

INTRODUCTION

CHAPTER 13

ROSETTE-SHAPED STRUCTURES

ROSETTE-SHAPED STRUCTURE

13.1. INTRODUCTION

Rosette-shaped trace fossils are common, and their form has attracted much attention of the ichnologist. Many different types of rosette-shaped (also known as star-shaped) trace fossils have been discovered in rocks of various ages from ?Precambrian and Cambrian to Recent. In the past they were normally classified in one group and considered to be 'Medusae'. More recent research on these structures has been carried out by many workers, but there is still no agreement on their classification; firstly, because some of them are still of unknown origin, and secondly, there are many different types of rosette-shaped trace fossils produced by different organisms, different patterns of behavior, and some may not even be of biogenetic origin.

13.2. EXISTING CLASSIFICATIONS OF ROSETTE-SHAPED STRUCTURES

Rosette-shaped trace fossils are briefly reviewed and their possible origins are also discussed here with the suggestion that they result from the activities of a number of different kinds of organisms. The rosette structures concerned with here are restricted to those which originate from the life activity of an organism. Such rosette-shaped structures can originate from the activities of several different kinds of animals: e.g., worms, molluscs, crabs, starfish, even fish and some are of still unknown biogenic origin (i.e., the producer organism remains unknown). Recent attempts to classify these structures have been based mainly on the type of organism that produced them (Grubic, 1970; and Häntzschel, 1970), but not based on the ethology or

TABLE 13.1. Ichnotaxonomic classification and interpreted ethology of rosette-shaped trace fossils based on the inferred taxonomic affinity of the producer organism (from Grubic, 1970 with additions from Häntzschel, 1970)

Inferred taxonomic group of producer organism.	Ethology
(1) Resulting from activity of a worm.	feeding (fodinichnia).
(2) Resulting from activity of a bivalve siphon.	feeding (fodinichnia).
(3) Resulting from activity of a dibranchiate cephalopod tentacles.	feeding/resting (fodinichnia/cubichnia).
(4) Resulting from activity of a crab.	feeding (fodinichnia).
(5) Resulting from the resting behavior of an asterozoan.	resting/escaping (cubichnia/fugichnia).
(6) Resulting from biogenic activity of unknown taxa.	?

activity of the organism that made them. The underlying principle in these latter classifications is that these traces can only be categorized on the basis of the producing organism. However, only in a very small number of cases can the likely producing organism be confidently demonstrated. In these schemes six major groups are recognized and result from different producer organisms, the classification being based solely on the morphology of these rosette-shaped structures (Table 13.1).

No attempt has been made to explain the origin of the various kinds of rosette-shaped trace fossils of uncertain taxonomic affinity although these have been discussed at some length by Dawson (1890), and Książkiewicz (1960), as well as also listed in Häntzschel (1970). In the meanwhile, many names for 'ichnogen-era' and 'ichnospecies' of rosette-shaped trace fossils have been erected on purely morphological criteria (e.g. Książkiewicz, 1968). These should therefore be relegated to 'nomina oblita' status in accordance with the international rules of zoological nomenclature. Yet other rosette-shaped trace fossils have been given the name of a rosette-shaped animal or plant because they were considered by some authors to constitute actual body fossils. Rather, some of them are probably radiating feeding- or grazing- traces surrounding a vertical burrow or else they were produced as a result of resting or movement of asterozoans or dibranchiate cephalopods etc. The classification presented here deals only with rosette-shaped true trace fossils and not with forms of doubtful interpretation (i.e., medusae or other animal body fossils or plant fossils); also, description of the latter are excluded here.

The classification proposed here is based mainly on the behavior (ethology) of the organism that produced the trace, but not the taxonomy or morphology of the organism itself. Several difficulties arise when attempting to devise a classification for these rosette-shaped traces. The first problem is that of obtaining access to the type specimens for the purposes of revision of ichnogenera erected many decades ago. Secondly, the generic names that are used in a new scheme will possibly be discovered to be synonyms of pre-existing ichnotaxa after thorough investigation of many well preserved specimens of the latter. The classification proposed here (Text-Fig. 13.1) will hopefully contribute to a better understanding of the type of behavior of the organisms that produced these rosette-shaped traces. However, the interpretation and assignment of these rosette-shaped trace fossils to ichnogenera and ichnospecies obviously depends on one's judgment and evaluation of the various morphological features and ethological criteria of these trace fossils (cf. Table 13.3). The terminology of these features is very important in the proposed classification, hence it is necessary to clarify it before discussing the classification itself. The definitions or meanings of the salient morphological features used here in the proposed classification (emended in some cases) are given in Table 13.2.

13.3. INTERPRETATION OF ROSETTE-SHAPED STRUCTURES

These rosette-shaped trace fossils are known from the Cambrian (and possibly from the Precambrian) to Recent. The recognition of their ecological significance and their producers

TABLE 13.2. Terminology used here in regard to rosette-shaped trace fossils and their classification. Some terms are emended from their original or normal usage.

Terminology of morphological features

Rosette-shaped - star-shaped.

Epichnial trace - trace developed on the top of a bed.

Hypichnial trace - trace developed on the bottom of a bed.

Arm (rib, or rays) - radial arrangement of features from a centre produced by feeding activities or comprising an original resting impression.

Planispiral orientation - development of arms/rays arranged in one plane.

Helicoidal orientation - development of arms/rays arranged in trochospiral plane.

Irregular orientation - radial pattern of arms/rays arranged irregularly.

Complex orientation - development of arms/rays organized in a complex pattern.

Spreite - see Chapter 10.

(1) Simple - spreite developed simply (protrusively or retrusively).

(2) Radial - spreite developed radially (protrusively from the main central area).

(3) Subradial - spreite developed subradially (protrusively forward and downward).

(4) Protrusive spreite - formed by forward movements (see Chapter 10).

(5) Retrusive spreite - formed by backward movements (see Chapter 10).

Width - diameter of a rosette-shaped structure.

Length - length of an arm.

Thickness - diameter of a cylindrical-shaped arm.

Areola - feature developed in the central area surrounded by arms, measured by diameter.

Tubercule - knob in the central area.

Central column - vertical column formed in the centre of the structure where the organism is preserved to have lived.

Depth - depth of a burrow from the sediment-water interface (both for epichnial and hypichnial forms).

have been facilitated by the observation of modern forms in present-day environments. The rosette-shaped structures (both modern and ancient) are referable to two major groups (Text-Fig. 13.1). The first group belongs to feeding- or grazing-traces, in most of which cases the arms/rays are connected to a central column (or dwelling-burrow); they can comprise either epichnial or hypichnial forms, and all have full-relief. The second group belongs to resting- (cubichnia), swimming- or moving- (movichnia) traces (see Text-Fig. 13.1).

13.3.1. Rosette-shaped traces resulting from feeding or grazing

Traces produced by some worms and some bivalves can have rosette-shaped patterns. These organisms produce such traces as a result of either feeding or grazing (in some cases), and these rosette-shaped structures are invariably connected to a central dwelling column or chamber which the organism occupied most of the time. These types of structures can be developed on either the top or bottom of the bed depending on the nature of the producer organism and they invariably occur as full-relief forms.

Most of these structures are developed by a pedicle, or by an arm, or by ribs/rays (depending on the producer), starting from the centre of the rosette and moving downwards or upwards. In the centre a high (in epichnial forms) or low (in hypichnial forms) area can occur manifesting the living area or dwelling-burrow occupied by the animal that produced the star-like pattern on the surface of the sediment or even within it (in the latter case these would be hypichnial forms). Most of these structures

(including helicoidal forms) are not very deep. Normally the organism lives in a sandy environment and feeds or grazes on underlying or overlying nutritious mud. The burrow infillings can either be of passive or active types, similar or different from the host sediments, with or without spreite. The wall of the burrow is normally well defined and different from both the infilling and host sediment. The diameter of the rosette-shaped structures is about 5 to 10 cm and they normally exhibit from 10 to 16 rays or ribs in the one individual structure.

The interpretation embodied in the proposed classification that these radiating structures result mainly from the feeding and grazing activities of organisms (mainly worms or bivalve molluscs) living in the sediment is compelling. However, notwithstanding this some explanation is still needed to account for the non-fossilization/preservation of body fossils within such burrows, especially in examples which are believed to have been produced by pelecypods.

One type of hypichnial feeding rosette-trail called Lorenzina (Gabelli, 1900) consists of 16 to 24 rays of equal length and identical shape. The middle part of the rosette is circular, and flat or even weakly concave. In detail however, such rosette-shaped trails show much variation and degrees of complexity (see Text-Fig. 13.1). One form (Sublorenzina Ksiazkiewicz, 1968) consists of a circular set of small uneven knobs, another (Bassaenia Renz, 1925) of two annular series of knobs. The typical rosette-shaped pattern seen in Lorenzina is thought to manifest the feeding activity of crabs (Nowak, 1957).

Nowak's idea is now generally accepted by other workers including Grubic (1961), Slaczka (1964), and Lucas & Rech-Frello (1964). Lorenzinia is best known from flysch sediments of the Upper Cretaceous and Eocene of the Alps (Ksiazkiewicz, 1977).

13.3.2. Rosette-shaped structures produced by resting or moving

The pattern of these structures varies from five-rayed traces to eight-rayed traces, depending on the morphology of the producer organism. Most of these traces normally occur as half-relief impressions on the top surface of the bed. In the five-rayed pattern the traces of individual rays are slender and such forms are undoubtedly the resting-traces of brittle stars (auluroids or asteriods) known from Silurian to Recent globally. Some of them indicate escape movement by the organism, with the resting-trace of the former position also preserved (e.g., Asteriacites lumbricalis Seilacher, 1953). Another group of rosette-shaped traces characterized by eight very evenly distributed radial furrows was produced by an activity involving the tentacles of dibranchiate cephalopods and is called Asterichnites Häntzschel (1962 p. W184) (see Text-Fig. 13.1). In the middle part of the structure there is a featureless disc (areola).

13.3.3. Rosette-shaped traces of uncertain origin

The rosette-shaped traces discussed above are ones whose origin has been resolved with a reasonable degree of certainty. There are other rosette-shaped traces whose origin is less certain (see appendix of Häntzschel, 1970), and no attempt has been made here to explain the origin of these traces. Several other particularly interesting rosette-shaped traces of previous-

ly unknown affinity described by Ksiazkiewicz (1966) from the deep-marine deposits of the Carpathian flysch were later revised and properly named by him (1977).

13.3.4. Unnamed modern rosette-shaped structures

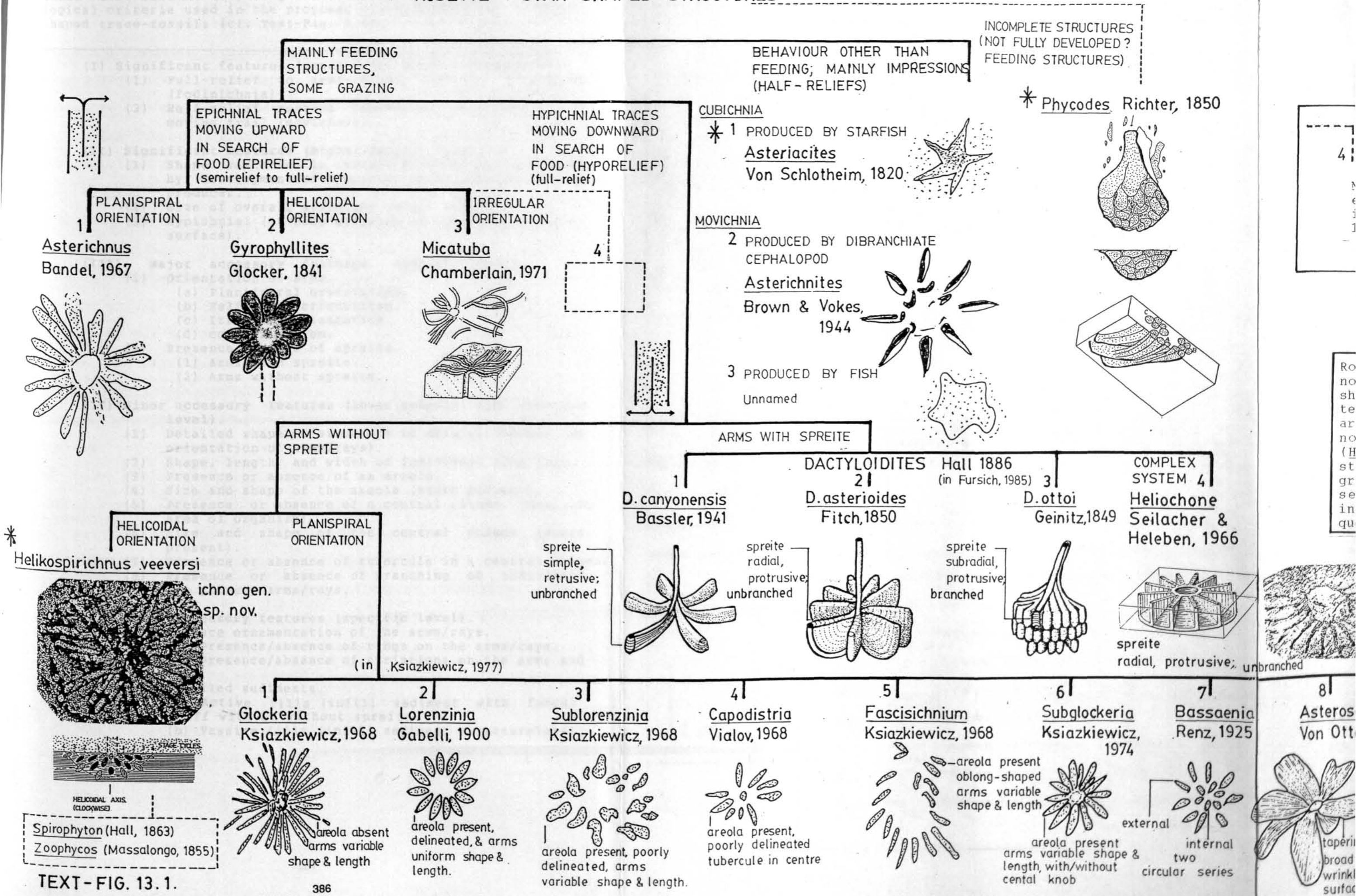
Most of the previously described rosette-shaped structures were collected and studied from deep-marine flysch-type deposits. Very few rosette-shaped trace fossils were described from shallow-marine to brackish-marine areas until Seilacher (1977) discovered a large number of different types of rosette-shaped traces (produced by different organisms) in modern-day intertidal mud-flat environments. The rosette-shaped traces occur in these intertidal mud-flat areas because the nutrient content of the muds in such areas is similar to that on the floor of the deep sea. However, notwithstanding this similarity the restriction of meandering traces (Helminthoida), or spiral feeding-traces (Zoophycos), and grazing-traces (Paleodictyon) to the deep-sea-floor environment remains unexplained.

13.3.5 Incomplete? rosette-shaped structures

The shape and morphology of individual species of Phycodes vary considerably (from broom-shaped to flabellate-shaped). Some of these structures can be interpreted as incomplete rosette-shaped feeding tunnels and can be accommodated in the proposed classification as incomplete? or not fully developed rosette-shaped structures (Text-Fig. 13.1).

TEXT-FIG. 13.1. Proposed classification of rosette-shaped trace fossils based on ethological considerations and preservational criteria (cf. Table 13.3). Incomplete ?rosette-shaped structures belonging to some ichnogenera (e.g. Phycodes) are tentatively placed in the classification. Modern unnamed traces produced by several organisms and which are exposed on intertidal mud-flats (cf. Seilacher, 1977) are included but are not illustrated. Burrow types present in the study area are indicated by an asterisk.

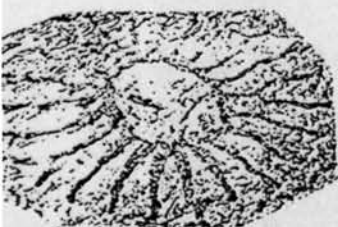
ROSETTE - / STAR-SHAPED STRUCTURES



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Modern unnamed rosette-shaped traces exposed on intertidal mud-flats are not illustrated here (Seilacher, 1977, fig. 10 A - G)

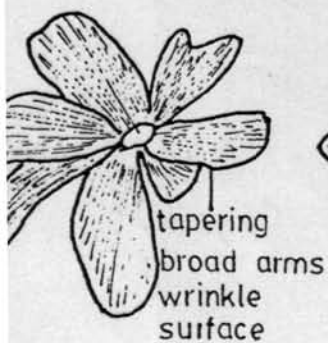
Rosette-shaped trace fossils are found not only in the deep sea but also in shallow intertidal mud flats, because in terms of food distribution these areas are closely resembles. But still we do not know why the meandering (Helminthoida), spiral feeding structures (Zoophycos), and pattern grazing traces (Paleodictyon) as in deep sea are missing in the shallow intertidal mud flat areas is still a question without answer.



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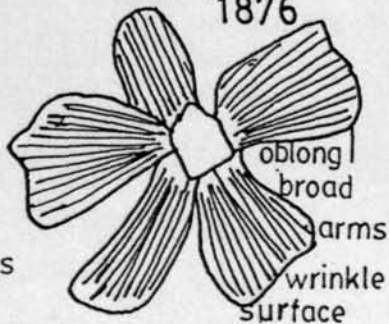
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Asterosoma
Von Otto, 1854



9

Asterophycus
Lesquereux,
1876



10

Bifasciculus
Volk, 1960



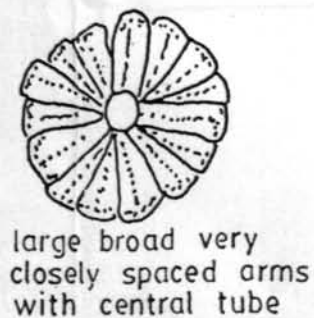
11

Oldhamia
Forbes, 1849



12

Stelloglyphus
Vialov, 1964



-----OTHERS

TABLE 13.3 Salient morphological features, attributes and ethological criteria used in the proposed classification of rosette-shaped trace-fossils (cf. Text-Fig. 8.1).

-
- (I) Significant features (group level above ichnogenera).
 - (1) Full-relief to semi-relief feeding structures (fodinichnia).
 - (2) Half-relief resting impression (cubichnia) or moving trail (movichnia).
 - (II) Significant features (higher generic level).
 - (1) Shape variation in overall structures (reflected by development of arms/rays or morphology of the producer).
 - (2) Size of overall structure (i.e., diameter).
 - (3) Hypichnial (on sole surface) or epichnial (on top surface).
 - (III) Major accessory features (generic level).
 - (1) Orientation of arms.
 - (a) Planispiral orientation.
 - (b) Helicoidal orientation.
 - (c) Irregular orientation.
 - (d) complex system.
 - (2) Presence/absence of spreite.
 - (1) Arms with spreite.
 - (2) Arms without spreite.
 - (IV) Minor accessory features (lower generic and specific level).
 - (1) Detailed shape of structure in details (formed by orientation of arms/rays).
 - (2) Shape, length, and width of individual arms/rays.
 - (3) Presence or absence of an areola.
 - (4) Size and shape of the areola (where present).
 - (5) Presence or absence of a central column (dwelling area of organism).
 - (6) Size and shape of the central column (where present).
 - (7) Presence or absence of tubercule in a central column.
 - (8) Presence or absence of branching of individual arm primary arms/rays.
 - (V) Minor accessory features (specific level).
 - (1) Surface ornamentation of the arms/rays.
 - (a) Presence/absence of rings on the arms/rays.
 - (b) Presence/absence of striations on the arms and rays.
 - (2) Infilled sediments.
 - (a) Active fills (infill sediment with faecal stuff with or without spreite).
 - (b) Passive fills (infill sediment structureless).

13.4. PROPOSED CLASSIFICATION OF ROSETTE-SHAPED STRUCTURES

Formulation of the proposed new classification for rosette-shaped or star-shaped structures is necessary because many difficulties were encountered (as with the U-shaped structures) in trying to deal with taxonomic considerations, especially at the generic level. It was also found necessary to revise the existing classification of Grubic (1970) to provide a logical meaning of the structures in explanation of the producing organisms' behavior. In the morphological classification of previous workers (Grubic, 1970; Häntzschel, 1970; and Książkiewicz, 1977) the ichnogenera and ichnospecies were related wholly to the morphology of the producer organism and to preservational phenomena, but not to the organisms' behavior that produced these traces. The classification proposed here is based on significant morphological features which are responsible for and involved in certain behavioral patterns of ethological value to the producer. However, the proposed classification still reveals and reflects to some degree the morphology and taxonomy of the producer, especially at the higher level of the classification, and results in genetically competent ichnogenera which are therefore more meaningful to palaeoecology and sedimentology.

The proposed present classification attempts to eliminate the various problems by resolving which major or essential features are to be considered important at the group level (i.e., the level above ichnogenera) and hence should be regarded as significant features at this level. Other significant major and minor accessory features should be regarded as important features at the intergeneric and intra-generic level. In addi-

tion, there are also minor accessory features which are regarded as important features at the inter-specific and intra-specific (variety) levels.

The classification excludes rosette-shaped structures of uncertain origin, or of probable inorganic mechanical origin, and also rosette-shaped structures produced by plants. The various features/relationships/criteria used at the different ichnotaxonomic levels in the proposed classification are rational and the justification for their selection is elaborated in Table 13.3.

13.5. SYSTEMATIC ICHNOTAXONOMY

Helikospirichnus ichno. gen. nov.

H. veeversi ichno. sp. nov. (type species)

Plate 45, Fig. a (holotype)
Plate 45, Figs. b & c (paratypes)
Plate 46, Figs. a - c (")
Plate 47, Figs. a - c (")

Derivation of the generic name: 'Heliko' comes from Greek 'Helix - ikos' and 'spiri' for spirally coiling, meaning helicospirally coiling. 'Ichnus' also from Greek 'iknos', meaning trace.

Generic assignment: Hypichnial rosette-shaped feeding-structure with helicoidal arrangement of arms. Detailed taxonomic descriptions are discussed in specific description.

Derivation of the specific name: Named for Associate Professor J. J. Veevers of the School of Earth Sciences, Macquarie University.

Specific assignment: Subcircular rosette-shaped feeding-structure, consisting of 5 to 12 helicoidally arranged unbranched arms of variable length and of uniform shape. Areola present.

Diagnostic features: Subcircular rosette-shaped structures consisting of unbranched helicoidal arrangement of rays or arms (somewhat like compressed DNA structures) on the sole surface of the bed. Areola present but not fully developed and arms or rays extend from the central column where the organism resided. The arms comprise straight or slightly sinuous features of uniform shape, and increasing length at each different stage. The arms are passively infilled with overlying fine sand, and are internally structureless (without spreite). The surface of the arms is not ornamentated.

Description and ethology: Subcircular rosette-shaped feeding-structures consisting of unbranched radiated arms which originally comprised straight or slightly sinuous tubes 0.3 cm in diameter, and up to 3.5 - 4 cm in length. The rosette is up to 8 cm in diameter and the tubes/rays are arranged in a systematic pattern radiating from a central column. The rosette trace develops in a sequence of discrete stages that involve the progressive introduction of a larger number of longer rays/arms at each stage and at progressively lower levels in the muddy sediment as well as the progressive clockwise rotation of the arms/rays at each separate stage relative to their position at the previous stage (Text-Fig. 13.2). The initial stage is characterized by only five rays/arms and an inter-arm angle (α) ranging from 70° to 80° (Text-Fig. 13.2). This stage is developed within about 0.5 cm of the sediment surface. Stage two develops below stage one (i.e., between about 0.5 cm and 0.8 cm below the sediment surface), has between 12 and 16 arms/rays inserted clockwise and between the arms/rays of stage one and with an inter-arm angle (β_1) of about

TEXT-FIG. 13.2. Reconstruction of the multistage helicoidal development of the hyporelief trace fossil Helikospirichnus veeversi.

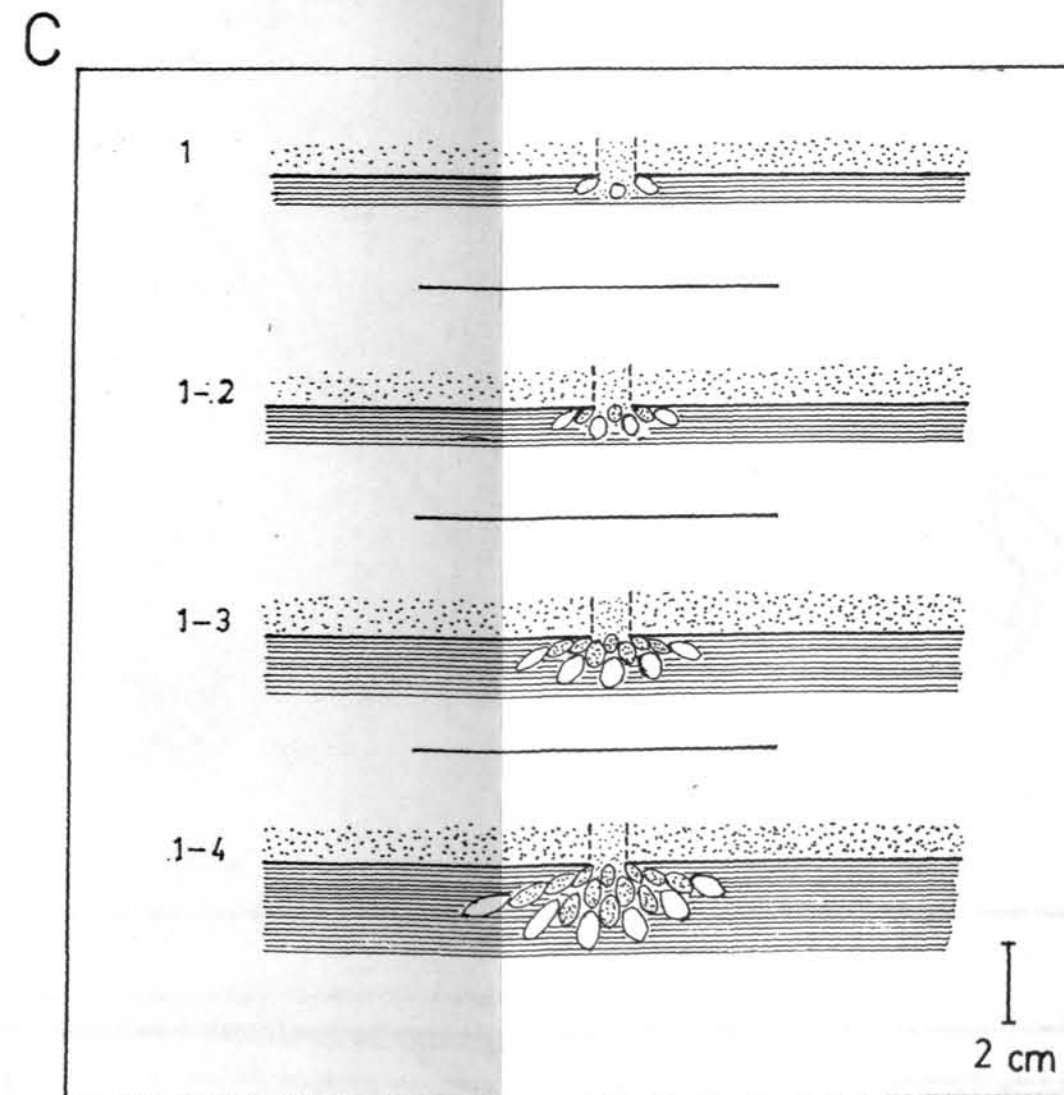
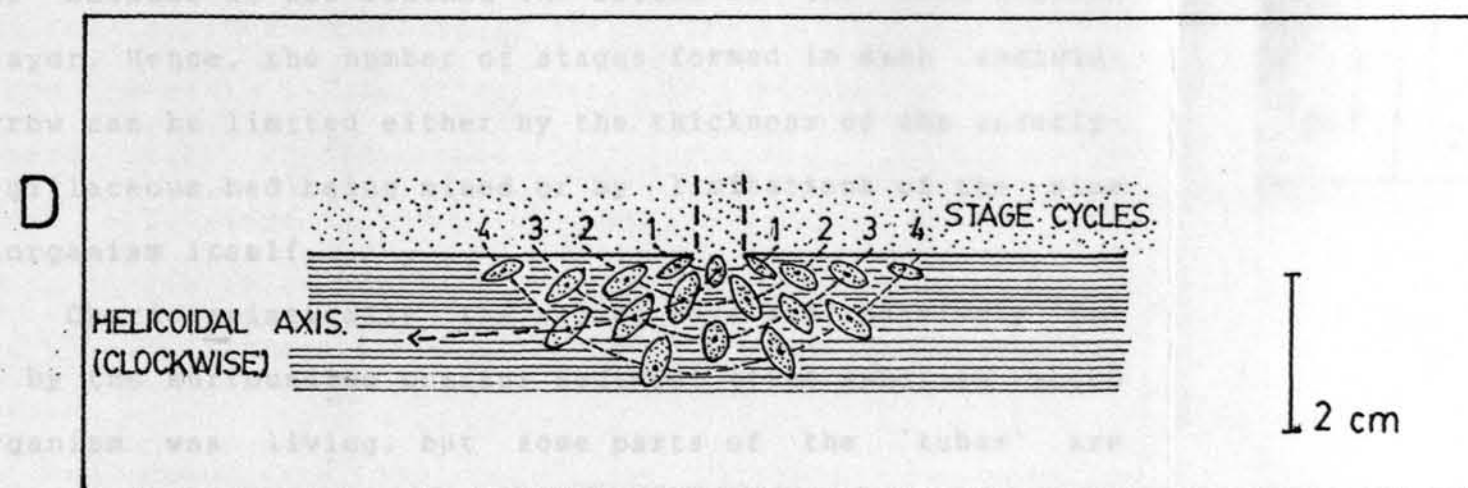
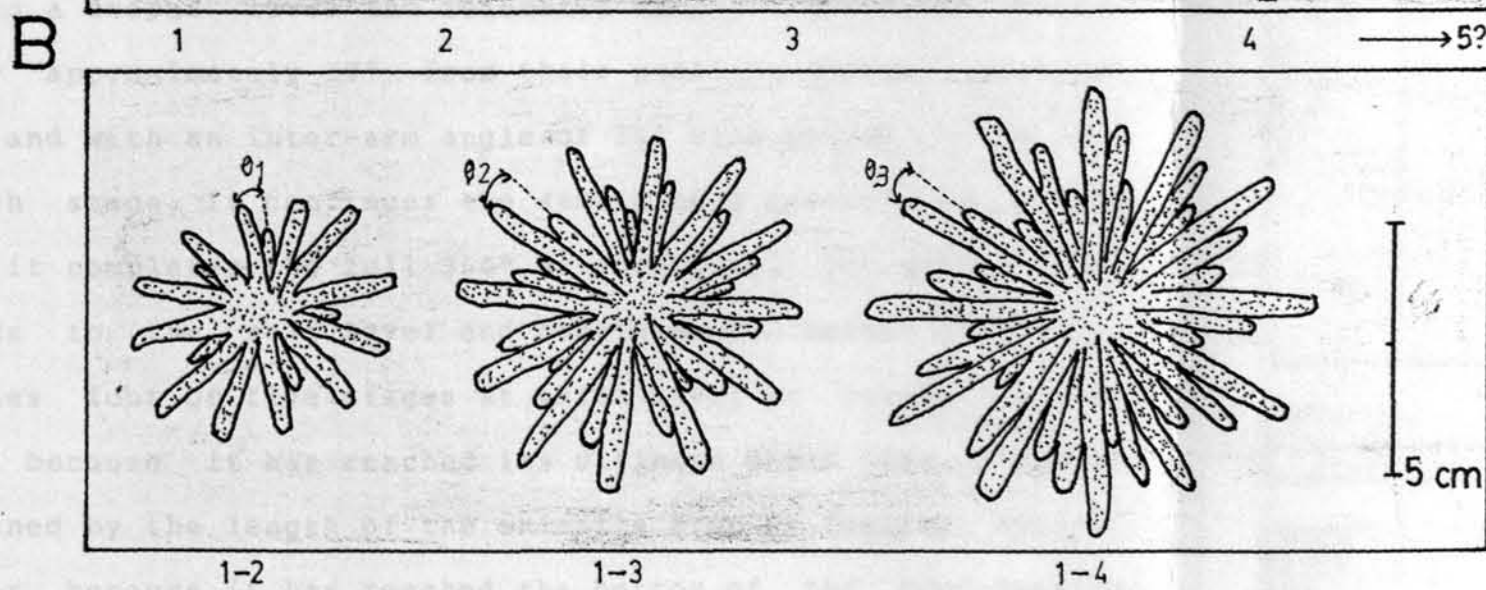
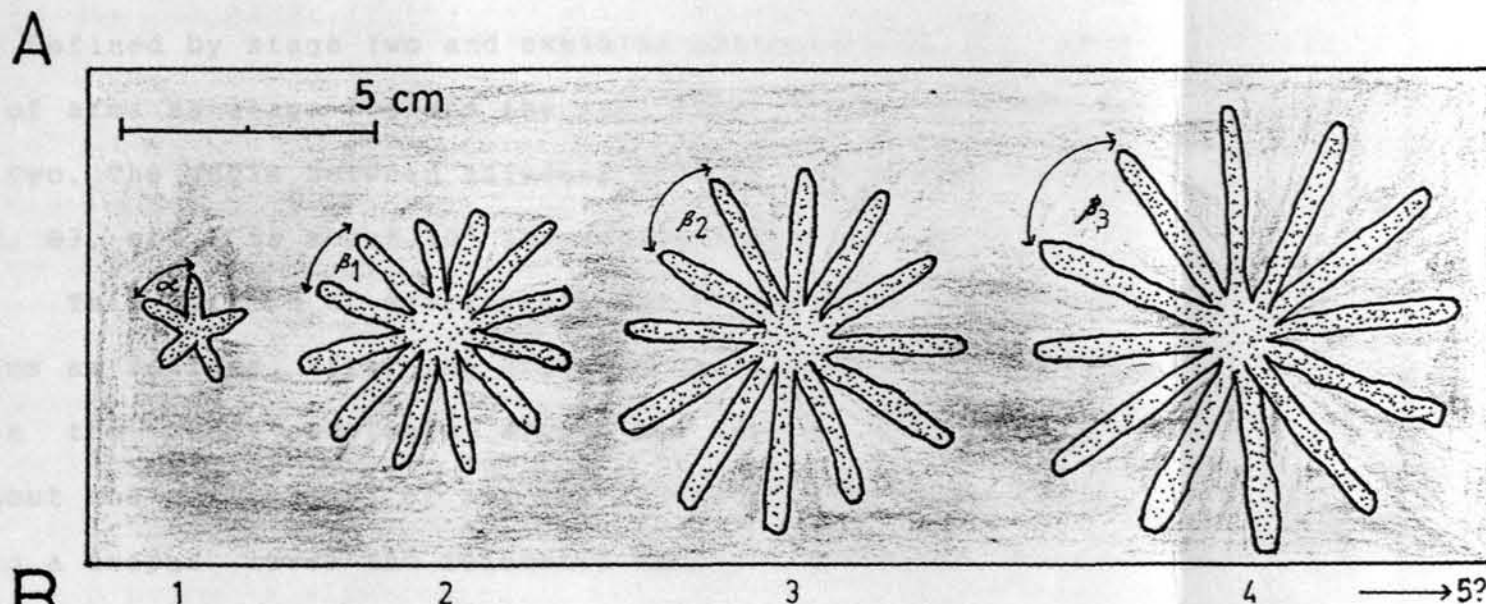
A. Successive stages (1 to 4) shown separately at a common relative scale and with preservation of the relative angular relationships of the arms/rays within and between each of the stages. View is upwards onto the sole of the bed.

B. Successive stages (1 to 4) superimposed. View is upwards onto the sole of the bed.

C. Cross-sectional reviews showing the successive development of the burrow from stage 1 to stage 4.

D. Cross-sectional views as in C, lower diagram, but additionally annotated to emphasize the clockwise helicoidal pattern of development of the successive stages.

(See text for additional description and explanation).



EXPLANATION

1 - 4 Stages of burrowing.

- α — Angle between two adjacent arms of stage 1 (70°-80°).
- β_1 — Angle between two adjacent arms of stage 2 (30°-40°).
- β_2 — Angle between two adjacent arms of stage 3 (30°-40°).
- β_3 — Angle between two adjacent arms of stage 4 (30°-40°).
- θ_1 — Angle between two arms of adjacent stages 1 & 2 (>10°).
- θ_2 — Angle between two arms of adjacent stages 2 & 3 (>10°).
- θ_3 — Angle between two arms of adjacent stages 3 & 4 (>10°).

30° - 40° (i.e., between the arms/rays of this stage) (Text-Fig. 13.2). Stage three develops in a similar way with respect to the pattern defined by stage two and exhibits approximately the same number of arms as stage two and the same inter-arm angle (β_2) as stage two. The angle between adjacent arms of successive stages (θ_1 , θ_2 , θ_3 , etc.) is about 10° throughout (Text-Fig. 13.2).

This pattern of development can be explain in ethological terms as follows. After the organism has finished mining for food in the muddy substrate around and below itself (i.e., throughout the entire 360° of any one stage, it penetrates downwards to a deeper level and relocates each of its arms clockwise by approximately 10° from their position during previous stage, and with an inter-arm angle of 30° with regard to the arms of each stage. It continues the same mining process as before until it completes the full 360° at that level. The animal then descends to the next level and continues as before until it completes four or five stages at which level it ceases mining, either because it has reached its ultimate depth (as probably determined by the length of the animal's arms or feeding apparatus) or because it has reached the bottom of the food-bearing muddy layer. Hence, the number of stages formed in each individual burrow can be limited either by the thickness of the underlying argillaceous bed being mined or by limitations of the size of the organism itself.

Characteristically the radial rays are passively infilled by the surrounding coarser sediment (fine sand) in which the organism was living, but some parts of the 'tubes' are

infilled with faecal stuff which probably manifests active filling, but without spreite.

The diameter of the subcircular rosette-shaped structure increases in proportion to the number of feeding stages present (Text-Fig. 13.2). The rosette normally consists of 4 to 5 stages and reaches a diameter of 7 to 8 cm. The central column is filled with the proximal part of the arms/rays with or without a small areola (the latter feature being less than a centimetre in diameter). The length of the arms is variable and is proportional to the stage in which they developed (their thickness and length increases in each successive stage) because the size of the organism probably also increased with each developing stage. Most of the arms are straight or slightly sinuous. The cross-sectional shape of the arms is uniform (cylindrical-like features) throughout all stages.

These structures occur as hypichnial, normally full-relief traces, and probably manifest the feeding pattern of a variety of worm. The rosette-shaped trace evidently indicates a progressive clockwise spiral pattern of sediment mining about a vertical axis by the organism in the underlying nutritious mud. This spiral pattern of mining is very efficient in harvesting food from a maximum volume of sediment in a minimal area. The ichnogenera under consideration, characterized by a clockwise helicoidal multistage pattern of radiating arms which lack spreite is unique among the rosette-shaped trace fossils. Consequently, this reflects a unique behavioral pattern of the producer organism.

Remarks and comparison: The present new ichnogenus is totally

different from other rosette-shaped structures that are formed as surface resting or resting-like impressions (e.g. Asteriacites, and Asterichnites) or manifest epichnial feeding traces on the surface of the bed (such as Asterichnus, Gyrophyllites and Micatuba; see Text-Fig. 13.1). Several types of rosette-shaped hypichnial trace fossils remain to be compared here at the generic level. Some of these are spreite-bearing forms as described by Seilacher & Helemben (1966) and Fürsich (1985), and can be readily differentiated from the non-spreite-bearing forms. The helicoidal nature of the mining pattern in Helikospirichnus veeversi permitted the harvesting of food from the entire surrounding area within the one plane at each stage but without vertical movement of each of the feeding 'tubes' (either upwards or downwards) in any way that would inevitably result in the formation of spreite. The multistage helicoidal pattern of the arms in H. veeversi is not comparable to, and manifests a much more efficient pattern of food-harvesting per unit volume of sediment than, any other hypichnial rosette-shaped trace fossil. In respect to its food harvesting efficiency H. veeversi resembles Spirophyton and Zoophycos to some extent but the pattern of helicoidally mining in each of the latter is different to that of H. veeversi, involving as it does a continuous corkscrew-like pattern of the animal.

Studied material: All the studied specimens came from a unit exposed at two adjacent localities. Most of the specimens are from Bangalley Head (areas 8a and 8b) and one specimen was collected from the same unit exposed at the Hole in the Wall area

(area 11). Three other specimens were collected from the St. Michaels Cave area (area 5). The holotype specimen was chosen from material collected from Bangalley Head (sample. 803/MU.44420 shown in Plate 45 Fig. a), and the paratypes were selected from among several traces of H. veeversi in rock samples 803/MU.44420 and 804/MU.44421, and 802/MU.44419.

Distribution: All of the studied material comes from trace fossil interval IE (subintervals IE1 - IE5), from the Middle Newport Member exposed at Bangalley Head (area 8), St. Michaels Cave (area 5) and the Hole in the Wall (area 11).

Preservation and association: All the studied specimens are preserved as full-relief hypichnial traces (exposed on the sole surface of the sandstone beds). The producing organism lived in sand and burrowed into the underlying muddy sediment for feeding (cf. Text-Fig. 13.2). These rosette-shaped structures are invariably associated with escape-structures (Plate 44, Fig. b) and collapse-structures (Plate. 78, Fig. e). Their spatial distribution is such that even in a crowded situation, the traces never overlap each other, and are at least about 2 to 3 cm apart from each other (i.e., measured in terms of distance to nearest neighbor).

Ichnofacies and palaeoenvironmental affinities: Rosette-shaped trace fossils were first discovered in ancient deep-marine flysch deposits of the Nereites ichnofacies. More recently, many of them have been recorded in modern-day shallow-marine to brackish-marine intertidal mud-flat and mixed-flat areas of the Skolithos ichnofacies (Seilacher, 1977). Food distribution in sediments of these shallow areas is similar to that in bottom sediments of the

deep sea. In the study area H. veeversi occurs within the Skolithos ichnofacies. The association of collapse-structures and escape-structures with the Triassic rosette traces described here favors a brackish- to shallow-marine intertidal interpretation.

Asteriacites Von Schlotheim, 1820

Ichnospecies sp?

Plate 75, Fig. b

Diagnostic features: Resting-traces comprising star-shaped impressions (concave epirelief) with five short radiated arms produced by a small asterozoan.

Description and ethology: Star-shaped trace fossils about 3 to 5 cm in diameter consisting of five short rays projecting outward from a central area approximately about 1 cm in diameter. The individual rays are short and taper to a sharp pointed tip. Preserved as concave-epirelief impressions lacking surface texture/ornamentation. No migration or movement of the arms or body is evident in the specimens studied.

Remarks and comparison: Seilacher (1953) described A. quinquefolius made by a burrowing and resting sea star (star fish); and A. lumbricalis, described by Von Schlotheim (1820), was produced by brittle stars (ophiuroids). Chamberlain (1971) described Asteriacites from Pennsylvanian rocks in Oklahoma and grouped them into three different forms defined by their morphology and ornamentation. He also named A. lumbricalis as hiding forms and regarded them as true resting traces. The nomenclatural status of Asteriacites is still confused. The Triassic specimens of Asteriacites studied here are small and the rays are uniformly

short with sharp tips. The shape of these rays is similar to that in A. quinquefolius, but the details of the Sydney Basin traces are not sufficiently well preserved to allow them to be referred to other species. The specimens show no evidence of migration or movement of the organism's body or arms such as is illustrated by Seilacher (1953).

Distribution: The specimens studied here occur in measured section 10b.1.1 of trace fossil subinterval IE1 in the Middle Newport Member exposed at Bilgola Head (area 10b). The specimens have not been retrieved from the field.

Preservation and association: The studied specimens are preserved as concave epirelief forms on the top surface of a sandstone bed. They are not associated with any other trace fossils.

Ichnofacies and palaeoenvironmental affinities: The most likely producer of these traces is one or more types of asterozoan. Asterozoans are most commonly reported from shallow-marine environments of normal salinity. However, some modern ophiuroids and asteroids can inhabit very low-salinity, brackish-water environments. The Triassic specimens studied here occur in a thin-bedded sandstone facies which can be interpreted as tidal-flat (mix-flat) deposits. This interpretation is supported also by the small size of the traces which suggests the producing organism lived in restricted marine (brackish) conditions. Asteriacites is a characteristic trace fossil of the Skolithos ichnofacies and also occurs in this ichnofacies in the study area.

P. bischoffi ichno. sp. nov.

Plate 73, Figs. a & b

Derivation of the name: Named for Dr. G. C. O. Bischoff of the School of Earth Sciences, Macquarie University.

Generic assignment: Flabellate or broom-like hypichnial feeding structure. In the present classification (Text-Fig. 13.1) this burrow is tentatively regarded as an incomplete? or not fully developed rosette structure.

Specific assignment: Bundle-shaped feeding burrows with separate distinct stages of feeding pattern.

Diagnostic features: Horizontal flabellate or broom-like pattern of hypichnial traces, consisting of three main or master cylindrical horizontal tunnels at the proximal part, each of which divides distally into several small free tunnelets at acute angles. The tunnelets show distally a pattern similar to that characteristic of retrusive spreite (Text-Fig. 13.3A & D). The surface of the wall shows no sign of ornamentation.

Description and ethology: The traces are characterized by a very distinct set of three separate master tunnels in the proximal part of the burrow system, but in the distal part these assume a more complex interwoven burrow network involving division of the master tunnels into several smaller free cylindrical tunnelets (see Text-Fig. 13.4). The smaller tunnelets in the distal part of the burrow form simple Y-shaped elements about 1 cm long and 0.5 cm in burrow diameter. The overall structure is 7 cm in length, 3 cm in diameter, and 1 cm in thickness. Some small isolate tunnelets, especially in the first stage (stage A) are partly com-

TEXT-FIG. 13.3. Overlay drawing from a photograph of the specimen (07/MU. 44499) of the new convex hyporelief ichnospecies Phycodes bischoffi showing broom-shaped or flabellate-shaped (semi-circular) development of subparallel feeding stages.

A-C. Development of the individual stages shown separately in plan (top frames) and transverse cross-section (bottom frames).

D. Superposition of all stages of developed of the burrow seen in plan (top frame) and transverse cross-section (bottom frame).

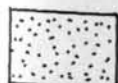
EXPLANATION

- Frame A. First stage (A) with substages (A1-A5), and transverse section from the distal part shown in the lower box.
- " B. Second stage (B) with substages (B1-B6), and transverse section from the distal part shown in the lower box.
- " C. Third stage (C) with substages (C1-C4), and transverse section from the distal part shown in the lower box.
- " D. Superposition of all stages (A-C), and transverse cross-section from the distal part shown in the lower box.

- L Length of the burrow.
- W Width of the burrow.
- T Thickness of the burrow.



Associated Planolites.



Fine-grained sandstone (overlying and infilling).



Siltstone (host rock).



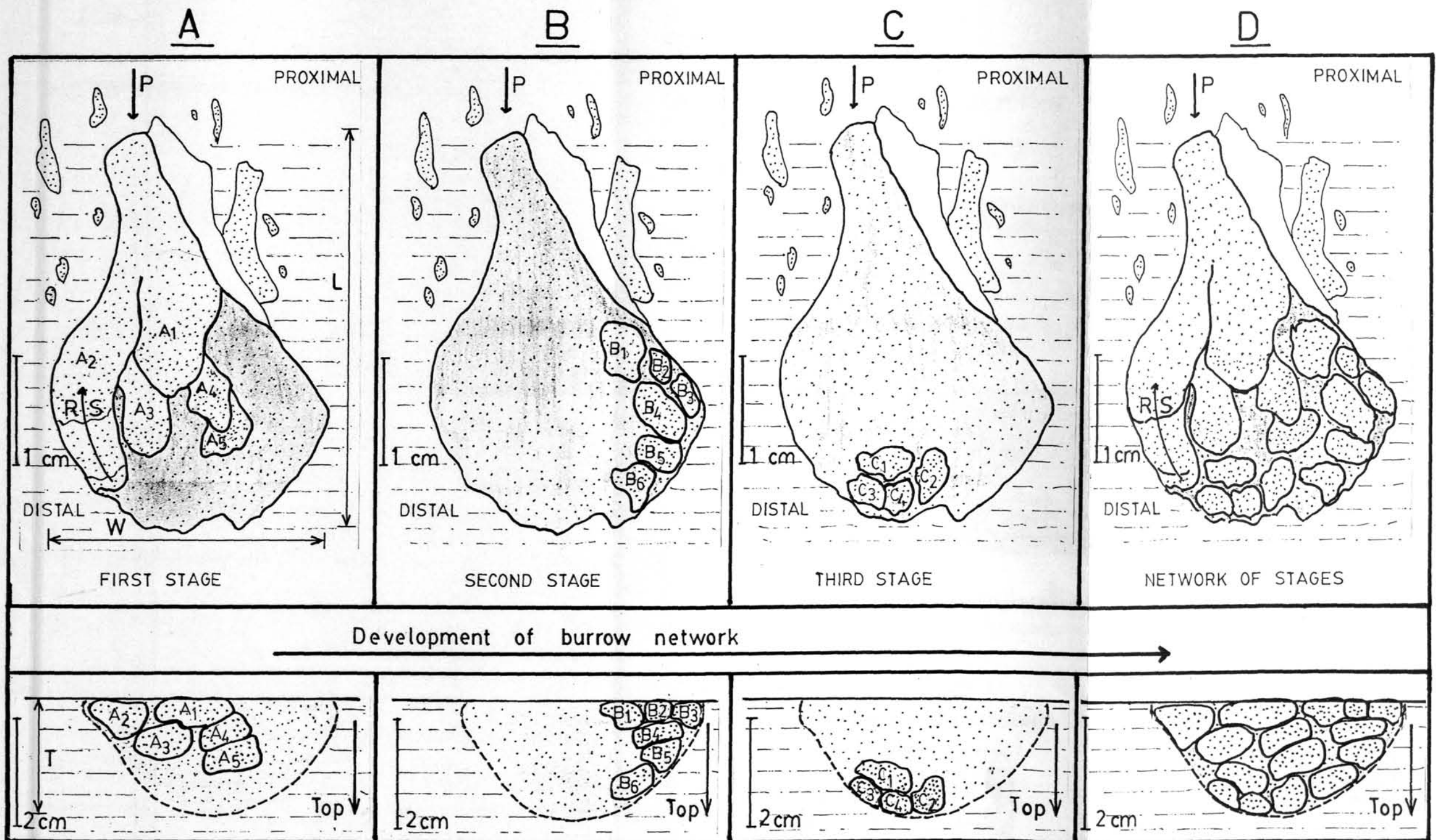
Inferred boundary of the trace fossil.

Position of the producer organism.

Way up.



Retrusive spreite (and movement direction of the organism).

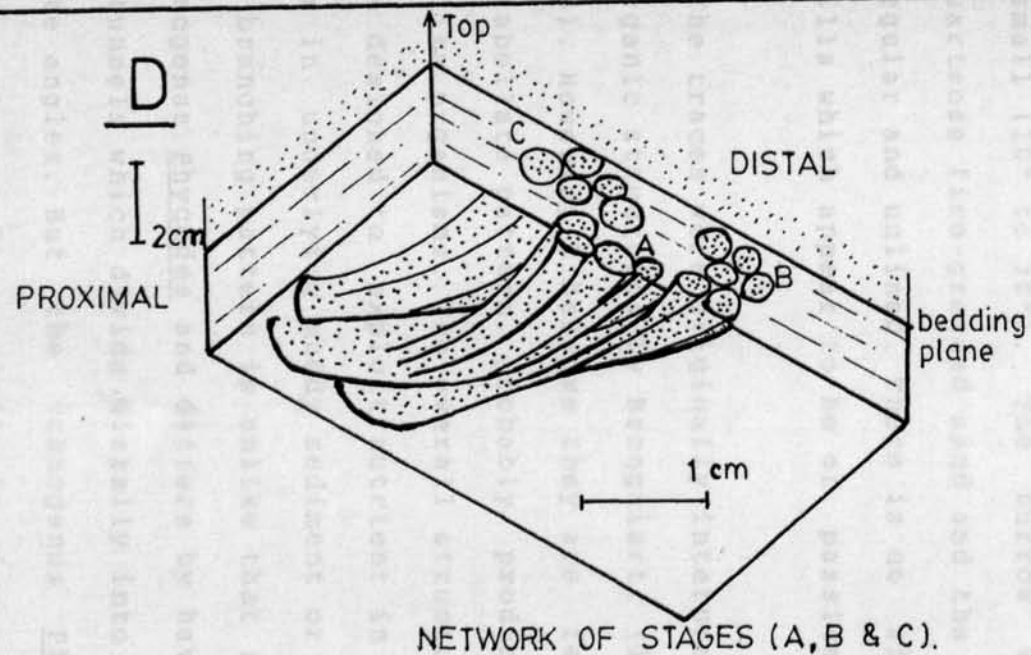
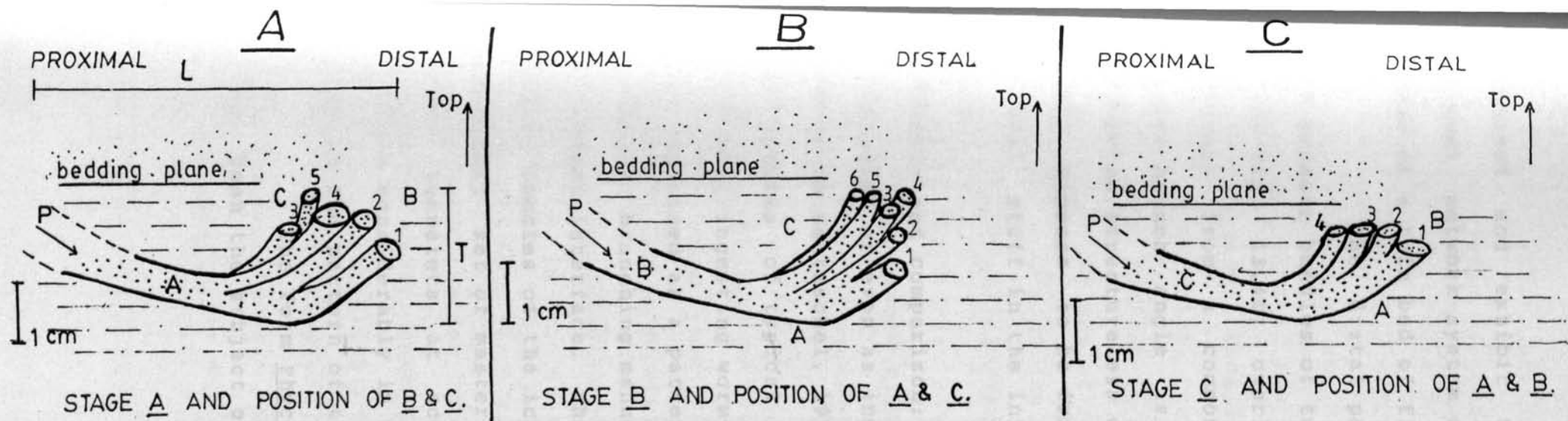


TEXT-FIG. 13.3.

TEXT-FIG. 13.4. Reconstruction of the new convex hyporelief ichnospecies Phycodes bischoffi.

A - C. Longitudinal views of each of three successive feeding stages shown separately but in each case relative to the position of each other.

D. Three-dimensional reconstruction of all three stages seen in oblique view looking upwards onto the sole of the host bed.



TEXT-FIG. 13.4.

pressed and exhibit the retrusive spreite-like pattern. The tunnel network system occurs as convex hypichnial traces on the base of a thin bed of fine sandstone.

The distal part is composed of interwoven dichotomous or palmate bundles of tunnelets at slightly different levels (cf. Text-Fig. 13.4D) overlying one another, and which appear to diverge from a common centre like the roots of a tree. The inter-branch angle is small (10° to 30°). The burrow infills comprise structureless quartzose fine-grained sand and the burrow wall appears to be irregular and unlined. There is no sign of faecal stuff in the infills which appear to be of passive origin.

Remarks and comparison: The traces were originally interpreted as 'fucoids' or even as inorganic structures by Brongniart, (1828 - cited in Häntzschel, 1975). However, I believe they are feeding-structures of typical flabellate pattern, probably produced by sediment-ingesting worm-like organisms. The overall structure can be explained as a pattern designed to exploit nutrient in a systematic branching manner in underlying muddy sediment or at a sediment interface. The branching pattern is unlike that in any other species of the ichnogenus Phycodes and differs by having a distinct set of master tunnels which divide distally into small free tunnelets at acute angles. But the ichnogenus Phycodes varies considerably in morphology and especially in size, shape, and in the pattern of the feeding tunnels.

The form Phycodes Richter (1850) (or comparable forms) has been the subject of three excellent studies: Sarle (1906),

Magdefrau (1934), and Seilacher (1953) have each contributed to our knowledge of these bundle-shaped feeding-traces known from the lower Palaeozoic of North America, Europe, and Asia.

The size of the specimens studied here are much smaller than most of the specimens of P. cincinnatum described by Magdefrau (1934). The free branches or tunnelets of P. bischoffi are also larger than those in P. cincinnatum and have less preferred orientation. The wall surface is smooth rather than irregular. The pattern of spreite resembles that in P. cincinnatum described by Seilacher (1955). One specimen exhibits retrusive spreite in one of the tunnelets but spreite are not present in the free branches (Text-Fig. 13.3). P. pedum described by Seilacher (1953) is also dissimilar in having gently-inclined distal tunnels and bifurcating horizontal shafts at depth to give rise to short free tunnels as vertical branches.

It is very difficult to generalize the overall pattern of P. flabellum described by Miller & Dyer (1878), because the species shows much variation; but the specimen chosen as the type species is more flabellate. Again, the new species described here as P. bischoffi is much smaller and has a lesser number of tunnelets in the distal parts (i.e., less crowded branches). Although some free branches of the Triassic specimens studied here are curved or curvilinear as in P. palmata Hall (figured in Osgood, 1970), and P. curvipalmatum Pollard (1981), the new species is relatively larger in size than these forms, more fan- or flabellate-shaped, has well defined orientation of the master branches or tunnels, and also a fewer number of tunnelets. In P. curvipalmatum the master branches show a crude pattern of retru-

sive spreite in their proximal parts but not in the tunnelets.

The most detailed ethological analysis of Phycodes was given by Seilacher (1955). He considered it a feeding- structure (fodinichnia) where the organism systematically mined out the nutrient-rich layer along a silt-mud interface. The animal first burrowed down through the silt, then moved horizontally along the interface before once again angling up into the silt bed. The resulting structure resembles a broad 'U' in which one limb is steeper than the other. Following this, the organism withdrew from the distal portion of the burrow and proceeded to excavate a new tunnel adjacent to the old one. This activity resulted in a retrusive spreite pattern, and when a given area was mined out a new master tunnel was formed in another adjacent location and the entire process was repeated again.

Seilacher (1955) drew an analogy between the bundled feeding shafts of Arenicola marina and those of Phycodes, but directly comparable Recent structures are still unknown. The fact remains that the basic feeding pattern of Phycodes could have been made by any one of a number of organisms.

Studied material: The holotype specimen (Plate 73, Figs. a & b) was chosen from only two examples of this trace fossil, both of which occur in sample no. 07/MU.44499. The paratype specimen is the other example in the same sample.

Distribution: The rock sample studied here was collected from section 8.1.1, in trace fossil subinterval IE3 of the Middle Newport Member exposed at Bangalley Head (area 8).

Preservation and association: The specimens studied here are

preserved as convex-hyporelief (sole surface) forms in a quartzose sandstone bed and are associated with Planolites.

Ichnofacies and palaeoenvironmental affinities: The burrows of Phycodes have been recorded in both marine (Osgood, 1970) and non-marine (Pollard, 1981) palaeoenvironments. The present traces are regarded as feeding-burrows of infaunal worms that exploited organic materials in muddy sediment in a systematic manner and their association with the ichnogenus Planolites may reflect a more brackish-marine to normal-marine environmental preference. It is not possible to discount either of these particular palaeoenvironments in the case of the Newport Formation examples on the basis of the trace fossil assemblage itself. Phycodes can occur in various ichnofacies but in the study area it occurs within the Skolithos ichnofacies.