CHAPTER 17

MISCELLANEOUS TRACES

17.1. INTRODUCTION

This chapter deals with traces of various kinds that are not essentially related to each other nor to the other groups of traces described in Chapters 6 to 16. The morphological and ethologial definitions of some of the traces described in the present chapter may overlap those of some of the trace fossils described in previous chapters in terms of preservational phenomena but are otherwise different from them in terms of inferred ethology; e.g., the new ichnotaxon Colichnites howardi (described in the present chapter) is a simple bedding-parallel trace but the burrow itself tends to undulate with respect to bedding and this characteristic sets it apart ethologically from other kinds of bedding-parallel burrows described in Chapter 11. Some traces or burrows are described in this chapter which are unclassified either because of their poor preservation or because of their unknown ethological origin and producers, and in some cases they may even be of inorganic origin.

Following below is a list of the traces and burrows that are described in this chapter: (1) Beaconites antarcticus Vialov, 1962; (2) Bifungites Desio, 1940; (3) Brookvalichnus Webby, 1970; (4) Colichnites howardi ichno. gen. sp. nov.; (5) flask-, J- and L-shaped structures; (6) Fuersichnus Bromley & Asgaard, 1979; (7) Imbrichnus Hallam, 1970; (8) network systems (unknown producer); (9) ring-structures (type A to type D)., (10) Scalarituba Weller, 1899., (11) Scoyenia White, 1929; (12) straight horizontal filled burrows; (13) stuffed burrows; and (14) unclassified small bean-shaped burrows.

17.2.1. Beaconites antarcticus? Vialov, 1962

Plate 71, Fig. a

Diagnosis (taxonomic assignment): Large bedding-parallel or partly inclined trace with continuously segmented or septate meniscus packed-interior; the burrows are slightly sinuous and occur as relatively isolated entities. The burrows are semi-circular in cross-section with spherical or slightly enlarged terminations.

Remarks (diagnostic features): Two large specimens of Beaconites antarcticus? were encountered in the study area in the upper part of the Bald Hill Claystone at Turimetta Head (area 2). These burrows are of very large size, about 5 cm to 7 cm in diameter and 28 cm to 30 cm in length. The burrows lie almost parallel to bedding (some parts of the burrows are oblique), are somewhat sinuous or relatively straight, are not crowded and have a circular cross-section. The meniscate septal partitions are numerous, occur throughout the length of the trace, and are developed in a regular pattern showing a series of crescent-shaped discs. Believed to have been developed by the packed back-filling habit of the producer organism (retrusive type). The burrows terminate in a somewhat globose or slightly enlarged end. The boundary of the burrows is unlined, and is simply de-fined by the crescent-shaped meniscus.

Description and ethology: These large bedding-parallel to subpar-allel burrows have been observed to occur only on bedding-plane surfaces within the Bald Hill Claystone. The burrows are pre-served as epichnia (half-relief) and partly endichnia (full-relief) forms. There is no major difference between the sediment

within the trace fossils and the host sediment, but the menis-
ci or septal areas are infilled with coarser particles that are
more indurated and of darker (dark-brown) colour. The definition
of the burrows is enhanced by differential weathering between the
host rock (softer) and the septal meniscus traces (which are
harder). The burrows are cylindrical-shaped in three dimensions
and apparently terminate in a rounded (globose or subspherical)
distal end. The burrows are not crowded as in the type area in
Antarctica (Vialov, 1962; Webby, 1968; Gevers et al., 1971;
Bradshaw, 1981), and in the northern hemisphere Old Red Sandstone
ichnofauna (Graham & Pollard, 1982; Eager et al., 1985). The
width or diameter of the burrows is about 5 cm to 7 cm and the
length including the globose termination or probable turn-around
is about 28 cm to 30 cm. The burrows are unlined, but their edges
are defined by the crenulated terminations of the crescent-shaped
meniscus septa. These meniscate packed-backfill infills are
preserved as alternating transverse crescent-shaped ridges and
grooves (Plate 71 Fig. a) whose definition results from differen-
tial weathering between the menisci and burrow fills. The move-
ment or locomotion direction of the producer organism is toward
the concave side of the retrusive type septa (i.e., the concavity
is towards the opening end and the convexity towards the termi-
nal end). No bidirectional type of meniscus pattern has been
observed (cf. Graham & Pollard, 1982). The meniscate septa are
continuously developed across the width of the burrow (that is,
they are not longitudinally discontinuous between the two
walls). Previous interpretations of the producer(s) of <u>Beaco-</u>

nites include a wide variety of different organisms living in non-marine fluvial and marine littoral environments (Graham & Pollard, 1982; Bradshaw, 1981; Vialov, 1962). The wide variety of producers include: worms (Laming, 1970; Gevers et al., 1971); burrowing lungfish (Scott et al., 1976; Donovan et al., 1978); amphibians (Pollard, 1976); reptiles (Ridgeway, 1974); and arthropods (Muller, 1975; Rolfe, 1980; and Allen & Willaims, 1981). In ichnologic studies there are many similar types of trace fossils that can be produced by entirely different animals. Beaconites is probably one such trace of polygenetic origin and in the case of each occurrence of this trace we must also be mindful of the producer's likely habitat or environment. The presently described examples of Beaconites may provide some insight as to their producer organism, but no final conclusion can be made regarding this problem. Bradshaw (1981) has suggested that the possible producer is a large marine multilegged myriapod (or physically similar arthropod). Such a multilegged, elongated animal is only capable of producing a Beaconites-like burrow by excavating with its forelegs, and compacting the sediment behind it with its hindlegs and body. Each meniscus may manifest a single phase of sediment back-filling activity separated by a resting period. However, I am willing to agree in some regards to the hypothesis of an arthropod producer for several reasons: (1) the meniscus does not manifest faecal back-packing (this precludes production by worms); (2) the meniscus clearly results from back-packing as a consequence of locomotion suggesting that the producer is probably either a vertebrate or arthropod; (3) in the present study area the Beaconites burrows are

associated with other burrows produced by arthropod crustaceans (e.g. Ophiomorpha, Thalassinoides, and the new ichnogenus Turimettichnus; see Chapters 6 and 9). Crustacean burrows are normally packed with these locomotion back-fillings, and the nature of the globose terminus is believed to constitute a turn-around, both of these manifestations being quite common in crustacean life-history.

Comparison: The observed characteristics of the two specimens recorded from the study area accord well with those of Beaconites as defined by other workers (Vialov, 1962; Webby, 1968; Gevers et al., 1971; Hantzschel, 1975; Bradshaw, 1981; Graham & Pollard, 1982; and Eager et al., 1985). The present examples of Beaconites are also considerably larger than similar ichnogenera described as Laminites (Ghent & Henderson, 1966), Kerkia (Glocker, 1841; McCarthy, 1979).

Distribution: The burrows have a very restricted stratigraphic and geographic occurrence in the study area. The burrow illustrated in Plate 71 Fig. a is from trace fossil subinterval IC2 of the upper part of the Bald Hill Claystone at Turimetta Head (area 2). Only two examples are known from that area.

Studied material: The burrows described here have not been retrieved from the field (having been eroded and lost on account of wave erosion during 1989).

Preservation and association: The burrows described here are/were preserved as epirelief semi-relief or full-relief forms on the surface of the bedding plane. They are/were associated with Turimettichnus, Ophiomorpha, and Thalassinoides, and several

varieties of pellets believed to have been produced by crusta-
ceans.

Ichnofacies and palaeoenvironmental affinities: Globally, the
environmental habitats of Beaconites vary from non-marine/ fluvi-
al to shallow littoral-marine, judged by the associated sedimen-
tary structures and consideration of possible producers (Gevers
et al., 1971; Graham & Pollard, 1982; Bradshaw, 1981). The
original burrows described from the Antarctic Beacon Super-Group
by Vialov (1962) are believed to be of aqueous but not aeolian
affinity on the basis of associated aqueously formed ripples. In
general, sandstones of the Beacon Super-Group indicate deposition
in shallow water. Beaconites and similar burrows of the ichnoge-
nus Scolicia from the same rocks in Antarctica were later studied
by Webby (1968) leading him to believe that these spreite-bear-
ing traces manifest grazing or feeding activities and that the
enveloping cylindrical cavity manifests the dwelling- or rest-
ing-burrow of a worm. The shallow-marine affinity of these
Antarctic rocks was independently assessed and confirmed by shaw
(1968) and Harrington & Speden (1962). However, such a marine
origin was criticized by Hamilton & Hays (1963), Gunn & Warren
(1962) and Webb (1963) because of the lack of preserved marine
body fossils. Suggested (alternative) non-marine environments
include lacustrine and estuarine dunefields (Webb, 1963). Gev-
ers (1971) believed that the whole lower Beacon succession is
probably an alternation of marine and non-marine deposits and
that the traces of Beaconites were made by marine polychaete
annelid worms. The Beaconites traces associated with crustacean
burrows in the Taylor Group of the Beacon Super-Group of Antarc-

tica suggest a fluctuating coastal margin (Bradshaw, 1981). However, Beaconites traces in the Lower Carboniferous of Mayo County, Ireland, suggest a fluvial origin (Graham & Pollard, 1982). Large Beaconites burrows have been widely recorded in northern hemisphere fluvial channel and overbank facies of both the Devonian (Old Red Sandstone, Allen & Williams, 1981), and Lower Carboniferous (Chisholm, 1977).

The present examples of Beaconites antarcticus? are associated with crustacean burrows and hence are believed to have been formed in a shallow area or proximal part of a coastal lagoon or estuarine environment. Therefore, in the study area Beaconites antarcticus? belongs to the Skolithos ichnofacies.

17.2.2. Bifungites Desio, 1940

Plate 73, Fig. c

Diagnosis (generic assignment): Large burrows of dumbbell-like or arrow-shaped form, in which both terminal swellings or ends are commonly hemispherical or somewhat arrow-shaped. Burrows are preserved as convex hyporelief and more rarely as full-relief forms on bedding-plane surfaces. No trace of spreite occurs between the two vertical shafts.

Remarks (diagnostic features): The examples of Bifungites in the present study area are very large indeed and lack vertical spreiten structures between the U-tubes. This lack of spreite is the major criterion of differentiation between this and other spreite-bearing U-tubes. The presence of spreite in vertical U-shaped burrows is regarded as a significant generic feature by Fursich (1974) and in the present study (Chapter 7) in regard to
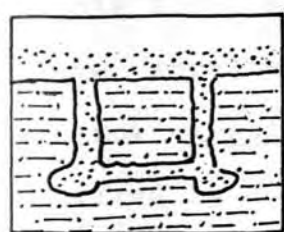
TEXT-FIG. 17.1. Diagrammatic interpretation of the ichnogenus Bifungites (Desio, 1940) based on field observation of examples in the present study area and the descriptions of Gutschick and Lamborn (1975).

A. Cross-sectional reconstruction of a single complete burrow illustrating its vertical U-shaped geometry and spreite-free character. Note the similarity of the shape of the burrow to the inverted Greek letter ii.

B. vertical-oblique upward view of basal part of the burrow showing its dumpbell-like form on the bedding plane and upward-projecting (hidden) vertical shafts (diagonally hachured). Note also the arrow-head shape of the lateral swellings that constitute the dumpbell. Dimensional parameters defined as shown. Drawing based on the burrow illustrated in Plate 73 Fig. c and on illustration in Gutschick and Lamborn (1975).
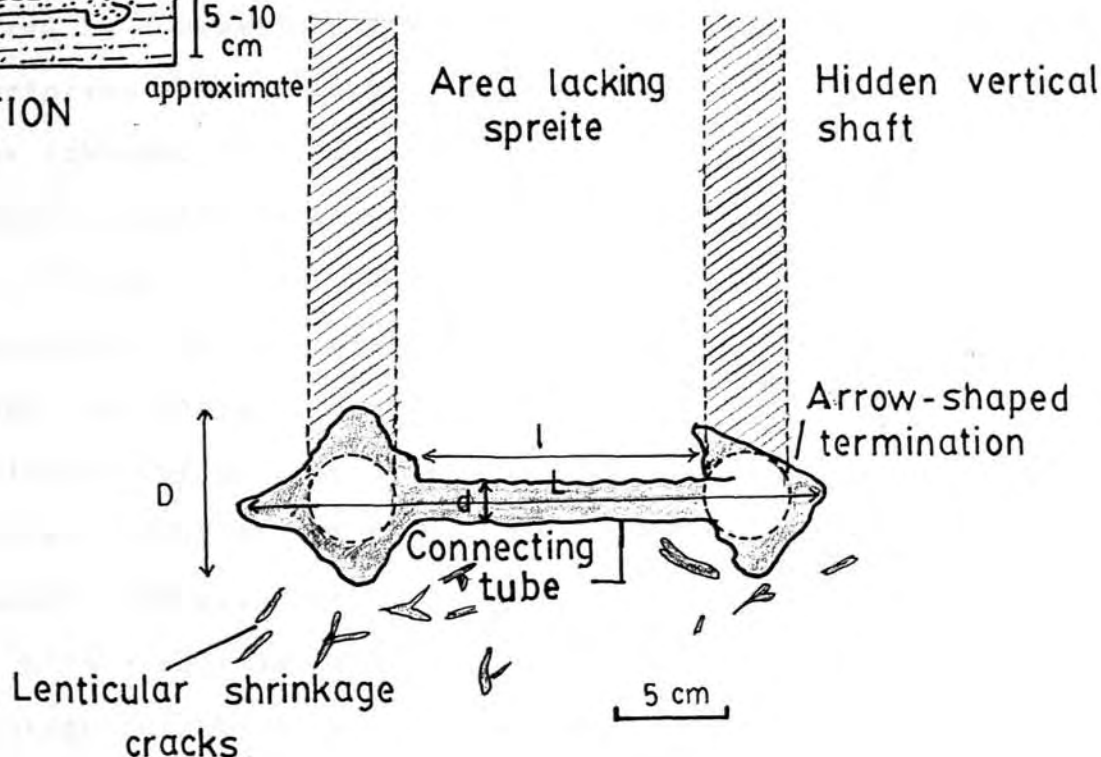
A SECTION

5 - 10 cm approximate

B

Area lacking spreite

Hidden vertical shaft

Arrow-shaped termination

Connecting tube

Lenticular shrinkage cracks

5 cm

EXPLANATION

L   Length of the burrow
     (Measured between two terminal ends)
l   Length of the connecting tube
D   Diameter (or length) of the dumpbell
d   Diameter of the connecting tube

TEXT-FIG. 17.1.

the vertical spreite-bearing U-tubes of Diplocraterion. Bifungites is also placed in questionable synonymy list with the ichnogenus Corophioides by Osgood (1970) and Knox (1973) (see Table 7.4). However, this is incorrect since Bifungites does not have spreiten. The other spreite-free vertically orientated burrow Arenicolites is relatively very small and is not characterized by dumbbell-shaped structures in any situation.

Description and ethology: The ichnogenus Bifungites originated as a new ichnogenus by virtue of having a dumbbell-shaped expression on bedding-plane surfaces of Upper Devonian rocks in Fezzan Province, Libya (Desio, 1940). In the present study Bifungites is represented as a trace formed in a dumbbell-shaped or arrow-shaped horizontal (bedding-parallel) shaft, which is the lower termination or sole of a vertical U-shaped burrow shaped like an inverted Greek letter pi (π) (see Text-Fig. 17.1). The examples studied here are most commonly preserved as convex hyporeliefs and more rarely as full-relief forms associated with lenticular shrinkage cracks in a very fine sandstone bed. These burrows show no sign of retrusive or protrusive spreite between the two vertical shafts. They are the largest Bifungites burrows yet reported from the geologic record. Some dimensions are cited in respect of the burrow illustrated in Plate 73 Fig. c (Text-Fig. 17.1): length (L) 25 cm; diameter (D) or length of a dumbbell or arrow termination 5 cm to 7 cm; diameter of the connecting tube (d) 2 cm, and length of the connecting tube (l) about 14 cm. The burrows are believed to have been produced by suspension-feeders for dwelling purpose (Gutschick & Lamborn, 1975).

Comparison: Gutschick and Lamborn (1975) have used the statistical analysis of their _Bifungites_ specimens from Devonian-Mississippian rocks of Pennsylvania and Montana of the USA to define three different ichnospecies of _Bifungites_:
B. bisagittula, _B. bisagitta_, and (largest of all) _B. bieurysagitta_ . One of their obvious defining characteristics was the burrow length (i.e., distance between the two terminal swellings; see Text-Fig. 17.1). According to their classification scheme their largest burrows (length more than 5 cm) are much smaller than the present examples; nor did they differentiate their burrows into ichnospecies on the basis of relative size. The examples studied here are also much larger than the other species of _Bifungites_ described by Desio (1940) (i.e., _B. fezza-nensis_ and _B. halli_) and the species of _Bifungites_ described by Bjerstedt (1987 & 1988).

Distribution: The burrow illustrated in Plate 73 Fig. c is from trace fossil subinterval IE4 of the Middle Newport Member at Bangalley Head (area 8). In the study area _Bifungites_ is restricted on present knowledge to that particular area and subinterval.

Preservation and association: The dumbbell-shaped burrows of _Bifungites_ are preserved as convex hyporelief or full-relief forms on the bedding-plane surfaces or modern erosional surfaces of a bed of fine sandstone. They are associated with the new ichnotaxon _Helikospirichnus veeversi_ (discussed in Chapter 13) and with collapse-structures (discussed in Chapter 14) and with lenticular shrinkage cracks (cf. Collinson & Thompson, 1982, p.141).

Ichnofacies and palaeoenvironmental affinities: The ichnogenus Bifungites can be attributed to a variety of environmental settings (Bjerstedt, 1987 & 1988) ranging from bioturbated prodelta shales, bar-washover sands, inner-shelf facies, shoreline (littoral) sands, tidal-flat facies, and thinly-bedded fine-grained sands and silts of probable estuarine affinity in the Devonian-Mississippian of west Virginia, Pennsylvanian, and Maryland of the USA. Gutschick & Lamborn (1975) interpreted their examples of Bifungites to have developed in a prograded deltaic complex. This complex is interpreted to have included: nearshore estuarine marshes, tidal-flats, delta-platform and delta-front, bar-fingers, channel sands, bar and bar-margin areas, shallow basin, and offshore prodelta deeper-water environments. However, the present examples of Bifungites are believed to have developed in shallow parts of a fluvially- dominated estuarine or lagoonal type of environment that can be ascribed to the Skolithos ichnofacies.

17.2.3. Brookvalichnus obliquus Webby, 1970

Plate 72, Fig. c & d

Diagnosis (taxonomic assignment): Flat ribbon-like structure, formation in groups, relatively straight to slightly curved, unbranched, bedding-subparallel to inclined burrows. The inclination is up to 15 from horizontal and the burrow length up to 9 cm long with uniform width of 0.5 cm.

Remarks (diagnostic features): The flat ribbon-like traces were presumably formed by collapse of the originally hollow tube-like or cylindrical burrows. In most places, the burrows exhibit

faint impressions of the transverse annulation bounded by a darker lining or wall on both side.

Description and ethology The flat ribbon-like trails with uniform width of 0.5 cm and length of several centimetres represent collapsed originally tube-like hollow burrows. The burrows are distinctly lined with a thin dark (carbonaceous) layer (Plate 72, Fig. c). The burrows are internally, transversely annulated with thin faint rings or with a structureless interior of normally finer greenish-grey clay. The flattened burrows can be readily distinguished by their annulations, finer grain-size and greenish-grey interior sediment compared with the gray host siltstone and silty shales. In bedding-transverse or in oblique sections the burrows occur in clusters or groups, each trace approximately parallel to the other and crossing the bedding lamination obliquely (Plate 72, Fig. c) commonly at about 15. and causing the rock to part along this direction obliquely transverse to bedding. These burrows are believed to have been produced for dwelling in a ponded freshwater environment by a worm-like organism or an insect larva (Webby, 1970).

Comparison: According to Webby (1970), the burrows are not strictly comparable with any other trace fossils. However, there are many modern organic traces produced by terrestrial aquatic organisms which are formed as bedding-parallel or bedding-oblique structures including flattened or collapsed burrows produced by worm-like organisms (e.g. Bromley & Asgaard, 1979; Chamberlain, 1975, and many others). However there are no trace fossils is to be strictly comparable with these burrows.

Distribution: The burrows illustrated in Plate 72 Figs. c - d are from trace fossil interval IG where they occur in a fossiliferous shale lens of possible lacustrine origin exposed in a now-abandoned quarry in the Hawkesbury Sandstone at Beacon Hill, Brookvale (Webby, 1970). The studied trace fossils come from the higher part of the silty shale unit exposed at this location. (GR.4490 7737 1:25,000 orthophoto map series of Mona Vale, sheet 9130-I-S).

Studied material: The burrows illustrated in the Plate 72 Figs c & d occur in collected sample no. 2601/MU. 44457.

Preservation and association: The studied traces are commonly preserved as full-relief endichnial forms of infaunal origin in siltstone or silty shale. The burrows occur in a consistently oblique orientation to the bedding plane and parting along this orientation transects the prominent bedding lamination in the rock (Plate 72 Fig. d). The burrows are not associated with any other trace fossils.

Ichnofacies and palaeoenvironmental affinities: As described by Webby (1970) the burrows are believed to be of possible lacustrine origin produced by a freshwater, worm-like organism or an insect larva. Consequently, these burrows are probably attributable to the Scoyenia ichnofacies.

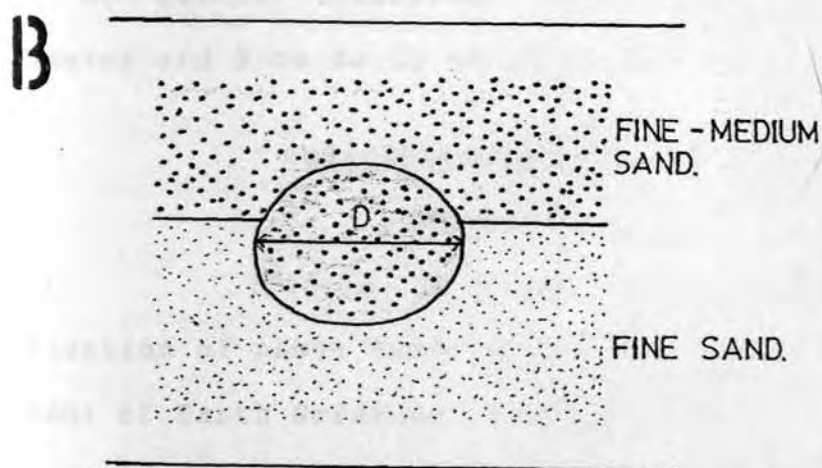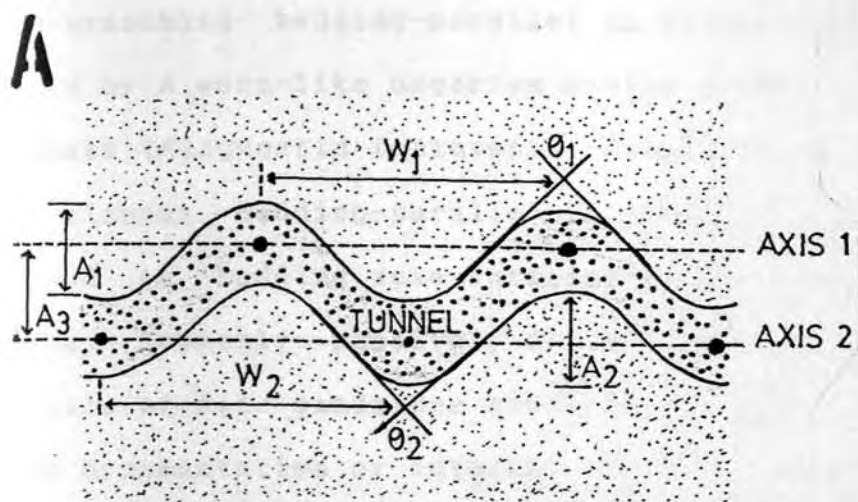### 17.2.4. Colichnites ichno. gen. nov.

Type species: C. howardi

Derivation of name: `Colic' meaning `intestine', inasmuch as these trace fossils resemble in shape the lower part of the food canal between the stomach and the anus.

TEXT-FIG. 17.2. Dimensional and angular measurements of the new ichnotaxon _Colichnites howardi_ and their crossplot relationship with the same parameters of _Cochlichnus kochi_ (Elliott, 1985).

A. Burrow viewed in longitudinal section. Measurements of amplitude A1 and A2 (between crest and base) and alternative amplitude A3 (between the two axes); measurements of wavelength (W1) and alternative wavelength (W2); and measurement of angle between asymptotes $\Theta1$ and alternative asymptotes $\Theta2$.

B. Burrow viewed in transverse cross-section. Measurement of diameter (D) of the burrow, and diagrammatic nature of the burrow preservation and orientation.

C. Crossplot diagram of tan $\Theta/2$ diagram versus W/A showing relationship between linear regression lines, and loci of clothoid curves and sine curves computed from dimensional data of the new ichnotaxon _Colichnites howardi_ and the ichnotaxon _Cochlichnus kochi_ from the East Pennine Coalfield of Britain (Elliott, 1985). All data for _Colichnites howardi_ come from measurements of burrows in the Middle Triassic Newport Formation at Bangalley Head, St. Michaels Cave and Bilgola Head. Data for _Colichnites howardi_ are from examples in the Carboniferous of the East Pennine Coalfield, England (cf. Elliott, 1985). Note the very small area of overlap in the distribution of the two ichnogenera.

A

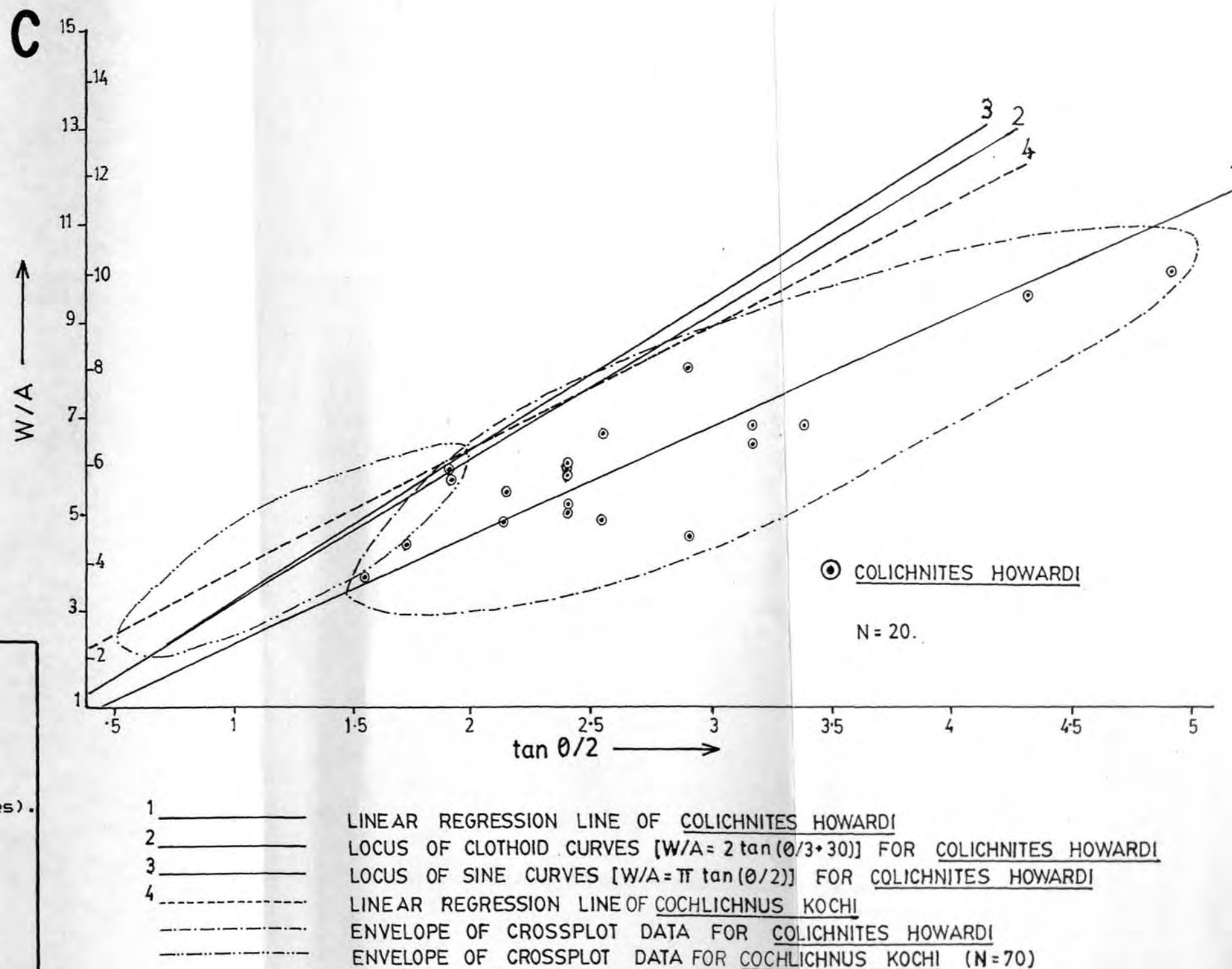W_1 θ_1 AXIS 1 A_1 A_3 TUNNEL AXIS 2 W_2 A_2 θ_2

B

FINE - MEDIUM SAND.
D
FINE SAND.

C

W/A

tan θ/2 ⟶

⊙ COLICHNITES HOWARDI

N = 20.

EXPLANATION

Measurements

A1 & A2 Amplitude (between crest and base).

A3 Alternative amplitude (between two axes).

W1 Wave length.

W2 Alternative wave length.

θ1 Angle between asymptotes.

θ2 Angle between alternative asymptotes.

D Diameter of a burrow.

Calculations

Clothoid curves [W/A = 2tan (θ/3 + 30)]
Sine curves [W/A = ii tan (θ/2)]

A   A1, A2 or A3

W   W1 or W2

θ   θ1 or θ2

1 ———— LINEAR REGRESSION LINE OF <u>COLICHNITES HOWARDI</u>
2 ———— LOCUS OF CLOTHOID CURVES [W/A = 2 tan (θ/3 + 30)] FOR <u>COLICHNITES HOWARDI</u>
3 ———— LOCUS OF SINE CURVES [W/A = π tan (θ/2)] FOR <u>COLICHNITES HOWARDI</u>
4 ------------ LINEAR REGRESSION LINE OF <u>COCHLICHNUS KOCHI</u>
———·———·— ENVELOPE OF CROSSPLOT DATA FOR <u>COLICHNITES HOWARDI</u>
———··———··— ENVELOPE OF CROSSPLOT DATA FOR <u>COCHLICHNUS KOCHI</u> (N = 70)

TEXT-FIG. 17.2

Diagnosis: (generic assignment): Gently curved to sinuous, non-branching bedding-parallel to slightly oblique trails produced by a worm-like organism moving within the sediment.

Remarks (diagnostic features): Simple uniformly-thick, straight or sinuous, bedding-parallel to slightly inclined trails, preserved on bedding sole surfaces as semi-relief or full-relief forms. Commonly passively filled with dark-brown (limonitic) infills or fine sandstone similar to the host sediment. No surface ornamentation or internal structures are recognized. Burrows may be partly collapsed. The burrows are 0.6 cm to 1 cm in diameter and 2 cm to 10 cm in length.

Colichnites howardi ichno. sp. nov.

Plate 48, Figs. a - j

(Fig. e, holotype and other paratypes)

Derivation of name: Named after Emeritus Professor P. F. Howard, School of Earth Sciences, Macquarie University.

Diagnosis (specific assignment): Thick, simple and regularly meandering or sinuous (resembling a sine curve) unbranched burrows. Burrow orientation is bedding-parallel or bedding-oblique in some places. Burrow infill materials may have been passively produced and are either similar to or different from the host sediment. The sine-wave-like pattern of the burrows is relatively even with a long wavelength and short amplitude.

Remarks: The thickness of the burrow is commonly uniform throughout its entire length. The meandering pattern is almost regular, and the axes of the burrows (disregarding their sinuousity) are straight to gently curved with no abrupt turning point (asymp-

totes) (cf. Text-Fig. 17.2A). The burrows are either partially infilled or collapsed and their surface is normally smooth without recognizable ornamentation. Internally the burrows are structureless and lack faeces.

Description and ethology: The simple regularly sinuous or meanderous non-branching mainly bedding-parallel burrows are normally about 1 cm in diameter and several cm in length (Table 17.1). The thickness of the burrows is almost uniform throughout their length. Some parts of the burrow may be shallowly inclined to bedding and even steeper, approaching near-vertical in rare cases. The burrows are well preserved as semi- or full-hyporelief forms in beds of light-grey fine sandstone (Plate 48 Figs. a - j). The burrows are smooth or unornamented and infillings are structureless. The tunnel of the burrows is commonly collapsed, and is interpreted to have been passively filled with dark-brown (now limonitic) structureless very fine to fine sand (in Plate 48 Figs. a - g this infilling sediment is different from the host sediment and in Plate 48 Figs. h - j it is similar). Measurements of the burrow wavelength, the amplitude of the sinuousities and other parameters are detailed in Table 17.1. The overall burrow axis, with sinuousity discounted, is straight to gently curved, commonly with an abrupt termination.

The producer organism is believed to have been a vermiform organism as constrained by the shape of the tunnel (burrow configuration); the producer organism must have had:

(a) a circular body cross-section of 0.5 cm to 1 cm diameter (D);

(b) a length commensurate with a sinusoidal pattern of

TABLE 17.1. Dimensional and angular measurements of the new ichnogenus <u>Colichnites howardi</u> and its clothoid curve and sine curve values used in Text-Fig. 17.1.

No.	D cm.	W cm.	A cm.	Θ.
1.	1.2	2.95	0.61	137
2.	0.69	3.62	0.81	142
3.	0.77	2.95	0.5	125
4.	1.15	2.83	0.52	130
5.	0.85	2.5	0.38	137
6.	1.08	4.21	0.88	130
7.	0.65	1.54	0.27	125
8.	1.17	2.93	0.49	135
9.	0.81	2.31	0.64	115
10.	1.0	2.38	0.35	145
11.	0.87	2.21	0.43	135
12.	0.86	2.1	0.22	154
13.	1.41	3.37	0.57	135
14.	0.78	2.17	0.27	142
15.	0.54	2.26	0.45	135
16.	0.92	2.4	0.24	175
17.	0.9	2.63	0.41	145
18.	0.7	2.54	0.44	135
19.	0.73	1.96	0.46	120
20.	0.98	2.58	0.38	147
Total.	18.6	52.44	9.32	2726
Mean.	0.9	2.6	.47	136

No.	W/A.	tan $\Theta/2$.	CC.	SC.
1.	4.8	2.54	7.83	7.98
2.	4.5	2.9	8.9	9.12
3.	5.9	1.92	6.04	6.04
4.	5.4	2.15	6.68	6.74
5.	6.6	2.54	7.83	7.98
6.	4.8	2.15	6.68	6.74
7.	5.7	1.92	6.04	6.04
8.	6.0	2.41	7.46	7.59
9.	3.6	1.57	5.03	4.93
10.	6.8	3.17	9.69	9.96
11.	5.1	2.41	7.46	7.59
12.	9.5	4.33	13.12	13.61
13.	5.9	2.41	7.46	7.59
14.	8.0	2.9	8.9	9.12
15.	5.0	2.41	7.46	7.59
16.	10.0	4.92	14.86	15.44
17.	6.4	3.17	9.69	9.96
18.	5.8	2.41	7.46	7.59
19.	4.3	1.73	5.5	5.44
20.	6.8	3.38	10.3	10.61
Total.	120.9	53.34	164.39	167.66
Mean.	6.05	2.67	8.22	8.38

TABLE 17.1 (continued)

CC - Clothoid curves - W/A = 2tan (Θ/3 + 30).
SC - Sine curves   - W/A = tan (Θ/2).

Linear regression (W/A plotted against tan Θ/2).

tan Θ/2.	Mean(W/A).
.5	1.13
1.0	2.27
1.5	3.41
2.0	4.54
2.5	5.68
3.0	6.81
3.5	7.95
4.0	9.08

Clothoid curves (CC plotted against tan Θ/2) (W/A=2tan (Θ/3+30).

tan Θ/2.	Mean(W/A).
.5	1.54
1.0	3.07
1.5	4.61
2.0	6.15
2.5	7.7
3.0	9.24
3.5	10.7
4.0	12.32

Sine curves (SC plotted against tan Θ/2) (W/A= tan Θ/2).

tan Θ/2.	Mean(W/A).
.5	1.56
1.0	3.14
1.5	4.71
2.0	6.28
2.5	7.85
3.0	9.42
3.5	10.99
4.0	12.55

movement involving a wavelength of 2.6 cm on average (W);

(c) very small amplitude of sinusoidal movement, averaging 0.5 cm (A);

(d) very smooth (wide) asymptotic angle of curvature (0);

(e) no parapodia, bristles or other protuberances that would not result in a smooth tunnel;

(f) a nervous system and musculature capable of transmitting bending waves anterio-posteriorly along the body (hydrostatic skeleton); the organism probably would have had an elastic body wall and musculature that generated the propulsion force with high body fluid pressure which facilitates the well-developed somewhat snake-like movements of worms and other vermiform organisms (cf. Elliott, 1985);

(g) probably no hard parts inside the body since these would tend to stiffen it and preclude its smooth wave-like pattern of movement;

(h) an affinity for living in a brackish-marine habitat.

Chamberlain (1975) and Elliott (1985) have suggested that the pattern of their `sinuous trails' is similar to those produced by modern nematodes in particular (but the latter have a smaller width: 0.5 to 0.9 mm). Consequently, most of the above-mentioned criteria are compatible with the morphology and behavior of modern nematodes as well. However, the larger diameter of the burrows studied here eliminates that kind of origin for them and it is likely that they are more referable to other larger worm-like organisms.

The snake-like locomotion movements of a worm-like body

resulting in a sinusoidal trail was studied in detail by Elliott (1985). He emphasized that the sine curve is not appropriate to describe this pattern leading him to use as an alternative the clothoid curve because it embodies a constant arithmetical rate of change of curvature along its length. Text-Fig. 17.2 and Table 17.1 compare these two families of curves (clothoid and sine curves), in terms of the parameters W, A, and 0 in respect of 20 burrows from the present study area and those described by Elliott (1985) from the Carboniferous of Great Britain. The clothoid curve gives a closer fit than the sine curve and the linear regression line is shown to aid in the comparison. Elliott's data and those from the presently described burrows indicate some general preferred relationships among the dimensional parameters of the burrows: the preference is for a shorter wavelength, and larger amplitude, and smaller 0 angle (i.e., angle of asymptotes). The range of variation of the crossplot data shown in Text-Fig. 17.2 may result from several factors: (1) resistance to the organisms locomotion probably related to variation of water content in the host sediment; (2) sex differences (male/female) and possibly size differences related thereto; (3) size variation as a function of the organism's age ; and less probable, (4) taxonomic differences between the various individual organisms that produced the traces.

Comparison: The new ichnotaxon differs from the previously assigned ichnogenus _Cochlichnus_ Hitchcock, 1858; Webby, 1970; Elliott, 1985, by virtue of its larger diameter, and greater variation in amplitude and wavelength. The producer organism is also believed to have been a large worm-like organism rather than a

small nematode. The scattered data on the crossplot of the new ichnogenus Colichnites are overlapped by less than 25% of the data from the previously described ichnogenus Cochlichnus kochi (Elliott, 1985) (Text-Fig. 17.2).

Distribution: Burrows of the new ichnogenus are known from two trace fossil intervals and two different localities. The first of these are subintervals ID1, ID2 and ID3 of the Lower Newport Member at Bilgola Head (area 10b); the others are trace fossil subintervals IE1 and IE2 of the Middle Newport Member at Bangalley Head (area 8).

Studied material: The burrows illustrated in Plate 48 Fig. a (from sample 1013/MU.44435), Fig.b (from sample 1014/MU.44437), and Figs. e & g (from sample 1017/MU.44439) were collected from trace fossil subinterval ID1, ID2 and ID3 of the Lower Newport Member at Bilgola Head (area 10b). The rest of the burrows illustrated in Plate 48 have not been retrieved from the field.

Preservation and association: All of the studied burrows occur as semi-relief or full-relief forms on the sole surfaces of beds of fine sandstone. The burrows can be more accurately interpreted as endichnial tunnels produced by a vermiform animal's progressive locomotion beneath a bed of fine sand, this movement being either locomotion for its own sake or partly for feeding. These burrows are passively infilled by dark-brown (now limonitic) sediment or with similar fine sand from the host sediment. The burrows in Plate 48 Figs. a - g are not associated with any other type of trace fossils and those are in Plate 48 Figs. h - j associated with Skolithos and Palaeophycus.

Ichnofacies and palaeoenvironmental affinities: The present new ichnogenus C. howardi and related ichnotaxa of similar shape, such as Cochlichnus, Sinuites, Sinusia, and Belorhaphe, are recorded from a wide range of environments and stratigraphic horizons. The interpreted palaeoenvironments include: Middle Cambrian neritic sandstones of the Grand Canyon, USA; Carboniferous freshwater sediments of the Ruhr region and epicontinental Jurassic sandstones of the Wurttemberg area, Germany (Seilacher, 1955); moderately shallow, relatively low-energy offshore neritic sediments of the Precambrian Lintiss Vale Beds of the Torrowangee Group, NSW (Webby, 1970); and freshwater to brackish-marine Carboniferous sediments in the East Pennine Coalfield of Britain (Elliott, 1985).

The new ichnogenus can be attributed to the Skolithos ichnofacies, even though the association lacks other bioturbation structures including the vertical shafts of Skolithos and traces of other suspension-feeders. This implies a somewhat deeper environment than is generally characteristic of the Skolithos ichnofacies. However, in the shallow brackish littoral-marine palaeoenvironment believed to apply to the present study area this apparent disparity might be due to the inferred back-barrier protected nature of the environment.

17.2.5. Flask-shaped, and J- and L-shaped burrows

Plate 70, Figs. b & c (flask-shaped burrows)
Plate 70, Figs. a & d (J- and L-shaped burrows)

The flask-shaped structures are preserved as endichnial vertically orientated full-relief forms with either a rounded, circular, bean-shaped, or irregular opening exposed on the bed-

ding-plane surfaces of beds of fine sandstone. These vertical burrows are somewhat cylindrical-shaped in their upper part but become gradually enlarged towards the bottom. These burrows are commonly mostly filled with stuff from the host sediment but with a dark brownish (ferrugenous) thick wall-lining (Plate 70 Figs. b & c). The surrounding laminations bend downwards in the immediate vicinity of the burrow for which reason they resemble the escape-burrows produced by bivalve molluscs (discussed in Chapter 14). These flask-shaped burrows are believed to be of similar origin. The cylindrical upper part of the burrows is 2 cm to 3 cm in diameter and the enlarged part in the bottom is about 3 cm to 4 cm in diameter. The length of the burrows ranges from about 14 cm to 20 cm.

The observed burrows illustrated in Plate 70 Figs. b & c are from trace fossil subinterval ID2 of the Lower Newport Member at Little Reef (area 12). The burrows are associated with J- and L-shaped structures (Plate 70 Figs. a & d) which were possibly produced as a result of similar behavior by a different organism to that which produced the flask-shaped structure or probably produced by crustaceans (the producer perhaps having been one and the same as that which produced Thalassinoides). All these structures are also associated with the vertical U-shaped spreite-bearing dwelling-burrow Diplocraterion discussed in Chapter 7.

17.2.6. Fuersichnus communis? Bromley and Asgaard, 1979

Plate 71, Figs. b & c

Diagnosis (taxonomic assignment): Crescent-shaped, bedding-

parallel burrows, resembling somewhat the shape of bananas and comprising disordered clusters showing various degrees of burrow density. In other situations individual burrows occur as isolated or semi-isolated entities. A spreite-like structure is present but poorly developed.

Remarks (diagnostic features): Burrows are simple, bedding-parallel, crescent-, or bow-, or banana-shaped with varying degrees of mutual proximity ranging from densely crowded clusters to isolated individuals. The resemblance to a banana-shape is quite unique. The burrows do not have recognizable protrusive or retrusive spreite in the form of ordered successions of inter-leaved broad curves notwithstanding the presence of a crude spreite-like structure on the concave side of the burrow in some cases. Very rarely the burrows may exhibit a J- or L-shape. Diameter of curvature (= length of the burrow) is 1.5 cm to 2 cm on average, and the diameter of the tube is about 0.5 cm.

Description and ethology: Typically the burrows occur as densely crowded clusters so that the host sandstone is almost totally bioturbated. Only rarely do the burrows occur as less crowded and isolated individuals. The burrows are commonly preserved as semi-relief to full-relief forms on the sole bedding-plane sur-faces of sandstone beds and normally occur in a bedding-parallel to subparallel orientation. In dense clusters crossovers occur, but interpenetration or reburrowing is obscured. The burrows commonly exhibit a confused or disordered array of intersecting curved or bow-shaped individuals arranged in subparallel groups (Plate 71 Fig. b). The presence of retrusive spreite as in the

type species (F. communis Bromley & Asgaard, 1979) is not clearly recognizable. The burrows are interpreted to have been actively filled by similar stuff to that of the host sediment.

These traces can be interpreted to have resulted from the movements of a deposit-feeding organism mining along a curved axis for food, actively back-filling as it did so and commonly extending its feeding pattern in such a way as to systematically exploit sediment immediately adjacent to its previous position. No surface ornamentation or internal structure are present apart from the crude ?retrusive spreite-like structures on the concave side of some burrows. The habitat of the unknown producer organism was an aquatic environment of brackish- to shallow-marine character.

Comparison: The studied examples of Fuersichnus communis? occur only in a very small area at one locality, as is also true of the type species described by Bromley & Asgaard (1979). The present examples of Fuersichnus are also much larger than those of the type species and, unlike the latter, apparently lack conspicuous retrusive spreite, probably suggesting that they were produced by a different organism.

Distribution: The burrows illustrated in Plate 71 Figs. b & c are from trace fossil subinterval IE1 of the Middle Newport Member at St. Michaels Cave (area 5). Such burrows are not known to occur at any other stratigraphic levels or geographic localities in the study area.

Studied material: The studied examples illustrated in Plate 71 Figs. b & c have not been retrieved from the field.

Preservation and association: In the present study Fuersichnus

commonly occurs in clusters which almost completely bioturbate the host sediment of very fine sandstone. The traces are preserved as semi-relief or full-relief forms developed on the sole surfaces of the bed. These burrows are not associated with any other traces.

Ichnofacies and palaeoenvironmental affinities: The association of ichnogenus Pelecypodichnus and stuffed burrows in the case of the type species in the Triassic Carlsberg Fjord Formation, East Greenland (Bromley & Asgaard, 1979) is believed to imply an aquatic freshwater lacustrine origin. The present examples of Fuersichnus probably belong to the Skolithos and/or Scoyenia ichnofacies developed in the restricted proximal part of fluvially-dominated very shallow brackish-marine estuarine or coastal lagoonal environments.

17.2.7. Imbrichnus Hallam, 1970
Plate 76, Fig. c

Diagnosis (generic assignment): Bedding-parallel winding burrows of semi-relief to full-relief form, preserved on the sole surface of sandstone beds, and characterized by a conspicuous imbricate structure formed on the surface of the burrows as successive overlapping pads of the sandy dark-brown sediment.

Remarks (diagnostic features): The characteristic imbricate structure is made up of sand-filled pad-like extensions from the central burrow tube. The burrows are typically bedding-parallel, and only locally are slightly oblique to bedding as a result of the locally ascending or descending course of the tubes. The burrows are 0.5 cm to 1 cm in diameter and about 2 cm to 5 cm in
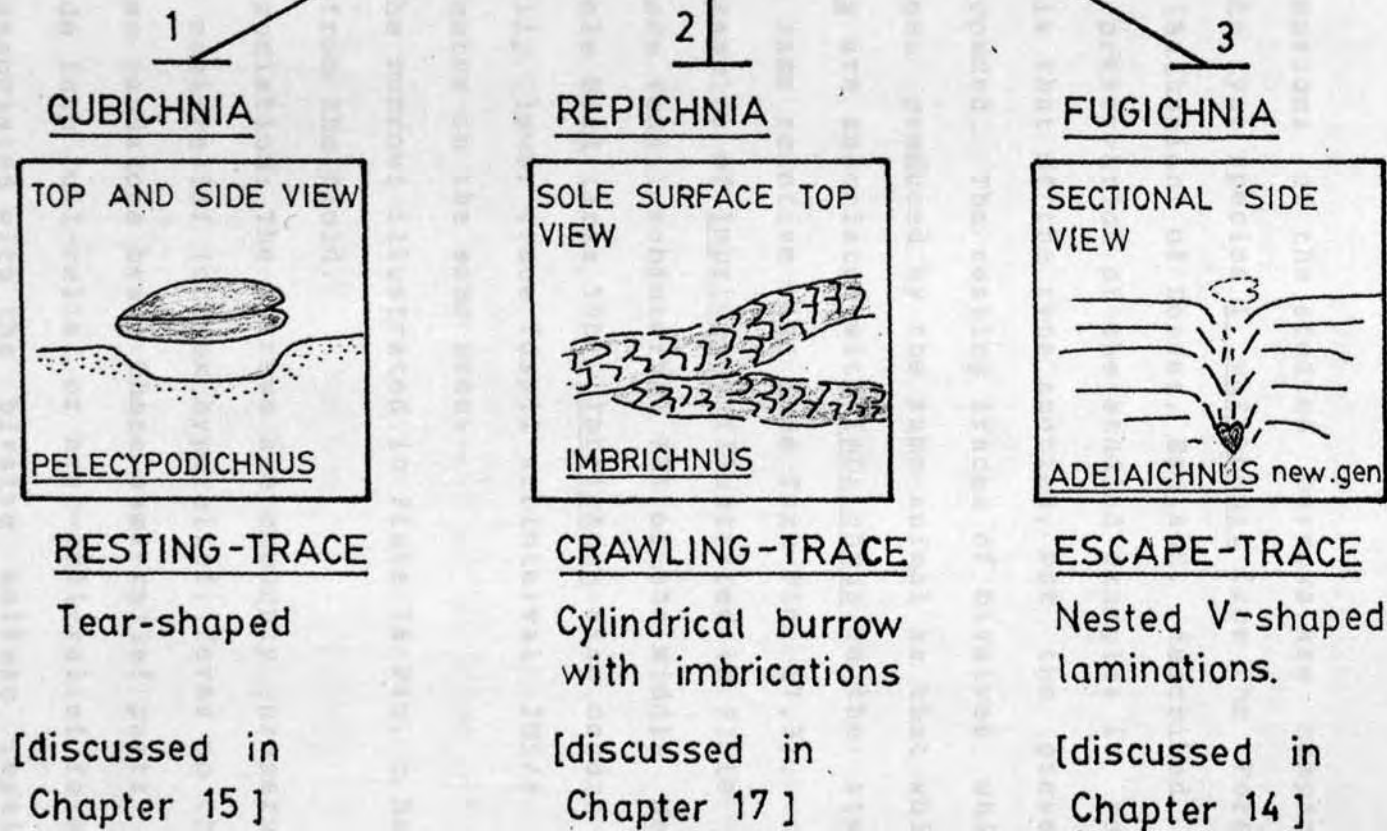
length.

Description and ethology: The traces comprise well-developed imbricate, winding dark-brown sand-filled burrows preserved on the sole surface of fine sandstone beds as convex hyporelief forms. The burrows are winding, but more or less subparallel to bedding and grade from semi-relief forms to full-relief forms depending on the degree to which the trace is endichnial or exichnial. Localized decent and ascent occurs where the burrows crossover one another. The most characteristic feature is the surficial imbricated pattern made up of successive very small overlapping sand-pads inclined away from the horizontal axis of the tube. Localized differential weathering may destroy this imbricated pattern in which case the traces assume an apparently smooth-walled structure; consequently it can be concluded that the imbrication is only a surficial feature of the burrows.

Hallam (1970) interpreted these traces characterized by surficial imbricated pads as the locomotion trails of a bivalve. In the present study area the joint occurrences of Imbrichnus with Pelecypodichnus (Plate 76, Fig. c) would seem to confirm such an origin. A bivalve commonly moves by extending its foot into the sand to act as an anchor, followed by contraction of the foot muscle to move the whole body and shell forward. The repetition of this locomotion behavior may result in the trace assigned to the ichnogenus Imbrichnus. The surficial imbricated pads suggest that they are produced through the passive infilling of the marks made by the periodic extension of the foot of a small bivalve mollusc during locomotion. The non-imbricate internal

TEXT-FIG. 17.3. Definition of ethological differences in different ichnogenera produced by a bivalve mollusc based on the examples described by Seilacher (1953) and Hallam (1970), and those from the present study area. The relationship between these different traces and the transitional behavior patterns that produced them must be clearly understood for valid ethological diagnosis and the ichnogeneric attribution.

ICHNOLOGY OF BIVALVES

1

CUBICHNIA

TOP AND SIDE VIEW

PELECYPODICHNUS

RESTING-TRACE

Tear-shaped

[discussed in
Chapter 15]

2

REPICHNIA

SOLE SURFACE TOP
VIEW

IMBRICHNUS

CRAWLING-TRACE

Cylindrical burrow
with imbrications

[discussed in
Chapter 17]

3

FUGICHNIA

SECTIONAL SIDE
VIEW

ADEIAICHNUS new.gen

ESCAPE-TRACE

Nested V-shaped
laminations.

[discussed in
Chapter 14]

TEXT-FIG. 17.3

core of the trace marks the movement of the smooth shell along the trail. However, in regard to the producers of the burrow, it is known that these imbricate structures can result from the activity of several other types of organisms (e.g. crustaceans) (Hallam, 1970).

Comparison: The dimensions of the studied burrows are comparable with those of the type species I. wattonensi from the Forest Marble Formation (Bathonian) of Dorset, England, described by Hallam (1970). The preservation of the studied examples is reasonably good, as is that of the type species, but the present examples are less crowded. The resting traces of bivalves which I believe to have been produced by the same animal as that which produced Imbrichnus are associated with Imbrichnus in the study area and are of the same relative size (see Text-Fig. 17.3).

Distribution: The examples of Imbrichnus illustrated in Plate 76 Fig. c are from trace fossil subinterval IE1 of the Middle Newport Member at Bilgola Head (area 10b). Imbrichnus also occurs in the stratigraphically lower trace fossil subinterval ID5/6 of the Lower Newport Member in the same area.

Studied material: The burrows illustrated in Plate 76 Fig. c have not been retrieved from the field.

Preservation and association: The burrows are commonly preserved as bedding-parallel semi-relief (convex hyporelief) forms on the sole surfaces of fine sandstone beds. These semi-relief parts of the burrows may grade into full-relief or near-full-relief forms. The burrows are associated with the bivalve mollusc resting structure Pelecypodichnus of similar relative width to Imbrichnus and which I believe to have been produced by the same organism

responsible for Imbrichnus (Text-Fig. 17.3.)

Ichnofacies and palaeoenvironmental affinities: The type species I. wattonensis (Hallam, 1970), was believed to have been produced in a shallow, marginal-marine lagoonal type of environment. In the present study area Imbrichnus is associated with its resting trace and is believed to belong to the Skolithos ichnofacies developed in a fluvially-dominated brackish-marine environment of an estuary or coastal lagoon.

17.2.8.   Network system (unknown producer)
Plate 75. Fig. a

The network system burrows are preserved as endichnial full-relief structures in a bed of fine grey sandstone. The burrows are infilled (passively or actively) with brownish slightly coarser-grained fine sand. The burrow system consists of elongated enlarged chambers (used for living, breeding , or hibernation purposes) about 1.5 cm to 2 cm in diameter and 5 cm in length. These enlarged chambers are connected by narrower tunnels arranged in perpendicular orientation to the axes of the chambers. No surface ornamentation or lining is evident in these burrows either in the connecting tunnels or the chambers. The network systems are laid out in a rather irregular pattern, the branching being both perpendicular and angular and with sporadic curving or looping at the terminii of some tunnels. The burrow network system is of unknown origin but it somewhat resembles the network system produced by modern-day crickets (cf. Chamberlain, 1975).

The observed network system illustrated in Plate 75

Fig. a is from trace fossil subinterval ID2 of the Lower New-
port Member at Little Reef (area 12). The network systems are
associated with flask-shaped, J- and L-shaped burrows and Diplo-
craterion (the latter being discussed in Chapter 7). No exam-
ples are presently known from other trace fossil intervals or
localities.

17.2.9. Ring-structures
Introduction.

The origin of ring-structures by organic and/or inor-
ganic agencies has been the subject of much discussion and
dispute for some decades. Vologdin (1964) described such struc-
tures from the Precambrian and Middle Cambrian of the northern
Siberian Platform. He described all his structures as having a
core surrounded by concentric helicoidally arranged rings and
concluded that these rings were `Liesegang rings' which developed
during post-depositional stages by rhythmic precipitation of a
colloidal gel-like material. Alf (1959) thought differently about
the ring-structures preserved in red siltstone and quartzite from
the Precambrian Bass Formation of the Grand Canyon, Arizona, USA,
believing them to be the remains of medusae. Later, Cloud (1968)
thought that these same Bass Formation examples were imprints of
raindrops. Glaessner (1969), after restudying the same specimens,
rejected the idea of raindrops because falling raindrops produce
intersecting circles, and these were not found in Alf's speci-
mens. He challenged the idea that the structures had formed as
gelatinous sheaths of algal colonies. Germs,   (1972) found
similar concentric structures in the Nama System, South West

Africa, and he believed them to be of biological origin involving disc-shaped algal colonies that grew as horizontal mats rather than forming domal stromatolitic structures.

Seilacher (1953, p.430, fig. 5.) interpreted these concentric ring-structures as having been made by the waving tentacles of a polychaete worm. However, these peculiar ring-structures have no correlation with the polychaete morphology. Henbest (1960), Osgood (1970), Häntzschel (1975) and Jordan (1985) described them as either Palaeoscia Caster, 1942, or Laevicyclus Quenstedt, 1879, both genera actually having been described as corals.
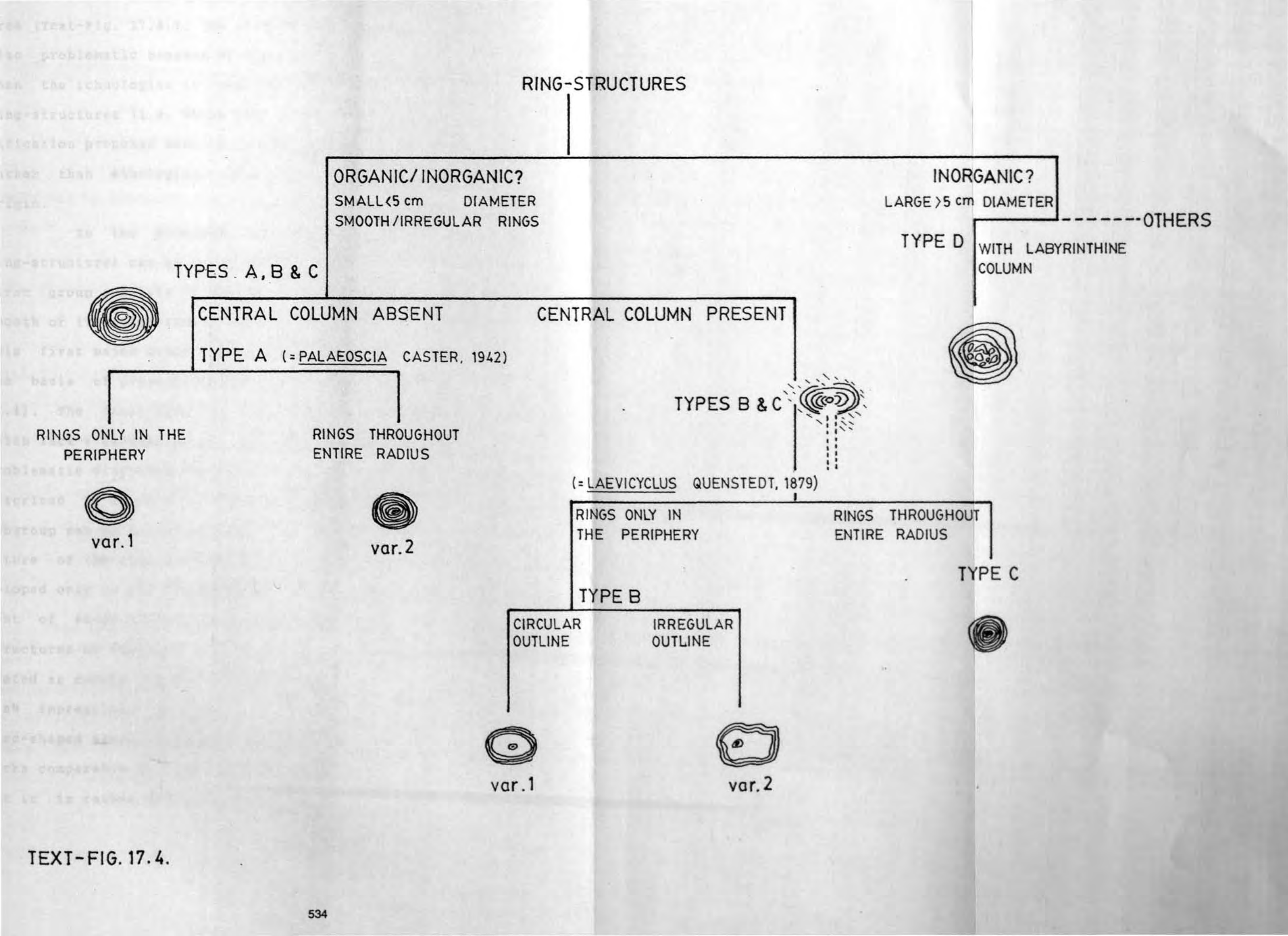
Schmidt (1934) interpreted these structures differently and suggested them to be inorganic structures made by gas-exhalations from water under pressure within sediment. This type of inorganic explanation was later supported by Boyd (1975) who argued that localized upwelling of gas in sufficient quantity, especially in muddy sediment, produces a blister at the surface which collapses to produce rings, the concentric pattern being enhanced if the process is repeated. He also made a comparison with similar holes produced on sand beaches by air expelled from pores as the water-table rises with the incoming tides. Frey (1970) reviews the arguments regarding both the organic and inorganic origin of these structures on the basis of Cretaceous specimens from Kansas, USA, and found the evidence for an unequivocal origin to be inconclusive.

Proposed classification

The proposed classification is partly based on Seilach-

TEXT-FIG. 17.4. Classification diagram of ring-structures based on Seilacher (1953), Häntzschel (1975), and specimens observed in the study present area. The classification is mainly based on morphologically (inorganic ring-structures) and ethologically (organic ring-structures) important characteristics the central column. The presence and nature of the central column and the nature of the rings developed in the structures play an important role in the classification. Several other unexplained ring-structures described in the literature are excluded from the classification. All the varieties of ring-structures illustrated in this diagram occur in the present study area.

RING-STRUCTURES

ORGANIC/INORGANIC?
SMALL <5 cm   DIAMETER
SMOOTH/IRREGULAR RINGS

INORGANIC?
LARGE >5 cm DIAMETER
- - - - - - - - OTHERS

TYPE D WITH LABYRINTHINE
COLUMN

TYPES A, B & C

CENTRAL COLUMN ABSENT   CENTRAL COLUMN PRESENT

TYPE A (= PALAEOSCIA CASTER, 1942)

TYPES B & C

RINGS ONLY IN THE   RINGS THROUGHOUT
PERIPHERY   ENTIRE RADIUS

(= LAEVICYCLUS QUENSTEDT, 1879)

var.1   var.2

RINGS ONLY IN   RINGS THROUGHOUT
THE PERIPHERY   ENTIRE RADIUS

TYPE C

TYPE B

CIRCULAR   IRREGULAR
OUTLINE   OUTLINE

var.1   var.2

TEXT-FIG. 17. 4.

er (1953), Häntzschel (1975) and examples from the present study area (Text-Fig. 17.4.). The classification of ring-structures is also problematic because of their unsettled origin, especially when the ichnologist is concerned with the smaller varieties of ring-structures (i.e. those less than 5 cm diameter). The classification proposed here is based more on morphological criteria rather than ethological criteria because of their uncertain origin.

In the proposed classification two major types of ring-structures can be recognized on the basis of their size. The first group consists of smaller entities (<5 cm diameter) with smooth or irregular rings, and with or without a central column. This first major group can be subdivided into two subgroups on the basis of presence/absence of a central column (Text-Fig. 17.4). The first subgroup (type A) comprises ring-structures which lack a central column. These type A structures resemble the problematic disc-like impression or medusae-like ring-structures described by Hantzschel (1975) as Palaeoscia Caster, 1942. This subgroup can be further divided into two varieties defined by the nature of the ring development; var. 1 is defined by rings developed only in the periphery; and var. 2 is defined by development of rings throughout the whole radius. These type A ring-structures or features like them were originally variously interpreted as corals (Harrington & Moore, 1956), medusae-like jellyfish impressions or concentric structures which originated as disc-shaped algal colonies (Glaessner, 1969), or tentacle sweepmarks comparable to those in Dystactophycus Miller & Dyer, 1878. But it is rather difficult to explain the origin of such postu-

lated tentacle sweep-marks produced by, for example, <u>Scolecole-</u><u>pis</u>, without preserved evidence of a central column as a record of the main body of the producer organism (see Seilacher, 1953, p.430, fig.5). The other subdivisions (types B and C) belong to another small group of ring-structures which are more comparable to the ichnogenus <u>Laevicyclus</u> Quenstedt, 1839, in Häntzschel (1975). The producers of these types of ring-structures are well explained by Seilacher (1953), Henbest (1960) and Osgood (1970). However, these types of structures also resemble the gas blisters or gas expulsion marks described by Boyd (1975). The pattern of the rings in these structures allows their differentiation into types B and C. In the type B category the rings are developed only in the periphery and in the type C category the rings are developed throughout the entire radius. The type B ring-structures can be further subdivided into two varieties on the basis of the regular or irregular nature or shape of the rings.

The second major first-order category of ring-structures is defined by their comparatively large size (diameter > 5 cm). They are rather peculiar in having a large labyrinthine interior and are of uncertain but probably inorganic origin.

Ichnotaxonomy

Type A (small ring-structures without central column)

Plate 52, Fig. a

Diagnosis (type assignment): Small ring-structures (less than 5 cm diameter) without a central column; rings may occur only in the periphery or throughout the entire radius.

Remarks (diagnostic features): These small ring-structures which

lack a central column are commonly preserved on the surface of bedding planes in the study area. Two varieties can be defined on the basis of the pattern of ring development. The first variety has rings only in the periphery whereas the second variety has rings throughout the entire radius.

Description: These small ring-structures (which are typically about 3 cm to 4 cm in diameter) lack a central column and are preserved on the bedding-plane surface as semi-relief forms. The nature of the rings is more clearly exhibited in the periphery rather than in the centre. The variety 1 structures exhibit rings only in the periphery whereas variety 2 structures exhibit rings throughout their entire width. Both varieties occur together with the type C ring-structures which have a central column (to be discussed below). The central portion of the variety 2 ring-structures have a small central depression (about 1 cm wide) with rings. The other variety (variety 1) has no central depression or central rings but is instead more or less flat and structureless in its centre, like a disc.

Comparison: The type A ring-structures somewhat resemble the ring-structures described as _Palaeoscia_ by Häntzschel (1975), the 'thin concentric structures' from the Grand Canyon, Arizona (Glaessner, 1969), and the ring-structures from the Nama System, South West Africa (Germs, 1972).

Distribution: The ring-structures illustrated in Plate 52 Fig. a are known only from trace fossil subinterval ID5/6 from the Lower Newport Member at Mona Vale Head (area 14).

Studied material: The example illustrated in Plate 52 has not

been retrieved from the field.

Preservation and association: The type A ring-structures (both varieties 1 and 2) are preserved as semi-relief forms on the bedding-plane surface of a bed of fine sandstone and are associated with type C ring-structures which have a central column.

Ichnofacies and palaeoenvironmental affinities: These ring-structures have commonly been reported from deep-sea (e.g. Kennedy, 1975) to shallow-marine environments (e.g. Frey & Howard, 1970; and Jordan, 1985). In the present study area this type of ring-structure is believed to have been developed in a shallow brackish-marine lagoon or estuarine type of environment.

Type B (small ring-structures with ring development only in the periphery and with a central column)

Plate 50, Figs. b & c (var. 1, circular-shaped)
Plate 50, Figs. d & e (var. 2, irregular-shaped).

Diagnosis (type assignment): Small ring-structures (less than 5 cm diameter) with a small central column; in the examples from the present study area the rings occur only in the periphery.

Remarks (diagnostic features): Type B small ring-structures occur as vertically orientated full-relief forms with a central column and with a surface impression of thin concentric rings. Two varieties can be recognized on the basis of the nature of the rings: variety 1 is characteristically circular- to subcircular-shaped with narrow rings; variety 2 is irregular-shaped with relatively wide rings. The central column is preserved as a simple vertical structure evident in bedding-plain view as a small area in the centre of the smallest ring, and in bedding-normal view in sections that intersect the axis of the ring-

structure, as a column of about 3 to 5 cm length.

Description and ethology: Type B small ring-structures (which are about 2 cm to 3 cm in diameter) with a small central column (about 0.1 cm to 0.5 cm in diameter) are preserved as thin concentric rings and discernible central vertical column. The rings are developed regularly and are narrow to very narrow in variety 1 with characteristically very small central column (Plate 50 Figs. b & c). In variety 2 the rings are irregularly arranged and are relatively wide and the central column is relatively larger (about 0.5 cm diameter). This cylindrical column-like structure is believed to manifest the location of the producer organism (e.g. dwelling-shaft of the polychaete worm _Scolecolepis_, Seilacher, 1953), and the peripheral rings are probably made by the wavy tentacles (as scraping circles) of the producer worm.

Comparison: The type B ring-structures described from the present study area accord with the ring-structures described by Seilacher (1953) and Osgood (1970) as feeding-structures and burrows produced by polychaete worms from who's dwelling-shafts in the centre are produced sweeping circles by tentacles scavenging for food in the surrounding area, or as in the ichnogenus _Laevicyclus_ Quenstedt, 1879, described by Häntzschel (1970). Alternatively, in a non-organic explanation the central column can be interpreted as a conduit of gas flow or expulsion of gas trapped under the sediments (cf. Schmidt, 1934; and Boyd, 1975).

Distribution: The type B variety 1 ring-structures illustrated in Plate 50 Figs. b & c are from trace fossil subinterval IC5 of the Bald Hill Claystone at Turimetta Head (area 2). The variety 2

539

ring-structures illustrated in Plate 50 Figs. d & e are from trace fossil subintervals ID1 and ID2 of the Lower Newport Member at Bungan Head (area 13). No other examples of these types of ring-structures are presently known from other trace fossil subintervals or localities.

Studied material: Among the type B ring-structures illustrated in Plate 50, only one sample (containing variety 2 ring-structures) was collected (1005b/MU.44427), the others not having been retrieved from the field.

Preservation and association: The type B ring-structures are preserved as thin to thick impressions of concentric rings on the bedding-plane surfaces and the central column occurs as a vertically orientated shaft. Examples of type B variety 2 ring-structures in trace fossil subinterval IC5 are associated with crustacean burrows; and type B variety 2 ring-structures in trace fossil subintervals ID1 and ID2 are associated with many other different trace fossils in the various headlands (see Text-Figs. 4.1 & 4.2).

Ichnofacies and palaeoenvironmental affinities: As for type A ring-structures.

Type C (small ring-structures with ring development throughout the entire radius and with a central column)

Plate 50, Figs. a & b
Plate 51, Figs. a - d

Diagnosis (type assignment): Small ring-structures (less than 5 cm diameter) with a central column and ring development throughout the entire radius.

Remarks (diagnostic features): These type C small ring-structures

are preserved as thin circular impressions on the bedding-plane surfaces together with a vertically orientated small to relatively large central column that is commonly infilled either with similar or dissimilar material to that of the host sediment (the infilling sediment is commonly dark-brown fine sand).

Description and ethology: The type C ring-structures are the smallest of the ring-structures which have a central column, and are the commonest type of ring-structure in the study area. The development of the rings is almost regularly circular and they vary from being narrow to wide but are more well-defined in the peripheral areas. The vertically orientated central column is commonly preserved as a central mound but in some cases is eccentric (Plate 52, Fig. b). The central column is commonly filled with similar material (fine sand) to that of the host sediment; some are filled with darker brown-coloured material identical to that in the rings. As in the case of the type B ring-structures the central column is believed to represent the dwelling-shaft of the producer organism in an organic interpretation, and gas expulsion shaft in the case of the inorganic explanations of Schmidt (1934) and Boyd (1975).

Comparison: Type C ring-structures also accord with the ring-structures described by Seilacher (1953) and Osgood (1970) as feeding-structures developed by polychaete worms (_Scolecolepis_) represented in this view by the dwelling-shaft in the centre of the ring-structure and the scraping/feeding rings surrounding this. Häntzschel (1975) regards them as a trace fossil in his treatise under the name _Laevicyclus_ Quenstedt, 1879. These ring-

structures also somewhat resemble the gas-expulsion structures described above in reference to the type B ring-stuctures.

Distribution: Type C ring-structures are the commonest ring-structures present in the study area. Most of them are developed in trace fossil interval IC of the Bald Hill Claystone, interval ID of the Lower Newport Member, and interval IE of the Middle Newport Member and occur in almost all areas where these rock units are exposed. The detailed distribution of these ring-structures is documented in Text-Figs. 4.1 & 4.2.

Studied material: None of the studied materials has been retrieved from the field.

Preservation and association: Type C ring-structures are preserved as thin to relatively thick impressions on the bedding-plane surfaces, normally in fine sandstone units, and invariably with the central column oriented vertically into the underlying host sediment. These ring-structures are not commonly associated with other trace fossils but in Plate 52 Fig. c they are associated with small bean-shaped unclassified trace fossils.

Ichnofacies and palaeoenvironmental affinities: As for the type A and type B ring-structures.

Type D (large ring-structures of inorganic or unknown origin)
Plate 50, Fig. a

Diagnosis (type assignment): Large (more than 5 cm diameter) ring-structures, thick regularly ringed with large labyrinthine central column (Text-Fig. 17.4). These ring-structures are characteristically obliquely orientated to the bedding plane.

Remarks (diagnostic features): These large type D ring-structures

are preserved as full-relief to half-relief forms on the top surface of the bedding plane. The rings are wide, regularly arranged and are normally preferentially developed in the peripheral region of the structure. The central column is relatively large, commonly off-centered, and comprises a labyrinthine arrangement probably of broken parts of previously developed internal rings.

Description: These large type D ring-structures are the least common of all the different kinds of ring-structures present in the study area and are restricted to one localized area (Little Head). The rings are about 17 cm in diameter and the central column is about 8 cm to 9 cm in diameter. The length of the central column is at least tens of cm, but its true length is difficult to assess as it is not entirely exposed. The structure is normally preserved as a bedding-oblique form and normally disrupts the original bedding-plane laminations. The thick rings are regularly developed especially in the periphery, and the central labyrinthine column is normally eccentric. The producer of these large ring-structures is unknown and they are probably of inorganic origin.

Comparison: No strictly comparably structure to these is known to me in the geological literature.

Distribution: The type D ring-structures illustrated in Plate 50 Fig. a are from trace fossil subinterval IE7 of the Middle Newport Member at Little Head (area 7) and their known distribution is restricted to that area.

Preservation and association: These large ring-structures are commonly preserved as full-relief to half-relief forms exposed on

bedding-plane surfaces. They are not associated with any other trace fossils.

Ichnofacies and palaeoenvironmental affinities: The ichnofacies and palaeoenvironmental affinities are unknown, but the ring-structures seem to have developed in the shallow proximal parts of a fluvially-dominated brackish-marine lagoon or estuary.

### 17.2.10. Scalarituba Weller, 1899

Neonereites Seilacher, 1960.

Plate 72, Figs. a & b

Diagnosis (taxonomic assignment): Full-relief, bedding-parallel to partly oblique subcylindrical sinuous vermicular scalariform burrows, probably produced by unknown worm.

Remarks (diagnostic features): Scalariform burrows, preserved as full-relief forms on the sole surface of a grey siltstone bed. The scalariform segments are arranged in regular form but a median crawlway gallery and lateral feeding lobes (cf. Chamberlain, 1971) are absent (Text-Fig. 17.5).

Description and ethology: The ichnogenus Scalarituba was first named from the worm burrows which penetrate a siltstone in random directions (i.e. no preferred orientation) from a vermicular sandstone in the lower Mississippian of Missouri, USA. The burrows are normally packed in the well-laminated siltstone units. The burrows described here from the present study area are invariably somewhat crowded, each burrow rarely being a distance of more than 2 cm to 3 cm from its two nearest neighbours. The burrows are commonly arranged in a disorientated manner upon the bedding surface of the rocks (Plate 72 Fig. a). The burrows are

TEXT-FIG. 17.5. Diagrammatic illustration of a scalariform burrow
with definition of dimensional parameters documented in Table
17.2. The reconstructed position of the median crawlway and
lateral feeding lobes (absent in the present examples) are shown,
as is the inferred direction of progressive movement of the
worm-like producer organism relative to the concave/convex polar-
ity of the scalariform ridges. For simplicity of visualization,
the scalariform lobes are not shown in the hachured segments.
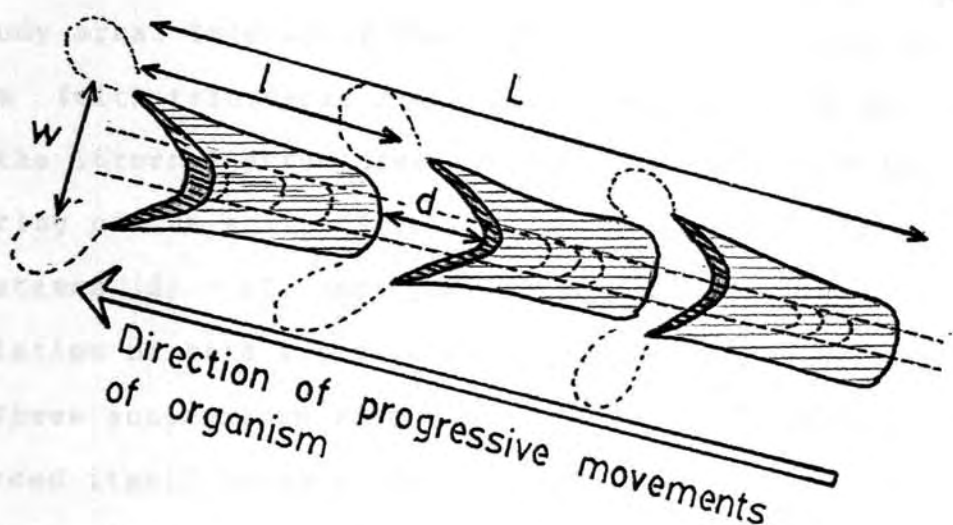
L = Length of overall or exposed segment of scalariform tube
l = Length of individual scalariform tube
w = Width of scalariform tube
d = Distance between two scalariform segments

⎯⎯ normal position of median crawlway and lateral feeding lobes.

TEXT-FIG. 17.5.

subcylindrical, fairly straight to sinuous, 0.3 cm in diameter (W), and 5 cm (maximum) and 1 cm (minimum) in length (L) (some can be measured only in terms of exposed length) (Text-Fig. 17.5). Table 17.2 gives measurements of studied specimens from the study area. Internally these burrows are conspicuously scalariform (with transverse ridges) in those parts of the burrows where the internal structures are open and available for study. The spacing of the scalariform ridges (here termed the interscalar distance (d) - cf. Text-Fig. 17.5) is typically 1 to 3 mm. The variation of this interscalar distance is documented in Table 17.2. These scalariform ridges were evidently formed by a worm that forced itself forward through the mud, the posterior extremity of the animal pushing up small ridges of the plastic material behind to serve as a brace while the anterior extremity was forced forward (cf. Conkin & Conkin, 1968). If this was the method of formation of these ridges, then the direction of progress of the worm itself was always away from the concave side of the ridges (similar to the formation of spreite) (see Text-Fig. 17.5).

The burrows are now filled with material different to that which surrounds them (the latter being grey siltstone). The burrow-filling sediment is darker in colour, finer-grained or of similar texture and harder than the host sediment, so that on weathered surfaces the burrows become etched out through the removal of the softer, lighter-coloured host sediment. The unweathered fresh surfaces of the burrows are conspicuous because of their colour contrast relative to the host sediment (the

TABLE 17. 2. Dimensional measurements of <u>Scalarituba</u> burrows from trace fossil subinterval IE2 of the Middle Newport Member at St. Michaels Cave (area 5).

overall length L (cm)	Individual scalariform tube									Length/ width ratio (w/l)
	Length (l) (cm)			Width (w) (cm)			Interscalar distance (d) (cm)			
	Max.	Min.	Avg. (l)	Max.	Min.	Avg. (w)	Max.	Min.	Avg. (d)	
1. 5.89	0.36	0.16	0.26	0.46	0.36	0.41	0.50	0.32	0.41	1.58
2. 5.18	0.54	0.50	0.52	0.48	0.30	0.39	0.27	0.23	0.25	0.75
3. 3.41	0.57	0.38	0.48	0.29	0.13	0.21	0.20	0.12	0.16	0.44
4. 2.71	0.57	0.45	0.51	0.27	0.18	0.23	0.30	0.10	0.20	0.45
5. 2.64	0.91	0.50	0.71	0.25	0.09	0.17	0.57	0.27	0.42	0.24

n 5 —————— 5 —————— 5 —————— 5

$\bar{x}$ 3.97 —————— 0.5 —————— 0.28 —————— 0.29

σ_n 1.33 —————— 0.14 —————— 0.10 —————— 0.11

σ_{n-1} 1.48 —————— 0.16 —————— 0.11 —————— 0.12

Σx 19.83 —————— 2.48 —————— 1.41 —————— 1.44

Σx^2 87.47 —————— 1.33 —————— 0.45 —————— 0.47

darker colour of the burrow infills is due to the reducing conditions that existed in the digestive tract of the worm during its life) and differential hardness. The absence of the medial crawlway gallery and lateral feeding lobes can be attributed to both behavioral and preservational aspects (Text-Fig. 17.5). Probably the animal was living within sand laminae and feeding on underlying or overlying mud laminae and the median crawlway and lateral feeding lobes extended into the mud or silt above and below the sand laminae. Consequently, the median crawlway and lateral feeding lobes were not as well preserved in the mudstone. Although the traces look like simple feeding burrows, they are in fact intricate structures as discussed by Chamberlain (1971, text-fig. 5A-I). Both of the possibilities that Chamberlain discussed for the way in which the feeding-lobe structures developed are plausible as he interpreted them to be the result of deposit-feeding activities of an infaunal worm-like organism. Conkin and Conkin (1968) also accepted the possibility of a marine worm producer living in shallow water, probably of tidal-flat character, but certainly not in a deep-water environment.

Comparison: The present examples of Scalarituba are much smaller than the scalarituboid (S. missouriensis) form described by Conkin and Conkin (1968), Chamberlain (1971), and Miller and Knox (1985). All examples of Scalarituba from the study area lack the median crawlway and lateral feeding lobes characteristic of Scalarituba burrows described by the above mentioned authors.

Distribution: The burrows illustrated in Plate 72 Figs. a & b are from trace fossil subinterval IE2 of the Middle Newport Member at St. Michaels Cave (area 5). No other examples are presently known

from other trace fossil intervals or localities in the study area.

Studied material: The burrows illustrated in Plate 72 Figs. a & b have not been retrieved from the field. One large slab (506/MU. 44522) was collected from the field as a reference sample but no burrows in this slab are illustrated here .

Preservation and association: In the present study area the Scalarituba burrows occur in an alternation of thin claystone and siltstone layers. The burrows developed along the clay/silt interface, with siltstone above and the Scalarituba burrows preserved in the very basal part of the siltstone that became impressed into the shale below as a half-relief form on the base of the siltstone unit. Segments of the burrows that are oblique to bedding may exhibit a full-relief form in siltstone. The burrows are not associated with any other trace fossils.

Ichnofacies and palaeoenvironmental affinities: The Scalarituba burrows probably belong to the Skolithos ichnofacies because of their presence in rippled sandstone deposits in an inferred lower tidal-flat palaeoenvironment in a Pennsylvanian coal-bearing sequence (Miller & Knox, 1985). Chamberlain (1971) interpreted Scalarituba burrows of the Ouachita Mountain core regions to have resulted from the deposit-feeding activities of an infaunal worm-like organism, showing a eurybathic capacity under conditions of slow deposition (i.e., starved basin conditions). Conkin and Conkin (1968) regarded scalarituba as having been produced by a marine worm living in shallow water, probably in a tidal-flat habitat, but certainly not in a deep-water environment. On

the contrary, Nereites with a similar or identical behavior pattern has been regarded by most authors (e.g. Seilacher, 1960; Chamberlain, 1971) as of deep-sea affinity. However, the present examples of scalariform burrows are believed to have been produced by infaunal marine worms in a shallow fluvially-dominated brackish -marine environment developed in a coastal lagoon or estuary.

17.2.11. Scoyenia gracilis White, 1929

Plate 49, Figs. a - d

Diagnosis (taxonomic assignment): Straight to slightly curved or flattened (collapsed), unbranched, slender burrows with rope-like surface ornamentation. Burrows preserved as full-relief or half-relief forms, commonly bedding-parallel or horizontal; some may even occur in bedding-oblique or vertical orientations; infilled with stuffed meniscus backfillings.

Remarks (diagnostic features): Burrows are slightly curved to straight and are unbranched, and commonly occur in a bedding-parallel crowded pattern with individual burrows crossing each other; preserved normally as full-relief and half-relief forms, both on the top and bottom of the beds. Some parts of the burrows show slight peristaltic thickening and the surface is covered with clusters of fine wrinkles and longitudinal striations. Internally the burrows are filled with stuffed meniscus backfills which are especially evident in examples of full-relief preservation exposed by modern-day erosion and/or weathering.

Description and ethology: The present examples of Scoyenia gracilis burrows consist of slender, unbranched, straight to gently

curved traces with well-preserved rope-like surface ornamentation. The burrows are about 1 cm to 1.5 cm in diameter and 5 cm to 7 cm in length. The burrows are commonly preserved as bedding-parallel, convex hyporelief structures and may be flattened by compaction (Plate 49, Fig. b). The burrows show no branching but overcrossing of each other may simulate branching (Plate 49 Fig. b). The burrows are commonly of cylindrical-shape but sporadically the cylindrical-shape is altered by peristaltic thickening or clusters of wrinkles which are densely arranged (Plate 49 Fig. b). The burrows are backfilled with meniscus-forming stuff which is especially evident upon weathering (Plate 49 Fig. b). According to Miller (1979) these burrows were produced by a polychaete worm or some similar kind. Scoyenia is an index fossil of non-marine or freshwater ichnofacies (Seilacher, 1969), representing the non-marine sands and shales, fluvial deposits, and particularly redbeds and palaeosols. The Scoyenia burrows are associated with plant remains (Plate 49 Fig. d) and Skolithos (Plate 49, Fig. c).

Comparison: The dimensional parameters and morphological characteristics of the Scoyenia burrows from the study area are almost comparable with the type species S. gracilis described by White (1929) from the Hermit Shale, of the Grand Canyon area of Arizona, USA.

Distribution: Scoyenia burrows in the study area are known from two trace fossil subintervals and from two localities. The burrows illustrated in Plate 49 Figs. a , c and d are from trace fossil subinterval IE7 of the Middle Newport Member at Little Head (area 7). The burrow illustrated in Plate 49 Fig. b is from

trace fossil subinterval ID2 of the Lower Newport Member at Hole in the Wall (area 11).

Studied material: Among the burrows illustrated in Plate 49, two rock samples were collected for detailed study. These are sample no. 707/MU.44413 (illustrated in Fig. c), and sample no. 710/MU.44416 illustrated in Fig. a .

Preservation and association: The Scoyenia burrows present in the study area are commonly preserved as convex hyporelief forms (in semi-relief) but with some parts of burrows preserved in full-relief or being flattened because of compaction of the sediment. All Scoyenia burrows in the study area are associated with abundant plant remains of all kinds and also are associated with vertically orientated Skolithos burrows (Plate 49 Fig. c).

Ichnofacies and palaeoenvironmental affinities: Scoyenia is the index trace fossil for the `Scoyenia ichnofacies' (Seilacher, 1967, p.415), representing non-marine deposits, commonly redbeds and palaeosols. The Scoyenia burrows in the study area are associated with plant remains which are land-derived (transported) and suggestive of proximity of freshwater influx. However, the environment is still generally held to represent a marginal brackish-marine estuary or coastal lagoon. The association of vertically orientated Skolithos burrows confirms that the environment was an aquatic one.

17.2.12. Straight horizontal filled burrows

Plate 76, Fig. b

The straight horizontal filled burrows are preserved as half-relief to (partly) full-relief forms on the surface of bed-

ding planes in fine sandstone units and are infilled with similar fine sand from the host sediment. The burrows are 0.8 cm to 1 cm in diameter and about 20 cm in length, and are associated with the small burrow Arenicolites whose presence is evident as small vertical openings in the sample shown in Plate 76. These small vertical Arenicolites burrows were formed later than and penetrate the older straight horizontal burrows.

The straight horizontal filled burrow illustrated in Plate 76 Fig. b is from trace fossil subinterval IE1 of the Upper Newport Member at Mona Vale Head (area 14). The burrow has not been retrieved from the field.

17.2.13.   Stuffed burrows
Plate 71, Figs. e - g

The stuffed burrows are preserved mainly as horizontal or partly inclined sporadically branched, half-relief to partly full-relief forms on the sole surface of a bed of fine sandstone. The burrows are passively filled with dark-brown-coloured medium-grained structureless infills. These stuffed burrows are about 1 cm to 1.7 cm in diameter and nearly 5 cm in length. The burrows are not associated with other kinds of trace fossils. The burrows illustrated in Plate 71 Figs. e - g are from trace fossil subinterval IC5.3 of the uppermost part of the Bald Hill Claystone at Turimetta Head (area 2). The other stuffed burrows illustrated in Fig.g of the same plate occur in a loose block from the same location, but probably come from a higher stratigraphic level above trace fossil subinterval IC5.3. The burrows in the loose rocks are associated with Skolithos. The burrows

illustrated in Plate 71 Figs. e - f have not been retrieved from the field.

17.2.14. Unclassified (small bean-shaped) burrows

Plate 52. Fig. c

The   small (less than 0.5 cm in length and 0.15 cm in width)   bean-shaped unclassified burrows occur as   concave-epirelief half-relief forms on the bedding-plane surface. These small burrows are associated with type C ring-structures, and occur in trace fossil subinterval IE2 of the Lower Newport Member at Bangalley Head (area 8).