CHAPTER 9

THALASSINOIDES, OPHIOMORPHA, SPONGELIOMORPHA, AND TURN-AROUNDS

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THALASSINOIDES, OPHIOMORPHA, SPONGELIOMORPHA, AND TURN-AROUNDS

Redescription and taxonomic evaluation of the trace Thalassinoides Ehrenberg, 1944, Ophiomorpha Lundgren, fossils 1891, and Spongeliomorpha Saporta, 1887 was done in much detail by Fürsich (1973) and Bromley & Frey (1974). The individual or branching burrow system of these ichnogenera vary widely in morphological details but have long been accepted as having been made by crustaceans (Chamberlain & Baer, 1973). The distinctive general characteristics of these ichnogenera are: absence of а wall-lining in the ichnogenus Thalassinoides; distinctive pelletal or mammillated wall-lining in the ichnogenus Ophiomorpha; and networks with scratch marks on the burrow surface in the ichnogenus Spongeliomorpha. These three characteristics may all occur separately in different parts of the same burrow network including different segments of the same tubular burrow (Chamberlain & Baer, 1973). However, these prominent morphological traits within each of these three ichnogenera have their own distinctiveness and most burrows of this general kind can readily be differenti-教堂報 "这种样,或该各些。"这个声音,他说了了话,"你们,你们们,你不能……" ated ichnogenerically.

The use here of the turn-around as an important ichnotaxonomic characteristic is new, and it plays a significant role here in the redescription and reclassification of the ichnogenus <u>Spongeliomorpha</u> whose ichnotaxonomic definition by Fürsich (1973) I regard as having been error as also indicated by abandonment of Fursich's (1973) concept of <u>Spongeliomorpha</u> Bromley & Frey (1974). The turn-around plays an important part in the

life history of the burrow. The establishment of the turn-around can be for many reasons: firstly, simply that the organism may turn-around within the burrow; secondly, the turn-around can serve as a breeding or farming ground (Dworschak, 1983); thirdly, in the case of some large turn-arounds they probably accommodatmore than one individual and hence could serve as a matinged ground or central meeting chamber (Fürsich, 1973) or be similarly used for other unexplained ethological behavior. For interpretive purposes, another important value of the turn-around (at least type A turn-around in Text-Figs. 9.1 & 9.2) is that the the diameter of the globular chamber can be used as an estimate of the length of the inhabitant crustacean. Previously, the bodywidth of the producer organism was estimated only by reference to modern crustaceans and their burrows and has been found to be 1/4 to 1/3 of the burrow width (Rice & Chapman, 1971; Dworschak, 1983). Most crustaceans produce these turn-arounds not only to allow them to turn their bodies but also for several other reasons as outlined above. For these various reasons, the turnaround constitutes an important ichnotaxonomic criterion in the description of the burrow and also in interpreting the producer's history.

The classification proposed here (Text-Fig. 9.1) is based on specimens of the three ichnogenera <u>Thalassinoides</u>, <u>Ophiomorpha</u>, and <u>Spongeliomorpha</u> from the study area. Some specimens of the ichnogenus <u>Thalassinoides</u> have type A and type B turn-arounds in both species, <u>T. suevicus</u> and <u>T. paradoxicus</u>. The ichnogenus <u>Spongeliomorpha</u> normally doesn't have turn-arounds (see Text-Figs. 9.1 & 9.3) simply because they are functionally

burrows TEXT-FIG. 9.1. Proposed classification of the crustacean Ichnogenera Thalassinoides, and Spongeliomorpha. Ophiomorpha, mentioned in the boxes are included to show their relationship in not the classification, but are not illustrated because they are turn-around recorded from the present study area. Two types of are recorded from the study area: type A accommodating a solitary ot room type B (communal turn-around; central organism; and an Fursich, 1973). The presence or absence of the turn-around is in important feature in the proposed classification, especially Asterrespect of the ichnogenus Spongeliomorpha (= T. ornatus). isks indicate burrow forms that are present in the study area.

The rationale of approach and the various features used at the different ichnotaxonomic levels in the classification are detailed in Table 9.1. Thalassinoides Ehrenberg, 1944; Spongeliomorpha Saporta, 1887; and turn-around types



TABLE. 9.1. Rational of approach and various features used at the different ichnotaxonimic levels in the proposed classification of <u>Thalassinoides</u> Ehrenberg, 1944 and <u>Spongeliomorpha</u> Sapporta, 1887 and the differentiation of three two ichnogenera from <u>Ophiomorpha</u> nodosa Lundgren, 1891 (cf. Text-Fig. 9.1)

- I. Significant features (group level above ichnogenera) Type of producer organism.
- II. Significant features (generic level).
 - (1) Geometry and orientation of the burrows/burrow networks; e.g. Horizontal cylindrical three dimensional networks or vertical or horizontal cylindrical-shaped individual burrows.
 - (2) Presence/absence of wall lining;
 - e.g. with or without pelletal or mammillated wall.(3) Presence/absence of turn-arounds; turn-arounds completely absent only in the case of

Spongeliomorpha (= Thalassinoides ornatus).

III. Major accessory features (higher specific level).

- Type of wall lining;
 - e.g. (1) single-pellet wall-lining
 - (as in Ophiomorpha nodosa).
 - (2) Double-pellet wall-lining
 - (as in Ophiomorpha borneensis).
 - (3) Irregularly arranged pellet wall-lining
 - (as in <u>Ophiomorpha irregulaire</u>).
- Branching pattern and burrow outline; angle of branching; shape of the burrow; e.g. Hexagonal-shaped, Y-, T-, or V-shaped.
- (3) Size of the burrow.

width - diameter of the cylindrical burrow. length - distance between two junctions (or bifurcations) in the case of networks and total length in the case of individual cylindrical burrows.

IV. Minor accessory features (lower specific level).

- (1) Type of turn-around. type A (solitary behaviour);
 - type B (communal behaviour).
- (2) Internal structures. type of infilling sediments; presence/absence of faecal stuff; presence/absence of meniscus; presence/absence of spreite.

V. Other features. Density of burrows (population sparse or crowded).

TEXT-FIG. 9.2. Interpretation of the different types of turnarounds in <u>Thalassinoides</u> with hypothetical reconstruction of the crustacean organisms. The diameter D of the type A turn-around is equivalent to the length of the inhabitant crustacean. Sketches are not to relative scale.

A. Type A turn-arounds (reflecting solitary behavior) with simple cylindrical-shape (var. 1) and V-shape (var. 2). Reconstruction of both varieties of turn-around is based on examples present in T. paradoxicus.

B. Type A turn-around (reflecting solitary behavior) with Y-shape (var.2) from the ichnogenus <u>T. suevicus</u>.

C & D. Type B turn-arounds (reflecting communal use) with subspherical-shape (var. 1) and angular V-shape (var.2) from the ichnogenus <u>T. paradoxicus</u>.



unnecessary: The tunnel system of this ichnogenus is extremely well interconnected, and hence the inhabitant crustaceans can easily reverse their orientation via the 'loops' of the interconnected tunnels. This is the most likely reason why <u>Spongeliomor-</u> <u>pha</u> lacks turn-arounds. It is very important to restrict the ichnogenus <u>Spongeliomorpha</u> Saporta, 1887, to burrows forminginterconnected networks, lacking turn-arounds, with or without scratch marks on the wall surface of the burrows.

Two major types of the ichnogenus Thalassinoides Ehrenberg, 1944 are present in the study area (Text-Fig.9.1-9.3): type A belongs to T. suevicus; these are medium to large-diameter (width 5 cm), cylindrical or Y-shaped burrows with or without spreite and turn-arounds; type B belongs to T. paradoxicus; these are small-diameter burrows (1 to 2 cm width), normally variable in shape, either cylindrical, Y-shaped or comprising networks (but not interconnected), without spreite and possessing two types of turn-around (type A manifesting solitary behavior and type B manifesting communal behavior) (Text-Fig. 9.2). <u>T. saxoni-</u> Cus, which is characterized by the largest diameter tunnels of all species of this genus has not been encountered in the study area. and the first state of the stat

The ichnogenus <u>Ophiomorpha</u> Lundgren, 1891, is characterized by a distinctive wall-layer construction involving a hierarchial arrangement of pellets (Text-Fig. 9.4), and is recorded here from the Bald Hill Claystone and the lower part of the Lower Newport Member. The spiral burrow system <u>Gyrolithes</u> (Bromley & Frey, 1974), and another distinctive branching burrow



TEXT-FIG: 9.3. Reconstruction of Thalassinoides paradoxicus (type οt networks networks, their turn-arounds (types A and B), B) ichnogenus the different size classes distinctly of Spongeliomorpha, and three varieties (involving two size classes R . Rhizocorallium: of Rhizocorallium jenense var. jenense, planispirus irregulare var. bifurcatum, and R. uliarense var. slab made from the sole surface of a large The drawing was South collected from a bed in trace fossils interval IE9.2 at the Palm Beach (area 4b; sample no. 410/M.U 44516). Details of the to diagram, are somewhat schematic, totally so in regard Τ. background small-scale network of Spongeliomorpha. In (i.e., TN in the diagram) many of the apparently paradoxicus rock actual burrows or branches can be seen in the short side the to terminate approximately where shown to do so in sample vertical Others may continue through the bed either as diagram. or horizontal shafts.



EXPLANATION

RIb-	Rhizocorallium irregulare var. bifurcatum
RUp-	Rhizocorallium uliarense var. planuspirus
RJj -	Rhizocorallium jenense var. jenense (large)
RJ -	Rhizocorallium jenense var. jenense (small)
S -	Spongeliomorpha kalia ichnosp. nov.
TA1-	Turn-around type A
TA2-	Turn-around type B
TN -	Thalassinoides paradoxicus (networks)

called <u>Ardelia</u> (Chamberlain & Baer, 1973) which is characteristized by bifurcations that radiate from the wall of main galleries and a special type of wall-layer, both of which genera are similar to and can be associated with any or all of the abovementioned crustaceans burrows are not present in the study area.

Measurements of the population density of the apertural openings of <u>Ophiomorpha nodosa</u> are used to interpret the likely palaeoenvironment of the upper part of the Bald Hill Claystone and the lower part of the Lower Newport Member exposed at Turimetta Head.

9.2. THE DIAGNOSES OF <u>THALASSINOIDES</u>, <u>OPHIOMORPHA</u> AND <u>SPONGELIOMORPHA</u>

The diagnosis of Thalassinoides (Ehrenberg, 1944) was given by Kennedy (1967 p.131) as follows: "Extensive burrow system with both vertical and horizontal elements. Burrows are cylindrical, between 2 and 20 cm in diameter. Branching regular, characterized by Y-shaped bifurcations, swollen at point of branching. Horizontal elements joining to form polygons. Burrow dimension variable within a system. Horizontal system connecting to surface by vertical or steeply inclined shafts, widely associated with callianassid remains". Kennedy's (1967, p.150) diagnosis of Spongeliomorpha (Saporta 1887) is as follows: "Medium size, elongated, cylindrical, branching tunnel system, surface covered with networks of fine ridges, interpreted as scratch marks". Kennedy & Macdougall (1969 p.460) described the ichnogenus <u>Ophiomorpha</u> (Lundgren, 1891) as: "Medium-size, threedimensional tunnel system branching dichotomously at acute

angles, swollen at the point of branching. Tunnels internally smooth, sometimes filled or lined with ovoid pellets when the surface of the filling is mammillated."

three ichnogenera are thus characterized These by similar diagnoses, the main differences among them being the mammillated outer surface in the case of Ophiomorpha in contrast to smooth walls in Thalassinoides, and longitudinally corrugated walls in Spongeliomorpha. Intermediate forms and forms that exhibit more than one of these characteristics separately in different segments of the same tunnel or different tunnels of the same tunnel network, have been recorded by Kember (1968), Kennedy & Macdougall (1969), Kennedy & Sellwood (1970), Müller (1970) and Rasmussen (1971). Thus the separation of these three ichnogenera is often problematical, but important morphological and ethological differences still remain and merit the classification of < **BOY2** 0 1900 these forms as separate ichnotaxa. A reevaluation of their detailed morphological features of inferred ethological value is necessary to resolve their separate ichnogeneric and ichnospecif-ic significance and the same is true for accessory features (Table 9.1).

9.3. SIGNIFICANT MORPHOLOGICAL FEATURES

The ichnogenera <u>Thalassinoides</u> and <u>Spongeliomorpha</u> are recorded mainly as horizontal networks or individual burrow systems (Kennedy, 1967; and Fürsich, 1973) whereas the <u>Ophiomorpha</u> burrow system comprises both vertical shafts and horizontal networks (Kennedy & Macdougall, 1969) or predominantly

only vertical burrow systems (Seidel, 1956; Baatz, 1959; and Hillmer, 1963). Individually they can all occur as simple cylindrical Y-shaped or T-shaped burrows. The ichnogenus Gyrolithes (Bromley & Frey, 1974) occurs as a spiral burrow pattern Thalassinoides saxonicus, described by Geinitz (1842) comand interconnected polygonal networks. However, erosion prises can remove the normal vertical opening shaft and thus may leave remaining only the horizontal network system. The geometry of the burrow is clearly in important ichnogeneric criterion in the diagnosis of the ichnogenera <u>Gyrolithes</u> (which is spirally arranged) and T. saxonicus (which is characterized by networks comprising large polygons). 17 B - 1 💇 t**in**g di fram sue giressione d'estres . test

9.3.2. Ornamentation on wall surface

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. . Bioglyphs in the form of longitudinal furrows on the burrow walls are well known feature of crustacean burrows and have been described in <u>T. ornatus</u> (Kennedy, 1967), <u>O. nodosa</u> (Kennedy & Macdougall, 1969), Spongeliomorpha (Saporta, 1887), Rhizocorallium (Zenker, 1836), Diplocraterion (Torell, 1870), Strophichnus (Fürsich et al., 1981), and are presently described here in the new ichnogenus Turimettichnus conaghani. The bioglyphs are important for distinguishing Spongeliomorpha from other crustacean burrows. Although the use of bioglyphs as an ichnogeneric criterion does not seem to be justified, they may well prove useful for separation at the specific level. Again, bioglyphs can not be regarded as important significant features for ichnotaxonomic classification because their preservation depends mainly on the grain-size and consistency of the sediment.

Furthermore, unlike scratch marks developed by trilobites (e.g., Cruziana and Rusophycus) and by crustaceans in in the newly described ichnogenus Turimettichnus in all of which the bioglyphs have a systematic/well-ordered pattern relative to the longitudii art 「「のこのよびな」 - はない起来は影響の、 内 ささた。 axis of the trace, the scratch marks in the crustacean nal burrows discussed in this chapter are characteristically less well ordered even though they are generally parallel to the burrow **学校设备学家进行性学**系是一级学习的最近重要的第三人称单数的工作中,最优先的问题的考虑 axis. \$**4.6**

9.3.3. Wall-lining TONSESSION CONTRACTORS SEEN STATES 0.018 The mammillated or pelletal wall-lining in the ichnogenus Ophiomorpha is regarded as the most important diagnostic feature capable of separating it from the otherwise similar but smooth-walled Thalassinoides and Spongeliomorpha. The pelletal nature of the burrows of Ophiomorpha manifests important an behavior of the producer: normally the producer (crustacean) molds and cements pellets of sediment and pushes them into the burrow wall to stabilize and reinforce the burrow tunnel (see 1.19 Text-Fig. 9.4 and MacGinite in Häntzchel 1952 p. 150). This type οf reinforced wall is quite distinctive and appears to be restricted to the ichnogenus Ophiomorpha. However, there is some confusion about the value of the pelletal wall-lining аs an ichnogeneric criterion, because some burrow systems feature both smooth walls and pelletal walls in different places in the same tunnel or tunnel-network (Kennedy, 1967). Thus, some authors suggest that of the nature of the wall should be regarded as ichnospecific value only (Fürsich, 1973). The ichnogenus Ardelia has special type of perforated wall-lining a described by as

Chamberlain & Baer (1973).

9.3.4. Size of the burrow (width and length of the tunnel)

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In the study area the burrows of the ichnogenera Ophiomorpha, Thalassinoides and Spongeliomorpha commonly occur in distinctly different size categories in the same bed (see Text-Fig. 9.3), and are consequently regarded as different ichnotaxa. A compilation of burrow size data of Thalassinoides and Ophiomorpha was made by Fürsich (1973) and showed that separation of these two genera on the basis of size cannot be ruled out totally at the specific level. However, it is not justified to use the burrow diameter alone as a taxonomic criterion. The size of the burrow is measured both by width (diameter of an individual tunnel) and length (measured along the axis of the burrow).

9.3.5. Internal structures

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Meniscus: The meniscus structure is present in the burrow fills of some crustacean burrows (Kennedy & MacDougall, 1969; Kennedy & Sellwood, 1970; and Müller, 1970). These meniscus structures represent active back-filling by the inhabitant crustacean in order to relocate waste materials or faecal stuff into segments of the tunnel system which are no longer occupied (Brown, 1939), or perhaps to store away material from new sites of excavation (Kennedy & MacDougall, 1969).

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Internal lamination: Internal laminations are normally found in the floor of burrows of the modern crustacean <u>Callianas-</u> <u>sa</u> (Shinn, 1968), and are also present in fossil counterparts (e.g., Kennedy, 1967; and Fürsich, 1973). The laminated floor deposits evidently manifest excavation of the roof of the burrow

by the animal while it moves through the burrow, or sediment infilling passively from the outside; in either case the sediment was evidently then pressed into the burrow floor. It is quite clear that this internal lamination of the floor deposits cannot be accorded any value as an ichnotaxonomic criterion. Laminated floor deposits are also very common in dwelling-burrows as a result of the inhabitant organisms dumping unwanted sediments therein.

Spreite: Some crustacean burrows exhibit a curved or cresent-shaped internal structure clearly shown in the type A forms of <u>Thalassinoides suevicus</u> (Text-Fig.9.1; Plate 71, Fig. a) from the Bald Hill Claystone at Turimetta Head. These spreite normally occur in horizontal burrow networks rather than in vertical ones and are of the retrusive type. Hester & Pryor (1972), recorded an example of Ophiomorpha of Eocene Age with retrusive spreite. The spreite structures are believed to result from sediment exploitation by the inhabitant during its search for food. The crustacean producer of the modern equivalent of Ophiomorpha is known to search for its food by shifting sand or detritus inside the burrow. Whatever the behavior reflected by the spreite, the spreite should not be regarded as an important ichnotaxonomic characteristic.

9.3.6. Type of branching and burrow outline

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Shape of branching: Y-, T-, V-shapes or simple cylindrical-shapes are quite common in modern crustacean burrows and largely reflect taxonomic differences within this group. Some variation can also be ascribed to environmental control (Fürsich,

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1973). Branching characteristics of fossil crustacean burrows may therefore be useful as environmental indicators by comparison with their Recent counterparts (cf. Text-Fig. 9.5).

Branching angle: The branching angle or angle of bifurcation was studied in examples of these ichnogenera by Rieth (1932), Häntzchel (1964), Müller (1970), Farrow (1971), and Fürsich (1973). However, Fürsich's graph (1973, fig. 3) shows that there is no way of distinguishing among groups with a similar angle of branching, because in no case could significant differences be found.

Angularity of the branching point: The angularity of the branching point can be either acute or smooth (Text-Figs. 9.1 & 9.2). Since both shapes can be found in the one burrow system use of this feature as an ichnotaxonomic criterion can not be justified. This feature provides no more than a hint of the movements of the inhabitant organism inside the burrow at that particular place. Acute and smooth corners can both be found especially in the tunnels of burrow systems joined to communal (i.e., type B) turn-arounds (see Text-Fig. 9.2C & D).

Branching pattern, burrow outlines, and turn-arounds: A distinctive branching pattern or burrow outline permits differentiation among <u>Thalassinoides saxonicus</u>, <u>T. suevicus</u>, <u>T. paradoxi**cus**</u>, and <u>Spongeliomorpha</u> (Müller, 1970; and Kennedy, 1967). In <u>T. saxonicus</u> the branching involves large polygonal-shaped patterns, whereas in <u>T. suevicus</u> it involves simple regular Y-, V-, or <u>T-shaped</u> patterns and in <u>T. paradoxicus</u> it displays a distinctly different irregular and normally non-interconnected

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dichotomous pattern. Moreover, the burrow outline of T. paradoxias seen in bedding-plane view (normally either the scale cus or top of the bed containing the burrow system) is characterized by presence of short, apparently abandoned side-tunnels the (Text-Fig.9.3) regardless of whether the turn-around present in an individual burrow is the solitary (i.e., type A) or communal type B) variety. This pattern of short side-tunnels (i.e., is absent in all the other species of Thalassinoides. The ichnogenus <u>Spongeliomorpha</u> comprises an interconnected network system of narrow burrows which normally lack turn-arounds or branchingpoint structures (these are not necessary because the branching tunnels are so thoroughly interconnected that they readily allow the inhabitant organism to reverse its orientation). The presence/absence of turn-arounds is an important ichnotaxonomic criterion in discriminating between the burrow network systems of T. paradoxicus, and T. ornatus on the one hand, and Spongeliomorpha on the other. ·晨耀勇能是自己的时间,近期的一个方面。

16 These differences in the burrow outline, branching pattern be and presence/absence of turn-arounds seem to distinctive enough to justify their use both at the ichnogeneric and ichnospecific case of levels (especially the in 使人的 编制 化合金 2 Berlin States Thalassinoides).

9.3.7. Population density of burrows

The first population density studies of modern crustacean burrows were carried out by Pryor (1973), Allen & Curran (1974), and Frey et al. (1978). The population density measured in terms of aperture density per square metre and the geometry of

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the burrow system varies as a function of environmental energy level and water depth (Text-Figs. 9.5 & 9.6). The population density tends to decrease in high-energy intertidal conditions concomitant with the predominance there of more vertical burrows (Text-Fig. 9.5). Under especially favorable conditions in intertidal and shallow protected sub-tidal environments the burrows tend to increase their numbers to as many as ten times the frequency in the higher-energy environments (cf. Text-Figs. 9.5 & 9.6), and the burrow geometry assumes a more boxwork or maze-like pattern (Text-Fig. 9.5).

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The population density study can be made by counting the number of burrow openings/apertures in a unit area. However, this technique can only be applied to vertically orientated burrows, and also assumes that the producer-organism-to-burrow relationship involves one animal to one burrow. The relative population density of modern crustacean burrows as a function of environment is very promising (cf. Pryor, 1973), but the use of this criterion is not considered to be justified as an ichnotaxonomic characteristic in the way that it is used for example in respect of <u>Skolithos</u> and <u>Tigillites</u>. 10000020C 12897 计接载字句

9.4. SUMMARY OF MORPHOLOGICAL CRITERIA AND REVISION OF ICHNOTAXA

In summarizing the morphological features described above, only a few are here considered to be important and their use as ichnotaxonomic features justified: (1) geometry and orientation of the burrows; (2) wall-lining; and (3) branching pattern, general burrow outline (particularly as seen in beddingplane view) and turn-around. A proposed reclassification of <u>Tha-</u>

TABLE 9.2. Proposed revision of the crustacean burrows <u>Thalassi-</u>				
the basis of t	he morphologica	<u>omorpha</u> and cross l criteria deta:	iled in Table	9.1.
Geometry and orientation of burrow or burrow network	Presence/ absence and nature of wall-lining	Branching pattern, burrow outline, and presence/ absence of turn-	Previous name	Proposed scientific name
	Brazincily	arounds		
(1) Mainly horizontal network, large-scale pattern.	Smooth unlined wall.	Y- or V-shaped networks with or without turn-arounds.	<u>T. saxonicus</u> (Geinitz, 1842) <u>S. saxonicus</u> (= Fürsich, 1973).	<u>T.</u> <u>saxonicus</u> (Geinitz, 1842).
<pre>(2) Mainly horizontal network/ pattern or individual solitary</pre>	Smooth unlined wall.	Y- or V-shaped or simple unbranched cylindrical burrow, with turn-arounds.	<u>T. suevicus</u> (Rieth, 1932) <u>S. suevicus</u> (= Fürsich, 1973).	<u>T.</u> suevicus (Reith, 1932).
cylindrical shafts.		Entropy College View	ie – Lettanie –	
<pre>(3) Mainly horizontal irregular network/ pattern.</pre>	Smooth unlined wall.	Irregularly arranged non-inter- connected network pattern, with turn-arounds.	T. paradoxicus (Woodward, 1830) S. paradoxicus (= Fürsich, 1973).	<u>T.</u> paradoxicus (Woodward, 1830).
<pre>(4) 3-D cylindrical branching network systems and vertical shaft with openings are common.</pre>	Distinctly mammillated single-pellet wall-lining.	Y-shaped bifurcated 3-D networks, vertical shaft predominates with or without turn- arounds.	<u>O. nodosa</u> Lundgren, 1887.	<u>O.</u> nodosa Lundgren, 1887.
(5) Simple to complex burrow networks.	Distinctly mammillated double-pellet wall-lining.	Y-shaped bifurcated networks with turn-arounds?	<u>O. borneensis</u> Keij, 1965.	<u>O.</u> <u>borneensis</u> Keij, 1965.
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Geometry and orientation or burrow network	Presence/ absence and nature of wall-lining	Branching pattern, burrow outline, and presence/ absence of turn-arounds	Previous name	Proposed scientific name
<pre>(6) Mainly horizontal network patterns.</pre>	Distinctly mammillated irregularly arranged pellet wall- lining.	Connected Y- shaped network pattern; junction of burrows swollen (?=turn-around)	<u>O. irregulaire</u> Frey & et al., 1978.	<u>O.</u> irregulaime Frey & et al., 1978.
<pre>(7) Mainly horizontal 3-D network burrow system joined by vertical and oblique shafts.</pre>	Special wall type with perforations (highly & irregularly nodose).	Y-shaped horizontal networks without turn- arounds.	<u>A. socialia</u> Chamberlain & Baer, 1973.	<u>A.</u> <u>socialia</u> Chamberlain & Baer, 1973.
<pre>(8) Mainly horizontal small twig- shaped with rather regular branching.</pre>	Distinctly mammillated single-pellet wall-lining.	Regular Y- shaped pattern without turn- arounds.	<u>G. repanda</u> (Pomel, 1849).	<u>G.</u> <u>repanda</u> (Pomel, 1849).
<pre>(9) Small diameter cylinderical branches forming a 3-D network system.</pre>	Smooth unlined wall.	Y- or T-shaped networks with longitudinal scratch marks on wall surface, without turn- arounds.	<u>S. iberica</u> Saporta, 1887.	<u>S.</u> iberica Saporta, 1887.
<pre>(10) Small diameter cylindrical branches forming a 3-D network system.</pre>	Smooth unlined wall.	Y- or T-shaped bifurcated 3-D networks, with or without scratch marks, without turn- arounds.	<u>T. ornatus</u> Frey & et al., 1978.	<u>S. ornatus</u> Frey et al 1978.

Table 9.2. (continued)

Table 9.2. (continued)

Geometry and orientation or burrow network	Presence/ absence and nature of wall-lining	Branching pattern, burrow outline, and presence/ absence of turn-arounds	Previous name	Proposed scientific name
(11) Small diameter cylindrical branches forming a 3-D network.	Smooth unlined wall.	Y- or T- shaped bifurcated 3-D networks, with or with- out scratch marks and with out turn-around	Not previously recorded or named. h- nds.	<u>S. kalia</u> ichnosp- nov.
(12) Long subhorizontal to oblique cylindrical individual burrows.	Smooth unlined wall.	Solitary cylindrical unbranched burrows with scratch marks, and twisted pouch-like tur around in the middle of the burrow.	<u>S. xystus</u> Fürsich & et al., 1981.	<u>S.</u> <u>xystus</u> Fürsich & et al., 1981.
<pre>(13) Cylindrical spiral-shaped burrow with circular helix (both dextral & sinistral) orientated upright in the sediment.</pre>	Smooth unlined wall.	Spiral-shaped burrow without branching, with scratch marks and a turn-around which can be in the reverse coiling direct to the main burrow	<u>G. davreuxi</u> t Saporta, 1884. e tion	<u>G.</u> <u>davreuxi</u> Saporta, 1884 (in Bromley & Frey, 1974.
ABBREVIATIONS: <u>A. social</u> <u>G. repand</u> <u>G. davreu</u> <u>O. nodosa</u> <u>O. bornee</u> <u>O. irregu</u> <u>S. iberic</u> <u>S. kalia</u> <u>S. xystus</u> <u>T. saxoni</u> <u>T. suevic</u> <u>T. parado</u> <u>T. ornatu</u>	ia - Ardelia so <u>a</u> - <u>Granularia</u> <u>xi</u> - <u>Gyrolithe</u> <u>ophiomorpha</u> <u>nsis</u> - <u>Ophiomor</u> <u>laire</u> - <u>Ophiomo</u> <u>a</u> - <u>Spongeliomor</u> <u>spongeliomor</u> <u>strophichnus</u> <u>cus</u> - <u>Thalassino</u> <u>s</u> - <u>Thalassino</u> <u>s</u> - <u>Thalassino</u>	ocialia repanda s davreuxi nodosa rpha borneensis orpha irregulain orpha iberica pha kalia s xystus noides saxonicus oides suevicus sinoides paradon	<u>re</u> <u>s</u> <u>xicus</u>	

<u>lassinoides</u>, <u>Ophiomorpha</u>, <u>Spongeliomorpha</u> and closely related forms on the basis of these and other criteria (detailed in Table 9.1) is given in Table 9.2.

9.5. SYSTEMATIC ICHNOTAXONOMY

9.5.1. Ophiomorpha Lundgren, 1891 (for synonymy, see Hantzchel, 1975, p. W85-W86)

Diagnosis (generic assignment): Burrow geometry ranges from a simple solitary shaft to a three-dimensional burrow network with vertical shaft extensions from the horizontal elements. Burrow wall is distinctly lined with mammillated or pelletal structure (Text-Fig.9.4). Interiorly, burrow-lining is more or less smooth but densely mammillated exteriorly. Individual pellets are irregular in shape and consist of agglutinated detrital sand grains (Text-Fig. 9.4). The grain-size range of the detrital sand is fine to medium.

Remarks (diagnostic features): Simple solitary shaft to threedimensional network with distinctive pellet-lined walls.

O. nodosa Lundgren, 1891

Plate 31, Figs. a - c Plate 32, Figs. a - c Plate 33, Figs. a & b

<u>0. nodosa</u> Lundgren; Kennedy & Macdougall, 1969.
<u>0. nodosa</u> Lundgren; Chamberlain & Baer, 1973.
<u>0. nodosa</u> Lundgren; Müller, 1969, fig. 1, pls. 1-2.
<u>0. nodosa</u> Lundgren; Kennedy & Sellwood, 1970, p. 100-109, fig. 2, pls. 10-11.
<u>0. nodosa</u> Lundgren; Radwanski, 1970, p.378, fig. 3, pl. 5.
<u>0. nodosa</u> Lundgren; Bromley & Frey, 1974, p.329-330, fig.11.
<u>0. nodosa</u> Lundgren; Frey, 1975, fig.2.2.
<u>0. nodosa</u> Lundgren; Radwanski & et al., 1975, p.239-240, fig.11.
<u>0. nodosa</u> Lundgren; Curran, 1976, p. 253, text-fig. 5.
<u>0. cf. nodosa</u> lundgren; Macstosay, 1967, p.33, figs. 53, 54 &

59.
O. sp.; Asgaard & Bromley, 1974, p. 12-14, figs. 2-3.
<u>Spongeliomorpha nodosa</u> Lundgren; Fürsich, 1973, p. 729, fig.
6; 1974, fig. 3; and 1975, p. 19-21, fig. 15.
<u>S. saxonica</u> (Geinitz); Fürsich, 1973, p. 729, fig. 6; 1974,
fig. 3; abd 1975, p.22, figs. 16a, b, & d.
Callianassid burrows; DeWindt, 1974, figs. 4-5.
<u>Halyminites major</u> Brown; Brown, 1939, pl.62, figs. 1-7, and

pl.63, figs. 1 & 2. <u>Walpia</u> White; White, 1929. Diagnosis (specific assignment): Burrow walls consisting predomi-

nantly of dense, regularly arranged single-pellet wall-lining in which the pellets are of irregular to ovoid shape.

Remarks (diagnostic features): Simple burrow system in which vertically orientated shafts predominate, but with extensions forming horizontal networks. Not interconnected with but juxtaposed with smooth-walled shafts of <u>Thalassinoides</u>. Preservation of the burrows is sufficiently good to allow identification of the single-pellet mammillated wall-lining. Burrows are passively filled without distinctive internal structures.

Description and ethology: In the studied material the ichnogenus exhibits of two distinctive types of burrow geometry and orientation: the first type is characterized by vertically orientated cylindrical shafts and the second type by horizontal netinterconnected to form a three-dimensional works. Both are burrow network. Both vertical and horizontal burrow elements are distinctly lined with agglutinated pelletal sediment forming the mammillated or nodose exterior. Several generations of the subspherical to irregular pellets are observed in the wall-lining and show a pellet-within-pellet construction (cf. Frey et al., (see Text-Fig. 9.4). The convention adopted here to 1978) is

TEXT-FIG. 9.4. Reconstruction of the architecture and mammillated or pelletal wall structure of the ichnogenus <u>Ophiomorpha nodosa</u> Lundgren, 1891, based in part on Frey et al., 1978, figs. 1, 3 & 4) and in apart on material from the present study area (sample no. 214/M.U 44363, illustrated in Plate 31, FIgs. a & b).

A. Downward-tapering cylindrical shaft.

B & C. Details of wall structure of shaft showing two sizes of pellets, small (A) and Large (B) arranged in subvertical rows (1 to 5 in diagram B).





TEXT-FIG. 9.4.

refer to the small pellets as category A pellets and the large pellets as category B pellets (cf. Text-Fig.9.4). In most cases the wall layer is one or two pellets thick (normally less than a thick). The larger pellets (B) are possibly a by-product сm of excavation (cf. Allen & Curran, 1974) and consist of a large number of agglutinated smaller pellets (B; of non-indested feeding origin, cf. Allen & Curran, 1974) made up in turn of fine to medium detrital sand grains (cf. Text-Fig. 9.4).

The upper part of most of the vertical cylindrical shafts, i.e., "the apertural neck" (Frey et al., 1978), is not clearly evident, possibly because of imperfect preservation. Ιn the study area vertical shafts and complex boxworks and mazes comprising inclined/subhorizontal tunnels are respectively predominant at different stratigraphic levels. The vertical shafts are more predominant in trace fossil intervals IC3 and IC4 (see logged section 2.2.1 from Turimetta Head in Enclosure III.4), and are associated there with the new ichnospecies т. conaghani. Contrastingly, the horizontal networks are more predominant in trace fossil interval IC2 (see logged section 2.2.1 マール 保護 くずむ たい in Enclosure III.4), and are associated there with the other new species of <u>Turimettichnus</u>, i.e. <u>T. webbyi</u>. The inner surface of the burrow-lining is more or less smooth or smeared, probably as VELET COLLES a result of movements of the organism along the burrow.

The length of the vertical shaft is about 10 cm to 15 cm and the width is about 1 cm to 2 cm, in some cases tapering progressively to a relatively apical termination (cf. Text-fig. 9.4A, & Plate 31 Fig. a). In other cases the shafts do not taper and have more abrupt, blunter or rounded terminations. The length

or distance between successive bifurcation or branching points in the horizontal burrows is about 5 cm to 8 cm, but in some places it is more variable. Many of the branches terminate at some distance (or are connected with another burrow), giving the system an antler-like appearance (Plate 32, Fig. c); terminations are either rounded or blunt and represent abandoned or unfinished tunnels, or else are bulbous (interpreted as turnarounds).

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The most striking feature of the branching pattern is that the Y-forks occur in all orientations (cf. Text-Fig. 9.5C, right box) although the majority of these Y-junctions lie subparallel to bedding and form incomplete polygons (Plate 32, Fig. c). Individual elements of the horizontal networks can exit via interconnected short vertical shaft at several level (cf. tiering-level of Chamberlain & Baer, 1973). The whole system is connected to the sediment surface by long vertical or steeply inclined shafts. On bedding-plane surfaces as exposed for example in trace fossil interval IC2 of the Bald Hill Claystone at Turimetta Head, these vertical shafts occur as circular protuberances branching off from the horizontal networks (Plate 33 目電調査 見とり さけ Fig.A).

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The pelletoidal wall-lining has the very distinctive single-pellet structure (Plate 31, Figs. a & b). At least several generations of pellet formation are evident in the formation of the wall-lining (Text-Fig.9.4). The organism evidently established these wall linings rapidly and constructed a new burrow periodically (the Recent crab <u>Uca pugilator</u> excavates its burrow

twice a day according to Allen & Curran, 1974). Pellets formed during burrow excavation (? mainly during low tide) are later used to plug up the burrow aperture (as the tide rises?). The <u>Ophiomorpha</u> burrows do not have actual turn-arounds or enlargements but are wider at certain places, especially at branching points and sporadically at burrow terminations (Plate 31, Fig. c). They possess no internal structure (meniscus or spreite), suggesting that most of burrows were passively in filled.

Comparison: In the present study area the ichnogenus <u>Ophiomorpha</u> is associated with the other crustacean burrows <u>Thalassinoides</u> and <u>Turimettichnus</u>. These various different burrows overlap and intersect in many places, but those of <u>Ophiomorpha</u> are readily differentiable on the basis of their smaller burrow size and distinctive pelletal wall-lining. The main problems encountered in the identification of <u>Ophiomorpha</u> are in specimens in which the wall structures are poorly preserved and hence where <u>Ophio-</u> <u>morpha</u> may be confused with <u>Thalassinoides</u> (Plate 33, Fig.b).

Studied material: Two large specimens were collected for detailed study of <u>Ophiomorpha</u> from trace fossil interval IC3/4 of logged section 2.2.1 of the Bald Hill Claystone at Turimetta Head. These specimens (no. 203/MU.44364 and no. 214/MU.44363 were collected for various studies but some other burrows illustrated in the plates have not been retrieved from the field.

Distribution: Most of the mammillated-type burrows were recorded especially from the lower stratigraphic units of the study area (see stratigraphic distribution chart, Text-Fig. 4.2). The ichnogenus <u>Ophiomorpha</u> occurs mainly at two stratigraphic

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levels: firstly within trace fossil intervals IC1-5 in the upper part of the Bald Hill Claystone and secondly trace fossil interval ID2 in the lower part of the Lower Newport Member. The best exposed and best locations for studying these two stratigraphic levels are Turimetta Head, Bungan Head and the St. Michael's Cave area. The population-density study of the burrow apertures was made in trace fossil intervals IC3/4 and IC5 of the Bald Hill Claystone at Turimetta Head (cf. Table 9.3).

Preservation and association: Most of the ophiomorphid burrows are preserved as full-relief structures, either passively or (in part) actively filled. They are typically associated with the ichnogenera <u>Turimettichnus</u>, <u>Planolites</u>, and <u>Thalassinoides</u>, as well as with different sized pellets of faecal, excavation, and feeding origin.

Environmental interpretation and facies: In the upper part of the Bald Hill Claystone and in the lower part of the Lower Newport Member Ophiomorpha nodosa occurs abundantly in beds of siltstone, claystone and fine sandstone. In the Lower Newport Member they occur in association with <u>Skolithos</u> and ripple cross-laminations suggesting deposition in a nearshore tidal-flat environment in transition to a riverine estuary or coastal lagoon.

The specific environments can be deduced from the density of the apertural openings of the burrows as documented for crustacean burrows in modern environments by Swinbanks & Luternauer (1987), and from the predominance of morphological patterns (i.e., variation from simple vertical shafts to boxworks

and mazes). The ophiomorphid-like burrows of the modern crustaceans <u>Callianassa</u> (Pryor, 1975; Frey et al., 1978), <u>Uca</u> (Allen & Curran, 1974), <u>Upogebia</u> (Dworschak, 1983; Farrow, 1971; Rice & Chapman, 1971; Braithwaite & Talbot, 1972; DeWindt, 1974; Pemberton, 1976; Ott et al., 1976; Swinbanks & Luternauer, 1987) have all been studied to provide greater understanding of the ichnogenus <u>Ophiomorpha</u> and its palaeoenvironments.

Ophiomorphid-like burrows are normally found in a wide range of marine, and brackish-water mixed environments (including estuaries, bays, lagoons, tidal-flats, beaches and the shoreface, and in sediments as much as 1.5 km off-shore and depths of аt least 12 m (Pryor, 1973). It is on the basis of burrows in these various modern environments that the areal density of the apertural openings (Pryor, 1973), and the morphology of the burrow systems (Frey et al., 1978) have been studied. According to these studies the density of the apertures of the ophiomorphid burrows averages only 5/m2 in the high-energy open-marine shore zone but increases to an average of $20/m^2$ in water depths of 10 m 1 km off-shore. The greatest concentration of ophiomorphid burrow apertures, as many as 450/m2 (and probably more), occurs in the protected low-energy tidal pools of bays, lagoons and estuarine shores (Pryor, 1973). These discoveries do not support previous reports (e.g., Kennedy, 1967) that callianassid burrows and their ancient equivalents (such as <u>O. nodosa</u>) do not occur in the high-energy, open-marine littoral zone.

The orientation of the burrow and the general morphology of the burrow system also varies as a function of the environment, the greatest variation being between high-energy

TEXT-FIG. 9.5. Diagrammatic seaward profiles of bathymetry (A), abundance of burrow aperture (B) and contrasting burrow geometry (C) of <u>Callianassa major/Ophiomorpha nodosa</u> based on field studies by Frey et al., (1978) at several places along the Atlantic Coast of the USA and a fossil Upper Cretaceous Strandline in Alabama, USA. Diagram modified from Frey et al., (1978, fig.11).

MHT = mean high tide; MLT = mean low tide.



TEXT-FIG. 9.5.

TABLE 9.3. Result of 20 population density counts of the apertural openings of <u>Ophiomorpha nodosa</u> Lundgren, 1891, in the upper part of the Bald Hill Claystone exposed at Turimetta Head. See log-section 2.2.1 (in Enclosure III.4) for stratigraphic locations of the trace fossil subintervals.

SAMPLE NO.	TRACE FOSSIL Subinterval	NUMBER OF APERTURES COUNTED PER SQUARE METRE
1.	C3 / C4	456
2.	u	448
3.	rr .	424
4.	11	488
5.	II II	503
6.	11	621
7.	H	596
8.	11	497
9.	**	373
10.	11	402
11.	11	401
12.	11	336
13.	n	423
14.	11	542
15.	C 5	201
16.	17	477
17.	11	480
18.	11	383
19.	11	526
20.	Ħ	423.

= 20 n = 450 $\overline{\mathbf{x}}$ $\delta n = 90.88$ $\delta n - 1 = 93.24$

TEXT-FIG. 9.6. Model profile showing relationships between coastal physiography and energy levels and aperture density per square meter of the burrows of <u>Callianassa major/Ophiomorpha nodosa</u> in a transect across a linear clastic shoreline featuring a barrier system and back-barrier tidal lagoon system. Burrow aperture density data are from Frey et al., (1978), Pryor (1973) and Swinbanks and Luterneuer (1987). Range of Turimetta Head aperture density data is shown by arrow leeside scale at left.







open-marine and protected low-energy environments (cf. Text-Fig. 9.5C). In general, vertical and cylindrical burrows predominate in the high-energy littoral environment and boxworks and mazes (with major development of horizontal elements) dominate in the low-energy protected areas (Frey et al., 1978).

At the Turimetta Head locality, counts of the apertural opening of <u>O. nodosa</u> and study of the burrow morphologies in bedding-normal sections were made in order to deduce the palaeoenvironment of the upper part of the Bald Hill Claystone. Twenty samples of population density were counted with the aid of a 1 m quadrant on bedding surfaces within the logged sections (sections 2.1.1 & 2.2.1) in trace fossil subintervals IC3, IC4 and IC5 (cf. Table 9.3). The apertural counts range from 200/m2 to 600/m2 at that locality (Table 9.3). <u>Ophiomorpha nodosa</u> boxworks and maze patterns dominate trace fossil interval IC2 (Plate 32 Fig. c), and vertical cylindrical shafts are more prevalent in trace fossil subintervals IC3, IC4, and IC5 (Plate 31 Figs.a - c; Plate 32 Figs. a & b)

The resulting palaeoenvironmental interpretation of the upper part of the Bald Hill Claystone is of a low-energy protected area, possibly a back-barrier lagoon or an estuary (Text-Fig. 9.6). On the basis of the pattern of palaeocurrents in logged section 2.2.1 (Enclosure III.4), this protected palaeoenvironment is evidently influenced fluvially in the upper part of the section by a stream flowing to the southeast (Text-Fig. 5.2). Hence, a riverine influence of the postulated estuary or lagoon area is highlighted.

9.5.2. <u>Thalassinoides</u> Ehrenberg, 1944 (emended by Kennedy, 1967) Diagnosis (generic assignment): Horizontally developed Y-shaped burrow system, without wall-lining, and with sporadic swellings or turn-arounds at the junctions or termini of the tunnels. Remarks (diagnostic features): Horizontal burrow network comprising mainly simple cylindrical or bifurcated elements, ranging between 2 cm and 8 cm in diameter (but with little variation within the one system). Branching is regular and is characterized by Y-shaped bifurcations. Tunnels are wider at the points of branching and at tunnel termini. The horizontally disposed elements join to form incomplete polygons. The burrow systems are associated with and overlap those of <u>Ophiomorpha</u> but the two are not interconnected.

T. suevicus (Type A) (Rieth, 1932)

Plate 25, Figs. a - e 26, Figs. a - c 27, Figs. a - c 29, Figs. a - c

Spongites suevicus quenstedti Rieth, 1932, p. 274.
Spongites suevicus Quenstedt, 1932, p. 292
Cylindrites suevicus (Quenstedt) Rieth, 1932, pl. 13a, b.
Thalassinoides visurgiae Fiege, 1944, p. 416-421, 424, text-fig. 4.
Spongites suevicus (Quenstedt) Seilacher, 1955, text-figs. 5, & 57.
Thalassinoides sp. Häntzschel, 1964, p. 302, pl. 14, fig. 3.
Thalassinoides suevicus (Rieth) Häntzschel, 1964, p. 302.
Spongeliomorpha suevicus (Rieth) Fürsich, 1973, p. 730.
Diagnosis (specific assignment): Horizontal burrow system, consisting of bifurcated cylindrical elements forming incomplete polygons. Sporadically swollen at branching points or at termini (turn-around type A, cf. Text-Fig.9.2), and without significant

wall-lining. Burrow diameters range from about 2 cm to 8 cm, and

the length is about 20 cm between successive bifurcations. Description and ethology: The species consists mainly of a horizontally disposed system of cylindrical tunnels with sporadic vertical shafts. The horizontal elements bifurcate sporadically to form incomplete horizontal polygons (Plate 25, Fig. a; Plate 26, Fig. c).

Some burrows do not show bifurcations but are also horizontally disposed as simple cylindrical elements with terminal turn-arounds (i.e., type A turn-around; Text-Fig.9.2) (see Plate 25, Figs. b - e; and Plate 26, Figs. a & b). The diameter of the tunnels ranges from 2 cm to 8 cm but does not show much variation within the one system; tunnel length is about 20 cm between successive bifurcations. The branching angle is fairly distinct and commonly about 90° to the main branch (Plate 25, Fig. a; and Plate 26, Fig. c).

The burrow system seems to have been filled in part passively and in part actively. The infilling stuff is normally of fine-grained sand, in some cases with small feeding pellets. Sporadically, the internal structure exhibits retrusive spreite (reflecting active infilling) (Plate 71, Fig. a and Plate 29, Fig.c). There is no internal layering within the infilling floor deposits of fine-grained sand (where passively filled). The internal sediment and any structure it may possess is visually enhanced when the external part or wall of the burrow is weathered.

The burrow wall is simple and unlined (i.e., pellets are absent). The most striking feature of the burrow is the

subspherical turn-around, normally located at tunnel termini. These subspherical turn-arounds reflect a solitary (rather than communal) behavior and are termed type A turn-arounds here (cf. Text-Figs. 4.1 & 4.2). Type A turn-arounds occur in two varieties: Simple cylindrical burrows have type A variety 1 turnarounds and Y- or V-shaped burrows have type A variety 2 turnarounds (cf. Text-Figs. 9.1 & 9.2). The diameter of the turnaround in both varieties probably corresponds to the length of the inhabitant organism (approximately 8 cm to 10 cm).

Comparison: The ichnospecies described here on the basis ofd numerous specimens differs from <u>T. saxonicus</u> in respect of much smaller size of the burrow system and is also characterized by a very distinctive branching angle (about 90°). The orientation of the tunnel with respect to bedding and the tunnel diameter are comparable with <u>T. cf. suevicus</u> (Rieth, 1932) described by Kennedy (1967).

Studied material: Most of the studied specimens were collected from logged sections 2.1.1 and 2.2.1 at Turimetta Head (area 2). The specimens studied are: 208a/MU.44360; 208b/MU.44359; 208c/MU. 44358; 217a/MU.44361; 217b/MU.44362. Additional specimens studied are from logged sections 7.1.1 and 7.1.2 from the Little Reef area (area 7); the specimens that were studied are: 701/MU.4407, and 708/MU.44408. Other examples illustrated in the plates were not retrieved from the field (see stratigraphic distribution chart; Text-Fig. 4.2).

Distribution: This ichnospecies occurs mainly in two different trace fossil intervals (i.e., IC and ID) at two different localities. The first is throughout trace fossil subintervals IC2, IC3

and IC4 in the Bald Hill Claystone at Turimetta Head; the other is throughout subintervals IE5, IE6, IE7 and possibly IE8 in the Middle Newport Member at Little Reef (area 12).

Preservation and association: In trace fossil interval IC most of the horizontal burrow systems are preserved as full-relief structures and are associated with other crustacean burrow networks of <u>Ophiomorpha nodosa</u> and the new ichnogenus <u>Turimettichnus</u>. These burrows overlap each other but are not interconnected. In trace fossil interval IE they are also preserved as full-relief structures but are not associated there with any other trace fossils.

Ichnofacies and palaeoenvironmental affinities: A palaeoenvironmental interpretation can be drawn from the population-density studies of the associated burrows of Ophiomorpha nodosa in trace fossil interval IC, discussed in the previous section. However, this environmental inference can not be similarly made for T. suevicus where it occurs in trace fossil interval IE since neither Ophiomorpha nor any other burrows occur there. However, on the basis of other palaeoenvironmental studies, Thalassinoides is known to characterize mainly brackish-marine to shallowmarine areas. It is considered to be particularly characteristic of the Skolithos ichnofacies.

T. paradoxicus (type B) (Woodward, 1830)

Plate 27, Figs. b & c 28, Figs. a - c 30, Figs. a - d

<u>Spongia paradoxica</u> Woodward; Woodward, 1833, p. 29, 30 & 34. <u>Spongia paradoxica</u> Woodward; Wiltshire, 1859, p.275, 277, pl.

1, figs. 1 & 2. Spongia paradoxica Woodward; Seeley, 1864, p.331. Siphonica paradoxica Woodward; Wiltshire, 1869, p. 176. Spongia paradoxica Woodward; Hughes, 1884, p. 273-279. Spongia paradoxica Woodward; Whitaker & Jukes-Browne, 1899, p. 36 & 55. Spongia paradoxica Woodward; Jukes-Browne, 1900, p. 303. Spongia paradoxica Woodward; Peake & Hancock, 1961, p. 301 & 330. Spongia paradoxica Woodward; Häntzschel, 1962, p. W242. Spongeliomorpha paradoxica Woodward; Fürsich, 1973, p.730. (specific assignment): Medium-sized, either solitary Diagnosis cylindrical or irregularly-branching geometry with very extensive horizontal burrow networks. Short vertical shafts also are common and are erected from horizontal networks. Diameter of tunnels variable, ranging between 0.7 cm and 3 cm. Short blind tunnels turn-arounds are very common in the networks. Burrow walls and are unlined, and are either smooth or exhibit scratch marks on

the surface.

Remarks (diagnostic features): Medium-sized, solitary cylindrical or horizontal irregularly-branching burrow network system with unlined wall surface exhibiting sporadic scratch marks. Turnarounds are normally present and comprise either the type A or type B categories (cf. Text-Fig.9.2) and both types can occur in the same burrow system (cf. Text-Fig.9.3). Commonly present within omission surfaces (i.e., semi-consolidated substrate).

Description and ethology: <u>T. paradoxicus</u> is a much more irregularly-branched form than <u>T. suevicus</u>. This irregular network is three-dimensional with branches of variable diameter forming irregular incomplete polygons (Text-Fig.4.3) involving longer tunnels which give rise to side branches of much smaller diameter (Plates 27 & Plate 28). As in <u>T. suevicus</u> the principal pattern of branching is a Y-fork characterized by a locally wider diame-

ter at the junction of the Y. The tunnel tends to widen at the point of bifurcation or branching (see Text-Fig. 9.2, and Plate 30, Figs. a - d).

The distance between successive branching points is variable ranging from 1 cm to several cm (i.e., branching is not regular). Many of the branches terminate a short distance from their junction with the main tunnel, either with a turn-around or bluntly without a turn-around (see Text-Fig. 9.3). In beddingparallel sections above the base of the horizontal network small knobs are common and represent the sand-infilled vertical shafts erected from the main horizontal tunnels. These vertical shafts are normally very short unless their function was to reach the sediment-water interface. The thickness or diameter of the vertical shafts is comparable with the tunnels comprising the horizontal networks.

The wall-lining is smooth and simple (lacking pellets or any other structure) and is uniformly thin (i.e., less than 1 mm) throughout the structure. No internal structures have been observed. The burrows seem to have been filled passively by younger sediment.

Two distinct types of turn-around with several varieties are observed in this species (Text-Figs. 9.2 & 9.3). The first type (type A) is a turn-around especially designed for individual convenience and was evidently established for use of only up one individual organism. In terms of its shape there are at least two varieties: variety 1 is a simple flask- or bottleshaped termination of a single tunnel (Text-Figs. 9.2 and 9.3 and

Plate 27, Figs. a & c); and variety two is a bulbous terminationlocated at the stem of a Y-shaped or V-shaped tunnel bifurcation. Each variety of this type of turn-around can be measured in terms of its diameter, and this measure should correspond approximately to the length of the inhabitant producer organism. The second type of turn-around (type B) comprises a larger chamber of variable' shape, of larger diameter than the type A turn-arounds, and featuring several small entrance/exit tunnels (Text-Fig. 9.2). This type of turn-around was evidently established as a communal facility for a number of animals and functioned as a central shared area (Fürsich, 1973). More than one such communal turn-around was possibly shared by the same community of animals in this way and these chambers were possibly used for a number of puroses including farming, mating and breeding. These communal turn-arounds can also be categorised into two varieties on the basis of shape (Text-Fig. 9.1 & 9.2). The first variety has a subspherical shape and has several small connecting tunnels (Text-Fig. 9.2 and Plate 28, Fig. a). The second variety is Y shaped with connecting tunnels, is normally located at joints or branches or bifurcations of the tunnel system, and is more common than variety one (see Text-Fig. 9.2 and Plate 28, Fig. b). The diameter of these turn-arounds varies, ranging from a minimum of 5 cm to a maximum of 10 cm. The diameter of turn-around type B cannot be regarded as commemsurate with the length of the producer organism, because the chamber is a communal structure and is likely therefore to be larger and longer than the organism. Comparison: <u>T. paradoxica</u> is readily distinguishable from T.suevicus by the geometry, diameter, and orientation of the

burrows which typically comprise an extensive nework of medium-to-small-diameter tunnels which are irregular in regard both to orientation and size. Turn-arounds are more prevalent in this ichnospecies than in any other ichnospecies collected from the study area. The tunnel networks of <u>T. paradoxicus</u> overlap other crustacean burrows including those of <u>Rhizocorallium</u> (with extremely well-preserved scratch marks) and <u>Spongeliomorpha</u> (which comprise extensive small-scale networks), but none of these burrows are interconnected (see Text-Figs. 9.3 and 7.13). This ichnotaxon as represented in the rocks of the study area is comparable with <u>T. paradoxica</u> described by Kennedy (1967) and Bromley (1975) from hardground or omission-surface situations (which is also the substrate association of this species in the study area).

Studied material: Most of the studied material was colleced from logged section 4b.1.1 of trace fossil subinteral IE9 within the top of the Middle Newport Member exposed in the South Palm Beach area (area 4b). The samples collected from this area are: 408ac/MU.44514; 410/MU.44516; 411/MU.44517; and 401/MU.44394. Specimens collected from elsewhere in the study area are: 1003/MU. 44424; and 1004/MU.44425; these were collected from trace fossil interval ID of the Lower Newport Member at Biogola Head (area 10b). Still other specimens illustrated in the plates (i.e., Plate 27, Figs. a-c, and Plate 28, Fig. c) were not retrieved from the field (see geographic distribution chart, Text-Fig. 4.2)

Distribution: <u>T. paradoxicus</u> is especially prevalent in trace

fossil intervals IE9 and IE10 of the Middle Newport Member in the South Palm Beach area (area 4b) and also in adjacent areas where these trace fossil intervals are exposed (Little Head, Careel Head, and Bangalley Head, areas 12, 9, and 8a respectively, see Enclosures III.1 & III.2). It also occurs in the lower stratigraphic levels of the Lower Newport Member in trace fossil interval ID at Bilgola head (area 10a), but is not nearly as extensive there as in the former trace fossil interval and does not occur there in a hardground situation.

Preservation and association: <u>T. paradoxica</u> is preserved as a full-relief form in the relatively hardground conditions of two omission surfaces (see Text-Fig. 7.13) in trace fossil interval IE9 of the South Palm Beach area. This association with hardground ommission surfaces is indicated in the caption of Text-Fig. 7.13 and in the text of Chapter 7. This hardground situation is found only in trace fossil subinterval IE9 and does not occur in interval ID.

Ichnofacies and palaeoenvironmental affinities: <u>T. paradoxica</u> normally belongs to the <u>Skolithos</u> ichnofacies in soft-substrate areas, but can also occur in hardground substrates (i.e., in the <u>Glossifungites</u> ichnofacies). The material studied here indicates that although <u>T. paradoxica</u> is preferentially associated with marine to brackish-marine littoral to sublitoral omission surface hardgrounds, its burrows in such situations pre-date th lithification of the hardground substrate (cf. Text-Fig. 7.13). A protected, moderate-energy setting in marine to brackish-marine litoral to sublittoral areas is envisaged for the generation of the semiconsolidated substrate and non-erosional omission surfaces that were colonized by the producer organism of this ichnospecies.

9.5.3. Spongeliomorpha (type C) Saporta, 1887

Spongeliomorpha Saporta; de Laubenfels, 1955, p. E36.

Spongeliomorpha Saporta; Häntzschel, 1962, p. W216. Felixium de laubenfels; Häntzschel, 1965, p. 35. Spongeliomorpha Saporta; Häntzschel, 1965, p. 87. Thalassinoides ornatus Kennedy, 1967, p. 141, pl. 6, fig. 4 & pl. 7, fig. 6. Non Spongeliomorpha Saporta; (Fürsich, 1973), p. 729, fig. 6. Non Spongeliomorpha saxonica (Fürsich, 1973); Carey, 1978 p. 449, fig. 21.

Diagnosis (generic assignment): Small- to medium-diameter, elongated cylindrical burrows, with or without turn-arounds, branching to form a three-dimensional network; tunnel surfaces bear conspicuous scratch marks.

Remarks (diagnostic features): Small- to medium- diameter cylindrical burrows forming a very extensive three-dimensional network; the branching pattern is different from that in <u>Thalassi-</u> <u>noides</u> and <u>Ophiomorpha</u>; burrow surface is normally covered with subparallel or criss-crossing scratch marks that are subparallel to the burrow axis; turn-arounds may or may not be present.

S. kalia ichnosp. nov.

Plate 28 Figs. a - c

Derivation of name: 'Kalia' is a Greek word meaning bird-nest or the house of a bird.

Diagnosis (specific assignment): Small-diameter cylindrical burrows forming a three-dimensional highly interconnected dense network; the burrow surface is covered with subparallel scratch marks; turn-arounds are absent.

Remarks (diagnostic features): Same as for specific assignment. Description and ethology: This new species is defined by the pattern of branching that forms the networks, this pattern being totally different from that in other networks produced by crustaceans (thalassinids and ophiomorphids). In S. kalia the network system has a much stronger tendency to be three-dimentional (like the fabic of a birds-nest or sponge) than in the others. Secondorder and third-order branches are very common. These branches or tunnels are ralatively short, crowded and interconnected. The size of the individual burrows is conspicuously smaller than those of the associated thalassinids and rhizocoralliids (Text-Figs. 9.1, 9.3, and Plate 28, Figs. a - c, and Plate 20, Figs. a - c). The distance between successive bifurcations or branching is normally less than 1 cm and the bifurcation angle is points invariably acute (less than 90°). The diameter of the cylindrical burrows ranges from about 0.2 cm to 0.8 cm.

The surface is normally (when not weathered) covered with regular, burrow-parallel uniform corrugations (bioglyphs). The bioglyphs of the ichnogenus <u>Spongeliomorpha</u> can be regarded as having been produced by crustaceans of similar kind to those that gave rise to the ichnogenera <u>Thalassinoides</u>, <u>Ophiomorpha</u> and <u>Rhizocorallium</u> as a result of the inhabitant organisms digging or moving through the burrow. The same pattern of ornamentation characterises the burrows of modern crustaceans, hence the crustacean affinities of these fossil burrows is quite clear. The burrows of <u>S. kalia</u> are also associated with other knowncrustacean burrows, specifically <u>Thalassinoides</u> and <u>Rhizocoralli-</u>

The wall is unlined (pellets are absent) and no internal structures are present. Hence, the burrows would seem to have been filled passively by younger sediment. The burrow networks have no turn-arounds (these were probably not necessary because of the extreme tunnel interconnection), and lacked vertical shafts to connect with the sediment-water interface. The burrow networks were evidently development just a few cm below the actual sediment-water interface.

Comparison: The present ichnospecies differs from the monotypic ichnogenus S. iberica Saporta, (1887) by its greater tendency towards three-dimensional branching, its smaller tunnel diameter, and the invariable acute-angle brancing pattern of the secondand third-order branches. It also differs from the ichnospecies described as T. ornatus by Kennedy, (1967) (= Spongeliomorpha ornatus in the present classification) on account of the absence of turn-arounds. The ichnospecies S. saportai Meunier, 1889 (in Fürsich, 1973) differs by its tendency towards dichotomous branching and more widely spaced bifurcations. This new ichnospecies is readily distinguishable from the other bioglyph-bearing ichnotaxa (T. suevicus and Rhizocorallium species) by its narrower burrow diameter and the three-dimensional nature of the burrow network. It is invariably present as the smallest-scale background network in trace fossil suites that involve several different ichnotaxa (Text-Fig. 9.3).

Studied material: Several specimens containing <u>S. kalia</u> were collected from logged section 4b.1.1 of trace fossil subinterval IE9 within the top of the Middle Newport Member in the South

um.

Palm Beach area (area 4b). The specimens collected from this area are: 408a-c/MU.44514; 409/MU.44515; and 411/MU.44517.

Distribution: This ichnogenus is known in the study area only from trace fossil subinterval IE9 within the top of the Middle Newport Member, exposed in the South Palm Beach area (area 4b). Preservation and association: <u>S. kalia</u> is preserved as fullrelief structures which are associated with other (thalassinid and rhizocoralliid) crustacean burrows (see details of these relationships in Chapter 7).

Ichnofacies and palaeoenvironmental affinities: As for <u>T. suevi-</u> <u>Cus</u>.