

## Distinguishing trace fossils and similar-shaped body fossils using sedimentological criteria – an example from the Miocene of New Zealand

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### Abstract

The activity of mainly benthic organisms and plants results in the creation of new sedimentary features. Therefore, sedimentological analyses may provide significant data for identification of a biogenic morphology resembling either a trace fossil or a body fossil. Ferruginous tubes, 5-10 mm in diameter and filled with silt, occur in the Miocene turbiditic sequence of the Waitemata Group near Auckland (New Zealand). These tubes branch and radiate horizontally from a mesial initial tube for a rather short distance. Branching segments with different radiating centres overlie each other without cutting adjacent tubes and lack an upwardly inclined entry shaft. All occur on top of ferruginous bedding planes, suggesting that both the bedding plane and the overlying radiating structures were simultaneously covered by the mineralization precursor. Their previous interpretation as feeding burrows (ichnogenus *Phycodes*) of a worm-like organism is therefore questioned. The similarity of these tubes to the extant alga *Codium fragile* (SURINGAR, 1867) suggests that the tubular structure is the mineralized periphery of this kind of algae carried downslope with land-derived siliciclasts and terrestrial plant material. Therefore, in cases of a suspected ichnofossil, in addition to its morphological affinities, the sedimentological setting of the host-rock and the diagenetic history of the fossil should be considered.

**Keywords:** Trace and body fossils, sedimentology, diagenesis, Miocene, New Zealand.

### Résumé

L'activité d'organismes et de plantes essentiellement benthiques résulte en la formation de nouvelles figures sédimentaires. De ce fait, l'analyse sédimentologique peut fournir des renseignements importants pouvant aider l'identification de morphologies biogéniques ressemblant soit à un fossile de trace ou à un fossile

de corps. Des tubes ferrugineux de 5 à 10 mm de diamètre à remplissage de silt se rencontrent dans la séquence turbiditique d'âge Miocène du Groupe de Waitemata près d'Auckland, Nouvelle Zélande. Ces tubes ramifiés rayonnent à partir d'un tube radial initial sur une assez courte distance. Des segments ramifiés rayonnant de différents centres se superposent mutuellement sans recouper les tubes adjacents et sans présenter une voie d'entrée inclinée vers le haut. Tous apparaissent au sommet de plans de litages ferrugineux, suggérant qu'aussi bien les plans de litage que les structures radiaires qui les surmontent ont été tous les deux perminéralisés. L'interprétation antérieure de ces structures comme figures de fousissements nutritives (ichnogénus *Phycodes*) d'un organisme de type ver est par conséquent remise en question. La ressemblance de ces tubes à l'algue *Codium fragile* (SURINGAR, 1867) suggère que ces structures tubulaires sont les périphéries mineralisées de ce type d'algues transportées vers les zones bassinales, mélangées à du matériel siliciclastique terrestre et autres débris de plantes. En conséquence, dans le cas d'un ichnofossil suspect, outre ses affinités morphologiques, le contexte sédimentologique de la roche encaissante et l'histoire diagénétique du fossile doivent être également considérées.

**Mots-clés:** Fossile de trace ou de corps, sédimentologie, diagénèse, Miocène, Nouvelle Zélande.

### Introduction

Sixty years ago, BARTRUM (1948) compared a fossil from the Waitemata Group of northern New Zealand to the cast of a sponge or seaweed. Subsequently, BALLANCE (1964) and GREGORY (1969) interpreted this fossil as the mineralized periphery of feeding burrows of some kind of worm, but both authors failed to provide substantiating evidence. New outcrops with well-preserved specimens have recently been discovered along the coast of Auckland. Their shape, mode of occurrence and diagenetic mineralization in relation to the host sediment raise doubts about the ichnofossil nature of these fossils.

The Waitemata Group is a late Cenozoic (early Miocene, Otaian) siliciclastic turbiditic sequence with a minor carbonate content of mainly biogenic origin

(BALLANCE, 1964). The benthic foraminifera recorded from this unit are a mixture of neritic to bathyal species (mainly upper and middle bathyal, with some lower bathyal ones), demonstrating the allochthonous nature of much of the sediment except for ichnofossils and planktonic foraminifera (HAYWARD & BUZAS, 1979). Layers containing plant remains (wood fragments and branches) and ichnofossils characteristic of deep-marine environments reflect these mixed palaeoecologic settings as well (BALLANCE, 1964; GREGORY, 1969).

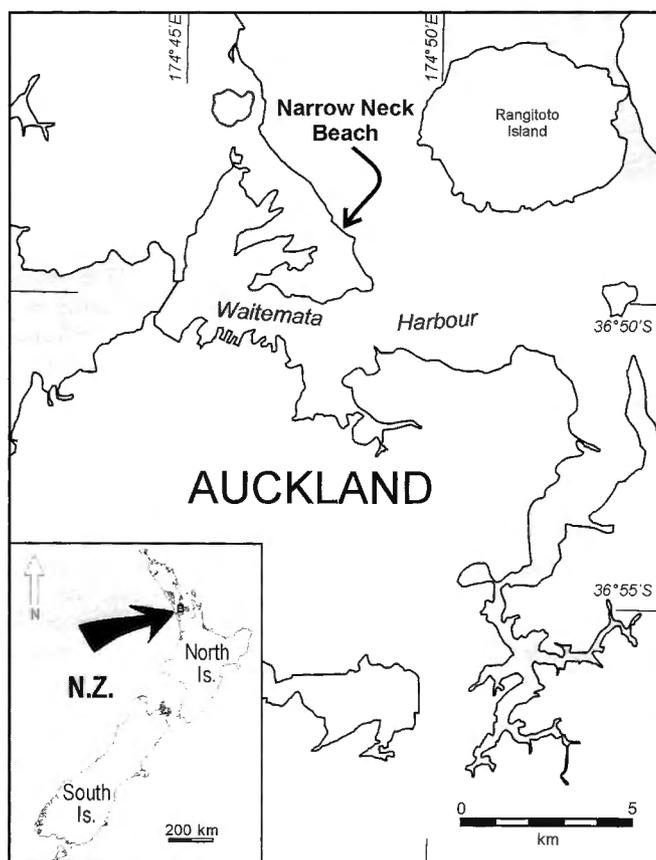


Fig. 1 — Locality map of the Auckland area (North Island, New Zealand) with the Narrow Neck Beach site.

The Waitemata Group exposed along the beaches of Auckland consists of bedded mudstone, siltstone and argillaceous sandstone (BALLANCE *et al.*, 1984). This friable sediment has been abraded by coastal waves and shaped into steep coastal cliffs and a narrow abrasion platform, which is exposed during low tide only. About 150 m north of Narrow Neck Beach (Fig. 1), northeast of Devonport, the bedded sequence dips about 20 degrees towards the coast, exposing, at low tide, several tens of metres of Waitemata Group sediments. Wave

action on the differentially lithified beds has formed a serrate (saw-toothed) exposure (Fig. 3). Many beds are capped by a ferruginous crust that in places comprises bundles of branching tubes 5-10 mm in diameter made of a similar ferruginous substance (Fig. 2). These ferruginous surfaces are overlain by friable, non-mineralized sediment which is easily removed by wave action, exposing the mineralized fossils. These have an irregular distribution in the sequence and are absent from most of the ferruginous bedding planes exposed. A certain interval of the bedded turbiditic sequence at Narrow Neck exposes four to six successive ferruginous levels with the tubular fossils (Fig. 2).



Fig. 2 — Ferruginous bedding planes with or without the ferruginous fossil, alternating with friable argillaceous silt.

#### Previous identifications

The radiating tubular structure is the commonest fossil in the Waitemata Group around Auckland and is thus of



Fig. 3 — Gently inclined beds of the Waitemata Group turbiditic sequence with the fossils exposed on wave-cut platform at low tide, 150 m north of Narrow Neck Beach (North Island, New Zealand).

significance for the sedimentary history of the group. The fossil was first identified as the cast of a sponge or a seaweed (BARTRUM, 1948), but was subsequently interpreted as an ichnofossil reflecting the burrowing activity of an infaunal worm-like organism searching for food in an area around a central initial burrow (BALLANCE, 1964). The organism supposedly burrowed back and forth, forming feeding forays radiating from a central dwelling locale. It was compared to the ichnogenus *Phycodes*, although the sediment filling the tubes did not show any internal structures resembling 'spreiten'. GREGORY (1969) described several ichnofossils from the Waitemata Group, accepting the generic identification of *Phycodes* isp. without providing any new supporting data that the horizontally radiating tubes confined to bedding planes were feeding burrows.

#### Re-examination of *Phycodes* isp. from the Waitemata Group

The recently discovered fossils provide new evidence that renders unlikely the ichnofossil nature of these ferruginous radiating tubular structures. They usually

occur as isolated segments, but form clusters as well. In these clusters, two to three segments are often superimposed on each other, each radiating horizontally from a different centre without cutting adjacent tubes (Fig. 4). All segments branch dichotomously or comb-like along one side (Figs 4, 5), extending to a radius of about 15 cm. Differences in mineralization intensity and slight compaction resulted in variations in maximum tube width (5-10 mm). The initial tube at the centre of each radiation does not show any upward bending as would be expected of an entry shaft. In superimposed segments, no tube cuts through another. All these horizontally radiating ferruginous structures occur on top of similarly mineralized bedding planes. The siliciclastic sediment above and below is not affected and is thus friable and easily washed away by wave action, exposing the hard ferruginous crust on the bedding planes and the incorporated structures (Fig. 2). The ferruginous mineralization thins and disappears into the subsurface, suggesting that mineralization results from the alteration of a mineralogical precursor that selectively accumulated on the bedding plane and around the radiating structures. Successive beds with the radiating fossils occur about 2 m above a ferruginous sandy layer (about 40 cm thick) rich in tree-

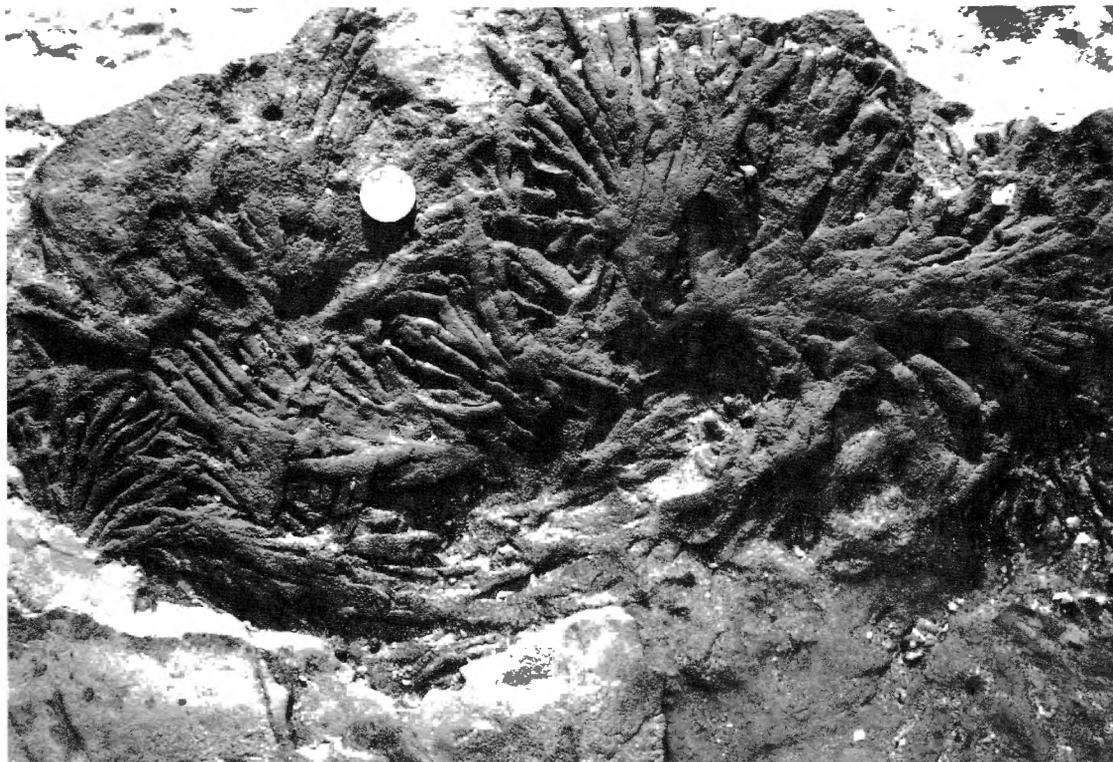


Fig. 4 — Branching, ferruginous, sediment-filled tubes radiating from different centres, on top of a ferruginous bedding plane, underlain and overlain by non-mineralized, white, argillaceous silt (diameter of coin: 22 mm; detail of Fig. 2).

trunk fragments, branches and small pieces of wood (Fig. 6). Accordingly, the land-derived siliciclastic sediments carried terrestrial plant remains into the deep sea where they accumulated in turbidites.

#### Associated fossils

The interpretation of these structures as ichnofossils may have been influenced by the occurrence of unequivocal burrow fills within the sandy layers of the Waitemata Group (not on bedding planes) of this sequence, such as *Chondrites* and *Scolicia* (GREGORY, 1969). The associated *Radionereites ballancei* GREGORY, 1969 consists of ferruginous coating of radiating stems 3–4 mm in diameter, each bearing two laterally paired or alternating branchlets about 15 mm long. They are bottle shaped, narrow at the stem and inflate into an elliptical longitudinal cross-section. They were originally suggested to be casts of seaweed (BARTRUM, 1948) and later defined by GREGORY (1969) as feeding burrows. BRADLEY (1980) interpreted the occurrence of *Scolicia* just above the tubular *Phycodes* isp. to represent the feeding activity of a sea pen such as *Renilla*. A year later, BRADLEY (1981) opined that the vertical succession of *Phycodes* isp., overlain by *Chondrites* isp.

and *Radionereites ballancei*, was the result of activity by another sea pen such as *Anthoptilum*. No evidence of these ichnofossil successions as compiled by BRADLEY were found in the field. The supposed mineralization of certain postures of a moving sea pen as suggested by BRADLEY (1980, 1981) is impossible.

#### Discussion

The occurrence of the mineralized tubular radiating structures on a similarly ferruginous bedding plane raises doubts as to their identification as feeding burrows. The latter are made at an incidental level within the sediment which has no potential for later selective mineralization along the bedding plane that comprises the burrow fill, unless this bedding plane is enriched in organic matter (phobotaxis). The Waitemata Group turbiditic succession comprises numerous bedding planes, only a few of which became mineralized and some of them comprise the discussed fossil. It is doubtful whether only these few levels were enriched in organic matter. This observation adds to the absence of an upward-inclined entry shaft and the lack of any cross-cutting tubes in the superimposed sets of fossils.

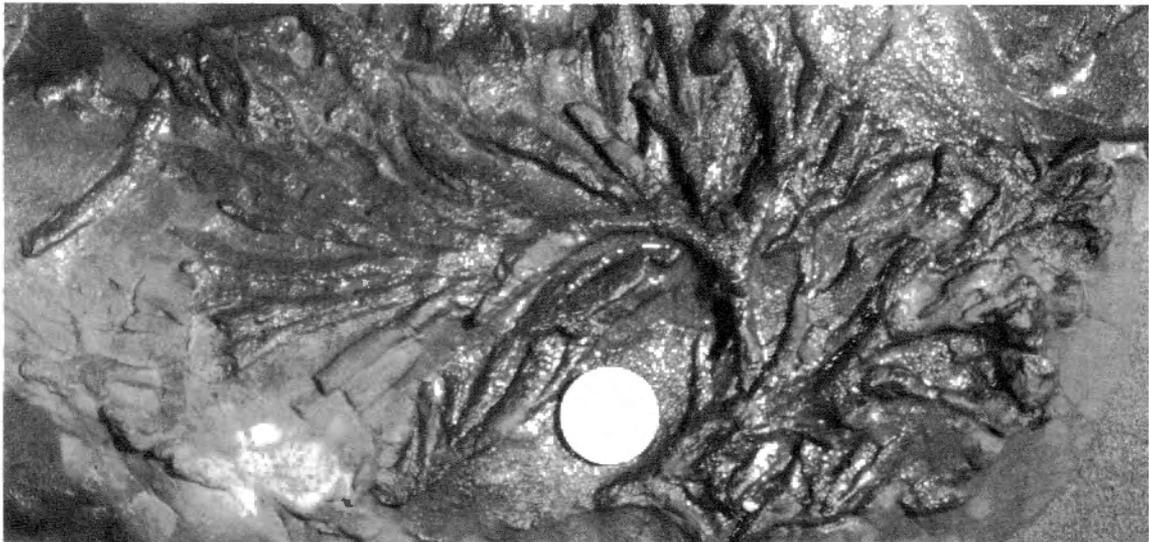


Fig. 5 — Another horizontally radiating fossil with overlying (not cross-cutting) branches (diameter of coin: 22 mm).

The ferruginous mineralization is a late diagenetic process due to the exposure of the sediment to meteoric and sea water. The oxygen-bearing water oxidizes a precursor mineral restricted to the sedimentary bedding planes and the associated horizontally radiating tubular fossils. Such a precursor of iron-oxides may be tiny pyrite crystals (*e.g.*, BRADLEY, 1981). These would have precipitated under anoxic conditions as the result of decomposing organic matter in the presence of

dissolved ferrous iron. The Waitemata Group contains volcanic components (volcaniclasts) either forming beds or dispersed as tiny particles in the sediment which, in addition to other sources, contributed iron. The ferrous iron was absorbed onto the degrading organic components. Micro-organisms, such as benthic foraminifera (HAYWARD & BUZAS, 1979), settled phytoplankton and bacteria living on the seafloor may have enriched this surface with organic matter during

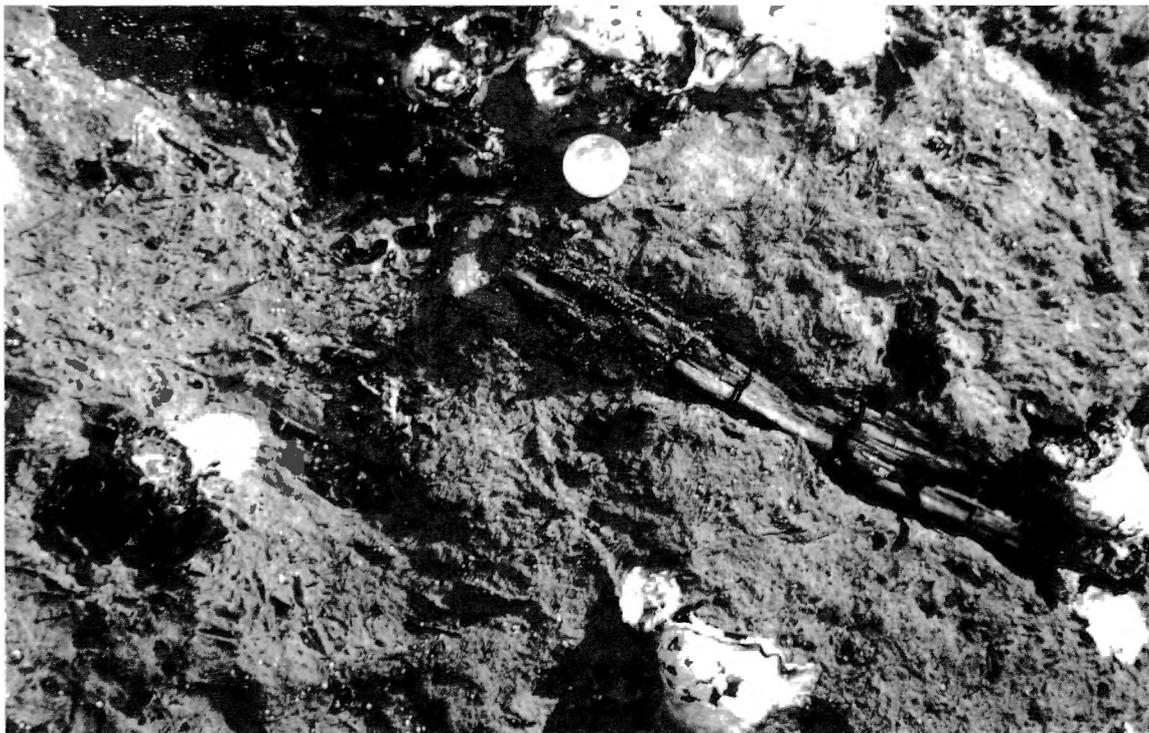


Fig. 6 — Coarse and fine plant remains in ferruginous sandstone directly underlying the fossil-bearing beds, encrusted by live oysters (diameter of coin: 22 mm).

a period of non-deposition. Such a pulsate mode of deposition characterizes this turbiditic sequence. During some long-term sedimentary omissions organic matter accumulated on the seafloor. After being covered by the next sedimentary pulse, the degrading buried organic material resulted in local reducing conditions (BRADLEY, 1981).

The periphery of dwelling burrows may be stabilized by an organic film. Therefore, the periphery of these burrows has the potential of becoming mineralized by pyrite, which may later be altered into iron-oxide. However, since the organic precursor is confined to the burrows, mineralization should not have extended beyond them, especially not onto a bedding plane that was incidentally reached by the burrower and thus usually lacks this precursor of mineralization. The fact that the bedding plane and the incorporated horizontally radiating structure are both similarly mineralized indicates that the precursor accumulated on both of them.

The absence of vertical entry shafts cannot be explained by submarine erosion. Any exposure of a level with feeding burrows by bottom currents should have truncated parts of the friable burrow fill, not only

the vertical shaft. Such a recurring process for the radiating structures, all of which are well preserved, is impossible. Lack of any cross-cutting tubes in clustered burrows may be explained by phototaxis, which should not preclude the presence of the vertical entry shaft in between the tubes of superimposed sets. These, however, were not observed. The similar tube size and radius of all the structures studied are not in accord with the ontogenetic size variation in a population of burrowers.

### Revised identity

During a survey of the Waitemata Group exposed along the beaches of Auckland, bundles of a branching sponge (Fig. 7; lower right-hand side) and the marine green alga *Codium fragile* (Fig. 7; lower left-hand side) were found washed ashore (see ADAMS, 1994). Externally, both resemble in shape and size the cylindrical fossil previously identified as *Phycodes* isp. (Fig. 7; upper half). However, when bent the flexible branches of the sponge straighten and cannot form the curved cylinders seen in some of the fossils (Fig. 7; upper left-hand



Fig. 7 — A bedding surface with several radiating fossils with curved branches in one segment superimposed on another (upper left-hand corner), similarly looking extant alga *Codium fragile* (lower left-hand) and a branching sponge (lower right-hand) (diameter of coin: 22 mm).

corner). The sponge slightly swells and contracts along its branches, in contrast to the fairly constant diameter of all branches in each algal specimen, as well as in the tubular fossils (Figs 5, 7). The thallus of the alga has a circular cross-section, branching and radiating from the initial thallus. The texture of this alga is firm, keeping the cylindrical shape for a long time when in water or in wet sediment. This fleshy structure is quite strong, forming highly flexible branches which are not easily torn apart by wave action and high-energy currents. This seaweed usually occurs in shallow-marine waters, and may become detached from its substrate and washed ashore. The transport and deposition of these algae on the deep-marine bottom suggested here is supported by the occurrence of 40 cm long wood fragments, branches and small plant remains in beds adjacent to those comprising the fossils (Fig. 6). If the water-soaked terrestrial plant debris could be carried down and deposited at great depth, then so could the algae segments.

The mode of occurrence and preservation of the fossil under discussion can be compared to fossilization of the algae *Codium* deposited on the deep-sea bottom. The turbiditic sequence of the Waitemata Group accumulated in intermittent pulses of rapid deposition of transported masses of siliciclastic sediments separated by periods of non-deposition. During the latter, algal segments and the last suspended fine particles settled on the bottom, including fine plant particles and marine phytoplankton. Microbial colonies may have developed on the bottom during intervals of non-deposition. Iron derived from the volcanic particles or clay in the Waitemata Group sediment was preferentially absorbed onto the organic matter that accumulated on the seafloor and on the exposed algae. The probable low-oxygen content at this deep-sea bottom was probably further reduced where organic matter degraded under the mucus cover of microbial mats, or beneath the next sediment cover. Under these anoxic conditions, tiny pyrite crystals or a pyrite film developed during decomposition of the selective accumulations of organic matter. The fleshy algae sustained compaction in the sediment that gradually stabilized around it as a result of early diagenetic processes (pyrite precipitation, probably with some cementation) at the periphery of the algae. The algae buried in the sediment were further consumed by micro-organisms while silt and fine sand filled the spaces. Recent exposure of the sandy turbiditic sequence to oxygenated meteoric and sea water resulted in oxidation of the pyrite crystals into ferruginous substances.

## Summary and conclusions

Ferruginous tubes filled with structureless sand and silt radiate horizontally on top of similarly ferruginous bedding planes of the turbiditic sequence of the Miocene Waitemata Group. The tubes branch and radiate in the same pattern up to a certain distance from the initial horizontal tube, forming segments of a circle. Tubes in close vertical and lateral contact do not cut each other and no vertical entry shaft was observed to cut through superimposed segments. Mineralization must have altered a precursor (pyrite crystals precipitated upon degrading organic matter) that selectively accumulated on the seafloor (bedding plane) and the radiating structures. Their shape and dimensions are identical to the shallow-marine alga *Codium*, washed ashore along the beaches of Auckland. Terrestrial plant remains in beds adjacent to the fossil-bearing layers suggest that the radiating fossil is the mineralized cast of a species of *Codium* also carried downslope by turbidity currents that formed the Waitemata Group. During a period of non-deposition, organic matter settled on the bottom on which the algal segments accumulated. These were covered by the next turbiditic sedimentary cycle. Degradation of this buried organic matter resulted in local reducing conditions and the precipitation of pyrite from altered volcanoclasts in the sediment.

Many ichnofossils were once regarded as seaweeds or plants ('age of the fucoids'; OSGOOD, 1970, 1975), as hinted at by the *-phycus* suffix of many genera or the name *Phycodes*. However, this does not rule out the possibility that some seaweed-like organisms without hard parts may become fossilized. Therefore the morphological affinities, which are sufficient to identify body fossils, should be accompanied by sedimentological, taphonomic and other available criteria to substantiate or contradict the ichnofossil nature of the biogenic structure.

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