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Crinoids from the Wooster Shale Member of the Cuyahoga Formation, Carboniferous (Mississippian, Tournaisian) of northeastern Ohio

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Abstract.—Nine crinoids are described from the Wooster Shale Member of the Cuyahoga Formation from Wayne and Ashland counties, Ohio, USA. Identifiable elements of the fauna include five camerate crinoids, one flexible crinoid, and three other eucladid crinoids. Five new species are described, including *Cactocrinus woosterensis* n. sp., *Cusacrinus brushi* n. sp., *Agaricocrinus murphyi* n. sp., *Decadocrinus laevis* n. sp., and *Decadocrinus inordinatus* n. sp. Overall, the distribution of crinoid clades in the Wooster Shale is similar to that of the stratigraphically lower Meadville Shale Member of the Cuyahoga Formation, although less diverse and with only one species (*Cyathocrinites simplex*) in common. Many of the Wooster Shale Member crinoids are completely or partially preserved with siderite either in nodules or within siderite beds. These crinoids are commonly preserved in trauma postures, which is characteristic of burial in episodic high turbulence events. The paleoenvironments and taxa of the two Cuyahoga Formation crinoid faunas more closely resemble Viséan faunas in siliciclastic settings than typical carbonate faunas of the Tournaisian.

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Introduction

A relatively small crinoid fauna is described herein from the Wooster Shale Member of the Cuyahoga Formation from Wayne and Ashland counties, Ohio, USA (Mississippian, Tournaisian). Although distinct (five new species), the Wooster Shale fauna is similar to the fauna of the stratigraphically lower Meadville Shale Member of the Cuyahoga Formation. The Wooster Shale Member fauna also has a much lower biodiversity that the Meadville Shale Member (Tables 1 and 2). Both faunas contain actinocrinitids, platycrinitids, *Taxocrinus*, *Cyathocrinites*, and decadocrinids. The only shared species between these faunas is *Cyathocrinites simplex* Kammer and Roeser, 2012. Five new species are described herein from the Wooster Shale Member: *Cactocrinus woosterensis* n. sp., *Cusacrinus brushi* n. sp., *Agaricocrinus murphyi* n. sp., *Decadocrinus laevis* n. sp., and *Decadocrinus inordinatus* n. sp. In addition, *Megistocrinus*? sp. is also described from the Wooster Shale Member. Unlike the Meadville Shale Member crinoids, many of the Wooster Shale Member crinoids are completely or partially preserved with siderite. Crinoids associated with siderite occur either in siderite nodules or within siderite beds. The paleoenvironmental setting and faunal content of these two Cuyahoga Formation crinoid faunas are in many ways more similar to Viséan faunas in siliciclastic settings than to other Tournaisian faunas. Despite being nearly contemporaneous, clade-specific occurrences of new species is consistent with species longevity distinctions discussed by Kammer et al. (1997, 1998).

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Geologic setting

Stratigraphy.—The Wooster Shale Member is a member of the Cuyahoga Formation in northeastern and central Ohio (Table 1). Its age has been debated. Szmuc (1957), in his initial description of the member, and Rodriquez (1961) suggested that the Wooster Shale Member was later Kinderhookian to early Osagean based on its brachiopod fauna. Szmuc (1970) further described the members of the Cuyahoga Formation, noting that the Wooster Shale Member was distinguished by its homogenous dark shale with abundant fossiliferous concretions dominated by large syringothyrid brachiopods and platyceratid snails. Using miospores, Clayton et al. (1998) confirmed that the Wooster Shale Member was middle Tournaisian and likely late Kinderhookian. Matchen and Kammer (2006) suggested that the Wooster Shale Member was deposited during a transition between the Kinderhookian and Osagean, represented by a hiatus of two conodont zones in the Mississippi River Valley (see also Kammer and Matchen, 2008). In any case, we are confident that the Wooster Shale Member is middle Tournaisian in global stratigraphic terminology.

Depositional environment.—The Wooster Shale Member, with its diverse fauna of brachiopods, crinoids, and mollusks, is clearly marine in origin. Clayton et al. (1998) noted that the

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Table 1. Members of the Cuyahoga Formation in northeastern Ohio with approximate thicknesses; data from Szmuc, 1970; Coogan et al., 1981; Matchen and Kammer, 2006 (modified from Kammer and Roeser, 2012).

Cuyahoga Formation
Black Hand Sandstone Member (0–60 m)
Wooster Shale Member (21 m)
Armstrong Member (9 m)
Rittman Sandstone Member (12 m)
Meadville Shale Member (70 m)
Strongsville Member (5 m)
Sharpsville Member (21 m)
Orangeville Shale Member (34 m)
Sunbury Shale Member (2 m)

abundance of terrestrial kerogens in the member at its type locality in Wooster, along with miospore tetrads and megaspores, indicates that it was deposited in a nearshore environment. Specifically, Clayton et al. (1998, p. 190) suggested that the occurrences of acanthomorph acritarchs, tasmanitids, and *Botryococcus* in the Wooster Shale Member "are consistent with deposition in an interdistributary setting associated with a true deltaic environment."

Materials and methods

Specimen collection.—The Wooster Shale Member of the Cuyahoga Formation is exposed primarily along small streams in Wayne and Ashland counties, Ohio. These outcrops confirm that Wooster Shale Member crinoids are preserved encased in gray shale or associated with siderite concretions, matching the specimens in museum collections. However, bedding-plane exposures of the shale are very limited in stream banks, so few identifiable remains have been recovered from these outcrops.

The crinoids described here are primarily from historical collections from the College of Wooster; the Orton Geological Museum, The Ohio State University (James L. Murphy collection); the Cleveland Museum of Natural History (Gary Meszaros collection); and Ashland College (Nigel Brush collection). None of the primary localities of these collections remains accessible for collection. Most specimens are from the abandoned Medal Brick and Tile Quarry in Wooster. Other specimens described here are from an abandoned shale pit in Ruggles Township (Ashland County), a grassed-over Interstate 71 outcrop in Wayne County, and an outcrop along Shade Creek in Wayne County (Fig. 1). There can be little expectation of collecting many well-preserved new specimens unless new shale quarries are opened in the future.

Repositories and institutional abbreviations.—New specimens reported in this study are deposited at the Cleveland Museum of Natural History, Cleveland, Ohio (CMNH) and in the Orton Geology Museum, The Ohio State University, Columbus, Ohio (OSU).

Systematic paleontology

Classification and terminology.—Ordinal and superordinal classification of crinoids follows Cole (2017, 2018), Wright (2017a, b), and Wright et al. (2017). Family-level classification follows Moore and Teichert (1978). Morphologic terminology is from Webster (1974), Ubaghs (1978a), Webster and Maples (2008), Kammer et al. (2013), Ausich et al. (2020), and Ausich and Donovan (in press). Interray plating is indicated by the number of plates in each range from the proximal-most plate to the last range before the tegmen (e.g., 1-2-2-1). In the posterior interray, the primanal is designated by "P," and in regular interrays the proximal-most plate is designated by "1."

Table 2. Comparison of the crinoid faunas in the Wooster Shale and Meadville Shale members of the Cuyahoga Formation. Meadville Shale Member data from Ausich and Roeser (2012), Kammer and Roeser (2012), and Webster (2014).

Clade	Taxon	Meadville Shale	Wooster Shale
Camerates			
	Agaricocrinus murphyi n. sp.	0	1
	Amphoracrinus viminalis Hall, 1863	1	0
	Aorocrinus helice (Hall, 1823)	1	0
	Aorocrinus meyeri Ausich and Roeser, 2012	1	0
	Aryballocrinus martini Ausich and Roeser, 2012	1	0
	Cactocrinus woosterensis n. sp.	0	1
	Cusacrinus daphne	1	0
	Cusacrinus brushi n. sp.	0	1
	Megistocrinus? sp.	0	1
	Platycrinites s.l. *burkei*	1	0
	Platycrinites s.l. *contritus*	1	0
	Platycrinites s.l. *graphicus*	1	0
	Platycrinites s.l. *lodensis*	1	0
	Platycrinites s.l. sp.	0	1
Disparids			
	Halysiocrinus sp.	1	0
Eucladid: Flexibles			
	Dactylocrinus tardus	1	0
	Taxocrinus hollandi	1	0
	Taxocrinus intermedius	1	0
	Taxocrinus sp.	0	1
Eucladid: Cyathoformes			
	Cyathocrinites lamellosus	1	0
	Cyathocrinites simplex	1	1
Eucladid: Cyathoformes incertae sedis: 'Poteriocrinda'			
	Acylocrinus lyriope (Hall, 1863)	1	0
	Aphelecrinus gracilis Kammer and Roeser, 2012	1	0
	Ascetocrinus whitei (Hall, 1861a)	1	0
	Atelestocrinus meszarosi Kammer and Roeser, 2012	1	0
	Cuyahogacrinus lodiensis Kammer and Roeser, 2012	1	0
	Cosmetocrinus crineus (Hall, 1863)	1	0
	Decadocrinus laevis n. sp.	0	1
	Decadocrinus inordinatus n. sp.	0	1
	Goniocrinus sceletus Kammer and Roeser, 2012	1	0
	Histocrinus aegina (Hall, 1863)	1	0
	Lebetocrinus ohioensis Kammer and Roeser, 2012	1	0
	Linocrinus merope (Hall, 1863)	1	0
	Linocrinus paternus (Hall, 1863)	1	0
	Logocrinus warreni (Laudon et al., 1952)	1	0
	Pachylocrinus subtortuosus (Hall, 1863)	1	0
	Paracosmetocrinus richfieldensis (Worthen, 1882)	1	0
	Paracosmetocrinus corycia (Hall, 1863)	1	0
	Totals	30	9

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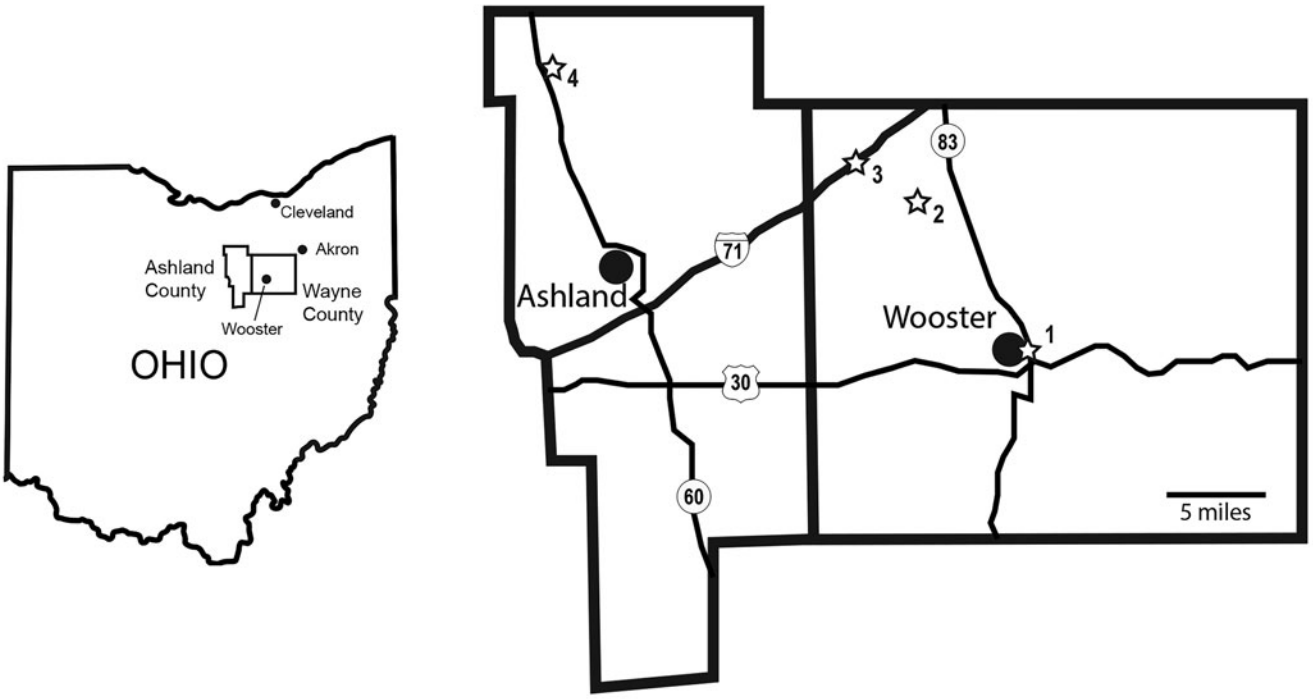

Figure 1. Locality map in northeastern Ohio for crinoid occurrences in the Wooster Shale Member; approximate positions indicated by stars (as discussed in text, these localities are no longer accessible for collection): 1—abandoned Medal Brick and Tile Quarry, Wooster, Wayne County, Ohio; 2—Shade Creek in Wayne County, Ohio; 3—grassed-over roadcut along Interstate 71, south of County Road 126, sec. 10, Congress Township, Wayne County; 4—abandoned shale pit ~1.5 miles south of New London, east side of Highway 60, Ruggles Township, Ashland County, Ohio.

A, B, C, D, and E represent echinoderm rays following the Carpenter Ray system (see Ubaghs, 1978a, p. T63). Heteromorphic column patterns are indicated using the Webster (1974) system.

In specimen measurements, abbreviations are as follows: ACH, aboral cup height; ACW, aboral cup width; CaH, calyx height; CaW, calyx width; ColH, column height; CrH, crown height. All measurements are in mm; * after a measurement indicates the specimen is crushed or the feature is incomplete.

Sources for the list of species included in each genus differ among genera. For *Cactocrinus* and *Cusacrinus*, the included species are from a comprehensive review of the Actinocrinitidae (Rhenberg et al., 2015). Species lists in the other genera are taken uncritically from Webster (2014).

Class Crinoidea Miller, 1821
Subclass Camerata Wachsmuth and Springer, 1885
Infraclass Eucamerata Cole, 2017
Order Monobathrida Moore and Laudon, 1943
Suborder Compsocrinina Ubaghs, 1978
Family Periechocrinidae Bronn, 1849
Genus *Megistocrinus* Morris, 1843

Type species.—*Megistocrinus evansii* (Owen and Shumard, 1850).

Included species.—*Megistocrinus abnormis* (Lyon, 1857); *M. broadheadi* Branson and Wilson, 1922; *M. circulus* Rowley, 1904b; *M. clarkei* Thomas, 1924; *M. concavus* Wachsmuth, 1885; *M. corniger* Rowley, 1901b; *M. depressus* (Hall, 1862); *M. devonicus* Charlesworth, 1914; *M. evansii* (Owen and Shumard, 1850); *M. evansii crassus* White, 1862; *M. expansus* Miller and Gurley, 1894; *M. expansus inflatus* Rowley, 1901b; *M. expansus magniventrus* Rowley, 1903a; *M. farnsworthi* White, 1876; *M. fitzpatricki* Thomas, 1924; *M. hemisphericus* Miler and Gurley, 1895; *M. indianensis* Miller and Gurley, 1896a; *M. knappi* (Lyon, 1862); *M. latus* (Hall, 1858); *M. merrilli* Thomas, 1924; *M. mineolaensis* Branson and Wilson, 1922; *M. missouriensis* Branson and Wilson, 1922; *M. multidecoratus* (Barris, 1886); *M. nobilis* Wachsmuth and Springer in Miller, 1889; *M. nodosus* Barris, 1880; *M. novus* (Wood, 1904); *M. ontario* (Hall, 1862); *M. oppelti* Rowley, 1903c; *M. ornatus* Miller and Gurley, 1895; *M. pernodosus* Thomas, 1924; *M. reeftonensis* Prokop, 1970; *M. regularis* Wood, 1904; *M. robustus* Thomas, 1924; *M. rugosus* Lyon and Casseday, 1859; *M. rugosus spinuliferus* Rowley, 1903a; *M. sphaeralis* Wood, 1904; *M. spinosulus* Lyon, 1862; *M. tuberatus* Wood, 1904; *M. unicornis* Rowley, 1901b; and *M. whitehalli* Laudon, 1973.

Megistocrinus? sp.
Figure 2.1

Occurrence.—Mississippian (Tournaisian) Wooster Shale Member, Cuyahoga Formation at the abandoned Medal Brick and Tile Quarry, Wooster, Wayne County, Ohio.

Material.—CMNH 18011.

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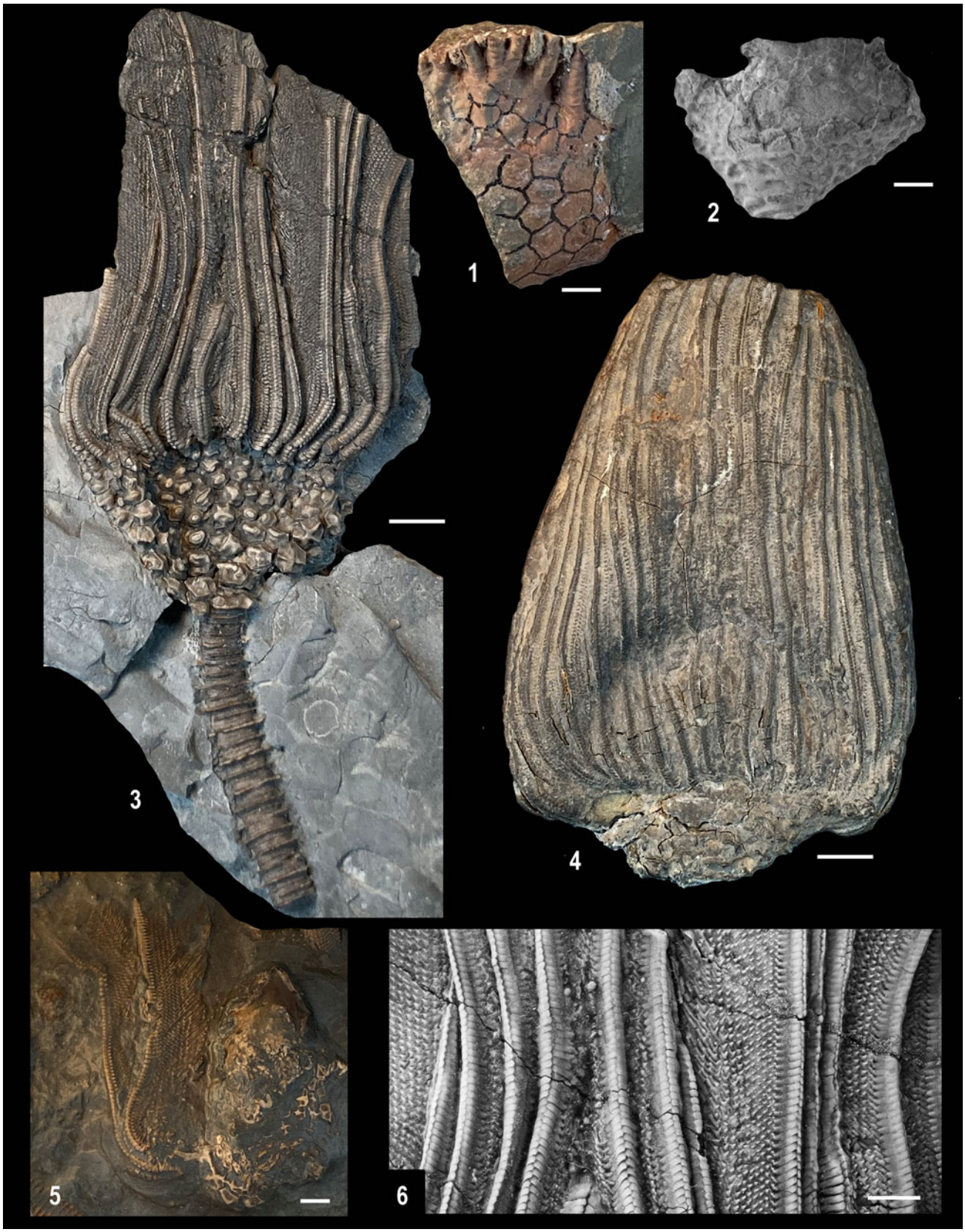

Figure 2. Wooster Shale Member camerate crinoids. (**1**) CMNH 18011, partial crown of *Megistocrinus*? sp. completely replaced by siderite. (**2–4, 6**) *Cactocrinus woosterensis* n. sp.; (**2**) OSU 53550, paratype, specimen in a siderite concretion (compare to Fig. 6.2); (**3**) CMNH 5212, holotype, somewhat collapsed crown with the proximal portion of the column attached; note small plates in calyx with variable sculpturing; (**4**) CMNH 18012, paratype, complete set of arms with very poorly preserved calyx; (**6**) CMNH 5212, holotype, enlargement of the arms at mid-height illustrating spines on pinnulars. (**5**) *Cusacrinus brushi* n. sp., CMNH 18014, poorly preserved partial crown of that is at least partially replaced with siderite and with an attached *Platyceras* gastropod. Scale bar represents 5.0 mm in (**1, 2, 5, 6**) and 10.0 mm in (**3, 4**). Specimens in (**2**) and (**6**) coated with ammonium chloride sublimate for photography.

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Measurements.—CMNH 18011: CaH, 24.0*; CaW, 26.0*; AH, 4.0*.

Remarks.—Approximately one-eighth of an articulated, uncompacted calyx is preserved in siderite surrounded by gray shale (CMNH 18011). Some secundibrachials through quartibrachials are fixed into the calyx (Fig. 2.1). A median ray ridge is present from at least the fixed tertibrachials through the remaining fixed brachials. The distal portion of one half-ray is well preserved, which has four arms. The outer half of the half-ray is unbranched, whereas the inner portion of the half-ray branches twice. The distal-most fixed brachials are uniserial, but the free arms are biserial.

This specimen is too incomplete to assign to a genus and species with confidence, but the morphology that is preserved is consistent with that of *Megistocrinus*. *Megistocrinus* is primarily a Devonian camerate crinoid; however, two species are present in Tournaisian strata of the United States. *Megistocrinus evansii*, which is the type species of this genus, is known from the lower Burlington Formation of Iowa and the Lake Valley Formation of New Mexico, and *M. nobilis* is known from the Maynes Creek Formation of Iowa. Both of these species have much larger and more robust calyx plates and, as known so far, do not have fixed quintibrachials. However, this specimen is too incomplete to be the basis of a new species.

Family Actinocrinitidae Austin and Austin, 1842

Remarks.—The Actinocrinitidae is a diverse, cosmopolitan family that was a dominant element of many Mississippian paleocommunities. The Wooster Shale Member of the Cuyahoga Formation contains two species belonging to the Actinocrinitidae: *Cactocrinus woosterensis* n. sp. and *Cusacrinus brushi* n. sp. These two species have sharply contrasting morphologies that are distinct from *Cusacrinus dafne* (Hall, 1863), which occurs in the Meadville Shale Member of the Cuyahoga Formation (Ausich and Roeser, 2012). Interestingly, all three of these species (as well as some other species in these genera) have peculiar arms (i.e., the pinnules have spines projecting from pinnular plates). As discussed below, both of the species conform well to the diagnosis of their respective genera in the recent revision of the Actinocrinitidae (Rhenberg et al., 2015), but the diagnoses of Rhenberg et al. (2015) must be modified slightly to accommodate the inclusion of these two species.

Subfamily Cactocrininae Ubaghs, 1978
Genus *Cactocrinus* Bowsher, 1955

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

Included species.—*Cactocrinus arrosus* (Miller, 1892a); *C. baccatus* Wood, 1914; *C. bischoffi* (Miller and Gurley, 1896b); *C. clarus* (Hall, 1861a); *C. extensus* Wachsmuth and Springer, 1897; *C. fossatus* (Miller, 1892a); *C. glans* (Hall, 1859); *C. hurdianus* (McChesney, 1860); *C. imperator* (Laudon, 1933); *C. lucina* (Hall, 1861b); *C. magnidactylus* Laudon and Severson, 1953; *C. multibrachiatus* (Hall, 1858); *C. obesus* (Keyes, 1894); *C. opusculus* (Hall, 1859); *C. platybrachiatus* Wood, 1914; *C. proboscidialis* (Hall, 1858); *C. sexarmatus* (Hall, 1859); *C. springeri* (Rowley, 1900); *C. thalia* (Hall, 1861b); and *C. woosterensis* n. sp.

Diagnosis.—Basal circlet low; one or two fixed secundibrachials, secundibrachials or tertibrachials highest brachitaxis in vertical wall of calyx; two or three ranges of interradial plates in regular interrays, three ranges of interradial plates in posterior interray, interrays not in contact with tegmen, plating in proximal interrays 1–2; fixed intrabrachials between half-rays; arms not grouped, arm lobes absent; free arms atomous; tegmen height similar to calyx height, comprised of many plates, anal tube central (modified from Rhenberg et al., 2015).

Occurrence.—Mississippian (Tournaisian) of North America.

Remarks.—Placement of *C. woosterensis* n. sp. in *Cactocrinus* is based on a low basal circlet, low radial circlet, number of ranges of plates in regular interrays, interrays not in contact with the tegmen, 1-2 plating in proximal regular interrays, arms not grouped, arm lobes absent, and fixed intrabrachials between half-rays (see Rhenberg et al., 2015). Inclusion of *C. woosterensis* n. sp. in *Cactocrinus* expands the diagnosis of this genus because *C. woosterensis* n. sp. has two fixed secundibrachials rather than only one.

Cactocrinus woosterensis new species
Figures 2.2–2.4, 2.6, 6.2–6.4

Types.—Holotype: CMNH 5212; paratypes: CMNH 18012, CMNH 18013, OSU 53550.

Diagnosis.—Radial plates wider than high: irregular radiating ridged sculpturing, sculpturing along rays inconsistent; first primibrachial larger than second primibrachial, two fixed secundibrachials, tertibrachials highest brachitaxis in vertical wall of calyx; interradial and intrabrachial plates with one large, central node, with a smaller node above (calyx shape, and characters of the tegmen unknown).

Occurrence.—Mississippian (Tournaisian) Wooster Shale Member, Cuyahoga Formation at the abandoned Medal Brick and Tile Quarry, Wooster, Wayne County, Ohio; Shade Creek in Wayne County; and a grassed-over roadcut along I-71 south of County Road 126, SE1/4, NW1/4, sec. 10, Congress Township, Wayne County, Ohio.

Description.—Crown large. Calyx large, cone shaped without a basal concavity (Fig. 2.3). Calyx plate sculpturing prominent but highly variable. Basal circlet ~10% of calyx height; basal plates presumably three, visible in lateral view; with narrow, undulating ridge around base of basal circlet, arcuate outer rim of facet with radial plate above, and a vertical ridge centered below the center of the facet for the radial plate and extending down to the rim at the base of the basal plate. Radial circlet ~20% of calyx height, presumably in lateral contact in all interrays except the CD interray; radial plates small, five,

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hexagonal, as wide as high. Radial plate sculpturing irregular and varied; vertical ridge from basal plate connects to a ridge on the radial plate that extends to the middle of the radial plate where it joins a dominant horizontal ridge, from this horizontal ridge various irregular ridges or nodes may be present with the pattern different on different radial plates.

Regular interrays not in contact with tegmen (Fig. 2.3), interradial plates small, hexagonal. Fixed interradial plates with a large central node covering most of plate and a smaller central node on top of the larger node. First interradial plate wider than high with prominent horizontal ridge. Regular interray plating 1-2-3-?. CD interray unknown.

Fixed brachials at least through the first quartibrachial; with various, irregular sculpturing; typically, prominent three, four, or five radiating ridges, a single horizontal ridge or a single node. Fixed brachials ~70% of calyx height; fixed intrabrachials between fixed secundibrachials, with a central spine.

Tegmen unknown.

Free arms 40, high, atomous (Fig. 2.3, 2.4), chisel biserial after the third quartibrachial, as wide as high and deeper than wide (Fig. 2.6). Pinnules long; pinnulars with spine projecting obliquely upward and more or less perpendicular to the pinnule attitude if arms closed (Fig. 2.6).

Column circular, heteromorphic, N212 pattern (Fig. 2.3). Nodal with prominent, wide, thin ridge around latus; priminternodal with a narrower, thin ridge around latus; secundinternodal with a flat latus.

Etymology.—The species name recognizes the College of Wooster in Wooster, Ohio, for its decades of support of paleontological research. The holotype of *Cactocrinus woosterensis* n. sp. and many other specimens in this fauna were collected by professors and students from the Department of Geology at The College of Wooster.

Additional specimen.—CMNH 18018.

Measurements.—CMNH 5212: CrH, 110.0*; CaH, 27.0*, CaW, 54.0*; AH, 88.0*; ColH, 46.0*. CMNH 18012: CrH, 112.0*; CaW, 35.0*; AH, 93.0. OSU 53550: CaH, 19.1; CaW, 24.0*.

Remarks.—The holotype of *Cactocrinus woosterensis* n. sp. is a nearly complete crown with ~48 mm of attached column. Unfortunately, the calyx is compacted with most of the calyx plates separated but basically in their proper relative positions. This means that the calyx shape and dimensions can only be approximated.

Twenty species are now recognized in *Cactocrinus* (see Rhenberg et al., 2015). These species can be subdivided into two major groups: 1, those species with ray plate sculpturing dominated by some arrangement of radiating ridges (single ridges connecting with like ridges of adjoining plates); and 2, those species with other types of plate sculpturing, such as smooth sculpturing or plates dominated by a single spine. Thirteen species have radiating ridges as the type of ray plate sculpturing, including *C. woosterensis* n. sp. (see Supplemental Table 1). Some of these species have a central node (sizes variable), but all have a more or less uniform character of radiating ridges along a ray.

Cactocrinus woosterensis n. sp. and *Cactocrinus imperator* (Laudon, 1933) are unique among *Cactocrinus* species because tertibrachials are the highest fixed brachials in the vertical wall of the calyx. These two species are distinguished because *Cactocrinus woosterensis* n. sp. has inconsistent plate sculpturing along ray plates, two fixed secundibrachials, and a distinctive double node sculpturing on fixed interradial plates. In contrast, *C. imperator* has similar plate sculpturing along ray plates, one fixed secundibrachial, and radiating ridges as plate sculpturing on fixed interradial plates.

One paratype of *C. woosterensis* n. sp. (CMNH 18012) (Fig. 2.4) is also oddly preserved with a complete set of arms and a compressed, poorly preserved calyx. OSU 53550, also a paratype, is a partial, uncompressed calyx preserved in a siderite nodule. In addition, partial specimens presumably assignable to *Cactocrinus woosterensis* n. sp. were observed (but not collected) at various stream exposures in Wayne and Ashland counties.

Two actinocrinitid camerates are present in the Wooster Shale Member of the Cuyahoga Formation. This contrasts with the Meadville Shale Member of the Cuyahoga Formation, which has only one actinocrinitid species, *Cusacrinus daphne* (Hall, 1863) (Ausich and Roeser, 2012). The primary, striking distinction between *Cactocrinus* and *Cusacrinus* is the size and number of calyx plates. The *Cactocrinus* calyx is constructed of numerous, small plates, whereas, *Cusacrinus* has relatively few, large calyx plates (Ausich and Roeser, 2012).

Genus *Cusacrinus* Bowsher, 1955

Type species.—*Actinocrinites proboscidialis* Hall, 1858, by original designation.

Included species.—*Cusacrinus arnoldi* (Wachsmuth and Springer in Miller, 1889); *C. asperrimus* (Meek and Worthen, 1870); *C. brushi* n. sp., *C. chloris* (Hall, 1861a); *C. coelatus* (Hall, 1858); *C. daphne* (Hall, 1863); *C. denticulatus* (Wachsmuth and Springer, 1897); *C. ectypus* (Meek and Worthen, 1870); *C. kuenzii* (Laudon, Parks, and Spreng, 1952); *C. limabrachiatus* (Hall, 1861a); *C. longus* (Meek and Worthen, 1870); *C. nodobrachiatus* (Wachsmuth and Springer in Miller, 1889); *C. ornatissimus* (Wachsmuth and Springer in Miller, 1897); *C. penicillus* (Meek and Worthen, 1870); *C. sampsoni* (Miller and Gurley, 1896b); *C. sobrinus* (Miller and Gurley, 1896b); *C. spectabilis* (Miller and Gurley, 1896b); *C. spinotentaculus* (Hall, 1859); *C. subscitulus* (Miller and Gurley, 1896b); *C. tenuisculptus* (McChesney, 1860); *C. thetis* (Hall, 1861b); *C. tuberculosus* (Wachsmuth and Springer, 1897); and *C. viaticus* (White, 1874).

Diagnosis.—Basal circlet high or low; radial circlet high; one fixed secundibrachial; secundibrachitaxis highest brachitaxis in vertical wall of calyx; four ranges in regular interray; six ranges in posterior interray; interrays in contact with tegmen; plating in proximal interrays 1–2; fixed intrabrachials between half-rays present; arms weakly grouped; arm lobes absent; tegmen lower than or same height as calyx; many medium-sized plates on tegmen; anal tube central (modified from Rhenberg et al., 2015).

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Occurrence.—Mississippian (Tournaisian) of North America.

Remarks.—Characters of *Cusacrinus brushi* n. sp. are consistent with those used to define the genus *Cusacrinus* in Rhenberg et al. (2015).

Cusacrinus brushi new species
Figures 2.5, 3, 4.6

Type.—Holotype: CMNH 18015a.

Diagnosis.—Calyx shape low bowl, radial plates relatively high, stellate ray plate sculpturing (only one ridge to adjoining plates), median ray ridges present, two fixed primibrachials, one fixed secundibrachial, quartibrachials highest fixed brachials, stellate or nodose sculpturing on fixed interradial plates, fixed intraradial plates present, regular interray plates in contact with tegmen, ~6 free arms in each ray, and short spines on pinnulars (note: nature of the connection between the CD interray and the tegmen and the shape of the tegmen are unknown).

Occurrence.—Mississippian (Tournaisian) Wooster Shale Member, Cuyahoga Formation at the abandoned Medal Brick and Tile Quarry, Wooster, Wayne County, Ohio, and along Shade Creek in Wayne County, Ohio.

Description.—Crown large. Calyx large, cone shaped without a basal concavity. Calyx plate sculpturing prominent but highly variable (Fig. 3). Basal circlet ~10% of calyx height; basal plates presumably three, visible in lateral view but poorly preserved. Radial circlet ~15% of calyx height, presumably in lateral contact in all interrays except the CD interray; radial plates large, presumably five, hexagonal, approximately as wide as high. Radial plate sculpturing prominent stellate ridges connecting to adjoining plates and forming the beginning of ray ridges (Fig. 3.2).

Regular interrays in narrow contact with tegmen, interradial plates large proximally and small distally, mostly hexagonal. First interradial plate slightly higher than wide with subtle radiating ridges (Fig. 3.2). Regular interray plating 1-2-3-3-4-2 (completely known on only one interray); plates in second range with subtle radiating ridges, plates in higher ranges slightly concave, with or without a low central node. CD interray not known.

Fixed brachials through at least the second or third quartibrachial, ~75% of calyx height; in each ray two primibrachials, one secundibrachial, two tertibrachials if branched or more if unbranched, 2 or more quartibrachials if present. Primibrachials through tertibrachials dominated by medial ray ridge; primibrachials through tertibrachials rectilinear uniserial, fixed quartibrachials weakly cuneate uniserial. Fixed intrabrachials medial between fixed secundibrachials and tertibrachials and between tertibrachials and quartibrachials in half-rays (Fig. 3.1, 3.2).

Tegmen unknown.

Free arms 30–40, high, atomous. Brachials chisel biserial after the third quartibrachial and deeper than wide. Pinnules long; pinnulars with spine projecting obliquely upward and more or less perpendicular to the pinnule attitude if arms closed.

Column circular with circular lumen. Other details unknown (Fig. 3.1, 3.2).

Etymology.—This species recognizes Professor Nigel Brush, Ashland University and The College of Wooster, for his long geological and archaeological teaching career and his field work that has advanced our understanding of the Wooster Shale Member and its fossils.

Additional material.—Three additional specimens are also assigned to this species: CMNH 4874a, CMNH 4874b, and CMNH 18014.

Measurements.—CMNH 18015a: CrH, 112.0*; CaH, 42.0*, ACH, 15.0; CMNH 4874a: CaH, 36.0*; CaW, 57.0*; ColH, 61.0*.

Remarks.—*Cusacrinus* has wide variability in character states (Supplementary Table 2). *Cusacrinus brushi* n. sp. is similar to a group of species that share the following character states: median ray ridges, two fixed primibrachials, one fixed secundibrachial, quartibrachials the highest fixed brachials in the calyx, regular interrays in contact with the tegmen, and ~6 free arms per ray. These species include *Cusacrinus coelatus* (lower Burlington Formation), *Cusacrinus daphne* (Meadville Shale Member, Cuyahoga Formation), *Cusacrinus limabrachiatus* (lower Burlington Formation), possibly *Cusacrinus spectabilis* (unspecified position in the Burlington Formation), and *Cusacrinus spinotentaculus* (lower Burlington Formation). These five species differ from *Cusacrinus brushi* n. sp. in a variety of ways. *Cusacrinus coelatus* has a low cone-shaped calyx, relatively low radial plates, stellate and multistellate ray-plate sculpturing (where stellate refers to those with a single ridge connecting to like ridges of adjoining plates and multistellate is the character state in which more than one ridge connects to like ridges to each adjoining plate), stellate sculpturing on interradial plates, fixed intraradial plates absent, regular interrays may or may not be in contact with the tegmen, the posterior interray is in relatively narrow contact with the tegmen, and the tegmen is a low cone shape (the presence or absence of spines on pinnulars is unknown). *Cusacrinus daphne* has a low cone-shaped calyx, relatively low radial plates, multistellate ray plate sculpturing on ray plates, multistellate plate sculpturing on interradial plates, fixed intraradial plates absent, regular interrays in contact with tegmen, and short spines on pinnulars (tegmen shape is unknown). *Cusacrinus limabrachiatus* has a low cone-shaped calyx, relatively low radial plates, stellate ray plate sculpturing, stellate plate sculpturing on fixed interradial plates, fixed intraradial plates absent, regular interrays in contact with tegmen, and short spines on pinnulars (tegmen shape is unknown). *Cusacrinus spectabilis* has a medium cone-shaped calyx, relatively high radial plates, smooth ray plate sculpturing, smooth sculpturing on interradial plates, and fixed intrabrachial plates absent (nature of the contact between the regular interrays, tegmen shape, and presence or absence of spines on pinnulars unknown). *Cusacrinus spinotentaculus* has a low cone- to urn-shaped calyx, relatively low radial plates, stellate or multistellate ray plate sculpturing, stellate

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Figure 3. *Cusacrinus brushi* n. sp., CMNH 18015. (**1**) Bed containing holotype that is completely replaced by siderite; note three crinoid specimens on slab, CMNH 18015a, holotype, large specimen on slab; CMNH 18015b, a *Platycrinites* s.l. on the left side of the calyx, CMNH 18015c, a Camerata indeterminate on the right side of the slab; a *Platyceras* gastropod mold is also above the calyx. (**2**) CMNH 18015a: enlargement of holotype, note fixed interradial and intraradial plates and variable plate sculpturing in interradial plates and short spines on pinnulars; *Platycrinites* s.l. on the left side of the calyx, a *Platyceras* gastropod mold above the calyx. Scale bar represents 10.0 mm in (**1**) and 5.0 mm in (**2**). Specimen in (**2**) coated with ammonium chloride sublimate for photography.

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sculpturing on interradial plates, fixed intraradial plates absent, regular interrays in contact with the tegmen, and a low cone shape (the presence or absence of spines on pinnulars could not be confirmed despite the species name "*spinotentaculus*"). In contrast, *Cusacrinus brushi* n. sp. has a low bowl-shaped calyx, relatively high radial plates, stellate ray plate sculpturing, stellate or nodose sculpturing on interradial plates, fixed intrabrachial plates present, regular interrays in contact with tegmen, and spines present on pinnulars (tegmen shape unknown).

Most species of *Cusacrinus* occur in Tournaisian carbonate settings (e.g., the Burlington Formation and Chouteau Limestone of Illinois, Iowa, and Missouri; the Maynes Creek Formation of Iowa; the Lake Valley Formation in New Mexico; the Henderson Canyon Formation of Utah; the Anchor Limestone of Nevada; the Lodgepole Formation of Montana; and the Banff Formation of Alberta, Canada) (see Webster, 2014). The only *Cusacrinus* species known from siliciclastic-dominated facies are from the Cuyahoga Formation (Tournaisian) of Ohio: *Cusacrinus daphne* from the Meadville Shale Member and *Cusacrinus brushi* n. sp. from the Wooster Shale Member. These are distinct species, as noted above.

Two very poorly preserved camerate specimens are assigned to *Cusacrinus brushi* n. sp. CMNH 4874a is the proximal half of a calyx with ~60 mm of column attached (Fig. 4.6.). A smaller specimen (CMNH 4874b) is only the proximal portion a calyx. Both are preserved in dark gray shale and are similar to *Cusacrinus brushi* n. sp. by having large calyx plates. However, the preservation is insufficient to identify these specimens with confidence. CMNH 18014 is also assigned to *Cusacrinus brushi* n. sp. based on the sculpturing of fixed brachials. This specimen is a poorly exposed calyx with parts of one arm visible (Fig. 2.5). Also, this specimen has a *Platyceras* Conrad, 1840, gastropod attached to the tegmen. Curiously, the only other specimen of *Cusacrinus brushi* n. sp. with arms preserved (CMNH 18015a) also has a *Platyceras* gastropod attached (Fig. 3). Platyceratids are not preserved on other crinoids from this fauna.

Superfamily Carpocrinacea de Koninck and Le Hon, 1854
Family Coelocrinidae Bather, 1899
Genus *Agaricocrinus* Hall, 1858

Type species.—*Agaricocrinus tuberosus* Hall, 1858.

Included species.—*Agaricocrinus americanus* (Roemer, 1854); *A. bellatrema* Hall, 1861a; *A. bellatrema major* Wachsmuth and Springer, 1897; *A. blairi* Miller, 1892b; *A. brevis* (Hall, 1858); *A. bullatus* Hall, 1858; *A. conicus* Wachsmuth and Springer, 1897; *A. convexus* (Hall, 1859); *A. coreyi* Lyon and Casseday, 1860; *A. crassus* Wetherby, 1881; *A.*? *depressus* (Casseday and Lyon, 1862); *A. excavatus* Hall, 1861b; *A. fiscellus* (Hall, 1861a); *A. geometricus* (Hall, 1859); *A. gracilis* Meek and Worthen, 1861; *A. hodgsoni* Miller and Gurley, 1896a; *A. illinoisensis* Miller and Gurley, 1896a; *A. inflatus* Hall, 1861b; *A. iowensis* Miller and Gurley, 1897; *A. jerseyensis* (Worthen, 1890); *A. louisianensis* Rowley, 1900; *A. montgomeryensis* Peck and Keyte, 1938; *A. murphyi* n. sp.; *A. nodosus* Meek and Worthen, 1870; *A. nodulosus* Worthen in Miller, 1889; *A. nodulosus macadamsi* Worthen in Miller, 1889; *A. planoconvexus* Hall, 1861b; *A. praecursor* Rowley, 1902b; *A. pyramidatus* (Hall, 1858); *A. sampsoni* Miller, 1892b; *A. spendens* Miller and Gurley, 1890; *A. stellatus* (Hall, 1858); *A. tuberosus* Hall, 1858; *A. whitfieldi* Hall, 1858; and *A. wortheni* Hall, 1858.

Occurrence.—Mississippian (Tournaisian to Viséan); United States.

Agaricocrinus murphyi new species
Figure 4.7, 4.8

Types.—Holotype: OSU 55204.

Diagnosis.—Thecal size small, flat cone-shaped aboral cup, pentalobate calyx outline, narrow and small basal concavity, only basal plates in basal concavity, nodose outer surface of radial plate, small plates in the CD interray, convex outer surface of primibrachials, convex outer surface of first interradial plates, small plates in CD interray, small tegmen plates, convex or nodose fixed ambulacral cover plates, very nodose to spinose posterior primary peristomial cover plate, protuberant anal region, anus on side of tegmen, arm facets as wide as high, free arm facets project laterally, and 12 or more arms (tegmen shape, outer surface of non-CD interray primary peristomial cover plates unknown).

Occurrence.—Wooster Shale Member, Cuyahoga Formation (Mississippian, Tournaisian) at abandoned shale pit ~1.5 miles south of New London, east side of Highway 60, Ruggles Township, Ashland County, Ohio.

Description.—Calyx small, flat cone shape with narrow, shallow basal concavity (Fig. 4.7). Calyx plates modestly to very convex, with pustulose plate sculpturing, calyx plate triple junctions depressed (Fig. 4.7). Basal circlet confined entirely to the basal concavity. Radial circlet forms base of calyx, interrupted in CD interray. Radial plates five, heptagonal, wider that high, strongly convex (Fig. 4.7).

Regular interrays in contact with tegmen; first interradial higher than wide, smaller than radial plates and larger than primibrachials. Regular interray plating 1-?. Primanal hexagonal, wider than high, approximately the same size as radial plates, interrupts the radial circlet; plating in CD interray incompletely known; CD interray in contact with tegmen.

In the A, B, and E rays, two primibrachials and two to three secundibrachials fixed, in D and E rays two primibrachials, one to three secundibrachials, and three tertibrachials fixed with secundaxil on CD interray side of C and D rays. Fixed brachials convex and uniserial.

Tegmen multiplated, pustulose plate sculpturing, large plates around outer perimeter and decreasing plate size toward center of tegmen with the exception of one very large nodose to spinose tegmen plate peripherally located in each ray (Fig. 4.8). Tegmen connection to calyx broad with numerous plates (plating pattern unknown). Anal opening on a small, loosely plated protuberance.

Twelve free arms, two from A, B, and C rays and three from C and D rays.

Free arms and column unknown.

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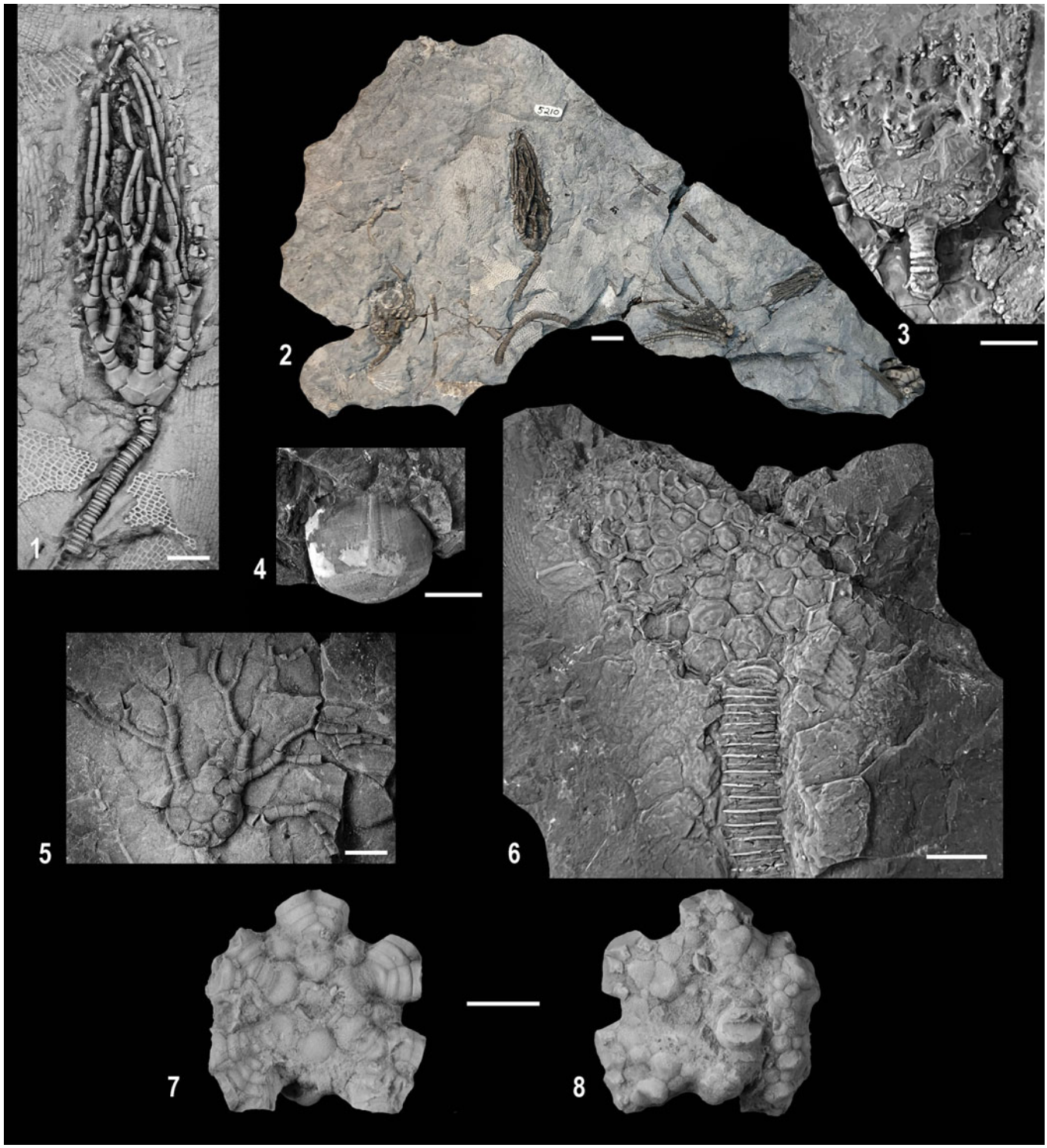

Figure 4. Wooster Shale Member crinoids. (**1, 2, 5**) *Cyathocrinites simplex* (**1, 2**) CMNH 5210; (**1**) CMNH 5210a, well-preserved specimen with partial arms and column; (**2**) bedding surface with well-preserved specimen shown in (**1**) with partial arms and column; (**5**) CMNH 5211a, oblique lateral view of a partially preserved specimen in the CD interray and three partial arms spread out illustrating arm branching. (**3, 4**) *Platycrinites* s.l. sp. (**3**) CMNH 18015b, poorly preserved, partly collapsed specimen with very poorly preserved brachials above and proximal column below; (**4**) CMNH 18016, internal mold of calyx. (**6**) *Cusacrinus brushi* n. sp., CMNH 4874a, internal mold of calyx and proximal column. (**7, 8**) *Agaricocrinus murphyi* n. sp., holotype, OSU 55204; (**7**) aboral view; note flat basal of calyx with basal plates in a concavity and very convex radial plates; (**8**) oral view of poorly preserved tegmen. Scale bar represents 5.0 mm in (**1–6**) and 10.0 mm in (**7, 8**). Specimens in (**1, 3–8**) coated with ammonium chloride sublimate for photography.

Etymology.—This name recognizes the late James L. Murphy, who collected the holotype of this new species as well as other Wooster Shale Member crinoids described in this paper. Now deceased, James L. Murphy was a librarian at The Ohio State University and an avocational paleontologist and archaeologist. His paleontological collections are

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housed in the Orton Geological Museum, The Ohio State University.

Measurements.—OSU 55204 (holotype): CaH, 7.5*: CaW, 14.7*.

Remarks.—A single Wooster Shale Member specimen (OSU 55204) is assigned to *Agaricocrinus murphyi* n. sp. This is a small individual with a flat calyx and a collapsed tegmen. Numerous species are assigned to *Agaricocrinus* (Webster, 2014), which is a characteristic and common crinoid in the Tournaisian and early Viséan of North America. As presently understood, 33 species (and two subspecies) are assigned to *Agaricocrinus*. The genus as a whole has not had a recent comprehensive review, and valid species concepts undoubtedly require revisions. However, such a review is beyond the scope of the present paper.

One criterion by which to group *Agaricocrinus* species is by the thecal outline (from either an oral or aboral perspective). Most species have a pentalobate outline, but some have either a pentagonal or circular outline (Supplemental Table 3). *Agaricocrinus* species with a pentalobate outline can be further differentiated by the width and depth of the basal concavity and by the plate circlet(s) that are present in the basal concavity. *Agaricocrinus montgomeryensis* Peck and Keyte, 1938; *A. sampsoni* Miller, 1892b; and *A. murphyi* n. sp. all have a narrow and shallow basal concavity and only basal plates in the basal concavity. Further, these three species are all from lower Tournaisian strata. These three species can be differentiated because *A. montgomeryensis* has a very low cone- to urn-shaped calyx, convex radial plates, large plates in the posterior interray, large tegmen plates, spinose primary peristomial cover plates, spinose CD interray primary peristomial cover plate, arm facets wider than high, and ten free arms; and *A. sampsoni* has convex radial plates and ten free arms (other aspects of its morphology are unknown). In contrast, *A. murphyi* n. sp. has a flat cone-shaped calyx, nodose radial plates, small plates in the posterior interray, small tegmen plates, very convex primary peristomial cover plates, very nodose CD interray primary peristomial cover plate, arm facets as wide as high, and probably twelve free arms or more (Supplemental Table 3).

Suborder Glyptocrinina Moore, 1952
Superfamily Platycrinitoidea Austin and Austin, 1842
Family Platycrinitidae Austin and Austin, 1842
Genus *Platycrinites* Miller, 1821

Type species.—*Platycrinites laevis* Miller, 1821.

Remarks.—*Platycrinites* was described by Miller (1821) in the same publication in which he defined the Crinoidea. Consequently, this genus name has been used widely. As discussed in Ausich and Kammer (2009), the helically twisted column historically used as a diagnostic character for *Platycrinites* is a diagnostic character for the Platycrinitidae, and genera are largely differentiated by different non-column characters. Key among these is knowledge of the tegmen: is an anal tube or a simple anal opening present on the tegmen? Unfortunately, this key character is unknown on many species that were historically assigned to *Platycrinites*. Species should be assigned to *Platycrinites* sensu lato if the morphology of the tegmen and/or other generic diagnostic characters are unknown (Ausich and Kammer, 2009). Accordingly, the Wooster Shale Member platycrinitid is assigned to *Platycrinites* s.l. sp.

Platycrinites s.l. sp.
Figures 3.2, 4.3, 4.4

Occurrence.—Mississippian (Tournaisian) Wooster Shale Member, Cuyahoga Formation at the abandoned Medal Brick and Tile Quarry, Wooster, Wayne County, Ohio.

Description.—Aboral cup medium bowl shape, plates thin. Basal circlet convex, ~20% of calyx height, sculpturing concentric ridges around entire basal circlet and centered on column facet; basal plates five, pentagonal. Radial circlet ~80% of calyx height; radial plates five, hexagonal, higher than wide, diagonal ridge sculpturing possible on radial plates. No fixed interradial plates or fixed brachials. CD interray, tegmen, arms, and column unknown.

Materials.—CMNH 18015b, CMNH 18016.

Measurements.—CMNH 18016: AcH, 11.0*; CaW, 12.2.

Remarks.—Two incomplete and poorly preserved specimens of *Platycrinites* are known from the Wooster Shale Member. CMHN 18016 is preserved as a partial internal mold. Only the basal circlet and two partial radial plates are visible on this specimen (Fig. 4.4). The basal circlet appears to have low concentric ridge sculpturing, and the radial plates are upright. CMNH 18015b is a crushed aboral cup with a few disarticulated brachials and a few proximal columnals preserved (Fig. 4.3).

As preservation allows, Wooster Shale Member specimens are different from all *Platycrinites* species known from the Meadville Shale Member of the Cuyahoga Formation (Ausich and Roeser, 2012) (i.e., *P.* s.l. *burkei* Ausich and Roeser, 2012; *P.* s.l. *contritus* [Hall, 1863]; *P.* s.l. *graphicus* [Hall, 1863]; and *P.* s.l. *lodensis* [Hall and Whitfield, 1875]). Wooster Shale Member specimens are too incompletely known to place it in a species with confidence; therefore, it is left in open nomenclature as *Platycrinites* s.l. sp.

Subclass Pentacrinoidea Jaekel,1894
Infraclass Inadunata Wachsmuth and Springer, 1885
Parvclass Cladida Moore and Laudon, 1943
Magorder Eucladida Wright, 2017
Superorder Cyathoformes Wright et al., 2017
Cyathoformes incertae sedis: "Cyathocrinida" Bather, 1899
Family Cyathocrinidae Bassler, 1938
Genus *Cyathocrinites* Miller, 1821

Included species.—*Cyathocrinites abbreviatus* Miller, 1821; *C. asperrimus* (Springer, 1911); *C. barrisi* (Hall, 1861a); *C. barydactylus* (Wachsmuth and Springer, 1878); *C. bursa* (Phillips, 1836); *C. calcaratus* (Phillips, 1836);

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C. chouteauensis (Miller and Gurley, 1896a); *C. decaphyllus* Roemer, 1843; *C. distortus* (Gilbertson in Phillips, 1836); *C. dubius* (Münster, 1840); *C. elongatus* (Knod, 1908); *C. faberi* (Miller and Gurley, 1896b); *C. farleyi* (Meek and Worthen, 1866); *C. fischeri* (Spandel, 1899); *C.*? *fonei* Donovan et al., 2010; *C. formosus* (Rowley, 1905); *C. foveolatus* (Eichwald, 1856); *C. gilesi* (Wachsmuth and Springer, 1878); *C. glenni* Ausich and Lane, 1982; *C. globosus* (Troost in Wood, 1909); *C. gosae* (Roemer, 1866); *C. granulatus* (Münster, 1839); *C. harrodi* (Wachsmuth and Springer, 1880); *C. ignotus* (Trenkner, 1868); *C.*? *inaequidactylus* (M'Coy, 1844); *C. iowensis* (Owen and Shumard, 1850); *C. irregularis* (Trenkner, 1868); *C. kelloggi* (White, 1862); *C. lamellosus* (White, 1863); *C. macadamsi* (Miller and Gurley, 1895); *C. mammillaris* (Phillips, 1836); *C. marshallensis* (Worthen, 1882); *C. milleri* (M'Coy, 1844); *C. multibrachiatus* (Lyon and Casseday, 1859); *C. multibrachiatus squarrosa* (Hall, 1872); *C. patulosus* (Wright, 1935); *C. planus* Miller, 1821; *C.*? *radiatus* (Austin and Austin, 1843) (non Eichwald, 1856); *C. radiatus* (Eichwald, 1856) (non Austin and Austin, 1843); *C.*? *ramosus* (Schlotheim, 1817); *C. rarus* (Lyon, 1869); *C. rigidus* (White, 1862); *C. rockfordensis* (Thomas, 1924); *C. saffordi* (Meek and Worthen, 1860); *C. sampsoni* (Miller, 1891); *C. simplex* Kammer and Roeser, 2012; *C. sphaericus* (Steininger, 1849); *C. stubblefieldi* Wright, J., 1952; *C. subtuberculatus* (Roemer, 1866); *C. tenuidactylus* Meek and Worthen, 1868; *C. teres* (Münster, 1840); *C. tricarinatus* Roemer, 1843; *C. tuberculatus* (Roemer, 1850) (non Miller, 1821); *C. turbinatus* (Weller, 1900); *C. variabilis* (Phillips, 1841); and *C. virgalensis* (Waagen, 1887).

Cyathocrinites simplex Kammer and Roeser, 2012
Figure 4.1, 4.2, 4.5

Type.—Holotype: CMCIP 46159; paratypes: CMCIP 5718-20, and CMCIP 5956-10.

Diagnosis.—*Cyathocrinites* with a low bowl-shaped aboral cup; infrabasals visible in lateral view, thin plates; smooth sculpturing; and smooth, elongate brachials (modified from Kammer and Roeser, 2012).

Occurrence.—Meadville Shale and Wooster Shale members of the Cuyahoga Formation in northeastern Ohio; Mississippian (Tournaisian). New occurrences in the Wooster Shale member are from Wooster, Ohio, in the abandoned Medal Brick and Tile Quarry, Wooster, Wayne County, Ohio.

Description.—Crown small in size, subcylindrical. Aboral cup low bowl shape, plates thin with smooth sculpturing other than very subtle radiating folding (Fig. 4.1). Infrabasal circlet ~6.8% of aboral cup height; presumably five, equal in size, as known. Basal circlet ~38.6% of aboral cup height; basal plates five, hexagonal, slightly larger than radial plates, ~1.3 times wider than high. Radial circlet ~54.5% of aboral cup height; radial plates five, heptagonal, wider than high. Radial facet angustary (Fig. 4.1), ~42% of distal radial plate width, semicircular, declivate; radial facet topography unknown.

CD interray with only the radianal within aboral cup (Fig. 4.5). Anal sac presumably cylindrical, ~70% of height of arms, distal anal sac with small plates, distalmost portion of sac surrounded by a ring of nodose plates.

Arms slender, branch three or four times with poor isotomy. Primibrachial dimensions variable, higher than wide or wider than high. Third to fifth primibrachial axillary (Fig. 4.1, 4.5), primaxil as wide as high. Secundibrachial higher than wide, third to fifth secundibrachial axillary. All brachials rectangular uniserial, sharply convex, straight sides. Free arms progressively smaller above each axillary, free arm shape at axillaries more of a U-shape than a V-shape (the latter of which is more typical in crinoids).

Proximal column circular, heteromorphic; columnar index N212, holomeric. Nodals with variable, small nodes around latus; holdfast unknown.

Material.—Wooster Shale Member specimens CMNH 5210a–CMNH 5110c, CMNH 5211a, and CMNH 5211b.

Measurements.—CMNH 5210a: CrH, 41.5; ACH, 5.4; ACW, 8.5; CoH, 18.0*.

Remarks.—*Cyathocrinites* is a geographically and temporally widespread genus. *Cyathocrinites* belongs to the primitive cladid clade (sensu Kammer et al., 1997, 1998) or the Cyathoformes incertae sedis: "Cyathocrinida" clade (sensu Wright et al., 2017). *Cyathocrinites simplex* was first described from the Meadville Shale Member of the Cuyahoga Formation, and it also occurs in the Wooster Shale Member of the Cuyahoga Formation. CMNH 5210a is an excellently preserved specimen and adds to our understanding of this species. Kammer and Roeser (2012, p. 473) outlined the species characters that differentiate *C. simplex* from other lower Tournaisian *Cyathocrinites* species.

Superorder Flexibilia Zittel, 1895
Order Taxocrinida Springer, 1913
Family Taxocrinidae Angelin, 1878
Genus *Taxocrinus* Phillips in Morris, 1843

Type species.—*Cyathocrinus*? *macrodactylus* Phillips, 1841, by subsequent designation.

Other species.—*Taxocrinus anomalus* Waters et al., 2003; *T. belgicus* Springer, 1920; *T. bellmanensis* Wright, 1954; *T. colletti* White, 1881; *T. communis* (Hall, 1863); *T. coplowensis* Wright, 1946; *T. delabolei* Wright, 1937; *T. giddingsi* (Hall, 1858); *T. granulatus* Salter, 1873; *T. hibernicus* (Wright, 1934); *T. hollandi* Laudon and Beane, 1937; *T. huntsvillae* Springer, 1920; *T. intermedius* Wachsmuth and Springer, 1888; *T. interscapularis* Hall, 1858; *T. juvenis* (Hall, 1861a); *T. kellogi* (Hall, 1863); *T. lobatus* (Hall, 1862); *T. macrodactylus* (Phillips, 1841); *T. nobilis* (Phillips, 1836); *T. ornatus* Springer, 1920; *T. praestans* Springer, 1920; *T. priscus* Steininger, 1853; *T. pustulosus* Springer, 1920; *T. ramulosus* (Hall, 1859); *T. shumardianus* (Hall, 1858); *T. strimplei* Knox and Kendrick, 1987; *T. stultus* Whidborne, 1896; *T. telleri* Springer, 1920; *T. ungula* Miller and Gurley, 1896a; and *T. whitfieldi* (Hall, 1858).

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Occurrence.—Devonian (Givetian) to Mississippian (Serpukhovian); Belgium, China, Germany, Ireland, United Kingdom, United States.

Taxocrinus sp.
Figure 5.5

Occurrence.—Mississippian (Tournaisian) Wooster Shale Member, Cuyahoga Formation in the abandoned Medal Brick and Tile Quarry, Wooster, Wayne County, Ohio.

Description.—Crown medium in size. Aboral cup low cone shaped (Fig. 5.5), height to width ratio ~0.6; basal concavity rimmed by ridge on basal plates, plates gently convex, smooth plate sculpturing.

Infrabasal circlet confined to basal concavity, not visible in lateral view. Basal circlet ~37% of aboral cup height, ridge around the basal circlet at the proximal lateral edge of aboral cup; basal plates presumably five, hexagonal, ~1.6 times wider than high, much smaller than radial plates. Radial circlet ~63% of aboral cup height; radial plates presumably five, pentagonal, slightly higher than wide. Radial facets plenary, indentation on margin of radial facet for patelloid process of first primibrachial.

CD interray and anal sac unknown.

Arms robust, branch two times as known with poor isotomy (Fig. 5.5). Brachials rectangular uniserial, convex, straight sides, wider than high, well-developed patelloid processes, smooth plate sculpturing.

Column circular in shape, holomeric, heteromorphic, distinct proxistele and mesistele. Proxistele homeomorphic, columnals ~10 times wider than high, latus convex; mesistele heteromorphic, distal portion of preserved mesistele with N212 pattern, nodals significantly larger than internodals (Fig. 5.5). Distal mesistele, dististele, and holdfast not known.

Materials.—CMNH 5215.

Measurements.—CMNH 5215: CrH, 35.9; ACH, 4.4; ACW, 8.9; CoH, 29.0*.

Remarks.—A single, incomplete flexible crinoid is known from the Wooster Shale Member. This is a specimen with an aboral cup, most of one arm, a bit of a second arm, the proxistele, and the proximal portion of the mesistele (Fig. 5.5). This specimen may be a new species; but a full understanding of the arm branching pattern and posterior interray is needed to assign this specimen to a species.

Taxocrinus is a geographically widespread and temporally long-ranging Mississippian–Devonian flexible crinoid. Four species of *Taxocrinus* have been reported from the early Tournaisian of North America, including *T. communis* and *T. kellogi* from the Cuyahoga Shale Member of the Cuyahoga Formation and *T. hollandi* and *T. intermedius* from the Maynes Creek Formation. In addition, *Dactylocrinus tardus* (Hall, 1862) is also known from the Meadville Shale Member of the Cuyahoga Formation. *Dactylocrinus tardus* has endotomous arm branching above the primaxil, which sharply contrasts with *Taxocrinus*, in general, and with *Taxocrinus* sp. from the Wooster Shale Member. *Taxocrinus* sp. is also distinct from the other four early Tournaisian species assigned to *Taxocrinus*. *Taxocrinus communis* differs by having first interradial plates sutured between first primibrachials and adjoining rays, and the proximal portion of the mesistele is homeomorphic with large columnals. In contrast, *T.* sp. from the Wooster Shale Member lacks an interradial plate between first primibrachials and has a heteromorphic proximal portion of the mesistele. *Taxocrinus hollandi* has infrabasal plates visible in lateral view, basal plates the largest plates in the aboral cup, narrow arms with brachials higher than wide, and an indistinct boundary between the proxistele and mesistele, whereas *T.* sp. from the Wooster Shale Member has infrabasals not visible in lateral view, radial plates the largest plates of the aboral cup, wide arms with brachials wider than high, and a distinct boundary between the proxistele and mesistele. *Taxocrinus intermedius* has a subspherical-shaped crown, infrabasals visible in lateral view, as many as four ranges of regular interradial plates between radials and fixed primibrachials of regular interrays, and intraradials between secundibrachials within a ray; whereas *T.* sp. presumably has an elongate crown, infrabasals are not visible in lateral view, and does not have either interradial or intraradial plates. *Taxocrinus kellogi* has infrabasal plates visible in lateral view, one interradial between first primibrachials of adjacent regular interrays, and short, stout spines on every axillary brachial; whereas *T.* sp. from the Wooster Shale does not have infrabasal plates visible in lateral view, lacks interradial plates, and lacks spines on axillary brachials.

The Wooster Shale Member *Taxocrinus* specimen (Fig. 5.5) is distinct from any known congener. However, the morphology of this specimen is insufficiently known to justify naming a new species, so this single specimen is left in open nomenclature as *Taxocrinus* sp.

Magnorder Eucladida Wright, 2017
Cyathoformes incertae sedis: 'Poteriocrinida' Jaekel, 1918
Family Decadocrinidae Bather, 1890
Genus *Decadocrinus* Wachsmuth and Springer, 1880

Type species.—*Poteriocrinus* (*Scaphocrinus*) *scalaris* Meek and Worthen, 1870.

Included species.—*Decadocrinus aegina* (Hall, 1863); *D. baumgardeneri* Laudon and Beane, 1937; *D. brazeauensis* Laudon, Parks, and Spreng, 1952; "*D.*" *constrictus* Lane, Waters, and Maples, 1997; *D. crassidactylus* Laudon, 1936; *D. clypeus* Webster, Maples, and Yazdi, 2007; *D. decemnodosus* Goldring, 1923; "*D.*" *elongatus* Lane, Waters, and Maples, 1997; *D.*? *exornatus* Hauser, 1999; *D. gregarious* (Williams, 1882); *D. hughwingi* Kesling, 1964; *D. inordinatus* n. sp.; *D. insolens* Goldring, 1923; *D. kersadiouensis* Le Menn, 1985; *D. killawogensis* Goldring, 1923; *D. laevis* n. sp.; *D. liriope* Wachsmuth and Springer, 1880; *D. multinodosus* Goldring, 1923; *D. multinodosus* var. *serratobrachiatus* Goldring, 1923; *D. nereus* (Hall, 1862); *D. oaktrovensis* Webby, 1961; *D. ornatus* Goldring, 1954; *D. pachydactylus* Laudon, 1936; *D. penicilliformis* (Worthen, 1882); *D. regulatis* Strimple, 1939; *D. rugistriatus* Goldring, 1923; "*D.*" *rugosus* Lane, Waters, and Maples, 1997; *D. scalaris* (Meek and Worthen, 1870); *D. spinobrachiatus*

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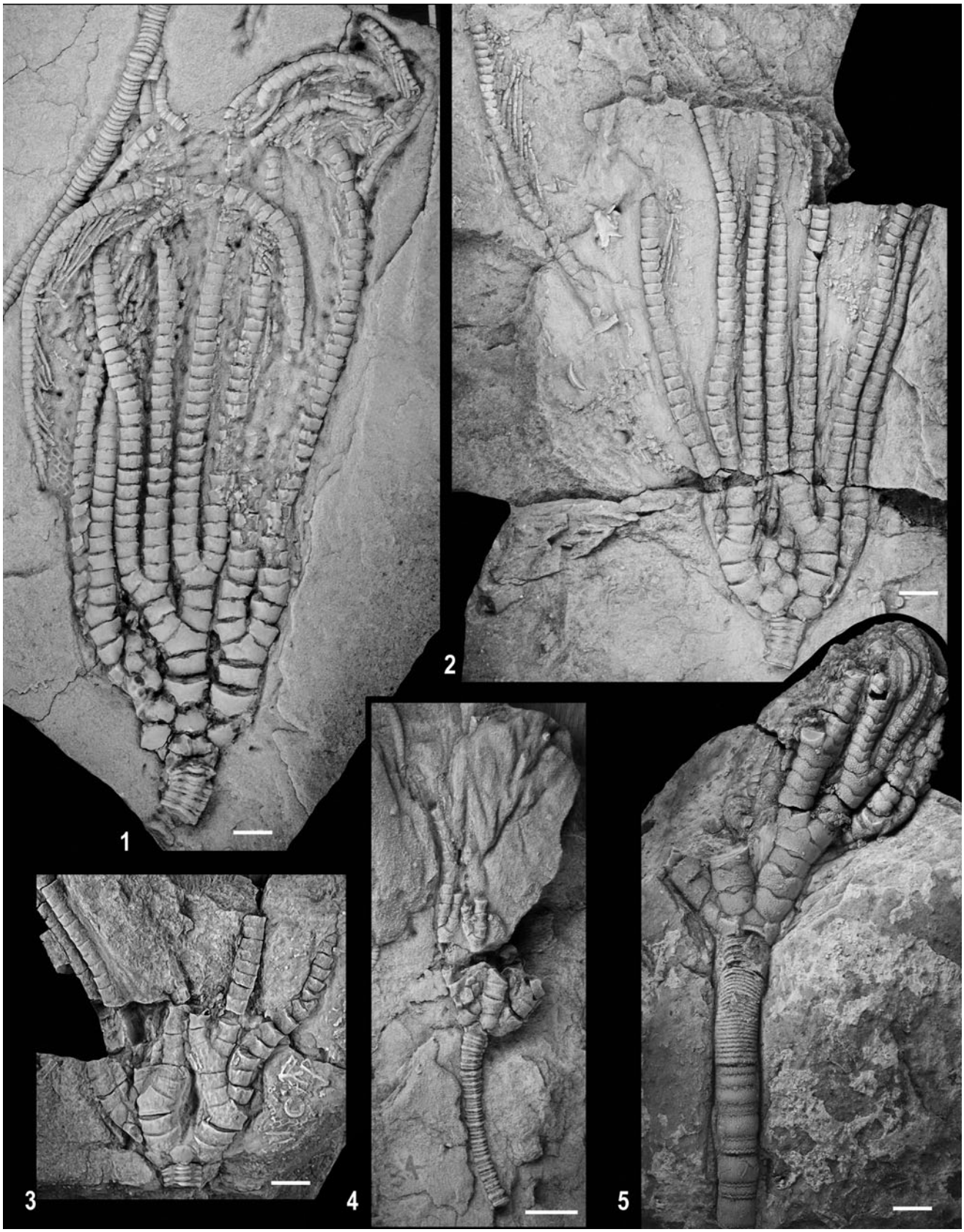

Figure 5. Eucladid crinoids from the Wooster Shale Member. (**1**) *Decadocrinus laevis* n. sp., CMNH 4873, holotype, lateral view of partially disarticulated crown with proximal column attached. (**2, 3**) *Decadocrinus inordinatus* n. sp.; (**2**) OSU 53548, holotype, CD-interray view of partial crown with proximal column attached; (**3**) CMNH 5214a, paratype, lateral view of a partial crown with proximal column attached. (**4**) Eucladid indeterminate, CMNH 5213, juvenile specimen with a partial crown and proximal portion of the column preserved. (**5**) *Taxocrinus* sp., CMNH 5215, partial crown with column, note the striking contrast between columnals of the proxistele versus the mesistele. Scale bar represents 5.0 mm in all. All specimens coated with ammonium chloride sublimate for photography.

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Goldring, 1938; *D. spinulifer* Laudon, 1936; *D. stewartae* Kier, 1952; *D. tumidulus* (Miller and Gurley, 1893); "*D.*" *usitatus* Lane, Waters, and Maples, 1997; *D. vintonensis* Thomas, 1924; *D. wrightae* Goldring, 1954; and *D. wrightae silicaensis* Kesling, 1971.

Occurrence.—Devonian to Pennsylvanian; Canada, China, France, Iran, United Kingdom, United States.

Remarks.—Generic assignment of Wooster Shale Member eucladids is problematic. These taxa may represent a new genus, but our lack of knowledge of key morphological features (e.g., the nature of arm branching in the A ray) precludes erecting a new genus for these species. These crinoids are most closely associated with *Decadocrinus* and *Pachylocrinus* Wachsmuth and Springer, 1880 (see Kammer and Ausich, 1993, table 1); however, both *Decadocrinus* and *Pachylocrinus* have historically served as catch-all genera for Devonian and Mississippian eucladids with two primibrachials (T.W. Kammer, personal communication, 2023). Further, as presently understood (see Webster, 2014), both of these genera are exceedingly long-ranging (Devonian to Pennsylvanian) and morphologically diverse. Kammer and Ausich (1993) tackled this problem for some early Viséan species, but further work is necessary. The type species of *Decadocrinus* and *Pachylocrinus*, *D. scalaris* and *P. aequalis*, respectively, are strikingly distinct, but species currently assigned to each genus blur the distinctions of the type species. A systematic review of the genus concepts of eucladids with two primibrachials and assignment of species is much needed, but such an analysis is beyond the scope of the present study.

As noted above, the type specimens of *Decadocrinus* and *Pachylocrinus* are distinct, but neither closely resembles the two Wooster Shale Member eucladids under consideration herein. However, it is our judgement that these two Wooster Shale Member species more closely resemble the collection of species currently recognized in *Decadocrinus* than those assigned to *Pachylocrinus*. Therefore, for this study, we assign these two new species to *Decadocrinus* with full recognition that they may be reassigned to a new genus after further systematic study. Assignment of these species to *Decadocrinus* is considered tentative pending further study.

The two Wooster Shale Member species of *Decadocrinus* share the following characteristics: infrabasals visible in lateral view, number of primibrachials, number of secundibrachials if branched, free arm branching, shape of the brachials, shape of pinnules, and column shape. As discussed below, they have contrasting aboral cup shape, aboral cup and brachial sculpturing, and shape of the radial plates. The Wooster Shale Member *Decadocrinus* species are compared to other current species in this genus in Supplemental Table 4.

Decadocrinus laevis new species
Figure 5.1

Type.—Holotype: CMNH 4873.

Diagnosis.—Low cone aboral cup shape; plate sculpturing smooth with scalloped plate margins; infrabasal plates visible in lateral view; radial plates ~1.25 times wider than high; radial facets plenary, declivate, crescentic; 12 or more total free arms; arm branching isotomous; second primibrachial axillary; third secundibrachial axillary if secundibrachitaxis branches; depression at midpoint along brachial-to-brachial sutures; brachials rectilinear uniserial; column shape pentalobate.

Occurrence.—Wooster Shale Member, Cuyahoga Formation; Wooster, Wayne County, Ohio in the abandoned Medal Brick and Tile Quarry, Wooster, Wayne County, Ohio.

Description.—Crown large in size. Aboral cup probably low cone shape (if uncompacted), height to width ratio of compressed aboral cup ~0.8; plates gently convex, smooth sculpturing, scalloped plate margins (Fig. 5.1).

Infrabasals presumably five and equal in size as known, visible in lateral view. Basal plates presumably five, hexagonal, smaller than radial plates, ~1.56 times wider than high. Radials presumably five, pentagonal, ~2.0 times wider than high. Radial facets plenary, crescentic, declivate, articular ridge across width of facet, an aboral ligament groove across most of the width of the facet.

CD interray plating slightly disarticulated, presumably three posterior plates in aboral cup interpreted as follows: radianal plate beneath and to the left of the C ray radial plate, anal X above to left of radianal and between C and D radial plates, and proximal part of right sac plate in articulation with the C radial to right and radianal beneath; above these plates a biseries of higher than wide plates lead to anal sac (Fig. 5.1).

Anal sac unknown.

Arms long, pinnulate, branch once or twice with poor isotomy; 12 or more total free arms. Primibrachials wider than high, primibrachial 2 axillary, primaxil wider than high. Secundibrachials wider than high, if secundibrachials branched secundibrachial 3 axillary. All brachials rectangular uniserial, gently convex aborally, straight sides, and a central depression along suture with adjacent brachials. Pinnules long, slender.

Proximal column pentalobate, holomeric, heteromorphic (N1) (Fig. 5.1). Lumen and holdfast unknown.

Etymology.—The species name, *laevis*, means smooth (L., m.) and refers to the smooth aboral cup plate sculpturing.

Measurements.—CMNH 4873 (holotype): CrH, 119.0; ACH, 11.0*; ACW, 15.0*; ColH, 7.0*.

Remarks.—*Decadocrinus laevis* n. sp. is distinguished from *D. inordinatus* n. sp. because the former has a low cone-shaped aboral cup, smooth plate sculpturing with scalloped aboral cup margins, radial plates ~1.25 times wider than high, and a depression at the midpoint along brachial-to-brachial sutures. In contrast, *D. inordinatus* n. sp. has a low bowl-shaped aboral cup, irregularly reticulate plate sculpturing that approaches irregular ridges on radial plates, plate margins not scalloped, radial plates ~1.6 times wider than high, and irregularly reticulate plate sculpturing on brachials.

Comparison to other species of *Decadocrinus* is in Supplemental Table 4.

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Decadocrinus inordinatus new species
Figure 5.2, 5.3

Type.—Holotype: OSU 53548; paratypes: CMNH 5214a, CMNH 5214b.

Diagnosis.—Low bowl aboral cup shape; plate sculpturing irregularly reticulate and approaches irregular ridges on radial plates; infrabasal plates visible in lateral view; radial plates ~1.6 times wider than high; radial facets plenary, declivate, crescentic; 12 or more total free arms; arm branching isotomous; second primibrachial axillary; third secundibrachial axillary if secundibrachitaxis branches; irregularly reticulate sculpturing on brachials; brachials rectilinear uniserial; column shape pentalobate.

Occurrence.—Wooster Shale Member, Cuyahoga Formation; Wooster, Wayne County, Ohio, in the abandoned Medal Brick and Tile Quarry, Wooster, Wayne County, Ohio.

Description.—Crown large in size (Fig. 5.2), aboral cup low bowl shaped, height to width ratio ~0.43, plates gently convex with irregularly reticulate sculpturing that on radial plates approaches irregular ridges projecting obliquely downward from rim of radial facets (Fig. 5.3).

Infrabasals circlet ~11% of aboral cup height, visible in lateral view; infrabasal plates presumably five. Basal circlet ~41% of aboral cup height; basal plates presumably five, hexagonal, smaller than radial plates ~1.5 times wider than high. Radial circlet ~48% of aboral cup height; radials presumably five, pentagonal, ~1.7 times wider than high. Radial facets plenary, slightly crescentic, radial facet topography unknown.

CD interray with three posterior plates in aboral cup, radianal below and to the left of the C radial plate, anal X above to the left of radianal and sutured to the D radial plate, right sac plate with proximal part in sutural contact with radianal below and C radial to the right (Fig. 5.2).

Anal sac unknown.

Arms long, slender, branch once or twice with poor isotomy; 12 or more total free arms. Primibrachials wider than high; if branched, primibrachial 2–3 axillary, primaxil wider than high. Secundibrachials wider than high; if branched, secundibrachials 3 or higher axillary. All brachials rectangular uniserial, convex aborally, straight sides, and plate sculpturing same as aboral cup plate sculpturing. Pinnules long, slender.

Proximal column pentalobate (Fig. 5.2), holomeric, heteromorphic, lumen pentalobate, holdfast unknown.

Etymology.—The species name means irregular (Latin) and refers to the sculpturing on the aboral cup plates.

Measurements.—OSU 53548 (holotype): CrH, 50.0*, ACH, 4.7: ACW, 14.0*; ColH, 3.0*. CMNH 5214a (paratype): CrH, 64.9*, ACH, 5.6: ACW, 14.3; ColH, 7.4*. CMNH 5214b (paratype): CrH, 47.0*.

Remarks.—*Decadocrinus inordinatus* n. sp. is compared to *D. laevis* n. sp. in the discussion of *D. laevis* n. sp. and to all species currently assigned to *Decadocrinus* in Supplemental Table 4.

Eucladida indeterminate
Figure 5.4

Remarks.—CMNH 5213 (Fig. 5.4) is a juvenile eucladid crinoid with a pentalobate column, infrabasal plates not visible, in lateral view, three or more primibrachials, and arms that probably branch two times. The presence of three primibrachials distinguishes this crinoid from the Wooster Shale Member *Decadocrinus* species, but the lack of other known characters precludes assigning this specimen to a genus or species, Thus, it is left in open nomenclature as Eucladida indeterminate.

Preservation

As described above, the Wooster Shale Member is predominantly dark gray shale with common siderite concretions and scattered concentrations of brachiopods, crinoids, mollusks, and bryozoans. The most prominent fossils on the outcrop are brachiopods (large spiriferinids and rhynchonellids), crinoid pluricolumnals, and platyceratid gastropods. Crinoids are variously preserved from completely disarticulated fragments to complete crowns with the proximal column attached. The most common crinoidal remains are individual columnals and lengths of pluricolumnals. If multiple pluricolumnals are preserved together, they are either randomly oriented or strongly aligned. Individual lengths of a pluricolumnal also may be broken into shorter "broken stick" column segments (Baumiller and Ausich, 1992), suggesting that these pluricolumnals laid exposed on the sea floor for a short time.

Crinoids are preserved in both the "shaving brush" and "starburst" trauma postures (Baumiller et al., 2008; Messing et al., 2021). Two of the five specimens of *C. simplex* are preserved in a partial starburst posture (e.g., Fig. 4.5), but the majority of other specimens are preserved in a well-defined shaving brush posture (e.g., Figs. 2.4, 4.1, 5.1). The occurrence of crinoids in these trauma postures is consistent with episodic high turbulence events, which is suggested by lenses of crinoidal packstone (some with shale rip-up clasts) in the Wooster Shale Member. This is consistent with a relatively shallow depositional environment between the fair-weather and storm wave bases (Clayton et al., 1998).

Individual crinoid specimens occur in several preservational modes, indicating a complex diagenetic history for these fossils. Perhaps the most common state of preservation is for crinoid plates to be preserved as external molds on outcrop bedding surfaces. In this condition, specimens simply disintegrate due to weathering, and collected specimens are very fragile. Crinoid plates are also commonly preserved with their original calcite. Specimens that retain calcite preservation of their plates are encased in shale (e.g., Figs. 2.3, 5.1, 5.2, 5.5).

Fossils in the Wooster Shale, including the crinoids, are commonly preserved in discrete siderite concretions (Fig. 6.1, 6.2). Siderite-replaced crinoids also may be weathered free, implying that the calcite plates were replaced by siderite even though the specimen was totally encased in shale (Fig. 2.1). Crinoids also may occur in a siderite bed completely or partially replaced by siderite (Fig. 3). If partially replaced, several variations of replacement occur. For example, the outer portion of crinoid plates may be replaced by siderite, the inner portion is

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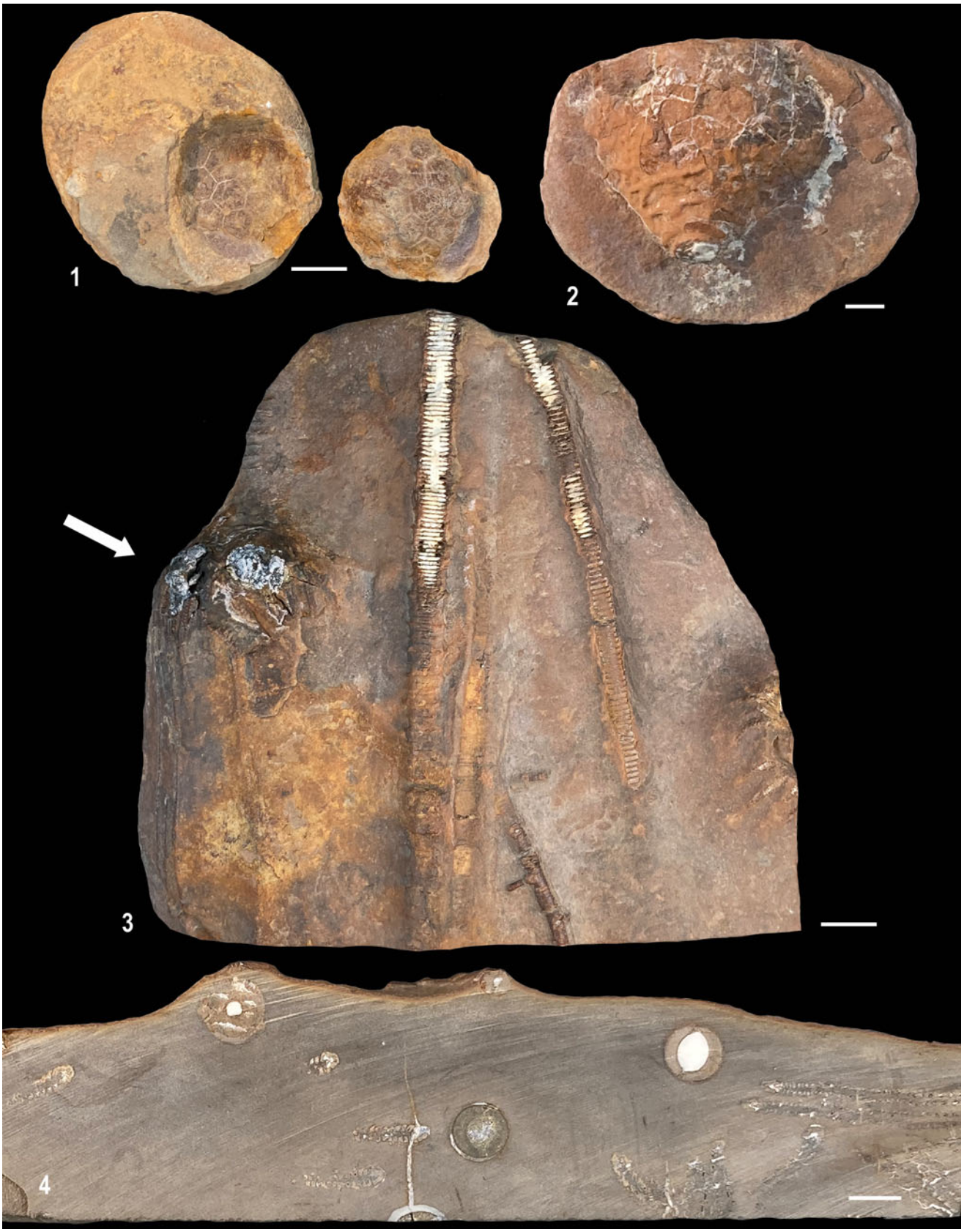

Figure 6. Siderite preservation of crinoids in the Wooster Shale (all specimens uncoated). (**1**) CMNH 18017, two parts of a siderite concretion with an unidentifiable camerate crinoid. (**2**) *Cactocrinus woosterensis* n. sp., OSU 53550, paratype, specimen in a siderite concretion (compare to Fig. 2.2). (**3, 4**) CMNH 18018 bed completely replaced by siderite with crinoids partially replaced (white is calcite, gray coloration at arrow is pyrite, remainder of bed is siderite); (**3**) upper part of bedding surface with partially replaced columnals; on left side of bed an upside down *Cactocrinus woosterensis* n. sp., specimen replaced with siderite, partially buried, and with "pyrite rot" destroying the calyx; (**4**) cross section through bed illustrating various modes of columnal replacement with siderite; note infilling of fractures with calcite. Scale bar represents 5.0 mm in (**1, 2, 4**) and 10.0 mm in (**3**).

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Figure 7. CMNH 18019 bed largely replaced by siderite (white is calcite). (**1**) Upper part of bedding surface completely replaced; (**2**) cross section through bed illustrating various modes of replacement of columnals with siderite; note infilling of fractures with calcite; bed is slightly tilted to illustrate that the pattern of replacement on the cross section continues into the bed. Scale bar represents 5.0 mm in (**2**), 10.0 mm in (**1**).

calcite (Fig. 6.3, 6.4), or the opposite may occur (Fig. 7.2). Alternatively, the distribution of siderite and calcite may be more random (Figs. 6.4, 7.2). In beds with crinoids preserved in both calcite and siderite, the calcite is secondary. The original crinoid plates, which were composed of a single crystal of calcite, have been replaced by a fine- to medium-grained calcite (Figs. 6.4, 7.2). Further, in some instance, the surrounding siderite bed may have calcite-filled fractures that are connected to calcite portions of crinoid plates (Figs. 6.4, 7.2). A few crinoids in siderite concretions are also replaced with pyrite.

Because most of the specimens with moldic preservation disintegrate with weathering on the outcrop, it is impossible to determine the most common mode of preservation in the Wooster Shale Member. However, we presume that calcite preservation

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is the dominant mode. Based on collected specimens, preservation associated with siderite beds and preservation in shale are co-dominant, and preservation in small, definable siderite concretions (Fig. 6.1, 6.2) is the rarest.

The preservation of crinoids within siderite concretions has been described previously in the upper Carboniferous Francis Creek shale of Illinois (Lane, 1969) and the upper Carboniferous Copan crinoid Lagerstätte of Oklahoma by Thomka and Lewis (2013). The Wooster Shale Member concretions closely resemble "Type 1 large concretions lacking distinct nuclei" (Thomka and Lewis, 2013), which are oblong in shape, with the longest axes measuring at least seven cm and often significantly larger (up to 25 cm). These concretions are parallel to bedding, which Seilacher (2001) attributed to burial compaction during formation. The fossils in the Francis Creek shale, Copan Lagerstätte, and Wooster Shale Member siderite are uncrushed, indicating that the concretions formed early within the top meter of the sediment column. Thomka and Lewis (2013) proposed that these large siderite concretions formed in a stable alkaline environment rich in ferrous iron and bicarbonate over a prolonged period, likely during a time of sediment starvation.

Mississippian crinoid faunas

The Mississippian is the "Age of Crinoids" (Kammer and Ausich, 2006), and crinoids were important faunal elements in many depositional settings during the Mississippian. Cuyahoga Formation faunas (Hall, 1863; Ausich and Roeser, 2012; Kammer and Roeser, 2012) are preserved in siliciclastic facies, which is atypical for many Tournaisian crinoid faunas (e.g., Ausich, 1999a, b, and references therein). Rather, the composition of the Cuyahoga crinoids and the paleoenvironmental setting are more similar to some early Viséan faunas in siliciclastic settings, such as at Crawfordsville, Indiana (van Sant and Lane, 1964; Lane, 1973; Ausich, 1999c).

In comparison to the Meadville Shale Member of the Cuyahoga Formation, the Wooster Shale Member crinoid fauna is small (30 in the former and nine in the latter) (Table 2). Representatives of every major clade occur in the Meadville Shale Member, and the Wooster Shale Member has every clade represented except the disparids. As discussed in detail above, three new species of camerates and two new species of eucladids (Cyathoformes incertae sedis: 'Poteriocrinida') are described from the Wooster Shale Member fauna. Only one taxon, *Cyathocrinites simplex*, is shared in both faunas.

Another interesting aspect of the Wooster Shale Member crinoid fauna is the distribution of new species among clades. Kammer et al. (1997, 1998) identified differential species longevities among different major crinoid clades. Disparids and primitive cladids (cyathoformes incertae sedis: Cyathocrinida, herein) have longer species longevities and were regarded as niche generalists. In contrast, camerates, flexibles, and advanced cladids (Cyathoformes incertae sedis: Poteriocrinida, herein) had shorter species durations and were regarded as niche specialists. Sample size of the Wooster Shale Member fauna is too small to suggest any robust conclusions. However, all five new species (*Agaricocrinus murphyi* n. sp.; *Cactocrinus woosterensis* n. sp.; *Cusacrinus brushi* n. sp.; *Decadocrinus laevis* n. sp.; and *Decadocrinus inordinatus* n. sp.) that we described from the Wooster Shale Member belong to niche specialist clades with shorter species duration, which is consistent with the conclusions of Kammer et al. (1997, 1998).

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Declaration of competing interests

The authors declare none.

Data availability statement

Data available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.qnk98sfmr.

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