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AN ENIGMATIC BLASTOZOAN ECHINODERM FAUNA FROM CENTRAL KENTUCKY

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ABSTRACT—A series of small road cuts of lower Boyle Formation (Middle Devonian: Givetian) near Waco, Kentucky, has produced numerous specimens of three blastozoan clades, including both "anachronistic" diploporan and rhombiferan "cystoids" and relatively advanced Granatocrinid blastoids. This unusual assemblage occurs within a basal grainstone unit of the Boyle Limestone, apparently recording a local shoal deposit. Diploporans, the most abundant articulated echinoderms, are represented by a new protocrinitid species, *Tristomiocystis globosus* n. gen. and sp. Glyptocystitoid rhombiferans are represented by isolated thecal plates assignable to Callocystitidae. Three species of blastoids, all previously undescribed, include numerous thecae of the schizoblastid *Hydroblastus hendyi* n. gen. and sp., the rare nucleocrinid *Nucleocrinus bosei* n. sp., and an enigmatic troosticrinid radial. The blastoid *Nucleocrinus* is typical for the age; however, the callocystitid and schizoblastid and protocrinitid are not. *Hydroblastus* is the oldest known schizoblastid. Middle and Upper Devonian callocystitids have been previously reported only from Iowa, Michigan USA with unpublished reports from Missouri USA and the Northwest Territories, Canada. This occurrence is thus the first report of a Middle Devonian rhombiferan from the Appalachian foreland basin. *Tristomiocystis* is the first known protocrinitid in North America and the only protocrinitid younger than Late Ordovician. This occurrence thus represents a range extension of nearly 50 million years for protocrinids. This extraordinary sample of echinoderms in a Middle Devonian limestone from a well-studied area of North America highlights the incompleteness of the known fossil record, at least in fragile organisms such as echinoderms.

INTRODUCTION

BLASTOZOA IS a diverse grouping of primitively stemmed echinoderms that bear small feeding appendages called brachioles, a wide variety of thecal penetrating respiratory structures, and growth lines on the outer surface of the thecal plates (Sprinkle, 1973). Although the height of diversity of blastozoans was Middle Ordovician, three clades persisted into the middle and upper Paleozoic: Diploporata, Glyptocystitida, and Blastoidea. All three of these clades co-occur in a single unit in the Middle Devonian (Givetian) Boyle Formation in central Kentucky. This fauna is unusual because most of the taxa represent geographic and or stratigraphic extension of their inclusive clades. The blastoid *Nucleocrinus bosei* n. sp. is somewhat morphologically unusual for the genus, which is a common Middle Devonian form. However, *Hydroblastus hendyi* n. gen. and sp. is the oldest known schizoblastid and the only pre-Mississippian member of the clade. The diploporan *Tristomiocystis globosus* n. gen. and sp. is the only protocrinitid known from strata younger than the Late Ordovician and the only known taxon of the clade in North America. Although poorly documented, Callocystitid rhombiferan plates present in the Boyle Formation are the only known Middle Devonian callocystitids outside an outcrop belt including Missouri, Iowa, Michigan, and the Northwest Territories, Canada.

Although the fauna described here is unique in bearing all three of these clades preserved in an encrinite bed, the lateral extent of the unit is extremely limited, cropping out in a small area adjacent to Drowning Creek in Madison and Estill Counties, east of Waco, Kentucky. The discovery of these poorly known taxa occurring in a geographically limited area suggests that large stratigraphic gaps noted in the echinoderm fossil record may simply result from poor sampling of clades that were geographically or ecologically isolated.

STUDY AREA

The blastozoans described in this study were collected in a series of exposures of Middle Devonian rocks in central Kentucky east of the Cincinnati Arch (Fig. 1), in Madison and Estill counties, Kentucky. This succession is particularly well exposed in a series of recently improved roadcuts along KY Rte. 52 between Waco and Irvine, Kentucky. The echinoderms occur on weathered joint facies of the Boyle Limestone in a series of four roadcuts, ranging from 1 km west of Drowning Creek (Madison/Estill County line) to about 2 km east of the creek (Fig. 1).

GENERAL STRATIGRAPHY OF THE MIDDLE DEVONIAN BOYLE FORMATION IN CENTRAL KENTUCKY

Blastozoans described in this report were collected from the Middle Devonian (Givetian) Boyle Formation. Fossils were obtained from non-cherty pack- to grainstone facies, generally in the lowest half meter of the Boyle Formation; however, specimens of blastoids and diploporans have been observed from near the unconformable base of the Boyle upward to as much as 2 meters into the unit in a section about 1 km east of Drowning Creek in which the grainstone facies is exceptionally thick. In no case are they found in the cherty micritic facies of the Boyle Formation, nor have they been found in any of the numerous outcrops outside the immediate Drowning Creek region.

The Boyle Formation is a sandy skeletal limestone and cherty dolostone exposed locally in central Kentucky (Figs. 1, 2). The Boyle rests with profound unconformity on beds of Early Silurian to Late Ordovician age; this is a local manifestation of the Wallbridge Unconformity (Sloss, 1963).

Middle Devonian rocks exposed in central Kentucky have a long history of study. The faunas and stratigraphy of these rocks were documented in considerable detail by early workers

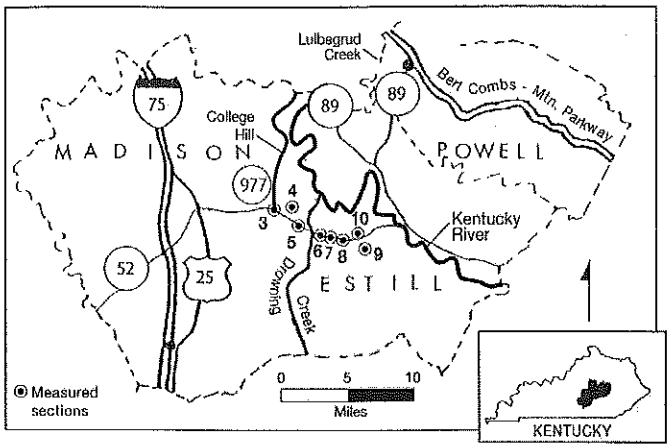

FIGURE 1—Location map for Lower Boyle study sections discussed (numbering follows Brett et al., (2004). 3, Cuts along both sides of KY Rte. 52, 0.2 miles east of KY Rte. 977 at Waco, KY; 4, Bybee (type Portwood; former McLaughlin Farm); 5, newly enlarged cut on north side of KY Rte. 52, 1.2 miles west of Drowning Creek; 6, cuts along both sides of KY Rte. 52, 0.9 miles east of Drowning Creek near Winston Road; 7, weathered cut on North side of KY Rte. 52, 1.3 miles east of drowning creek; 8, cut on south side of KY Rte. 52, 1.5 miles east of Drowning Creek; 9, cut on abandoned county road near Rice Station, KY; 10, cut on north side of KY Rte. 52, opposite Emmanuel Baptist Church, 3.9 miles west of Kentucky River Bridge in Irvine, KY. Modified from Brett et al., (2004).

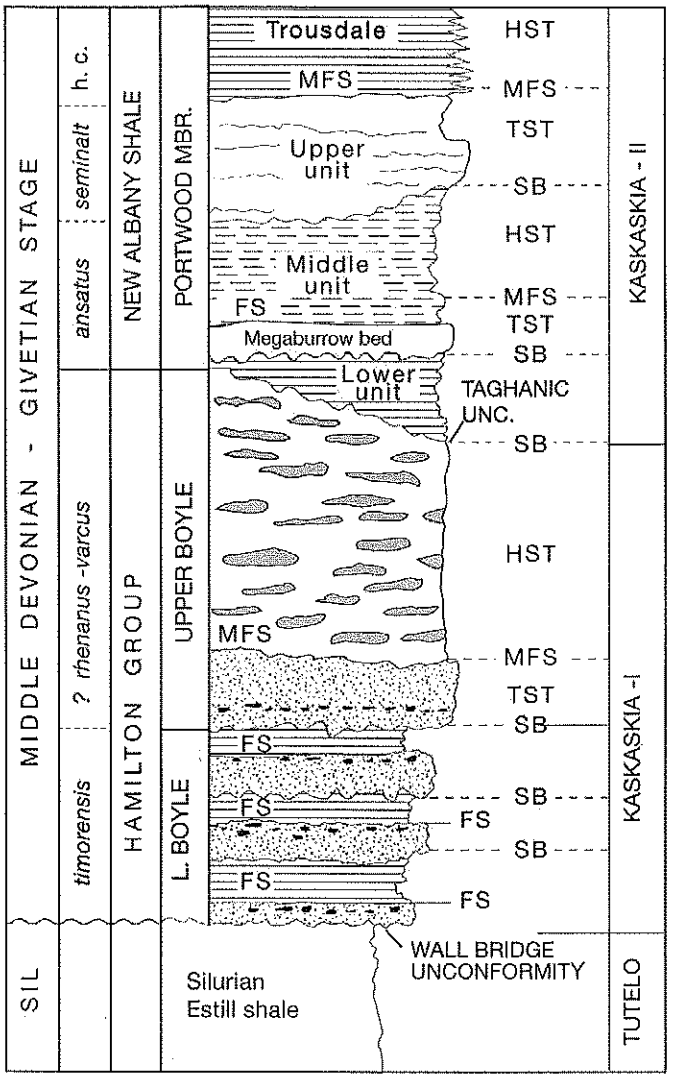

FIGURE 2—Sequence stratigraphic framework for the Boyle Formation and Portwood Member with tentative correlation with sequences recognized in New York State. Sloss megasequences listed on right. Blastozoan echinoderm fauna was collected from the lower Boyle Formation. FS = flooding surface; HST = highstand systems tract; MFS = maximum flooding surface; SB = sequence boundary; SSB = minor sequences; TST = transgressive systems tract. (Modified from Brett et al., 2004).

including Linney (1882), Girty (1898), and Foerste (1906). More recent work includes studies of stratigraphy and bone beds (Conkin et al., 1973, 1976), diagenesis (Johnson, 1980), depositional environments (Stephenson, 1979), syntectonic sedimentation (Ettensohn, 1987, 1991, 1992a, 1992b, 1994, 2004; Barnett and Ettensohn, 1992; Barnett et al., 1993), ichnofossils (Jordan, 1977), conodonts (Runge, 1959; Pieracacos, 1983; Pieracacos and Helfrich, 1984), and sequence stratigraphy (Brett et al., 2004). Despite this extensive study, none of the echinoderms discussed herein have been described previously.

The main, upper part of the Boyle Formation is highly variable in thickness, ranging from 0 to 10 m (Fig. 3). This interval is medium gray, orange-buff weathering dolostone and dolomitic limestone, typically with numerous layers of irregular, ellipsoidal, pale cream-colored chert nodules.

The age of the formation based on conodonts is Middle Devonian. The presence of *Icriodus l. latericrescens* (Clark, 1944) and *Polygnathus l. linguiformis* (Hinde, 1879) in samples from near Irvine indicates a Givetian age (D. J. Over, pers. com., 2004). Pieracacos and Helfrich (1984) report conodonts of the lower *varcus* Zone in central Kentucky.

In localities near the Drowning Creek Valley, the basal unit of the upper Boyle comprises 0.5 to 1.5 m of echinoderm grainstone to silty packstone, containing fenestrate bryozoans, the trilobite *Eldredgeops* cf. *E. rana* (Green, 1832), a few atrypid and cyrtinid brachiopods, and the unique blastozoan fauna described herein, including new species of protocrinitid diploporans, callocystitid rhombiferan, and blastoids (Dexter et al., 2004). This interval is planar to cross-bedded and shows a basal limestone breccia at Drowning Creek area localities. Stephenson (1979) reported a small mound of breccia about 40 cm high and about 1 m across, from the Rte. 52 cut about 1.2 mi east of Drowning Creek (Fig. 3). This basal unit grades upward into laminated, fine-grained grainstone/calcisiltite, with bands of light gray to cream colored chert nodules (cherty dolowackestone or dolomicstone facies of Stephenson, 1979). Rare fossils, including the sponge *Hindia* (Duncan, 1879), commonly as nuclei of chert nodules (Fig. 3), and a few small brachiopods (*Ambocoelia* Hall, 1860), atrypids, favositids, solitary rugose corals, and encrusting stromatoporoids occur within this facies.

The basal grainstones of the main Boyle Formation and their lateral equivalents are thought to record a transgressive systems tract. Earlier workers tentatively correlated the grainstone unit with the Beechwood Member of the Sellersburg Formation. The Beechwood Member comprises fossiliferous crinoidal grainstones of the *timorensis* Zone age, expressed widely in southern Indiana and northern Kentucky west of the Cincinnati arch. The basal conglomerate present east of Drowning Creek is interpretable as an erosion lag deposit and provides evidence for substantial erosion at the contact. Similar erosion is seen at the base of the Beechwood Limestone in the Louisville area (Savage, 1930; McFarlan and White, 1952). The grainstones pass upward gradationally into

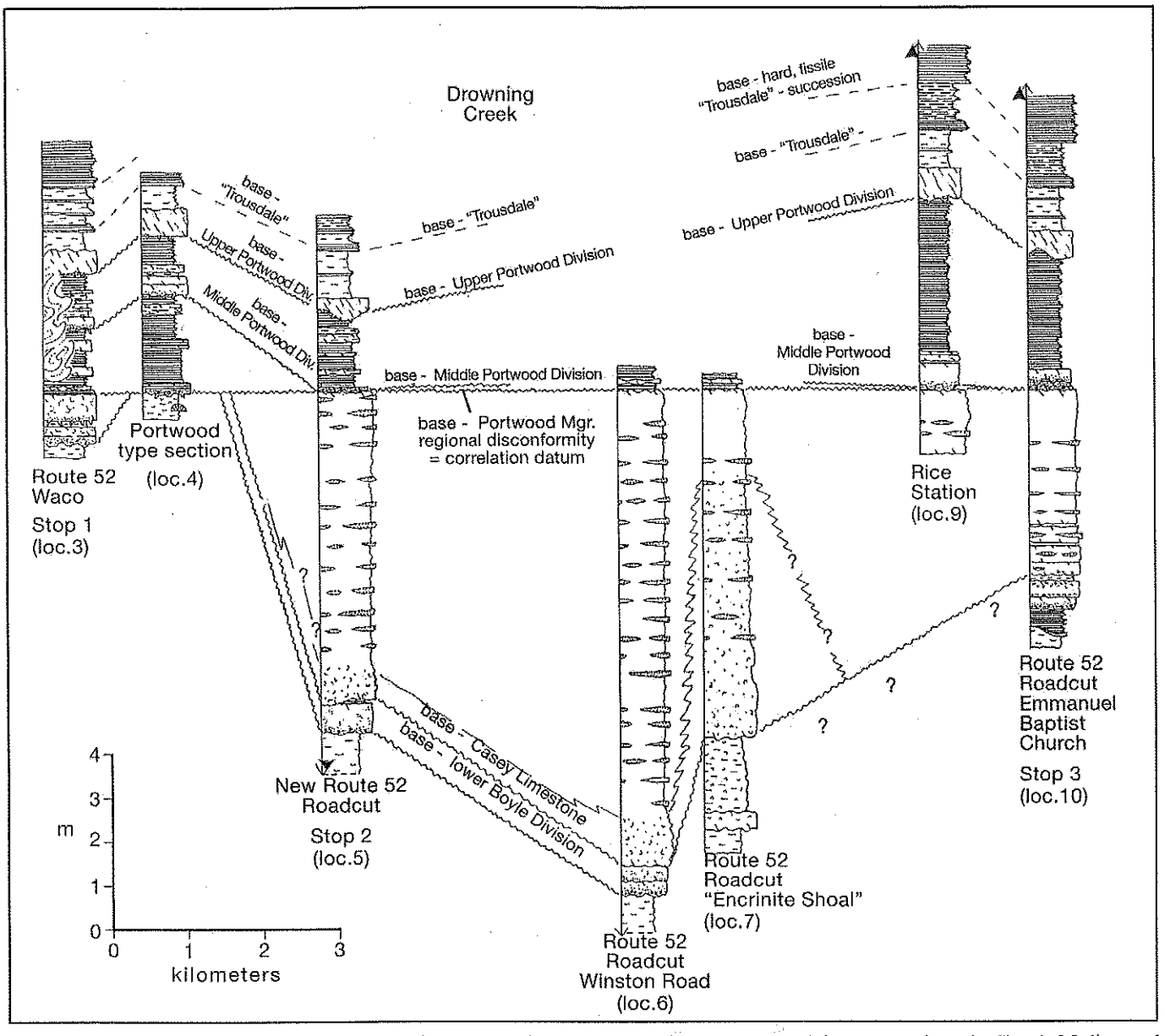

FIGURE 3—Correlation of Boyle and Portwood sections along and near KY Rte. 52 between Waco and the Emmanuel Baptist Church, Madison and Estill Counties, Kentucky. Note the extreme variation in thickness of the Boyle Formation and the erosional removal of lower Portwood division beneath a megaburrow base bed. After Brett et al., (2004).

sparsely fossiliferous laminated medium gray cherty facies of the main Boyle Limestone. We consider this a highstand facies equivalent to Ludlowville Formation shales of the classic Hamilton Group in the Appalachian Basin.

The upper or main portion of the Boyle records lateral facies changes between pelmatozoan grainstone and cherty calcisiltite facies. Grainstone is typical of the lower few centimeters of the unit but in some cases may extend upward for 1.5 meters or more from the base. These changes can occur at the scale of a single outcrop. The grainstone unit in part records local shoals, possibly associated with bioherms, and intershoal areas; the latter are typified by cherty calcisiltite to fine calcarenite (packstone) facies. In places, a very high percentage of the rock is chert. The source of silica involved in formation of cherts within the Boyle is uncertain, but is likely to have been biogenic. The occurrence of well-preserved *Hindia* (Duncan, 1879) sponges within the chert nodules shows that sponges were present and locally common within the calcisiltite and fine calcarenite facies. The timing of silicification however cannot be determined precisely from field relationships.

TAPHONOMY AND PALEOECOLOGY

Specimens described in this study were collected from an encrinite unit of the basal Boyle Formation (Devonian: Givetian) cropping out in the vicinity of Drowning Creek, Madison and Estill Counties Kentucky (Fig. 1). Much of the echinoderm material from this unit consists of grain-supported, disarticulated unicrystalline echinoderm ossicles with syntaxial calcite overgrowths in a matrix of clay-rich fine-grained dolomite. The matrix material readily weathers, exposing echinoderm material. There is minor silicification of some of the specimens that obliterates much of the detail.

Because the mixture of archaic diploporan cystoids and relatively advanced blastoids is so unusual it is critical to establish that the former were not reworked. All echinoderm taxa found at this locality are visually and petrographically similar, strongly indicating that there is not a reworking of Ordovician or Silurian diploporans into younger Devonian sediment. Indeed specimens of the diploporans are filled with a dolomitic mudstone matrix similar to that of the surrounding Boyle Formation. The fragile, multi-plated nature of the diploporans could not have survived reworking, which surely would have fragmented these specimens. Moreover, the majority of the specimens are highly compressed and concordant with bedding; none of the compressed specimens is reoriented out of the horizontal. Thus, the assemblage of fossils appears all to be contemporaneous and of the same age as the matrix, i.e., Middle Devonian.

Both isolated plates and more fully articulated echinoderm material are found, including specimens that are nearly complete and uncrushed, uncrushed but somewhat disarticulated, fully articulated and suffering post mortem compaction, and fully disarticulated. Obviously, the majority of multi-element echinoderm skeletons underwent complete disarticulation, as the deposit is composed of individual sand- to gravel-sized echinoderm plates. In all sections, crushed specimens of the diploporan *Tristomiocystis* n. gen. are the most common identifiable echinoderms and among the most common larger fossils. Some of these specimens are of moderate size, up to 3–4 cm across and are strongly compressed yet fully articulated thecae. Diploporan specimens that are compacted show flattening of the theca and radial cracks that compensate for shape changes. These preservation modes are fully gradational and probably represent a combination of decay time on the sea floor, speed of burial, and extent of early diagenesis of accumulated sediment. Blastoids that are more robust, in general, are more articulated and show a lesser degree of compaction than diploporan specimens.

In no cases are portions of brachioles, ambulacral cover plates, or columns preserved on any of the echinoderms. Furthermore, there does not appear to be a single bedding plane or a few such planes that yield most of the specimens; rather, articulated individuals occur scattered through the poorly bedded crinoidal matrix. Hence, while the diploporans and blastoids must have been buried rapidly, they did undergo a period of minor decay prior to their interment rather than being parts of instantaneous burial or obrution horizons. Similar abundant occurrences of large globular cystoids in skeletal grainstones are known in the Late Ordovician *Echinosphaerites* beds in the Chambersburg Limestone of Pennsylvania/Maryland and the Kimswick Limestone in Missouri (see Bassler and Moodey, 1943). We suggest that in all such cases, shifting skeletal sands were resuspended and repeatedly buried remains of organisms that lived in the near vicinity with minimal transport. Remarkably, these buried remains were not subsequently exhumed but remained buried. This implies both rapid aggradation of the skeletal sands and an environment that was below normal wave base but perhaps close to average storm wave base, such that sediments was intermittently remobilized.

Evidently, the blastozoans flourished in the vicinity of a skeletal shoal where their feeding may have been aided by moderate water turbulence. The abundant diploporans lived in the lowest benthic tier, feeding a few centimeters above the bottom and simply resting on the substrate or loosely attached to skeletal debris by the bases of their thecae. This mode of life further implies an environment that was normally relatively quiescent. However, their mode of life may have rendered the diploporans particularly subject to mortality and burial during storms. Indeed, this may explain their intact preservation, in contrast to rhombiferans. At first pass this situation seems paradoxical, given that the diploporan thecae were composed of a much larger number of articulated plates. But we suspect that rhombiferans may have survived many of the events that killed and preserved the diploporans.

The blastoids and rhombiferans probably formed an intermediate benthic tier, being elevated perhaps a few centimeters above the substrate on short columns (although the lengths can not be determined from present material and can only be speculated based on similar blastoids found articulated). Presumably these animals were attached by cemented holdfasts to larger skeletal substrates, such as bryozoans or corals. Blastoids and rhombiferans underwent normal mortality, but in no case were they buried fully intact. The relatively resistant thecae of blastoids were preserved intact in some cases, however. Conversely, associated rhombiferans were rarely, if ever, preserved intact, suggesting that their less tightly sutured thecae underwent full disarticulation during the same time spans while blastoid thecae remained articulated.

Surprisingly, these Boyle exposures have, to date, yielded no complete calices of crinoids and relatively little intact columns or pluricolumnals, although columnals and calyx plates attributable to crinoids are the predominant skeletal constituents of the grainstones. Again, this may suggest predominantly low rates of burial and normal, gradual mortality in which crinoids, like rombiferans, underwent full decay and disarticulation. The abundance of fully disarticulated crinoid debris may alternatively be explained by being sourced elsewhere and being transported into the depositional environment.

Associated fossils were relatively few and mainly disarticulated and fragmented. However, the Boyle grainstones do yield fenestrate and fistuliporoid bryozoans, a few solitary rugose corals and brachiopods, including atrypids, spiriferids such as *Cyrtina* (Davidson, 1858) and *Megakozlowskiella*, (Boucot, 1957), and small smooth athyrids, such as *Meristella* (Hall, 1859). Rare specimens of the typical Hamilton trilobite *Eldredgeops rana* (Green, 1832) were also present, although no articulated specimens have been discovered. The absence of many Hamilton forms that are for example typical of the nearly coeval Beechwood in the Louisville, Kentucky southern Indiana region, together, with the abundance of unusual pelmatozoans, indicates that the shoals in the area of Drowning Creek represent an unusual environment.

It is certainly unclear what factors may have been responsible for the maintenance of such an atypical environment. It is evident that this distal portion of the Devonian Appalachian basin was both a refugium for a very archaic taxa of diploporan and rhombiferan cystoids and in some senses a "cradle" for advanced blastoids.

STRATIGRAPHIC AND PALEOGEOGRAPHIC SIGNIFICANCE

The Boyle fauna is significant because most of the taxa represent geographic and or stratigraphic extension of their inclusive clades. Although somewhat morphologically unusual for the genus, the blastoid *Nucleocrinus bosei* n. sp. is overall similar to other Middle Devonian species. *Hydroblastus hendyi* n. gen. and sp. is the oldest known schizoblastid and the only pre-Mississippian member of the clade. This species is morphologically similar to common Mississippian taxa but

unlike the more typical Devonoian blastoid fauna. Unlike other Devonian blastoids, this species has relatively wide ambulacra. However, this condition, common in many Mississippian taxa, is accomplished by the broad exposure of the lancet plate along the ambulacral midline. In *Hydroblastus hendyi*, the lancet is small and covered by extremely wide side plates that meet along the ambulacral midline.

The diploporan *Tristomiocystis globosus* n. gen. and sp. is the only protocrinitid known from strata younger than the Late Ordovician and the only known taxon of the clade in North America. Other protocrinitids are known from Baltica and Morocco, North Africa (Kesling, 1967; Chauvel, 1978). Although poorly documented, the Callocystitid rhombiferan plates present in the Boyle Formation are the only known Middle Devonian callocystitids outside an outcrop belt including Missouri, Iowa, Michigan, and the Northwest Territories, Canada (Sumrall, 2001).

In the absence of intermediates for any of these taxa we cannot make inferences about biogeographic source areas that may have influenced this part of the Kentucky foreland basin. The forerunners of schizoblastids are uncertain and the diploporan's closest relatives occur in the Late Ordovician of Estonia and Morocco. We are left to remark on the obvious deficiencies of the known fossil record, for this isolated occurrence clearly shows how much of that record, especially among relatively fragile organisms such as echinoderms, remains unknown.

SYSTMATIC PALEONTOLOGY

Discussion.—Inclusion of Linnaean ranks reflects editorial policy rather than the views of the authors.

Subphylum BLASTOZOA Sprinkle, 1973
Class DIPLOPORATA Müller, 1854
Family PROTOCRINITIDAE Bather, 1899
Genus TRISTOMIOCYSTIS n. gen.

Type species.—*Tristomiocystis globosus* n. gen. and sp.

Diagnosis.—Protocrinitid with large globular theca lacking stem, diplopores lacking from posterior oral plates, oral cover plates fused over peristome.

Discussion.—*Tristomiocystis* n. gen. is assigned to Protocrinitidae based on the sac-like theca without stem, and the presence of diplopores on the irregular interambulacral and ambulacral floor plates. It differs from other protocrinitids by the presence of fused cover plates over the peristome causing the A, shared BC, and shared DE ambulacra to enter the mouth in separate peristomial openings, similar to the situation seen in paracrinoid *Bistomiocystis* (Sprinkle and Parsley, 1982; Sumrall and Deline, in press). It seems likely that all three peristomial openings meet beneath the fused peristomial cover plates and enter the digestive tract through a single pore through the theca.

Etymology.—*Tristomiocystis* n. gen. refers to the presence of three peristomial openings on this diploporan.

TRISTOMIOCYSTIS GLOBOSUS n. gen. and sp.
Figures 4, 5

Diagnosis.—Same as generic diagnosis because of monotypy.

Description.—Theca globular, roughly spherical, with large number of irregular plates; summit composed only of oral plates probably with fused peristomial cover plates (Figs. 4.1, 4.12, 5.1); peristomal opening covered by four plates, O1, O6 in CD interarea andO3 and O4 in AE and AB interareas; O2 and O5 abut these four orals and mark point of lateral bifurcation of ambulacra; O2–O5 have diplopores distally; CD oral area with two equal plates (O1, O6) lacking diplopores (Figs. 4.1, 4.12, 5.1); cover plates either fused to oral plates or absent, consequently peristome permanently covered such that the A ambulacrum, B and C ambulacra, and D and E ambulacra enter mouth with different peristomial openings (Fig. 4.1, 4.12); hydropore long, narrow slit across O1 and O6, 3.6 mm wide in 36 mm diameter specimen, many specimens show circular termination on left; gonopore circular pore placed in O1 below left edge of hydropore (Figs. 4.1, 4.11, 5.1); periproct in proximal CD interambulacrum, bordered proximally by O1 and O6, laterally by proximal C and D ray floor plates and distally by 1–3 interambulacral plates, 5.4 mm diameter in 36 mm diameter specimen (Figs. 4.1, 4.12, 5.1); gonopore and anal pyramids not preserved; ambulacra in 2-1-2 arrangement, typically unbranched except for abnormal paratype CMC IP-51228 where B ambulacrum has one proximal branch and several distal branches (Fig. 4.2, 4.6), extend from summit to about one half distance to aboral pole (Fig. 4.7, 4.9); ambulacra composed of large, biserial floor plates that form thecal wall and food groove (Figs. 4.4, 5.2); food groove wide, 0.8 mm in 36 mm specimen narrowing distally; longest observed ambulacrum with about 38 brachiole facets; ambulacral food groove begins at distal end of oral plates where it enters tunnel beneath oral plates to peristome; side ambulacra join prior to entering tunnel; all ambulacra with first brachiole facet on left shared between oral plate and first floor plate (Figs. 4.1, 5.1); each floor plate with single brachiole facet medially along plate length, generally poorly preserved in available material; elevated with two large shallow brachiolar pits, forms highest point of plate, short side food groove enters main food groove near proximal end of plate; each floor plate with diplopores along abradial side bounding brachiole facet (Figs. 4.4, 4.5, 5.2); brachioles and cover plates not preserved; interambulacral plating irregular; plates typically pentagonal through heptagonal with roughly equal suture lengths, though there is much variation; typical plates 4–5 mm across; plate centers slightly raised above slightly depressed sutures, outer surfaces smooth to pustulose in association with diplopores, without evident growth lines (Fig. 4.13); new plates added anywhere in theca; diplopores in the form of simple paired perpendicular canals within shallow, elliptical peripore (Fig. 4.13); average distance between perpendicular canals 0.40 mm but varies between 0.45 mm and 0.35 mm; diameter of perpendicular canals consistently 0.20 mm; each pair of perpendicular canals enter coelom separately; diplopores generally irregularly clustered in plate centers and noticeably absent from plate sutures except rarely where new plates are being inserted (Fig. 4.13), borne on all plates except O1 and O6; rarely diplopores cross plate sutures in these cases; thecal base flush to slightly constricted; attachment surface small, other details not preserved in available material (Fig. 4.9, 4.10).

Discussion.—No ontogenetic information is preserved either from small individuals or growth lines. Paratype CMCIP 51228 shows two possibly related developmental anomalies. First, the B ambulacrum bifurcates immediately after leaving the BC peristomial opening and runs parallel to the A ambulacrum (Fig. 4.6). Secondly, this extra B ambulacrum and the A ambulacrum are longer than normal, extending well down the theca, and also have terminal branching. Interestingly, these branches are on the right side of the ambulacrum only and the branch of the extra B ambulacrum also has a branch (Fig. 4.2). The plating of these branches, however, is undifferentiated from the plating of more typical ambulacra.

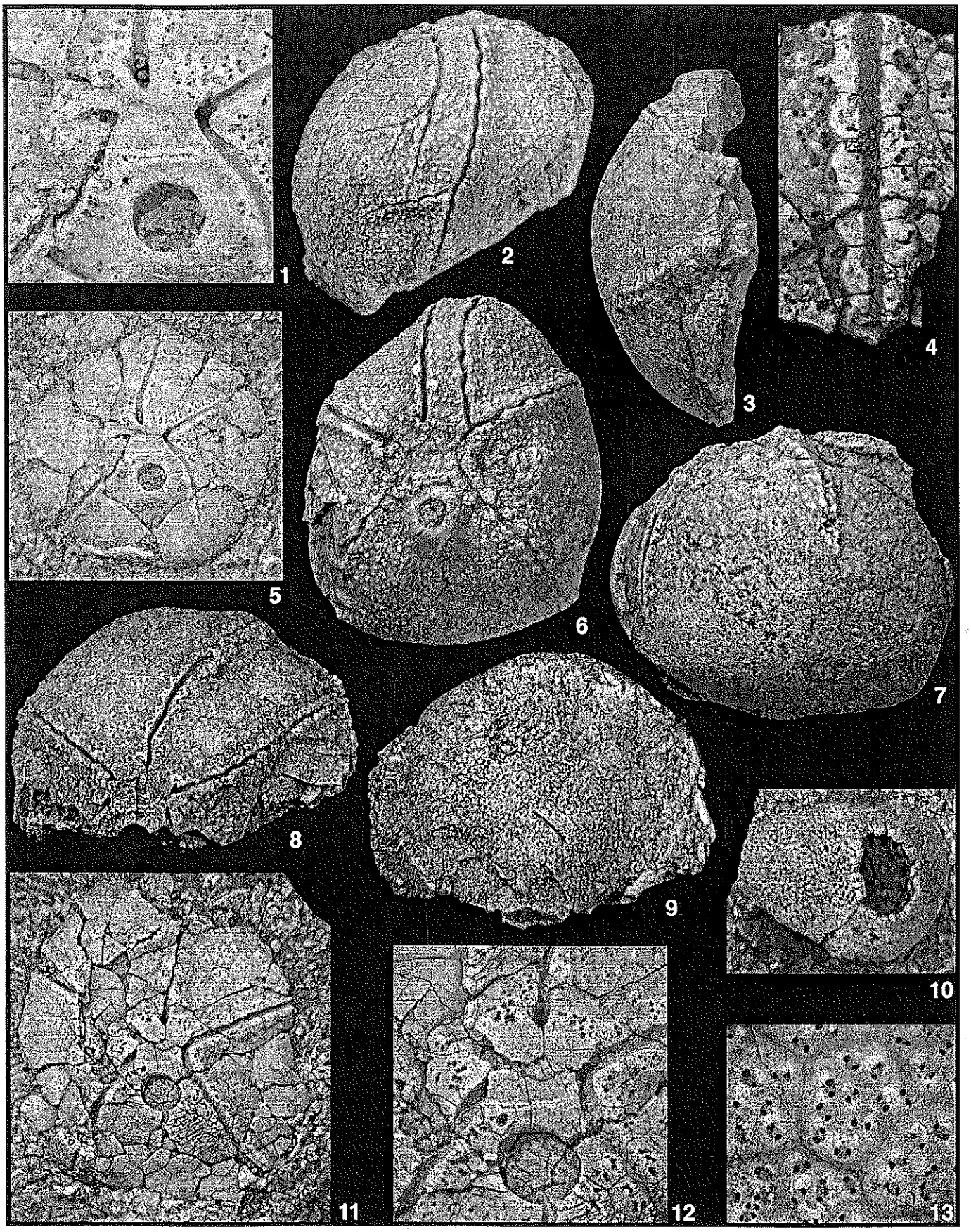

FIGURE 4—All specimens *Tristomiocystis globosus* n. gen. and sp., whitened. *1*, *5*, paratype CMCIP-51227; *1*, enlargement of summit of showing three separate peristomial openings, slit-like hydropore, small gonopore and enlarged anal opening, ×4; *5*, upper surface of crushed specimen, ×1.5; *2*, *6*,

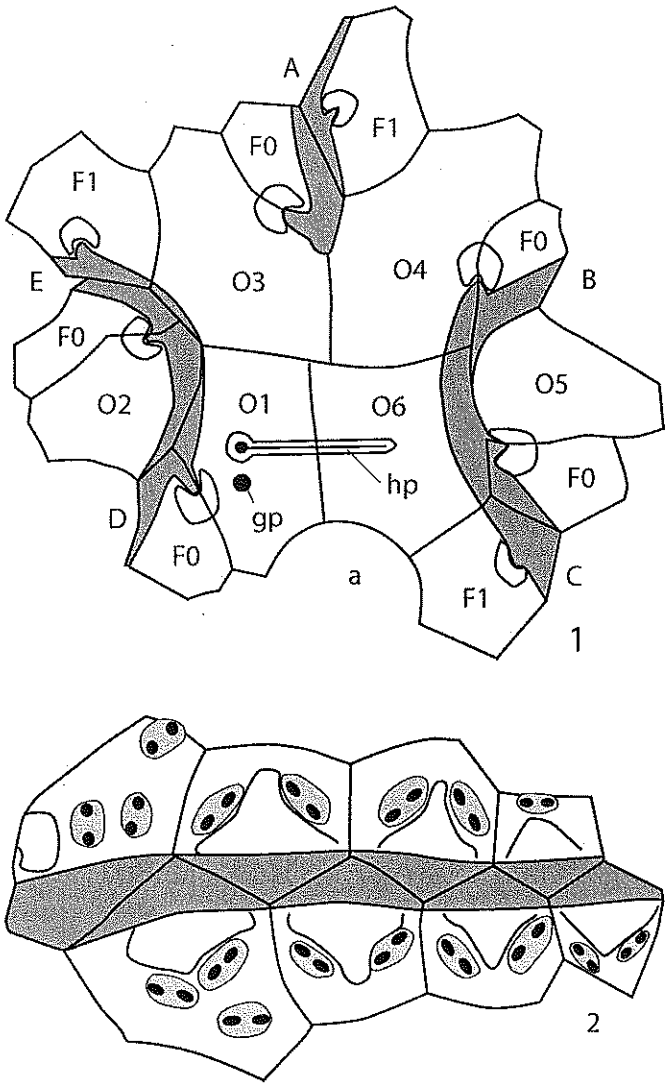

FIGURE 5—Drawings of *Tristomiocystis globosus* n. gen. and sp. *1*, composite summit view showing oral plates (O1–O6), first and second floor plates (F0, F1), hydropore (hp), gonopore (gp), and anal opening (a), ×8; A–E are ambulacral designations; *2*, detail of A ambulacrum (mouth left) of paratype CMCIP-51227 showing biserial floor plates bearing single brachiole facets and diplopores, ×10.

Etymology.—The trivial name refers to the globular shape of the theca.

Types.—Holotype CMCIP-51232, paratypes CMCIP-51227-51231, 51233, additional assigned material CMCIP-51244.

Occurrence.—*Tristomiocystis globosus* n. gen. and sp. is known only from the Middle Devonian (Givetian) lower Boyle Formation, Madison and Estill Counties, Kentucky, USA.

Order GLYPTOCYSTITIDA Bather, 1899
Family CALLOCYSTITIDAE Bernard, 1895
INCERTAE SEDIS
Figure 6.5, 6.9

Discussion.—This taxon is clearly a callocystitid based on the lack of ridges and the general shape of the pectinirhombs. The lack of obvious ambulacral scars on the plates seen suggest that the ambulacra were short and unbranched. This is the only report of a middle Devonian callocystitid outside of Missouri, Iowa, and Michigan USA and Northwest Territories, Canada (Sumrall, 2001).

Specimens.—Two figured specimens of rhomb-bearing plates, CMCIP-51225, 51226 collected from the Middle Devonian (Givetian) lower Boyle Formation, Maddison and Estill Counties, Kentucky, USA.

Class BLASTOIDEA Say, 1825
Order GRANATOCRINIDA Bather, 1900
Family SCHIZOBLASTIDAE Etheridge and Carpenter, 1886
Genus HYDROBLASTUS n. gen.

Diagnosis.—Schizoblastid with long petaloid ambulacra with side plates completely covering lancet plates; hypodeltoid large and hood-shaped; cryptodeltoids seen along lateral edges of anus; flattened stem facet.

Discussion.—*Hydroblastus* n. gen. is easily diagnosable as a schizoblastid by bearing a summit with ten paired spiracles, separate anal pore, and anal side deltoid complex including an epideltoid, hypodeltoid, and paired cryptodeltoids. It is similar to *Lophoblastus* Rowley 1901 in bearing a greatly enlarged hypodeltoid, but the lancet plates of *Hydroblastus* are fully covered by side plates (Figs. 7.28, 8.1).

Etymology.—*Hydroblastus* n. gen. is a compound of the Greek *Hydros*, water and *Blastos* bud, an appropriate common name for blastoids in general, and also in honor of J. A. Waters for his work on understanding blastoids.

Type species.—Hydroblastus hendyi n. gen. and sp.

HYDROBLASTUS HENDYI n. gen. and sp.
Figures 7, 8

Diagnosis.—Same as generic diagnosis because of monotypy.

Description.—Theca obconicle, pelvis flattened conical, vault truncated conical to parabolic; summit depressed with deltoids projecting above summit especially in CD interray (Fig. 7.14, 7.23); thecal plate surfaces covered with strong, tightly spaced growth lines (Fig. 7.20, 7.21); specimens average in size with thecal height 18 mm in available material; height to width ratio highly variable, ranging between 1.32 and 2.30, averaging 1.74 (n-11), with increase ontogenetically; vault to pelvis ratio highly variable between 1.41 and 3.04 averaging 1.98 (n-11), with some increase ontogenetically; largest thecal width between thecal mid-height and radial lips depending on thecal shape; interambulacral areas slightly concave; basals three, normally arranged into 45-45-90 triangular basal circlet (Fig. 7.11, 7.13, 7.19); represent about 50 percent of pelvis height, two zygous basals form broad flat

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paratype CMCIP-51228, lateral A ambulacral and upper views of uncrushed specimen. Note that this specimen is abnormal, having two B ambulacra that bear distal branches, ×1.5; *3*, *7*, upper and lateral views of broken uncrushed paratype CMCIP-51229, ×1.5; *4*, ambulacrum of paratype CMCIP-51230 showing biserial plating, single brachiole facets centers in plates and diplopores in the floor plates, ×6; *8*, *9*, upper and lower surfaces of paratype CMCIP-51231, ×1.5; *10*, Nearly complete attachment surface of paratype CMCIP-51233, ×1.5; *11–13*, crushed holotype CMCIP-51232; *11*, upper surface; *12*, detail of oral area showing three peristomial openings, slit-like hydropore, small gonopore and enlarged anal opening, ×3; *13*, detail of AB interambulacrum showing diplopore positioned in plate centers, ×6.

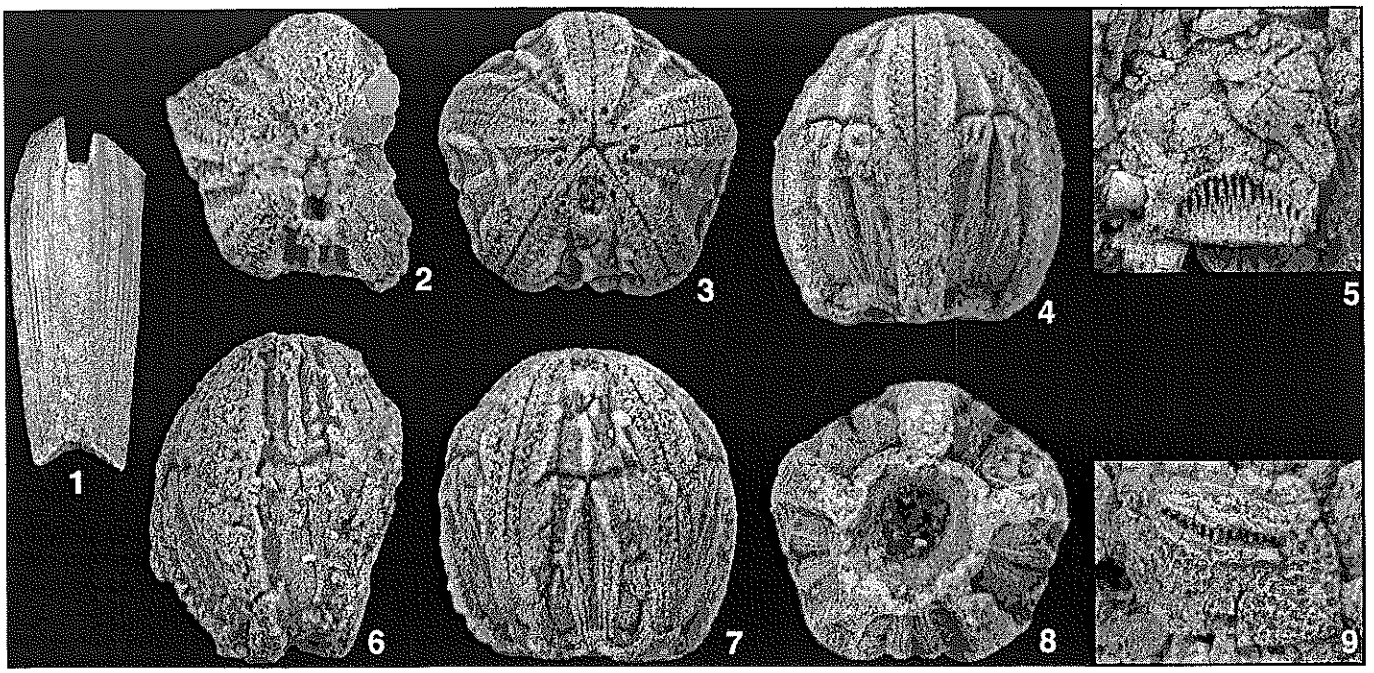

FIGURE 6—All figures whitened. *1*, isolated troosticrinid radial plate CMCIP 51222, ×4; *2, 6,* summit and D ambulacral views of paratype CMCIP 51224, ×5; *3, 4, 7, 8,* summit, B ambulacral, CD interambulacral and basal views of holotype CMCIP 51223 showing short deltoid plates and strong thecal ornamentation, ×5; *5,* interior view of callocystitid rhombiferan plate CMCIP 51225 showing interior slits of the dichopores, ×6; *9,* exterior view of callocystitid rhombiferan plate CMCIP 51226 showing vestibule rim around excurrent half rhomb, ×6.

area in D ambulacral area, flat area opposite azygous basal; stem facet flattened (Fig. 7.14, 7.15); radials five, equal in size in all radii, form about 50 percent of pelvis and between 60 to 75 percent of vault height; slight radial lip present along the ambulacral margin of each plate; ambulacral invagination between 60 and 75 percent of radial plate height, strongly overlap deltoids; regular deltoids four; medium-sized, body diamond-shaped, slightly coronate (Fig. 7.14, 7.22); v-shaped suture with radials acute between 30 and 45 degrees with slight parabolic shape; deltoid septa extend proximally to peristomial opening that is formed by curved deltoid lips; spiracles formed on each side of deltoid septa and adjacent lancet plates, paired along deltoid, radially elongate (Figs. 7.24, 8.1); peristome small, pentagonal, slightly wider than high; anal deltoids four in number, hypodeltoid larger than body of normal deltoid bodies, slightly wider, more protuberant, extends higher above summit (Fig. 7.4, 7.20, 7.21); superdeltoid slightly wider than deltoid lips of normal deltoids but otherwise undifferentiated; paired cryptodeltoids form lateral margins of periproct and anal side spiracles (Fig. 8.1); anal side spiracles formed between epideltoid and adjacent lancet plates; partitions on distal edges of spiracles form proximal edge of radially elongate, oval periproctal opening, distal half of periproct formed by proximal edge of hypodeltoid (Figs. 7.24, 8.1); lancet runs length of ambulacra, triangular in cross section, one third width of ambulacrum throughout length, exposed only at summit (Figs. 7.28, 8.1); ambulacra five, relatively long, of equal length, wide with blunt termination, somewhat concave; side plates from both sides of ambulacrum meet along primary food groove completely covering lancet plate (Figs. 7.28, 8.1); 3.16 side plates per mm in holotype; side food grooves extend laterally and slightly distally from main food groove, proximally along suture between adjacent primary side plates, distally along suture between primary and secondary side plate pairs, terminate in small, elevated, arcuate brachiole facet dominantly on primary side plate (Figs. 7.25, 8.2); four small lobes along primary food groove of each primary side plate; hydrospires in ten groups of four; placed on both sides of ambulacra; hydrospire pores small, placed along suture between secondary side plate and next to more proximal primary side plate (Fig. 8.2), oval, elongate parallel to secondary food grooves; brachioles, stems, and ambulacral cover plates not preserved in present material.

Discussion.—*Hydroblastus hendyi* n. gen. and sp. is rather variable in terms of thecal proportions. Such plasticity in shape is not unusual in blastoids (Waters et al, 1985). Consistency in thecal ornamentation, ambulacral concavity, and details of morphology indicate that all specimens are conspecific. This species is the oldest known schizoblastid.

Etymology.—The trivial name *hendyi* refers to Austin Hendy, who discovered the first specimens of this species.

Types.—Holotype CMCIP-51237, paratypes CMCIP-51234-51236, 51238-51243, additional material CMCIP 51245. Note that paratypes CMCIP 51242 and 51243 are sectioned.

Occurrence.—*Hydroblastus hendyi* n. gen. and sp. is known only from the Middle Devonian (Givetian) lower Boyle Formation, Maddison and Estill Counties, Kentucky, USA.

Family NUCLEOCRINIDAE Bather, 1899
Genus NUCLEOCRINUS Conrad, 1842
NUCLEOCRINUS BOSEI n. sp.
Figure 6.2–6.4, 6.6–6.8

Diagnosis.—*Nucleocrinus* with small, nearly spherical theca, strong ornament on thecal plates, and short deltoids comprising less than half the height of vault.

Description.—Theca small, up to 8.5 mm high in known material, nearly spherical with deep basal cavity; summit flush with thecal surface, height to width ratio 1.25 and 1.16 in available material; maximum width at mid-height of theca; interambulacral areas slightly depressed (Fig. 6.3); basals lie at bottom of basal cavity, number and arrangement

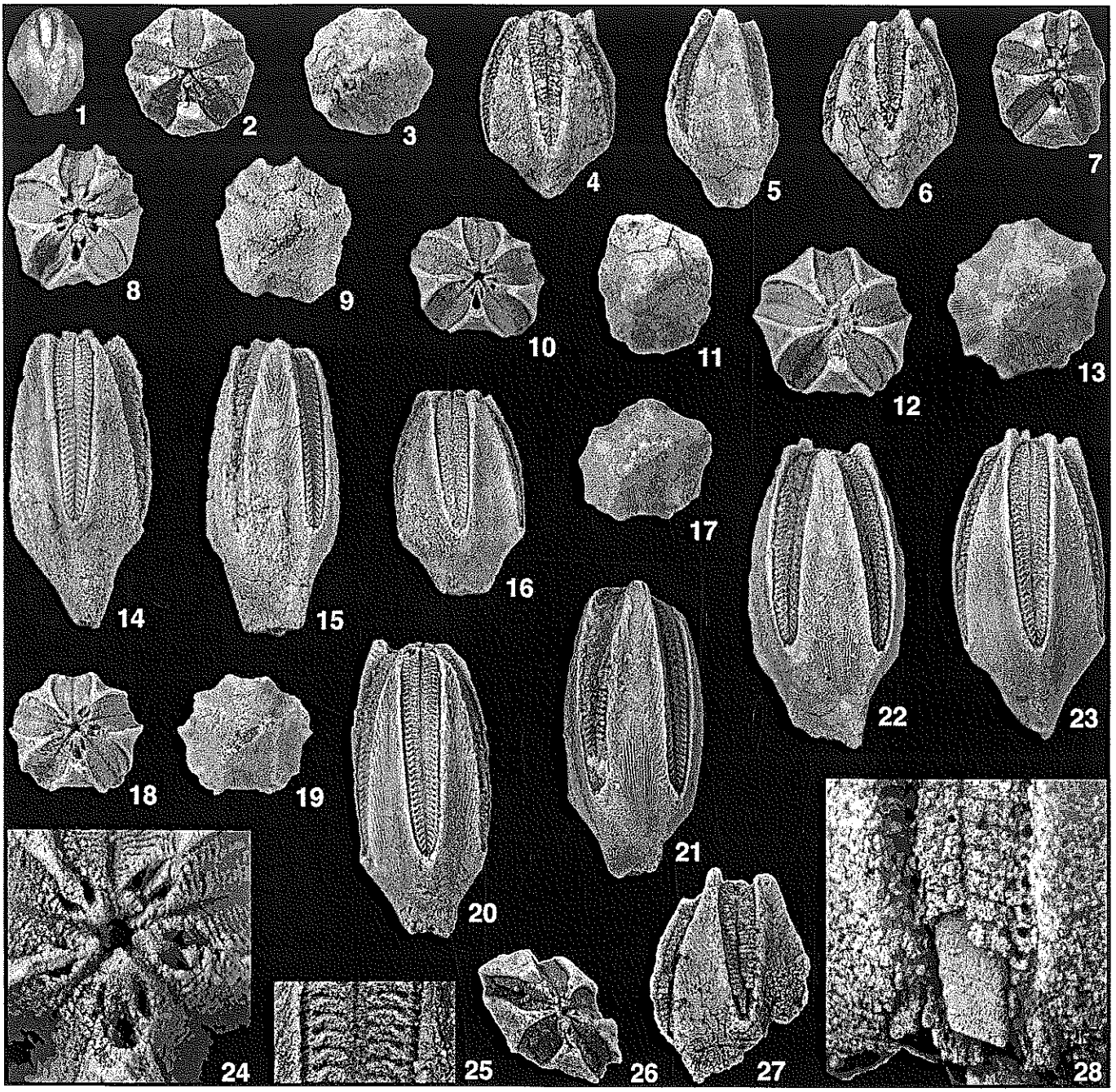

FIGURE 7—All specimens *Hydroblastus hendyi* n. gen. and sp., whitened, ×3 unless otherwise noted. *1*, A ambulacral view of paratype CMCIP 51234 showing lancet plate where side plates stripped away; *2–4*, summit, basal and E ambulacral view of paratype CMCIP 51235. Note the protuberant hypodeltoid upper right; *5–7, 11*, CD interambulacral, E ambulacral, summit, and basal views of crushed paratype CMCIP 51236; *8, 9, 14, 15*, summit, basal, C ambulacral and CD interambulacral views of paratype CMCIP 51238. Note the flat shape of the basal circlet; *10, 16, 17*, summit, D ambulacral and basal views of paratype CMCIP 51239; *12, 13, 22, 23*, summit, basal, CD interambulacral, and E ambulacral views of paratype CMCIP 51240. Note the possible boring in *22*; *18–21, 24, 25*, holotype CMCIP 51237; *18–21*, summit, basal, B ambulacral and CD interambulacral views. Note the protuberant hypodeltoid and strong growth lines; *24*, detail of the summit showing the spiracles, peristome and periproct, ×10; *25*, detail of the B ambulacrum showing side plates, hydrospire pores and brachiole facets, ×10; *26–28*, paratype CMCIP 51241; *26, 27*, summit and D ambulacral views of eroded specimen; *28*, detail of B ambulacrum showing lancet plate being covered by side plates, ×15.

indeterminate, basal cavity rounded pentagonal, bordered by strong ridge (Fig. 6.8); radials five, extend up from thecal base 60 percent of vault, strongly recurved at base forming basal cavity (Fig. 6.4, 6.7); deeply invaginated for ambulacrum, radial-radial suture incised; plates strongly ornamented with ridges running length of plate making elongate diamonds along radial-radial sutures (Fig. 6.4, 6.7); normal deltoids large, deltoid body triangular, with adradial corners projecting distally along ambulacral edge, forming 40 percent of thecal wall; deltoid radial sutures deeply incised, ornamented with medial ridge and marginal ridges along ambulacral margin (Fig. 6.4); deltoid lips forming corner of peristome; spiracles paired, formed along margin of deltoids where in contact with lancet plates, small, nearly circular (Fig. 6.3); anal side deltoids comprised of hypodeltoid, paired cryptodeltoids and superdeltoid, ornamentation similar to normal deltoids;

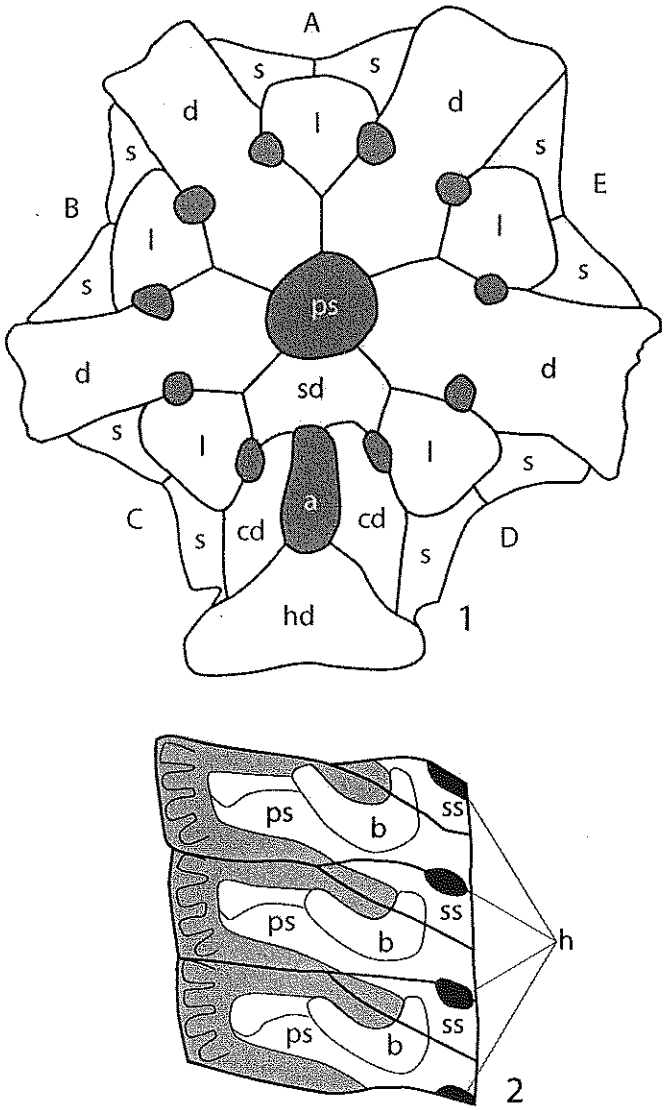

FIGURE 8—Camera lucida drawings of *Hydroblastus hendyi* n. gen. and sp. *1*, section through summit of paratype CMCIP-51243 showing the relationships between the superdeltoid (sd), cryptodeltoids (cd) and hypodeltoid (hd) to the anal opening (a). Note that the spiracles lie along the sutures between the normal deltoids (d) and lancet plated (l), and that the lancet plates are hidden beneath the side plates (s), ×14; *2*, detail of side plates from the B ambulacrum of holotype CMCIP-51237 with the food groove shaded, ×35; b = brachiole facet, h-hydrospire pore, ps = primary side plate, ss = secondary side plate.

hypodeltoid smaller than deltoid bodies of other deltoids, sutures deeply incised laterally and distally, bearing distal margin of periproct on proximal margin (Fig. 6.3, 6.7); cryptodeltoids adradial to hypodeltoid, bear lateral margins of periproct along abradial margins and spiracles along suture with lancet plates; superdeltoid fully exposed, proximally forms posterior edge of peristome and distally forms proximal edge of periproct (Fig. 6.2, 6.3); peristomial opening pentagonal, wider than high showing remnant of 2-1-2 symmetry, bordered by deltoid lips of normal deltoids and superdeltoid; periproct flush with theca proximally, protuberant distally; ambulacra five, narrow, long running length of theca, end in blunt termination; lancet plate covered by side plates; side plates seem to be normally arranged but not well preserved in specimens, about 3.3 per mm in holotype; brachiole facets present but details not preserved; hydrospire pores lie along ambulacral margin, small, poorly preserved; hydrospires, brachioles, cover plates and stems not preserved in available material.

Discussion.—*Nucleocrinus bosei* n. sp. differs from other species of *Nucleocrinus* by the relatively short radials comprising only 40 percent of the interambulacra rather than 80 to 90 percent as seen in other species. The strong surface ornamentation is also diagnostic. Unusual for *Nucleocrinus* is the nature of the superdeltoid, which is completely exposed as in *Elaeacrinus* Roemer, 1851 and *Placoblastus* Fay, 1961. These later two genera have much more elongate thecae than *Nucleocrinus* and smaller peristomial cover plates that are not preserved in specimens of *Nucleocrinus bosei.* Consequently, generic assignment is tentative pending discovery of better-preserved material.

Types.—Holotype CMCIP-51223 and broken paratype CMCIP-51224.

Occurrence.—*Nucleocrinus bosei* n. sp. is known only from the Middle Devonian (Givetian) lower Boyle Formation, Madison and Estill Counties, Kentucky, USA.

Etymology.—The trivial name is in honor of Nicholas Bose (University of Cincinnati), who collected a number of the specimens described in this manuscript.

Family TROOSTICRINIDAE Bather, 1899
Figure 6.1

Description.—Known from single, nearly complete, isolated radial plate 12.5 mm high and 4.5 mm wide; proximal portion with one deltoid suture preserved, beveled distally; basal suture not preserved; narrow invagination for ambulacrum, straight sided, 2.6 mm long, 0.8 mm wide; surface covered with tightly spaced growth lines.

Discussion.—The strong growth lines on the outer surface of the plate diagnoses it as blastozoan (Sprinkle, 1973). The short, narrow ambulacral invagination coupled with the elongate outline of this plate places it clearly as a troosticrinid. Further taxonomic detail is unclear pending discovery of more material.

Material.—A single figured radial plate CMCIP-51222 collected from the Middle Devonian (Givetian) lower Boyle Formation, Madison Co, Kentucky, USA.

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