MISSISSIPPIAN BROMALITES FROM BLUE BEACH, NOVA SCOTIA, CANADA

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Abstract—At Blue Beach (Horton Bluff), Nova Scotia, Canada, the Lower Mississippian Horton Bluff Formation yields a significant record of plant, vertebrate and invertebrate body fossils and invertebrate and vertebrate trace fossils in addition to cololites and coprolites. The cololites from this locality are comparatively large for Mississippian cololites, and the rhizodont *Letognathus* is the likely tracemaker. Six coprolite morphotypes are recognized from Blue Beach: (1) ovoid pellets, some spiraled; (2) elongate pellets, some spiraled; (3) twisted pellets, known from a single example; (4) a flattened regular mass; (5) an irregular flattened mass; and (6) an irregular coprolitic mass. The Horton Bluff coprolite ichnofauna is similar to other Mississippian coprolite assemblages including the Viséan of East Kirkton and, to a lesser extent, the Dinantian site of Foulden, which is the nearest equivalent in both age and fauna to the Nova Scotian locality.

INTRODUCTION

Horton Bluff, on the northern coast of Nova Scotia, eastern Canada (Fig. 1), occupies an important place in the history of ichnology. For here, in 1841, Canadian geologist W. E. Logan found the first Carboniferous tetrapod footprints ever discovered, heralding Nova Scotia as yielding the most substantial Carboniferous track record in the world (Sarjeant and Mossman, 1978a; Lucas et al., 2004, 2010b; Hunt et al., 2004). The outcrops of the Horton Bluff Formation at Blue Beach are now known to produce one of the most important Mississippian fossil records, including diverse continental vertebrate and invertebrate trace fossils, a terrestrial flora representing some of the earliest forests (Bell, 1960; Rygel et al., 2006), and a diverse vertebrate fauna of Early Carboniferous fishes and tetrapods (Carroll et al., 1972; Clack and Carroll, 2000; Anderson et al., 2005), and a few small non-marine invertebrates (*Spirorbis*, ostracodes, and estheriids) (Bell, 1960; Tibert and Scott, 1999). In particular, the vertebrate and invertebrate fossils provide rare insight into a poorly-sampled interval known as Romer's gap (Coates and Clack, 1995; Smithson et al., 2012). Here we describe and interpret a neglected group of Horton Bluff Formation fossils, the bromalites, which consist of cololites and coprolites. All fossils described here are part of the Blue Beach Fossil Museum Collection, Hantsport, Nova Scotia.

GEOLOGICAL CONTEXT

At Blue Beach, about 250 m of the Horton Bluff Formation are exposed (Martel and Gibling, 1996). These strata are assigned to the shale-dominated Blue Beach Member, overlain by the sandier Hurd Creek Member. These are strata of Tournaisian age.

Detailed studies of the sedimentology and stratigraphy of the Horton Bluff Formation at Blue Beach have been completed by Bell (1960), Hesse and Reading (1978), and Tibert and Scott (1999). The Horton Bluff Formation was long believed to be strictly lacustrine in origin (e.g., a freshwater lake – Bell, 1929, 1960; Hesse and Reading, 1978; Martel, 1990; Martel and Gibling, 1991), but is now understood to have been at least periodically brackish; either a sizeable lagoon or a restricted marine bay with periodic connections to the sea (Tibert and Scott, 1999).

The Horton Bluff Formation strata consist of upward-coarsening cycles, representing repeated sedimentation and subsidence in the Windsor sub-basin of Nova Scotia (Martel, 1990; Martel and Gibling, 1991, 1996). The cycles contain four facies: (1) gray clay shales, overlain by (2) gray planar siltstones and wave-rippled planar sandstones, which, in turn are usually overlain by (3) greenish mudstones that are heavily pedoturbated, and contain a large number of in-situ tree casts and detached stems (Bell, 1960; Martel and Gibling, 1991). The greenish mudstones are often overlain by (4) nodular or bedded dolomitic beds, marking the top of "one cycle" (Martel and Gibling, 1991).

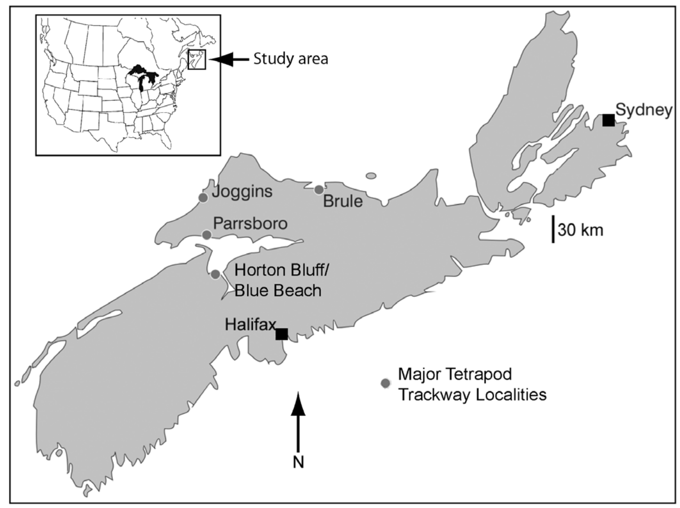

FIGURE 1. Index map of Nova Scotia showing location of Horton Bluff/ Blue Beach.

PALEONTOLOGY OF BLUE BEACH

To provide context and understanding of the potential makers of the bromalites, we provide a summary of the paleontology of the Mississippian strata exposed at Blue Beach.

The coastal exposures at Blue Beach are almost 4 km in length, with relatively undisturbed sedimentary strata forming wide, wave-cut benches and tall cliffs that are prone to collapse when undercut. The larger-than-average tidal range here can exceed 16 m, and it is this powerful combination of moving-water and waves that work to regularly expose most of the new fossil material. The type section of the Horton Bluff Formation, at Blue Beach, yields a rich assortment of Early Mississippian (Tournaisian) trace and body fossils. Besides bromalites, the trace fossil assemblage includes tunnels, tracks, trails, resting traces, and burrows. The body fossil assemblage includes terrestrial and nearshore plants, non-marine invertebrates, and a vertebrate fauna of fishes and early tetrapods (Table 1). The following sections are provided as both a review, and an update, on the progress of paleontology in the Horton Bluff Formation.

Plants

The Horton Bluff Formation flora is typically Tournaisian, with the plants mainly preserved as simple compression fossils. Plant macrofossils were originally studied by Dawson (1863, 1868, 1873), and later by Bell (1929, 1960), and ongoing studies on the forested wetlands were recently added by Melrose and Gibling (2003) and Rygel et al. (2006).

Plant miospores were studied by Hacquebard (1957, 1972), Playford (1963), Utting (1987), Utting et al. (1989), and Glasspool and Scott (2005). The large number of miospore taxa discovered in the Windsor sub-basin indicates that a far greater diversity of plants were present than the known Horton Bluff macrofossil record would suggest (Glasspool and Scott, 2005). There is also one report of a new genus and species of green algae in a thin-section from Blue Beach (Mamet, 1995).

Trace Fossils

The trace fossils of the Horton Bluff Formation have been mentioned in scientific publications for well over a century, with increasing frequency in recent years (Dawson, 1868, 1895; Matthew, 1903, 1904, 1905; Sternberg, 1933; Kuhn, 1963; Haubold, 1970, 1971; Carroll et al., 1972; Sarjeant and Mossman, 1978a, b; Mossman and Sarjeant, 1980; Martel, 1990; Martel and Gibling, 1991, 1996; Wood, 1999; Weir, 2002;Carroll and Green, 2003; Lucas et al., 2004, 2010a, b; Hunt et al., 2004; Scott et al., 2005; Mossman and Grantham, 2008). Newly collected material currently being studied by the authors reveals several previously unreported ichnotaxa, and numerous revisions to the nomenclature of previous workers is required (Lucas et al., 2004, 2010a, b).

The cyclic sedimentation and fine-grained sediments of the Blue Beach section favor preservation of a diverse assemblage of traces in a variety of contexts. The repeating cycles contain hundreds of productive nearshore trace fossil beds. The shallowing-upward trend of the cyclic sedimentation ended as slow basin infilling was repeatedly followed by sudden basin subsidence (Martel, 1990; Martel and Gibling, 1991, 1996). There are over 60 repeated cycles in the Blue Beach section (Martel and Gibling, 1991). The abundant preservation of traces in these various facies-contexts clearly provide further opportunities for paleoecological and ichnological investigation.

The trace fossils of the Horton Bluff Formation are unusually diverse considering the low diversity of Devonian continental ichnofossil assemblages (Gevers et al., 1971; Miller, 1979; Allen and Williams, 1981; O'Sullivan et al., 1986; Gordon, 1988; Morrissey and Braddy, 2004). The invertebrate traces include various tunnels (*Palaeophycus*, *Planolites*, *Skolithos*, *Gordia*), arthropod resting traces (*Rusophycus*, *Limulocubichnus*, *Arborichnus*), and diverse arthropod trails (*Diplopodichnus*, *Diplichnites*, *Kouphichnium*, *Protichnites*, *Paleohelcura*, *Cruziana*). Large burrows attributable to *Taenidium* are also locally present in small numbers. The trace-makers of these burrows are not known, although they may have been either large invertebrates, or more possibly, small lungfishes, (a rare component of the Blue Beach fauna). The majority of the invertebrate traces occur as two separate facies-controlled associations (a *Palaeophycus* association, and a *Rusophycus* association).

The Horton Bluff Formation ichnofossil assemblage has previously been interpreted as belonging to the relatively low-diversity *Rusophycus* ichnofacies (Wood, 1999). Recent work shows that the ichnofacies association is essentially of a modern aspect, reflected by an increase in ecospace utilization, with deep and complex burrowing forms evident. The Horton ichno-assemblage clearly thus represents the *Scoyenia* ichnofacies (Buatois et al., 1998; Lucas et al., 2010a). Traditional examples of the *Scoyenia* ichnofacies were strictly Permian or younger, but recent evidence from the Lower Carboniferous of Pennsylvania (Fillmore et. al., 2010, 2012) has significantly extended this record. The Horton Bluff ichnofossil assemblage now extends this record even further, confirming continental invertebrate communities had achieved an essentially modern aspect in terrestrial nearshore settings far earlier than once believed.

TABLE 1. Floral and faunal list for the Horton Bluff Formation (after Martel, 1990).

PLANTS (excluding miospores and algae)
- *Lepidodendropsis corrugata* (Dawson)
- *Lepidophyllum* (*Lepidostrobophyllum*) *fimbriatum* (Jongmans, Gothan and Darrah)
- *Archaeocalamites* (*Asterocalamites*) *scrobiculatus* (Schlotheim)
- *Aneimites acadica* (Dawson)
- *Diplotnema patentissimum* (Ettingshausen)
- *Carpolithus tenellus* (Dawson)
- *Genselina* sp. (Pat Gensel, pers. comm.. 2005)

NON-MARINE INVERTEBRATES
- *Spirorbis avonensis* (Bell)
- *Limnoprimitia* (?) *hortonensis* (Bell)
- *Copelandella novascotia* (Jones and Kirkby)
- *Carbonita* cf. *C. subdula* (Jones and Kirkby)
- *Eoleaia leaiaformis* (Raymond)
- *Paraparchites* sp.
- *Euproops* sp.

FISH
- *Elonichthys* cf. *E. brownii* (Jackson)
- *Rhadinichthys* sp.
- *Canobius* sp.
- "*Acrolepis hortonensis*" (Dawson)
- *Letognathus* (*Strepsodus*) *hardingi* (Dawson)
- ?*Ctenodus* sp.
- *Gyracanthides* (*Gyracanthus*) sp.
- *Gyracanthus* sp.
- ?*Climatius* sp.
- indet. acanthodid
- ?*Ctenacanthus* sp.
- indet. ctenacanthid

TETRAPODS
- indet. whatcheeriid
- ? indet. colosteiid
- ? indet. anthracosaur
- ? indet. acanthostegid / ichthyostegid
- Tetrapoda incertae sedis

A diverse record of vertebrate traces includes more than one ichnospecies of the fish-swimming trace *Undichna*, unnamed traces of large "crawling" sarcopterygian fishes, five ichnogenera of tetrapod footprints and trackways (*Batrachichnus*, *Palaeosauropus*, *Hylopus*, *Pseudobradypus*, *Attenosaurus*), and rare examples of the tetrapod resting-trace *Ctenerpeton* (*sensu* Aldrich and Jones, 1930).

The Horton Bluff tracks are unique in their importance, as they comprise the oldest diverse assemblage of footprints known (Lucas et al., 2004, 2010b). The tracks are seen to represent the earliest diverse community of pentadactyl/tetradactyl tetrapods, and the earliest-known tetrapods capable of fully-terrestrial locomotion (Lucas et al., 2004, 2010b; Carroll and Green, 2003). The Blue Beach Museum has a collection of over 2000 specimens to date, which is the largest collection of Carboniferous tracks. Vertebrate tracks are presently known to occur at more than 80 different stratigraphic horizons in the type section at Blue Beach.

Vertebrate and Invertebrate Faunas

The vertebrate and invertebrate faunas of the Horton Bluff Formation contain numerous taxa, including the earliest terrestrial tetrapods, whose association has been characterized as the "Mississippian Tetrapod Province" (Milner, 1993). The fossil record of Mississippian tetrapods is very poor, most of it belonging to the Late Mississippian, with a paleogeographic distribution that is restricted to an equatorial belt along the southern part of Euramerica (Milner, 1993; Thulborn et al., 1996). The less-understood Mississippian vertebrate assemblages are seen as distinct from assemblages of Devonian and Pennsylvanian deposits. The characteristic groups in such faunas usually include certain bony fishes (palaeoniscoids and sarcopterygians, especially dipnoans), early Carboniferous freshwater sharks (elasmobranchs), acanthodian fishes (especially large gyracanthiids), and early tetrapods. Typical associated nonmarine invertebrates include ostracodes, spirorbid worms, and estheriids.

Invertebrates

Invertebrate fossils from Blue Beach have been studied in some depth by Dawson (1879), Jones and Kirkby (1884), Bell (1929, 1960), Bless and Jordan (1971), and Tibert and Scott (1999). Dawson (1868) noted that there seemed to be a problem with the interpretation of the Horton Bluff ostracodes as strictly lacustrine, because they were also known to occur alongside marine microfossils in certain Carboniferous strata. Bell (1960) went on to describe an invertebrate fauna that included *Spirorbis*, ostracodes, and estheriids, noting their resemblance to brackish-marine assemblages from western Europe, but nonetheless believing the Horton Bluff ostracodes were freshwater-adapted forms. Carroll et al. (1972) added the limuloid *Euproops* to the assemblage, and speculated that the Horton paleoenvironment may possibly have been brackish occasionally. With the discovery of agglutinated foraminifera (coastal-marsh indicators), Tibert and Scott (1999) redefined the assemblage as "marginal marine," concluding that the sedimentological and microfossil evidence at Blue Beach indicated it was probably a large lagoon, or isolated marine embayment, that was periodically connected to the sea.

Vertebrates

Fish fossils were described in the past by several workers (Dawson, 1863, 1868; Woodward, 1890; Lambe, 1908, 1910; Zidek, 1977), and amphibian fossils by Carroll et al. (1972). New information on the Horton Bluff vertebrates has begun to emerge (Dilkes et al.,1995 Clack and Carroll, 2000; Cameron et al., 2000; Brazeau and Parker, 2004; Brazeau, 2005; Anderson et al., 2005; Scott et al., 2005; Brazeau and Jeffery, 2006), and the Horton Bluff material is often commented on as a comparison in other studies (e.g., Lebedev and Coates, 1995; Thulborn et al., 1996; Johanson et al., 2000; Warren and Turner, 2004; Clack and Finney, 2005; Parker et al., 2005; Turner et al., 2005; Smithson et al., 2012), but most of the newly-collected material at the Blue Beach Museum still needs review. Several new morphotypes of tetrapods are now known, albeit very incompletely, mainly from isolated bones. The fish fauna can also be seen to contain previously undescribed types.

This report discusses two cololites that, because of their size, were probably made by rhizodonts. The Devonian and Carboniferous Rhizodontida were very large (up to 8 m long) sarcopterygian fishes that are now considered to be basal tetrapodomorphs (Jeffery, 2001, 2006; Ahlberg and Johanson, 1998). Their anatomy and physiology are perhaps the mostly poorly understood of any lobe-finned group, as they are mostly known from fragmentary fossils (Johanson and Ahlberg, 1998; Brazeau and Parker, 2004). Rhizodonts are believed to have been ambush predators with feeding strategies in many ways similar to those of modern alligators (Andrews, 1985). Prey typically would have either been swallowed whole or reduced to manageable pieces.

BROMALITES

The cololites and coprolites reported here (Figs. 2-5) were collected from the Blue Beach section. They are derived from Tournaisian-aged strata assigned to both the Blue Beach and Hurd Creek members of the Horton Bluff Formation (Martel and Gibling, 1991).

Description

Cololites

Several large specimens from Blue Beach consist of irregularly shaped phosphatic masses, many of which contain fish or tetrapod bones. Based on their size and bone content we tentatively interpret these specimens as portions of infilled fossil intestine preserved independent of a carcass (*sensu* Hunt and Lucas, 2012).

The cololites from Blue Beach (Fig. 2) are very large for their age and are unusual for Paleozoic cololites in containing large, intact bones. Their large size strongly implies they were made by the rhizodont *Letognathus* – an abundant predator in the Horton Bluff fauna with a body length that exceeded 5 m.

CM 9516 (Fig. 2A-B) is a relatively small cololite (~ 30 cm by 15 cm, with a maximum thickness of about 3 cm) that has been planed-off by the tides to provide a clear internal view. The interior contains a large number of acanthodian fin spines, together with a single tetrapod femur. The fin spines belong to modest-sized fishes (less than 0.3 m long), whereas the tetrapod was probably about 0.6 m long. The cololite-maker was thus of substantial size, and for reasons mentioned above, was therefore likely a rhizodont. It probably exceeded 1.5 m in body length.

CM 9538 (Fig. 2C-D) is a large mass (roughly 45 cm by 30 cm oval, and about 12 cm maximum thickness) that resembles a nodule, but was found in facies 1 clay shale, where nodular masses are not present. The majority of fossil bones occurring in the clay shale of facies 1 are imbedded in the clay shale itself. In contrast, the specimen shown here was surrounded by the clay shale, but itself consists of coarser sediments, interpreted as later infilling. The convexity on both top and bottom implies a physical constraint such as a gut-lining or intestinal tract was holding the contents in a rounded shape while the slow deposition of the clay shales worked to bury it. The cololite contains a significant number of large bones, apparently belonging to a single, medium-sized (about 0.3 m long) rhizodont, while the individual to whom the cololite belonged was certainly much larger, perhaps about 3 m in length. Medium-sized rhizodont girdle and fin elements evident on the upper exterior surface include 2 clavicles, 1 scapulocoracoid, 1 humerus, 1 radius, 2 ulnae, and distal fin elements, plus some other unidentified elements, including scales. Smaller bones scattered across the top of the specimen include hundreds of small palaeoniscoid scales and a few fin spines of acanthodians. The surrounding clay shales have one of the rhizodontid clavicles upon them. The protruding (anterior) edge of the clavicle is thin and sharp, and probably punctured the gut-lining sometime after burial, probably as a result of loading. This breach in the wall of the gut-lining allowed the clavicle to project out onto the clay shale, and for coarser overlying infill to later invade the interior.

The larger cololite (CM 9538) contains examples of articulated and associated vertebrate remains, which is something almost never seen in the Blue Beach vertebrate record (Dilkes et al., 1995; Clack and Carroll, 2000; Anderson et al., 2005; Smithson et al., 2012). While the fin and girdle elements in this cololite are important finds in their own right, as they are helpful in reconstructing the anatomy of *Letognathus*, this suggests another interesting avenue for future fieldwork in the Horton Bluff Formation. It may prove worthwhile to search for other large cololites because these may have provided a kind of "protective environment" that prevented the elements from scattering and allowed for the preservation of significant skeletal remains.

Coprolites

Coprolites from Blue Beach (Figs. 3-5) are generally very dark, almost black, in color. Vertebrate bones from the locality are also almost universally dark in color, as are ostracodes and the carbon-rich remains of plants. Coprolites may easily be distinguished from similarly-shaped nodules or concretionary structures by their darker hue and phosphatic composition. Also, mud-balls and coal-balls can often resemble some

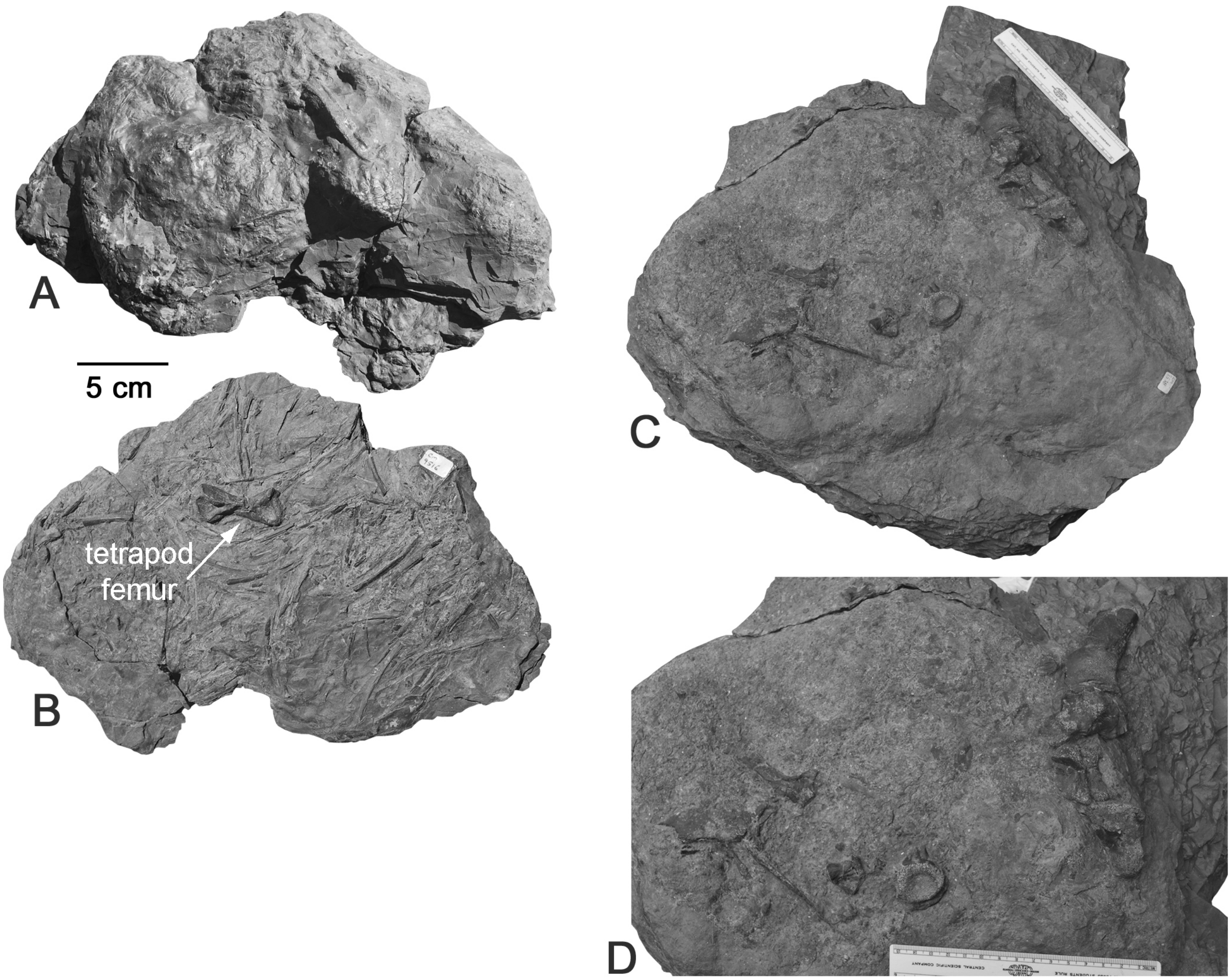

FIGURE 2. **A-B**, Cololite, CM 9516, in two views. **C-D**, Cololite, CM 9538, **C**, overview of specimen and **D**, close up of specimen. Scale on left applies to **A-B**. Scale on right in cm.

coprolites in both shape and color, but these are easily identified under magnification for what they are. Coal balls are relatively scarce at Blue Beach, as are noticeable beds of coal. We divide the Blue Beach coprolites into two types with six distinct morphotypes (Table 2). The ovoid and elongate coprolites may be further subdivided into at least three varieties. These varieties may be either primary morphotypes or products of taphonomic variability.

The first two morphotypes are small pellets (less than 10 mm by 30 mm) that are ovoid (1) (e.g., Fig. 4D-F) or elongate (2) (e.g., Fig. 3D-E), some of which are of the spiral variety (e.g., Fig. 3J, K; Fig. 4A). When spiral structure is visible, the whorls are most clearly seen in the cross-section of broken coprolites. Both morphotypes can closely resemble "coal balls" or "mudballs," are often dark in color, and usually contain no recognizable skeletal contents. One series of ovoid pellets, which were carefully weathered from two slabs of vertebrate/ostracod-bearing shale (facies 1) in the Blue Beach Member of the Horton Bluff Formation (Fig. 3A, C, H, L, M), also appear to be of the spiral variety. They include no visible vertebrate remains on their external surface. Some of the other pellets (Fig 3B, F, G) are similar in size and shape to the spiral variety noted above, but display sparse remains of vertebrates (palaeoniscid fish scales, etc.) on their exterior surface. One specimen (CM 12305: Fig. 5A-B) contains a bedded mass of small elongate pellets, including one in cross-section that displays both spiral form and visible vertebrate content, which demonstrates the presence or absence of macrovertebrate content cannot be used to distinguish between these small pellet morphotypes. One coprolite (Fig. 3M) has a uniform dark interior resembling that of a coal ball, but surficial texture suggests this is another coprolite, perhaps of the spiral variety. Additionally, both ovoid and elongate types also occur in clusters (e.g., CM 12228 – Fig. 5C).

Another variety of coprolites (e.g., CM 12334 – Fig. 4C) are light tan or off-white in color. These appear to be calcareous in nature, rather than dark and phosphatic, but are not recognized as a separate morphotype at this time. The external surfaces of the coprolitic pellets are often irregular or slightly lumpy in contour, rather than perfectly smooth. In cross-section they do not usually reveal any spiral-structure until somewhat weathered, whereupon the spiral pattern becomes more evident. It is not known if they all possess spiral structure, or if some are homogenous throughout, so the spiral pellets will also be treated as varieties, and not separate morphotypes. Small ovoid and elongate pellets, taken on the whole, are the most common forms of coprolites in the Blue Beach section.

Another morphotype of coprolite (3), the twisted pellet, is known from a single example (CM 12251 – Fig. 4B). This example is rather blunt on the exposed end, but cannot be verified as "bullet-shaped"

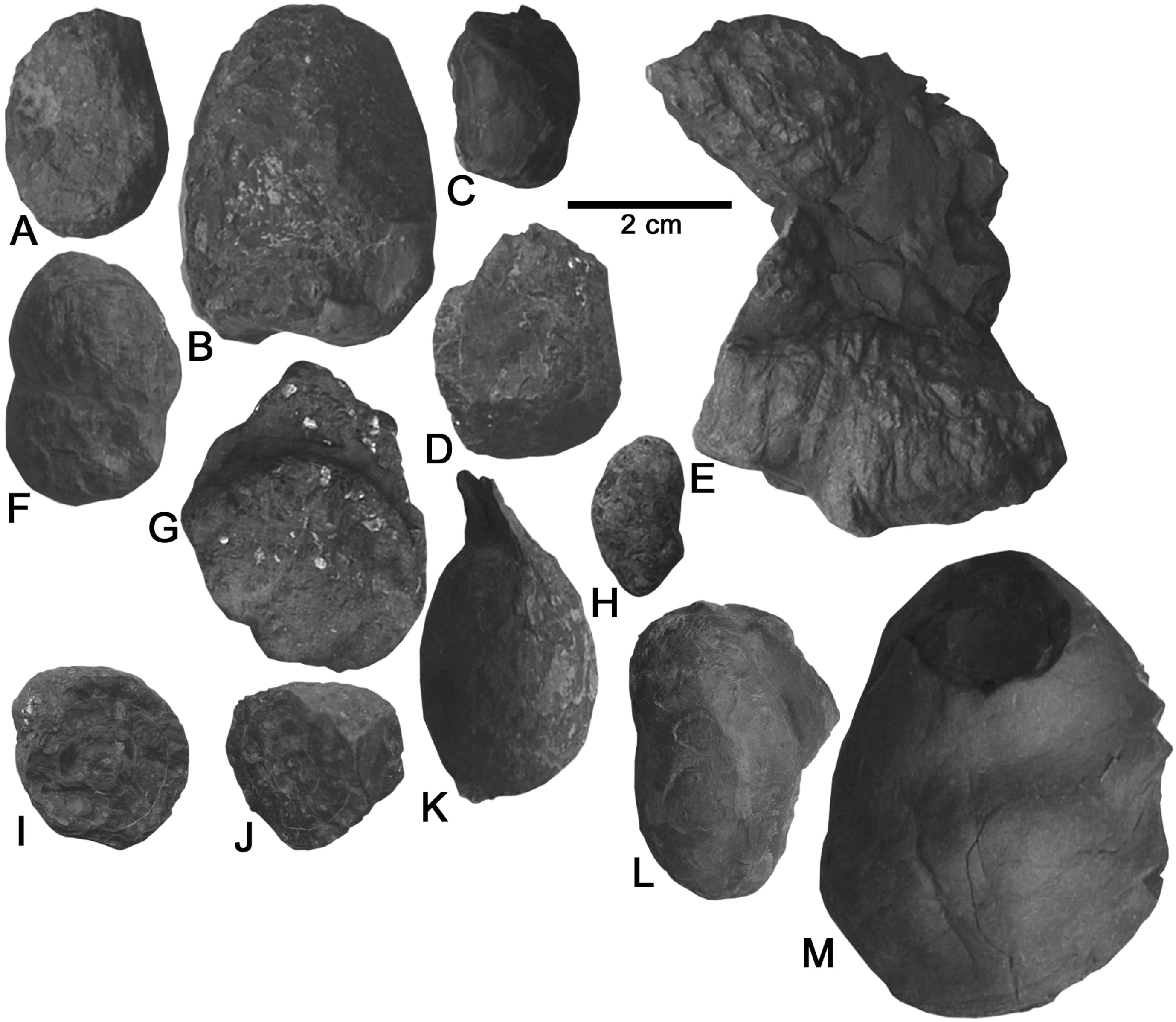

FIGURE 3. Coprolites from Blue Beach. **A**, CM 12319. **B**, CM 12321. **C**, CM 12320. **D**, CM 12318. **E**, CM 12322. **F**, CM 12327. **G**, CM 12326. **H**, CM 12324. **I-J**, CM 12317. **K**, CM 12323. **L**, CM 12316. **M**, CM 12328.

because the opposing end is not exposed. Its unique twist may be a product of spiral-variety structure, but the external twist distinguishes it from either the ovoid or elongate pellets. It is somewhat lighter-colored than usual, and contains no visible vertebrate remains.

Another morphotype of coprolite cannot be described as a pellet, but rather as (4) a somewhat flattened but regular mass (Fig. 3E). It displays a curious structure of loose, external wrinkles that mark it as unique. Preservation is pyritic instead of phosphatic. No vertebrate remains are visible.

The most common irregular coprolitic morphotype from Blue Beach consists of (5) irregular flattened masses (e.g., CM 12310 – Fig. 5F), recognizable by their high concentration of fish scales. This example was deposited in facies 1 clay shale (Martel and Gibling, 1991). Its rounded, but slightly irregular, outline and apparent flattening (plus inclusions) makes it appear similar to "lagoonal" coprolites like those from the Late Pennsylvanian Kinney Brick Quarry in New Mexico (Hunt, 1992). Since non-compressed pellet-coprolites can co-occur in these same clay shales, we do not consider the flattening to be an artifact of loading, but rather as an indication of a distinct morphotype. Like the pellet coprolites, irregular flattened masses are also a common morphotype at Blue Beach.

CM 12340 (Fig. 5G-H) is neither a pellet nor a flattened mass, but another morphotype (6) of irregular coprolitic masses. It is somewhat rounded with a flat bottom and shows, internally and externally, a high concentration of vertebrate and ostracod remains.

Besides the irregular coprolitic masses discussed above, even larger irregular masses may be present, but these have not yet been recognized. Small masses are easily recognizable when they occur in relatively unfossiliferous strata, but would be difficult to identify in beds with dense vertebrate fossil accumulations. As for larger masses, they become increasingly difficult to recognize as their sizes increase – where they begin to resemble lenses (produced by current sorting), or purely random accumulations, both of which also occur at many stratigraphic levels in the Blue Beach section.

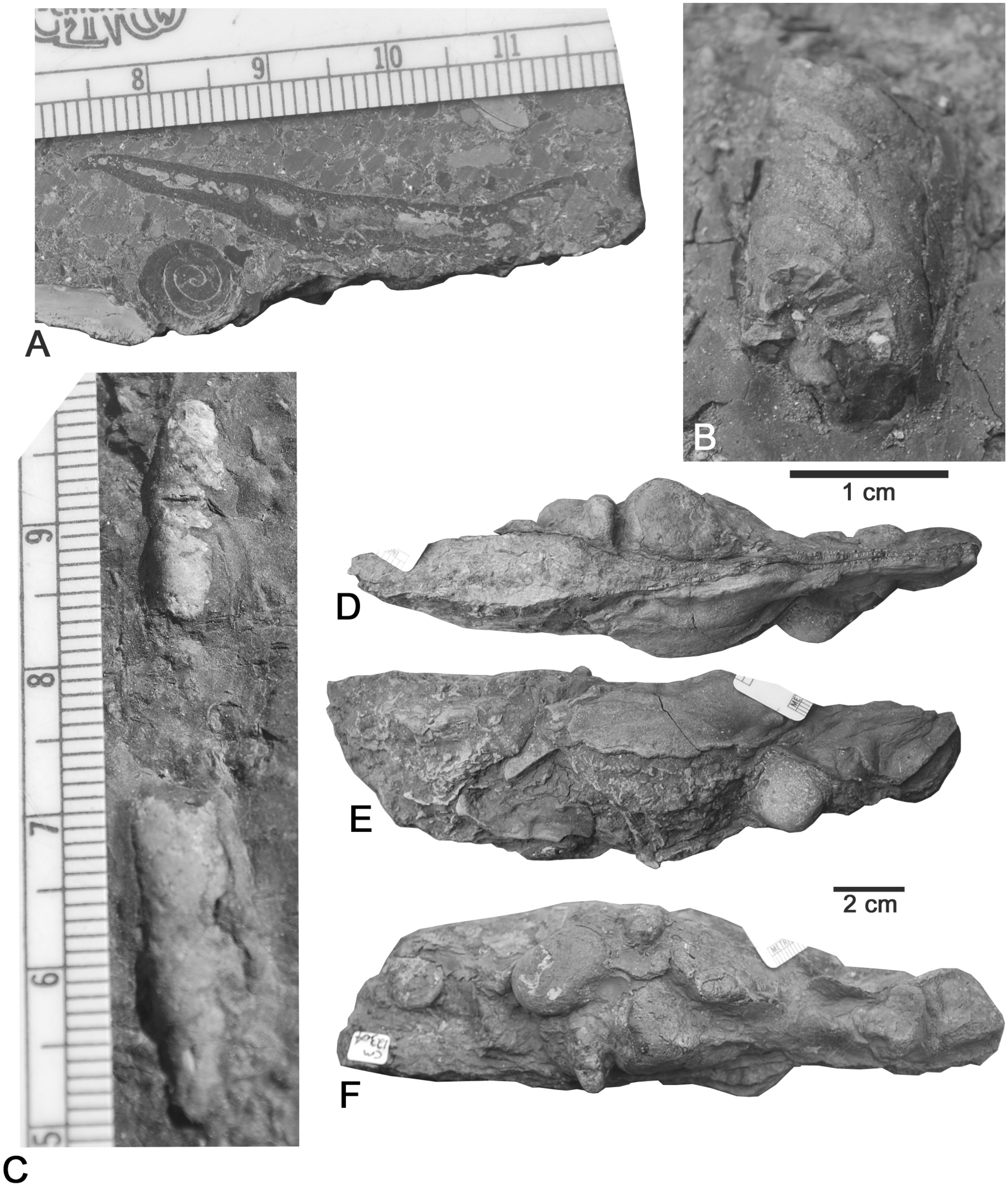

FIGURE 4. Coprolites from Blue Beach. **A**, NSM 07.GF.045.1268.2, Cross section of coprolite. **B**, CM 12251, Twisted coprolite in end view. **C**, CM 12334, Elongate coprolite in axial view. **D-F**, CM 12304, Coprolite mass in three views. Scales in **A**, **C**, in cm, upper right scale bar applies to **B**, and lower right scale bar applies to **D-F**.

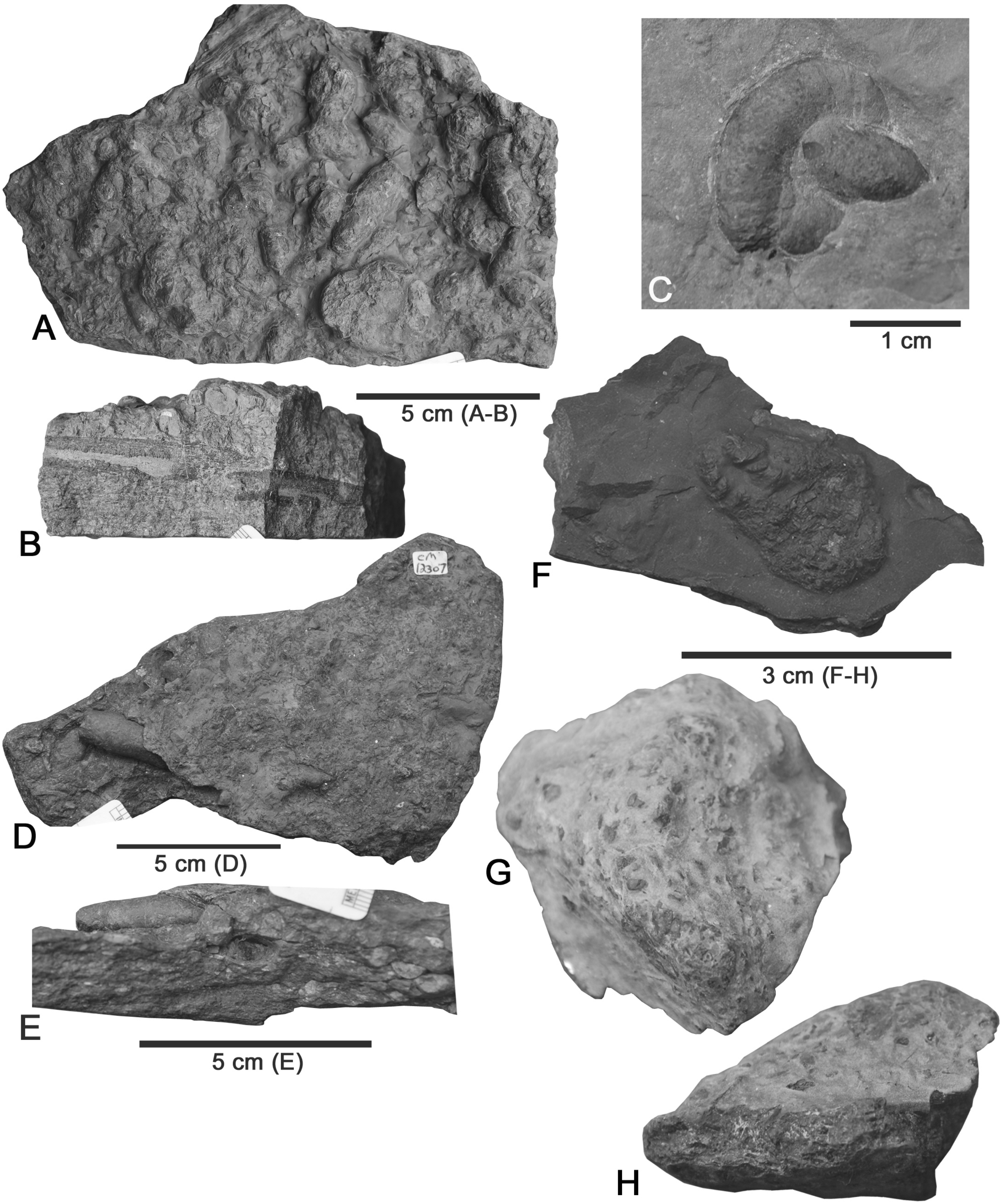

FIGURE 5. Coprolites from Blue Beach. **A-B**, CM 12305, Latrinite with multiple elongate coprolites on a single bedding plane in **A**, overview and **B**, cross sectional view. **C**, CM 12228, Close up of comma-shaped coprolite cluster. **D-E**, CM 12307, Elongate cylindrical coprolite in **D**, overview and **E**, cross sectional view. **F**, CM 12310, Coprolite on slab. **G-H**, CM 12340, Coprolite in **G**, overview and **H**, cross sectional view.

TABLE 2. Classification of Blue Beach coprolites.

Division A: "regular masses"
(1) ovoid pellets
(2) elongate pellets
(3) twisted pellets
(4) regular "wrinkled" masses

Division B: "irregular masses"
(5) irregular flattened masses (with vertebrate inclusions)
(6) irregular non-flattened masses (with vertebrate and ostracod inclusions)

DISCUSSION

The Horton Bluff Formation coprolites from Blue Beach share similarities with other Mississippian coprolite assemblages, notably in the Viséan of East Kirkton (Sumner, 1994), and to a lesser extent, with the Tournaisian site of Foulden (Pollard, 1985), which is otherwise considered the nearest Horton equivalent in both age and fauna (Smithson et al., 2012). All three localities share a mixture of forms that can be roughly divided into either "regular masses" or "irregular masses." Sumner (1994) describes and classifies a number of morphotypes for the East Kirkton coprolites that we use here for comparison.

The majority of the Blue Beach coprolites are comparable to Sumner's morphotypes 1 (spheroidal pellets), 2b (cigar-shaped pellets), 2d (small pellets), and 2e (small spiral pellets) with morphotypes 4a (large irregular phosphatic masses without inclusions), 4b (small irregular clusters with inclusions) also present. All of the Blue Beach coprolites are smaller than 10 mm by 30 mm, so morphotype 3 (large elongate pellets) is not represented. The East Kirkton coprolite assemblage also appears to be more diverse with additional morphotypes 2a (bullet-shaped pellets), 2c (string-like pellets), and 4c (roundish scattered masses of ostracodes and plants).

The Foulden site (Pollard, 1985) contains: (1) elongate pellets, probably closest to morphotypes 2b or 2e. It is unknown if these are of the spiral variety. Two unique morphotypes from Foulden that have not been recognized at East Kirkton or Blue Beach are described as (2) discoidal pellets, and (3) noded or beaded pellets. It is worth pointing out that the East Kirkton coprolites are extremely abundant and were well-sampled (Sumner, 1994), whereas neither the Fouldenn or the Blue Beach localities have yet been as extensively sampled. In part, the less-diverse copro-faunas of the earlier Tournaisian sites may prove to be an artifact of their smaller sample sizes.

Small round pellets, bullet-shaped pellets, and cigar-shaped pellets are often common forms at other Lower Carboniferous sites (Sumner, 1994), where they are found associated with faunas of palaeoniscoids, elasmobranchs, and acanthodians. Some of the small pellets may also have been made by tetrapods (Sumner, 1994). Spiral pellets, large or small, are almost always associated with elasmobranchs. The interpretation of the irregular forms of coprolites is more problematic, and some may even be regurgitalites, which can be difficult to discern (Sumner, 1994).

The Blue Beach fauna had a number of predators that were capable of ingesting vertebrates and producing coprolites containing bones, including: a large rhizodont (1 to 5 m) (*Letognathus*), a medium (1.5 m) dipnoan, at least 4 genera of small to medium palaeoniscoid fishes, and 5 to 7 genera of small, medium, and large tetrapods (small-medium = 1 m, large = 2 m). The coprolites of larger predators are not accounted for in the Blue Beach section, partly because of the problem cited above – a failure to recognize these among other "massed" accumulations of bony material. Large specimens attributable to (most likely) a rhizodont are interpreted as cololites rather than coprolites or regurgitalites because of their convex undersides, the secondary infill, and their occurrence in facies 1 clay shale, which rules out the possibility of a nodular origin.

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