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CRINOID ASSEMBLAGES FROM THE FORT PAYNE FORMATION (LATE OSAGEAN, EARLY VISÉAN, MISSISSIPPIAN) FROM KENTUCKY, TENNESSEE, AND ALABAMA

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ABSTRACT—The Mississippian Fort Payne Formation of Kentucky, Tennessee, and Alabama is well known for its abundant crinoids and a diverse array of autochthonous and allochthonous carbonate and siliciclastic facies. Using Principal Coordinate Analysis and Non-Metric Multidimensional Scaling, it is demonstrated that distinct, contemporaneous, and geographically adjacent autochthonous facies in south-central Kentucky supported distinct crinoid assemblages. The two carbonate buildup facies had different assemblages dominated by camerate crinoids, carbonate channel-fill deposits were dominated by advanced cladid crinoids and the camerate *Elegantocrinus hemisphaericus*, and green shale facies supported a fauna dominated by disparids and primitive cladid crinoids. Allochthonous facies contain neither distinctive nor exotic taxa. Thus, these transported assemblages are considered a mixture of elements from the recognized, autochthonous facies. Faunal assemblages from Dale Hollow Reservoir are allochthonous; and faunas in north-central Alabama and south-central Tennessee are different from others, which may reflect slight biogeographic distinctions.

INTRODUCTION

Reefs and other mound facies may contain identifiable frame-building or frame-binding organisms, and these settings typically also supported an abundant and diverse associated fauna. During the Paleozoic, this associated fauna is commonly comprised of brachiopods, bryozoans, and stalked echinoderms and is typically treated as allochthonous (transported) debris with limited information for delineation of sedimentary facies. Alternatively, many of these fossils are parautochthonous (i.e., not in situ but preserved in the facies in which they lived) (Kidwell et al., 1986).

Here we examine this question with more than 5,200 crinoid calyxes and blastoid thecae identified from distinct sedimentary facies in the Lower Mississippian Fort Payne Formation (late Osagean, early Viséan) from the Lake Cumberland region in south-central Kentucky (Fig. 1). Using various multivariate statistical methods, we test whether different authochthonous sedimentary facies supported distinct crinoid assemblages and, thus, were part of separate paleocommunities. Further, additional coeval crinoid faunas are evaluated from allochthonous facies from the Lake Cumberland region, from north-central Tennessee, south-central Tennessee, and north-central Alabama, in order to understand better the Lake Cumberland occurrences and to test whether any assemblages from the Lake Cumberland region can be identified elsewhere.

Crinoidal debris is the most abundant fossil in the Fort Payne Formation, and encrinite beds are common. Systematically, the echinoderm fauna is diverse with crinoid and blastoid remains most common. For taphonomic reasons, camerate crinoid thecae are the most abundant crinoids (Meyer et al., 1989), but every major Mississippian crinoid clade is present in the Fort Payne fauna (Table 1). In most cases partial calyxes and individual calyx plates can be identified to species.

GEOLOGICAL SETTING

The Fort Payne Formation is a time-transgressive Mississippian sediment wedge that persists from Georgia to southern Illinois. The north-south outcrop belt from south-central Kentucky to north-central Alabama is late Osagean (early Viséan) in age based on conodont and crinoid biostratigraphy (Ausich and Meyer, 1990; Leslie et al., 1996; Krivicich et al., 2013). The formation includes a diverse suite of siliciclastic and carbonate lithofacies with distinct lithologies in different local geographic areas. In south-central Kentucky (Lake Cumberland region) and north-central Tennessee, the Fort Payne is lithologically diverse including both autochthonous and allochthonous carbonate and siliciclastic lithologies. In northern Alabama and south-central Tennessee (this stratigraphic unit is referred to as the Fort Payne Chert in Alabama), the Fort Payne has a high content of chert and is deeply weathered so that the rocks are informally referred to as "chert dirt." Early interpretations by Chowns and Elkins (1974) and MacQuown and Perkins (1982) suggested that the Fort Payne Formation was deposited in very shallow water. In contrast, Lewis and Potter (1978), Pryor and Sable (1974), Ausich and Meyer (1990), and others concluded that the Fort Payne Formation was a record of epicontinental basin sedimentation. Today, the Fort Payne Formation is regarded as a progradational, shoaling-upward, basin-filling sequence (Ausich and Meyer, 1990; Khetani and Read, 2002; Krause and Meyer, 2004; Greb et al., 2008). The sequence architecture of the Fort Payne and related units is discussed in Johnson (2003), Khetani and Reed (2002), and Krause and Meyer (2004).

South-central Kentucky.—The Fort Payne Formation is well exposed in the Cumberland Saddle region of south-central Kentucky, particularly along the shores of Lake Cumberland in Russell, Wayne, and Clinton counties (Lewis and Potter, 1978; Meyer et al., 1995). The formation ranges in thickness from 76 m (250 ft) in the southwest (Albany, Kentucky area) to 15 m (50 ft) in the northeast (Mt. Vernon, Kentucky area).

The Fort Payne thins abruptly along the "Borden Front" (Lewis and Potter, 1978; Ausich and Meyer, 1990; Meyer et al., 1995), which represents the western extent of the Borden Delta that prograded into central Kentucky and stopped. The Borden Front is approximately 16 km (10 mi) wide and was located along a northwest-southeast trend less than 32 km (20 mi) northeast of the

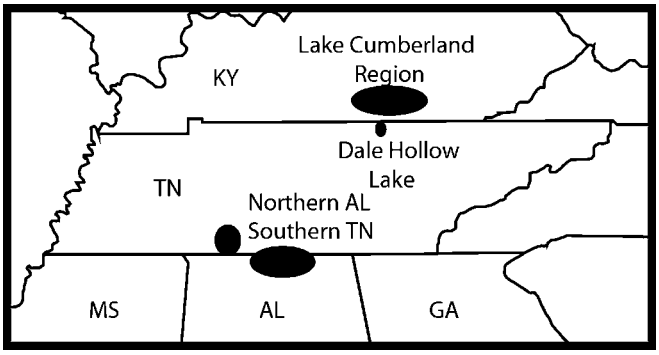

FIGURE 1—Regions under study with fossiliferous Fort Payne Formation rocks.

Lake Cumberland area (Meyer and Ausich, 1992). After reaching central Kentucky, the Borden progradation stopped, resulting in an abandoned clinoform. Renewed Borden siliciclastic deposition shifted to the north into Indiana. The break in sedimentation after the Borden is recorded by the presence of the Floyds Knob Bed, a thin glauconitic unit, indicating starved basin conditions. When deposition resumed in the basin, the Fort Payne Formation was deposited as a time transgressive unit from east to west (Ausich and Meyer, 1990). The Fort Payne is characterized by clinoform features indicative of progradational filling of a basin (Meyer et al., 1995).

In south-central Kentucky, deposition of the Fort Payne Formation took place within the late Osagean based on two lines of faunal evidence. First, the conodont, *Gnathodus texanus* Roundy, occurs in these rocks, which is characteristic of the late Osagean *Gnathodus texanus* Zone of Lane et al. (1980) and contemporaneous with the Keokuk Limestone of the Mississippi River Valley of North America (Ausich and Meyer, 1990; Meyer and Ausich, 1992; Krause et al., 2002). Second, at least 16 pelmatozoan echinoderm species from the Fort Payne also occur in the Keokuk (late Osagean) or its stratigraphic equivalents (Ausich and Meyer, 1990; Meyer and Ausich, 1992; Krivicich et al., 2013). The Fort Payne is coeval along strike from south-central Kentucky to north-central Alabama (Krivicich et al., 2013).

South-central Kentucky lithofacies.—Seven distinct Fort Payne lithofacies are recognized in the Lake Cumberland area. The siliciclastic lithofacies include the "background" siltstone facies, the Jabez Sandstone Member, and the fossiliferous green shale facies. The carbonate lithofacies include wackestone buildups, crinoidal packstone buildups, sheetlike packstones, and channel-form packstones (Ausich and Meyer, 1990). These facies can also be divided into those that are autochthonous and those that are allochthonous (Table 1). Autochthonous facies are characterized by having relatively common in situ crinoid holdfasts; longer lengths of crinoid pluricolumnals; and although still rare, relatively more crinoid specimens with arms preserved (Meyer et al., 1989). The autochthonous facies are discrete lithological facies enclosed within the background facies. These include the fossiliferous green shales, wackestone buildups, crinoidal packstone buildups, and channel-form packstones (note: the channel-form packstone facies has allochthonous channel fill, but an autochthonous fauna occurs in this facies based on an autochthonous taphonomic signature [Meyer et al., 1989]). Allochthonous facies are characterized by having very few in situ crinoid holdfasts, shorter lengths of pluricolumnals, and very few crinoid specimens with arms preserved. These include sheetlike packstones, siltstones (that dominate the Fort Payne), and the Jabez Sandstone. The names of the localities and their facies designations are listed in Table 2. More specific locality information is in Ausich and Meyer (1990) and Krivicich et al. (2013). Crinoid calyxes and disarticulated plates were collected from 23 localities in the south-central Kentucky region.

TABLE 1—List of crinoid and blastoid taxa in the Fort Payne Formation.

Monobathrid Camerate Crinoids
Abatocrinus grandis
Abatocrinus n. sp.
Abatocrinus steropes
Actinocrinites gibsoni
Agaricocrinus americanus
Agaricocrinus crassus
Agaricocrinus wortheni
Alloprosallocrinus conicus
Dorycrinus gouldi
Eretmocrinus magnificus
Eretmocrinus ramulosus
Eucladocrinus millebrachiatus
Macrocrinus sp.
Magnuscrinus kammeri
Magnuscrinus praegravis
Paradichocrinus planus
Platycrinites hemisphaericus
Platycrinites saffordi
Thinocrinus lowei
Thinocrinus sp. 1
Thinocrinus sp. 2
Thinocrinus sp. 3
Uperocrinus apheles
Uperocrinus nashvillae
Uperocrinus robustus
Diplobathrid Camerate Crinoid
Gilbertsocrinus tuberosus
Primitive Cladid Crinoids
Atelestocrinus sp.
Barycrinus rhombiferus
Barycrinus sculptus
Barycrinus spurius
Barycrinus stellatus
Costalocrinus cornutus
Cyathocrinites asperrimus
Cyathocrinites farleyi
Cyathocrinites iowensis
Cyathocrinites kelloggi
Cyathocrinites multibrachiatus
Advanced Cladid Crinoids
Abrotocrinus cf. A. unicus
Adinocrinus nodosus
Adinocrinus sp.
Cestocrinus? sp.
Holcocrinus nodobrachiatus
Holcocrinus sp. 1
Holcocrinus sp .2
Parisocrinus? sp.
Pelecocrinus n. sp.
Scytalocrinus decadactylus
Springericrinus magniventrus
Disparid Crinoids
Catillocrinus tennesseeae
Halysiocrinus cumberlandensis
Halysiocrinus tunicatus
Synbathocrinus swallovi
Flexible Crinoids
Forbesiocrinus wortheni
Gaulocrinus bordeni
Gaulocrinus symmetros
Gaulocrinus veryi
Lecocrinus springeri?
Mespilocrinus kentuckyensis
Mespilocrinus romingeri
Metichthyocrinus clarkensis
Metichthyocrinus spp.
Methichtyocrinus tiaraeformis
Nipterocrinus monroensis
Wachsmuthicrinus spinosulus
Blastoids
Deliablastus cumberlandensis
Euryoblastus veryi
Granatocrinus granulatus
Metablastus sp.
Xyeleblastus magnificus

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Ausich and Meyer (1990) concluded that after the Borden deltaic wedge prograded into the Lake Cumberland region a relatively minor episode of eustatic sea level rise trapped sediment proximally and cleared the turbidity from the water column, thus allowing an episode of in situ carbonate buildup deposition in an otherwise siliciclastic basin. The green shale facies accumulated in relatively small, circumscribed areas and presumably formed local seafloor highs (based on the association of green shale mounds beneath carbonate buildups) with an abundant fauna (Ausich and Meyer, 1990; Norris, 1991; Meyer et al., 1992). It is not clear whether green shale deposition produced conditions favorable to high biotic productivity or biological processes mediated green shale deposition. Green shale mounds may occur in isolation and encased within siltstones; but more commonly, this facies is buried beneath crinoid wackestone buildups or crinoid packstone buildups. In wackestone buildups, there was a sharp break in deposition between siliciclastic green shale beneath and carbonate wackestone above. An equally sharp break in the faunas mirrored this change in lithology. In the crinoidal packstone mounds, the green shale core was overlain by interbedded crinoidal packstone and green shale with extensive crinoidal packstone flanks.

A drop in sea level resulted in an episode of rapid Fort Payne progradation. The deeper part of the Fort Payne basin was filled with the siltstone and sheet-like carbonate facies; and as the Fort Payne clinoform prograded, the Jabez Sandstone Member and shelf-edge grainstones accumulated near the platform/slope break. These units were periodically incised and filled by submarine canyons bringing sediments from the platform into the basin. This is comparable to the interpretation of faunas of the New Providence Shale in north-central Kentucky (Kammer, 1985). As the basin filled, all of these allochthonous facies were juxtaposed with the autochthonous facies, creating the "vast, heterogenous, and puzzling" character of the Fort Payne Formation (Lewis and Potter, 1978).

Dale Hollow Reservoir lithofacies.—Localities along the shores of Dale Hollow Reservoir are located in Pickett County, Tennessee (Fig. 1). At these localities, Fort Payne carbonates are thin- to medium-bedded, slightly wavy, discontinuous crinoidal-bryozoan packstones and wackestones. At locality CC, green shales are interbedded with carbonates with no discernible mound structure (Terry, 1989). Along Obey Creek arm (localities grouped as OBC), carbonates are interbedded with mounded green shales toward the west; but toward the east, carbonates are interbedded with black shales and dolomitic siltstones (Terry, 1989).

North-central Alabama and south-central Tennessee lithofacies.—The Fort Payne Chert in north-central Alabama was originally described by E. A. Smith in 1890 (Ruppel, 1979) as the rocks above the Chattanooga Shale and below the Hartselle Sandstone. On outcrop, it is characterized by very light to light-olive gray, thin- to thick-bedded, fine- to coarse-grained bioclastic limestone containing abundant nodules and beds of light to dark gray chert (Ruppel, 1979). The upper part of the formation consists of light-bluish gray laminated siltstone containing vugs lined or filled with quartz. The Fort Payne is richly fossiliferous with crinoid stems and calyx fragments, spiriferid brachiopods, and solitary corals; however, the major collections of silicified fossils are from a weathered clay soil residuum. Thus, it is not possible to make any interpretations of the original facies in which these faunas occurred. The Fort Payne Chert in north-central Alabama and south-central Tennessee is also late Osagean in age, based on conodonts (Ruppel, 1979) and the crinoid fauna (Krivicich et al., 2013). The Fort Payne Chert in north-central Alabama and south-central Tennessee is at the southern extent of the outcrop belt and dominated by carbonate facies, similar to the Lake Cumberland region. This accumulation of carbonates is separated from carbonates of south-central Kentucky by a region with relatively little carbonate accumulation.

STATISTICAL METHODS

This study is based on collections of pelmatozoan echinoderms (crinoids and blastoids) from south-central Kentucky, north-central Tennessee, north-central Alabama, and south-central Tennessee made by WIA, DLM, and their students. Collections from north-central Tennessee are largely from Terry (1989), and those from north-central Alabama and south-central Tennessee are from Krivicich (2011) and Krivicich et al. (2013) (including collections from R. Keyes). Where possible, all taxa are identified to species according to recent systematic revisions of Mississippian crinoids (Ausich and Kammer, 1990, 1991a, 1991b, 1992, 2008, 2009, 2010; Ausich and Meyer, 1992; Ausich et al., 1997; Kammer and Ausich, 1992, 1993, 1994; Meyer and Ausich, 1997). For statistical analysis, raw data were culled to include only species that occurred at three or more sites and localities with at least five species present. With these constraints, 42 species-level taxa from 28 localities were analyzed herein. These include 21 localities in the Lake Cumberland vicinity (13 autochthonous localities, eight allochthonous localities), two localities from along Dale Hollow Reservoir, and five localities in north-central Alabama and south-central Tennessee.

Principal Coordinate Analysis (PCO) and Non-Metric Multidimensional Scaling (NMMS) were used to test whether sedimentary facies had distinct crinoid assemblages. Analyses were performed on the following sequence of data sets: 1) crinoid species for autochthonous facies in the Lake Cumberland region; 2) crinoid species for all localities in the Lake Cumberland region; 3) crinoid species for both autochthonous facies in the Lake Cumberland region and sites in the Dale Hollow Reservoir region; 4) crinoid species for both autochthonous and allochthonous facies in the Lake Cumberland region and sites in the Dale Hollow Reservoir region; and 5) crinoid species for autochthonous facies in the Lake Cumberland region and sites in south-central Kentucky and north-central Alabama. For consistency, all analyses use the Euclidean Distance measure based primarily on presence-absence data. Statistical analyses were completed with PAST (PAlaeontological STatistics) (Hammer et al., 2001; Hammer and Harper, 2006).

RESULTS

Autochthonous facies from the Lake Cumberland region, including the green shale localities, BF9 and Celina, were compared using Principal Coordinate Analysis and Non-Metric Multidimensional Scaling. Figure 2.1 is a PCO analysis using relative abundance data of all Lake Cumberland localities from autochthonous facies, and Figure 2.2 is a PCO of the same data using presence-absence data. A few taxa, such as *Actinocrinites gibsoni*, *Alloprosallocrinus conicus*, and *Eretmocrinus magnificus*, and a few localities, such as CSS, CSN, OBB, and GC, have very high abundance. CSS and GC each have more than

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FIGURE 2—Statistical results from crinoid assemblage comparisons from localities in the Lake Cumberland region. *1*, Principal Coordinates Analysis of autochthonous localities with relative abundance data; *2*, Principal Coordinates Analysis of autochthonous localities with presence-absence data; *3*, Principal

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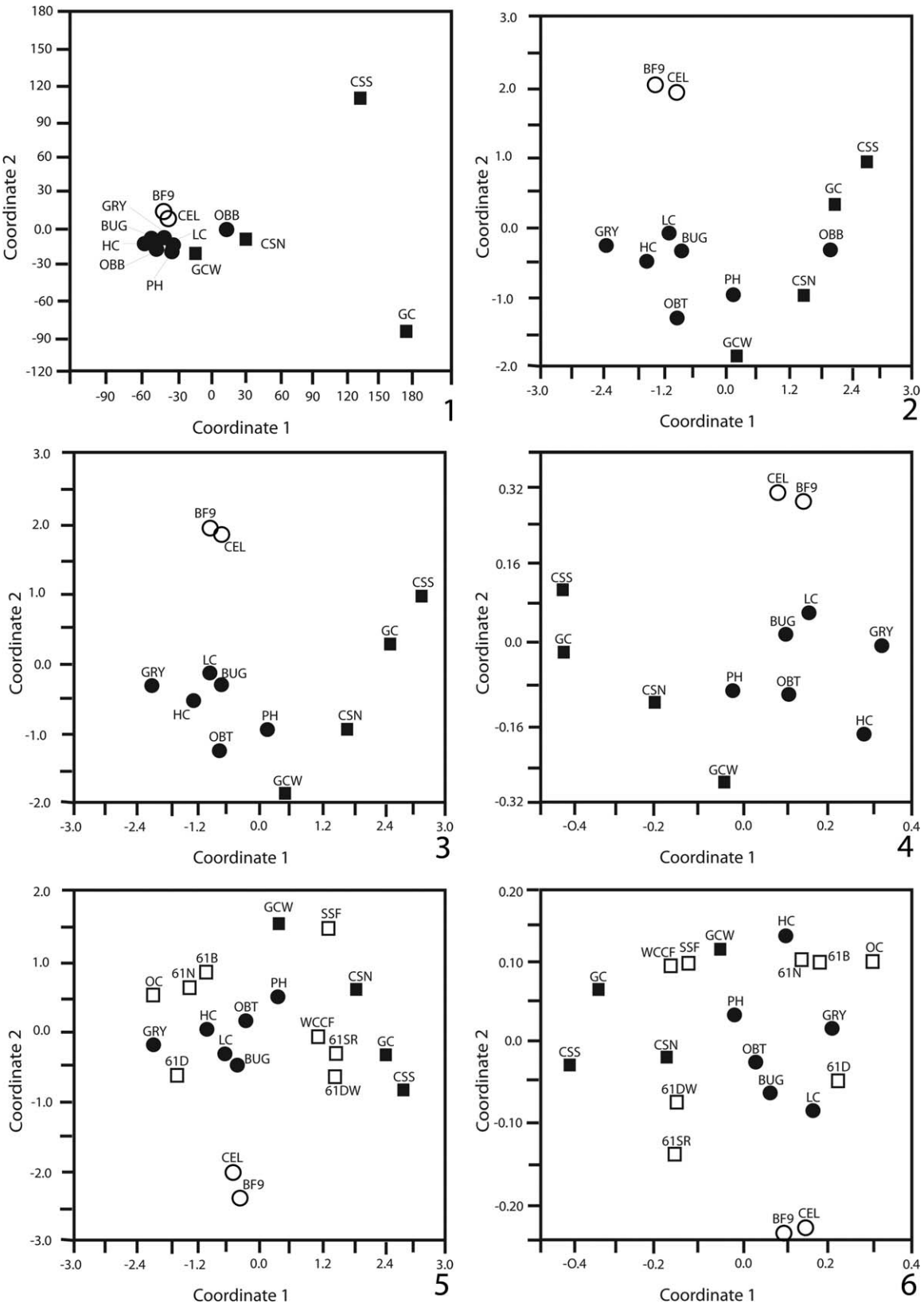

Coordinates Analysis of autochthonous localities with presence-absence data (without OBB locality); *4*, Non-Metric Multidimensional Scaling of autochthonous localities with presence-absence data (without OBB locality) (stress=1.67); *5*, Principal Coordinates Analysis of autochthonous and allochthonous localities with presence-absence data (without OBB locality); *6*, Non-Metric Multidimensional Scaling of autochthonous and allochthonous localities with presence-absence data (without OBB locality) (stress=0.249). Abbreviations given in Table 2; filled circle=wackestone buildup facies; open circle=green shale facies; filled square=packstone buildup facies; open square=allochthonous facies, Lake Cumberland; filled hexagon=Dale Hollow Reservoir localities; open hexagon=north-central Alabama and south-central Tennessee localities.

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TABLE 2—Localities analyzed in this study with facies, based on lithology bedding relationships (based on Ausich and Meyer, 1990; Terry, 1989; Krivicich, 2011; Krivicich et al. 2013).

Region and locality abbreviation	Locality	Facies
Lake Cumberland and South-Central Kentucky		
BF9	Black's Ferry 9	Green Shale
BT	Big Turbidite	Sheet-like Packstone
BUG	Bugwood	Wackestone Buildup
CSN	Cave Springs North	Packstone Buildup
CSS	Cave Springs South	Packstone Buildup
GC	Gross Creek	Packstone Buildup
GCW	Gross Creek West	Packstone Buildup
GRY	Greasy Creek	Wackestone Buildup
HC	Harmon Creek	Wackestone Buildup
HWY 61B	Highway 61B	Sheet-like Packstone
HWY 61D	Highway 61D	Sheet-like Packstone
HWY 61DW	Highway 61DW	Sheet-like Packstone
HWY 61N	Highway 61 North	Sheet-like Packstone
HWY 61RS	Highway 61RS	Green Shale
LC	Lily Creek	Wackestone Buildup
OBB	Owen's Branch Buildup	Green Shale
OBT	Owen's Branch Transect	Wackestone Buildup
OC	Otter Creek	Wackestone Buildup
PH	Pleasant Hill	Wackestone Buildup
SSF	Seventy-Six Falls	Packstone Buildup
SWPD	Swan Pond	Wackestone Buildup
WCCF	Wolf Creek/Caney Fork	Sheet-like Packstone
North-Central Tennessee		
CEL	Celina	Green Shale
Dale Hollow Reservoir—North-Central Tennessee		
CC	Cove Creek	Unknown
OBC	Obey Creek	Unknown
North-Central Alabama and South-Central Tennessee		
79		Unknown
301		Unknown
302		Unknown
306		Unknown
332		Unknown

twice the number of occurrences (709 and 646, respectively) than the next most abundant autochthonous locality. These disparities in abundance are undoubtedly responsible for the position of CSS and GC as outliers in Figure 2.1. Regardless of these very different data, the same basic structure also exists in Figure 2.2 that uses presence-absence data. Results from presence-absence data more clearly allow comparison among localities, so additional results presented are only from analyses using presence-absence data.

The crinoid assemblages correspond to the lithofacies identified based on sedimentologic, stratigraphic, and taphonomic criteria (Table 2). The only exception is Owens Branch Buildup (OBB) that is a very large, complex wackestone buildup with more than 300 specimens. In analyses, this fauna approaches that of the crinoid packstone buildups (Fig. 2.1, 2.2), presumably because the flank bed thickness and lithology of this wackestone buildup approached that of packstone buildup flank beds. For further analysis (Figs. 2.3–2.6, 3), OBB was omitted. Figure 2.3 and 2.4 results indicate that distinct crinoid assemblages correspond to distinct autochthonous lithofacies. The faunas from the green shale plot on nearly identical points in both analyses. In contrast, the carbonate facies are in a distinct region of the eigenvector space, with wackestone mounds and packstone mounds in distinct, adjacent regions.

All Lake Cumberland sites and localities to the west were compared (Fig. 2.5, 2.6) to assess the relationship between faunas from the autochthonous versus the allochthonous facies. The green shale facies still form a distinct group. However, in general, the distinction of the two carbonate buildups is blurred with some allochthonous facies plotting within the basic field of each buildup type. 61N is an assemblage associated with a wackestone mound, and it consistently plots among other wackestone mound assemblages.

Figure 3.1, 3.2 compare results from Dale Hollow Reservoir (Terry, 1989) to both autochthonous (only) and to autochthonous and allochthonous facies of the Lake Cumberland region, and Figure 3.3, 3.4 compares Dale Hollow Reservoir localities to all south-central Kentucky and north-central Tennessee localities. The two Dale Hollow localities plot close together and are most closely associated with a Fort Payne allochthonous facies. These two sites are more generally within the field of wackestone buildups; and from among crinoidal packstone localities, they are most similar to GCW.

Sites from south-central Tennessee and north-central Alabama are compared with the autochthonous facies of the Lake Cumberland region (Fig. 3.5, 3.6). Assemblages from south-central Tennessee and north-central Alabama are separated from the assemblages from the Lake Cumberland region but are closest to the GCW site.

DISCUSSION

Each autochthonous lithofacies in the Lake Cumberland region supported a distinctive assemblage of crinoid and blastoid species (Fig. 2.3, 2.4). The gross taxonomic composition of both carbonate buildups are very similar (Table 3). Camerate crinoids dominated both assemblages; disparids and primitive cladids are of modest importance and advanced cladids, flexibles, and blastoids rare. Although this abundance pattern is undoubtedly controlled in part due to taphonomic considerations (Meyer et al., 1989), the carbonate buildup composition stands in sharp contrast to the green shale and channel packstone facies.

The three most abundant crinoids in the wackestone buildup assemblage, with all localities summed, are *Agaricocrinus americanus* (27%), *Thinocrinus* sp. (23%), and *Alloprosallocrinus conicus* (13%). Of secondary importance are *Synbathocrinus swallowvi* (5%), *Catillocrinus tennesseeae* (4%), and *Eretmocrinus magnificus* (3%).

In the packstone buildup facies, the three most abundant taxa, with all localities summed, are *Eretmocrinus magnificus* (18%), *Actinocrinites gibsoni* (13%), and *Alloprosallocrinus conicus* (13%). Of secondary importance are *Halysiocrinus tunicatus* (9%) and *Agaricocrinus americanus* (8%). The primary distinction between the different carbonate buildups is that *Eretmocrinus magnificus* is dominant on packstone buildups and of only secondary importance on wackestone buildups, whereas *Agaricocrinus americanus* is of secondary importance on packstone buildups but dominant on wackestone buildups. Also a different actinocrinitid species dominates on each (*Thinocrinus* sp. on

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FIGURE 3—Statistical results from crinoid assemblage comparisons of Lake Cumberland region autochthonous localities to localities on Dale Hollow Reservoir and north-central Alabama/south-central Tennessee. *1*, Principal Coordinates Analysis comparing Lake Cumberland region autochthonous localities to Dale Hollow Reservoir localities with presence-absence data (without OBB locality); *2*, Non-Metric Multidimensional Scaling comparing Lake Cumberland region autochthonous localities to Dale Hollow Reservoir localities with presence-absence data (without OBB locality) (stress=0.627); *3*, Principal Coordinates Analysis comparing all Lake Cumberland region localities to Dale Hollow Reservoir localities with presence-absence data (without OBB locality); *4*, Non-Metric Multidimensional Scaling comparing all Lake Cumberland region localities to Dale Hollow Reservoir localities with presence-absence data (without

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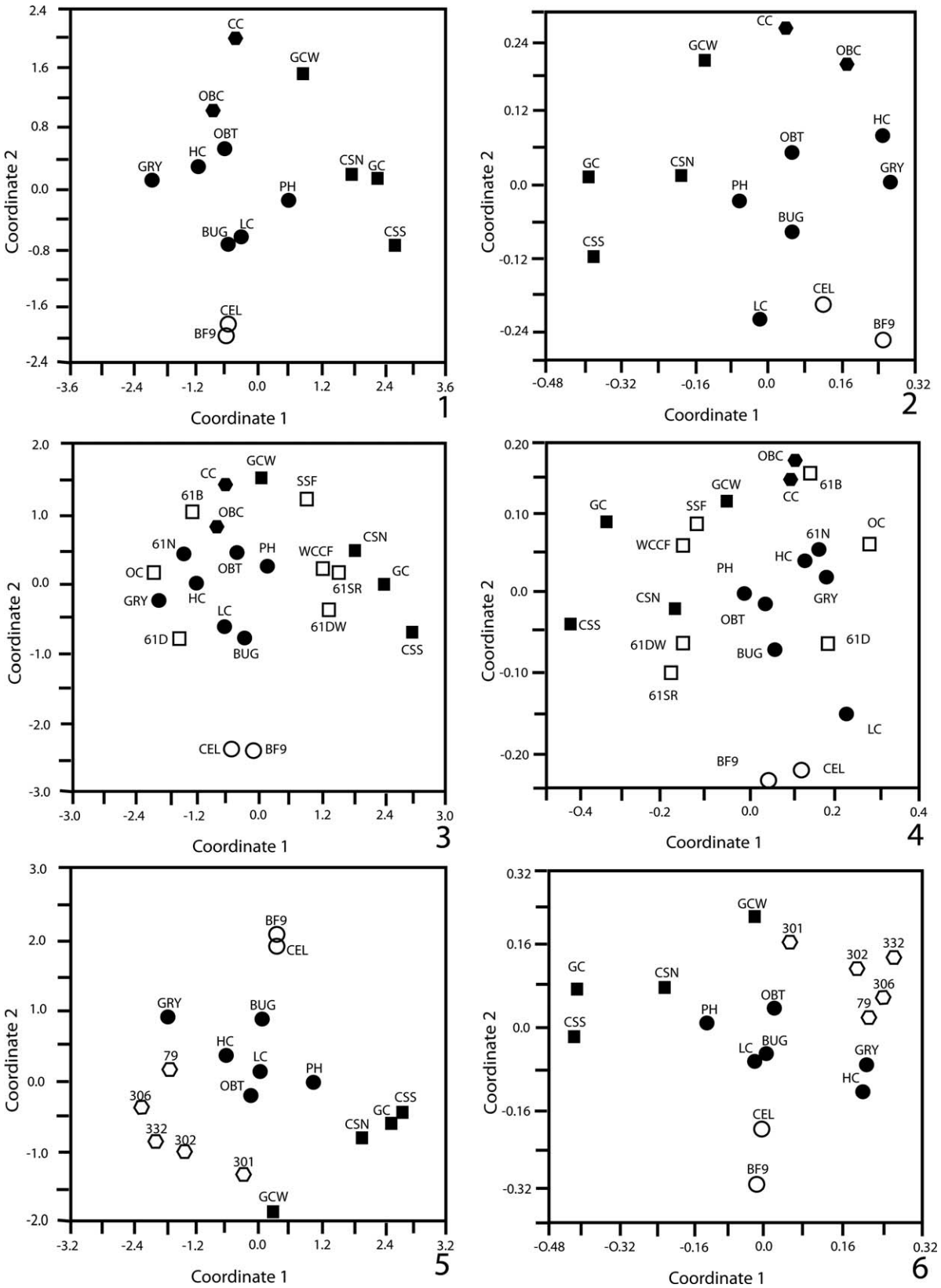

OBB locality) (stress=0.259); *5*, Principal Coordinates Analysis comparing Lake Cumberland region autochthonous localities to north-central Alabama/south-central Tennessee localities with presence-absence data (without OBB locality); *6*, Non-Metric Multidimensional Scaling comparing Lake Cumberland region autochthonous localities to north-central Alabama/south-central Tennessee localities with presence-absence data (without OBB locality) (stress=0.189). Abbreviations given in Table 2; filled circle=wackestone buildup facies; open circle=green shale facies; filled square=packstone buildup facies; open square=allochthonous facies, Lake Cumberland; filled hexagon=Dale Hollow Reservoir localities; open hexagon=north-central Alabama and south-central Tennessee localities.

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TABLE 3—Percent relative abundance among clades in assemblages from autochthonous facies Percentages for total of all localitiesof each facies type.

	Wackestone buildups	Packstone buildups	Green shale
Camerates	80%	76%	9%
Disparids	12%	15%	49%
Primitive Cladids	6%	7%	35%
Advanced Cladids	<1%	1%	2%
Flexibles	<1%	<1%	3%
Blastoids	1%	1%	2%

TABLE 4—Percent relative abundance among blastoid species in total assemblages from autochthonous facies. Percentages for total of all localities of each facies type.

	Wackestone buildups	Packstone buildups	Green shale
Deliacrinus cumberlandensis	1%	<1%	0%
Granatocrinus granulatus	<1%	<1%	2%
Xyeleblastus magnificus	<1%	1%	<1%

wackestone buildups, *Actinocrinites gibsoni* on packstone buildups). Although less striking, the two buildup types have contrasting relative abundances of disparids: wackestone buildups with *Synbathocrinus swallovi* (5%), *Catillocrinus tennesseeae* (4%), and *Halysiocrinus tunicatus* (3%); and packstone buildups with *Halysiocrinus tunicatus* (9%), *Synbathocrinus swallovi* (2%), and *Halysiocrinus cumberlandensis* (2%).

Both carbonate buildup types have a monobathrid camerate-dominated fauna and are broadly comparable to the coeval packstone buildups on the Borden delta platform of Indiana and the Keokuk Limestone carbonate ramp of Iowa, Illinois, and Missouri (Ausich, 1983; Ausich and Lane, 1985). Monobathrid camerates have pinnulate arms and, thus, had relatively dense filtration fans (Ausich, 1980) and were specialized for low turbidity carbonate facies (Kammer et al., 1998). However, unlike elsewhere during the late Osagean, two types of carbonate buildups occurred in the Fort Payne Formation, and each had a separate paleocommunity. As noted above, each had a distinct crinoid and blastoid assemblage. Overlap also occurred in other elements of these paleocommunities, but the packstone buildups supported a more diverse assemblage of cnidarians, bryozoans, and brachiopods (Ausich and Meyer, 1990).

In contrast, camerate crinoids are not an important crinoid clade in the green shale facies, but disparids and primitive cladids dominate (Table 3). With both localities summed, the two most abundant taxa in the green shale facies are *Synbathocrinus swallovi* (23%) and *Cyathocrinites iowensis* (19%). The five most abundant camerate crinoids listed above for carbonate facies are quite rare in this facies. The disparids and primitive cyathocrine cladids that dominated in this fauna lack pinnules and have less dense filtration fans than other clades (Ausich, 1980). These taxa were generally more eurytopic (Kammer et al., 1998). Further, this fauna was associated with the most diverse, non-echinoderm fauna, including many bryozoans and brachiopods (Ausich and Meyer, 1990; Norris, 1991). This fauna is present where the green shale facies occurred as isolated lenticular lenses, where the green shale facies was beneath a wackestone buildup, and where it was below and in the central portion of a packstone buildup. This basic green shale fauna is comparable to coeval Borden delta platform and prodeltaic mudstone facies reported by Ausich et al. (1979), Ausich (1983), and Kammer (1984).

The channel-form facies, not included in the statistical analyses because sample size is too low, is known from two sites along Lake Cumberland. The assemblage of this facies is dominated by advanced cladids and the camerate crinoid *Elegantocrinus hemisphaericus*. These taxa are also dominant in the higher-energy facies of the Borden delta in central and southern Indiana (e.g., Crawfordsville, Indiana) (Lane, 1973; Ausich and Lane, 1985; Ausich, 1983; Kammer and Ausich, 1987; Kammer et al., 1997, 1998). Blastoids are relatively rare in these assemblages. However, blastoids do have contrasting relative abundances among facies (Table 4). The channel-form packstone facies has a comparable fauna to the sandstone channel facies of the Borden delta platform (Ausich, 1983). Both are dominated by advanced, pinnulate cladid crinoids (relatively dense filtration fans) associated with a low diversity fauna comprised principally of crinoids, fenestrate bryozoans, and sponges. Advanced pinnulate cladids are the only Paleozoic crinoid clade that had muscular connective tissue along the arms (Ausich and Baumiller, 1993). These crinoids were specialized for high-energy settings (Ausich and Lane, 1985; Kammer et al., 1998).

Four potential explanations could account for the assemblages of the allochthonous lithofacies: 1) crinoids and blastoids in allochthonous facies include taxa introduced into the Fort Payne Basin downslope from contemporaneous platform environments having different faunal assemblages; 2) transported assemblages could have been sourced only from one or more of the deep-water autochthonous facies identified above; 3) the allochthonous assemblages could be a mixture of platform and deep basinal sources; or 4) the allochthonous assemblages could be a mixture of only deep basinal sources. The allochthonous assemblages have only the faunal elements of the deep-water authochthonous assemblages. Using PCO and NMMS, as noted above, the facies distinctiveness of the authochthonous assemblages disappears if autochthonous and allochthonous sites are combined (Fig. 2.5, 2.6). Further, there are no recognized exotic taxa. Thus, the fourth hypothesis is more probable; the allochthonous facies simply record redistribution of various assemblages of deep-water autochthonous carbonate facies into sheet-like carbonate deposits. Some allochthonous facies have crinoids dominated by a single authochthonous assemblage, whereas others appear to be a mixture of two or three autochthonous assemblages.

A diagnostic indicator of transportation from a shallow, shelf setting would be the appearance of specimens of the camerate crinoid *Dizygocrinus*. This crinoid is absent from autochthonous Fort Payne Facies, but it is a relatively common crinoid in shallower shelf settings of the Muldraugh Formation in central Kentucky (shallow-water equivalent of the Fort Payne Formation) (Ausich et al., 2000) and the Borden Delta platform facies in southern and central Indiana (Lane, 1973; Ausich, 1983). However, it is absent from the Fort Payne allochthonous facies, which supports the interpretation that all crinoidal deposits were sourced locally, within the basinal facies.

Dale Hollow assemblages are from facies that are largely horizontally bedded with only minor mounding or thickening and thinning of green shale facies (Terry, 1989). Monobathrid camerates are the dominant crinoid group, preserved with a high proportion of partial calyxes, which suggests either lower sedimentation rates, greater transportation, or a combination of both, compared to localities in Kentucky (Meyer et al., 1989). The faunal composition, preservation, and sedimentary facies at locality CC resemble the sheetlike packstones in the Lake Cumberland region (Terry, 1989; Meyer et al., 1989). The crinoid assemblage is dominated by an abundance of disarticulated actinocrinitid specimens, indicative of extended exposure and/or transportation. Overall, the localities on Dale Hollow

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Reservoir are poor in articulated specimens, indicative of extended exposure and/or transportation. Disparid crinoids exhibit the most complete crinoid preservation (Meyer et al., 1989). Monobathrid camerates are the most abundant taxa in these assemblages, a pattern that is not consistent with other examples of green shale facies. Thus, the Dale Hollow crinoids are interpreted as allochthonous assemblages.

Faunas from north-central Alabama and south-central Tennessee plot with faunas from Lake Cumberland carbonate facies but in a separate field in both PCO and NMMS analyses. In total, this field of points is adjacent to both packstone and wackestone buildup faunas. Because lithologic information is not available due to deep weathering, the interpretation must be made entirely from the fauna. Three possibilities exist. First, although the same age within biostratigraphic resolution, it is possible that the north-central Alabama/south-central Tennessee faunas are of a slightly different age; thus a slightly different faunal composition. Second, it is possible that the north-central Alabama/south-central Tennessee faunas are from a type of carbonate facies absent from the Lake Cumberland region. Third, distinction of this fauna could result from a slight biogeographic variation of carbonate faunas. We suspect the latter because the Lake Cumberland and north-central Alabama/south-central Tennessee carbonates are largely separated, but this interpretation is tentative.

CONCLUSIONS

The Fort Payne Formation of the Lake Cumberland region of south-central Kentucky is a complex of carbonate and siliciclastic facies. Each authochthonous facies supported a distinct assemblage of crinoids, thus distinct, contemporaneous paleocommunities existed in close proximity in the Fort Payne basin. Further, these assemblages parallel those identified from Indiana, Illinois, Iowa, and Missouri in numerous studies (Ausich, 1983; Ausich and Lane, 1985; Kammer and Ausich, 1987). Although not specifically addressed here, this work demonstrates the geographic extension of the distinct late Osagean (early Viséan) crinoid components of Ausich (1983). The crinoids from north-central Tennessee (Dale Hollow Reservoir) are consistent with allochthonous crinoid assemblages. In north-central Alabama/south-central Tennessee, the crinoid faunas from carbonate assemblages are distinct from those of the Lake Cumberland region, perhaps due to slight biogeographic differences.

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ACCESSIBILITY OF SUPPLEMENTAL DATA

Supplemental data deposited in Dryad repository: http://dx.doi.org/10.5061/dryad.bv432.

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