CHAPTER 12

DENDRITIC FEEDING-BURROWS

DENDRITIC FEEDING-BURROWS

12.1. INTRODUCTION

The name Chondrites was first introduced by K. Von Sternberg in 1833 for certain linear branching fossils (non-calcareous marine algae) from the flysch of the Alps. The same kinds of trace fossils are also common in the flysches of the Carpathians and the Apennines, the Lias of Germany and England, various Palaeozoic formations in North America (Upper Ordovician, Osgood, 1970; and Middle Ordovician, Shourd & Levin, 1976), and from the Miocene flysch near Auckland, New Zealand (Bradley, 1981). The fossil has become more problematical because of its wide variety of morphology. These varying forms were first described and explained as a mode of preservation (e.g. Fucoides Brongniart, 1823) that lacked taxonomic significance. Consideration of the different modes of preservation, as well as the morphology of the fossils, permits their interpretation as trace fossils manifesting the former presence of branching tunnels in the sediment.

The first attempt at a non-algal interpretation of the ichnogenus Chondrites was made by Fuchs (1895), who suggested that it consists of brood-chamber-burrows excavated in the sea-bed sediment by an unspecified animal and subsequently infilled with settling sediments. Reis (1910), in an important paper on the ichnogenus Chondrites, documented good evidence to show that (at least in the flysch deposits) these traces were in fact burrows that later were infilled by settling sediments; some of the examples that he illustrated appear to indicate even that the burrows are lined with faecal pellets. Finally, the trace fossil origin of these features was conclusively decided by Richter (1927) who described the phenomenon of phobotaxis in C. bollensis from the Lias of Wurttemberg and thus disproved the hypothesis that these features were the manifestations of fossil plants. Derichs (1928) was also able to demonstrate phobotaxis behavior of the producer organism in Chondrites (C. furcatus Von Sternberg, 1833) and hence to close the fucoid and algal origin controversy.

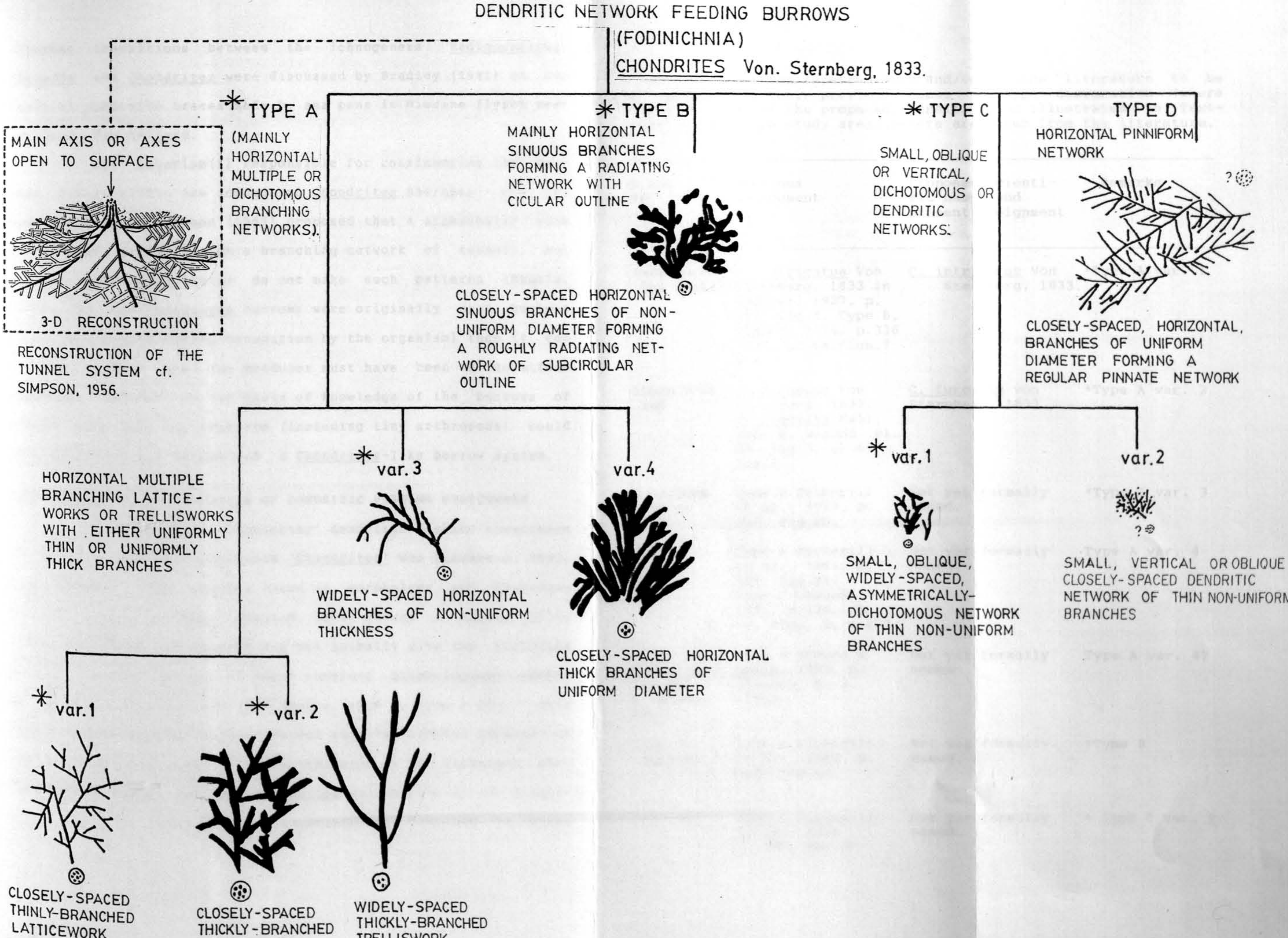
However, Richter's (1927) successful elimination of the ichnogenus Chondrites from the plant kingdom still left unresolved the true biological origin of the trace fossil. In his later papers Richter (1931, 1941) subsequently reconstructed the burrow system and suggested that Chondrites manifested a burrow system excavated by a mud-eating worm. In this hypothesis the mud-eating organism first probed outward or downward in the sediment to the maximum distance allowed by the size of its body and feeding apparatus, and then it retracted from the main tunnel but while doing so opened up shorter branches on either side of the main tunnel. Osgood (1970), on the other hand, described several forms of Chondrites from Cincinnatian (Upper Ordovician) rocks which in some cases exhibited interpenetration of branches. He concluded that the burrow system was most likely inhabited for much of the life of the inhabitant organism during which, he suggested, the organism extended the burrow progressively deeper into the sediment. He also explored the likely mechanism of infilling of the burrow system, assuming such infilling to have been passive, and designed laboratory experiments using a so-called Chondrites-apparatus (made of interconnected glass tubes) to test his ideas. These experiments helped him to resolve whether or not the passive infilling mechanism was sufficiently effective to completely fill the burrows in cases where the burrows were open to the sediment-water interface. These experiments demonstrated the effectiveness of the passive infill mechanism, but clearly are not applicable to Chondrites burrows which show evidence of active fill, in whole or in part. Most of the described forms of Chondrites were demonstrably connected to the sediment-water interface by one or more main open tunnels or axes through which the burrow could have been subsequently passively infilled.

Ferguson (1965) discussed the possibility that the burrow system was filled during or immediately after excavation of the burrow by the deposit-feeding organism. Taylor (1967) suggested that the branching tunnel system may have been excavated by an organism with numerous tentacles that worked simultaneously in the sediment but it is difficult to imagine an organism of this kind. Although Chondrites burrows commonly cut through other kinds of trace fossils, the latter rarely cut across Chondrites. This indicates that the producer of Chondrites burrows excavated through the sediment after the other traces were made. Assuming that sedimentation was continuous (i.e., uninterrupted) the organism that made the Chondrites burrow excavated it more deeply in the sediment than the burrows of many of the other organisms in the infaunal community succession, thus resulting in a tiering relationship among them (see Text-Fig. 12.2). The

TEXT-FIG. 12.1. Proposed classification of varieties of the dendritic network feeding-structure Chondrites Von Sternberg, 1833. The classification is mainly based on the burrow orientation, its branching pattern, general morphology, and density and size (including diameter) of the branches. The various features and criteria used at the type and variety levels in the classification and the rationale of approach used in their selection is detailed in Table 12.1. Diagram in frame at top-left is a three-dimensional reconstruction of a `Chondritor' burrows seen in oblique downward view; all other diagrams portray two-dimensional bedding-parallel views of the portions of the burrow networks in which no significance is intended in regards to the spatial orientation of the primary branches/axes. Forms present in the study area are indicating with an asterisk; other forms depicted here are taken from the literature, as detailed in Table 12.2. Depiction of the various forms in this diagram does not involve a common absolute scale. Details of the scale of each of the asterisked forms is given in the relevant plates (as cited in the text); and of the others in the relevant literature.

Type A structures belongs to essentially horizontally orientated burrows with multiple or dichotomous branching. This group is subdivided into four subcategories: variety 1 is characterized by dense thin horizontal latticeworks; variety 2 characterized by dense thick latticeworks or loose trellisworks; variety 3 by loose irregularly curved networks; and variety 4 by dense thick dichotomous networks. Type B consists of mainly horizontal/subhorizontal sinuous branches forming a radial network of roughly circular outline. Type C consists of branching networks that are typically oblique to bedding; the branches are typically small, either in loose dichotomous networks (variety 1); in closely-spaced dichotomous networks (variety 2). Type D comprises extensive pinniform horizontal networks.

The burrowing organism responsible for constructing the ichnogenus Chondrites has not yet been properly determined, but at the present these dendritic burrows are tentatively ascribed to the feeding activities of worms or worms-like (vermiform) organisms. Cross-sections of the main axis/axes (circled with dots -- the circle being simply an imaginary enveloping the burrow apertures) are depicted at the proximal end of the network. These axes terminated the sediment-water interface and were connected with the other branches in the distal parts.


DENDRITIC NETWORK FEEDING BURROWS
(FODINICHNIA)
CHONDRITES Von. Sternberg, 1833.
* TYPE A
(MAINLY HORIZONTAL MULTIPLE OR DICHOTOMOUS BRANCHING NETWORKS).
MAIN AXIS OR AXES OPEN TO SURFACE
3-D RECONSTRUCTION
RECONSTRUCTION OF THE TUNNEL SYSTEM cf. SIMPSON, 1956.
* TYPE B
MAINLY HORIZONTAL SINUOUS BRANCHES FORMING A RADIATING NETWORK WITH CICULAR OUTLINE
CLOSELY-SPACED HORIZONTAL SINUOUS BRANCHES OF NON-UNIFORM DIAMETER FORMING A ROUGHLY RADIATING NET-WORK OF SUBCIRCULAR OUTLINE
* TYPE C
SMALL, OBLIQUE OR VERTICAL, DICHOTOMOUS OR DENDRITIC NETWORKS.
TYPE D
HORIZONTAL PINNIFORM NETWORK
?
CLOSELY-SPACED, HORIZONTAL, BRANCHES OF UNIFORM DIAMETER FORMING A REGULAR PINNATE NETWORK
HORIZONTAL MULTIPLE BRANCHING LATTICE-WORKS OR TRELLISWORKS WITH EITHER UNIFORMLY THIN OR UNIFORMLY THICK BRANCHES
* var. 3
WIDELY-SPACED HORIZONTAL BRANCHES OF NON-UNIFORM THICKNESS
var. 4
CLOSELY-SPACED HORIZONTAL THICK BRANCHES OF UNIFORM DIAMETER
* var. 1
SMALL, OBLIQUE, WIDELY-SPACED, ASYMMETRICALLY-DICHOTOMOUS NETWORK OF THIN NON-UNIFORM BRANCHES
var. 2
?
SMALL, VERTICAL OR OBLIQUE CLOSELY-SPACED DENDRITIC NETWORK OF THIN NON-UNIFORM BRANCHES
* var. 1
CLOSELY-SPACED THINLY-BRANCHED LATTICEWORK
* var. 2
CLOSELY-SPACED THICKLY-BRANCHED LATTICEWORK
WIDELY-SPACED THICKLY-BRANCHED TRELLISWORK

TEXT-FIG. 12.1

apparent transitions between the ichnogenera Radionereites, Phycodes and Chondrites were discussed by Bradley (1981) on the basis of composite traces made by sea pens in Miocene flysch near Auckland, New Zealand.

The organism(s) responsible for constructing the burrows placed within the ichnogenus Chondrites has/have not yet been determined. Simpson (1957) proposed that a siphunculid worm could have produced such a branching network of tunnels, but modern siphunculid worms do not make such patterns (Ekdale, 1977). If the Chondrites burrows were originally open burrows (i.e., not filled during occupation by the organism) then it can not be claimed that the producer must have been a vermiform organism, because on the basis of knowledge of the burrows of modern organisms any organism (including tiny arthropods) could have excavated and maintained a Chondrites-like burrow system.

12.2 PROPOSED CLASSIFICATION OF DENDRITIC FEEDING STRUCTURES

Most of these `Chondritor' dendritic feeding structures are grouped into the ichnogenus `Chondrites' Von Sternberg, 1833, with several type species based on morphology and branching pattern. Later authors (Osgood, 1970; Shourd & Levin, 1976; Pickerill, et al., 1984; and others) did not normally give the varieties specific names because of their numerous morphological variations, but instead called them type a, type b, type c etc. This type of non-specific classification must be accepted because of the wide morphological and size variation of the different burrows grouped under the name Chondrites and because of the likelihood that different producer organisms were involved in their

TABLE 12.1. Rationale of approach and features used at the different apparent ichnotaxonomic levels in the proposed classification of varieties of Chondrites (cf. Text-Fig. 12.1). Proximal = Close to the main stem or branch. Distal = distance from the main stem or branch. Idealized illustrations of some of the features (characteristics) listed here are present in Text-Fig. 12.1 and are cross-indexed accordingly.

I. Orientation of branching pattern.

Inclination or attitude of the burrow.
(1) Vertical or steeply inclined.
(2) Oblique or shallowly inclined.
(3) Horizontal or bedding parallel.

II. Branching pattern.

Nature of branching.
(1) Regular or irregular.
(2) Symmetrical or Asymmetrical.
(3) Dichotomous (bifurcation).
(4) Multiple branching(e.g. lattice or trellis type of branching.
(5) Radiating curvilinear networks.
(6) Pinniform or (feather-like).

III. Dimensions of the burrow.

Thickness of the individual main stem or branch of the burrow size of the overall burrow network (e.g. small or large).
(1) Diameter of the main or branch (thick to thin).
(2) Thickness uniformity throughout the structure (uniform or irregular).
(3) Diameter of the overall burrow system (large or small network).

IV. Burrow density or frequency of branching within the burrow Spacing of burrow branches.

(1) Densely or closely-spaced.
(2) Loosely or widely-spaced.

V. Branching angle.

Angle measurement between branches.
(1) Angle between main (primary) stem and secondary branches.
(2) Angle between secondary and tertiary branches.

VI. Wall ornamentation.

Smooth or ornamented.

VII. Infills and internal structures.

Passive or active fills, faecal pellets, or presence/absence of spreite.

VIII. Other features and modes of preservation.

(1) Vertical extent of main axis/axes above level of secondary branches
(2) Unattached or attached to overlying bed providing source of passively infilled sediment (cf. Simpson, 1956, p.478).
(3) Preserved inside a nodule (cf. Simpson, 1956, p.478).
(4) Preserved on the surface of the other trace fossils (cf. Kilper, 1962 and Keij, 1965).
(5) preservation of structure involves special composition (cf. Rothpletz, 1896 and Tauber, 1949).
(6) Tiering and interpenetration relationship with other trace fossils (cf. Bromley and Ekdale, 1984).

excavation notwithstanding the evidence that such organisms shared a common unique ethology (i.e., a dendritic infaunal feeding habit). Nevertheless, many problems remain because these non-specific form-based classifications are not based on secure biological principles or criteria, including, most importantly, ethology. Hence, comparisons cannot be made between one type of Chondrites trace and another. The present classification (based on varieties of Chondrites in the study area and others documented in the literature cf. Text-Fig. 12.1 and Table 12.2) attempts to solve this problem by grouping together forms of similar pattern, because pattern is here judged to be of greater ethological significance that any other morphological criteria. The rationale of approach, and the various features used at the different apparent ichnotaxonomic levels in the proposed classification in Text-Fig. 12.1 are detailed in Table 12.2.

There are four distinctive types of `Chondritor' feeding burrows , called types A, B, C, and D in Text-Fig. 12.1. Type A burrows are characterized by mainly horizontal/subhorizontal branches bifurcating from the main axis or axes. The branches may be multiple and be regularly/irregularly or dichotomously arranged as latticeworks or trellisworks or irregular networks. The thickness of the branches is fairly uniform but some of the main stems may be thicker than the secondary branches. Type A burrows can be subdivided into four varieties (varieties 1 to 4; Text-Fig. 12.1) on the basis of morphological criteria (branching angle, branch density, branch dimensions, and overall pattern). Type B networks comprise mainly horizontal and partly oblique branches with sinuous branches of irregular thickness. Because of

TABLE 12.2. Diagnostic salient characteristics of various structures inferred here and/or in the literature to be dendritic feeding-burrows of 'Chondritor' origin together with their previous names or type designation (where applicable) and new or revised name or type designation in terms of the proposed classification illustrated in Text-Fig.12.1. Asterisked forms in right column are ones that occur in the study area; others are taken from the literature.

No.	Orientation, attitute and general shape of complete burrow system	Branching pattern and density	Dimension and uniformity	Previous assignment	Proposed scientific names and present assignment	Remarks
1	Horizontal angular, multiple branching network.	Dense latticework trellis network	Thin uniform both proximal and distal	C. intricatus Von Sternberg, 1833 in Richter, 1927, p. 217, fig.8. Type B, Osgood, 1970, p.336-337, pl.64, figs.7 & 8.	C. intricatus Von Sternberg, 1833.	*Type A var. 1
2	Horizontal angular, multiple branching network.	Fairly dense to loose trellis network.	Thick uniform both proximal and distal.	C. furcatus Von Sternberg, 1833. C. gracilis Hall, Type B, Osgood, pl. 64, fig.3. pl.65, fig.8.	C. furcatus von Sternberg, 1833	*Type A var. 2
3.	Horizontal, irregular arranfement	Doose, curved, irregular network.	Thin, not uniform with thicker in proximal part.	Type D Pickerill et al., 1984, p. 427, fig.8D.	Not yet formally named.	*Type A var. 3
4.	Essentially horizontal, irregular symmetrical network.	Dense, symmetrical dichotomous branching network.	Thick and uniform.	Type A Pickerill et al., 1984, p. 427, fig.8A. Type C Osgood, 1970, p.339, pl. 64, figs, 2, 4 & 5.	Not yet formally named.	Type A var. 4
5.	Horizontal, regular symmetrical network.	Dense, Symmetrical dichotomous branching network.	Thickness not uniform, thicker in proximal (main stem) and thinner in branches.	Type B Shourd & Levin, 1976, p. 264-265, pl.2, fig.2.	Not yet formally named	Type A var. 4?
6.	Horizontal to oblique, irregular cluster or compact network.	Dense, circular or radial branching network with crossovers.	Fairly thick to thin not uniform	Type C Pickerill et al., 1984, p. 427, fig.8C.	Not yet formally named.	*Type B
7.	Oblique, irregular, asymmetrical network.	Loose, dichotomous to irregular branching network.	Small, thin, not-uniform.	Type E Pickerill et al., 1984 p. 427, fig.8E	Not yet formally named.	* Type C var. 1

Table 12.2 (continued)

No.	Orientation, attitute and general shape of complete burrow system	Branching pattern and density	Dimension and uniformity	Previous assignment	Proposed scientific names and present assignment	Remarks
8.	Mainly vertical to steeply inclined, asymmetrical network.	Dense, oblique dendritic network.	Small, thin, not-uniform.	Type B Pickerill et al., 1984, p. 427, fig. 83. Type A Shourd & Levin, 1976, p. 264-265, pl.2, fig.1.	Not yet formally named.	Type C var. 1
9	Horizontal angular pinnate branching network.	Dense, pinnate branching network.	Thick, uniform	C. bollensis (Ziet, in Richter, 1927, p. 216. abb.7	C. bollensis Von Sternberg, 1833.	Type D.

the radial arrangement of the branches and the overall subcircular outline of the burrow network they appear as clusters of compact labyrinthine configuration. Type C networks consist of small oblique burrows which are manifested as small oblique openings or cross-sections on the bedding plane of the rocks. These small groups of oblique burrows are confined to particular areas (e.g. to the surface of other trace fossils; cf. Bromley & Ekdale, 1984). Type C networks can be subdivided into two categories on the basis of branch density (dense/closely-spaced or loose/widely-spaced) and branching pattern (i.e., arranged either dichotomously or in dendritic networks). Type D networks are characteristically horizontal with pinniform branching configuration and very likely have more than one main branch.

In the proposed classification it is assumed that these dendritic feeding-burrows (fodinichnia) were produced by endobenthic deposit-feeding worms or worm-like organisms that occupied the deeper anaerobic levels of the substrate, and that the primary axis/axes or stems in the proximal part of the burrows were originally open to the sediment-water interface and are invariably connected with the later-formed (normally smaller) branches in the distal parts.

12.3 SYSTEMATIC ICHNOTAXONOMY

Of the various form types and varieties of Chondrites featured in the classification of Text-Fig. 12.1 and Table 12.2 only those ones present in the study area (i.e., those indicated by an asterisk in the latter illustrations) are described in the following section.

Type form: Type A

<u>Chondrites</u> Von Sternberg, 1833

Diagnosis (type assignment): Mainly horizontal dendritic feeding-burrows. As reconstructed by Simpson (1956) the vertically orientated main stem or axis/axes which access the sediment-water interface is/are located at the proximal part of the branching system as a circular pattern of individual apertures as seen in cross-section. The secondary and higher order branches are mainly horizontal, but can vary in terms of thickness and uniformity of thickness of the branches both within and between the different varieties. The angle between the primary and secondary branches can vary between and within and individual varieties. The pattern of branching tends to be relatively systematic in all varieties, either regular or irregular, and forms burrows networks of either closely- or widely-spaced branches.

Type A var. 1

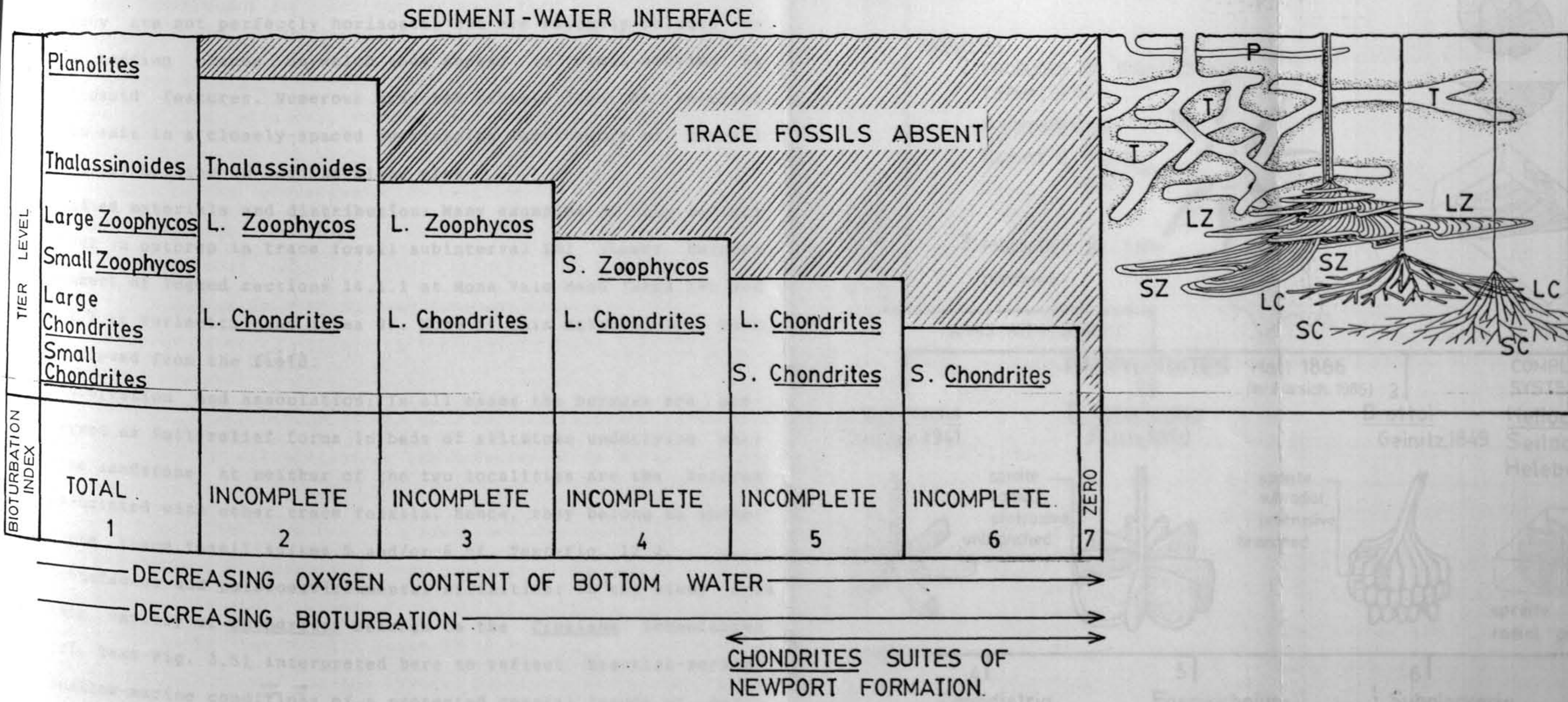
Plate 61, Fig. c
Plate 63, Fig. a

<u>Chondrites intricus</u> Von Sternberg, 1833: Richter, 1927, p. 217, fig. 8. Type B Osgood, 1970: Osgood, 1970, p.336-337, pl.64, figs. 7 & 8.

Diagnosis (variety assignment): Regularly thin horizontal dendritic (or multiple branches) formed as latticeworks.

Description and ethology: This variety occurs as regularly thin branches (i.e., with uniform thickness throughout the burrow network), forming a mainly horizontal latticework. In the study area this form is the most complete and commonest type of the five different varieties of <u>Chondrites</u> present there. Normally it

TEXT-FIG. 12.2. Idealized tiering relationship of trace fossil suites associated with the ichnogenus Chondrites in selected examples (1 to 7) in marine strata (cf. Bromley and Ekdale, 1984 & 1986) from several areas of Europe and America. The analogous trace fossils suites from the present study area are equivalent to suites 5 and 6, comprising incomplete assemblages insofar as the other trace fossils that commonly occur in association with Chondrites in the upper levels (`tiers') of the bioturbation profile are absent. The Newport Formation suites occur in trace fossil interval ID (Lower Newport Member) and IE (Middle Newport Member) exposed at several areas: St. Michaels Cave (area 5); Turimetta Head (area 2); Mona Vale Head (area 14); Hole in the Wall (area 11); Bungan Head (area 13); and Bilgola Head (area 10b) (see Text-Figs. 4.1 & 4.2).


SEDIMENT-WATER INTERFACE
TRACE FOSSILS ABSENT
TIER LEVEL
Planolites
Thalassinoides
Large Zoophycos
Small Zoophycos
Large Chondrites
Small Chondrites
Thalassinoides
L. Zoophycos
L. Chondrites
L. Zoophycos
L. Chondrites
S. Zoophycos
L. Chondrites
L. Chondrites
S. Chondrites
S. Chondrites
BIOTURBATION INDEX
TOTAL
1
INCOMPLETE
2
INCOMPLETE
3
INCOMPLETE
4
INCOMPLETE
5
INCOMPLETE
6
ZERO
7
P
T
T
T
LZ
LZ
SZ
SZ
LC
LC
SC
SC
DECREASING OXYGEN CONTENT OF BOTTOM WATER
DECREASING BIOTURBATION
CHONDRITES SUITES OF NEWPORT FORMATION.

TEXT-FIG. 12.2.

occurs in very fine grained sandstone in which its overall geometry is commonly conspicuous on the bedding planes as dendritic latticeworks. The branches radiate outward from what is inferred to have been a central vertical shaft (not exposed/preserved in the examples studied). These branches are very small, approximately 1 to 2 mm in diameter and with a bifurcation angle of 45°.

Comparison: Many of the branches in the less distal parts of the burrow are not perfectly horizontal but are slightly oblique to the bedding planes on which they appear in cross-section as ellipsoid features. Numerous branches radiate from an inferred main axis in a closely-spaced overlapping latticework of overall circular outline in bedding-plane view.

Studied materials and distribution: Many examples of this variety occur in outcrop in trace fossil subinterval ID2 (Lower Newport Member) of logged sections 14.1.1 at Mona Vale Head (area 14) and 2.1.1 at Turimetta Head (area 2). None of this material has been retrieved from the field.

Preservation and association: In all cases the burrows are preserved as full-relief forms in beds of siltstone underlying very fine sandstone. At neither of the two localities are the burrows associated with other trace fossils. Hence, they belong to incomplete trace fossil suites 5 and/or 6 cf. Text-Fig. 12.2.

Ichnofacies and palaeoenvironmental affinities: In the study area this variety of Chondrites belongs to the Cruziana ichnofacies (cf. Text-Fig. 3.5) interpreted here to reflect brackish-marine/shallow-marine conditions of a protected coastal lagoon or estuary (cf. Text-Fig. 5.2).

Type A var. 2

Plate 61, Figs. a & b
Plate 62, Fig. d
Plate 63, Fig. d (associated with Skolithos)

Chondrites furcatus Von Sternberg, 1833.
(partum) Chondrites gracilis Hall, 1852: Osgood, 1970, pl. 63, fig. 5.
Type B Osgood, 1970: Osgood, 1970, pl. 64, fig.3, and pl. 65, fig. 8.

Diagnosis (variety assignment): Horizontal, uniformly thick branches that comprise dendritic networks that vary from loose trellisworks to dense latticeworks. These networks are assumed to be connected with a vertically orientated main axis.

Description and ethology: In the study area this variety has uniformly thick stem and branches and forms an essentially horizontal latticework (where dense) or trelliswork (where loose) but is only known from incompletely preserved examples. This variety is one of the most common forms of Chondrites in the study area and mainly occurs in fine to very fine sandstone beds with part of the burrow geometry exposed on the bedding-plane surfaces. The system of branches develop horizontally outwards from the main axis or stem. The location of the main vertical stem can only be inferred from the orientation of the branches as no actual trace of it/them is exposed/preserved. The individual branches are also thicker than in the type A var. 1 from, are approximately 3 to 5 mm in diameter, and bifurcate at an angle of about 45° or less.

Comparison: The whole system of the entire branching network is bedding-parallel. The overall patterns is that of a latticework, but the pattern present in the largest specimens associated with the ichnogenus Skolithos (Plate 63, Fig. d) are looser and trellis-like. The size of the branches in the largest-scale example is quite comparable with the size of the branches in Buthotrepis (Hall, 1847), previously referred to as Chondrites, but in my view considered to be Phycodes. No main stems are preserved in the materials studied here.

Studied materials and distribution: Examples of the type A var. 2 Chondrites occur in trace fossil subinterval ID2 in the Lower Newport Member at St. Michaels Cave (area 5), Turimetta Head (area 2), Bilgola Head (area 10b) and Mona Vale Head (area 14). Sample 140/MU.44513 is the only specimen of the type A var. 2 collected from the study area, the other specimens not having been retrieved from the field.

Preservation and association: These burrow systems are preserved as full-reliefs forms in very fine sandstone. The association of Chondrites type A var. 2 with Skolithos in the sample illustrated in Plate 63 Fig. d, in which Skolithos cuts across Chondrites, is the reverse of the usual relationship between these two traces in situations of uninterrupted deposition (cf. Text-Fig. 12.2). In the examples illustrated in Plates 63 Fig. d Chondrites burrows were probably formed first in on incomplete suite of tiering (i.e., suites 5 and 6 in Text-Fig. 12.2), followed by erosion of the top of the bed and the subsequent introducing of Skolithos.

Ichnofacies and palaeoenvironmental affinities: In the study area Chondrites type A var. 2 belongs to the Cruziana ichnofacies (cf. Text-Fig. 3.5) interpreted here to reflect brackish-marine/shallow-marine conditions of a protected coastal lagoon or estuary (cf. Text-Fig. 5.2).

Type A var. 3

Plate 62, Fig. b

Type D Pickerill et al., 1984, p. 427, fig. 8A.

Diagnosis (variety assignment): Essentially horizontal, widely-spaced branches of variable thickness forming an irregular network.

Description and ethology: This variety occurs as relatively thinly-branched, irregularly arranged horizontal networks. The overall pattern invariably occurs as incomplete networks and is not a very common form of Chondrites in the study area. This variety normally occurs in very fine sandstone as full-relief forms on the sole surface of the bed. As seen in plan view the main vertical axis or stem is preserved in the proximal part as a small circular feature infilled with sand. The main branch-esradiate outwards from the main stem (which is 3 mm thick) and is thicker than the secondary branches (which average 1 mm across); the bifurcation angle is irregular and ranges from 30° to 70°.

Comparison: As seen in plan view this variety of Chondrites has an irregular outline to the entire burrow system and internally the branches are typically sinuous, irregular in thickness, widely-spaced, and lack strong systematic organization. The short irregular branches are mainly parallel to the bedding plane, but some individual short branches are slightly oblique or undulating and show ellipsoidal cross-sections on the bedding planes. This feeding pattern is characterized by comparatively few branches which lack overlapping relationships. This form is comparable with the form type D of Pickerill et al., (1984).

Studied material and distribution: Only one example of this variety is known in the study area. The studied material occurs only in trace fossil subinterval IE1 of the Middle Newport Member at Bungan Head (area 11). The material has not been retrieved from the field.

Preservation and association: The burrow network is preserved as a full-relief form in very fine sandstone and siltstone, and is not associated with other trace fossils.

Ichnofacies and palaeoenvironmental affinities: In the study area Chondrites type A var. 3 belongs to the Cruziana ichnofacies (cf. Text-Fig. 3.5) interpreted here to reflect tidal-flat brackish-marine/shallow-marine conditions of a coastal lagoon or estuary (cf. Text-Fig. 5.2).

Type form: Type B

Plate 62, Figs. a & c

Type C Pickerill et al., 1984, p.427, fig. 8C.

Diagnosis (type assignment): Essentially horizontal to partly oblique irregular sinuous branches forming radial networks of overall subcircular outline. Branches thin to thick with cross-overs.

Description and ethology: Type B Chondrites occurs as irregular or sinuous thin to thick branches arranged in horizontal to partly oblique radial patterns of overall circular outline. The overall structure is invariably defined as clusters or as compact groups of small branches on the sole surface of the bed. The main vertical axis or stem is not easy to define, nor are the proximal and distal portions of the system. The relative abundance of crossovers of small branches make it difficult to define the branches in terms of their thickness and length. Where they can be defined they are not thicker than a few millimetres and are about 1 cm in length.

Remarks and comparison: The burrow pattern is generally dense or compact with small irregular branches. This form is comparable with form type C of Pickerill et al., 1984.

Studied materials and distribution: The studied samples come from two localities: the first specimen (sample no. 1101/MU.44502) was collected from trace fossil subinterval ID3 of the Lower Newport Member at Hole in the Wall (area 11); and the second specimen comes from the same trace fossil subinterval at the St. Michaels Cave (area 5). The examples at the latter locality were not retrieved from the field.

Preservation and association: The studied specimens are preserved as full-relief forms in fine sandstone, and are not associated with other trace fossils.

Paleoenvironmental interpretation and ichnofacies: In the study area this variety of <u>Chondrites</u> belongs to <u>Cruziana</u> ichnofacies which is interpreted to reflect brackish-marine/ shallow-marine conditions of tidal-flats in a coastal lagoon or estuary (see Text-Fig. 5.2).

Type form: Type C var. 1

Plate 63, Fig. c

Type E Pickerill et al., 1984, p. 427, fig. 8E.

Type assignment: Small, essentially oblique or vertical network of thin dichotomous or dendritic widely-spaced branches.

Variety assignment: Small, essentially oblique to bedding, asymmetric dichotomously-branched loose networks.

Description and ethology: This variety occurs as irregular oblique branches. The main stems are approximately 5 cm thick and the secondary branches approximately 2 mm thick. The overall outline of individual networks is variable but appear to define essentially complete forms. The main axis is normally located at the proximal part (close to thicker branches) as a circular opening. The dichotomous branching angle is measurable in some cases and is about 30° to 45°. This variety of Chondrites occurs in fine to very fine sandstone but is not very common in the study area.

Remarks and comparison: The overall pattern of the feeding structure is normally very irregular in shape because of its very loose nature of branching. The short thick proximal branches and the small distal dichotomous branches are arranged in an undulose pattern with respect to bedding and this is a unique pattern among all the varieties of Chondrites described here. This undulose pattern of some segments of the branches is defined by their discontinuous exposure on bedding planes. The branches in some places show crossovers and overlaps. This variety is comparable with form type E of Pickerill et al., 1984.

Studied material and distribution: The studied materials occur in trace fossil subinterval IE1 of the Middle Newport Member at Bilgola Head (area 10b). They have not been retrieved from the field.

Preservation and association: The studied examples are preserved as full-relief forms in very fine siltstone and are not associated with other trace fossils.

Ichnofacies and palaeoenvironmental affinities: As for <u>Chondrites</u> type A var. 3.