UPPER CRETACEOUS TRACE FOSSILS,

BOOK CLIFFS OF UTAH:

A FIELD GUIDE

Robert W. Frey

Department of Geology
University of Georgia
Athens, Georgia 30602

James D. Howard

Skidaway Institute of Oceanography
P. O. Box 13687
Savannah, Georgia 31416

ABSTRACT

About 25 types of trace fossils occur in major marine facies of the Star Point and Blackhawk Formations in the Book Cliffs of Utah. Ichnogenera include Ancorichnus, Arenicolites, Aulichnites, Chondrites, Conichnus, Cylindrichnus, Medousichnus, Muensteria, Ophiomorpha, Palaeophycus, Planolites, Rosselia, Schaubcylindrichnus, Scolicia, Skolithos, Teichichnus, Teredolites, Thalassinoides, and Uchirites. Phoebichnus also may be present. Most trace fossils occur in characteristic suites of lithofacies and ichnofacies, which makes them useful in environmental interpretations. The ichnospecies are described herein.

INTRODUCTION

Upper Cretaceous rocks in the Book Cliffs of Utah are well-known examples of complexly intertonguing nonmarine, nearshore marine, and offshore marine facies, as is recounted elsewhere in this volume. Relative to many Cretaceous units in other regions, these rocks also exhibit

Depositional Facies of the Castlegate and Blackhawk Formations, Book Cliffs, Eastern Utah; Field Trip No. 10, 1985

remarkably diverse ichnofaunas. In marine facies of the Star Point and Blackhawk Formations (Fig. 1), we have documented at least 25 ichnospecies referable to about 20 ichnogenera.

Much of this research was reported in detail recently (Howard and Frey, 1984; Frey and Howard, 1985), and further work is in progress. Our present objective is (1) to offer a brief environmental synopsis of the ichnofacies, and (2) to present descriptions and illustrations of these trace fossils in a format suitable for field use.

MARINE ICHNOFACIES

Typical lithofacies and ichnofacies successions along depositional dip (Fig. 1) are summarized in Tables 1 and 2, which are adopted from Howard and Frey (1984). Transgressive hemicycles of deposition are poorly preserved to absent in the vertical sequence, although regressive hemicycles are well represented.

Most trace fossils occur in characteristic, although intergradational, ichnofacies which correlate with major lithofacies of regressive nearshore-to-offshore sequences. The latter include the foreshore, foreshore-shoreface transition, shoreface, and offshore facies. Landward facies consist mainly of clean, well sorted, well stratified, sparsely burrowed sandstones. Seaward facies, unless interrupted by hummocky bedded sandstones, typically consist of successively less pure, less well sorted and stratified, more intensely bioturbated, finer grained sandstones, siltstones, and mudstones. In terms of "universal" or archetypical ichnocoenoses (Frey and Pemberton, 1984), the main down-dip succession of trace fossils represents (1) the _Skolithos_ Ichnofacies--lower foreshore and the transition zone, (2) a mixed _Skolithos_-_Cruziana_ Ichnofacies--upper and middle shoreface, and (3)

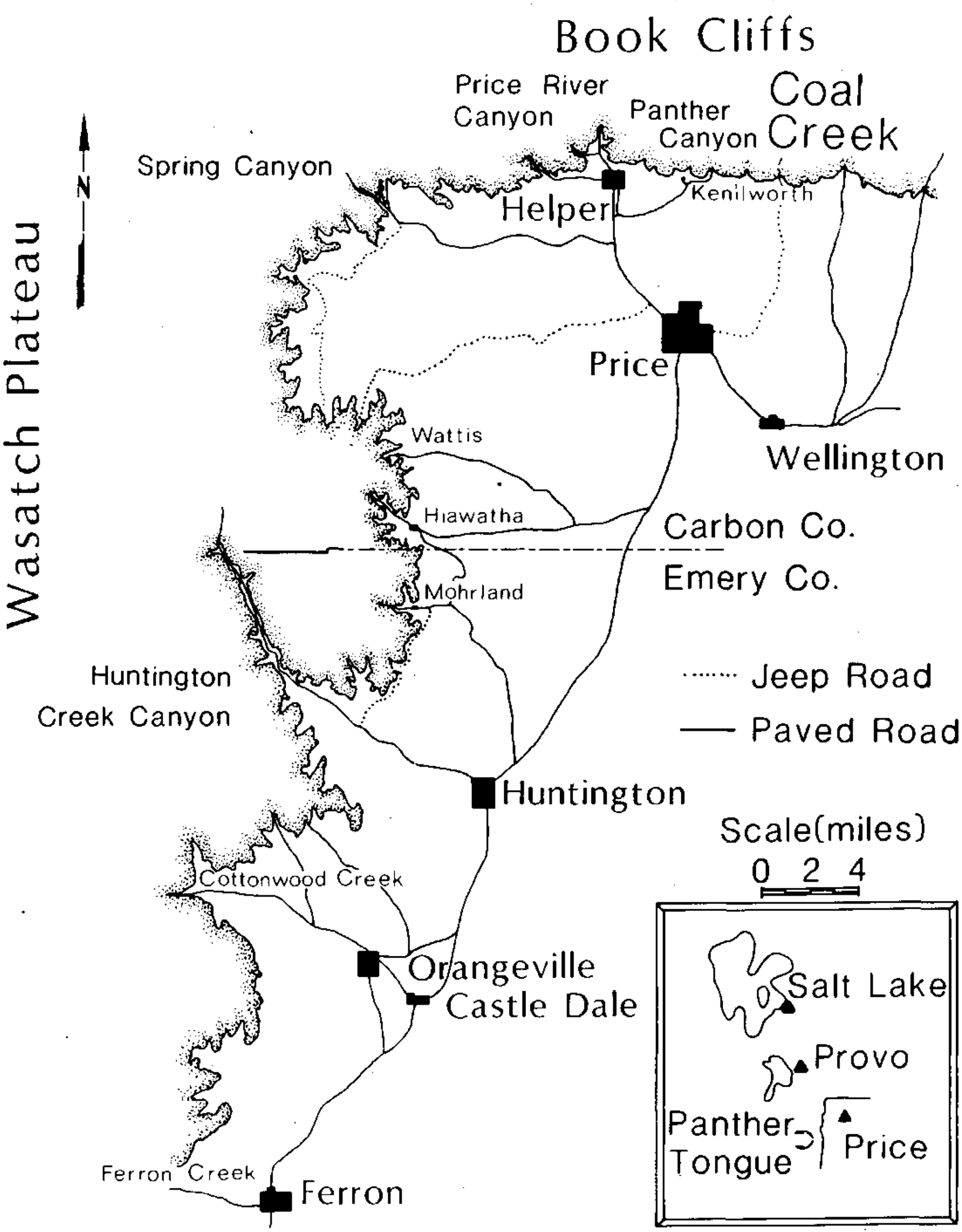

Fig. 1. General outcrop belt of Star Point Formation and overlying Blackhawk Formation, east-central Utah. North-south trends in Wasatch Plateau are along depositional strike. East-west trends in Book Cliffs are along depositional dip, the Coal Creek Canyon section being most distal.

TABLE 1. Facies distribution of characteristic trace fossils in foreshore to offshore sequences, Star Point and Blackhawk formations, Upper Cretaceous, east-central Utah.

Trace fossils	Facies							
	Lower foreshore	Transition zone	Upper shoreface	Middle shoreface	Lower shoreface	Upper offshore	Middle offshore	Lower offshore
Ophiomorpha nodosa	L	X	X	X	X	L	L	
Conichnus conicus	X							
*Medousichnus loculatus**			X					
Arenicolites sp. cf. *A. variabilis**			X					
Aulichnites parkerensis			X	X				
Teredolites clavatus			L	L				
Schaubcylindrichnus coronus			X	X	L			
Rosselia chonoides			X	X	L			
Skolithos linearis			X	X	L	L		
*Thalassinoides paradoxicus**				X				
Chondrites sp.				X	X			
Ophiomorpha irregulaire				X	X			
Rosselia socialis				X	X			
Teichichnus rectus				X	X	X		
Cylindrichnus concentricus			L	X	X	X	L	
Thalassinoides suevicus				X	X	X	X	
Planolites beverleyensis				X	X	X	X	X
Planolites montanus				X	X	X	X	X
Palaeophycus heberti				X	X	X	X	L
Scolicia sp.					X	X		
Ophiomorpha annulata					X	X	X	
Ancorichnus capronus					X	X	X	
Palaeophycus tubularis					X	X	X	

NOTES: X = main occurrences; L = local occurrences, depending upon local lithologies or substrate types.
*More common in Star Point Formation than in Blackhawk Formation.

the Cruziana Ichnofacies--lower shoreface through lower offshore zones. The mixed ichnofacies (2) reflects the smoothness or regularity of environmental gradients in the original depositional regime. Although Ophiomorpha nodosa exhibits a broad facies range (Table 1), vertical components of the burrow system predominate in the Skolithos Ichnofacies and horizontal components predominate in the Cruziana Ichnofacies.

Many of the local occurrences of trace fossils (L in Table 1) in the lower shoreface to lower offshore zones refer to clean thin sandstone beds representing higher energy conditions, or episodic sedimentation. Indeed,

storm deposits are common in some units, and their ichnologic aspects are presently being evaluated further. Preliminary results suggest physical

TABLE 2. Facies distribution of characteristic sediments and physical sedimentary structures in foreshore to offshore sequences, Star Point and Blackhawk formations, Upper Cretaceous, east-central Utah.

Foreshore—Clean, well sorted, fine- to medium-grained sand, parallel- to subparallel-laminated, in low-angle, gently seaward dipping, very thin wedge-shaped sets separated by subtle erosion planes; very sparsely bioturbated

Foreshore–shoreface transition—Clean, well sorted, medium-grained sand, in small- and large-scale trough cross-beds; very sparsely bioturbated

Upper shoreface—Clean, well sorted, fine- to medium-grained sand, in distinctly parallel-laminated to hummocky cross-bedded units separated by sharp erosion planes; parallel laminations, typically in low-angle, truncated sets, may be replaced locally by small-scale trough cross-beds; bedding units very sparsely bioturbated in lower part, becoming increasingly more bioturbated toward top

Middle shoreface—Clean to impure, well to poorly sorted, fine- to medium-grained sand, in parallel-laminated to hummocky cross-bedded units separated by erosion planes; bedding units less bioturbated in lower than in upper parts, but everywhere more bioturbated than in the upper shoreface

Lower shoreface—Poorly sorted, silty to clayey, fine-grained sand containing organic detritus, in laminated to hummocky cross-bedded units separated by erosion planes; intensely bioturbated, which may obscure physical stratification features; some hummocky beds are clean and sparsely bioturbated

Upper offshore—Impure sandy or clayey silt containing abundant organic detritus, in subtle thin beds; very intensely bioturbated; local very thin beds of clean, sparsely bioturbated, fine-grained sand

Middle offshore—Highly impure sandy or clayey silt, or mudstone, containing abundant organic detritus, subtly to indistinctly bedded; almost totally bioturbated

Lower offshore—Highly impure dark mudstone containing abundant organic detritus, indistinctly to massively bedded; totally bioturbated

NOTES: Beach-related facies are poorly developed among deltaic deposits of the Panther Member of the Star Point Formation, but shoreface and offshore deposits there are similar to those of the Spring Canyon Member of the Blackhawk Formation.

conditions and biogenic responses somewhat comparable to those observed in the Cardium Formation of Alberta (Pemberton and Frey, 1984).

MARGINAL MARINE ICHNOFACIES

Some of the ichnospecies listed in Table 1 also occur in marginal marine deposits (Kamola, 1984, Figs. 19-21), and indicate the influence of saline waters there. Rayhole structures, Teredolites, Pelecypodichnus, and Pholeus (? = Balanoglossites; see Häntzschel, 1975; cf. Kamola, 1984, Figs. 9, 10) are more prevalent there than in fully marine deposits. Additional summary information is presented elsewhere in this volume.

Despite the significant contributions of this initial reconnaissance on marginal marine ichnofacies, two important aspects require further work. (Indeed, both are important in analyses of marine to marginal marine or nonmarine transitions wherever they occur in the stratigraphic record.) One is an evaluation of patterns of backbarrier or deltaic bioturbation comparable to those studied along the modern Georgia coast (Howard and Frey, 1985, p. 90-96, 106-110). Ichnocoenoses in estuarine point bar deposits are especially diverse (ibid., p. 104-106). Such analyses would help clarify the relative influences not only of physical and biogenic processes but also of fluviatile, estuarine, and marine processes.

The other, although more nebulous, is an evaluation of the effects of landward excursions of the estuarine salt wedge in mesotidal settings. Along the modern Georgia-Florida coast, for example, we have documented ephemeral riverine occurrences of the mussel Brachidontes and the barnacle Balanus as much as 40 km inland from the sea (Frey et al., 1975, p. 283). These occurrences evidently are related to years of drought on the hinterland, diminished stream flow, and consequent intrusions of saline waters far upstream. Otherwise, the sedimentary record there is strictly nonmarine. Such circumstances can help explain perplexing or potentially ambiguous occurrences of many marine or marginal marine trace fossils in predominantly fluviatile or deltaic settings. Little previous work (e.g., Archer and Maples, 1984) has taken such variables into account.

TRACE FOSSIL DESCRIPTIONS

All major ichnospecies of marine traces found to date in the Star Point and Blackhawk Formations of the Book Cliffs area of Utah are included herein. Other trace fossils have been observed locally, including variant forms of Asterosoma and Teichichnus, probable Phoebichnus (cf. Pemberton and Frey, 1984, Fig. 9), and what we feel sure are rayholes (cf. Howard et al., 1977; Kamola, 1984) and amphipod cryptobioturbation (cf. Howard and Frey, 1985). Additional work is needed, however, before these latter forms can be incorporated within our general ichnofacies model (Table 1).

The following descriptions and illustrations are somewhat simplified. The taxa are listed alphabetically. Ichnogeneric characteristics are included only where more than one ichnospecies is indicated. Our "taxonomic key" is designed primarily for informal field use.

Informal Taxonomic/Morphologic Key

1. Resting traces--Medousichnus (Fig. 8).
2. Crawling traces:
    A. bilobed, unornamented--Aulichnites (Fig. 4).
    B. multilobed, ornamented--Scolicia (Fig. 15).
3. Burrows:
    A. shallow, conical--Conichnus (Fig. 6).
    B. U-shaped--Arenicolites (Fig. 3).
    C. cylindrical to subcylindrical:
        (1) simple, smooth walled--Skolithos (Fig. 7B).
        (2) concentrically walled--Cylindrichnus (Fig. 7A).
    D. bulbous or funnel shaped--Rosselia (Figs. 7C-G, 13).

E. well-lined, tubular:
   (1) singular tubes--*Palaeophycus* (Fig. 11).
   (2) sheafs of tubes--*Schaubcylindrichnus* (Fig. 14).
F. thinly lined, with chevron backfilling--*Ancorichnus* (Fig. 2).
G. unlined, straight to sinuous:
   (1) structureless filling--*Planolites* (Fig. 12).
   (2) meniscate backfilling--*Muensteria* (Fig. 9).
   (3) bilateral ribbing--*Uchirites* (Fig. 19).
H. tabular spreite structures--*Teichichnus* (Fig. 16).

4. Burrow systems:
   A. small, dichotomous--*Chondrites* (Fig. 5).
   B. large, ramifying:
      (1) smooth walled--*Thalassinoides* (Fig. 18).
      (2) knobby or mammillated--*Ophiomorpha* (Fig. 10).
5. Borings in wood--*Teredolites* (Fig. 17).

Ichnogenus *Ancorichnus* Heinberg 1974

Ancorichnus capronus Howard & Frey 1984

Fig. 2

Thinly lined, smooth walled, rarely branched, predominantly horizontal cylindrical burrows having distinct, chevron-laminated fills. Interpreted as backfilled feeding-dwelling structures, probably made by decapods.

Burrows are horizontal or gently inclined, and individual specimens are essentially constant in size. Different specimens range from 0.5 to 2

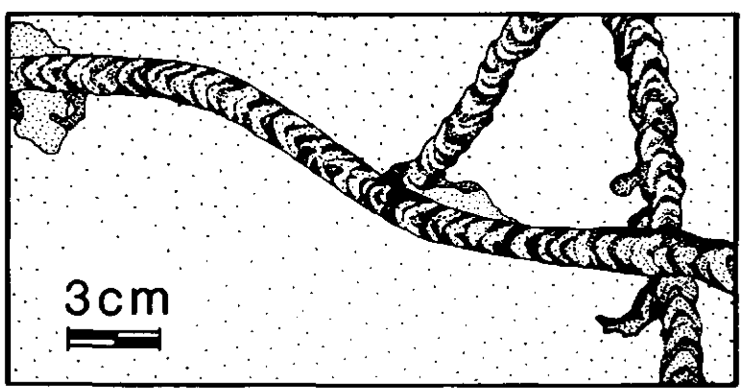

Fig. 2. *Ancorichnus capronus*. Composite diagram showing successive stages of weathering and destruction of wall lining, medium to coarse sandstone. Slightly weathered specimen (left-right); intermediate weathering (top center); pronounced weathering (right side). Plan view.

cm, and average about 1.2 cm, in diameter. Most burrows are straight, although some are slightly arcuate. Chevron fills consist of distinct alternations of coarser and finer sediments, commonly enhanced by color contrasts. Convexity of chevrons ranges from highly acute to somewhat obtuse angles. Thin but distinct burrow linings are present in fresh specimens; however, linings tend to weather rapidly on outcrop exposure.

Somewhat comparable chevron fills occur locally in Ophiomorpha and Thalassinoides. Yet, well-preserved segments remain distinctive and identifiable in most cases.

Ichnogenus Arenicolites Salter 1857

Arenicolites sp. cf. A. variabilis Fürsich 1974

Fig. 3

Simple, smooth-walled, very thinly lined, essentially vertical U-shaped burrows lacking spreiten; limbs of U somewhat variable in symmetry and configuration. Interpreted as feeding or feeding-dwelling structures of vermiform animals.

Burrows are slightly elliptical in cross-section; diameters are typically 5 to 6 mm. Burrow limbs may extend as much as 1 m into the substrate. In places burrow length is controlled by bed thickness, the base of the U lying at, or just above, the lower contact of the host stratum. Both limbs of the U tend to occur in a single vertical plane, but the limbs may be nearly vertical to gently or steeply inclined within that plane. Most burrows are approximately but not perfectly symmetrical about the longitudinal axis between limbs. Where well-preserved, apertures of burrow limbs tend to be slightly enlarged.

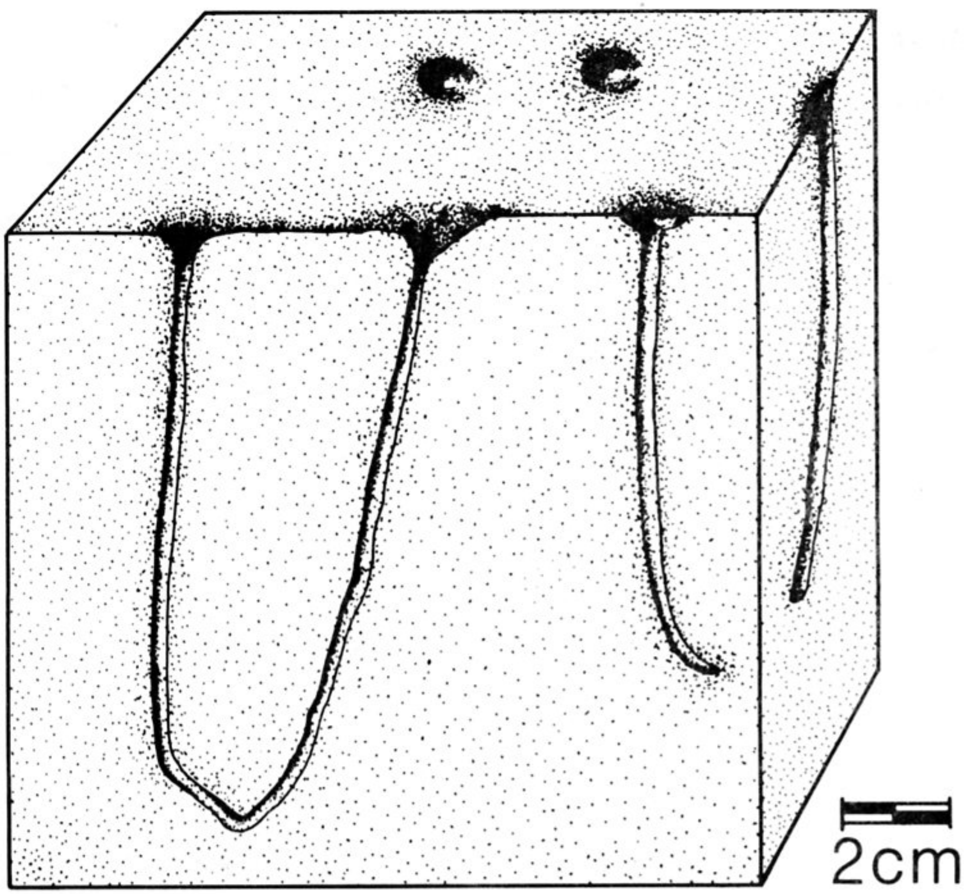

Fig. 3. Arenicolites sp. cf. A. variabilis.

Ichnogenus Aulichnites Fenton & Fenton 1937

Aulichnites parkerensis Fenton & Fenton 1937

Fig. 4

Sinuous to straight, unbranched, essentially unornamented bilobate trails having a narrow median furrow. Interpreted as crawling traces of gastropods or other animals of similar locomotor habits.

Given specimens are consistent in width; the size range observed among different specimens is about 0.5 to 1 cm. Crossovers are common locally, but the trails ordinarily do not intersect. In places, the lobes may exhi-

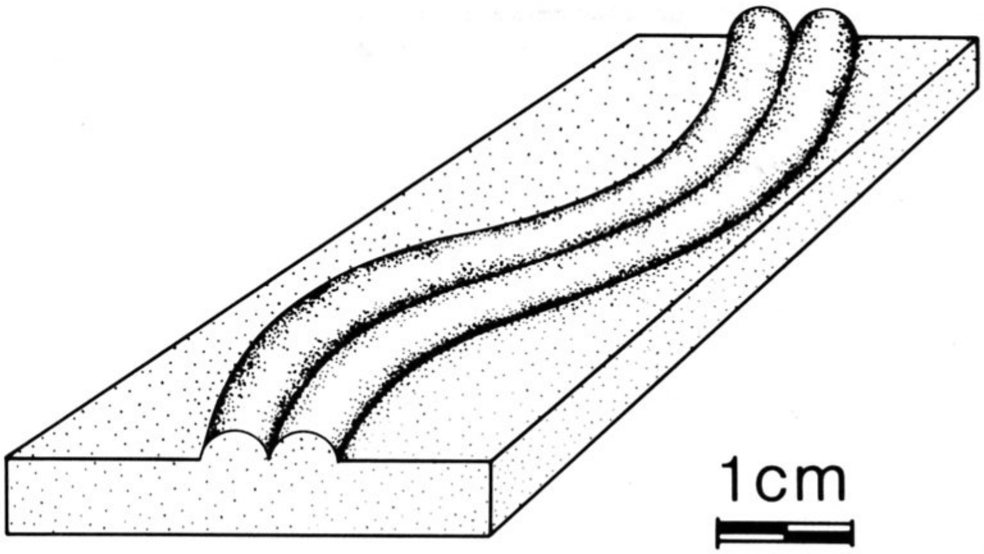

Fig. 4. Aulichnites parkerensis.

bit vague annulations, presumably related to peristalsis. Sinuosity of the trails is variable. Some are straight for appreciable lengths, whereas others are arcuate to meandrous.

Ichnogenus Chondrites von Sternberg 1833

Chondrites sp.

Fig. 5

Dendritic, smooth walled, regularly but asymmetrically branched small burrow systems that ordinarily do not interpenetrate or interconnect; diameter of components within a given system remains more or less constant. Interpreted as feeding structures of vermiform animals.

Burrow systems range from slightly irregular, sparsely branched, to pinnate, densely ramifying structures, all predominantly horizontal. Isolated pinnate segments, typically lacking obvious genetic relationship to nearby burrow systems, are most common. Components among different specimens range from 1 to 3 mm in diameter. Burrow fills commonly are lighter in color than, or otherwise contrast with, the enclosing sediment.

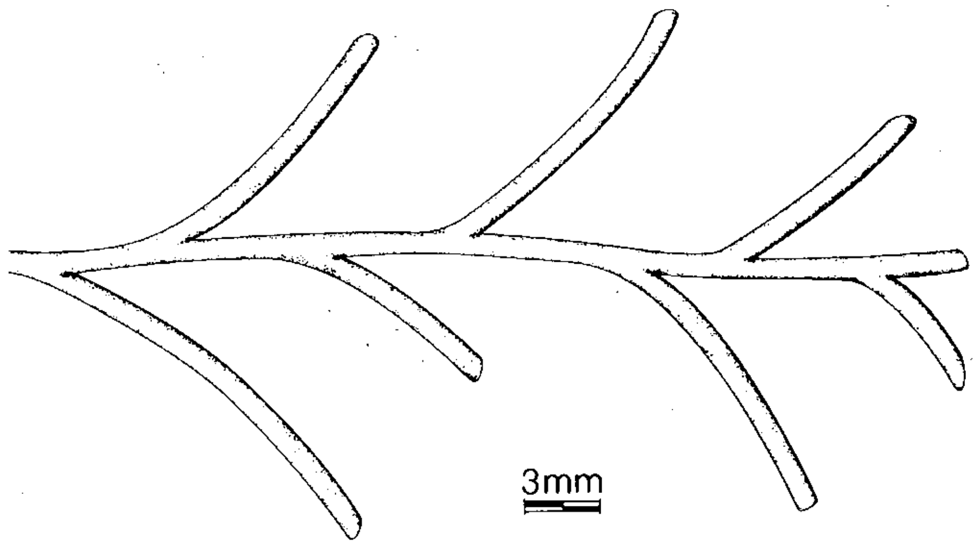

Fig. 5. Chondrites sp. Plan view.

Ichnogenus Conichnus Myannil 1966

Conichnus conicus Myannil 1966

Fig. 6

Conical to acuminated subcylindrical structures, vertically oriented, thinly lined, having a smooth, sharply rounded basal apex. Interpreted as resting-dwelling structures of anemones or anemone-like animals.

Specimens are slightly oval in cross-section, 3 to 6 by 4 to 8 cm in diameter, and about 12 to 20 cm long. Burrow linings are thin but distinct, and dark in color. Fillings are resistant to erosion; they may exhibit nested funnel-like laminae, convex down, but not radial symmetry across the top. Nested internal laminae suggest that the tracemaker kept pace with sedimentation in gradually aggrading substrates.

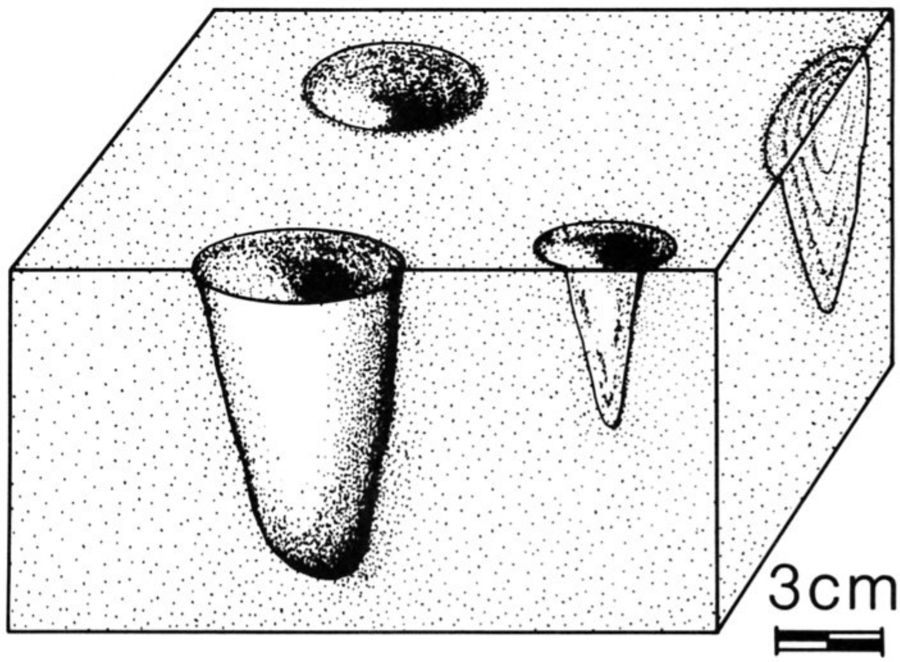

Fig. 6. Conichnus conicus.

Ichnogenus Cylindrichnus Howard 1966

Cylindrichnus concentricus Howard 1966

Fig. 7A

Long, subcylindrical to subconical burrows, straight to gently curved, vertical to horizontal, having concentrically layered walls. Interpreted as dwelling or feeding-dwelling structures of vermiform animals.

Other than small-scale irregularities in diameter along the structure, most specimens are essentially cylindrical; overall subconical taper is slight. Branches are comparatively rare. Maximum diameter is generally 0.5 to 2 cm; concentric layering consists of alternating layers of dark and light sediment. The tubular core, 2 to 4 mm in diameter, typically is well centered in the overall concentric structure, although eccentric cores occur. Most eccentric burrows are elliptical in cross-section.

Cylindrichnus concentricus is a distinct, isolated burrow in most

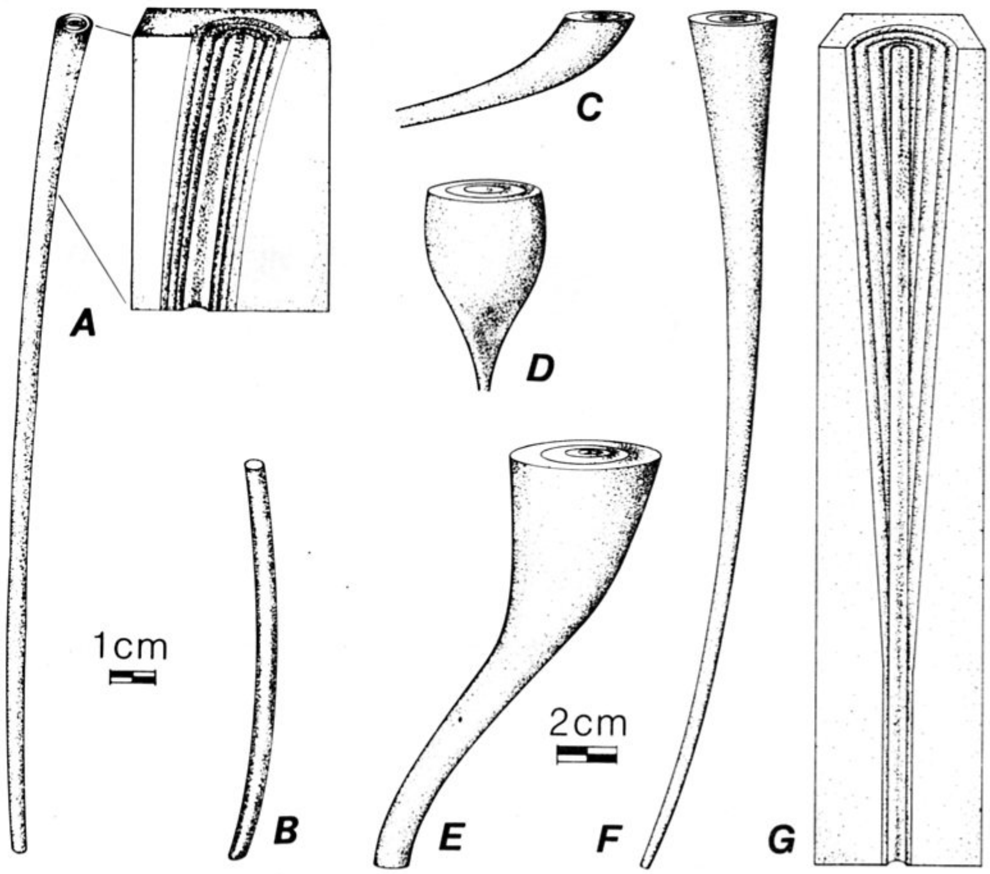

Fig. 7. Intergradational burrows. Compare with Fig. 13. A, Cylindrichnus concentricus. B, Skolithos linearis. C-G, Various perspectives of Rosselia socialis, including a schematic reconstruction (G).

occurrences. However, some specimens grade downward to a simple-walled basal structure identical with Skolithos linearis. Similarly, virtually every specimen of Rosselia socialis grades downward to a small basal stem identical with Cylindrichnus concentricus.

Ichnogenus Medousichnus Howard & Frey 1984

Medousichnus loculatus Howard & Frey 1984

Fig. 8

Subrounded to oval, horizontal, more or less radially symmetrical depressions flanked by a raised, marginal rim; radially disposed compart-

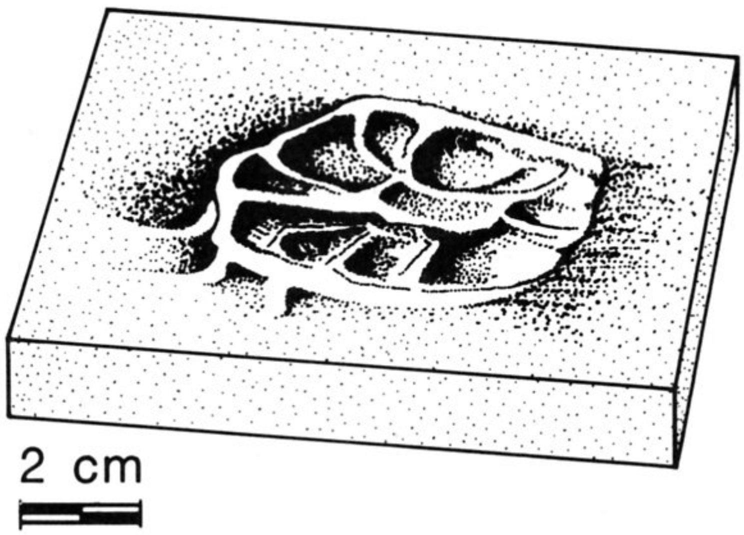

Fig. 8. Medousichnus loculatus.

ments surround a central boss. Interpreted as resting traces of medusoid animals.

Traces may be slightly elliptical in plan view and are typically 5 to 6 cm across. Interiorly, the trace generally is divided into about 8 to 12 radial compartments by raised thin ridges; in some specimens the radial pattern is poorly developed, evidently because of incohesive original sediment. Where well preserved, the marginal rim, up to about 1 cm wide, is somewhat variable in width and height, and is less sharply defined than the radial partitions, typically 1 to 2 mm wide. The thin ridges radiate from a poorly defined, raised central boss somewhat oval in outline and 1 to 2 cm across. Radial symmetry is imperfect, the individual compartments ranging from 0.5 to 1.5 cm in maximum width within a single specimen. Maximum relief, from the floor of compartments to the top of the marginal rim, is about 1.5 cm.

Ichnogenus Muensteria von Sternberg 1833

Muensteria sp.

Fig. 9

Distinctly meniscate, cylindrical to subcylindrical burrows having discernible but unlined wall structures. Interpreted as backfilled feeding or foraging burrows of vermiform animals.

Typical specimens are 5 to 8 mm in width. Lengths up to 15 cm have been observed, although the original structures must have been appreciably longer. All segments are essentially horizontal and straight to slightly sinuous. Menisci are rather evenly spaced, averaging 16 to 18 per centimeter of burrow length. In some populations of burrows, distal ends of menisci are deflected at an abrupt angle near the burrow periphery. The menisci evidently represent a combination of fecal stuffing and sediment bypassing around the body of the tracemaker.

The typical facies range of this burrow form remains unknown. In fact, the name Muensteria may prove to be invalid (Frey and Howard, 1985,

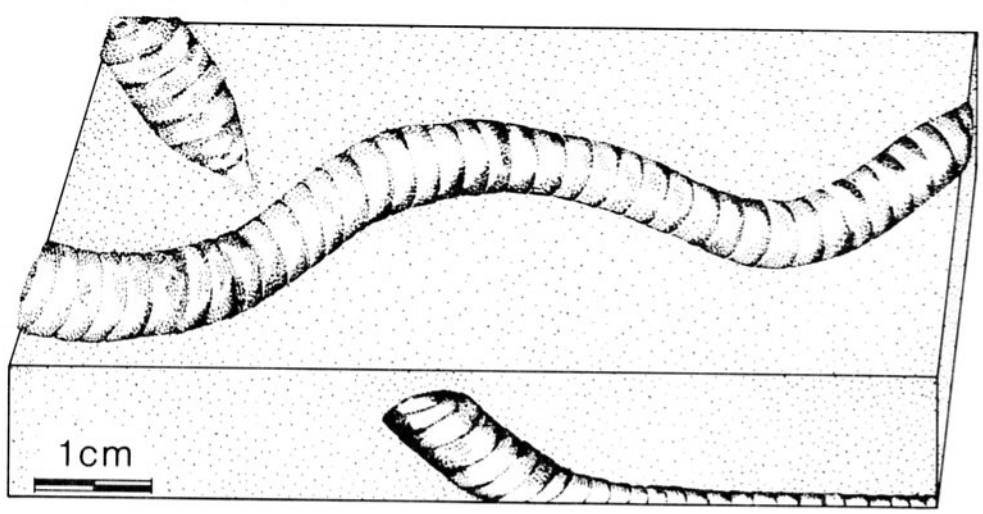

Fig. 9. Muensteria sp. Distinctly walled but unlined, cylindrical to sinuous meniscate structures.

p. 378-379); it is used at present because no other ichnogeneric name is available for these distinctive structures.

Ichnogenus Ophiomorpha Lundgren 1891

Simple to complex burrow systems distinctly lined with agglutinated pelletoidal sediment. Interpreted as dwelling or feeding-dwelling structures of decapods.

Locally, especially in highly bioturbated siltstones, wall linings are thin and pellets are poorly developed. Consequently, ichnospecies of Ophiomorpha may be difficult to differentiate.

Ophiomorpha annulata (Książkiewicz 1977)

Fig. 10A

Burrow walls consisting of evenly spaced, transverse rows of elliptical pellets. These end-to-end pellets form more or less continuous rings or annulations around burrow segments.

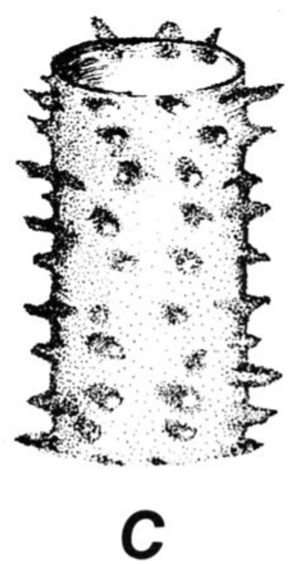

Fig. 10. Ophiomorpha ichnospecies. Vertical components. A, O. annulata. B, O. nodosa. C, O. irregulaire.

Typical, conspicuous specimens consist mainly of distinctly annulated external molds, the softer burrow walls and sediment fills having weathered away. Some specimens tend to have distinctly lined walls but somewhat poorly developed pelletoidal exteriors. Many pellets are rudimentary. Wall structure becomes increasingly well developed in more landward facies. Specimens are 0.5 to 2 cm in diameter and are branched somewhat less commonly than those of _O. nodosa_. Horizontal segments are much more abundant than vertical segments, and most of the latter are shorter in length.

Ophiomorpha irregulaire Frey, Howard & Pryor 1978

Fig. 10C

Burrow walls consisting predominantly of sparse, irregularly distributed, ovoid to mastoid or conical pellets or pelletal masses.

Sinuous, sparsely branched, horizontal burrows or burrow mazes predominate. In most horizontal specimens, knobs are well developed only on the top and sides of the structure. Short, vertical, cylindrical shafts have been observed locally; among these, all sides are equally pelleted. Horizontal segments are oval in cross-section, 2 to 5 cm wide and 1 to 2 cm high. Locally, the pelletal masses resemble "flame structures," reflecting soft-sediment deformation of the muddy wall lining.

Ophiomorpha nodosa Lundgren 1891

Fig. 10B

Burrow walls consisting predominantly of a mosaic of dense, regularly to irregularly distributed, discoid, ovoid, or polygonal pellets.

Burrow systems are somewhat variable in configuration. Sparsely branched vertical components predominate in nearshore, high-energy environments, whereas more densely branched horizontal components predominate in offshore, low-energy settings. As in O. annulata, most branches are Y-shaped and enlarged at points of bifurcation. However, specimens of O. nodosa, typically 1 to 2.5 cm in diameter, tend to be slightly larger than those of O. annulata. Burrow fills of both ichnospecies may consist either of structureless sediment or of chevron backfilling laminae (cf. Fig. 18A). Components of O. annulata and O. nodosa commonly interpenetrate, but true intergradations or interconnections between burrow systems have not been observed.

Ichnogenus Palaeophycus Hall 1847

Predominantly unbranched, distinctly lined, essentially cylindrical, horizontal to inclined burrows; sediment fills typically of same lithology as host stratum. Interpreted as dwelling structures of predaceous vermiform animals.

Palaeophycus is distinguished from Planolites primarily by having a distinct wall lining. Respective sediment fills typically differ also (Pemberton and Frey, 1982, p. 849, 850, 852).

Palaeophycus heberti (Saporta 1872)

Fig. 11A

Smooth walled, unornamented, thickly lined cylindrical burrows of somewhat variable orientation.

Horizontal to gently inclined burrows predominate, although steeply inclined burrows occur. Two size classes are commonly recognized. Small forms are about 1.5 to 5 mm in diameter and have walls 0.2 to 0.7 mm thick; large forms generally are 6 to 11 mm in diameter and have walls 1 to 2 mm thick. Although the environmental range of the two size classes overlaps

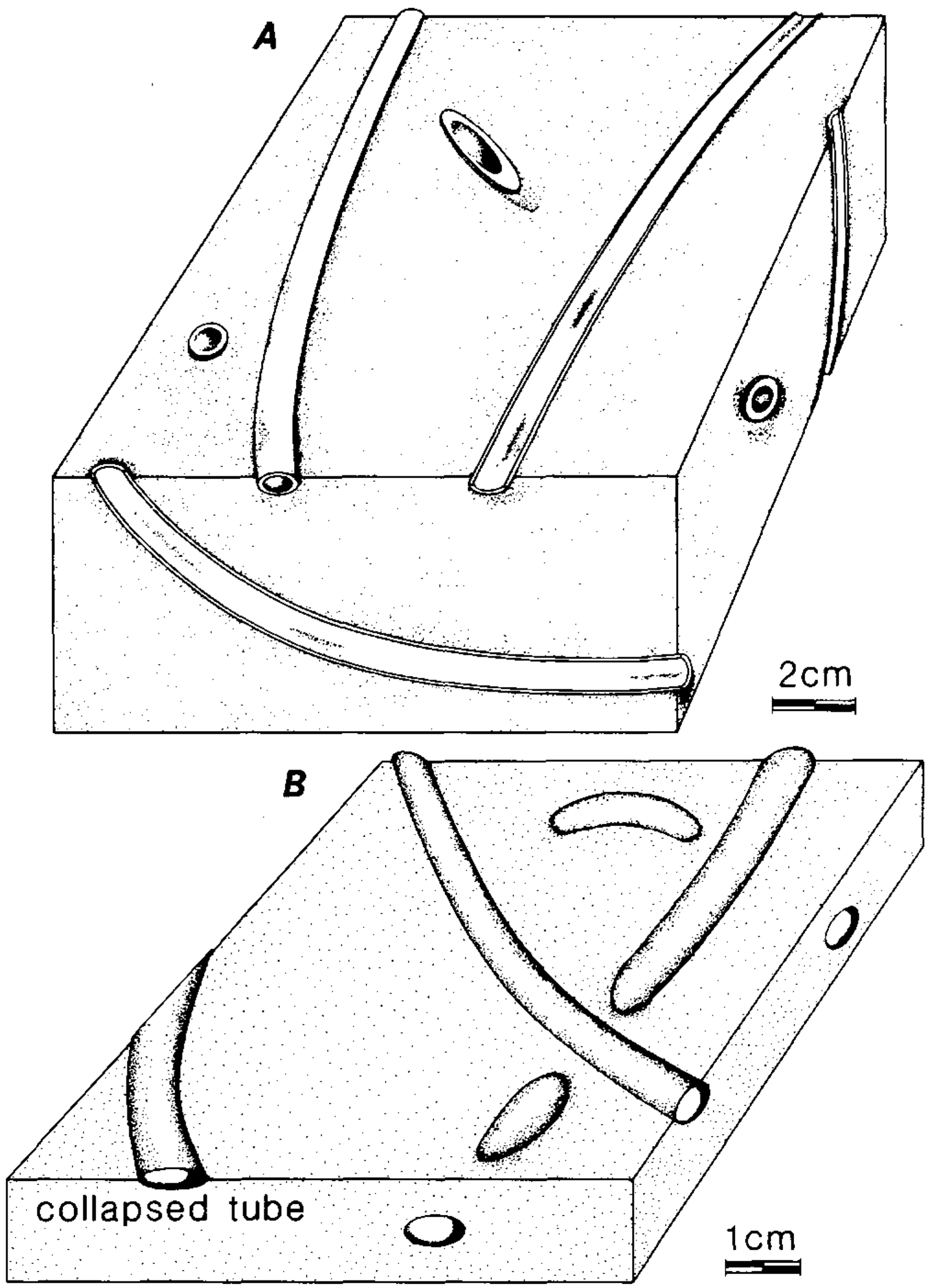

Fig. 11. Palaeophycus ichnospecies. A, P. heberti. B, P. tubularis.

broadly, small forms tend to be somewhat more abundant in low-energy settings and large forms in slightly higher energy settings. The thick, particulate wall lining tends to be lighter in color and better sorted than either the burrow fill or the host stratum.

Schaubcylindrichnus coronus has comparably thick, white walls, but is characterized by a multiple-tube configuration. In some previous literature, *Palaeophycus heberti* has been referred to *Siphonites*, which is an invalid ichnogenus.

Palaeophycus tubularis Hall 1847

Fig. 11B

Smooth walled, unornamented, predominantly horizontal, straight to sinuous cylindrical burrows, thinly but distinctly lined.

Most specimens are elliptical in cross-section because of bedding compression. Typical specimens are 5 to 10 mm across and 4 to 8 mm high. Some burrows are rather sinuous or undulant, coursing in no obviously preferred direction. Most are horizontal and only gently curved. Burrow fills are resistant to weathering, and tend to stand out in relief. Short segments work free and are seen commonly as float. Wall linings weather away rapidly on exposure; where preserved, they are very thin and dark gray to nearly black in color, in contrast with the thick white walls of *P. heberti*. Collapsed burrow segments, representing incomplete filling by sediments, are much more frequent in *P. tubularis* than in *P. heberti*.

Ichnogenus *Planolites* Nicholson 1873

Unlined, rarely branched, straight to contorted, smooth to irregularly walled burrows; sediment fills essentially structureless but lithologically different from host stratum. Interpreted as feeding structures of vermiform animals.

Planolites beverleyensis (Billings 1862)

Fig. 12A

Relatively large, smooth to somewhat irregularly walled, essentially cylindrical burrows, straight to gently curved or undulant.

Burrows typically are 6 to 12 mm in diameter; most are straight to slightly arcuate, and are oriented horizontally. Walls are discernible but are unlined and may not be sharply defined; burrow fills generally merge with the enclosing sediment, even though slightly different in composition. Because of its relative inconspicuousness the burrow is easily overlooked, even where well represented in the ichnofauna. In homogeneous but poorly sorted sediments, it is especially difficult to recognize. Its absolute abundance probably remains appreciable, however; vague, poorly preserved burrows of this general size and configuration are ubiquitous in many sections, and they account for considerable "background" bioturbation.

Planolites beverleyensis is distinguished from P. montanus by the consistently smaller size and typically more tortuous course of the latter (Pemberton and Frey, 1982, p. 866). Branching also is slightly more prevalent in P. montanus.

Planolites montanus Richter 1937

Fig. 12B

Small, smooth walled, rarely branched, typically curved to undulant or contorted burrows.

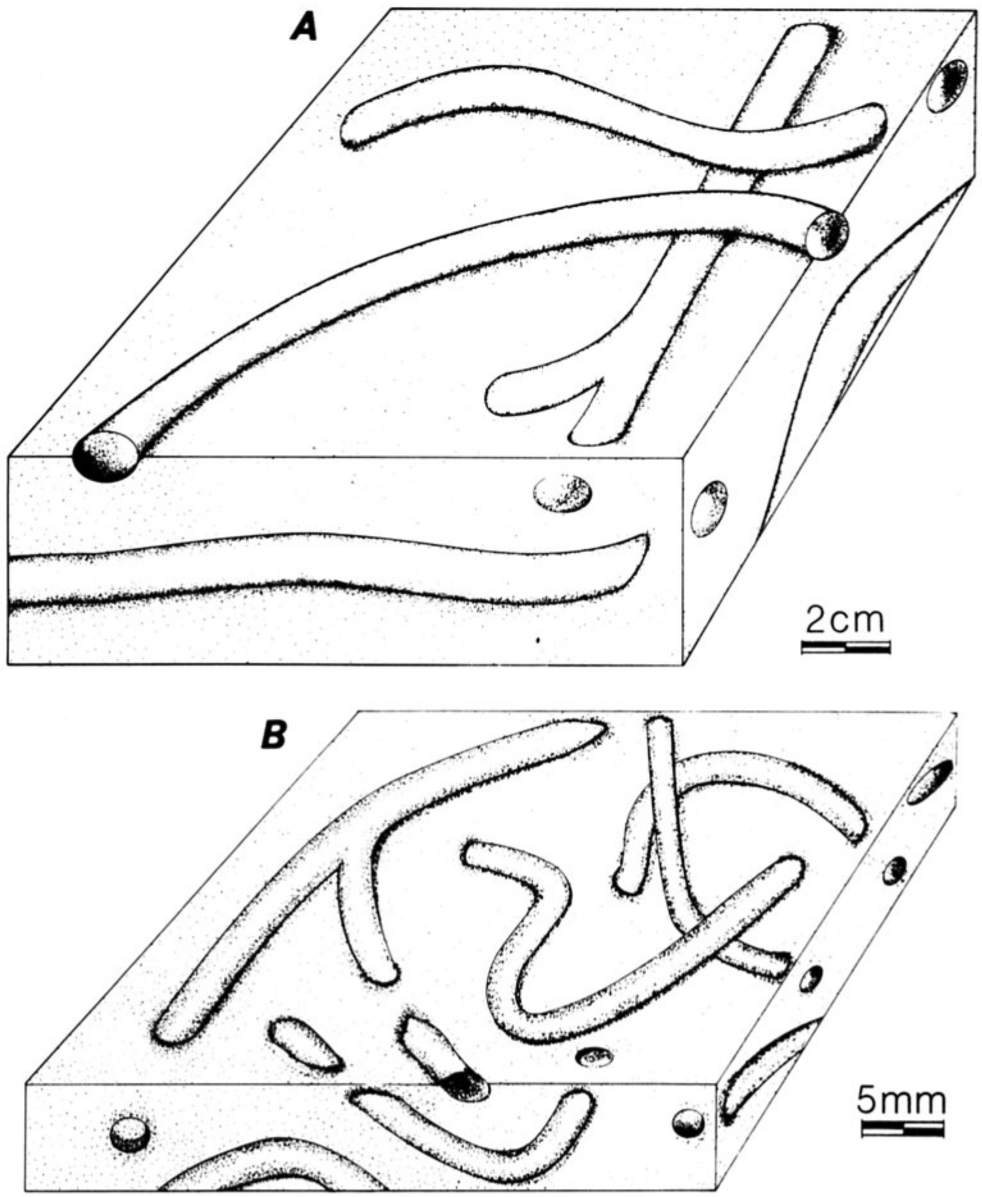

Fig. 12. Planolites ichnospecies. A, P. beverleyensis. B, P. montanus.

Two distinct size classes of P. montanus commonly are observed. The larger form, 1 to 2 mm in diameter, is considered to be typical of the ichnospecies as a whole (see Pemberton and Frey, 1982). The smaller form is distinctly less than 1 mm in diameter. Locally, small oxidation or reduction halos surround both forms. Like P. beverleyensis, P. montanus probably is considerably more abundant than the casual observance of discrete specimens would suggest. However, except for its small size, *P. montanus* generally is somewhat more obvious than *P. beverleyensis* because of textural contrasts.

Foregoing discussions refer mainly to isolated, albeit typically gregarious specimens observed in various strata. Specimens also are abundant within fills of other, larger burrows, especially *Ancorichnus capronus*, *Ophiomorpha annulata*, *O. irregulaire*, *O. nodosa*, *Palaeophycus tubularis*, *Planolites beverleyensis*, *Thalassinoides suevicus*, and, rarely, *Teichichnus rectus*.

Ichnogenus *Rosselia* Dahmer 1937

Conical to irregularly bulbous or funnel-shaped structures, vertical to horizontal, consisting either of a small central burrow surrounded by broad, concentric, cone-in-cone laminae, or of spreite-like helicoid swirls surrounding a cone, both tapering downward to a concentrically walled, subcylindrical stem. Interpreted as feeding structures of vermiform animals.

Rosselia chonoides Howard & Frey 1984

Fig. 13A-C

Large, squat, broadly bulbous to elongate, funnel-shaped burrows, predominantly vertical, consisting of helicoid swirls of reworked sediment, terminating downward in a subcylindrical stem.

Diameter of the funnel top ranges from about 4 to more than 25 cm. Sides of funnels typically slope inward at angles of 25 to 50°. Basal

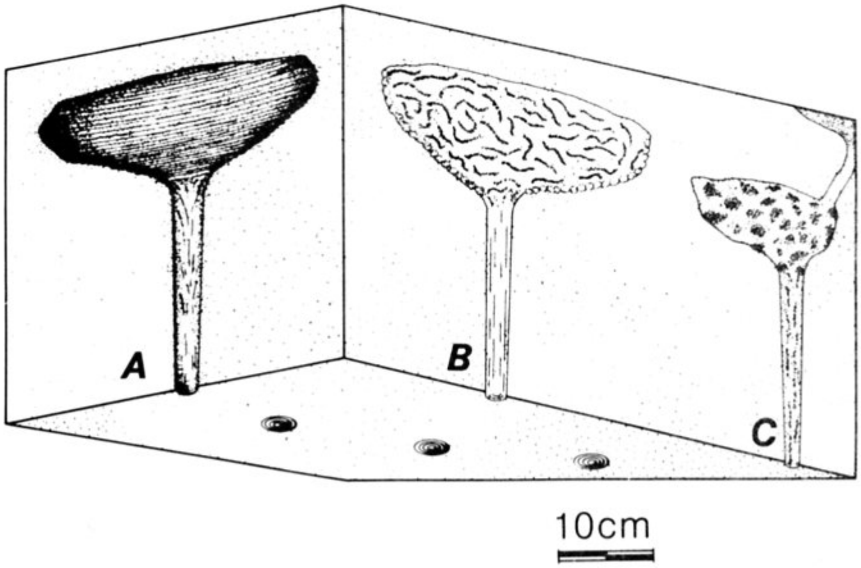

Fig. 13. Rosselia chonoides. Basal stem resembles Cylindrichnus concentricus. A, Cavity (external mold) left in rock upon removal of burrow fill by weathering processes. B, Longitudinal section through unweathered burrow; gneiss-like pattern of bioturbated coarse and fine sediment characterizes the "funnel". C, Longitudinal section through unweathered burrow filled primarily by bioturbated mud; another such structure branches off the top.

shafts range in diameter from abut 0.5 to 2 cm, and may be concentricaly walled. Where well preserved the outer wall of the funnel, as much as 1 cm thick, may exhibit a spreite-like whorl of small, tightly appressed, concentric, individual vermiform burrows accentuated by alternating light and dark laminae. These color segregations reflect biogenic sediment processing, resulting in the separation of sand and silt fractions. Interiors of such funnels consist of similar alternations of sediment, albeit in contorted, gneiss-like patterns. Commonly, the funnel filling has been removed by weathering, and the peripheral spreite-like whorl is represented only by small, half-relief burrows (grooves) etched into the enclosing sandstone. In some noneroded fills a small burrow, reminiscent of the central shaft in _Rosselia socialis_, courses irregularly through the interior of the structure. Funnels tend to be concentrated at particular horizons within host beds. Short, vertical or steeply inclined shafts commonly branch off funnel tops and give rise to another, overlying horizon of dense funnels.

Small funnels are intergradational with _R. socialis_. Like _R. socialis_, the base of _R. chonoides_ is intergradational with _Cylindrichnus concentricus_.

Rosselia socialis Dahmer 1937

Fig. 7C-G

Small central burrows surrounded by concentric, funnel-like laminae, nested convex downward, terminating in a subcylindrical, concentrically layered stem.

These cones typically are 1 to 6 cm in maximum diameter; the central core is 3 to 5 mm in diameter. Internal concentricity is imparted by alternating layers of dark and light sediment. Orientations range from vertical to horizontal, the latter being most common in distal lithofacies. Branching is common locally but is rare overall. Some branches are small laterovertical offshoots that lead upward to fully developed, successive rosselians. Others represent bifurcations of a single parent trunk leading to two or more geometrically simultaneous rosselians.

Isolated subconical specimens of _Cylindrichnus concentricus_ may overlap the morphology of small, incompletely expanded specimens of _Rosselia socialis_. In most cases, however, the robust development and conical flair of _R. socialis_ distinguish it from _C. concentricus_.

Ichnogenus *Schaubcylindrichnus* Frey & Howard 1981

Schaubcylindrichnus coronus Frey & Howard 1981

Fig. 14

Distinct bundles of closely grouped, congruent, well-lined tubes. Interpreted as dwelling structures of vermiform animals.

Burrows are gently curved, their upper part approximately vertical and their lower part approaching the horizontal. Configurations of tubes within the sheafs varies from linear rows to tightly packed clusters. The number of tubes per group ranges from 2 to nearly 20; most groups have about 5. Individual tubes are 4 to 8 mm in diameter; wall linings are about 1 to 2 mm thick, and adjacent walls may overlap. Congruence and

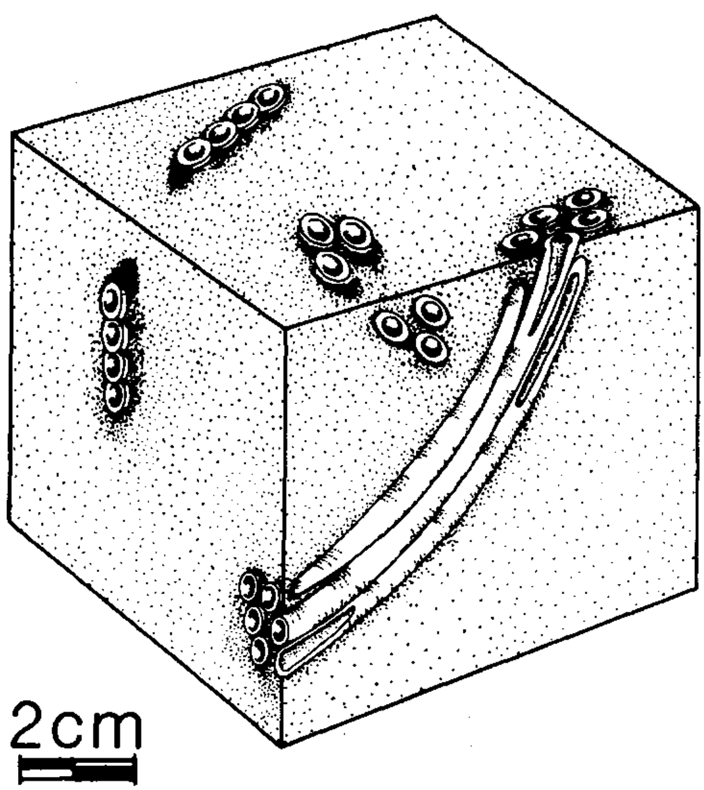

Fig. 14. *Schaubcylindrichnus coronus*.

persistent clustering of tubes indicate a close genetic relationship among components, yet interconnections have not been observed.

Exact modern analogs remain unknown. However, specimens observed recently in the Cretaceous of Delaware (Curran, 1985) confirm our original interpretation of the structures as domiciles of deep-probing deposit feeders (Frey and Howard, 1981).

Schaubcylindrichnus coronus is distinguished from Palaeophycus heberti by having multiple tubes and more consistent orientation.

Ichnogenus Scolicia de Quatrefages 1849

Scolicia sp.

Fig. 15

Closely and complexly annulated, essentially horizontal trilobed trails having major lateral lobes and a subordinate median lobe or furrow. Interpreted as crawling-feeding traces of gastropods or other animals of similar habit.

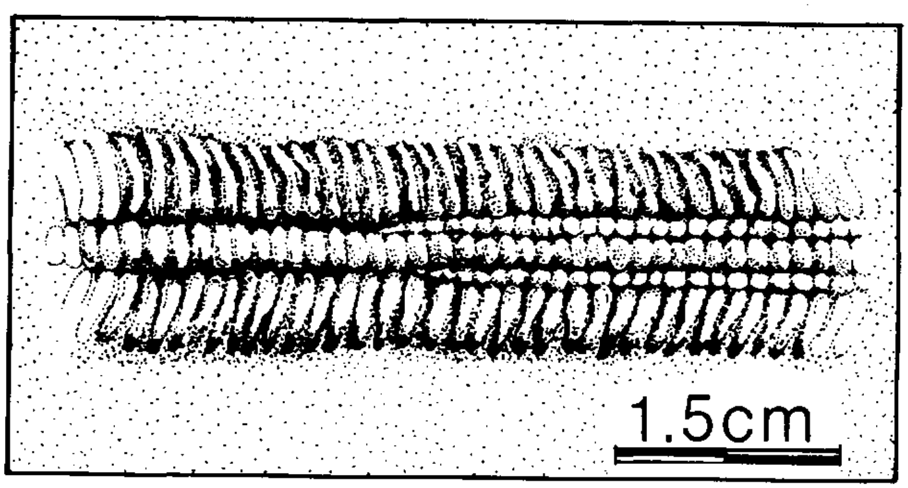

Fig. 15. Scolicia sp. Plan view.

This bilaterally symmetrical, gently to highly sinuous trace is typically 1 to 1.5 cm wide. The broad median lobe, commonly expressed as a flat furrow 4 to 5 mm wide, generally contains small, transversely annulate ridges; in places, however, the latter may be considerably less distinct than annulations in the main lateral lobes, and may consist of finer sediment and (or) a secondary beading between the median and lateral lobes. Expression of fine morphologic details of the structure depends partly on the plane of exposure, or weathering profile, through the trail. Along lateral peripheries of the trace, annulations tend to be deflected slightly, evidently representing sediment movement during the forward progress of the animal.

Ichnogenus *Skolithos* Haldeman 1840

Skolithos linearis Haldeman 1840

Fig. 7B

Cylindrical to slightly subcylindrical, straight to curved, distinctly walled, rarely branched, vertical to steeply inclined burrows. Interpreted as dwelling structures of vermiform animals.

Burrows are unornamented, simple, straight to slightly sinuous structures typicaly 3 to 6 mm in diameter and as much as 1 m in maximum length. Locally, burrow length is controlled by bed thickness. Rare specimens of a much larger form of *S. linearis* occur locally; but these structures, as much as 2 cm in diameter, seem to be relatively unimportant components of prevalent ichnofacies.

Although somewhat intergradational with *Cylindrichnus concentricus*, isolated specimens of *Skolithos linearis* are distinguished from *C. concentricus* by its concentrically layered wall.

Ichnogenus *Teichichnus* Seilacher 1955

Teichichnus rectus Seilacher 1955

Fig. 16

Vertical bladelike spreiten structures consisting of several closely concentric, horizontal or inclined, longitudinally nested individual burrows adjoining single parent trunks; burrows within the spreite are displaced upward (retrusive). Interpreted as feeding or feeding-dwelling structures of vermiform animals.

The spreite is more or less straight and lies in a vertical plane; long axes of spreiten may be straight to sinuous, however, and are oriented at various angles with respect to bedding. In addition to the major structural concentricity of burrows comprising the spreiten, a smaller scale, silty, concentric lamination may be present. Although some spreiten interpenetrate, true branching was not observed. Specimens are as much as 50 cm long, including the single parent burrow. Most specimens, typically incomplete, are 4 to 15 cm tall and 10 to 30 cm long; spreite width is 1 to 2 cm. Variant forms of *Teichichnus* may be important locally (Frey and Howard, 1985).

Fig. 16. *Teichichnus rectus*. Longitudinal and transverse views. Diagram incorporates vertical exaggeration.

Ichnogenus Teredolites Leymerie 1842

Teredolites clavatus Leymerie 1842

Fig. 17A-C

Stubby to highly elongate, slightly to markedly sinuous, irregularly subcylindrical borings. Preserved in carbonitized wood and, where the wood

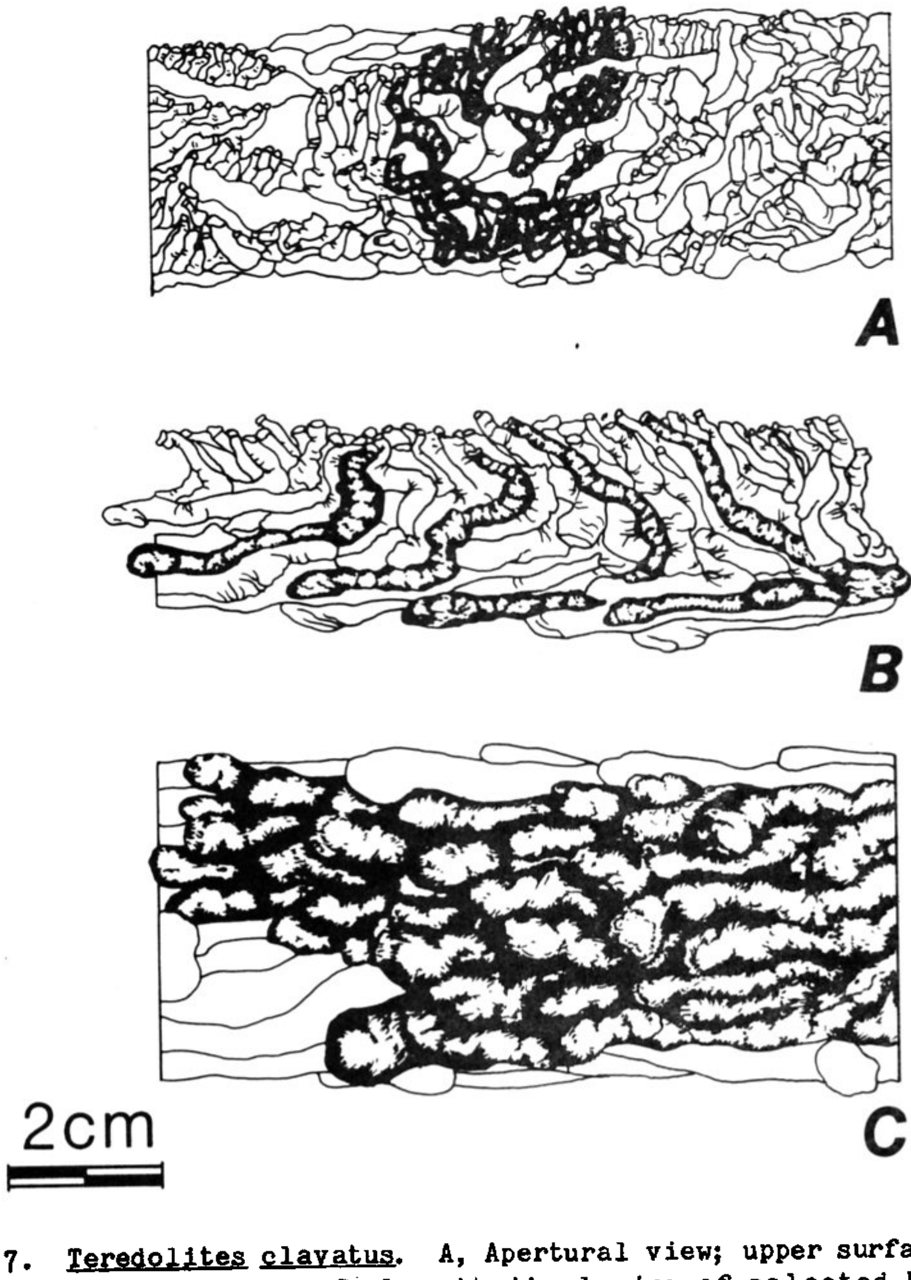

Fig. 17. Teredolites clavatus. A, Apertural view; upper surface of densely bored wood. B, Longitudinal view of selected borings. C, Basal view of borings; most wood removed.

has been replaced through decay, in clastic sediment. Interpreted as dwelling structures of bivalves.

Borings range from comparatively sparse, squat, pouch-like structures to profuse, tightly intertwined, long, labyrinthine castings. In the latter case, virtually no carbonitized wood remains between borings. Apertures tend to be approximately normal to the wood surface, but the main body of the boring is more nearly parallel with the long axis of the wood. The course of the borings may be extremely irregular, including acute angles. Traces are typically oval in cross-section due to compaction, and gradually increase in size away from the aperture. In many places, two distinct size classes are discernible; small forms are 1 to 2 mm in maximum diameter, and large forms are 8 to 10 mm.

The bored wood occurs most commonly in thick marine sands and in marginal marine channel fills. Even where little carbonitized or coalified wood remains, outlines of the original log or limb are generally recognizable. Elsewhere, dense accumulations of bored wood and other plant detritus have been designated as the Teredolites Ichnofacies (Bromley et al., 1984).

Ichnogenus Thalassinoides Ehrenberg 1944

Large burrow systems consisting of smooth-walled, essentially cylindrical components; branches are Y- to T-shaped, typically enlarged at points of bifurcation; burrow dimensions may vary within a given system. Interpreted as dwelling or feeding-dwelling burrows of decapods.

Very thinly lined to essentially unlined burrows are characteristic of coherent substrates, where wall reinforcement is unnecessary. Structureless to parallel-laminated or graded burrow fills indicate passive (gravitational) sedimentation, whereas meniscate or chevron-laminated sediments represent active backfilling. Local bulbous enlargements ("cells") along burrow segments are used as "turn arounds" by the animals (such cells also may be present in Ophiomorpha).

Thalassinoides paradoxicus (Woodward 1830)

Fig. 18C

Sparsely to densely but irregularly branched, subcylindrical to cylindrical burrows oriented at various angles with respect to bedding. T-shaped intersections are more common than Y-shaped bifurcations, and offshoots are not necessarily the same diameter as the parent trunk.

Main burrow segments typically range in diameter from 1 to 3.5 cm, and diameters may be inconsistent along a single shaft or tunnel. Some components display bulbous enlargements, especially at points of branching. Burrow components in a given setting may consist of sparse, rarely branched, essentially vertical or steeply inclined shafts, or of dense, highly branched, essentially horizontal boxworks. The latter may occupy as much as 50% of the area exposed on local bedding planes.

Additional work is needed to determine whether the preferred vertical or horizontal orientations of these burrow components have environmental significance comparable to equivalent orientations in Ophiomorpha nodosa (Frey et al., 1978, p. 218, Fig. 2A, E).

Thalassinoides suevicus (Rieth 1932)

Fig. 18A-B

Predominantly horizontal, more or less regularly branched, essentially cylindrical burrow systems. Dichotomous bifurcations are more common than T-shaped branches.

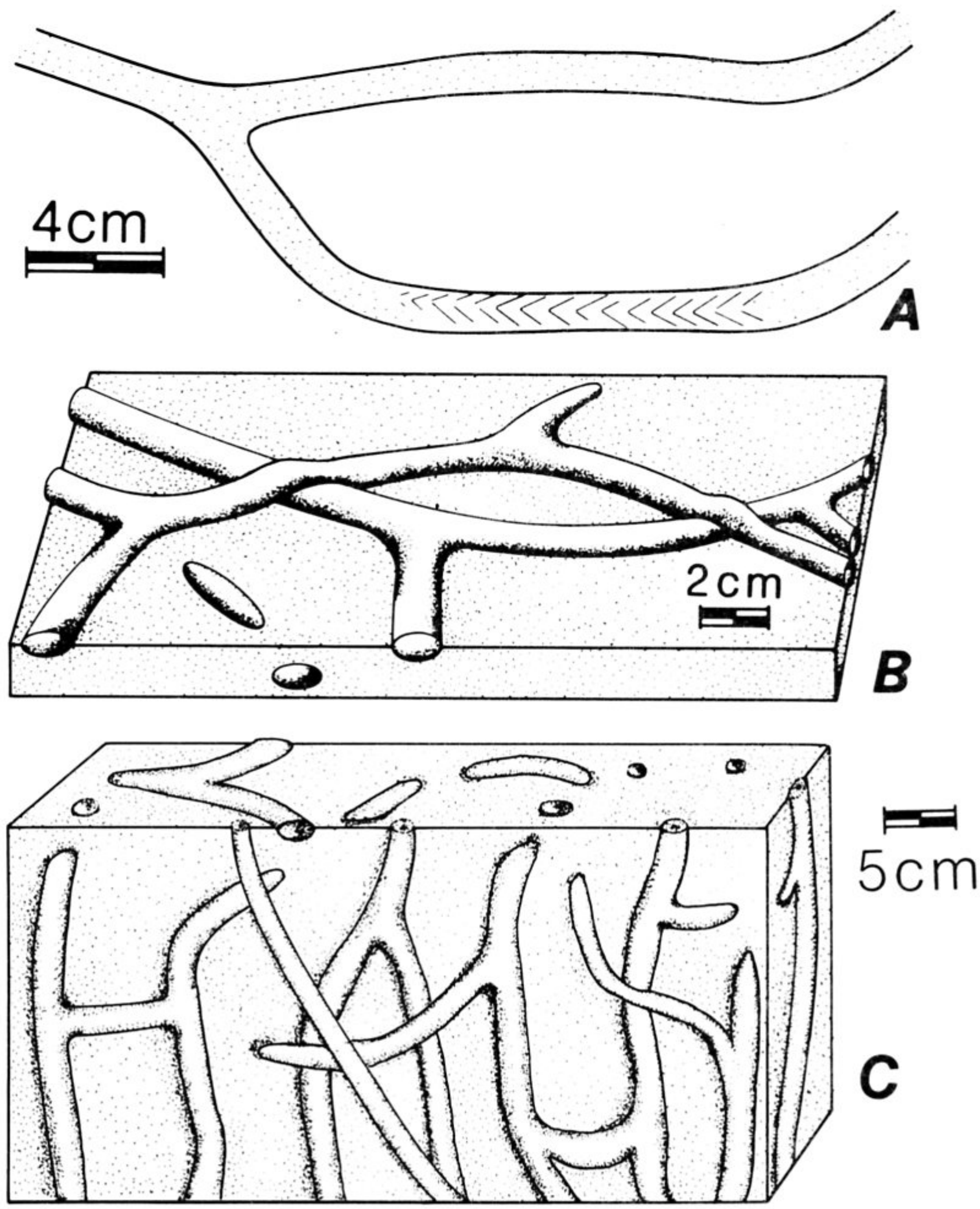

Fig. 18. Thalassinoides ichnospecies. A-B, T. suevicus; specimen in A, plan view, exhibits local chevron backfill. C, T. paradoxicus; in places, the disparity between configurations and diameters of burrow components is even more pronounced than indicated here.

Burrow segments typically range from 9 to 15 mm in diameter; the greatest overall length observed is approximately 90 cm, although the tunnels must have been of appreciably greater length originally. Vertical shafts have not been encountered. Walls are distinct, and many specimens exhibit definite linings. Rarely, the latter also include isolated small, vague knobs, suggesting a rudimentary interrelationship with Ophiomorpha. Burrow fills are structureless to chevron-laminated.

Despite the apparent paucity of Thalassinoides suevicus in some stratigraphic sections, the trace evidently was more common originally. Poorly preserved or poorly exposed, smooth walled, cylindrical burrow segments having structureless to chevron-laminated fills are common locally; but where these lack branches, they cannot be positively identified as Thalassinoides.

T. suevicus is distinguished from T. paradoxicus by the highly variable, irregularly branched systems of the latter.

Ichnogenus Uchirites Macsotay 1967

Uchirites sp.

Fig. 19

Small attenuated burrows, low and subtriangular in cross-section, the sloping flanks marked by oblique fine ridges. Interpreted as feeding structures.

Partly weathered specimens exhibit an elongate, slightly curved, elevated axis and gently sloping sides, giving the structure a low pyramidal shape in transverse section. Small, oblique ridges traverse the slopes and merge with the axis. Some specimens are nearly bilaterally

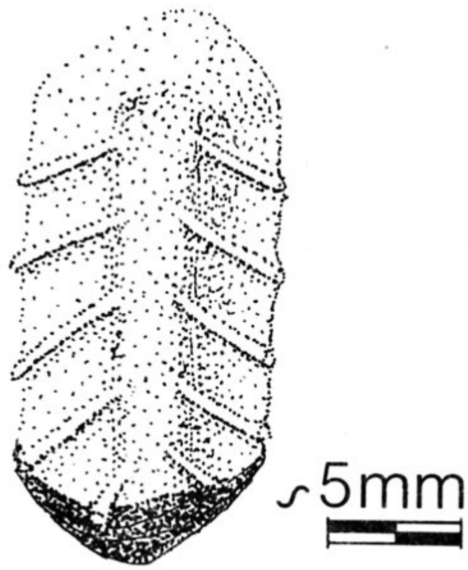

Fig. 19. Uchirites sp. Stylized reconstruction (cf. Frey and Howard, 1985, Fig. 10.7).

symmetrical whereas others are asymmetrical; among the latter, the oblique small ridges are much better developed on one side of the axis than on the other. Most specimens tend to be gently undulatory and are about 3 mm high, 5 to 6 mm wide, and 25 to 30 mm long. The ill-defined axis or median ridge is 1 to 2 mm wide. The oblique small ridges vary in width; their mean density is about 6 ridges per 7 mm of axial length.

The typical facies distribution of these small structures remains unknown. Sustergichnus (Chamberlain, 1971) is a junior synonym of Uchirites. Some forms are ogival in cross-section.

ACKNOWLEDGMENTS

We thank Armando Salazar-Jiménez for his field assistance in Utah. Helpful comments on trace fossil taxonomy were made by S. George Pemberton. The illustrations (except for Fig. 19) were drawn by Suzanne McIntosh. Recent field work was supported by National Science Foundation grant EAR 81-07695 (Howard) and by a grant from the University of Georgia Research Foundation (Frey).

REFERENCES

Archer, A. W. and Maples, C. G. 1984. Trace-fossil distribution across a marine-to-nonmarine gradient in the Pennsylvanian of southwestern Indiana. Jour. Paleont., v. 58, p. 448-466.

Bromley, R. G., Pemberton, S. G., and Rahmani, R. A. 1984. A Cretaceous woodground: the Teredolites Ichnofacies. Jour. Paleont., v. 58, p. 488-498.

Chamberlain, C. K. 1971. Morphology and ethology of trace fossils from the Ouachita Mountains, southeast Oklahoma. Jour. Paleont., v. 45, p. 212-246.

Curran, H. A. 1985. The trace fossil assemblage of a Cretaceous nearshore environment: Englishtown Formation of Delaware, U.S.A. In Curran, H. A. (ed.), Biogenic structures: their use in interpreting depositional environments. Soc. Econ. Paleont. Mineral., Spec. Publ. 35, p. 261-276.

Frey, R. W. and Howard, J. D. 1981. Conichnus and Schaubcylindrichnus: redefined trace fossils from the Upper Cretaceous of the Western Interior. Jour. Paleont., v. 55, p. 800-804.

Frey, R. W. and Howard, J. D. 1985. Trace fossils from the Panther Member, Star Point Formation (Upper Cretaceous), Coal Creek Canyon, Utah. Jour. Paleont., v. 59, p. 370-404.

Frey, R. W. and Pemberton, S. G. 1984. Trace fossil facies models. In Walker, R. G. (ed.), Facies models (2nd ed.). Geosci. Canada, Reprint Ser. 1, p. 189-207.

Frey, R. W., Howard, J. D., and Pryor, W. A. 1978. Ophiomorpha: its morphologic, taxonomic, and environmental significance. Palaeogeogr., Palaeoclimatol., Palaeoecol., v. 23, p. 199-229.

Frey, R. W., Voorhies, M. R., and Howard, J. D. 1975. Estuaries of the Georgia coast, U.S.A.: sedimentology and biology. VIII. Fossil and recent skeletal remains in Georgia estuaries. Senckenberg. marit., v. 7, p. 257-295.

Häntzschel, W. 1975. Trace fossils and problematica. In Teichert, C. (ed.), Treatise on invertebrate paleontology, Part W, Miscellanea, Supplement 1. Geol. Soc. Amer. and Univ. Kansas Press, 269 p.

Howard, J. D. and Frey, R. W. 1984. Characteristic trace fossils in nearshore to offshore sequences, Upper Cretaceous of east-central Utah. Canadian Jour. Earth Sci., v. 21, p. 200-219.

Howard, J. D. and Frey, R. W. 1985. Physical and biogenic aspects of backbarrier sedimentary sequences, Georgia coast, U.S.A. Marine Geol., v. 63, p. 77-127.

Howard, J. D., Mayou, T. V., and Heard, R. W. 1977. Biogenic sedimentary structures formed by rays. Jour. Sed. Petrol., v. 47, p. 339-346.

Kamola, D. L. 1984. Trace fossils from marginal-marine facies of the Spring Canyon Member, Blackhawk Formation (Upper Cretaceous), east-central Utah. Jour. Paleont., v. 58, p. 529-541.

Pemberton, S. G. and Frey, R. W. 1982. Trace fossil nomenclature and the Planolites-Palaeophycus dilemma. Jour. Paleont., v. 56, p. 843-881.

Pemberton, S. G. and Frey, R. W. 1984. Ichnology of storm-influenced shallow marine sequence: Cardium Formation (Upper Cretaceous) at Seebe, Alberta. In Stott, D. F. and Glass, D. J. (eds.), The Mesozoic of middle North America. Canadian Soc. Petrol. Geol., Mem. 9, p. 281-304.