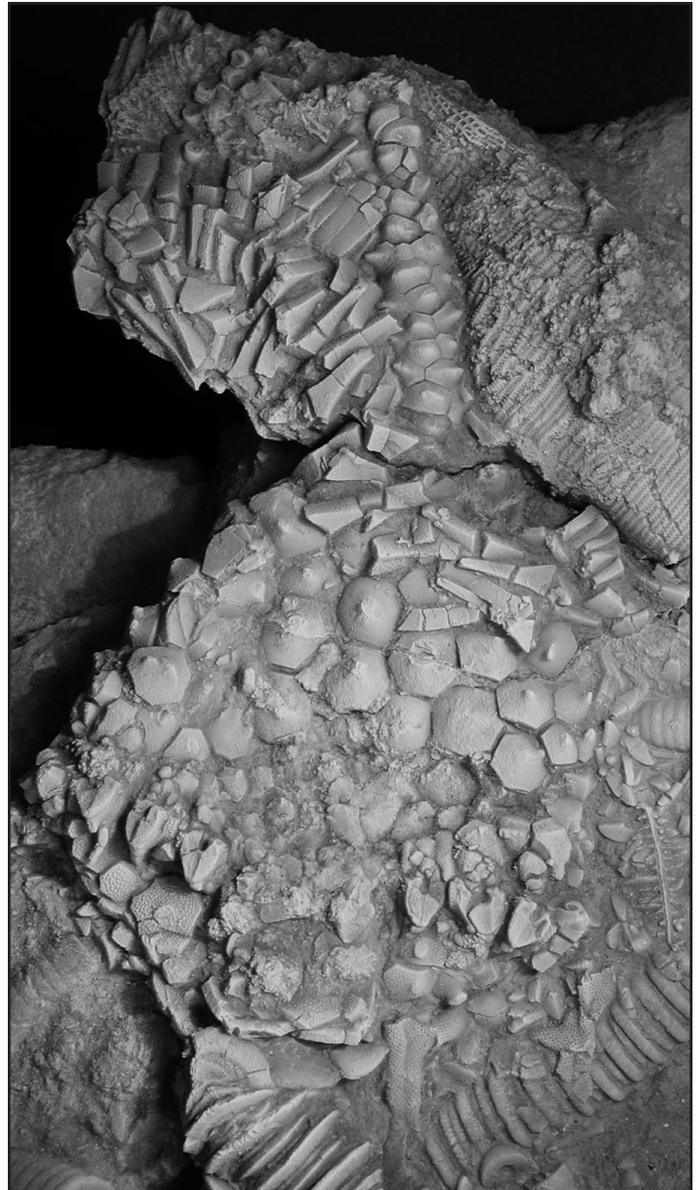


Figure 4. Calyx of *Eretmocrinus sawdoi* new species, holotype, DMNH 22457, x 1.65.

nodes on interprimibrachials and secundibrachials, with nodes aligned and forming linear ridges on secundibrachials. Tegmenals above small plates bordering ambulacral opening bear central short blunt to sharp nodes. Anal tube plates bear coarse transverse ridges. Arms free and biserial above third secundibrachial.

Basals large, 3, form basal flange (14.2 mm diameter visible) projecting beyond proximal round columnals (11.4 mm diameter). Primibrachials 2 minimal, possibly 3; proximal primibrachial rectangular, wider than long; distal primibrachial hexagonal, length 3.5 mm, width 2.9 mm, axillary. Fixed secundibrachials 3, wider than long, bear

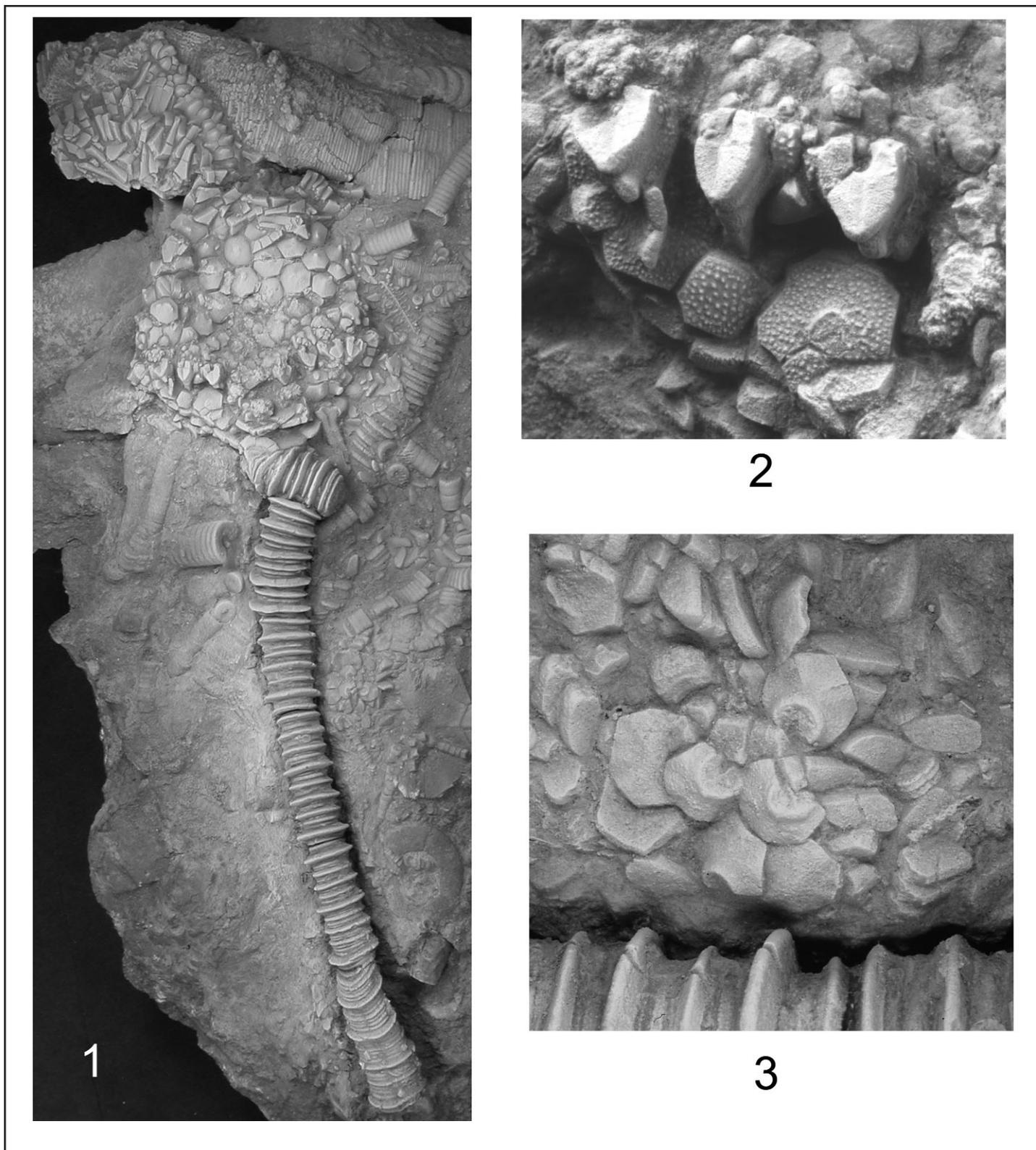


Figure 5. *Eretmocrinus sawdoi*, DMNH 22457, 1) calyx and stem, x 1; 2) detail of cup plates and brachials, x 5.4. 3) Dislocated cup plates of indeterminate codiacrinid?, DMNH 22458, among arm plates and above medial stem of holotype of *E. sawdoi*, x 4.9.

linear nodes merging into linear ridges along arm midline. Interprimibrachial large, 6 mm long, 5.5 mm wide, adjoined distally by 2 small plates. Secundibrachials in contact laterally arching over interprimibrachial series. Tegmen (35.3 mm long) more than twice cup length (15.4 mm), gently inflated. Numerous (5 to 7) small bulbous plates surrounding ambulacral openings above fixed secundibrachials; adjoin large polygonal plates distally. Tegmen formed of large polygonal plates with central blunt to moderately sharp central node or spine. Anal tube slender (5.8 mm wide proximally) tapering gently distally, minimally 38 mm long, formed of polygonal plates bearing coarse transverse ridges.

Arms rounded transversely proximally, expanding into flattened blades or spatula shapes distally. Proximal brachials short (0.6 mm length), much deeper (4.2 mm) than wide (1.6 mm), with wide V-shaped ambulacral groove bounded by inner edges. First biserial brachial covers 2/3 width of facet, all others slightly over 1/2 facet width; straight longitudinally, strongly convex near midline of arms and nearly straight along lateral sides inwardly. Distal brachials triangular transversely, short (1 mm), much wider (9.5 mm) than deep (2.9 mm) with wedge shaped lateral ends.

Column round transversely, heteromorphic proximally and medially; noditaxis N212 proximally becoming N434243414342434 medially. May be homeomorphic distally. Latus sharply angular on nodals and primary internodals, gently rounded on secondary internodals. Crenularium narrow with short undivided culmina. Areola wide, lumen moderately large.

Discussion. — The single crown of *Eretmocrinus sawdoi* n. sp. appears to have collapsed and been crushed by compaction in situ or within very minimal movement of the living site. The anal tube is positioned across what is probably part of the crushed homeomorphic distal stem. Distal spatulate or blade-shaped parts of one or two arms are dislocated along the left side of the anal tube and proximal parts of two or more arms are dislocated to the right and below the calyx. Cup plates are crushed, slightly to moderately dislocated, and in part covered by secondary microcrystalline quartz precipitates. The proximal-most columnals are slightly dislocated and the next 1.5 cm of the stem is crosswise to an 11.5 cm section extending away from the theca. The specimen also lies in part above another 11.5 cm section of the medial stem extending to the upper right side of the theca. The crushed, probable distal pluricolumnal has homeomorphic short columnals. The proximal pluricolumnal adjacent to the cup has the lumen crushed; it appears to have been circular in cross-section.

The specimen is assigned to *Eretmocrinus* on the basis of: 1, thecal plate arrangement, 2, theca shape, 3, elongate anal tube, 4, spatulate or blade shaped distal arms above

narrow rounded proximal arms, and 5, type of ornamentation. Although the radials and anals are unknown, the ornamentation is distinctive and can easily be used to recognize other specimens of the species should they be found.

Three other species of *Eretmocrinus*, *E. attenuatus* (Hall, 1861), *E. magnificus* Lyon and Casseday 1859, and *E. ramulosus* (Hall, 1858) also have nodose ridged ornament on the secundibrachials but all lack the associated granular ornament on the same plates as well as other thecal plates. Although some other species of *Eretmocrinus* have granular ornament, they all lack the nodose ridge ornament on the secundibrachials.

Material and locality. — Holotype, DMNH 22457, Locality 1.

Subclass CLADIDA Moore and Laudon, 1943

Order CYATHOCRINIDA Bather, 1899

Superfamily CODIACRINACEA Bather, 1890

Family CODIACRINIDAE Bather, 1890

Codiocrinid? indeterminate

Figure 5.3

Description. — Cup small, globose?, less than 1 cm in length or width (estimated); cup plates thinner at apices, slightly fluted with broad gentle stellate ornament extending across all plate boundaries. Basals hexagonal, wider (4.1 mm) than long (3.5 mm estimated), moderately convex transversely and longitudinally. Radials hexagonal, wider (3.9 mm) than long (3.5 mm), widest at lower radial-radial apices, narrowing gently distally, moderately convex longitudinally and transversely. Radial facet circular, angustate, width 1.8 mm, ratio $1.8/3.9 = 0.46$, on elevated platform, declivate, with small V-shaped ambulacral groove. Stem, anals, and arms unknown.

Discussion. — The specimen consists of dislocated plates of four radials, four basals, and possibly two of the three infrabasals on and among proximal arm plates of *Eretmocrinus sawdoi* along the medial stem of *E. sawdoi*. The distally tapering radials indicate a radial circlet that was distally smaller than the maximum diameter of the cup and suggest a globose shape. It is probably a codiacrinid with a general plate structure similar to *Paracydonocrinus*. Because the plates are dislocated and the anals are unknown the specimen is questionably assigned to the codiacrinids.

Material and locality. — One partial cup, DMNH 22458, Locality 1, collected by J. Sawdo.

Superfamily CROMYOCRINACEA Bather, 1890

Family CROMYOCRINIDAE Bather, 1890

Genus ULOCRINUS Miller and Gurley, 1890

ULOCRINUS ROCKYMONTANUS Strimple and Moore, 1973

Figures 6.1-6.4

Discussion. — A large (32.5 mm long, 49.3 mm wide) cup of *Ulocrinus rockymontanus* Strimple and Moore, 1973, is illustrated to show the effects of solution weathering and pressure dissolution on some specimens in the Minturn. At first glance the surface appears to have very coarse granular ornamentation. When viewed under the microscope the apparent ornamentation is recognized as pressure solution sculpture. Even the radial facets have lost most of their original surficial features. The solution work has followed the “stitching” along the plate sutures making the basals appear to have nodes along the outer edges. The stem facet was broken free of the proximal stem segment when the specimen popped out of matrix when collecting. The stem facet is not etched or abraded and the pentalobate axial canal in the center of the infrabasal circlet is filled with clear calcite cement. This makes an excellent unetched surface for comparison with etched and abraded surfaces. It would be easy to refer this specimen to a new species without recognition of the above features.

This specimen also shows variation in the anals of *U. rockymontanus*. Most specimens have two anals with the secundanal in the line of radials, positioned directly above the primanal with the distal tip slightly above the radial summit. In this specimen the anals are advanced in position where the secundanal is being pushed out of the cup, with only the proximal 1/3 below the radial summit and narrowly in contact with the primanal.

Material and locality. — One cup, DMNH 22459, Locality 2, collected by W. Bateman.

Genus *AGLAOCRINUS* Strimple, 1961
AGLAOCRINUS MAGNUS (Strimple, 1949)
Figures 7.1-7.3

Synonymy

Paracromyocrinus magnus Strimple and Moore, 1973, p. 14, figs. 9.10-9.11.

Aglacrinus magnus Webster and Houck, 1998, p. 1062, figs. 4.27-4.28.

Discussion. — The three cromyocrinid species, *Aglacrinus magnus*, *Synarmocrinus molasensis* (Strimple and Miller, 1971), and *Synarmocrinus cobbani* Itano and Bateman, 2001, have some similarities as recognized in the original descriptions of each. As additional specimens have become available and comparisons continue to be made of the three species the following differences are useful to recognize each. Size ranges of the cups of *A. magnus* and *S. cobbani* overlap and are not of specific value. Whole or partial cups of *A. magnus* are longer, relative to their diameter, than *S. cobbani*. The secundanal of *A. magnus* is squarish and makes a broader contact with the posterior basal (Fig. 7.3; Strimple and Moore, 1973, their fig. 9.11), while the secundanal on *S. cobbani* is narrow and tapers

proximally to a narrow contact with the subjacent posterior basal as it is being pushed out of the cup by the primanal (Itano and Bateman, 2001, their fig. 3.3). Articulated cups of *Synarmocrinus molasensis* have not yet been found in the Minturn Formation, but isolated plates have been found that resemble those of the holotype from the Pinkerton Trail Limestone of southwestern Colorado. These isolated plates are tentatively assigned to *Synarmocrinus molasensis* (Webster and Houck, 1998; Itano and Bateman, 2001). The difference between *S. molasensis* and *S. cobbani* is the coarseness of the ornament with *S. cobbani* having finer ornament than *S. molasensis* as is recognized in the illustrations of Itano and Bateman (2001, their figs. 3.1-3.5 vs 3.6) and Webster and Houck (1998, their figs. 4.14 vs 4.15-4.17). Cromyocrinid arm fragments probably belonging to one or more of the three species are present in the Minturn Formation. Hopefully cups with attached arms of all of these species will be found in the future.

Material and locality. — One cup, DMNH 13664, Locality 2, collected by W. Itano.

Indeterminate infrabasal circlets
Figures 6.5-6.6; 6.7-6.9

Discussion. — Three specimens of upflared infrabasal circlets and attached columnals represent an unidentified taxon from the Minturn. The infrabasals are large, (largest, 11 mm long, 14 mm wide) and the round heteromorphic columnals have a rounded latus with irregular nodes, a narrow crenularium with undivided straight culmina, a wide areola, and a pentalobate lumen. These specimens probably belong to one of the few late Paleozoic cladid genera with strongly upflared infrabasals such as *Haeretocrinus* Moore and Plummer, 1940, *Elibatocrinus* Moore, 1940, or *Moscovicrinus* Jaekel, 1918. They are illustrated for completeness of the Minturn fauna.

Material and localities. — DMNH 22460, DMNH 22461, Locality 3, collected by W. Itano; DMNH 22462, Locality 1, collected by J. Sawdo.

♂PENTARIDICA Moore and Jeffords, 1968

Type species. — *Pentaridica rothi* Moore and Jeffords, 1968.

Modified description. — Stem heteromorphic or homeomorphic, composed of straight-sided to gently convex pentagonal columnals with or without ornamentation. Articular facets characterized by strongly pentagonal outline, large areola, and even, straight crenulae normal to sides of facet, which may have a central, inwardly opening, small V- or Y-shaped culmina; moderately large circular axial canal, typically with thin claustra at midheight of columnals adjoined by stellate jugula.

Discussion. — See under *P. pentagonalis*.

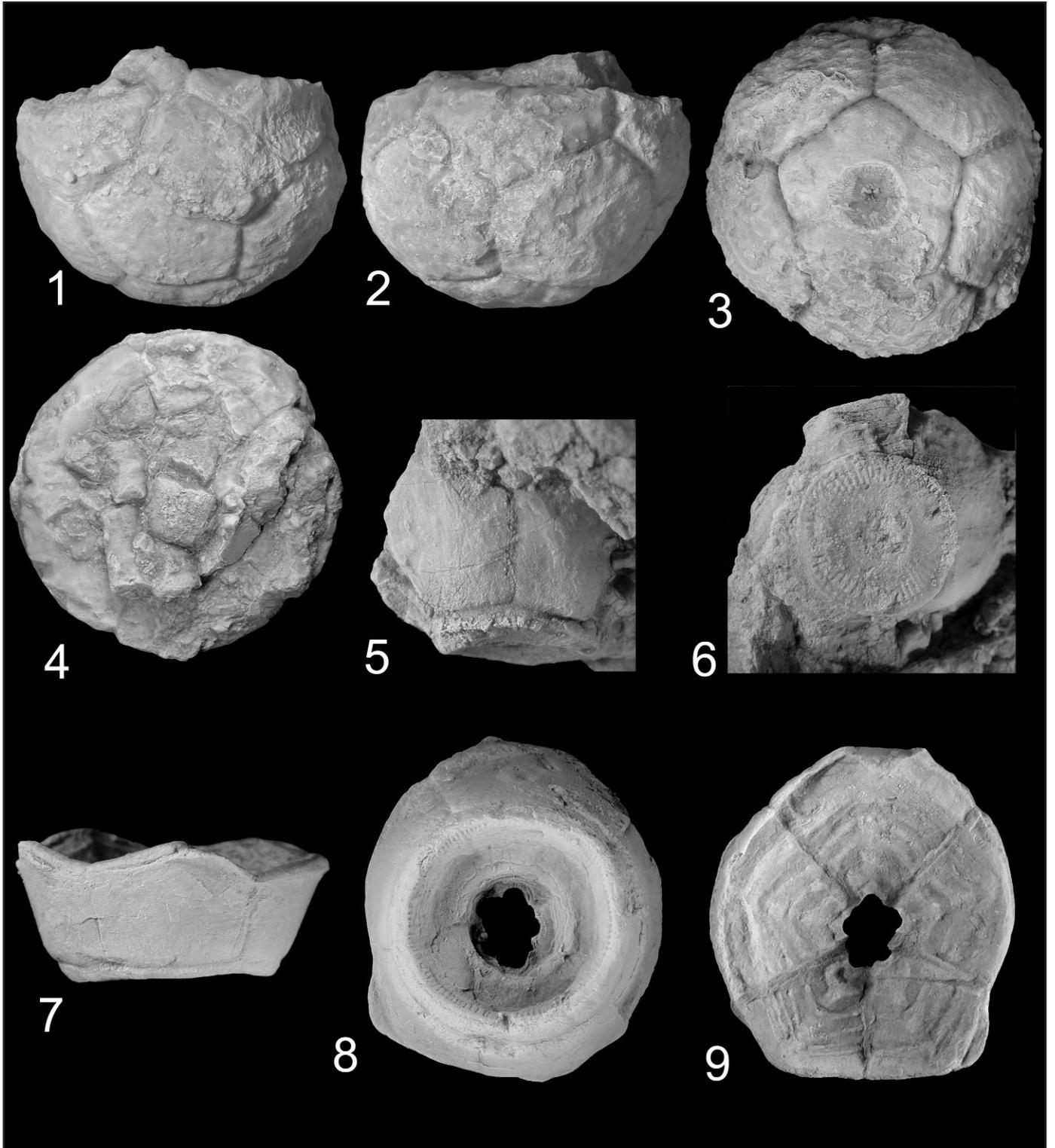


Figure 6. *Ulocrinus rockymontanus* Strimple, 1973, 1) posterior, 2) A ray, 3) basal, and 4) oral views, DMNH 22459, x 1.2. Indeterminate infrabasal circling, 5) lateral and 6) basal views, DMNH 22460, x 3.3; 7) lateral, 8) basal, and 9) oral views, DMNH 22462, x 2.5.

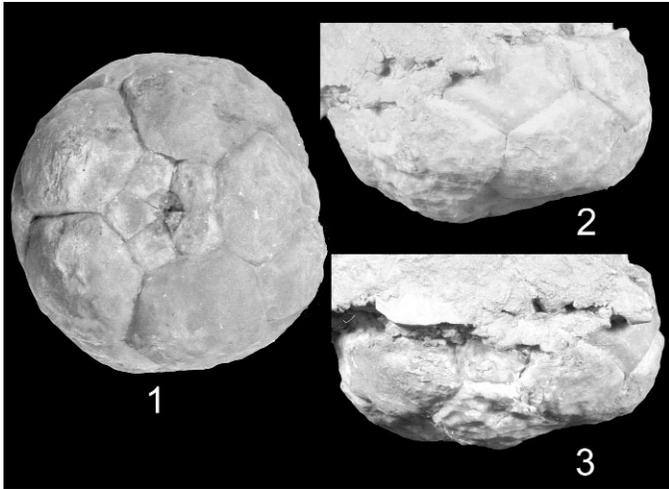


Figure 7. *Aglaocrinus magnus* (Strimple, 1949), 1) basal, 2) C ray, and 3) posterior views, DMNH 13664, x 0.9.

ØPENTARIDICA PENTAGONALIS Moore and Jeffords, 1968
 Figures 8.1-8.4

Modified description. — Pentagonal, homeomorphic and heteromorphic, noditaxis N212; latus gently convex, ornamented with short, fine, anastomosing, vermiform ridges. Facet pentagonal, each areola ray with crescentic shaped crenularium on outer 1/3 of facet; culmina straight with restricted, inwardly opening, central small V- or Y-shaped culmina on some facets. Areola wide, sloping inward with thin claustra and stellate-shaped false jugula. Lumen medium diameter, roundly pentagonal with small notches aligned with the angles of the exterior.

Discussion. — Most of the pluricolumnals have the claustra collapsed inward, distorting the lumen. Some specimens are slightly distorted and have solution or abrasion removal of the latus ornament. Variation exists in the presence or absence of the small central V- or Y-shaped culmina of some areola rays; most are lacking. Also, solution weathering has destroyed the inner edges of some of the crenularia of some rays. The false jugula are different density calcite filled parts of the original columnal and extend towards the edge of the columnal. They appear to approach pentameres from which they probably were derived. Specimen DMNH 22469 consists of three associated pluricolumnals that have a wider crenularium and are nearly round in cross-section. These specimens may represent a more distal part of the stem.

Moore and Jeffords (1968) recognized *Pentaridica* (a Middle to Late Pennsylvanian taxon) as having straight culmina. One of the species assigned to *Pentaridica*, *P. pentagonalis* Moore and Jeffords, 1968, is from the Minturn Formation. Apparently it was based on a single columnal or a homeomorphic pluricolumnal that has lost the vermiform

ornamentation and has straight culmina. Our specimens show the variation with some having the small V- or Y-shaped central culmina. We do not consider this sufficiently significant to assign the genus to *Pentagonostipes* Moore and Jeffords, 1968, a Middle Devonian taxon, with medial culmina of each areola ray having a distinct, internally opening, central V- or Y-shaped pattern.

Material and localities. — Three pluricolumnals in matrix, DMNH 22469, Locality 3, collected by W. Itano. Pluricolumnals, DMNH 22464, DMNH 22465, DMNH 22466, DMNH 22467, DMNH 22468, Locality 1, collected by W. Itano. Pluricolumnal, DMNH 22463, Locality 3, collected by W. Itano.

Class ECHINOIDEA Leske, 1778

Order CIDAROIDA Claus, 1880

Family ARCHAEOCIDARIDAE M'Coy, 1844

Discussion. — Carboniferous genera of the Archaeocidaridae are *Archaeocidaris* M'Coy, 1844, *Lepidocidaris* Meek and Worthen, 1873, *Polytaxicidaris* Kier, 1958, and *Aarchaeocidaris* Webster, 1997. The only genus of the Archaeocidaridae recognized in the Permian is *Archaeocidaris*. Type specimens of each of these genera are coronas. *Aarchaeocidaris* is distinguished by the lack of large tubercles and their supporting boss on the interambulacral plates. The other genera are distinguished on the number of rows of interambulacral plates (*Archaeocidaris* 4, *Polytaxicidaris* 6, and *Lepidocidaris* 6 to 8), differences in the ambulacral triads (those in *Lepidocidaris* are more regular than in the others), and differences in the scrobicular ring (*Lepidocidaris* has a raised tumid area within the ring which the other two genera lack).

Coronas of archaeocidarids are rarely found, but spines and interambulacral plates are relatively common in late Paleozoic shelf carbonates worldwide. Kier (1958) noted that isolated interambulacral plates and spines of *Archaeocidaris* and *Polytaxicidaris* are not diagnostic of either genus and he suggested species should not be based on such specimens. Isolated spines of *Lepidocidaris* are not diagnostic and cannot be distinguished from those of *Archaeocidaris* or *Polytaxicidaris*.

There are nearly 40 recognized species of *Archaeocidaris* in the literature (Lambert and Thiéry, 1909-1925; Kier and Lawson, 1978; Webster, unpublished). Less than 10 of these are based on coronas or partial coronas; all others are based on isolated spines, interambulacral plates, or both. No species of *Polytaxicidaris* or of *Lepidocidaris* has been recognized on isolated spines or interambulacral plates. We believe that isolated spines and interambulacral plates offer possibilities for stratigraphic correlation and paleoecological interpretations. This is because certain isolated spines and interambulacral plates are quite distinctive and easily recognized even though the coronas (and hence the correct

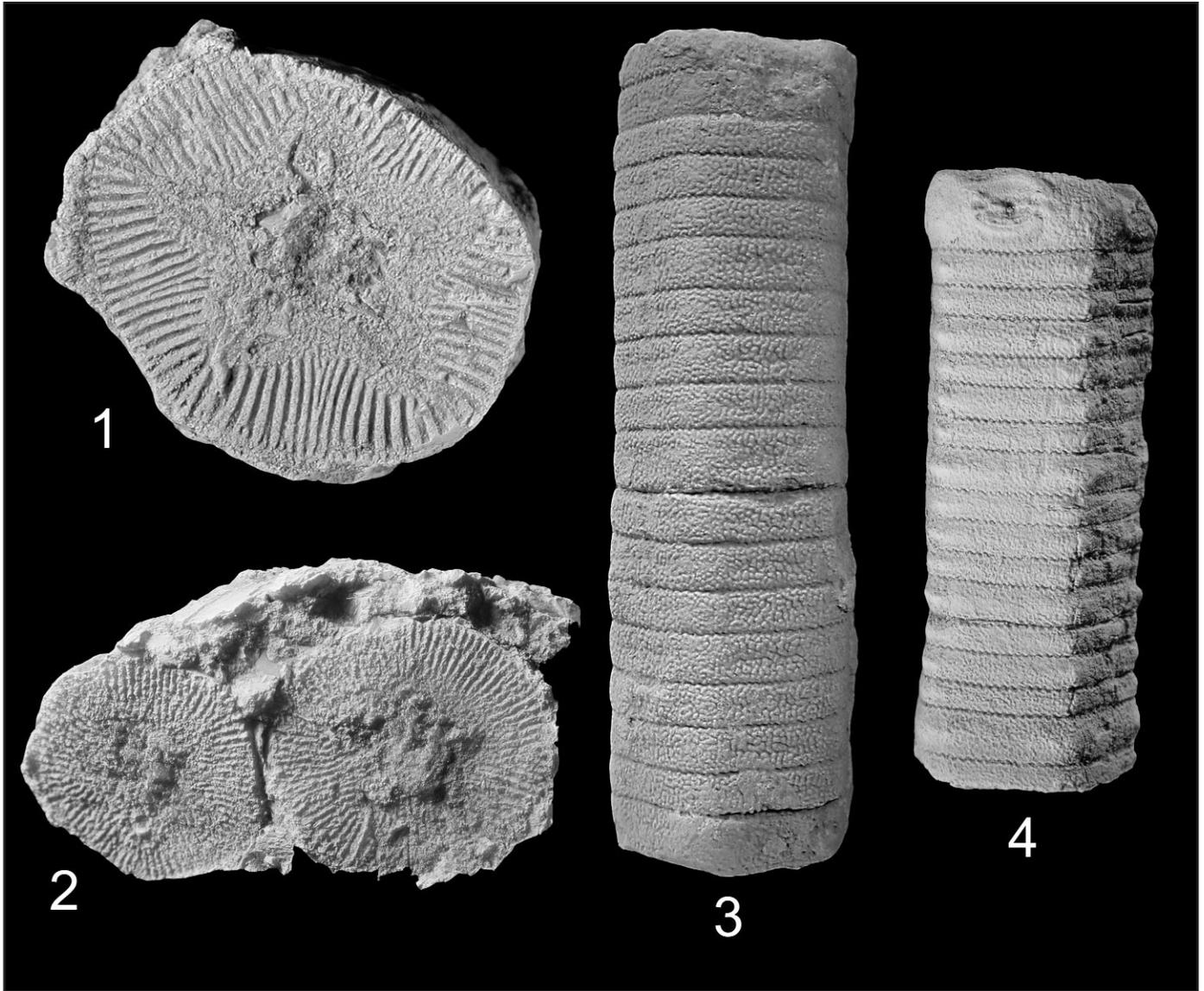


Figure 8. Pluricolumnals, *Pentaridica pentagonalis* Moore and Jeffords, 1968, 1) facet view, DMNH 22463, x 8.5; 2) facet view, DMNH 22469, x 4.5; 3) lateral view of homeomorphic pluricolumnal, DMNH 22464, x 5; 4) lateral view of heteromorphic pluricolumnal, DMNH 22465, x 5.

generic assignment) are unknown. The recognition of all of these as *Archaeocidaris* indeterminate or Archaeocidaridae indeterminate could lead to mass confusion and an unworkable mess. Therefore we support the practice of named species based on isolated spines and interambulacral plates, but only when coronas are not found. Because *Archaeocidaris* has become the repository name we suggest that it continue to be used rather than to start a nomenclature system based on isolated parts with a set of new names that could lead to greater confusion. Concerted efforts should be made to find and relate the corona to isolated spines and corona plates whenever possible.

Genus ARCHAEOCIDARIS M'Coy, 1844
 ARCHAEOCIDARIS OURAYENSIS Girty, 1903
 Figures 9.1-9.2, 9.6-9.8

Synonymy

Archaeocidaris ourayensis Girty, 1903, p. 329, pl. 1, fig. 14.
Archaeocidaris spp. Webster and Houck, 1998, part, p. 1070, fig. 5.27.

Description. — Interambulacral plate hexagonal, 12.1 mm transversely, 9.1 mm longitudinally. Tubercle moderately large, round, perforated, projects slightly above wide

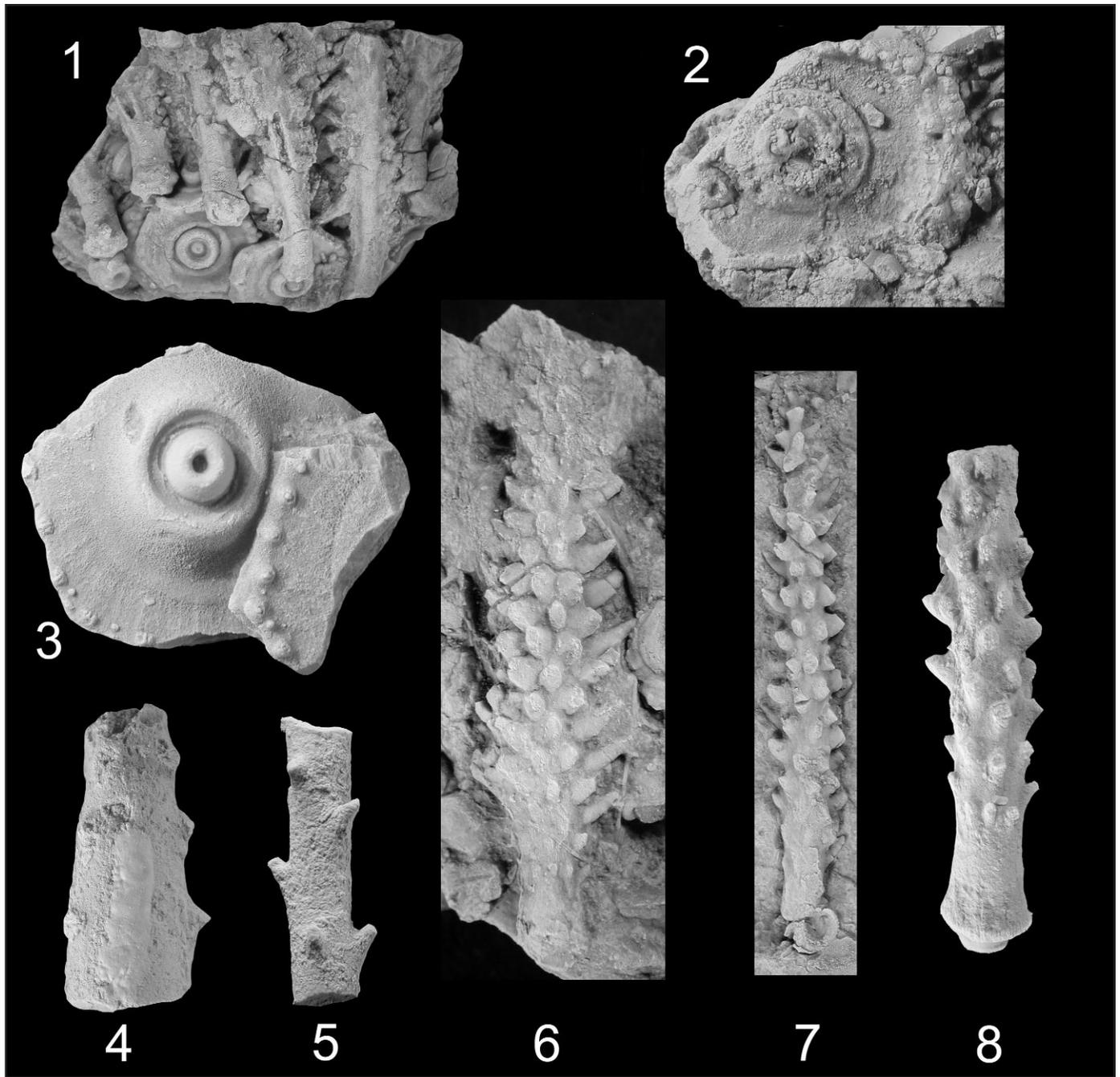


Figure 9. *Archaeocidaris ourayensis* Girty, 1903, 1) associated interambulacral plates and spines, DMNH 22470, x 1.5; 2) interambulacral plate, DMNH 22471, x 5; 6) spine, DMNH 22473, x 2.65; 7) spine, DMNH 22474, x 2.35; 8) spine, DMNH 22472, x 3.5. *Archaeocidaris triplex* White, 1881, 3) interambulacral plate, DMNH 22475, x 4.9; 4) spine, DMNH 22476, x 3.3. 5) *Archaeocidaris cratis* White, 1876, spine, DMNH 22477, x 5.3.

roundly convex parapet. Platform narrow trough. Secondary parapet wide roundly convex separated from platform by moderately deep narrow trough. Areole shallowly concave. Single ring of coalesced scrobicular tubercles form elevated terrace on all edges of plate, higher than secondary parapet,

nearly as high as parapet. Double row of scrobicular tubercles on elevated terrace on admedial side.

Spines fusiform, base short, perforated. Milled ring short, tapering distally to neck. Neck smooth, widens rapidly distally. Shaft round, hollow proximally, bears many short

distally projecting spinules in spiral arrangement; spinules sharply pointed to rounded to slightly linear ridges.

Discussion. — Two fragments of crushed coronas with associated spines nearly in place, DMNH 22470 and DMNH 22471, are recrystallized, which has destroyed smaller details of the scrobicular tubercles and spine bases. One recrystallized incomplete spine DMNH 22473 (40 mm length, 10 mm width) shows the distally-directed sharply-pointed spinules. An incomplete loose weathered spine DMNH 22472 (24 mm length, 5 mm width) (Fig. 9.8) has a perforated base and variation in degree of pointedness of the spinules. A third spine DMNH 22474 (41.5 mm length, 6.7 mm width) is recrystallized, has a broken milled ring showing the perforated base, and the spinules show variation from semiblunt to sharp.

Archaeocidaris ourayensis was described from the Hermosa Formation of southwestern Colorado by Girty (1903) on the basis of a single partial spine. The multiple, distally-directed, sharply-pointed spinules arranged in a spiral manner are quite distinctive from other Minturn species. The multiple spinules of *A. edgarensis* Worthen and Miller, 1883, described from Pennsylvanian strata of the Illinois Basin, are much shorter and the interambulacral plates lack the secondary parapet of *A. ourayensis*. Webster and Houck (1998) referred to the interambulacral plate of this form as morphotype 2 and lacked the spine.

Material and localities. — Fragment of crushed corona and associated spines, DMNH 22470; spine, DMNH 22472; Locality 2, collected by W. Bateman. Part of crushed corona and associated spines, DMNH 22471, Locality 2, collected by W. Itano. Spines, DMNH 22473 and DMNH 22474, Locality 3, collected by W. Itano.

ARCHAEOCIDARIS TRIPLEX White, 1881
Figures 9.3-9.4

Synonymy

Archaeocidaris triplex White, 1881, p. 22, pl. 4, figs. 3a-3c.
Archaeocidaris spp. Webster and Houck, 1998, part, p. 1070, figs. 5.25, 5.28.
Archaeocidaris sp. Olson, 1999, figs. 3.1-3.10.

Description. — Interambulacral plate hexagonal?, minimum 5.2 mm longitudinally, 12.5 mm transversely. Tubercle large, perforated, rounded with flat distal surface, base surrounded by wide flat platform bordered by rounded smooth parapet. Boss straight to slightly convex expanding upward to parapet. Areole gently inclined upward. All of the boss and tubercle above areole. Single ring of small widely spaced scrobicular tubercles along edges of plate. Internal side gently concave. Spines slender elongate; base expanding moderately to base of collar; shaft roundly triangular cross-section above round neck; spinules short, projecting at approximately 45 degrees from shaft, in three linear rows along the angles of the triangular shaft.

Discussion. — *Archaeocidaris triplex* was based on a fragmentary spine with a triangular cross-section (White, 1881). *Archaeocidaris triplex* (from the Upper Coal Measures of New Mexico) is similar to and may be synonymous with *A. cratis* White, 1876, from the Mid-Carboniferous at the confluence of Grand (now Colorado) and Green Rivers in Utah. The difference appears to be in a roundly triangular (*A. triplex*) versus round shaft (*A. cratis*) in cross-section. Both species have few short, widely-spaced, distally-directed, spinules. *A. triplex* has spinules arranged in three rows along the angles of the cross-section, while *A. cratis* has spinules arranged less regularly. Webster and Houck (1998) described round spines and an associated interambulacral plate (cross-section), but left them in open nomenclature. On reexamination, the cross-sections of the spine shafts which are free of matrix (e.g., DMNH 10350; Webster and Houck, 1998, their fig. 5.25) were found to be roundly triangular, except for the sections very near the base, which are round (e.g., DMNH 10351; Webster and Houck, 1998, their fig. 5.26). They are therefore assigned to *A. triplex*. Some spines embedded in matrix and associated with interambulacral plates have spinules arranged in longitudinal rows, consistent with *A. triplex* but not with *A. cratis* (DMNH 10349; Webster and Houck, 1998, their fig. 5.28). The cross-sectional spine shape is difficult to discern on the embedded spines. Interambulacral plates associated with the embedded spines were designated as morphotype 1 by Webster and Houck (1998). DMNH 22475 is a partial interambulacral plate belonging to this morphotype and is therefore assigned to *A. triplex*. DMNH 22476 is the distal tip of a spine with a roundly triangular cross-section and three longitudinal rows of short, distally-directed spinules along the angles of the triangular cross-section. It is assigned to *A. triplex*.

Material and localities. — Interambulacral plate, DMNH 22475, Locality 1, collected by W. Itano. Distal tip of spine, DMNH 22476, Locality 3, collected by W. Itano.

ARCHAEOCIDARIS CRATIS White, 1876
Figure 9.5

Synonymy

Archaeocidaris cratis White, 1876, p. 109.
Archaeocidaris cratis White, 1880, p. 130, pl. 33, fig. 2a.

Description. — Spine 2 mm diameter, smooth except for sparse, distally pointed, sharp spinules. Spinules arranged somewhat irregularly, not in a few longitudinal rows as in *A. triplex*. Shaft cross-section round.

Discussion. — See Discussion for *Archaeocidaris triplex*.

Material and localities. — Incomplete spines, DMNH 22477, DMNH 22478, Locality 4, collected by W. Itano.

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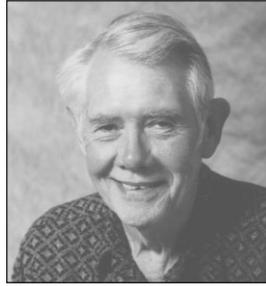
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