

## CHAPTER 10

### PELLETS AND OVOID-SHAPED STRUCTURES

## PELLETS AND OVOID-SHAPED STRUCTURES

### 10.1. INTRODUCTION

In the present study the ovoid and pellet structures are divided into two major groups based on their reconstructed or inferred organic or inorganic origin (see Text-Fig. 10.1). These two different categories of pellets and pellet-like features can be readily differentiated on the basis of shape, surface ornamentation, composition, internal structures and associations with body or trace fossils. This chapter is mainly concerned with the ovoid- or rod-shaped (short cylindrical) pellets produced organically by invertebrate organisms. These small pellets have previously been termed "microcoprolites" (Ekdale et al., 1984), "coprolites" (Häntzschel, 1975; Häntzschel et al., 1968), or "coprolithidii" (Vyalov, 1982). These coprolites or microcoprolites are produced by a number of different processes and by several different trophic groups of small invertebrate organisms involving a faecal origin. Additionally, there are certain pellets that are not produced exclusively as excrement (i.e., as faecal pellets) by suspension- or deposit-feeding organisms and these pellets cannot be considered as microcoprolites or coprolites. These pellets are simply produced by mouth-part appendages of crustaceans (Allen & Curran, 1974; Pope & McDonald, 1981). Many suspension-feeding organisms (bivalves in particular) also produce these pseudofaeces composed of material that is collected by the gills but considered inedible and consequently is beaded together as pellets by mucus and discarded at a later stage without being ingested. There are also ovoid-shaped structures which are formed inorganically (i.e., non-coprolites or non-

pseudofaeces origin); because these also constitute ovoid-shaped structures they are mentioned here for comparison.

The term coprolite has been defined in different ways (Amtutz, 1988), but the shortest definition was made by Häntzschel (1973) as "fossilized excrements of animals". This definition seems to be the best because it covers both size and composition and includes all large and small coprogenic sedimentary features. The major problem of the coprolites lies in regard to their 'systematic position'. Abel (1935) considered them as lebensspuren (together with their associated producer traces); however, Häntzschel (1975) accepted that the coprolites do not correspond entirely to the widely accepted definition of trace fossils. Thus, the special position of the coprolites requires them to be considered separately. Häntzschel's work has been published with others (Häntzschel et al., 1965) as an annotated bibliography of coprolites, covering 400 publications dealing exclusively or in part with coprolites. The term 'Coprolichnia' proposed by Macsotay (1967) for all coprolites is incorrect because the ending 'ichnia' means tracks (i.e., does not include features of faecal origin). Vialov (1982) coined the term 'Copro-lithidii' for all pellets of coprogene origin, which he further subdivided into genetic groups according to their producers. Bronnimann (1972) studied microcoprolites in thin-sections cut both longitudinally and transversely with respect to the long axis of the pellets and revealed the presence of internal canals with different morphologies and arrangements, and which he used to differentiate the different coprolites produced by anomuran

crustaceans.

These faecal pellets have fossilization potential because they are composed primarily of sediment rather than organic matter. Some pellets are more compact than the others and hence have more potential for preservation, especially where produced by burrowing organisms (worms and crustaceans). Such faecal pellets are normally formed together in clusters or infill Thalassinoides or Ophiomorpha burrows or both. The burrows and pellets must be studied separately and named differently but linkage of these two types of trace fossils must be recognized as they are produced by the same animal.

## 10.2. CLASSIFICATION

The pellets or ovoid-shaped structures are subdivided in the present classification scheme into two major groups. The first group comprises several types (types A, B, C, and D) which are formed organically; the second group contains only one type (type E) which is formed inorganically (see Text-Fig. 10.1).

The group of (organically formed) pellets can be further divided into two major categories on the basis of their size, shape, and the nature of the producer organism. The first category contains pellet types A, B, and C, the pellets of which are smaller, subspherical or cylindrical and are mainly produced by small invertebrates. The differentiation of these individual pellet types is based on their mode of formation or their ethological origin: type A comprises mainly spherical-, rod-, cylindrical-, or other similar shaped small pellets of faecal origin (microcoprolites); contrastingly, types B and C are of non-faecal

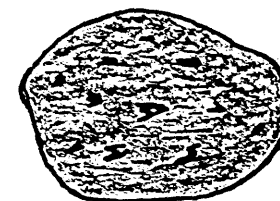
TEXT-FIG. 10.1. Proposed classification of organically produced pellets (of both coproge origin and non-coproge origin) and ovoid-shaped structures of inorganic origin (pseudotraces). The classification is based mainly on examples from the study area. The first group comprises the organically produced pellets of types A, B, C, and type D. These organically produced pellets are further subdivided into two groups on the basis of their origin. Pellets types A and E are of coproge origin, as defined by their shape, size and internal structures, and pellets types B and C are of non-coproge origin. Type B pellets result from feeding activities of deposit-feeding crustaceans and type C pellets from excavation activities using appendages of the mouth parts. The second group of pellets (type E) is of inorganic origin (pseudotraces) and are developed mechanically. Asterisks indicate those pellets and ovoid-structures that occur in the study area.

# PELLETS AND OVOID-SHAPED STRUCTURES.

ORGANIC ORIGIN;  
UNIFORM SIZE WITH  
EITHER SPHERICAL,  
CYLINDRICAL OR OTHER  
SHAPES.

\* TYPE E

INORGANIC ORIGIN;  
PSEUDOTRACES OF  
NON-COPROGENE ORIGIN;  
SIZE NOT UNIFORM,  
SPHERICAL, SUBSPHERICAL,  
OR ELLIPSOIDAL SHAPE.



NON-COPROGENE ORIGIN  
(PSEUDOFECES) SPHERICAL - TO  
IRREGULAR-SHAPED, MEDIUM  
TO LARGE SIZE, COMPRISING  
MAINLY OF SAND.

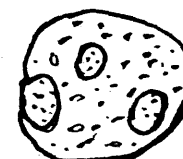


\* TYPE B

PRODUCED DURING FEEDING  
ACTIVITY; SIZE ABOUT 2mm;  
SPHERICAL-SHAPED AND  
FOUND BOTH INSIDE AND  
OUTSIDE THE BURROW.

\* TYPE C

PRODUCED DURING  
EXCAVATION ACTIVITY;  
SIZE ABOUT 2 TO 5mm;  
IRREGULAR-SHAPED, NORMALLY  
FOUND INSIDE THE BURROW  
AND WITHIN THE BURROW WALL.



COPROGENE ORIGIN;  
COPROLITES OR  
MICROCOPROLITES WITH  
VARIABLE SIZE, SHAPES,  
INCLUDING SPHERICAL,  
ELLIPSOIDAL AND  
CYLINDRICAL.

\* TYPE A

MICROCOPROLITES  
SEVERAL SPECIES CAN BE RECOGNIZED ON THE BASIS OF SIZE, SHAPE,  
SURFACE ORNAMENTATION, COMPOSITION, OCCURRENCE, PRESERVATION, AND  
FOSSILIZATION (NEED THIN-SECTIONAL STUDY FOR RESOLUTION OF INTERNAL  
STRUCTURES). MAINLY PRODUCED BY SMALL INVERTEBRATES.

TYPE D

COPROLITES;  
LARGE SIZE WITH VARIABLE  
SHAPE AND COMPOSITION;  
PRODUCED BY LARGER  
INVERTEBRATES AND  
VERTEBRATES.

A1



TYPE A1  
SUBTRIANGULAR-  
OR SUBSPHERICAL  
SHAPED;  
e.g., FAVREINA  
BRONNIMANN,  
1955.

A2



TYPE A2  
CYLINDRICAL - OR  
OBLONG-SHAPED;  
e.g., TIBIKOIA  
HATAL et al.,  
1970.

A3



TYPE A3  
ROD-SHAPED  
e.g., THARONETIA  
BRONNIMANN et al.,  
1972, AND  
PRETHOCOPROLITHUS  
ELLIOTT, 1962.

A4



TYPE A4  
OVAL - OR SUB-  
TRIANGULAR-SHAPED;  
e.g., PALAXIUS  
BRONNIMANN &  
NORTON, 1960.

A5



TYPE A5  
TEAR - OR DROP-  
SHAPED;  
e.g., CARPOLITHUS  
BROWN, 1937.

OTHERS

D1



TYPE D1  
FLAT BACILLIFORM  
e.g., BATRYLLIUM  
(HEER, 1853)

D2



TYPE D2  
ENTANGLED  
OR INTERTWINED  
STRINGS; e.g.,  
LUMBRICARIA  
MUNSTER, 1831.

D3



TYPE D3  
ZIGZAG;  
e.g.,  
DISCOTOMACULUM  
CHILONKAR & BADWE, 1972.

PELLETS OF MANY  
OTHER SHAPES  
COMPOSITIONS AND  
SIZES PRODUCED BY  
VERTEBRATES AND  
INVERTEBRATES.

TEXT-FIG. 10.1.

origin and consist of two sizes. Type B pellets are medium-sized (about 2 mm), produced by feeding behavior, and are located either in the burrow walls or are distributed outside the burrows. Type C pellets are of larger size (between 2 and 5 mm), are produced during excavation activity and are normally located in the burrow walls.

The latter group of non-faecal pellets comprise deposits formed by the feeding activities of infaunal anomuran crustaceans. In a modern equivalent, the crab Uca pugilata (Allen & Curran, 1974) excavates its burrow twice each day and constructs a new burrow periodically. The type C pellets, formed during burrow excavation, are later inserted into the burrow wall to enhance its stability or are plugged into the burrow's aperture to seal it as the tide rises. The second and smaller variety of non-faecal pellets, i.e., the type B pellets, are formed during feeding and consist of organic matter and sand grains rejected by the crustacean's specialized feeding appendages. This type of ecological behavior is also clearly seen in all 'bubbler crabs' (Pope & McDonald, 1981). The bubbler crab produces small spherical feeding pellets of sand arranged in a radial pattern about a central vertical burrow, like radial spokes in a wheel. When the tide is in, the animal remains buried in the burrow. The actual process of sand bubble formation takes place during low tide. The high tide spreads a thin sheet of organic matter on the substrate. When the tide ebbs, the bubbler crab begins to feed, using its front claws to scrape the film of organic matter and sand into its mouth. In the mouth parts are the various appendages which remove the food from the sand and move the sand grains

upwards to the top of the mouth (which is a vertical slit). The bubble of sand grows progressively until it reaches a size which the crab regards as too big to carry. It then puts down the sandball and sweeps it out of the way with a sideways kick of a rear foot. The crab begins to feed once more, creating a new 'spoke' of sand-bubbles next to the previous one. But this radial pattern is probably rarely preserved in the fossil record because it is washed away by the following tides.

The second major category of coprogenic features are referred to here as type D coprolites, but these have not been encountered in the study area; they are larger in size than the pellets of type A, exhibit variable shapes and are mainly produced by larger invertebrates or vertebrates.

The second major group of pellets, referred to here as type E pellets, are non-organic pellet- or ovoid-shaped structures (see Text-Fig. 10.1), examples of which occur in the study area.

### 10.3. SYSTEMATIC ICHNOTAXONOMY

#### Pellet type A (faecal pellets)

Plate 34, Fig. a  
Plate 35, Fig. c

Diagnosis: Small spherical, or subcylindrical pellets of faecal origin (microcoprolites).

Remarks (distinguishing features): Spherical- or oblong-shaped subcylindrical small (diameter or long dimension less than 2 mm) pellets of faecal origin. Such pellets are concentrated near the openings of vertical burrows of modern crustaceans (Ophiomorpha



or Thalassinoides. No ornamentation is evident on the pellets' surfaces and internally they seem to be structureless.

**Description and ethology:** The spherical- or oblong-shaped small pellets are believed to be of faecal origin and are invariably associated either with Ophiomorpha or with Thalassinoides. These faecal pellets are very small (less than 2 mm in diameter) and no distinctive ornamentation is evident on their surfaces. These pellets consist of dark brown clay (probably containing some organic matter) and grains of very fine sand. The pellets are also commonly enveloped by dark brown-coloured clay. This enveloping clay material possibly consisted of a mucus coating at the time of excretion but the other possibility is that it is of diagenetic origin. Two modes of occurrence of the pellets can be recognized: as loose pellets in sediments (Plate 34 Fig. a), and as closely-packed masses which in some places clearly infill entire burrows. The explanation of infilling is very clear: the rather loose packing of the pellets within the burrows suggests that they represent passive infills that have been washed into the burrows by current action rather than being stuffed into the burrows by the producer organism. These faecal pellets and the burrows of Ophiomorpha and Thalassinoides occur together in many places in the study area and are present in many horizons (especially in trace fossil interval IC).

**Comparison:** Type A pellets of faecal origin (microcoprolites) can be separated from Favreina and Favreina-like pellets by virtue of their smaller size and lack of surface ornamentation (Kennedy et al., 1969) and internal structures (Kennedy et al., 1969, and Ekdale et al., 1984).

**Distribution:** These faecal pellets or microcoprolites occur in many horizons of trace fossil interval IC of the study area and are commonly associated there with either Ophiomorpha or Thalassinoides or both.

**Studied materials:** Two examples of pellets are illustrated in Plate 34 Fig. a and Plate 35 Fig. c. Figure a is from sample 210/MU.44390 of trace fossil subinterval IC3/4 of the Bald Hill Claystone at Turimetta Head (area 2). Figure c is from trace fossil subinterval IE7 of the Middle Newport Member at Little Head (area 7). The latter material has not been retrieved from the field.

**Preservation and association:** These microcoprolites or faecal pellets are preserved as full-relief features and are associated with either Ophiomorpha or Thalassinoides or both.

**Ichnofacies and palaeoenvironmental affinities:** These faecal pellets, associated with Ophiomorpha and Thalassinoides belong to the Skolithos ichnofacies developed in palaeoenvironments of a brackish-marine or fluviially-dominated lagoon or estuary.

#### Pellet type B (feeding pellets)

Plate 35, Figs. b & c

**Diagnosis:** Medium-sized pellets of non-faecal origin comprising sand grains, produced by feeding.

**Remarks (distinguishing features):** Pellets of non-faecal origin of medium size, which are developed while feeding by appendages of the mouth parts of anomuran or brachyuran-like crustaceans that probably excavated the burrows Ophiomorpha and Thalassinoides.

**Description and ethology:** These non-faecal medium-sized pellets (about 2 mm diameter) comprise fine-grained sand and are developed by mouth parts of crustaceans during feeding. The feeding crustacean uses its front claws to scrape the film of sand and food into its mouth. In the mouth there are various appendages which remove the food from the sand grains and move the latter up into the top of the mouth where it is formed into a ball. These feeding balls or sand bubbles are then left behind on the substrate near the burrow when they become too large to be carried further. These sand bubbles are subsequently swept about by currents, many to become lodged into and hence infill the burrows, but others to remain outside the burrows as loose pellets in the sediments. These sandballs may be swept away some distance from the burrow of the producing crustacean and may or may not be associated with other relict Ophiomorpha and Thalassinoides burrows produced by the same animals.

In this context it should be mentioned that other feeding pellets that occur within the wall of Ophiomorpha burrows (Text-Fig. 4.4, Plate 31 Figs. a & b, and Plate 33 Figs. a & b.) have a different explanation. Most crustaceans are deposit-feeders when they are developing their burrows and change to suspension-feeders after burrow completion. While the crustaceans are digging their burrows and function as deposits-feeders they generate feeding pellets. But, instead of kicking the pellets away like the bubbler crab (which action is precluded by the fact that the animal is inside the burrow) the organism has no alternative but to push these balls into the wall of the burrow. These

feeding pellets will be later grouped together as larger excavation pellets (pellet type C) (Allen & Curran, 1974; and Fürsich, 1978).

The feeding pellets are normally clean (free from organic matter), more spherical than any other pellets formed organically in the study area, and, as mentioned above, are composed of fine-grained sand. No organic matter of faecal or non-faecal origin is associated with them. These pellets may or may not be associated with Ophiomorpha or Thalassinoides; however, in cases where they are present in close spatial association with these two different kinds of burrows, they have been used to demonstrate a common producer-animal origin for these burrows (e.g. see Kennedy et al., 1969). No external or internal structures are evident in these type B pellets.

**Comparison:** These type B pellets (non-faecal) are more spherical, lack organic matter and evidence of faecal origin, including internal structures. All these pellets are free from surface ornamentation and are composed mainly of fine-grained sand. Because they are genetically different from microcoprolites in origin, they are more comparable with the pellets formed by feeding activities of crustaceans (such as bubbler crabs, cf. Pope & McDonald, 1981), and also with the smaller-sized pellets produced by the modern crab Uca pugilata during feeding (cf. Allen & Curran, 1974).

**Distribution:** In the study area these type B feeding pellets commonly occur dispersed throughout the sediments, either associated with type A pellets (faecal pellets) or with type C pellets (excavation pellets). These feeding pellets occur in many

beds composed of fine to very fine sandstone and are invariably associated with the burrows Ophiomorpha and/or Thalassinoides which have probably been produced by the same organism. The pellets illustrated in Plate 35 Fig. b are from trace fossil subinterval IC5 of the Bald Hill Claystone at Turimetta Head (area 2), and those in Fig. c of the same plate are from trace fossil subinterval IE7 of the Middle Newport Member at Little Head (area 7).

**Studied material:** None of the studied material containing type B pellets has been retrieved from the field.

**Preservation and association:** The type B pellets are preserved as full-relief features and may be associated with pellets of other origin as well as Thalassinoides and Ophiomorpha burrows produced by the same organism that produced the type B pellets.

**Ichnofacies and palaeoenvironmental affinities:** These feeding pellets associated with Ophiomorpha and Thalassinoides burrows belong to the Skolithos ichnofacies developed in brackish-marine palaeoenvironments of a fluvially-dominated lagoon or estuary (Text-Fig. 5.2 and Text-Fig. 9.6). The modern crab Uca pugilata produces this type of pellet in the protected foreshore zone on the lagoon side of Shackleford Banks in the vicinity of Beaufort, North Carolina (Allen & Curran, 1974).

#### Pellet type C (excavation pellets)

Plate 31, Figs. a & b  
Plate 34, Fig. b  
Plate 35, Fig. b

**Diagnosis:** Larger pellets of non-faecal origin, produced by burrow excavation processes.

Remarks (distinguishing features): Non-faecal pellets of relatively large diameter (about 5 mm) that are fashioned by appendages during excavation of the burrow. These larger excavation pellets may consist in turn of smaller feeding pellets (i.e., type B pellets) (Text-Fig. 4.4). These type C pellets are associated with the burrows Ophiomorpha and Thalassinoides which were probably produced by the same organism that made the pellets.

Description and ethology: These (type C) excavation pellets are larger in size (about 5 mm) and more irregular in shape than the type B feeding pellets. These two types of pellets commonly occur both together (Plate 35, Fig. b) and separately (Plate 34, Fig. b). These excavation pellets are produced while the animal is excavating its burrow. Most crustaceans enlarge their burrows periodically (Allen & Curran, 1974). The pellets are subsequently used to plug up or to close the burrow's aperture or more commonly are plugged into the adjacent wall of the burrow in the immediate position of the animal at that particular stage of the excavation. These large excavation pellets are normally composed of smaller feeding pellets (i.e., type B pellets) which are pushed into the burrow wall in a series (cf. Text-Fig. 9.4) to form a mammillated wall-lining in most of the Ophiomorpha burrows. Two modes of occurrence can be recognized: as loose pellets in the sediment (Plate 34 Fig. b and Plate 35 Fig. b) or as closely-packed masses which clearly build the mammillated burrow walls of Ophiomorpha (Plate 31 Figs. a & b). The size of these excavation pellets can be relatively large (about 1 cm in diameter) and their shape rather variable. They are normally intact in

the burrow walls and are relatively larger than the feeding pellets because the producer organism's ability to carry them in its external appendages is not constrained by their size in contrast to the manner in which the feeding pellets are formed. The pellets comprise an agglutination of fine to medium sand grains and type B feeding pellets, and are commonly arranged in the burrow wall in a sequential manner (Text-Fig. 9.4).

**Comparison:** The type C pellets are the largest pellets that developed organically in the study area. The shapes of these pellets are much more irregular than the type B pellets. These larger type C pellets are more comparable with the excavation pellets produced by the modern crab Uca pugilata (Allen & Curran, 1974).

**Distribution:** The type C excavation pellets have two modes of occurrence: as loose entities dispersed through the host sediment or intact in the burrow wall of Ophiomorpha nodosa. The excavation pellets normally occur in beds with the burrows Ophiomorpha and Thalassinoides that were produced by the same organism that produced the type C pellets. The pellets illustrated in Plate 34 Fig. b are from trace fossil subinterval IE7 of the Middle Newport Member at Little Head (area 7), and those illustrated in Plate 35 Fig. b are from trace fossil subinterval IC5 of the Bald Hill Claystone at Bungan Head (area 13). In both areas the pellets occur as loose entities within the sediments. The pellets illustrated in Plate 31 (Figs. a & b) are from trace fossil subinterval IC3/4 of the Bald Hill Claystone at Turimetta Head (area 2). As far as I am aware, these type C pellets do not occur in any other trace fossil intervals of the study area apart

from those mentioned here.

**Studied material:** The pellets illustrated in Plate 34 Fig. b and Plate 35 Fig. b have not been retrieved from the field. Those illustrated in Plate 31 (Figs. a & b) are from sample 214/MU. 44363 of trace fossil subinterval IC3/4 of the Bald Hill Claystone at Turimetta Head (area 2).

**Preservation and association:** These excavation pellets are preserved as full-relief features either as dispersed entities or juxtaposed serially in the walls of the burrow Ophiomorpha.

**Ichnofacies and palaeoenvironmental affinities:** These larger excavation pellets are associated with the burrows Ophiomorpha and Thalassinoides which belong to the Skolithos ichnofacies developed in brackish-marine fluviially-dominated palaeoenvironments of a lagoon or estuary (Text-Fig. 5.2 and Text-Fig. 9.6). The modern crab Uca pugilata produces this type of excavation pellet in protected lagoons of the foreshore zone.

#### Pellet type D (large coprolites)

(Not recorded in the study area)

#### Pellet type E (inorganic ovoid-shaped structures)

Plate 34, Fig. c

Plate 35, Fig. a

Inorganic ovoid-shaped full-relief structures, here termed pellet type E, have a large diameter (5mm to 10 cm) and are normally found concentrated in discrete layers together with intra-formational mud clasts. The ovoid-shaped structures are dark-brown in colour due to the presence of iron oxides, and are well-polished and sorted. They are generally of subspherical



TEXT-FIG. 10.2. Schematic diagram showing the postulate inorganic origin of ferruginous ovoid-shaped clay pellets and pebbles in the Garie Formation (= basal Newport Formation as a result of mechanical reworking of mudrocks in the Bald Hill Claystone in the foreshore zone of a protected coastal lagoon or estuary during a regressive episode. This scenario applies to trace fossil subinterval ID1 at Turimetta Head (area 2). As it applies to the origin of the Garie Formation this general concept follows Bunny & Herbert (1971, p.70) and Bayer et al., (1985, p.376, fig. 18).

WEST

EAST

PALAEOSLOPE  
(exaggerated)

SEA LEVEL (2)

TRANSGRESSION

SEA LEVEL (1)

Lr NEWPORT

GARIE FORMATION

BULGO SANDSTONE

BALD HILL CLAYSTONE

TEXT-FIG. 10.2

shape, though some exhibit irregular shapes. These iron-oxide ovoid-shaped clasts have also been described as Fe-rich ooids/pisoliths and have frequently been interpreted as in situ alteration products (involving mainly oxidation) of preexisting iron-bearing minerals (Bayer et al., 1985). However, the distribution of these ovoid-shaped features in laminae clearly indicate their transported origin as detritus (Schiavon, 1988). These ovoid-shaped entities are more likely to have been formed contemporaneously in an adjacent nearshore environment before having been transported by tidal or other currents that developed in the fluviially-dominated brackish-marine lagoon or estuary (see Text-Fig. 10.2).

These type E non-organic ovoid-shaped features are typically confined only to trace fossil subinterval ID1 of the Lower Newport Member at Bilgola Head (area 10b). None of the examples illustrated in Plate 34 Fig. c and Plate 35 Fig. a have been retrieved from the field. Type E ovoid-shaped structures are not associated with any other trace fossils.



(Palaeophycus Hall, 1847 and Planolites Nicholson, 1873)

#### 11.1. INTRODUCTION:

The nomenclatural dilemma concerning the ichnogenera Palaeophycus and Planolites was discussed comprehensively by Pemberton & Frey (1982). Proposed classifications for each of these ichnogenera are discussed here and are based on their classification. The proposed classifications discussed here address some of the general nomenclatural difficulties that arise in respect of these widely cited but poorly understood ichnotaxa. These ichnotaxa are readily recognizable and comprise very simple horizontal or partly-inclined burrows. Both range in age from Proterozoic to Holocene (Häntzschel, 1975), and are found virtually in all sedimentary facies and have complicated ichnotaxonomic histories.

The ichnogenus Palaeophycus was originally defined by Hall (1847, p.7) as: "stem terete, simple or branched, cylindric or subcylindric; surface nearly smooth, without transverse ridges, apparently hollow". Later, Nicholson (1873) described somewhat similar burrows under the ichnogenic name Planolites. The definition was again modified by Nicholson & Hinde (1875, p.139) as: "Planolites consists... of casts of the burrows of marine worms formed by the ejecta of the animal, and they appear usually in the form of cylindrical or flattened stem-like bodies, which are often more or less matted together, and which may cross one another in every imaginable direction".

The first attempt to reconcile the classification of

these two ichnogenera was by Alpert (1975) who used the presence and absence of branching in these traces to conclude that Palaeophycus is branched and Planolites is unbranched. This approach to their differentiation was followed by numerous authors (e.g., Benton & Trewin, 1978; McCarthy, 1979; Miller, 1979; Pickerill & Fobes, 1979; and Ratcliffe & Fagerstrom, 1980). However, in consolidated/indurated rocks containing these burrows, crossovers or interpenetrations can give the impression of branching and in fact what is apparent branching in some cases is impossible to differentiate from true branching.

A more realistic approach was later taken by studying the burrow walls and internal burrow infills (e.g., Osgood, 1970; Frey & Chowns, 1972; and Häntzschel, 1975). The ichnogenus Palaeophycus is apparently meant to be hollow, and the trace maker constructed it for dwelling (domicile) purposes and hence did not actively fill the burrow. Consequently, segments of these burrows may exhibit burrow-collapse features (cf. Pemberton & Frey, 1982, P.849) with distinctly lined irregular burrow walls which indicate that they were formerly open burrows, subsequently deformed by compaction and/or later passively filled with sediment. In contrast, burrows of the ichnogenus Planolites are filled with sand or mud which the producer worm had passed through its digestive canal, implying that these burrows were actively back-filled by mobile deposit-feeding organisms. In addition, these types of burrows may exhibit (without collapse) distinctly lined smooth walls. The distinction between actively- and passively-filled burrows is an important ethological-based criterion for taxonomic classification. Both Palaeophycus and Planolites may or may not

show true branching.

## 11.2. THE CLASSIFICATION

In consequence of the above discussion some comprehensive revision of the classification and systematics of the ichnogenera Palaeophycus and Planolites are necessary.

The definitions that are used here for the ichnogenus Palaeophycus are as follows: (1) the burrows may or may not be branched; (2) the burrows are/were hollow and passively filled; (3) the burrows are infilled by material(s) identical to the host sediment; (4) no internal structures are present; (5) the burrows have a distinctly lined boundary with irregular wall; (6) segments of burrows may be collapsed or partly flattened; (7) these burrows were established for dwelling purposes (domichnia); and (8) the burrows can be preserved as hypichnial ridges, epichnial grooves or endichnial casts.

The definitions that are used in respect of the ichnogenus Planolites are as follow: (1) burrows are relatively small and unlined; (2) rarely branched, either straight or tortuous; (3) walls are either smooth or irregular and may be annulated; (4) circular or elliptical in cross-section; (5) dimensions and pattern of the burrows may exhibit both interspecific and intraspecific variation; (6) back-filled infillings are structureless; (7) infilling sediment differs in lithology from host sediments; (8) crowded or dense crossovers, interpenetrations and reburrowing are common; and (9) burrows can be preserved as endichnial casts, hypichnial ridges or epichnial grooves. The classifications and the taxonomic criteria on which they are



TEXT-FIG. 11.1. Classification of the ichnogenus Palaeophycus Hall, 1847 (bedding-parallel dwelling-burrows) and its definitions following (with addition) Pemberton and Frey (1982). The burrows are subdivided into two major groups: the first major group consists of smooth/unornamented burrows (i.e. type A, P. herberti Saporta, 1872, with thick wall, and type B, P. tubularis Hall, 1847, with thin wall); the second major group consists of well-ornamented burrows (i.e. type C, P. striatus Hall, 1847, with parallel striations, type D, P. sulcatus Pemberton and Frey, 1982, with irregular discontinuous striations, and type E, P. alternatus Pemberton and Frey, 1982, with alternating annulated and short striated segments. Asterisks indicate those ichnotaxa that occur in the study area.



PALAEOPHYCUS Hall, 1847.

- DEFINITIONS -
1. MAY OR MAY NOT BE BRANCHED.
  2. PASSIVELY FILLED (ORIGINALLY HOLLOW).
  3. INFILLED BY MATERIAL IDENTICAL TO HOST SEDIMENT.
  4. NO INTERNAL STRUCTURES.
  5. DISTINCTLY LINED WITH IRREGULAR WALL.
  6. EXHIBITS COLLAPSED SEGMENTS (PARTLY FLATTENED).
  7. DOMICHNIA (DWELLING-BURROWS).
  8. PRESERVED AS HYPICHNIAL RIDGES, EPICHNIAL GROOVES, OR ENDICHNIAL CASTS.

THIN TO THICK DISTINCT WALL  
SMOOTH (UNORNAMENTED) WALL

THIN DISTINCT WALL  
ORNAMENTED WALL WITH STRIATIONS

TYPE A

\*TYPE B

THICK WALL

THIN WALL

P. herberti  
Saporta, 1872.

P. tubularis  
Hall, 1847.



\*TYPE C

\*TYPE D

\*TYPE E

WITH CONTINUOUS  
PARALLEL STRIATIONS

WITH IRREGULAR  
DISCONTINUOUS  
STRIATIONS

WITH ALTERNATING  
ANNULATED AND SHORT  
STRIATED SEGMENTS

P. striatus  
Hall, 1847.

P. sulcatus  
Pemberton &  
Frey, 1982.

P. alternatus  
Pemberton &  
Frey, 1982.



TEXT-FIG. 11.1.

based are shown in Text-Fig. 11.1 for Palaeophycus and in Text-Fig. 11.2 for Planolites. Both of these schemes are based on the classification devised by Pemberton & Frey (1982).

Other bedding-parallel feeding- and/or dwelling-burrows that are not attributable to either Palaeophycus or Planolites burrows will be discussed in Chapter 17.

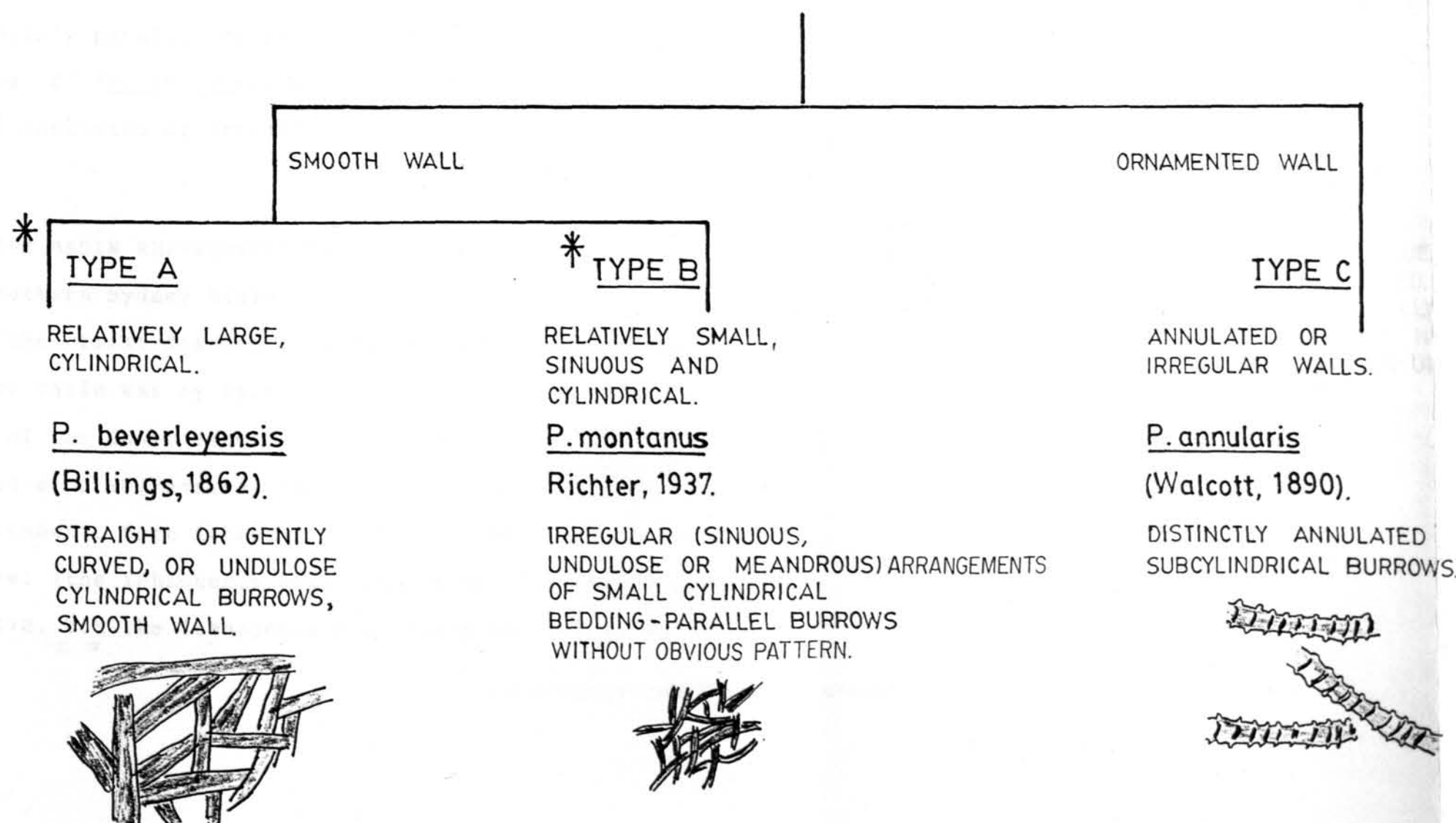
#### 11.2.1. Classification of the ichnogenus Palaeophycus Hall, 1847

Five different types of Palaeophycus can be recognized based primarily on the nature of the burrow wall-lining and surface ornamentation. In the proposed classification these five taxa form into two distinct groups (Text-Fig. 11.1). The first group consists of unornamented or smooth-walled burrows; and the second group, of burrows with well-ornamented irregular walls. Two species comprise the first group and are differentiated on the basis of wall thickness. The burrow which has a thick wall-layer is designated type A (P. herberti Saporta, 1873), and the burrow with a thin wall-layer is designated type B (P. tubularis Hall, 1847). The second group contains three species that are differentiable by the type of morphological ornamentation on the burrow surface. The first of these species is designated type C (P. striatus Hall, 1847) and is characterized by continuous parallel striations. The second species is designated type D (P. sulcatus Pemberton & Frey, 1982) and has irregular and discontinuous striations. The third species is designated type E (P. alternatus Pemberton & Frey, 1982) and has alternating annulations and short striations.

TEXT-FIG. 11.2 Classification of the ichnogenus Planolites Nicholson, 1873 (bedding-parallel feeding-burrows) and its definition following (with additions) Pemberton and Frey (1982). The burrows are subdivided into two major groups: the first major group consists of smooth-walled burrows i.e. type A, P. beverleyensis (Billings, 1862) which are large straight cylindrical burrows, and type B, P. montanus Richter 1937, which are small sinuous cylindrical burrows; the second major group consists of the single ichnospecies P. annularis (Walcott, 1890) with annulation and irregular wall. Asterisks indicate those ichnotaxa that occur in the study area.

# PLANOLITES Nicholson, 1873

- DEFINITIONS -
1. RELATIVELY SMALL AND UNLINED.
  2. RARELY BRANCHED.
  3. STRAIGHT OR TORTUOUS (UNDULOSE OR MEANDROUS).
  4. WALLS ARE EITHER SMOOTH, IRREGULAR, OR ANNULATED.
  5. CIRCULAR OR ELLIPTICAL IN CROSS-SECTION.
  6. VARIABLE DIMENSIONS AND BURROW CONFIGURATIONS.
  7. INFILLINGS STRUCTURELESS (ACTIVELY BACK-FILLED).
  8. INFILLINGS DIFFER IN LITHOLOGY FROM HOST SEDIMENT.
  9. CROWDED/DENSE BURROW PATTERN (CROSSOVERS, INTERPENETRATIONS AND REBURROWING ARE COMMON).
  10. FODINICHNIA (FEEDING-BURROWS)
  11. PRESERVED AS ENDICHNIAL CASTS, HYPICHNIAL RIDGES AND EPICHNIAL GROOVES.



TEXT-FIG. 11.2.

### 11.2.2. Classification of the ichnogenus Planolites Nicholson, 1873

Three distinctive types of Planolites can be recognized in the present classification which is mainly based on the nature of the burrow wall-lining, the size of the burrows and the pattern of burrow arrangement (Text-Fig.11.2). The first species is designated type A (P. beverleyensis Billings, 1862) and comprises relatively large, straight or gently-curved (undulose) cylindrical burrows with smooth walls. The second species is designated type B (P. montanus Richter, 1937) and is characterized by smooth-walled burrows that are relatively smaller than the type A burrows, arranged irregularly (in either a sinuous or meandering), crowded or dense (with no obvious pattern), and disposed mainly parallel to bedding. The third species is designated type C (P. annularis Walcott, 1890) and is defined by distinctly annulated or irregularly-walled subcylindrical-shaped burrows.

### 11.3. SYDNEY BASIN REPRESENTATIVES

#### 11.3.1. Southern Sydney Basin (Lower Permian)

The first discovery of Palaeophycus and Planolites in the Sydney Basin was by Carey (1978) from the southern coastal exposures of the Lower Permian Snapper Point Formation which she interpreted as a regressive interval of a linear-clastic-shoreline environment. Both ichnotaxa were described only to ichnogenic level (the ichnogenus Palaeophycus sp. was illustrated in her fig. 17e, but the ichnogenus Planolites was not illustrated).

### 11.3.2. Sydney Northshore (Triassic)

The discovery of Palaeophycus and Planolites in the Newport Formation of the upper Narrabeen Group of the study area is the first record for the Triassic of the Sydney Basin. Three ichnospecies and one doubtful ichnospecies of Palaeophycus, and two ichnospecies of Planolites are present in the study area and are described below.

### 11.4. SYSTEMATIC ICHNOTAXONOMY

#### Palaeophycus Hall, 1847

(see synonymy list in Pemberton & Frey, 1982)

**Diagnosis (generic assignment):** Branched or unbranched, originally hollow burrow with infillings typically structureless, and of same lithology as host sediment. The outer surface of the burrows is either smooth or ornamented and the walls are lined. The burrows are essentially cylindrical with variable diameter and predominantly bedding-parallel.

**Remarks (diagnostic features):** Burrows normally are branched and later passively filled by structureless infillings and also partly flattened due to collapse. Burrows normally are cylindrical where they are not collapsed. Distinctly lined with a thick to thin irregular boundary that demarcates the burrows from the host sediment. The burrows are believed to have been excavated for dwelling purposes (domichnia).

#### Palaeophycus tubularis Hall, 1847

Plate 66, Figs. a - c

**Diagnosis (specific assignment):** Various branching, and unbranched, smooth-walled or unornamented, distinctly-lined thin



wall and variable burrow diameter.

**Remarks (diagnostic features):** Burrows are passively filled by structureless infills identical to the host sediment. The burrows are mainly bedding-parallel and cylindrical where not collapsed. The burrows are distinctly lined with irregular thin walls. Branching as well as crossovers and interpenetrations are quite common.

**Description and ethology:** Burrows are straight to slightly-curved or undulose, but mainly lie in the bedding plane with smooth (unornamented) thin distinct wall-lining. True branching is sporadic and irregular. Crossovers, interpenetration or reburrowing are quite common. Dimensions (length and diameter of the burrow) vary within the same burrow. However, some burrow segments about 3 cm long are straight and with a diameter invariably about 0.5 cm. No highly-curved or meandering burrows have been observed. The burrows are normally preserved as hypichnial ridges.

**Comparison:** The present P. tubularis is smaller in diameter than the species P. tubularis (Hall, 1847) in Pemberton & Frey (1982). However, the diameter is more comparable with the Palaeophycus sp. with true branching in Frey & Chown (1972).

**Distribution:** The burrows illustrated in Plate 66, Fig. a, are from trace fossil subinterval ID4 of the Lower Newport Member at St. Michaels Cave (area 5), and those in Fig. b of the same plate are from trace fossil subinterval IE9 of the Middle Newport Member at South Palm Beach (area 4b). The burrows illustrated in Fig. c of the same plate are from trace fossil subinterval ID1 of

the Lower Newport Member at Bilgola Beach (area 10b). This ichnotaxon is not known to occur in any other trace fossil subintervals or geographic locations in the study area.

**Studied material:** The burrows illustrated in Plate 66, Fig. a (sample 502/MU.44402), and Fig. b (sample 405/MU.44398) were collected for detailed study; those illustrated in Fig. c were not retrieved from the field.

**Preservation and association:** The studied P. tubularis shown in Plate 66 Fig. b, from South Palm Beach, is associated with vertically orientated Skolithos, but the other burrows illustrated in the plate are not associated with any other trace fossils. All the studied burrows occur as hypichnial ridges in very fine to fine sandstone units.

**Ichnofacies and palaeoenvironmental affinities:** This ichnospecies occurs in various ichnofacies developed in the fluvially-dominated brackish-marine palaeoenvironments of a coastal lagoon or estuary.

#### Palaeophycus striatus Hall, 1847

Plate 67, Figs. a & d

**Diagnosis (specific assignment):** Variously branched and unbranched, thinly-lined wall ornamented with fine, continuous, subparallel and longitudinal striations.

**Remarks (diagnostic features):** The burrows are mainly bedding-parallel, straight, branched and unbranched with distinct thinly-lined wall bearing numerous subparallel longitudinal striations. Crossovers and interpenetrations (reburrowings) are quite common. Collapsed segments are rare, and the burrow diame-



ter is uniform throughout. In the latter regard P. striatus is different to the other species of the genus from the study area.

**Description and ethology:** The burrows are uniformly cylindrical and almost bedding-parallel (some are shallowly-inclined), mainly unbranched and straight. The burrows tend to be uncollapsed and of uniform diameter throughout the entire length of individual segments which vary from 2 to 5 cm. The surface of the thin and distinctly lined wall is ornamented with subparallel longitudinally arranged striations. The burrows are commonly preserved as endichnial traces.

**Comparison:** P. striatus illustrated in Plate 67 Fig. a has comparable dimensions with the P. striatus (= Planolites striatus Alpert, 1975), and also with P. striatus described by Pemberton & Frey (1982). The other specimen shown in Plate 67 Fig. d shows that the burrows are much smaller in diameter and shorter in length than the P. striatus described by Alpert (1975).

**Distribution:** The burrows illustrated in Plate 67 Fig. a are from trace fossil subinterval IE1 of the Middle Newport Member at Bungan Beach (area 14, Mona Vale Head), and those shown in Fig. d are from trace fossil subinterval ID5 of the Lower Newport Member at St. Michaels Cave (area 5). P. striatus actually occurs in all trace fossil subintervals of interval ID of the Lower Newport Member at St. Michaels Cave and in adjacent headland areas (area 11, Hole in the Wall) to the immediate south.

**Studied material:** The burrows illustrated in Plate 67 Fig. d are the only specimens (502b/MU.44402) of P. striatus collected from trace fossil subinterval ID5 of the Lower Newport Member at St. Michaels Cave. The others illustrated in Plate 67 Fig. a were not

retrieved from the field.

Preservation and association: The burrows of P. striatus illustrated in the Plate 67 Figs. a and d are associated with vertically orientated Skolithos, and all specimens are preserved as hypichnial ridges.

Ichnofacies and palaeoenvironmental affinities: P. striatus occurs in many ichnofacies including the Skolithos ichnofacies. In the present study area, the burrows are developed in fluvially-dominated brackish-marine palaeoenvironments of a coastal lagoon or estuary.

Palaeophycus sulcatus Pemberton & Frey, 1982

Plate 67, Figs. b, c & e

Diagnosis (specific assignment): Variously branched and unbranched, subcylindrical, distinctly lined thin wall ornamentated with irregular, discontinuous thin thread-like striations.

Remarks (diagnostic features): Burrows are rarely branched but show common interpenetration and crossovers. Burrow diameter is variable throughout the length of individual burrows. Burrows commonly preserved as endichnial or hypichnial ridges.

Description and ethology: The burrows are rarely branched and are mainly bedding-parallel or shallowly-inclined, more or less straight and of subcylindrical shape. The thin burrow wall is distinctly lined and well-ornamentated with fine irregular discontinuous striations. The striations are formed in an anastomosing pattern rather than longitudinally along the burrow side. These striations are believed to have been formed by digging strokes of the trace-makers' appendages (Pemberton & Frey, 1982).

The burrows exhibit crossovers and interpenetrations and these are common in all specimens. Burrow collapse is common. The burrows are commonly preserved as endichnial casts or hypichnial ridges. The length of the burrows is up to 5 cm or 7 cm and their diameter is about 0.5 cm to 1 cm.

**Comparison:** The size (diameter and length) of P. sulcatus illustrated in Plate 67 is comparable with P. sulcatus = Trichophycus sulcatum, Miller & Dyer, 1878, and with P. sulcatus described by Pemberton & Frey (1982). The fine thread-like striations on the thin distinct wall-lining are more irregular and discontinuous than those of P. sulcatus described by Pemberton & Frey (1982). Tensional microfaults which are characteristically developed at the base of the burrows described by Pemberton & Frey (1982) are absent in the burrows of the present study.

**Distribution:** The burrows illustrated in Plate 67, Figs. b, c and e, are from trace fossil subintervals ID4-ID5 of the Lower Newport Member at Mona Vale Head (area 14). This ichnotaxon is not known to occur in other trace fossil intervals or in any other geographic localities in the study area.

**Studied material:** No specimens were retrieved from the field.

**Preservation and association:** The burrows are commonly preserved as endichnial casts or hypichnial ridges, and are associated with other species of Palaeophycus.

**Ichnofacies and palaeoenvironmental affinities:** P. sulcatus occurs in various ichnofacies and environments. In the present study area, the burrows are believed to have been developed in fluvially-dominated brackish-marine palaeoenvironments of a

coastal lagoon or estuary.

Palaeophycus alternatus? Pemberton & Frey, 1982

Plate 66, Figs. d & e

**Diagnosis (specific assignment):** Burrows rarely branched, with short annulated segments alternating with longer striated segments on a thin distinct irregular wall-lining; other segments of the burrows are uniformly thick without annulated and striated segments. Burrow diameter is variable in the zone of annulation.

**Remarks (diagnostic features):** The burrows are rarely branched but show common interpenetration and crossovers. The irregular thinly-lined distinct burrows are of variable diameter, especially in the annulated segments. Very narrow short striations are developed only on the non-annulated segments of the burrows. The burrows are normally preserved as hypichnial ridges.

**Description and ethology:** The burrows are slightly-curved to straight, 2 cm to 5 cm in length and with a diameter less than 0.5 cm but wider in some specimens with well-defined annulations. Fine striations are developed only between annulations in annulated forms and sporadically in non-annulated forms. The annulation, non-annulation and striations probably manifest a distinct ethological pattern of periodic movements of the organism, involving direct locomotion of the body in the striated segments and peristaltic movements in the annulated segments (Pemberton & Frey, 1982). Annuli are not well developed in the burrows of the present study area, but where developed they are closely-spaced (i.e., about 2 mm apart). The burrows are uncollapsed. The burrows shown in Plate 66, Figs. d and e, are preserved as hypichni-

al ridges.

**Comparison:** The size (diameter and length) of the P. alternatus? illustrated in Plate 66, Figs. d and e is comparable with the ichnospecies P. alternatus described by Pemberton & Frey (1982), and Palaeophycus type B of Osgood (1970). However, the present burrows are more crowded and have fewer annulated and striated segments. Most segments of the burrows are structureless (i.e., without annulations and striations).

**Distribution:** The burrows illustrated in Plate 66 Figs. d and e are from trace fossil subinterval ID1 of the lower Newport Member at Bilgola Beach (area 10b). This ichnotaxon is not known to occur at any other geographic localities or in other trace fossil intervals.

**Studied material:** The specimens have not been retrieved from the field.

**Preservation and association:** The burrows are preserved as hypichnial ridges in fine sandstone units and are not associated with any other trace fossils.

**Ichnofacies and palaeoenvironmental affinities:** In the present study area P. alternatus occurs in various ichnofacies but is less common than the other species. The burrows are believed to have been developed in fluvially-dominated brackish-marine palaeoenvironments of a coastal lagoon or estuary.

#### Planolites Nicholson, 1873

(see synonymy list in Pemberton & Frey, 1982)

**Diagnosis (generic assignment):** Burrows are unlined and very rarely branched, straight or slightly-curved with smooth to

irregular or annulated walls. The burrows may be circular or elliptical in cross-section and of variable dimension and configuration. Burrows are uncollapsed and infills are structureless and may comprise faecal material essentially different in lithology from the host sediment. Burrows are produced for feeding purposes (fodinichnia).

**Remarks:** The burrows are straight to slightly-curved and cylindrical, rarely branched, and irregularly developed (i.e., exhibit no particular pattern). The burrows are unlined and the walls are normally smooth (without annulation) but can be closely annulated in some cases. Burrow dimensions are variable (several sizes of burrow may be crowded together). No particular pattern of the burrows is developed but their orientation is mainly bedding-parallel. Individual short segments may be inclined to bedding. Burrows normally are dense with crossovers and interpenetrations. Burrows are infilled by structureless materials different from the host sediment and they are preserved as endichnial casts and hypichnial ridges and epichnial grooves.

Planolites beverleyensis (Billings, 1862)

Plate 64, Figs. a - e  
Plate 65, Fig. e

**Diagnosis (specific assignment):** Relatively large straight or gently-curved cylindrical-shaped burrows, rarely branched with smooth walls.

**Remarks (diagnostic features):** P. beverleyensis is distinguished by its larger size and straighter form than the other species P. montanus. Burrows are typically cylindrical, smooth-walled and normally unbranched. The burrows are invariably more or less

parallel to the bedding and are preserved as endichnial casts or hypichnial ridges or as epichnial grooves.

**Description and ethology:** Burrows are predominantly bedding-parallel, and, relatively straight or gently-curved. They are unbranched but with numerous crossovers, and interpenetrations; reburrowing is common in crowded areas (Plate 64 Figs. b & d, and Plate 65 Fig. e). Burrow density and association with other burrows may modify the burrow configuration (Plate 64, Figs. b & e). The burrows' infillings are structureless and differ from the host sediments in being lighter in colour than the latter and of more variable grain-size (obviously due to mixing of the host sediment). The burrows illustrated in Plate 64 Fig. a are preserved as epichnial grooves and are associated with shrinkage cracks, asymmetrical ripple-marks and vertical U-shaped, spreite-bearing Arenicolites. The other burrows illustrated in Plate 64 are preserved either as hypichnial ridges or endichnial casts and are associated with vertical dwelling-shafts of Skolithos. Burrow length is normally more than 5 cm and width is about 0.8 cm to 1 cm.

**Comparison:** The burrows of P. beverleyensis studied here are larger, less crowded and straighter than the P. beverleyensis (Billings, 1862) described by Pemberton & Frey (1982).

**Distribution:** Globally, Planolites beverleyensis is widely distributed geographically and stratigraphically. The studied material illustrated in Plates 64 and 65 come from two trace fossil intervals: those in Plate 64, Fig. a are from trace fossil subinterval ID2 of the Lower Newport Member at Hole in the Wall (area

11); those in Figs. b to e are from trace fossil subintervals IE1 - IE2 of the Middle Newport Member at Bungan Head (Fig. b; area 13), Bangalley Head (Fig c; area 8), and Little Head (Figs. d and e; area 7). Those in Plate 65 Fig. e are from trace fossil subinterval ID1 of the Lower Newport Member at Bilgola Beach (area 10b).

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

**Preservation and association:** The burrows shown in Plate 64 Fig. a are preserved as epichnial grooves and are associated with Arenicolites, shrinkage cracks, and asymmetrical ripple-marks. The other examples illustrated in Plate 65 Fig. e occur as hypichnial ridges and are associated with vertically orientated shafts of the Skolithos.

**Ichnofacies and palaeoenvironmental affinities:** The ichnogenus Planolites ranges from shallow-marine to deep-marine environments and hence can occur in several ichnofacies. In the present study area the ichnospecies P. beverleyensis belongs to a brackish-marine environment developed in a fluvially-dominated coastal lagoon or estuary.

Planolites montanus Richter, 1937

Plate 65, Figs. a - d

**Diagnosis (specific assignment):** Relatively small highly-curved, contorted or irregular cylindrical-shaped smooth-walled burrows, rarely branched.

**Remarks (diagnostic features):** Its consistently smaller size, more contorted form and shorter length readily distinguish P.



montanus from the previously assigned ichnospecies P. beverleyensis. The burrows are not essentially bedding-parallel. The burrows are preserved as endichnial casts and hypichnial ridges or as epichnial grooves.

**Description and ethology:** Irregular, cylindrical, sinuous, undulose or meandering small burrows developed approximately parallel to bedding but with no obvious pattern (Plate 65, Figs. a & b). Burrow length is relatively short (less than 2 cm) and the diameter is small (less than 0.5 cm) but not uniform throughout a burrow. True branches are rare but can be confused with cross-overs, interpenetrations and reburrowings (Plate 65, Fig. a). Many burrows are short and curved where they were formed as vertical or bedding-oblique shafts. Burrow infills are lighter in colour, cleaner and of larger grain-size than the host sediment. The burrows are normally preserved as endichnial casts, hypichnial ridges or as epichnial grooves.

**Comparison:** The consistently smaller size and more curved nature of P. montanus readily distinguish it from P. beverleyensis. The irregular contortions of the burrows when seen in bedding-plane view may also give rise to an appearance of vertical or oblique short shafts. The studied material differs from P. montanus Richter (1937) illustrated in Pemberton & Frey (1982) in respect to the absence of true branching in the former and its superficial resemblance to the ichnogenus Chondrites.

**Distribution:** P. montanus is distributed in two stratigraphic intervals in two different areas. The burrows in Plate 65 Fig. b are from trace fossil subinterval IE9 of the Middle Newport Member at South Palm Beach (area 4b) and those illustrated in

Figs. a, c and d are from trace fossil subinterval ID1 of the Lower Newport Member at Bilgola Beach (area 10b).

**Studied material:** The burrows of P. montanus illustrated in Plate 65 Fig. b occur in sample 406/MU.44399, and those in Fig. d occur in sample 1016/MU.44438. The other samples of this ichnospecies illustrated in the plates have not been retrieved from the field.

**Preservation and association:** The studied traces are preserved as endichnial casts or hypichnial ridges and are not associated with any other trace fossils.

**Ichnofacies and palaeoenvironmental affinities:** In general P. montanus can occur in several ichnofacies, but in the present study area it occurs in the Skolithos ichnofacies developed in brackish-marine palaeoenvironments of a coastal lagoon or estuary.