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Trace Fossils from the Turbidite Facies of the Waitemata Group, Whangaparaoa Peninsula, Auckland

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Abstract

TRACE fossils common in siltstone beds of the turbidite facies of the Waitemata Group exposed on Whangaparaoa Peninsula are described. This ichnofauna is very similar to that typical of the flysch facies in many other countries. It affords evidence of extensive reworking of sediment by a rich and diverse infauna dominated by soft-bodied, sediment-eating organisms.

INTRODUCTION

A rich and varied assemblage of trace fossils, or ichnofossils—the *Lebensspuren* and *trace d'activité* of the German and French literature respectively—is present in siltstone beds of the Waitemata Group that outcrop widely about and to the north of the Auckland isthmus. The trace fossils are particularly conspicuous at many localities about Whangaparaoa Peninsula (Fig. 1) and the descriptions are based mainly on material collected from this area. Here the Waitemata Group is of Otaian age and consists largely of alternating sandstones and siltstones identified as a turbidite facies comparable with that of the Takapuna Section of the Waitemata Group recently described by Ballance (1964). Thick volcaniclastic grits of the type known locally as Parnell Grit (cf. Brothers, 1959) are interbedded with the turbidites along much of the northern coast of the peninsula east of Tarihunga. Two kinds of sequence can be recognised: (i) that in which thick and often composite bedded sandstones (turbidites) alternate with thin siltstones, and (ii) that consisting of thinly bedded alternating sandstones and siltstones—the sandstones of this latter type of sequence having been deposited from the weaker "tails" of turbidity currents or being turbidite sand reworked by bottom traction currents (Gregory, 1966). In general the trace fossils are only abundant in siltstones of the latter type of sequence.

At Whangaparaoa Peninsula (as in Waitemata beds elsewhere) trace fossils are commonly preserved as casts (e.g., Pl. 4, Fig. 1) and moulds (e.g., Pl. 2, Fig. 1), but "flattened" impressions (e.g., Pl. 5, Fig. 1) are not uncommon. The trace fossils tend to be accentuated by selective weathering and/or erosion for they have seldom been observed in unweathered rocks. Diagenetic processes are also important, for they improve the preservation of trace fossils (cf. Seilacher, 1964). The trace fossils described were best seen on weathered surfaces where subhorizontal,

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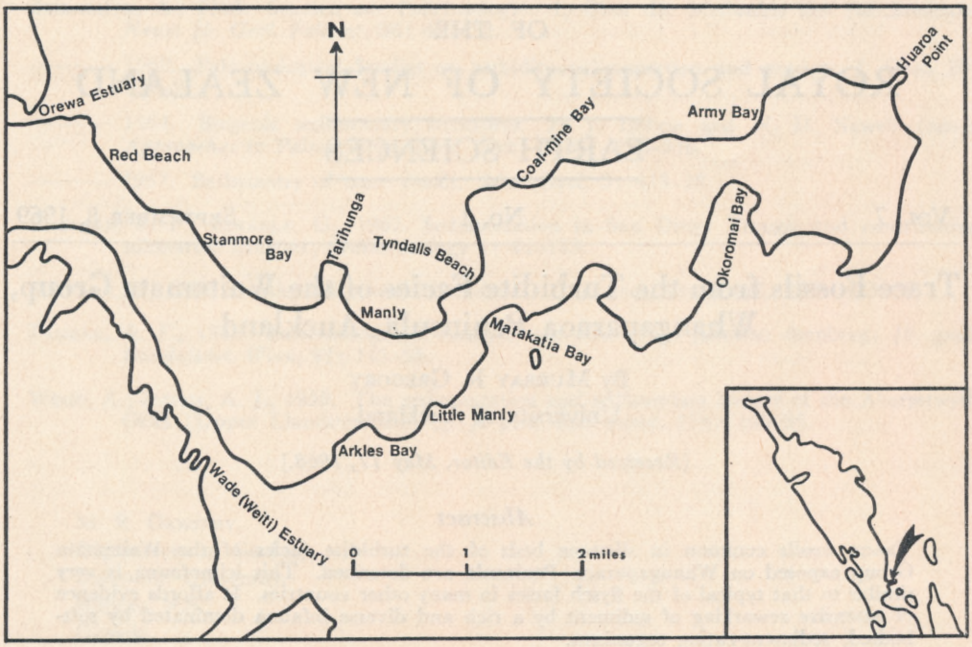

FIG. 1.—Locality map of Whangaparaoa Peninsula.

thinly bedded strata are exposed in the shore platforms and at the foot of the cliffs that back them (e.g., grid references N38/308907* and N38/265888). They are also conspicuous and very abundant in large blocks of similar lithology that rest on the shore platform at a number of localities (e.g., grid references N38/221912 and N38/286897) having fallen from high above in the actively retreating cliffs.

No hard parts of organisms that may have been responsible for the various trace fossils described have been recognised; indeed the only macrofossil known to the writer from sandstones or siltstones of the Waitemata Group in this area is a single crinoid collected from near Okoromai Bay. Presumably, then, these organisms were soft-bodied.

The manner of occurrence of the trace fossils suggests that most of them were made by burrowing, sediment-eating organisms, scavengers foraging a short distance below the contemporary sea-floor in nutrient-rich silty sediment (i.e., an infauna). This burrowing habit it clearly illustrated where primary sedimentary features are disturbed (Pl. 1, Fig. 1). Except for rare exceptions—e.g., *Paleodictyon*—trace fossils restricted to the soles of beds were not recognised, and there is little evidence for an infauna living along interfaces of turbidites and underlying silty sediments like that described by Seilacher (1962). Likewise, apart possibly from *Helminthoida,* there is little evidence suggestive of a fauna living on the contemporary sea-floor (i.e., an epifauna).

Trace fossils similar to some of those described have been recognised previously in Waitemata beds near Cape Rodney (Hopgood, 1956), at Takapuna (Bartrum, 1948; Ballance, 1964) and at Motutapu Island (Mayer, 1965), and the writer has observed others at a number of localities about the Auckland isthmus (e.g., St Heliers Bay) and to the north (e.g., Puketotara and Okahukura Peninsulas, Kaipara, and

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* All grid references refer to N.Z.M.S. 1 sheets.

near Waiwera). Two trace fossils not found to date at Whangaparaoa Peninsula but known from other localities are also included to complete the record of trace fossils known from the turbidite facies of the Waitemata Group.

Recently Cullen (1967) has commented on the paucity of trace fossils in New Zealand rocks. On the other hand, however, other studies (e.g., Glennie, 1959; Ballance, 1964; Ghent and Henderson, 1965; and this paper) indicate that trace fossils are far more abundant than a perusal of the earlier literature would imply. Undoubtedly the neglect of trace fossils in New Zealand is a measure of their limited value in stratigraphic correlation.

CLASSIFICATION AND NOMENCLATURE

A trace fossil can be defined (Simpson, 1957) as " a sedimentary structure resulting from the activity of an animal moving on or in the sediment at the time of its accumulation: includes tracks, burrows, feeding marks and traces ". For many phenomena of the kind recorded, an animal origin has long been recognised, as many detailed descriptions in early paleontological literature attest (e.g., Owen, 1852). Some forms, especially those once known collectively as fucoids, have been frequently described as fossil algae, on supposed resemblances to modern seaweeds. However, most of these are today accepted as being of animal origin (see footnote *infra*).

The problems of trace fossil classification and nomenclature have been discussed at length by Häntzschel (1962) in the *Treatise on Invertebrate Paleontology, part W*. The most acceptable system is a compromise one proposed by Seilacher (1953) in which higher categories are based on ethological interpretations and lower categories (ichnospecies) on taxonomic interpretations. Häntzschel on several occasions emphasises that " genera " and " species " when applied to trace fossils do not have the same standing or meaning as they do in normal taxonomic usage; he notes (Häntzschel, 1962: W178) that they " . . . are only supposed to indicate a certain formal assemblage ". He further comments (p. W178) that " the naming of fossils, their delimitation and thus their synonymy is nowhere in paleontology so dependent on personal opinion as in this group of fossils ". Despite the difficulty of applying zoological principles and general paleontological procedures to the classification of trace fossils it has been customary to use binary nomenclature when naming them. However, such names (ichnogenera and ichnospecies) are not universally accepted and are not recognised under the International Rules of Zoological Nomenclature.

Because of (i) the above difficulties; (ii) the caution expressed by Häntzschel (1962: W181) against too finely discriminated groupings of trace fossils—James (1894), for example, recorded almost 100 previously described " species " of *Fucoides;* (iii) Seilacher's (1964: 296–7) most pertinent observation that " . . . a surprising variety of traces may result from the same activity of the one animal depending on . . . " the nature of the substrate and that " if such differences are not realised and eliminated, nearly every specimen may be considered as a new ' species ' "; and (iv) the difficulty of collecting specimens and hence designating types; but also (v), accepting the comment made by Häntzschel (1962: W182) that " . . . unnamed forms usually escape notice in later literature ", the writer will not refer informally by notation to the various trace fossils recognised as he originally did (Gregory, 1966), and as did Ballance (1964) and Ghent and Henderson (1966), but finds it preferable to use generic names (only) in the broad sense advocated by Häntzschel. Notwithstanding the serious misgivings he has about erecting new taxa, the writer accepts convention and describes two new ichnogenera (*Cycloichnus* and *Radionereites*), designating a type species in each, as is formally required. Additionally there is some other discrimination at the " species " level. For convenience comparisons are made with the trace fossils Types A to E described by Ballance

(1964), and wherever possible reference is made to trace fossils described and/or figured by Häntzschel (1962) and by Lessertisseur (1955) and other workers. Again it is stressed that any formal names used are not equivalent to those of normal taxonomic usage and may not be universally accepted. Many of the ichnogenera here described occur in rocks of similar lithology throughout much of the geologic record and are indicative of similarities in adaptation to particular environments and/or modes of life in diverse and not necessarily closely related taxa, rather than of close phylogenetic relationships or the survival of a few taxa over long periods of time.

DESCRIPTIONS OF TRACE FOSSILS

Ichnogenus SCOLICIA de Quatrefages 1849

DIAGNOSIS: Large trails and burrows, flattened or subcircular in cross-section; filling frequently set in arched transverse laminations or "gill-like" structures; varied longitudinal markings.

Scolicia sp.

MATERIAL: Slab of medium sandstone (X10[1]) with short sections of two trails.

LOCALITY: Grid reference N38/269879, west of Manly. Further specimens abundant at numerous other localities about Whangaparaoa Peninsula (e.g., grid references N38/221912 and N38/292882).

DESCRIPTION: Non-branching meandering trails (Pl. 1, Figs. 2 and 3), varying in width from 2cm to, on rare occasions, 5cm, and orientated more or less parallel to bedding, are abundant and very conspicuous at many localities. The greatest distance over which any individual specimen could be traced was about 2 metres. The trails are mostly oval in cross-section, although some examples are subcircular and when viewed on surfaces normal to bedding frequently disturb primary sedimentary features (Pl. 1, Fig. 1). Type A described by Ballance (1964) is here identified as *Scolicia,* but the Whangaparaoa examples display a strong tendency to be gregarious rather than solitary, as are those from Takapuna. Exposed surfaces parallel to bedding are often densely and extensively covered with this trace fossil (see e.g., Pl. 2, Fig. 1), individual trails crossing and recrossing each other and their own earlier formed parts.

When preserved as casts this kind of trace fossil is filled with even-grained sediment, often of a lighter colour that the enclosing sediment but of comparable grain-size and indistinguishable from it in thin section. The filling is set commonly in a series of arched transverse laminae (e.g., Pl. 1, Fig. 3 and Pl. 2, Fig. 2) which may be emphasised by limonite staining and/or preferential weathering, and which in some instances are alternately light- and dark-coloured. These arched laminae may be continuous across the width of the trail (Fig. 2a) or may be broken by a longitudinal median gap (a groove or a ridge). If broken, the laminae may be offset across the median gap (Figs. 2b, 2c, also Pl. 2, Fig. 2). In rare instances, the arched laminae are broken by two closely spaced parallel gaps (Fig. 2d). Transitions between the above variations along the length of individual trails were observed.

From studying instances where trails cut across and obliterate their own earlier formed parts it is concluded that the direction of movement in *Scolicia* was away from the concave side of the arched laminae.

REMARKS: While those examples bearing median markings can be compared with S*colicia,* resemblances to the ichnogenus *Olivellites* illustrated and described

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[1] Catalogue number of specimen held in the Paleontology Collection, Geology Department, University of Auckland.

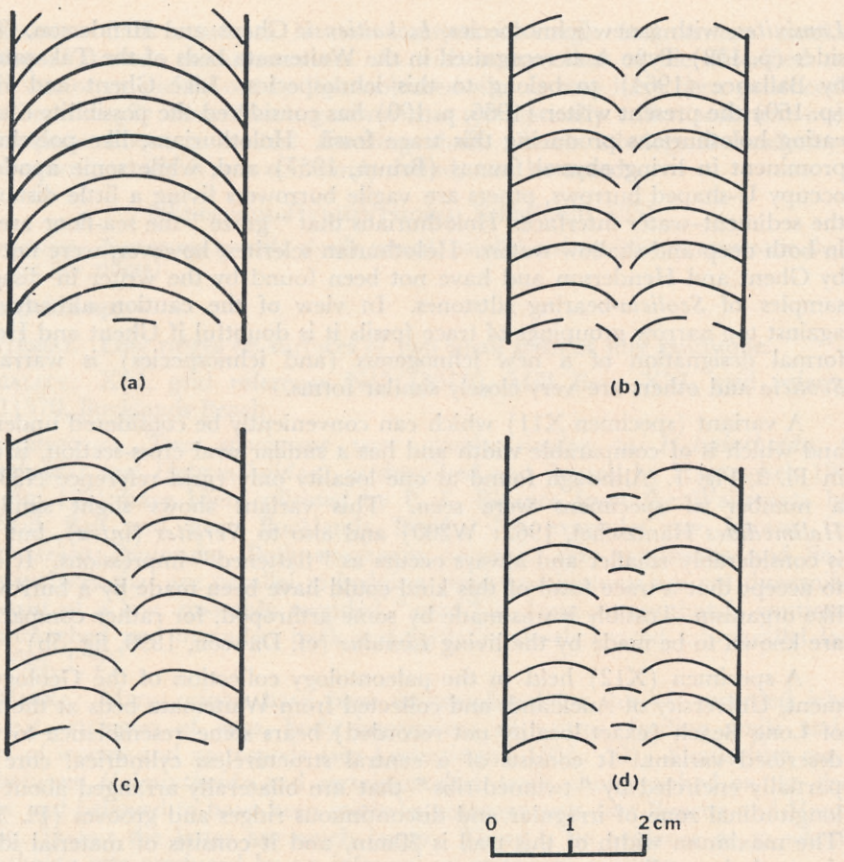

FIG. 2.—Diagrammatic representations of *Scolicia.* (a) Trail in which the arched transverse laminae are unbroken; (b) Trail in which the arched transverse laminae are broken by a longitudinal median gap but are not offset across it; (c) As in (b), but the arched transverse laminae are offset across the median gap; (d) Trail in which the arched transverse laminae are broken by two closely spaced gaps. Drawn from photographs and field sketches.

by Häntzschel (1962) as well as to *Subphyllochorda* and *Palaeobullia*[1] illustrated by Lessertisseur (1955) can be noted. For those examples in which arched laminae are unbroken by longitudinal markings some similarity to *Climactichnites* can be noted, although the oval resting impression with which this ichnogenus characteristically begins (Clark and Usher, 1948) has not been seen. Also *Climactichnites* is much larger, having widths of up to 15cm (e.g., see Burling, 1917).

It is commonly accepted (Häntzschel, 1962) that trace fossils such as *Scolicia* were made by gastropods. Ballance (1964) has commented that the very size of his Type A probably mitigated against its having been made by some kind of marine worm and has suggested that some large shell-less mollusc may have been responsible. However, errant polychaetes of sufficiently large size to produce this kind of trail are known—e.g., *Laetmonice producta* Grube which Hartman (1964) records as reaching lengths of 85–110mm and widths of 25–50mm and which is known from abyssal depths (Kirkegaard, 1954).

In their description of a number of trace fossils from Miocene turbidites at Kaiti Beach, Gisborne, Ghent and Henderson (1966) have erected a new ichnogenus,

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[1] In the *Treatise, Olivellites, Palaeobullia* and *Subphyllochorda* are considered by Häntzschel to belong to the same group as *Scolicia,* but are not classified as synonyms.

Laminites, with a new ichnospecies, *L. kaitiensis* Ghent and Henderson. They consider (p. 158) Type A as recognised in the Waitemata beds of the Takapuna section by Ballance (1964) to belong to this ichnospecies. Like Ghent and Henderson (p. 160) the present writer (1966, p. 190) has considered the possibility of sediment-eating holothurians producing this trace fossil. Holothurians, like polychaetes, are prominent in living abyssal faunas (Bruun, 1957) and, while some apodous forms occupy U-shaped burrows, others are vagile burrowers living a little distance below the sediment–water interface. Holothurians that " graze " the sea-floor are common in both deep and shallow waters. Holothurian sclerites, however, were not recorded by Ghent and Henderson and have not been found by the writer in disaggregated samples of *Scolicia*-bearing siltstones. In view of the caution already expressed against too narrow groupings of trace fossils it is doubtful if Ghent and Henderson's formal designation of a new ichnogenus (and ichnospecies) is warranted, for *Scolicia* and others are very closely similar forms.

A variant (specimen X11) which can conveniently be considered under *Scolicia,* and which is of comparable width and has a similar oval cross-section, is illustrated in Pl. 3, Fig. 1. Although found at one locality only (grid reference N38/295881) a number of specimens were seen. This variant shows slight similarities to *Halimedides* Häntzschel, 1962: W200) and also to *Nereites* (*infra*), but the latter is considerably smaller and always occurs as " flattened " impressions. It is difficult to accept that a trace fossil of this kind could have been made by a burrowing slug-like organism. Possibly it was made by some arthropod, for rather comparable trails are known to be made by the living *Limulus* (cf. Dawson, 1890, fig. 5b).

A specimen (X12) held in the paleontology collection of the Geology Department, University of Auckland, and collected from Waitemata beds at the north end of Long Beach (exact locality not recorded) bears some resemblance to the above described variant. It consists of a central structureless cylindrical core which is partially encircled by " twinned-ribs " that are bilaterally arranged about a narrow longitudinal zone of irregular and discontinuous ridges and grooves (Pl. 3, Fig. 2). The maximum width of this trail is 30mm, and it consists of material identical to the enclosing sediment.

Ichnogenus PLANOLITES Nicholson 1873

DIAGNOSIS: Simple featureless burrows penetrating strata in irregular course and directions but mostly parallel to bedding; filling structureless.

Two " species ", differentiated on size alone, are recognised. They will herein be called *Planolites* sp. a and *Planolites* sp. b.

Planolites sp. a

MATERIAL: Stuffed burrow in fine silty sandstone (X13).

LOCALITY: Grid reference N38/292882, Matakatia Bay, but common at other localities (e.g., grid references N38/221912 and N38/307907).

DESCRIPTION: Non-branching, meandering trails about 10mm across, which, like *Scolicia,* lie more or less parallel to bedding but which do not show the same tendency to be gregarious. They are oval or subcircular in cross-section and can sometimes be seen to disrupt primary sedimentary features. Isolated specimens extend for distances of 30–40cm but mostly they are less than 10cm in length. The filling, which is often structureless, can be either darker- or lighter-coloured and either coarser- or finer-grained than the enclosing sediment, and there is seldom a sharp boundary separating them. Occasionally, faint arched transverse laminae are discernible, which in some instances are continuous across the width of a trail, which in other instances are broken by longitudinal markings like those of *Scolicia,* and which in yet other instances are only conspicuous towards the margins of trails, being separated by a broad, ill defined structureless median zone. Rare examples are sharply segmented like Type B described by Ballance (1964: 489).

REMARKS: While examples in which the filling is structureless can be identified as *Planolites* (Häntzschel, 1962: W210), those examples which appear to be segmented and possibly those with arched transverse laminae may be better compared to *Scalarituba* (Häntzschel, 1962: W215). Trace fossils of these kinds may have been made by animals similar to but smaller than those responsible for *Scolicia*.

In a few instances this type of trace fossil is sharply demarcated from the enclosing sediment (Pl. 4, Fig. 1) and tends to break out in cylindrical segments of irregular length—a phenomenon also observed in some vertical burrows (*infra*). Here the filling is always structureless. This particular form can be referred to as *Cylindrites*—a general name for non-vertical, cylindrical burrow fillings (Häntzschel, 1962: W190). Here it is thought that the animal lined the wall of its burrow with sand grains cemented by mucus.

Planolites sp. b

MATERIAL: Block of silty sandstone (X14) with parts of a number of trails on limonite-stained surface.

LOCATION: Grid reference N38/283867, Little Manly; common at other localities.

DESCRIPTION: Small, simple, non-branching, irregularly meandering burrows and " flattened " impressions which have uniform widths of up to 4–5mm and extend for maximum measured distances of 12cm are common in many siltstones and with *Chondrites* (see later) are the only form at all abundant in the sequences in which thick turbidites alternate with thin siltstones. Size alone sharply distinguishes it from *Planolites* sp. a. The filling is structureless and is often a light-coloured powdery silt that contrasts strikingly with the enclosing sediment (e.g., Pl. 4, Fig. 2), although in some instances it is emphasised by limonite staining. Most examples of *Planolites* sp. b are orientated more or less parallel to bedding.

REMARKS: While *Planolites* sp. b is not strictly comparable with Ballance's (1964) Type C, for the latter branches, they also may have been produced by some small gregarious sediment-eating " worm " although in all probability the burrowing activities of more than one kind of small animal were responsible. Occasional trace fossils of this generalised form appear to have been infilled from above—evidence suggestive of their having been domicile burrows of hemisessile and possibly filter-feeding organisms rather than vagile sediment-eaters, the burrows being infilled upon death of, or vacation by, the occupant. There is never any evidence of either " species " of *Planolites* being packed with faecal pellets.

Ichnogenus CHONDRITES Sternberg 1833

DIAGNOSIS: Regularly ramifying tunnel systems; plant-like appearance; size variable.

MATERIAL: Fragmentary impressions on surface of small block of siltstone (X15).

LOCALITY: Grid reference N38/328909, Army Bay; common at other localities.

Chrondites sp.

DESCRIPTION: Small, non-meandering, cylindrical, and " flattened " borings which seldom exceed 3mm in width and typically occur in clusters (Pl. 4, Fig. 3), distinguished from *Planolites* sp. b, with which they are commonly associated, on their branching (both irregularly and dichotomously) habit and failure to display a preferred orientation parallel to bedding. These borings are filled with material identical to that described under *Planolites* sp. b.

Although the regular ramifying, plant-like tunnel systems considered characteristic of the somewhat variable trace fossil *Chondrites* (see, e.g., Simpson, 1957 and also Häntzschel, 1962: W190) were recognised on rare occasions only (e.g., Fig. 3) the nondescript borings illustrated in Pl. 4, Fig. 3 are also referred to this ichnogenus.

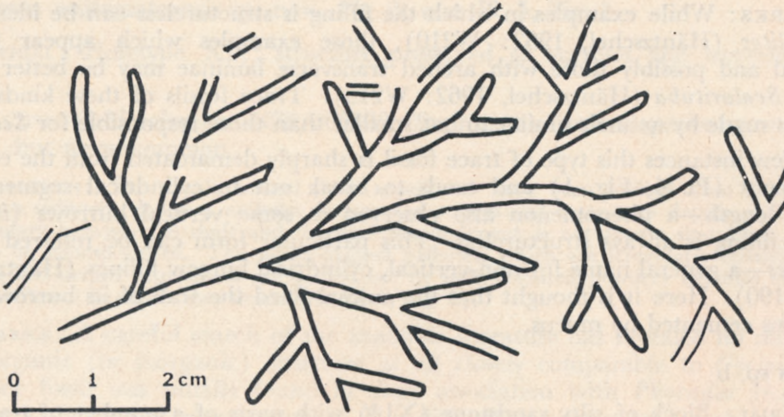

FIG. 3.—Regularly ramifying plant-like tunnel systems of this kind typify the ichnogenus *Chondrites*. This form is very rare at Whangaparaoa Peninsula. Drawn from field sketch, as seen on a parting surface in a siltstone.

REMARKS: Comparisons with reconstructions of *Chondrites* made by Simpson (1957) and others, e.g., Tauber (1949), were not possible although in some instances the behavioural phenomenon of phobotaxis—a phenomenon observed by Richter (1927) and Simpson in this ichnogenus—was clearly manifested.

The origin of *Chondrites* has been discussed by Simpson (1957) who, after commenting briefly on early theories (e.g., fossil algae,[1] brood-chamber burrows) and rejecting Tauber's (1949) concept of a hemisessile, surface-dwelling, presumably filter-feeding organism, interpreted it (albeit tentatively) " . . . as the product of a siphunculoid worm feeding on sediment by means of its extensible proboscis ". This is a refinement of Richter's (1931) interpretation of *Chondrites* as burrow systems excavated by sediment-eating worms. The trace fossils here identified as *Chondrites* may be of similar origin, for probably most examples are feeding burrows and suggest the burrowing and feeding activities of some small worm-like organism. On the other hand, a few examples seemingly infilled from above may well have been produced by some hemisessile organism.

Planolites sp. b and most examples of *Chondrites* are small, nondescript, and fragmentary, and it is only possible to discriminate readily between them on surfaces parallel to bedding. Trace fossils from the Takapuna section, which Ballance (1964) compared with *Chondrites* (his Type D) and which were considered to be the feeding burrows of worms, are much larger than those herein referred to this ichnogenus (widths of 10–25mm for the former, cf. 0.5–5.0mm for the latter). Type C trace fossils as recognised by Ballance may, however, well be examples of *Chondrites* —similarly the trace fossils Types 1 and 2 Ghent and Henderson (1966) record from Kaiti Beach may also be examples of *Chondrites*.

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[1] On supposed and imaginary similarities to modern seaweeds, many 19th century writers classified " fucoids " (a heterogeneous grouping that included *Chondrites* and other " genera " in addition to *Fucoides*) as algae. Minor dimensional variations, the angle of branching, etc., were taken to be of great taxonomic significance and many finely differentiated " species " were recognised—James (1894) recorded some 100 previously described " species " of *Fucoides*. After commenting on the unlikelihood of fossil preservation of modern algae, James (1884-85) previously had demonstrated that most of the forms then included in *Fucoides* were of animal origin and that while some were inorganic none was considered to be algal and he recommended that the generic name *Fucoides* be abandoned. Today it is used informally. Despite the convincing arguments of James and others there has been sporadic persistence of an algal interpretation for some " fucoids ", including a local example (see *infra*).

Ichnogenus Phycodes Richter 1850

Diagnosis: Stuffed burrows in bundled anastomosing systems.

Phycodes sp.

Material: No specimens collected from Whangaparaoa Peninsula, but abundant at a number of localities, e.g., grid reference N38/265885, Tarihunga. Casts etched on surface of a block of limonitised sandstone (X25) collected from the Takapuna section (grid reference N42/303673) by P. F. Ballance.

Description: As seen on surfaces parallel to bedding, *Phycodes* consists of a system of anastomosing bundles or clusters of "flattened" (cylindrical) markings that radiate from an ill-defined central zone and which are filled with structureless silty material lighter-coloured and finer-grained than the surrounding sediment (Pl. 5, Figs. 1, 2). The markings display a tendency to branch dichotomously and are often gently curved. Systems may reach diameters of 30cm or more; markings making up the systems have widths of 5–10mm.

Phycodes is a very common form, being abundant in siltstones at many localities.

Remarks: The trace fossil here identified as *Phycodes* closely resembles the supposed sponge described from Takapuna by Bartrum (1948) but whose similarity to *Phycodes* has since been noted and which has been re-interpreted as the feeding burrow of a worm systematically culling sediment about a central dwelling locale from which it made alternating radial forays and withdrawals (see Ballance, 1964: 492). This organism intensively utilised sediment within an area it could efficiently cover and then presumably moved on to a fresh locale.

At Whangaparaoa Peninsula *Phycodes* occurs as "flattened" impressions in siltstones and never as casts etched from limonitised sandstones, as do those described and figured by Ballance (1964: 492, Fig. 23). Sand-filled cylinders of the *Phycodes* kind occurring in thin siltstones of a thinly bedded sequence of the Waitemata Group at grid reference N33/857240 (Okahukura Peninsula, Kaipara) are filled with sand derived from beds immediately overlying those in which they are found and are possibly domicile burrows of hemisessile or vagile organisms infilled upon death of, or being vacated by, the occupants.

Other ichnogenera considered to be synonymous with *Phycodes* are *Arthrophycus* (Häntzschel, 1962: W184) and *Harlania* (Lessertisseur, 1955, Fig. 32 and Häntzschel, 1962: W184).

Ichnogenus Nereites Macleay 1839

Diagnosis: Meandering trails (and? burrows) with a central "stem" bilaterally flanked by regularly spaced leaf-shaped projections.

Nereites sp.

Material: Fragmentary limonite-stained impression in small block of siltstone (X16).

Locality: Grid reference N38/328908, Army Bay.

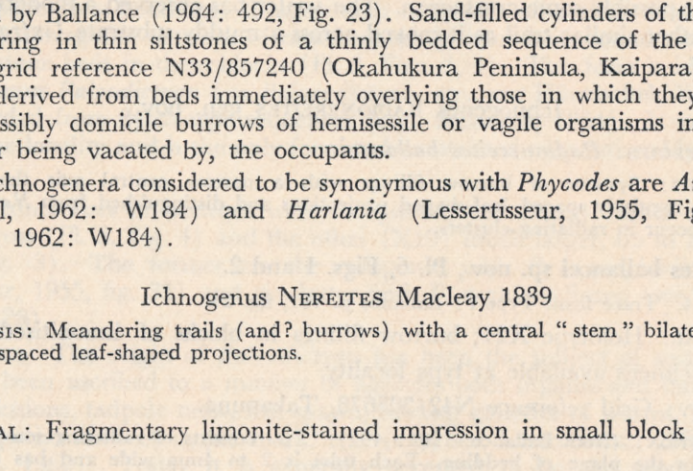


Fig. 4.—*Nereites*. Diagrammatic reconstructions drawn from field sketches of fragmentary specimens and X16.

DESCRIPTION: Isolated fragmentary specimens (e.g., X16) in which a narrow sharply defined " stem " is flanked by bilaterally arranged (pinnate), closely spaced side-shoots and which superficially resemble certain fern fronds and algae (Fig. 4) occur in some siltstones that contain few other trace fossils apart from nondescript ones of the kind described under *Planolites* sp. b and *Chondrites*. This trace fossil is here designated *Nereites*.

REMARKS: While the general morphology of *Nereites* bears some resemblance to *Radionereites* (described below) it is considerably smaller (maximum width of *c.* 1cm compared with 3cm), never displays the radiating habit of the latter and occurs as " flattened " impressions on parting surfaces in laminated siltstones and not as three-dimensional casts etched out of sandstone by selective weathering. Some impressions of *Nereites* are limonite-stained and others are picked out by silt lighter in colour than that surrounding them. It was impossible to determine whether these impressions were initially burrows made within sediment or whether they were trails made on the sea floor (i.e., whether they represent infaunal or epifaunal activities).

Although it is considerably smaller *Nereites* displays some resemblance to the variant of *Scolicia* illustrated in Pl. 3, Fig. 1. *Halimedides* (Häntzschel, 1962: W200, fig. 124) is also somewhat comparable except that it too is larger and its offshoots are reniform rather than ovate. Some functional similarity to the example of *Chondrites* illustrated in Fig. 3 can also be noted. *Nereites,* described by Häntzschel (1962: W205, fig. 127) as a feeding trail with a narrow central axis and regularly spaced leaf-shaped projections, is considered to have been produced by annelids or gastropods. If true burrows, the trace fossil here called *Nereites* may well have been produced by worms, as Ballance (1964) has suggested for his Type F; on the other hand, if surface trails they may equally well have been made by a gastropod or possibly some crustacean. The writer has observed a modern gastropod leaving a rather similar trail as it moved across a muddy substrate (*infra*).

Ichnogenus RADIONEREITES gen. nov.

TYPE SPECIES: *Radionereites ballancei.*

DIAGNOSIS: Systems of burrow fillings with a narrow central axis that is flanked bilaterally by regularly spaced leaf-shaped projections and distinguished from *Nereites* in that the burrows occur in radiating clusters.

Radionereites ballancei sp. nov., Pl. 6, Figs. 1 and 2.

1964. Trace fossil Type F: Ballance p. 492, fig. 24.

MATERIAL: Holotype X24; burrow fillings in blocks of limonitised sandstone. Further specimens available at type locality.

LOCALITY: Grid reference N42/303673, Takapuna.

DESCRIPTION: (from Ballance, 1964: 492) " . . . consists of radiating sets of sand-filled tubes lying in the plane of bedding. Each tube is 2 to 4mm wide and has two series of regularly arranged lobate side-shoots, each up to 1cm long; the direction of curvature in the lobate off-shoots is always to the centre of the radiating cluster and normally the two sets lie on either side of the main tube, in the plane of the whole specimen ".

REMARKS: This trace fossil, etched by selective weathering, is always limonitised and the sediment of the structure is of the same grain-size as the non-limonitised sediment in which they occur. Balance (1964) remarked that although there is abundant comminuted plant debris in many beds of the Waitemata Group in the Takapuna section there is a complete absence of carbonaceous material in beds in which *Radionereites* is found, indicating that it is unlikely to represent the cast of plant matter that decayed *in situ*. As Ballance has observed, *Radionereites* is a biogenic structure displaying much the same kind of functional activity as *Phycodes* does, but additionally the organism responsible was one that systematically culled sediment for a short distance either side of its path on each radial foray. The organism may have been a worm. This trace fossil had previously been recorded by

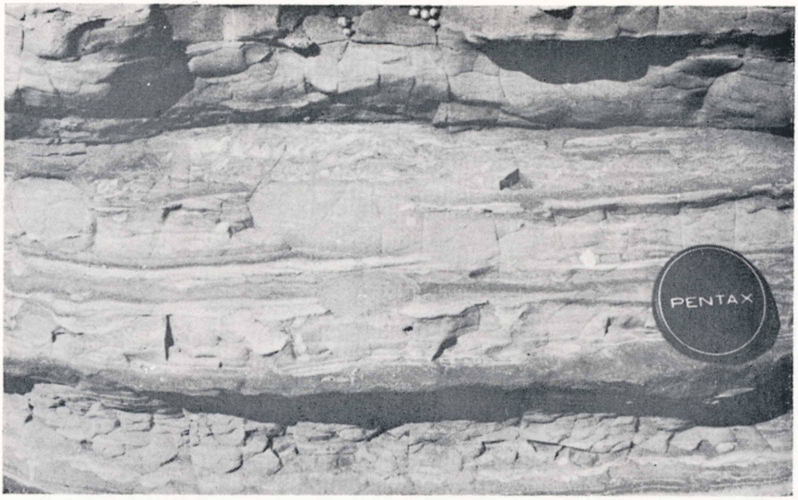


FIG. 1.—Trace fossil identified as *Scolicia* viewed in transverse section. That the animal responsible had a burrowing habit is quite apparent, for bedding features in silty sediments are disturbed. (Grid reference N38/309909; diameter of lens cap, 5cm.)

FIG. 2.—Few examples of the meandering non-branching trace fossil *Scolicia* can be followed continuously over distances as great as in this individual. (Grid reference N38/221912; length of hammer handle, 30cm.)

FIG. 3.—*Scolicia* displaying faint arched transverse laminae. (Grid reference N38/221912; diameter of coin *c.* 33mm.)

FIG. 1.—Surface densely covered with *Scolicia* (here emphasised by selective weathering) is evidence of extensive reworking of sediment. (Grid reference N38/297876; compass gives scale.)

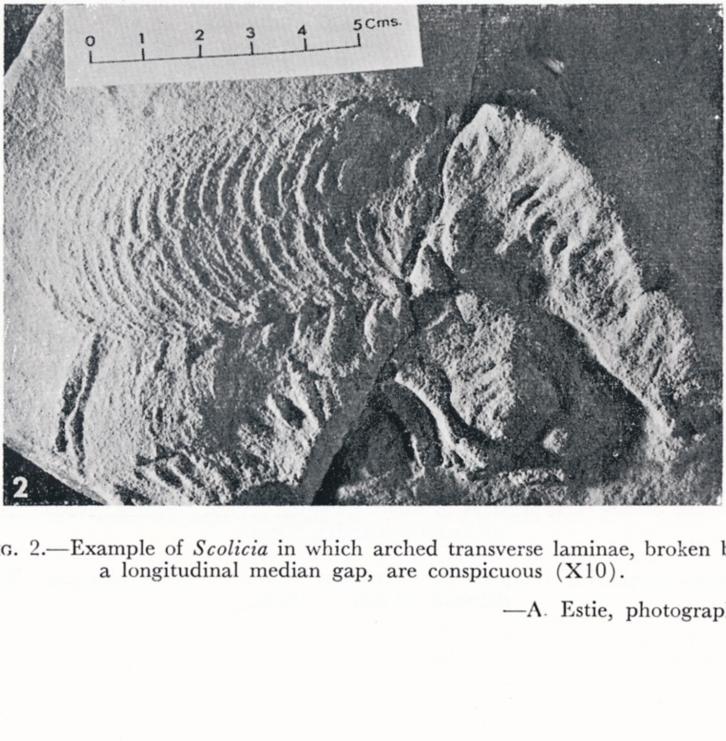


FIG. 2.—Example of *Scolicia* in which arched transverse laminae, broken by a longitudinal median gap, are conspicuous (X10).

—A. Estie, photograph.

FIG. 1.—Variant of *Scolicia* in which lobate offshoots are bilaterally arranged along a narrow structureless "stem" (X11).

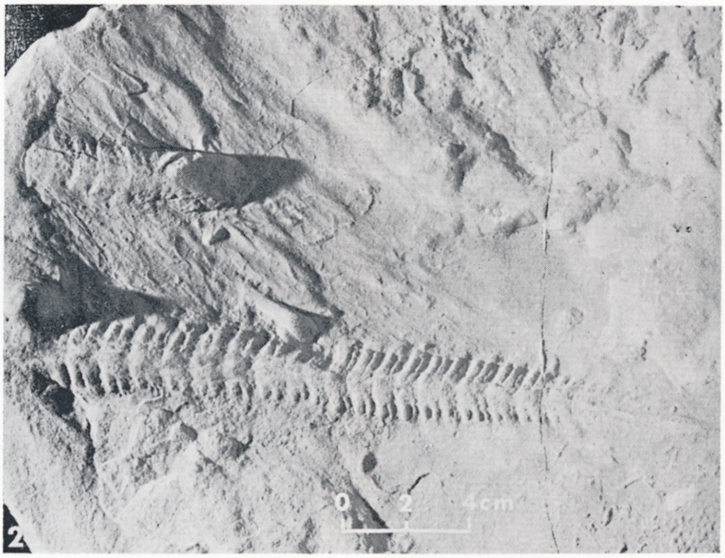


FIG. 2.—A further variant (?) of *Scolicia* (X12). Note the small fragmentary marking resembling *Paleodictyon* in lower right corner.

—A. Estie, photograph.

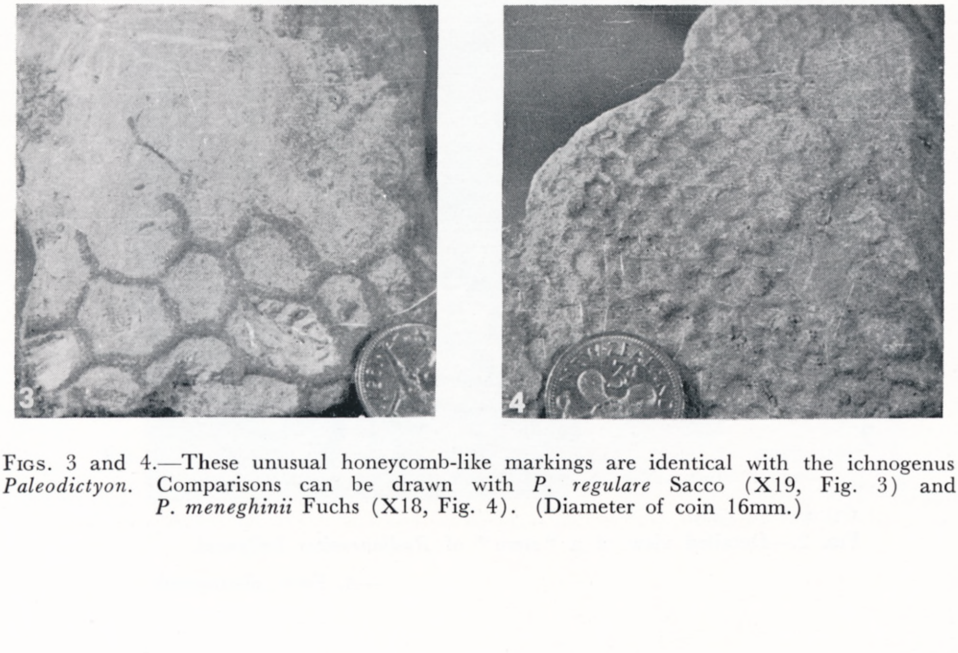
FIG. 1.—*Planolites* sp. a (X13). Specimen filled with structureless sediment darker-coloured and coarser-grained than that within which it is enclosed. Note the sharp boundary between trace fossil and enclosing sediment. This form can be compared with *Cylindrites*. (Diameter of coin 16mm.)

FIG. 2.—*Planolites* sp. b (X14). Small meandering and nondescript trails filled with powdery light-coloured silt.

FIG. 3.—Markings of this kind (X15) are compared to *Chondrites* but differ considerably from more characteristic examples of this ichnogenus (see Text-fig. 3).

FIG. 1.—Anastomosing clusters of "flattened" (cylindrical) markings identified as *Phycodes*. Note faint impression of *Cycloichnus waitemataensis* left centre. (Grid reference N38/265888; compass gives scale.)

FIG. 2.—*Phycodes* in a little more detail. (Diameter of coin 19mm.)



FIGS. 3 and 4.—These unusual honeycomb-like markings are identical with the ichnogenus *Paleodictyon*. Comparisons can be drawn with *P. regulare* Sacco (X19, Fig. 3) and *P. meneghinii* Fuchs (X18, Fig. 4). (Diameter of coin 16mm.)

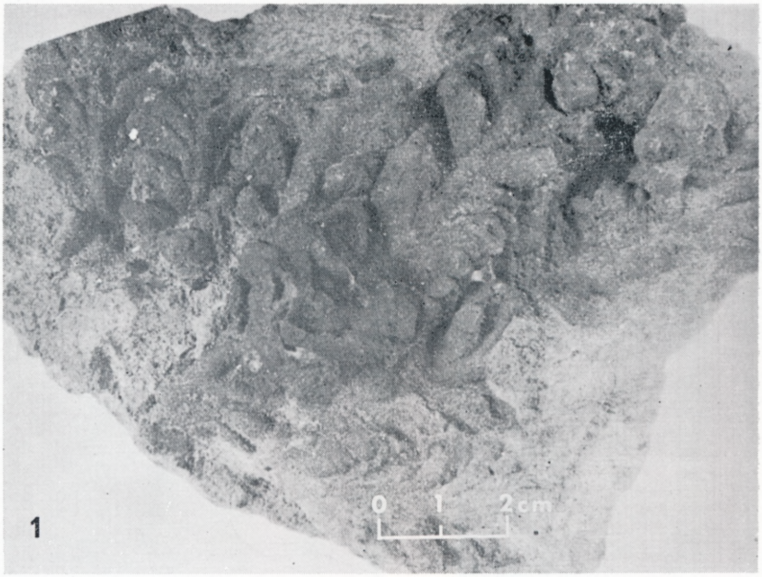


FIG. 1.—Limonitised cast of the trace fossil *Radionereites ballancei* (X24). Note the narrow " stem " and the lobate offshoots.

—A. Estie, photograph.

FIG. 2.—Detailed view of a " stem " of *Radionereites ballancei.*

—A. Estie, photograph.

FIG. 1.—Vertical burrows (" *Tigillites* ") in an interturbidite. They are filled with light-coloured sediment and terminate abruptly at the sole of the immediately overlying sandstone. (Grid reference N38/302906.)

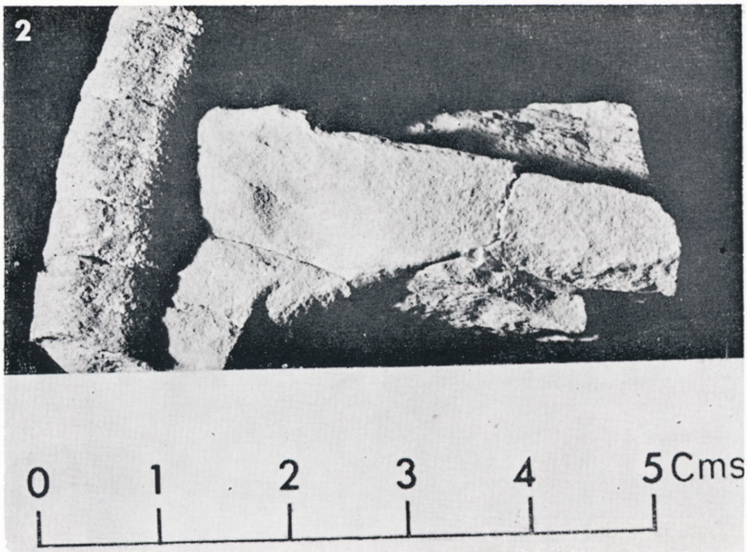


FIG. 2.—Plugged vertical burrow (X20) which displays the tendency to pull away cleanly from coarser-grained enclosing sediment in cylindrical segments.

—A. Estie, photograph.

FIG. 1.—Tight meanders of the trace fossil *Helminthoida* on a parting surface in a silty sandstone (X23).

—A. Estie, photograph.

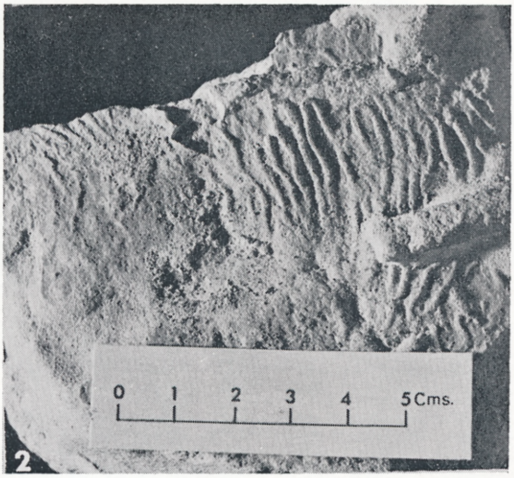


FIG. 2.—*Helminthoida* truncated by a later formed horizontal burrow of *Cylindrites* kind (X23).

—A. Estie, photograph.

Bartrum (1948), "fucoid" (i.e., seaweed) or sponge affinities being suggested. It has not been recognised at Whangaparaoa.

Ballance (1964) noted that *Polykampton*—interpreted as ". . . feeding burrow with alternating fanlike feeding fields" (Häntzschel, 1962: W210)—is a trace fossil displaying ethological similarities to his Type F (i.e., *Radionereites*). The feathery bilateral markings of *Polykampton* are duplicated vaguely at Whangaparaoa Peninsula in rare, inconspicuous markings (specimen X17) up to 4–5cm long and 1.5cm wide which have an ill-defined longitudinal central zone similarly flanked by faint feathery impressions, but which occur singly and not in clusters. This form lacks, however, the narrow zig-zag "stem" of *Polykampton,* and a distinction between it and *Planolites* may not be warranted.

Ichnogenus PALEODICTYON Meneghini 1850

DIAGNOSIS: Honeycomb-like network in relief on soles of beds; meshes 5- to 8-sided and often open to one side.

Paleodictyon sp.

MATERIAL: Two small blocks of silty sandstone (X18 and X19) with raised markings on surfaces.

LOCALITY: Grid reference N38/286896, north of Tyndalls Beach.

DESCRIPTION: At grid reference N38/286896 a number of large blocks have fallen from high in the cliff on to the shore platform. Tops and bottoms of beds in these blocks are readily revealed by small-scale sedimentary structures (e.g., graded bedding, micro-cross-bedding). Fragmentary examples of a trace fossil built of a more or less hexagonal network of raised markings have been found on the soles of some sandstone beds in these blocks (Pl. 5, Figs. 3, 4). This form is identical with the ichnogenus *Paleodictyon* (= *Palaeodictyon,* etc., see Häntzschel, 1962: W208) often recorded from flysch-type sequences (e.g., Seilacher, 1964). It was found at only the one locality and is the only form to be restricted unquestionably to the soles of beds.

Two distinct sizes of network were recognised, one (X18) rather small, about 4–5mm across (Pl. 5, Fig. 4) and the other (X19) much larger, up to 15mm across (Pl. 5, Fig. 3). The former can be compared with *P. meneghinii* Fuchs (see Lessertisseur, 1955, fig. 32) and the latter with *P. regulare* Sacco (see Häntzschel, 1962, fig. 128).

REMARKS: The origin of *Paleodictyon* has been the subject of some argument and it has been ascribed to a number of agencies both organic and inorganic, e.g., algae impressions, tadpole nests, fish spawn, feeding galleries of worms, infilled mud cracks, a special kind of ripple mark, etc. (e.g., see Lessertisseur, 1955, and also Häntzschel, 1962). Today it is generally accepted to be the product of some burrowing organism feeding preferentially along sand-silt interfaces, as advocated by Wood and Smith (1959). Despite the fact that examples of *Paleodictyon* at Whangaparaoa Peninsula were never seen to disturb primary sedimentary structures, they are interpreted tentatively to be of animal origin for the sediment filling of these trace fossils is identical with that of the bed on whose sole they occur. As in the case of *Radionereites,* although comminuted carbonaceous material is abundant in adjacent beds, there is no evidence of *Paleodictyon* being the cast of plant debris decaying *in situ.* Similarly, there is no evidence to suggest that either specimen is the impression of some colonial organism, alga, etc.

There is some experimental evidence to suggest that *Paleodictyon*-like structures may result from convection-like patterns of movement that occur in turbidity currents as particles carried in suspension begin to settle (see Dzulynski, 1966; Dzulynski and Simpson, 1966: 206–9). The crests of ridges in such non-biogenic structures appear, however, to be sharp, while those in the observed *Paleodictyon* are low and smoothly rounded.

Ichnogenus TIGILLITES Rouault 1850

DIAGNOSIS: Non-crowded, smooth or regularly annulated, simple vertical burrows stuffed with structureless sediment.

"Tigillites" sp.

MATERIAL: Small block of silty sandstone (X20) with section of one vertical burrow stuffed with sandy sediment.

LOCALITY: Grid reference N38/315910, to the west of Army Bay.

DESCRIPTION: Straight, simple, non-branching burrows orientated approximately normal to bedding are not common in the Waitemata beds. Those isolated examples seen by the writer at Whangaparaoa Peninsula (and elsewhere) were always simple in style, their walls lacked ornamentation and they were plugged with structureless sediment (e.g., Pl. 7, Fig. 1), often coarser-grained than that through which they passed. There was no evidence of a living chamber either at the base or along the length of burrows and faecal pellets were not seen to be concentrated in them. Generally they were circular in cross-section, but some were oval; diameter varied from as little as 2mm to as great as 20mm but was consistent along the length of any individual. Length varied from a few centimetres to, in one instance, almost a metre but no consistent relationship existed between length and diameter.

REMARKS: These vertical burrows are here designated "*Tigillites*" but this is not an entirely satisfactory identification. By Häntzschel (1962) *Tigillites* is distinguished from *Scolithos* on the basis that the plugged tubes of the former are never crowded together, while in the latter they commonly, but not invariably, are. This, as Hallam and Swett (1966) observe, is an unsatisfactory character upon which to distinguish these two ichnogenera for as they note *S. linearis* (the type species) displays no persistent crowding.

Vertical burrows ("*Tigillites*") can be grouped as follows:

1. Those that pass through a number of beds. These are more frequent in thinly bedded sequences and are often of great length.
2. Those that are restricted to a single siltstone layer, whether it is an interturbidite or the uppermost interval (d) of a turbidite.[1] They terminate abruptly at the sole of an overlying sandstone bed (usually a turbidite) and fail to enter intervals a, b, or c of an underlying turbidite.
3. Occasional examples pass completely through thicker sandstones (turbidites) and disappear in an underlying siltstone. Such burrows were never seen to penetrate beds more than 50cm thick.
4. Rare examples are restricted to the lower two intervals (a and b) of turbidites and do not pass upwards into intervals c, d, and e. These sometimes pass through the sole of a turbidite into an underlying siltstone.

Many vertical burrows (especially those plugged with sediment coarser-grained than that through which they pass) have been infilled from above. The filling of

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[1] Bouma (1962) has recognised five intervals in the typical turbidite rhythm:

(a) graded (and massive) interval	turbidite intervals
(b) lower interval of parallel laminations	
(c) interval of current ripple laminations	
(d) upper interval of parallel laminations	
(e) pelagic interval	interturbidite

In practice it is difficult to differentiate with certainty interturbidites (e) from the upper interval of parallel laminations (d).

most burrows of this kind is demarcated sharply from surrounding sediment and tends to break out in cylindrical segments of irregular length (Pl. 7, Fig. 2) a phenomenon otherwise only observed in a few examples of *Cylindrites.* It suggests that they originated as the domicile burrows of hemisessile and/or vagile organisms infilled upon death of, or being vacated by, the occupants, and that in life the burrows were lined with sand-grains cemented by mucus, for the walls are smooth, often almost glassy in appearance.

Other vertical burrows clearly have not been infilled from above. In these there is a transition between the sediment filling them and that through which they pass, rather than a sharp-walled contact. The absence of living chambers, concentrations of faecal pellets, or arched transverse laminae like those of *Scolicia* and *Planolites* sp. a suggests these burrows may have been made very rapidly and that the sediment filling them, although possibly having been passed through an organism's gut, was not necessarily used for nutritional purposes. Accordingly, the writer interprets them as being either:

(a) Escape routes: Organisms overwhelmed by newly emplaced turbidites were able to escape by burrowing rapidly upwards to the new sea floor, or

(b) Access routes: Those vertical burrows originating (or ending) in interturbidite siltstones and downwards penetrating one or more turbidites as well as those that pass through some thickness of thinly bedded sandstone–siltstone sequences may equally well be interpreted as access routes of organisms invading nutrient-rich silty sediments some distance below the sea-floor, like those recognised by Seilacher (1962).

Ichnogenus CYCLOICHNUS gen. nov.

TYPE SPECIES: *Cycloichnus waitemataensis.*

DIAGNOSIS: Structure seen on bedding planes as a central circular core surrounded by a variable number of concentric markings outside of which there may be further curved branches. Serial sectioning transverse to bedding reveals that the central core is a cylindrical shaft and that the concentric markings are a bedding-plane view of saucer-shaped galleries coming off the shaft at more or less regular intervals. The galleries do not appear to be spirally arranged on the central shaft, and although they branch to a limited extent they are not interconnected. For a schematic and diagrammatic reconstruction see Fig. 5.

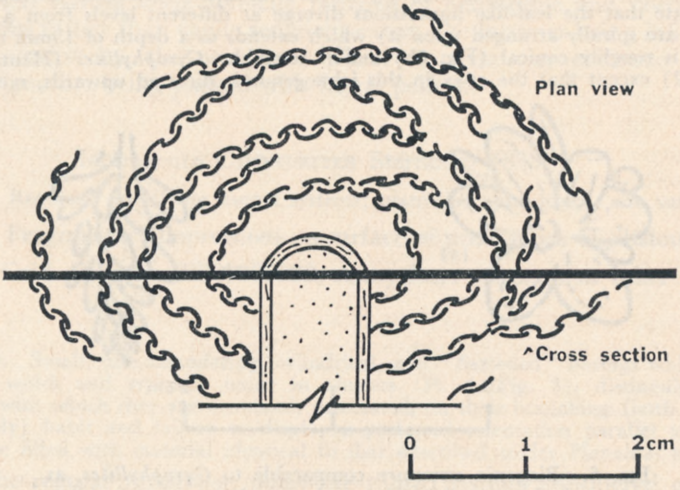

FIG. 5.—Diagrammatic reconstruction of *Cycloichnus waitemataensis* showing the central structureless core (? dwelling shaft) and the saucer-shaped galleries that diverge from it. Drawn from serial sectioning of X21, photographs, and field sketches.

Cycloichnus waitemataensis sp. nov., Fig. 5, also Pl. 5, Fig. 1.

Material: Holotype X21; structure preserved as burrows and impression in siltstone.

Locality: Grid reference N38/265888, Tarihunga; further specimens at other localities, but never common.

Description: The simple central shaft appears to have been infilled from above with structureless sediment; it has a uniform diameter of *c.* 1cm and extends to depths of 2.5+cm. The boundary between the shaft and the enclosing sediment is not always sharp, but it does appear to be smooth-walled. The saucer-shaped galleries, which are irregularly constricted to give small leaf-shaped impression, are picked out by light-coloured powdery silt that contrasts with the sediment in which they occur (see Pl. 5, Fig. 1).

Remarks: A careful search of the available literature has revealed no reference to any organic (or inorganic) structure at all closely comparable to *Cycloichnus.* This trace fossil was usually found in close association with *Phycodes* (e.g., see Pl. 5, Fig. 1) but it was never common. It is difficult to suggest any organism which could produce this structure. *Laevicyclus,* interpreted as the dwelling shaft of a worm (Häntzschel, 1962: W201), somewhat resembles the central shaft but it lacks the saucer-shaped galleries. Possibly *Cycloichnus* was formed by some proboscis-bearing organism (a siphunculoid worm?) that systematically culled sediment about a dwelling shaft in a manner somewhat analogous to that of *Chondrites* as described by Simpson (1957). As in the case of *Chondrites,* the behavioural phenomenon of phobotaxis is exhibited.

Ichnogenus GYROPHYLLITES Glocker 1840

Diagnosis: Vertical " stem ", from which lobate offshoots radiate at different levels; whole structures conical in shape.

Cf. Gyrophyllites

Locality: Grid reference N38/265888 Tarihunga; grid reference N38/308908 east of Coal-mine Bay, but never common.

Description: Small rosetted structures of overlapping, oval, leaf-shaped impressions (Fig. 6a) are found on weathered bedding surfaces at many localities. Sections normal to bedding indicate that the leaf-like impressions diverge at different levels from a central stem (possibly they are spirally arranged upon it) which extends to a depth of 15mm or more. The overall shape is roughly conical (Fig. 6b) and it resembles *Gyrophyllites* (Häntzschel, 1962: W200, fig. 122) except that the apex in this ichnogenus is directed upwards, not downwards.

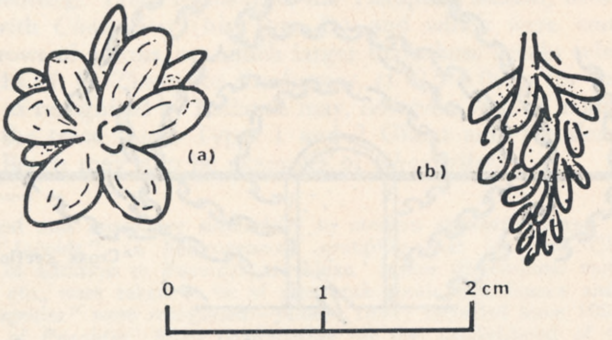

Fig. 6.—Biogenic structure comparable to *Gyrophyllites,* as seen on bedding surfaces (a) and viewed normal to bedding (b), showing the leaf-shaped protuberances from the central " stem ". Note the apex of this structure is directed downwards. Drawn from field sketches and notes.

Remarks: This structure is not common although fragmentary markings suggestive of it were not uncommon. As with many other of the described trace fossils it was often picked out by light-coloured silt. It may have been produced by hemisessile or vagile worm-like organisms that sytematically culled sediment over a short distance about a central dwelling shaft. Some ethological similarity to *Phycodes,* with which it was commonly found, can be noted.

Ichnogenus Helminthoida Schafhautl 1851

Diagnosis: Numerous, smooth, closely spaced, parallel and equidistant concentric shallow furrows (or low ridges).

Helminthoida sp.

Material: Low ridges on surfaces of two small slabs of silty sandstone.

Locality: X22, grid reference N42/130430, Mill Bay: X23, grid reference N42/411570, Bucklands Beach.

Description: Two specimens very closely similar to *Helminthoida* (= *Helminthoides* and *Helminthoidea*) as described and figured by Häntzschel, 1962: W200, fig. 122) have been collected by P. F. Balance from the Waitemata beds near Mill Bay and near Bucklands Beach. No examples are known from Whangaparaoa Peninsula. Both specimens occur in silty sandstones and lie on parting surfaces that are parallel to bedding (tops and bottoms are not discernible) and consist of a low, smoothly rounded " cord " *c.* 1mm across that is continuous and unbranched and meanders back and forth in closely spaced sub-parallel loops (Pl. 8, Figs. 1, 2).

Remarks: Many origins have been contemplated for this oft recorded ichnogenus, e.g., stringers of eggs, body impressions of worms, feeding trails and/or burrows of worms and gastropods (see Lessertisseur, 1955: 50). Similarities can be noted between *Helminthoida* and certain modern trails photographed on the deep-sea floor and believed to have been made by enteropneusts (see Bourne and Heezen, 1965, fig. 2) but the latter are much larger. There is no evidence as to whether *Helminthoida* was produced by an infaunal or epifaunal organism.

Cullen (1967) has recorded a trace fossil from mid-Tertiary deposits near Castle Point closely resembling the above described *Helminthoida* and has also drawn attention to the striking similarity between it and the modern enteropneust faecal casts described and figured by Bourne and Heezen (1965).

Additional Forms

In addition to the trace fossils described above, there are numerous examples in which, though they are of a fragmentary and indistinct nature, orderly structures repeatedly occur. While detailed descriptions of these are not warranted, some are vaguely comparable with a number of ichnogenera illustrated and/or described by Häntzschel (1962) and by Lessertisseur (1955). These include the following: *Bifasciculus, Gyrochorte* (= *Gyrochorda*), *Lorenzinia, Palaeophycus, " Spongia ", Stellascolites, Zoophycos.*

Most of these ichnogenera are to be interpreted as feeding structures of one sort or another, e.g., *Lorenzinia,* previously described as a medusoid (Scyphomedusae) (see Harrington and Moore, 1956: F43) is today generally regarded as a feeding burrow (see Häntzschel, 1962: W202; also Seilacher, 1962). The ichnofossil *" Spongia "* has been compared with the modern Porifera genus *Spongia* Linné (see e.g., Katto, 1960: 324) but is more likely the feeding burrow system of some worm or crustacean (Häntzschel, 1962: W218).

DISCUSSION

The trace fossil assemblage (ichnocoenosis) of the Waitemata beds of Whangaparaoa Peninsula, with also that of the Takapuna section described by

Ballance (1964), are closely comparable to that which Seilacher (1962) has shown to be characteristic of the flysch facies and which in 1964 he termed the *Nereites* facies. Of the five groups of trace fossils[1] recognised by Seilacher (1953), Pascichnia and Fodinichnia dominate this assemblage, Domichnia and Repichnia are less abundant and no Cubichnia elements were noted. It is generally accepted—perhaps uncritically, following the redeposition theory of Kuenen and Migliorini (1950)—that flysch-type sediments accumulated at great depth. Rocks of the Waitemata Group outcrop extensively over northern parts of the Auckland province and are believed to have been " . . . deposited in a marine basin within a continental borderland" (Ballance, 1964: 497). Within the group Ballance has recognised four NNW–SSE trending facies belts. The beds at Whangaparaoa Peninsula belong to the turbidite facies and are believed to have been deposited towards the axial parts of the basin (Gregory, 1966). If it is valid to draw (as does Ballance) comparisons with modern offshore marine basins of similar extent that are receiving the deposits of turbidity currents (e.g., the San Diego Trough off southern California) then depths in the axial parts of the basin may have been of the order of 1,500 metres.[2]

Modern representatives of the *Nereites* facies are known mainly from depths greater than 4,000 metres (Seilacher, 1967). However, the need for caution in attempts at paleoecological reconstructions using trace fossils and based on extrapolations from modern environments has been demonstrated by Cullen (1967). Nevertheless, there can be little question on the paleoecological value of trace fossils (see e.g., Martinson, 1965; Farrow, 1966; Seilacher, 1967).

Attention has been drawn by Cloud (1961) to similarities between the infauna of modern aphotic depths and that supposedly responsible for trace fossils of the flysch facies. Cloud suggested (p. 189) " . . . that the known benthonic megafauna of the flysch facies . . . represents an infauna of relatively deep water: probably mainly bathyal (below 200m) and perhaps locally even abyssal". A further factor to be considered is Henbest's (1960) record of trails and burrows closely comparable to some of the trace fossils typical of the flysch facies, but, in his opinion, occurring without doubt in sediments that accumulated in a shallow, well-aerated marine and possibly estuarine environment.

Some general conclusions can be drawn from the available evidence: (1) The described trace fossils have resulted largely from the burrowing and feeding activities of a rich and probably diverse infauna, in which, as previously noted, soft-bodied, sediment-eating organisms predominated. Like the ichnofauna considered by Seilacher (1962) to be characteristic of the flysch facies the organisms responsible for the trace fossils were mostly restricted to silty sediments. As Ghent and Henderson (1966) suggest, either silty substrates were richer in nutrients than sandy ones or the latter afforded a less hospitable habitat—one in which respiratory and other physiologic functions were inhibited.

(2) The abundance of trace fossils cannot be taken as evidence of an oxygen deficient environment with periods of stagnation between the arrival of successive

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[1] These groups are based on ethologic interpretations and are as follows:

Pascichnia: The winding and meandering trails and burrows of vagile mud-eating organisms.

Fodinichnia: Extensive burrow- and tunnel-systems made by hemisessile sediment-eaters.

Domichnia: Permanent domicile burrows made by vagile or hemisessile organisms feeding from without the sediment, e.g., predators and filter and suspension feeders. Simple in style or U-shaped and at right-angles to bedding.

Repichnia: Trails, burrows, tunnels left by vagile benthos during locomotion.

Cubichnia: Resting marks (or body impressions) left by vagile organisms temporarily resting on the sea-floor.

[2] The maximum depth of the San Diego Trough, given by Shepard and Einsele (1962) is 700 fathoms.

turbidity currents as has been argued by Kuenen and Sanders (1956). Rather it is evidence to the contrary—lack of trace fossils would (in part) be suggestive of euxinic conditions (see Seilacher, 1964). Evidence of a negative nature favouring a non-stagnant environment is: (a) the absence of U-shaped burrows—Lessertisseur (1955) has inferred that their presence is suggestive of oxygen-deficient conditions—and (b) the interruption of interturbidite intervals (siltstones) by discontinuous, thin, micro-cross-bedded sandstones suggests that the sea-floor was being swept intermittently by gentle traction currents.

U-shaped burrows of the kind known as *Arenicolites* (see Häntzschel, 1962: W183–4, fig. 109) were never recognised in the Waitemata beds of Whangaparaoa Peninsula, although a few obscure and indistinct markings reminiscent of them were seen in blocks of fine-grained volcaniclastic grit that rest on the shore platform at grid reference N38/299906 (east of Coal-mine Bay). Mayer (1965) has recorded U-shaped burrows from Waitemata beds at Motutapu Island, where they occur at the base of coarse-grained sandstones and volcanic grits and extend downwards into siltstones for depths of up to 13cm.

Nevertheless, local and restricted reducing environments may have existed in sandy substrates (as well as some silty ones) effectively preventing their colonisation by an infauna and marginal epifauna, for many beds (particularly turbidites) are conspicuously rich in comminuted carbonaceous material.

(3) A diverse infauna, which probably included worms, shell-less molluscs, holothurians, hemichordates, and crustaceans, is represented in the recorded ichnocoenosis. No reliable estimate of depth can be made from this assemblage; however, very great or very shallow depths seem improbable. Catastrophic emplacement of turbidites frequently led to the periodic destruction of this infauna. Thus, while trace fossils are abundant in thick sequences of thinly bedded strata (where tractive sandstones and/or thin silty sandstones deposited from the weaker " tails " of turbidity currents alternate with thin siltstones), they are less abundant in sequences where thin siltstones alternate with thick and often composite bedded sandstones (turbidites).

(4) Exposed surfaces covered in trace fossils are evidence of extensive reworking of sediment by burrowing, sediment-eating organisms, and although mottled textures like those illustrated by Moore and Scruton (1957, Fig. 12) are seldom conspicuous, some massive, homogeneous (structureless and non-laminated) silty sandstones may have originated in this way.

(5) No consistent relationship was found to exist between the ichnofauna of any bed and its thickness, or between the ichnofauna of a siltstone and the thickness of the immediately overlying sandstone (turbidite), except that, as noted previously, trace fossils were less common in thick sequences where thin siltstones alternated with thick turbidites than they were in thinly bedded sequences. This contrasts with Seilacher's (1962) description of the ichnofauna of flysch sediments in which certain trace fossils were not to be found in or below beds of certain maximum thicknesses—the thickness varying from type to type and being a measure of the depth range (within the sediment) of the organism responsible.

A more detailed interpretation will be feasible only when studies of modern trails, burrows, etc., in other than littoral environments have been made. As a concluding comment, illustrative of the need for this evaluation, it is perhaps pertinent to remark that the writer has observed two individuals of the same species—*Lunella smaragda* (Gmelin), the common New Zealand cat's-eye—leaving two distinct kinds of trail, comparable with *Planolites* and *Nereites,* as they moved across a muddy substrate within a few centimetres of each other.

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POSTSCRIPT

Since this paper was submitted for publication Dr R. Goldring has brought to the writer's attention an article by Gräf (1956) in which recent markings made by the modern gastropod *Littorina littorea* Linné are described and figured. In his text-fig. 2, Gräf (p. 311) schematically illustrates several different styles in which markings made by *L. littorea* can occur. These different styles are very closely comparable to the variations in *Scolicia* recognised by the writer in Fig. 2. Gräf attributed differences in markings produced by *L. littorea* to variations in grain-size and water content in the sediments in which they were made.

A number of excellent photographs of modern tracks and trails on the sea-floor have recently been presented by Ewing and Davis (1967). Many of the *Lebensspuren* these writers record display similarities to the trace fossils described in this paper.

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