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Field Trip 7
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Sedimentology and Ichnology of the Late Cretaceous Whakapohai Formation, South Westland Basin

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Photo: View of Monro Beach from Otumoto Point. Photograph: Jon Lindqvist.

Field Stops

Stop 1 Mid-late morning we examine Tauperikaka Coal Measures and Whakapohai Formation at the northeast end of Whakapohai Beach, then return to the vehicles for lunch.

Stop 2 We will look over equivalent beds at Monro Beach through the afternoon. This requires a ½ hour easy walk each-way from the Department of Conservation car park near Lake Moeraki.

INTRODUCTION

During this fieldtrip we will look at fluvial and marginal marine sediments of the Late Cretaceous Tauperikaka Coal Measures and Whakapohai Formation exposed near Whakapohai River outlet and at Monro Beach, some 25 km north of Haast township. The exposures are part of the uplifted eastern margin of the mainly-offshore South Westland Basin (Fig. 1). The coastal exposures of Whakapohai Formation comprise a lower tide-influenced heterolithic facies association and an upper heavily sandstone-dominated facies association of inferred shallow shelf origin. The marine succession overlies the Late Cretaceous Tauperikaka Coal Measures. We will examine sedimentary features of both stratigraphic units, including an unusually diverse trace fossil assemblage in Whakapohai Formation that includes several new-to-NZ ichnotaxa.

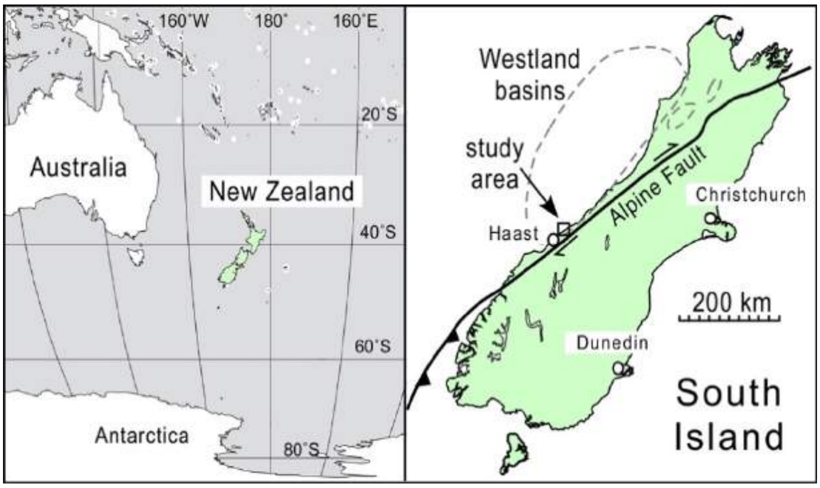


Fig. 1 Location of Whakapohai Formation exposures.

The general stratigraphy of on-land South Westland Basin was established by Nathan (1977) (Fig. 2). Adams (1987) examined the Late Cretaceous coastal succession in detail and figured several trace fossils from the marine beds. In contrast with Nathan (1977) he lumped both the Tauperikaka Coal Measures and Whakapohai Sandstone into his 'new' Tauperikaka Formation, subdividing it into three members (Table 1). Today we will revert to Nathan's (1977) nomenclature but include heterolithic tidal influenced sediments at the base of the distinguishable marine succession, together with heavily bioturbated sandstone forming the uppermost accessible exposures (Nathan's 1977 Whakapohai Sandstone), in an extended Whakapohai Formation.

Off-shore seismic shows the Cretaceous-Cenozoic succession thickening towards the present day coast, attaining a maximum thickness of ~6000 m (Sircombe & Kamp 1998, Berg & Thomasson 2002). On-shore the basal strata are upturned into a faulted anticlinal configuration along the South Westland Fault Zone (Fig. 3). The Late Cretaceous beds we examine generally strike parallel with the shoreline. The steeply dipping and consistently overturned strata forming part of a monoclinal structure recognised by Cotton (1956) and later authors represents the seaward western limb of the on-shore anticline (Adams 1987).

Table 1- Stratigraphic divisions of the Tauperikaka and Whakapohai formations in the Monro Beach area.

Nathan 1977	Adams 1987		This Field Guide	
Whakapohai Sandstone	Tauperikaka Formation	Rasselas Member	Whakapohai Formation	bioturbated sandstone
Tauperikaka Coal Measures	Tauperikaka Formation	Paringa Member transgressive erosion surface	Whakapohai Formation	heterolithic tidal beds
Tauperikaka Coal Measures	Tauperikaka Formation	Moeraki Member	Tauperikaka Coal Measures	

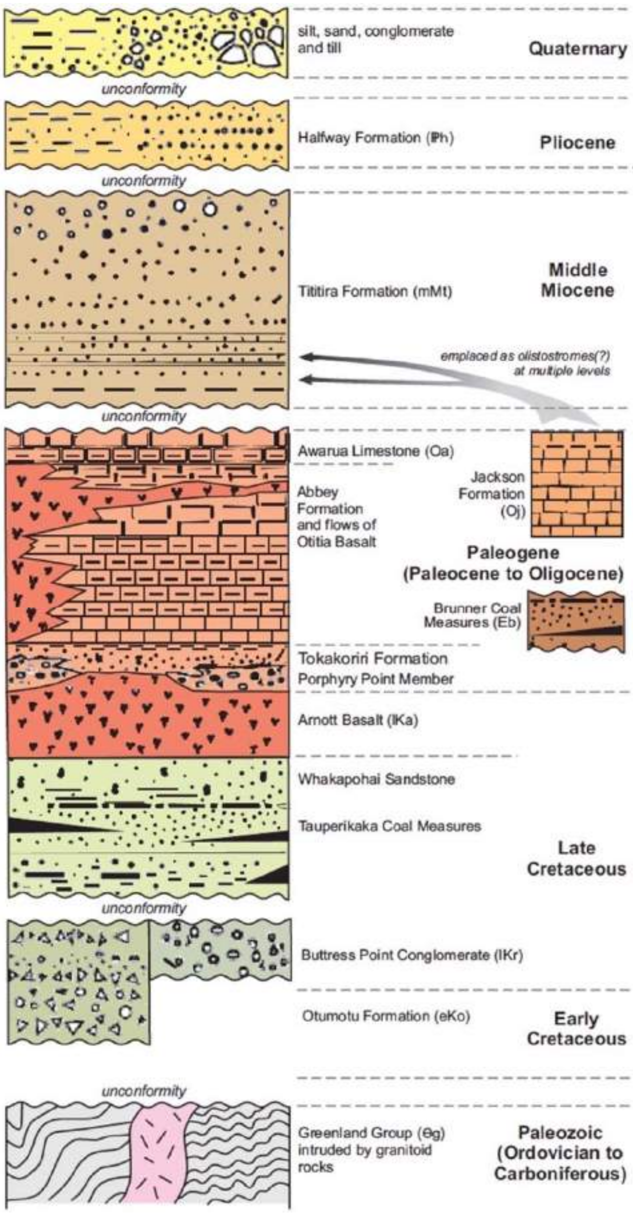


Fig. 2 Composite lithostratigraphy of Cretaceous to Miocene covering strata, south Westland (from Rattenbury et al. 2010; after Nathan 1977, and Phillips et al. 2005).

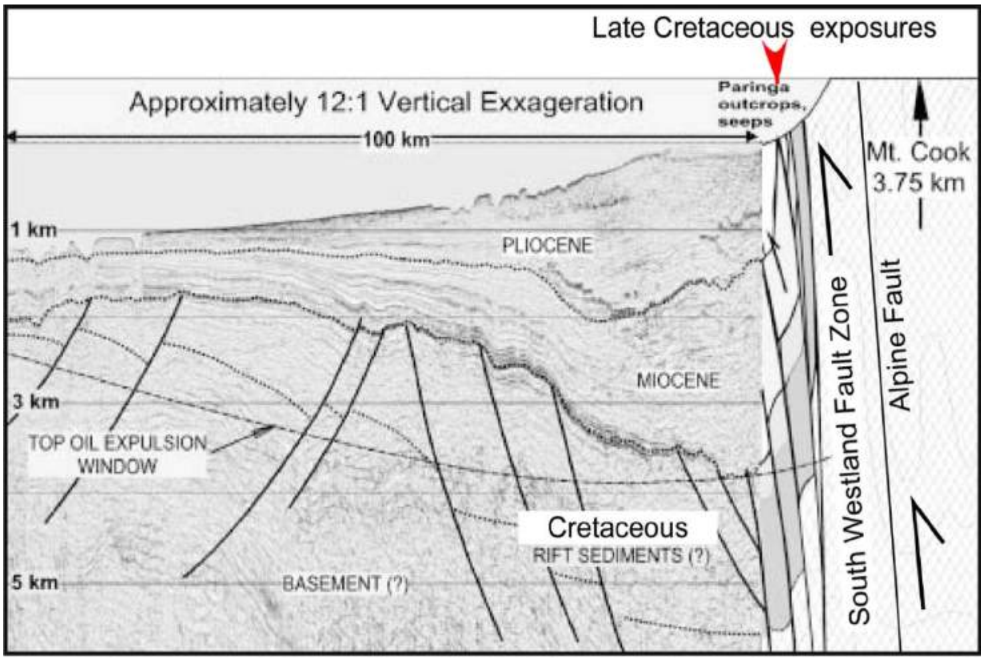


Fig. 3 Generalised South Westland Basin cross-section, from Berg & Thomasson (2002). Cretaceous and younger beds are uplifted along South Westland Fault Zone*.*

A paleogeographic reconstruction of the New Zealand region in Crampton et al. (2003) for the end-Cretaceous (Figure 4) shows shelf facies extending north-westward from South Westland around the bulge of Challenger Plateau, continuing northeast onto northwest Nelson and into the Taranaki Basin. This implies that the Tauperikaka and Whakapohai Formations comprise the most-southern (~67˚S) deposited Late Cretaceous nonmarine and marine sediments exposed in New Zealand.

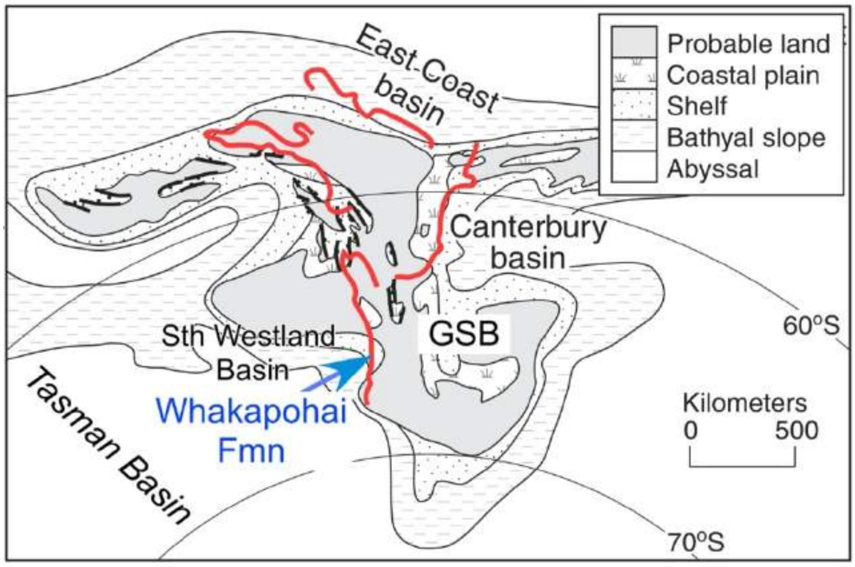


Fig. 4 Late Cretaceous New Zealand paleogeography (65 Ma), modified after Crampton et al. 2003. Note the ~67˚ high southern latitude of South Westland Basin, equivalent to the modern Antarctic coast.

Tauperikaka Coal Measures, Late Cretaceous (Stops 1 & 2; see Figure 5 location map)

The upper beds of Tauperikaka Coal Measures include several fining-upward coarse sandstone—siltstone—coaly shale cycles (Figure 6). Thicker coarse grained sandstones display low-angle inclined stratification consistent with lateral accretion deposition of point bars in a meandering river system. Compressed rootlet threads, angiosperm and conifer leaves, and rare sand-filled *Planolites* burrows are preserved in shales. Although the coarse grained beds are generally highly quartzose, a 20-50 cm thick conglomerate bed containing brick-red altered clasts presumed to be volcanic lapilli forms a local marker between the Monro Beach section and equivalent exposures at the northeast end of the beach at Moeraki River outlet.

Whakapohai Formation contact above Tauperikaka Coal Measures

The contact between Tauperikaka Coal Measures and overlying Whakapohai Formation is marked at both sections by a conglomerate layer of quartz and sandstone pebbles and boulders that overlies a thin (5-15 cm) mudstone bed. The mudstone infills an undulatory surface on white sandstone of Tauperikaka Coal Measures at Whakapohai Beach section, and thin bedded sandstone at Monro Beach (Figures 7 & 8). At both localities distinctive *Teichichus* (+/- *Paleophycus*) burrows are concentrated within the uppermost 20-30 cm of Tauperikaka Coal Measures sandstone, but appear to have been introduced into the sandstone from above and are therefore not strictly part of the coal measure succession. This contact at Monro Beach was recognised as a possible transgressive erosion surface by Adams (1987, fig. 5.29), between fluvial facies of the Moeraki Member and tidal facies of overlying Paringa Member of his extended Tauperikaka Formation.

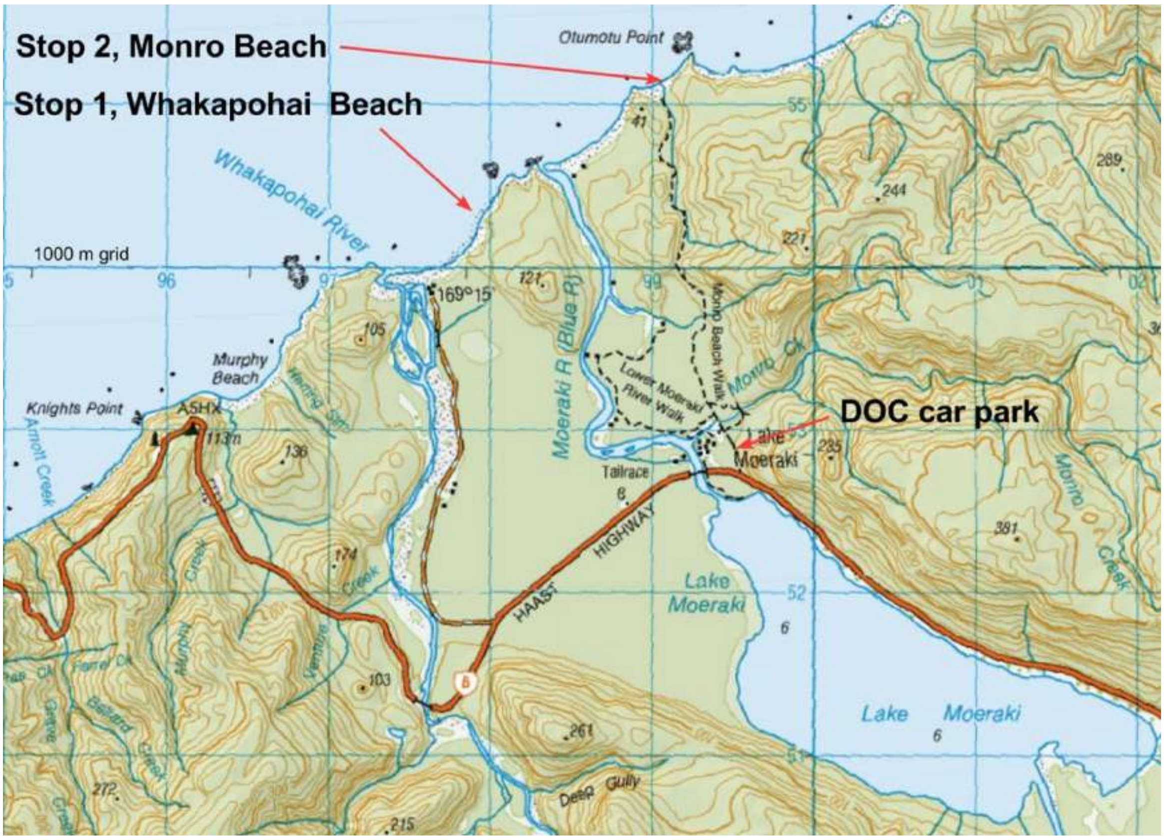


Fig. 5 Location of the Whakapohai and Monro Beach sections. Map extracted from LINZ topomap.

Fig. 6 Tauperikaka Coal Measures: (**A**) A fining-upwards sandstone-shale cycle in slightly overturned beds, younging to the left. Scale = 1 m. (**B**) Coalified angiosperm leaf from a shale bed.

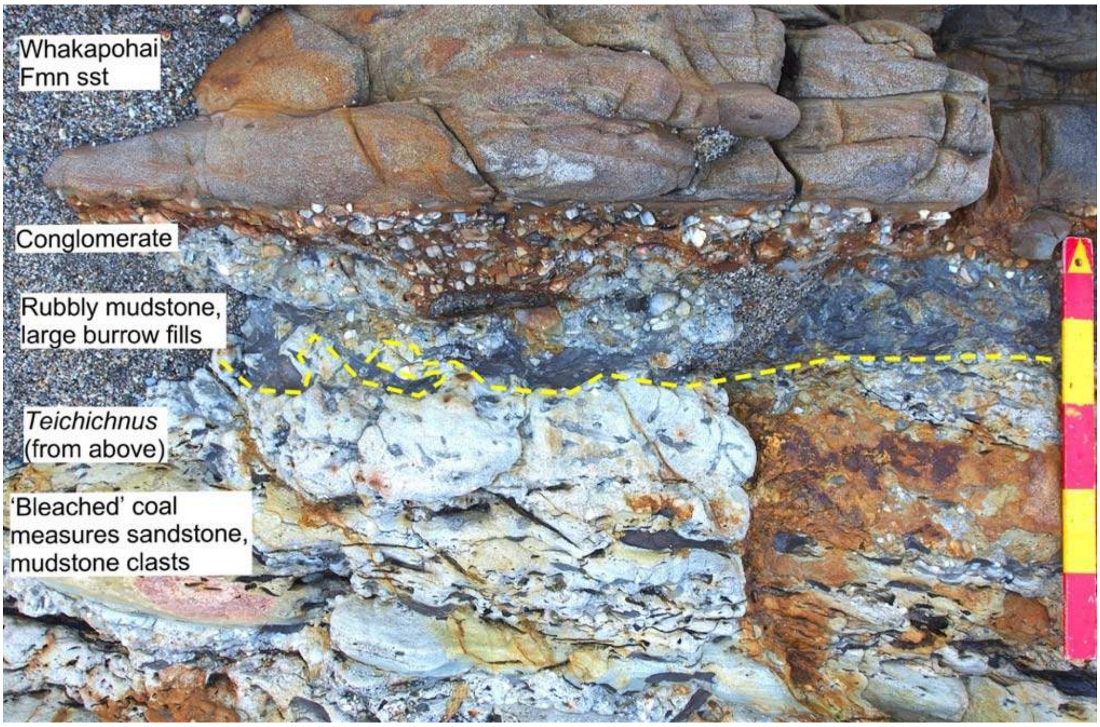


Fig. 7 Base of Whakapohai Formation at Whakapohai Beach. (**A**) The contact is marked by a thin lag of Greenland Group quartz and sandstone pebbles and cobbles overlying rubbly carbonaceous mudstone that also infills larger burrows in the coal measures sandstone. *Teichichnus* burrows, likely emanating down from above the contact, are the first field indication of [brackish] marine transgression. Scale 50 cm.

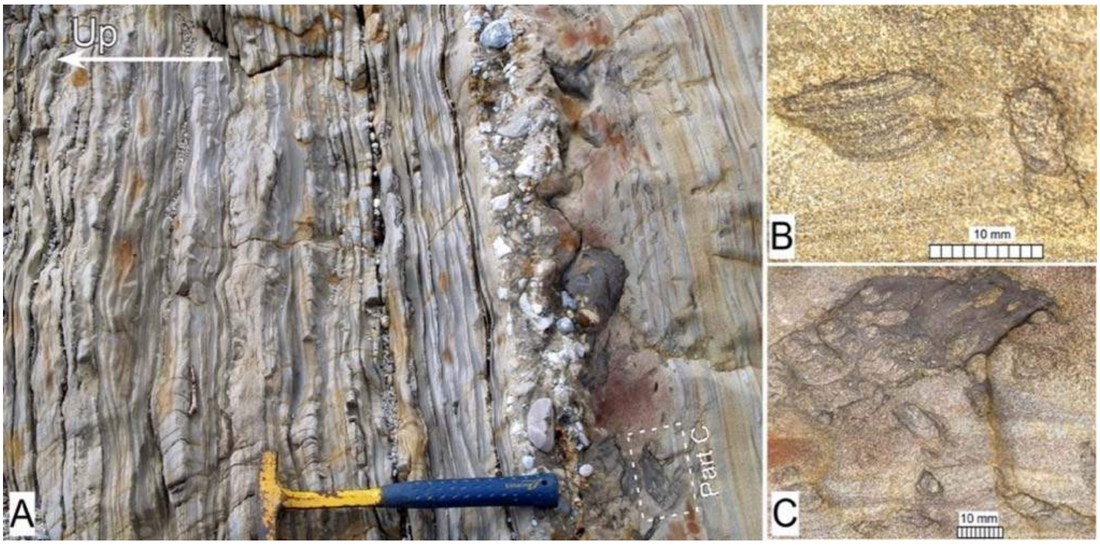


Fig. 8 Base of Whakapohai Formation at Monro Beach. (**A**) The conglomerate lag at is overlain by linsen- and wavy bedded sand and mudstone. (**B**) *Teichichnus* burrows in the underlying sandstone. (**C**) *Teichichnus* partly within mudstone infilling an earlier larger burrow in the underlying sandstone, outlined in Part-A.

Lower Whakapohai Formation

Whakapohai Beach northeast section

Here, the ~36 m thick assemblage of heterolithic beds comprises a basal 12 m thick sand-dominated interval composed of flaser bedded sands and minor wavy-bedded sand and mudstone units. This is overlain a 24 m interval of more-thinly interbedded inclined-laminated sandstones of 0.5~ 2 m thick, together with lenticular bedded and wavy bedded sand and mudstone packets (Figure 9). The upper unit includes several sands and heavily bioturbated muddy units that host *Rosselia socialis* burrows. An unusual assemblage of retrusive *Diplocraterion* burrows lacking marginal tubes, possibly escape structures, is preserved in one sandstone bed.

Fig. 9 Upper part of the slightly overturned heterolithic beds younging seawards (to the left) at Whakapohai Beach. Scale in foreground is 50 cm.

Monro Beach section

The ~40 m assemblage of heterolithic beds at Monro Beach (Figure 10) comprises a lower wavy and lenticular bedded sand and mudstone package. This is overlain by a prominent 20 m thick sandy interval of planar tabular cross-stratified coarse-medium grained sandstones, interpreted as an estuarine channel bar complex, intercalated with wavy- and lenticular-bedded sand and micaceous mudstone units (estuarine basin facies) (Figures 11 & 12). In contrast with southwest-facing foresets commonly seen in thicker coarse grained cross beds, possibly indicating the direction of combined river high stage and ebb tidal flow), ripple foresets within the fine grained lenticular bedded and wavy bedded units throughout the heterolithic succession generally face towards the northeast (Figure 13). Flaser laminae and double-mud drapes in sands, and probable neap-spring-related cyclic variations in thickness of interlaminated rippled sands and mudstone, accord with an estuarine setting. The upper heterolithic interval resembles that at Whakapohai Beach. The ichnofauna embracing *Asteriacites, Gyrochorte*, *Gyrolithes*, *Macaronichnus*, *Ophioichnus, Palaeophycus*, *Protovirgularia*, *Planolites*, *Rhizocorallium*, *Sinusichnus*, *Siphonichnus*, *Skolithos*, and *Teichichnus* compares with heterolithic tidal assemblages elsewhere (e.g. Mángano et al. 1998, McIlroy 2007, Carmona et al. 2010).

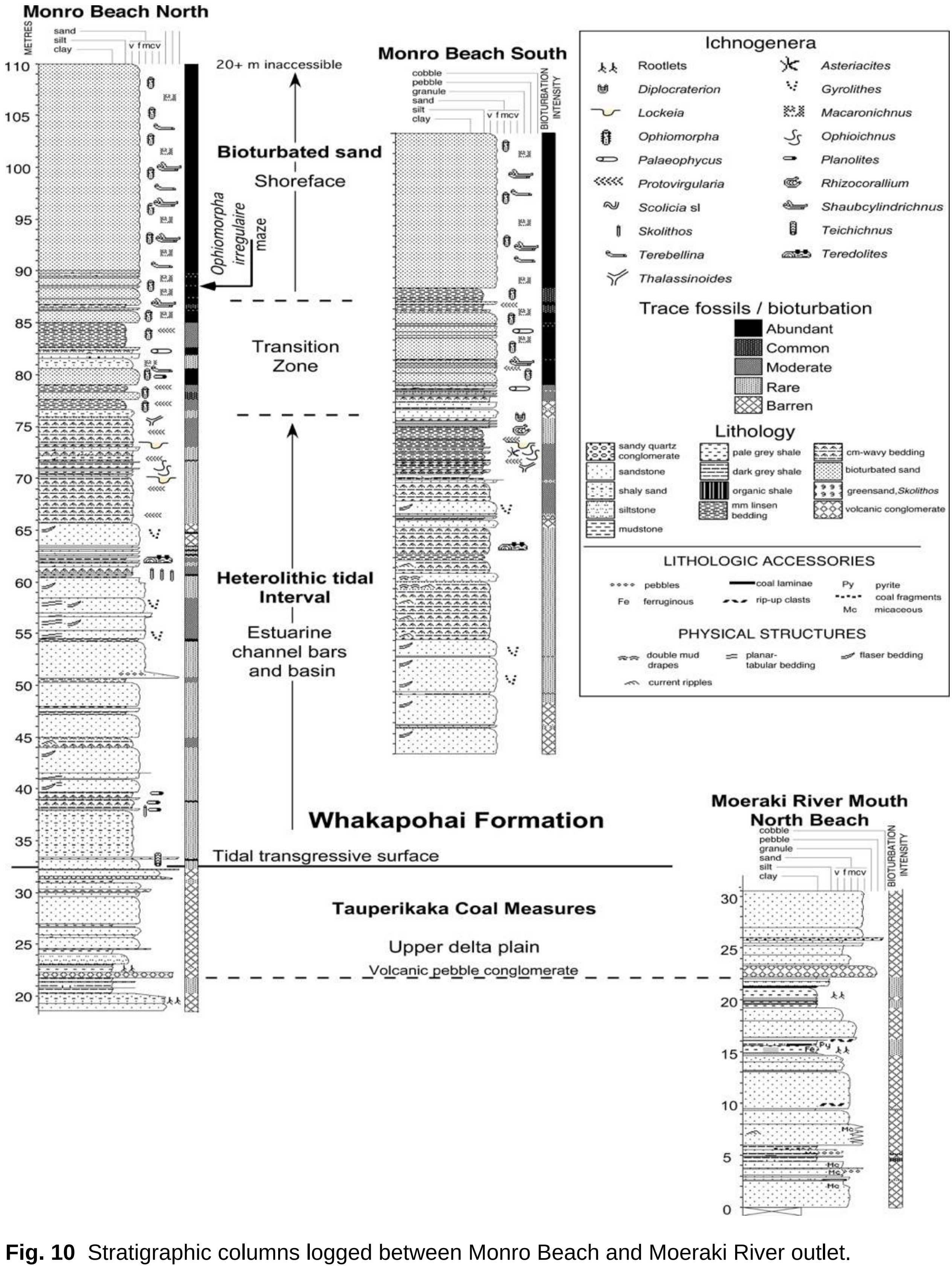


Fig. 10 Stratigraphic columns logged between Monro Beach and Moeraki River outlet.

Fig. 11 Overturned, seaward-younging beds of the Whakapohai Formation at Monro Beach. A thinly lenticular and wavy bedded interval on the right is overlain by stacked planar tabular sandstones in the centre of photo. Overlying heavily bioturbated sandstone forms Otumotu Point, far left.

Fig. 12 Close-up view of stacked planar tabular sandstone beds in the centre of Fig. 11. Note in centre of photo, horizontal lamination in the outcrop section oriented perpendicular to the foreset dip direction is a characteristic feature of planar cross strata. Foresets face southwest, towards the camera.

Fig. 13 A ~10 cm planar cross bed of medium sand at Monro Beach overlying a wavy bed of sand and thin mud laminae, and overlain by 1:1 lenticular sand and mudstone beds. As seen here, northeast-trending (to the right) ripple foresets, including the rippled top of the thicker sand, typically oppose southwest-trending (left) foresets of coarse grained beds. Scale divisions 10 cm.

Upper Whakapohai Formation

A 40+ m unit of thoroughly bioturbated fine-grained glauconitic quartzo-feldspathic sandstone is exposed on both Monro Beach headlands. A transitional ~10 m unit of 5~20 cm thick sets of very thinly lenticular-bedded sand and mudstone, intercalated with heavily bioturbated glauconitic sands is best seen at the south end of Monro Beach. The ichnofauna embracing *Macaronichnus*, *Paleophycus*, *Planolites*, *Scolicia* sl, *Shaubcylindrichnus*, and *Teichichnus* is dominated by the probable crustacean burrow *Ophiomorpha irregulaire* (Figure 14, + appended trace fossil notes). Although *O. irregulaire* is mostly observed in vertical sections, a few bedding planes reveal horizontal meandering maze structures. Features such as roughly conical burrow-lining pellets, concentration of mud pellets in roofs of galleries, large size, and sealed-off passages accord with descriptions of Frey et al. (1978), Howard & Frey (1984), Bromley & Ekdale (1998), and Pedersen and Bromley (2006) for this ichnospecies. Considered a diagnostic feature of *O. irregulaire* by Leaman et al. (2015), sand cores are not commonly present in muddy pellets that outline burrows. In vertical section shaft structures of *O. irregulaire* are generally inclined rather than vertical, and rarely exceed 30 cm in height.

Ophiomorpha irregulaire from the Late Cretaceous Whakapohai Formation differs significantly from well-exposed Paleocene examples of *Ophiomorpha nodosa and O. annulata* that are abundant in clean shoreface sands of Wangaloa Formation, southeast South Island (Lindqvist 1986). At Wangaloa *Ophiomorpha* consists of short to very long (often >2 m), and straight to crooked passages in the horizontal plane, numerous horizontal Y and T-junctions, and much deeper shafts. Near-vertical shafts regularly curve upwards from their intersections with horizontal passages.

This New Zealand occurrence of *Ophiomorpha irregulaire* extends its known distribution into Oceania and far from its 'home' in the Cretaceous Western Interior Seaway.

Ophiomorpha irregulaire is considered to be a rare trace fossil, and possibly misidentified in core material from outside its type area (Bromley & Pedersen 2008). However, a near-global distribution is supported by reports of *O. irregulaire* from the Jurassic of Argentina and elsewhere (McIlroy 2007, McIlroy et al. 2009, Boyd et al. 2012), the Late Cretaceous of southern India (Ramkumar & Sathish 2009), Australian Cretaceous NW Shelf (Burns & Hooper 2001), and this record.

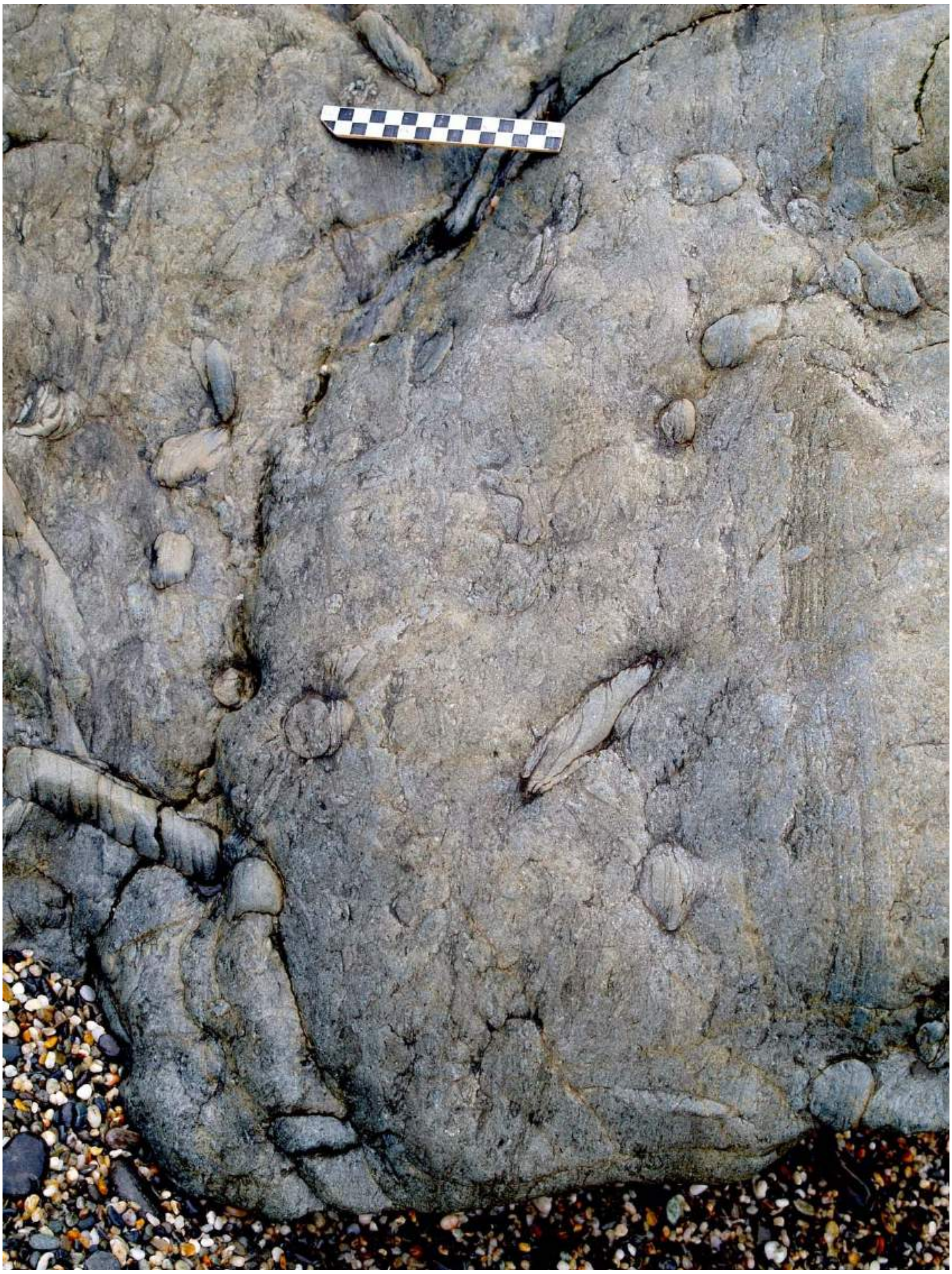
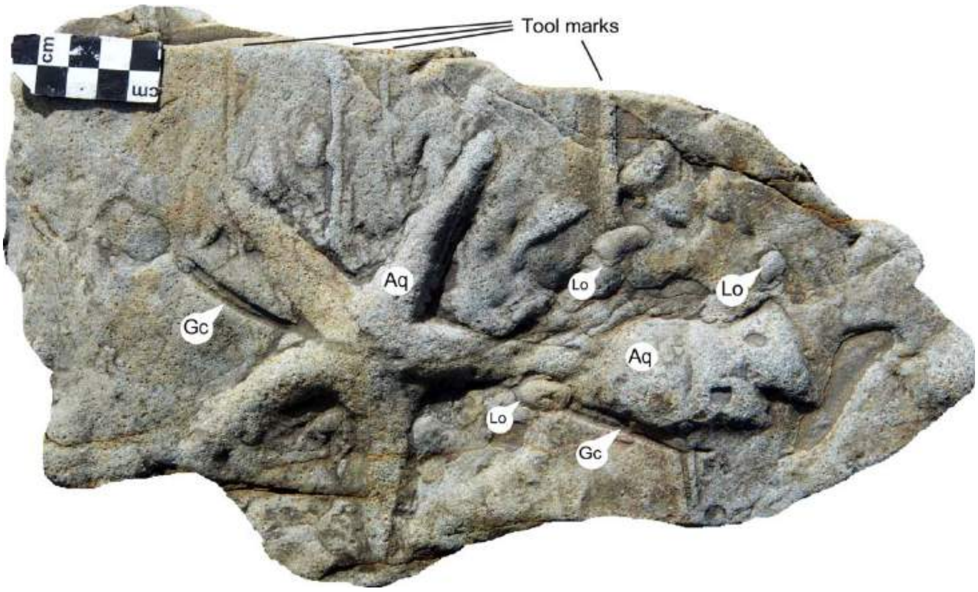


Fig. 14 Typical view of inclined shafts and horizontal galleries of *Ophiomorpha irregulaire* in heavily bioturbated sandstone matrix, Upper Whakapohai Formation shoreface beds, Monro Beach. Note apparent squeezing of pelletal mud into and away from burrow fills, and locally developed spaced cleavage; also a relict patch of finely laminated sand and mud, lower-right. The vertical beds young to the left. 15 cm scale.

Trace Fossil Notes

Following is an incomplete list of trace fossils found in Whakapohai Formation. Due to the vagaries of sea conditions, beach sand cover of rock exposures, limited time at the outcrop, and rarity of some ichnotaxa, not all are likely to be encountered during the fieldtrip.

Asteriacites quinquefolius Quenstedt 1876



A (above) **B** (below)

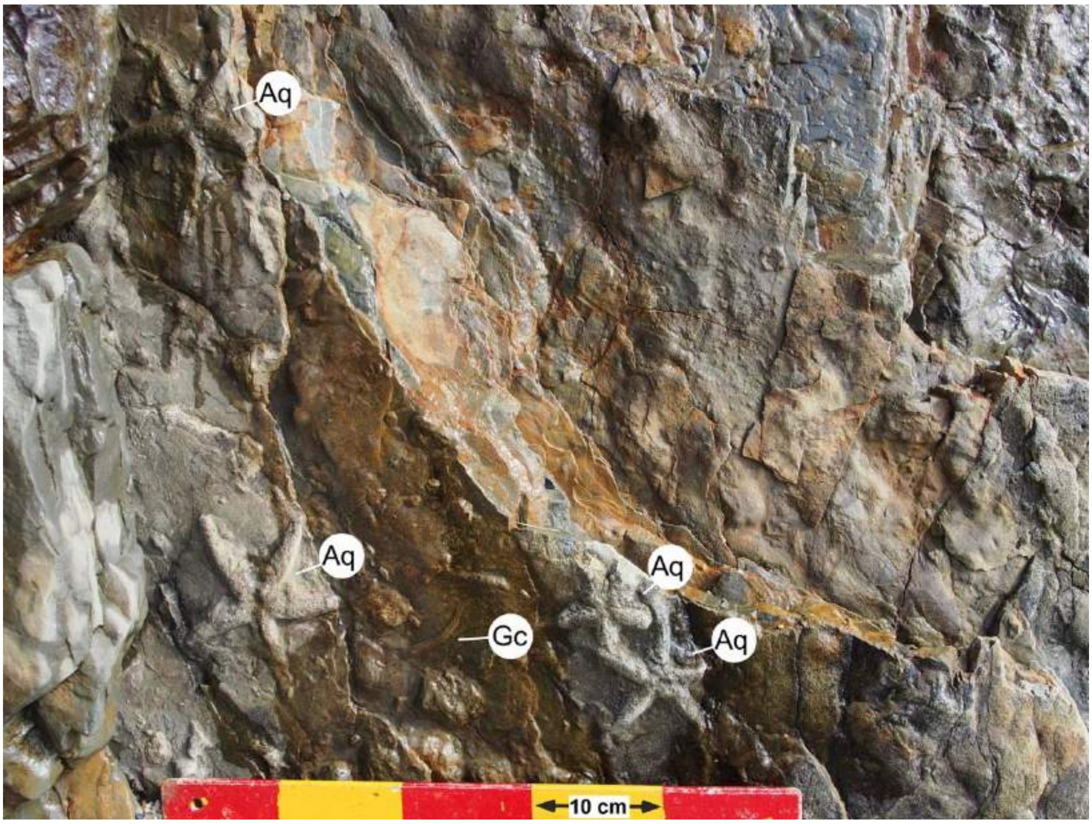


Fig. 15 Two ichnospecies of starfish 'resting' traces have been found in Whakapohai Formation. The larger form figured above, likely made by asteroids, was also reported by Adams (1987). (**A**) Underside of a loose slab salvaged from Moeraki River outlet shows *Asteriacites quinquefolius* (Aq) associated with (later) *Gyrochorte comosa* (Gc) trails, and the bivalve 'resting' trace *Lockeia* (Lo). Attendant tool marks were conceivably made by asteroids carried along in the current just prior to sand deposition. (**B**) Group of four A. *quinquefolius* on the base of a sand bed, Otumotu Point, are associated with *G. comosa* and (?)*Sinusichnus,* right of centre.

Asteriacites lumbricalis von Schlotheim 1820

Fig. 16 Delicate *Asteriacites lumbricalis* casts (As) on undersides of a muddy fine sand beds are thought to be the resting traces of ophiuroids (brittle stars). Heterolithic beds, Monro Beach south section. Vertical *Skolithos* burrows (Sk) and *Gyrochorte* trails (Gc) are also present. Also, see notes on *Ophioichnus*.

Diplocraterion parallelum Torell 1870

Fig. 17 Groups of vertical U-shaped burrows assignable to *Diplocraterion parallelum* are found in both outcrop areas. In this south Monro Beach example, an oblique view of the underside of a mudstone bed, some burrows have squared-off basal terminations against the underlying sand (cf. *D*. *parallelum* var. *quadrum* of Ekdale & Lewis 1991. Scale 15 cm.

Gyrochorte comosa Heer 1865

A (above) **B** (below)

Fig. 18 Horizontal arcuate and looping trails assigned to *Gyrochorte comosa* are relatively common in the upper part of the heterolithic beds. (**A**) In plan views *G. comosa* displays a tight braided structure of close-space pads arranged in an alternate zipper-like fashion. (**B**) Bed undersides display central sand 'keels'. *Gyrochorte* has a relatively deep wall structure composed of inclined forward-accreted elements (cf. Gibert & Benner 2002). This distinctive 5~8 mm wide trail provides a good structural 'way-up' indicator in the field.

Macaronichnus Clifton & Thompson 1978

A (above) **B** (below)

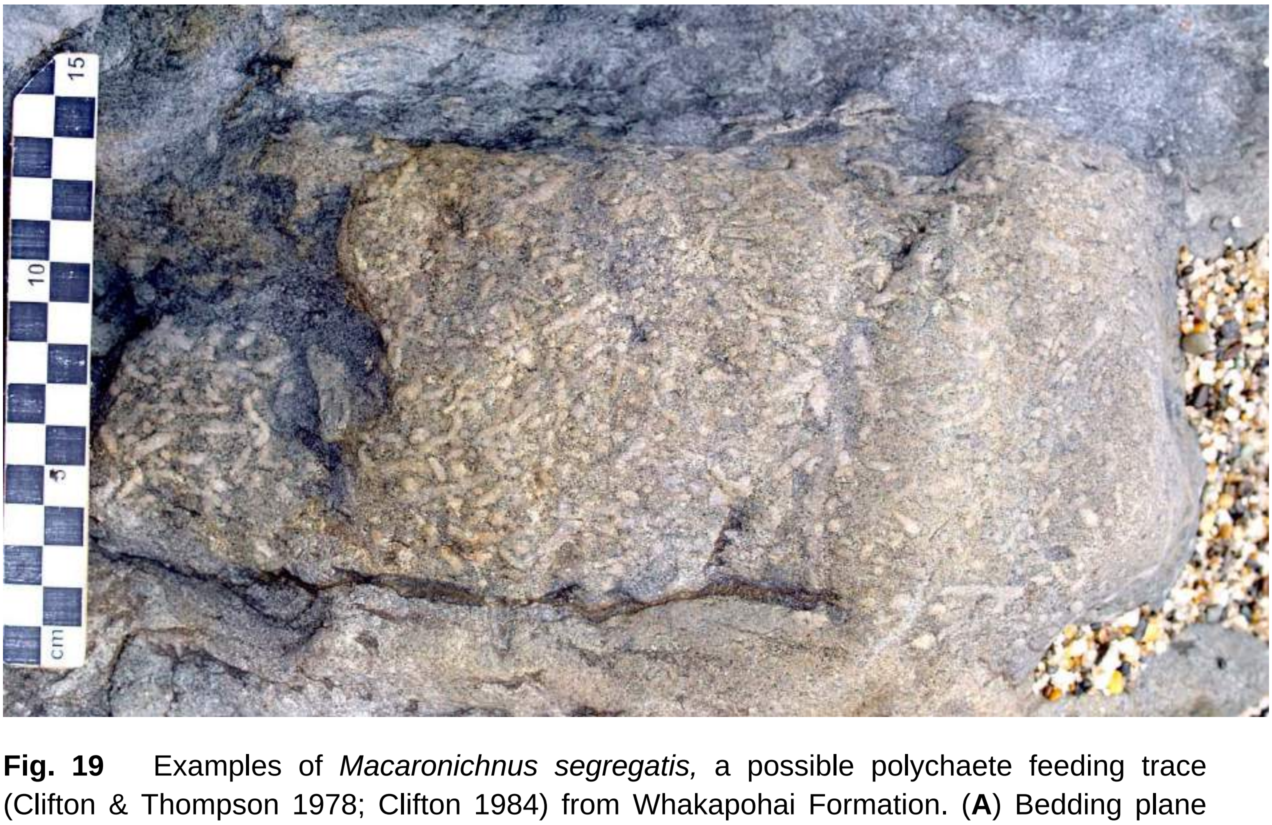


Fig. 19 Examples of *Macaronichnus segregatis,* a possible polychaete feeding trace (Clifton & Thompson 1978; Clifton 1984) from Whakapohai Formation. (**A**) Bedding plane view from the upper heterolithic interval, Whakapohai Beach section. Scale 5 cm. (**B**) Cross section view of *Macaronichnus segregatis* in an (?)early cemented sand bed, upper section, Monro Beach.

Nereites MacLeay 1839

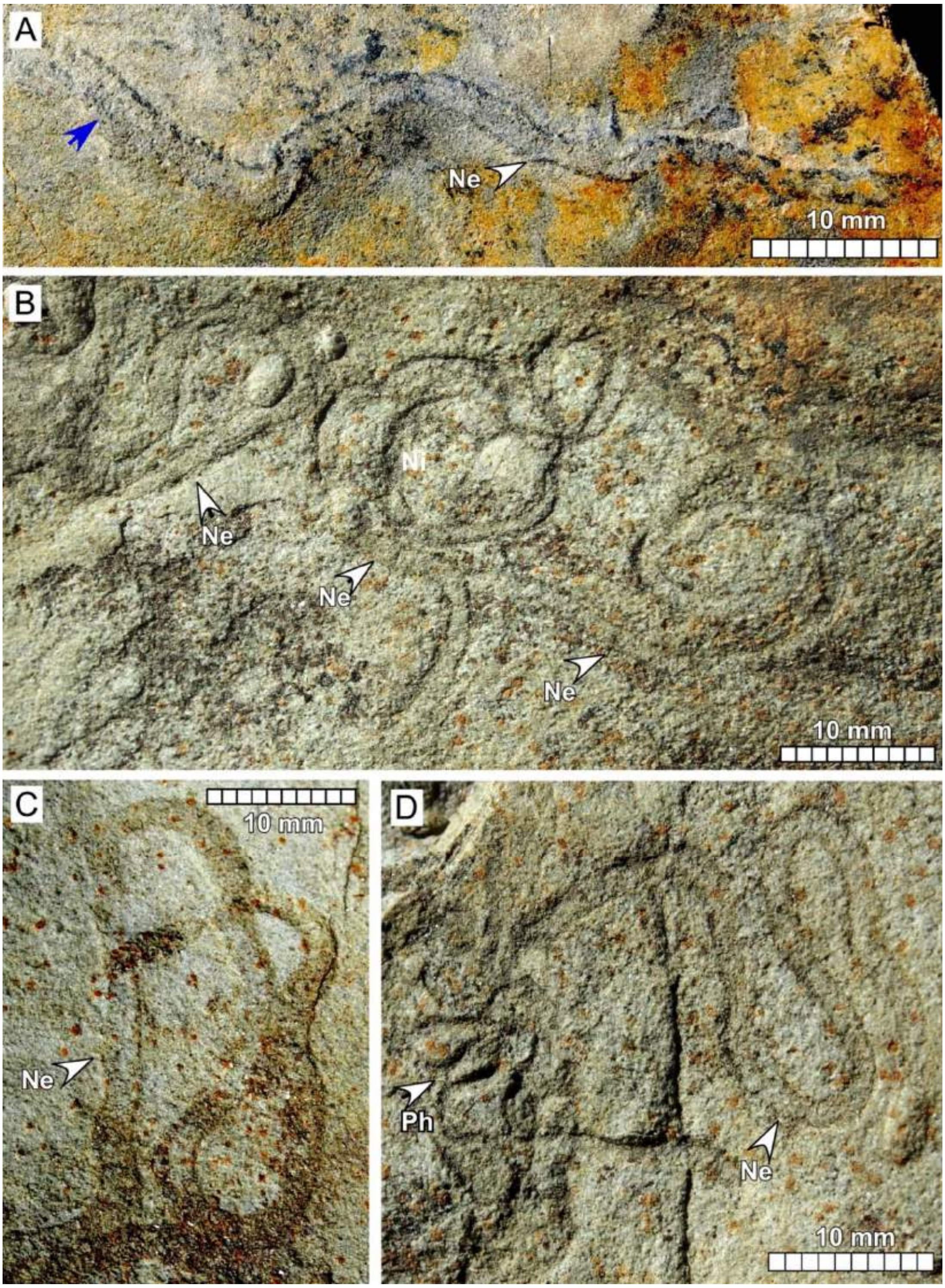


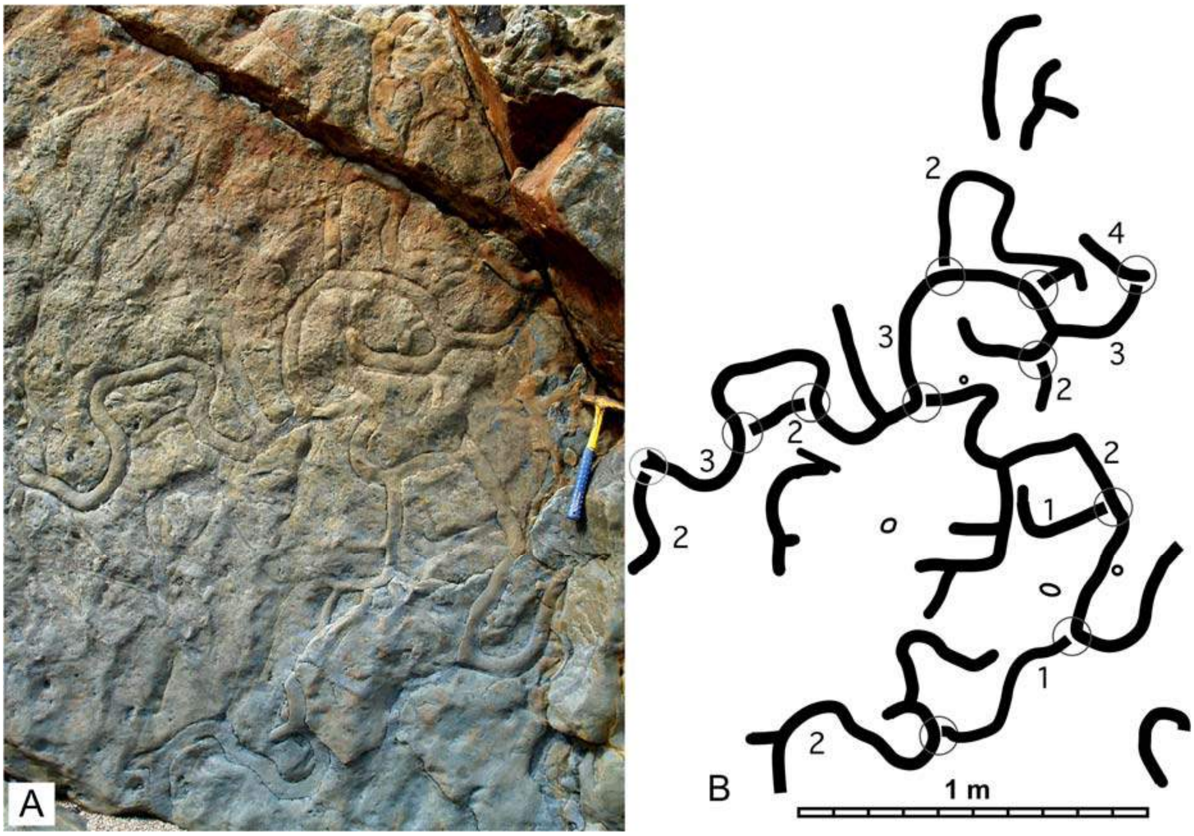
Fig. 20 ***(A-D)*** *Nereites irregularis* (Ne) from the upper heterolithic beds of Whakapohai Formation. *Nereites* is a 2-3 mm wide winding to irregularly meandering horizontal back-filled burrow enveloped by a variably wide lobate zone of reworked sediment. Although *Nereites* is commonly reported from deepwater turbidite sequences (cf. Seilacher's Nereites Ichnofacies; Frey & Seilacher 1980) it is also reported from tidal successions (Mangano et al. 2000; Carmona et al. 2009). Note also a smaller cross-cutting meandering *Phycosiphon incertum* trail (Ph), lower left of Part D

Ophioichnus aysenensis Bell 2004

A (above) **B** (below)

Fig. 21 (**A**) Sets of laterally repeated fishhook-shaped impressions, annotated here with parallel arrows, are thought to have been made by ophiuroids (brittle stars) 'sculling' over the muddy substrate (cf. Bell, 2004). Example from upper heterolithic beds, Monro beach. (**B**) *Ophioichnus aysenensis* from Whakapohai Beach section. Scale divisions in cm.

Ophiomorpha irregulaire Frey, Howard, & Pryor 1978



C (below)

Fig. 22 (**A, B**) *Ophiomorpha irregulaire* ‘meandering maze’ burrow system in plan view, from upper Whakapohai Formation, Monro Beach. The tracing reveals sections of the gallery system were progressively sealed-off at T- or Y-junctions, and abandoned. (**C**) Conical pellets are a distinctive feature of *O. irregulaire.*

Protovirgularia M’Coy 1850

A (above) **B** (below)

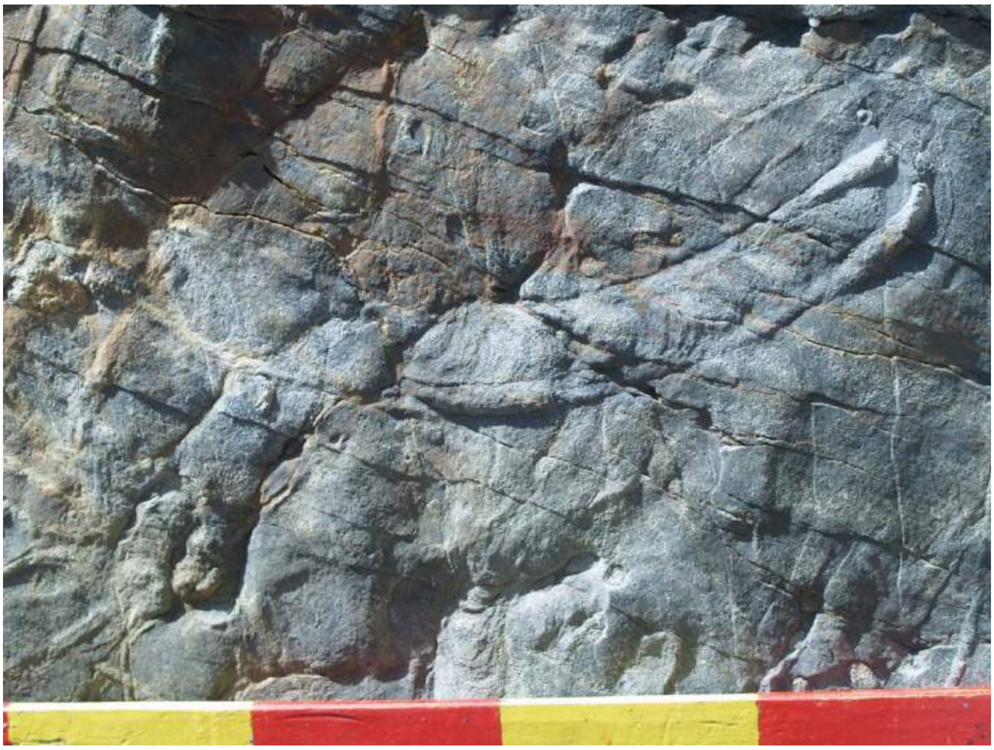
Fig. 23 (**A**) A relatively large *Protovirgularia* trail, Monro Beach south section. (**B**) Narrow cross-cutting, chevronate trails 1.5–3 mm wide are more commonly preserved in the tidal heterolithic beds. Scale 2 cm high. *Protovirgularia* trails are widely considered to have been made by cleft-footed protobranch bivalves (e.g. *Nucula*) (cf. Carmona et al., 2010; Ekdale & Bromley, 2001; Mángano & Buatois, 1998; Seilacher & Seilacher, 1994).

Phycosiphon Fischer-Ooster 1858

A (above) **B** (below)

Fig. 24 (**A**, **B**) Bedding plane preservation of tightly meandering and back-filled *Phycosiphon incertum* on mud-draped sand ripple crests, heterolithic beds of lower Whakapohai Formation. Also note a lined *Skolithos linearis* burrow, upper-middle of Part B. Although relatively common in offshore facies (Wetzel & Bromley 1994, Manley & Lewis 1994), *P. incertum* is also recorded from shallow environments (Buatois et al 2012).

Rhizocorallium Zenker 1836



A (above) **B** (below)

Fig. 25 (**A, B*)*** Examples of the horizontal U-shaped burrow *Rhizocorallium commune* var. *irregulare* (classification following Knaust 2013). *Rhizocorallium* on the undersides of this sand bed is associated with *Planolites* and *Gyrochorte comosa*. Note basal terminations of

U-shaped *Diplocraterion* burrows in an overlying bed, upper-right of Part-B. Upper heterolithic interval, Monro Beach. Scale divisions 10 cm.

Rosselia socialis Dahmer 1937

A (above) **B** (below)

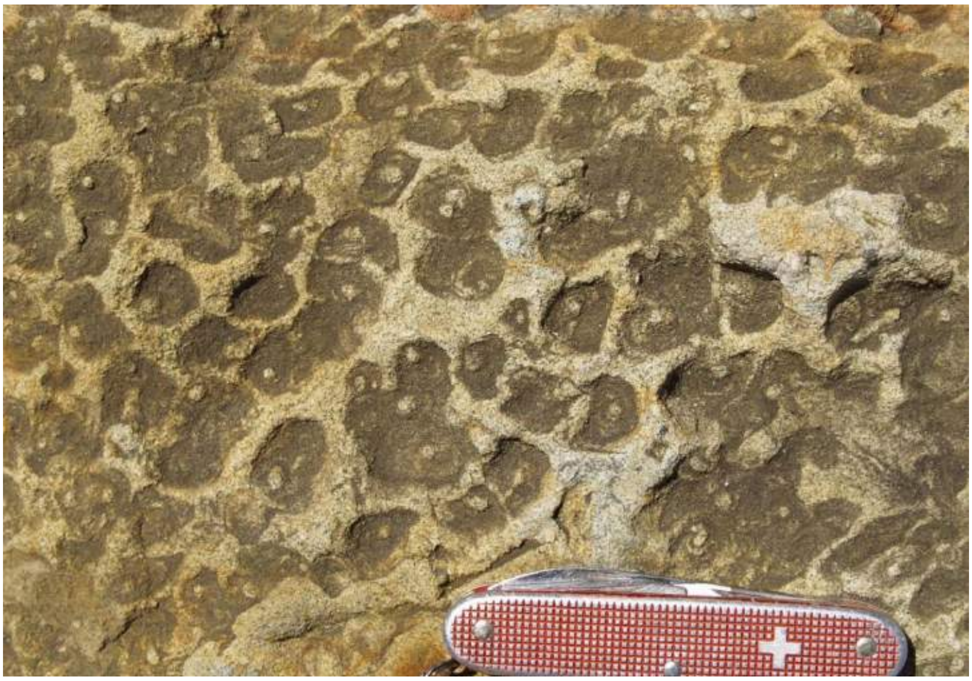


Fig. 26 Where complete, *Rosselia socialis* has a vertical spindle-shaped structure. However only the lower part is preserved in heterolithic beds of Whakapohai Formation. *R. socialis* has a long range from Cambrian to Holocene (Netto et al. 2014), and has been interpreted as a dwelling structure of terebellid polychaetes (Nara 1995, Buatois et al 2016).

(**A**) Cross sectional view, Whakapohai Beach section, where *R. socialis* is found in multiple beds. (**B**) Plan view of crowded *R. socialis,* Monro Beach section, displaying characteristic narrow sand-filled central shafts surrounded by a concentrically laminated muddy plug.

Scolicia de Quatrefages 1849

A (above) **B** (below)

Fig. 27 *'Scolicia'* is used in a general sense here for large meandering burrows (cf. *Laminites*). Bedding plane examples here are from a loose boulder, Monro Beach. (**A**) Looping of the central burrow in Part-A shows that back-filling laminae are concave away from the burrowing animal, possibly an irregular echinoid that travelled towards the lower left. Note abundant relatively small, 15-20 mm diameter *Ophiomorpha* (?)*irregulaire* burrows. Knife = 93 mm. (**B**) Scale = 50 cm.

Shaubcylindrichnus Frey & Howard 1981

A (above) **B** (below)

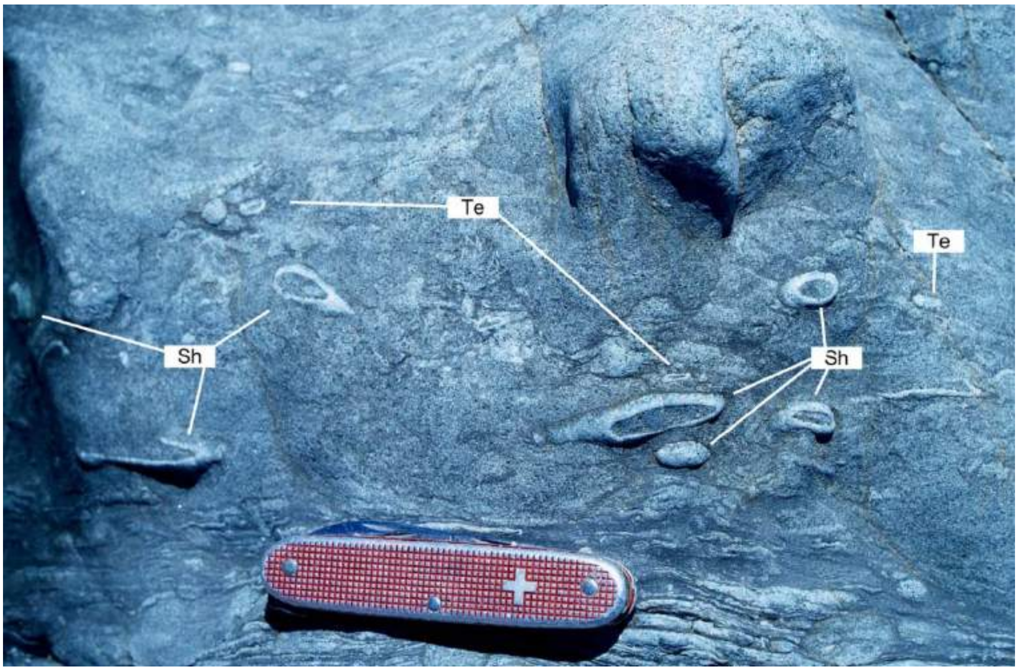


Fig. 28 (**B**) A cluster of robust sand tubes referable to *Shaubcylindrichnus* in well-bioturbated sand interbedded with pinstripe-laminated sand and mud, upper Monro Beach section. (B) *Shaubcylindrichnus* (Sh) is distinguishable from smaller solitary *Terebellina* tubes (Te). Similar small tubes elsewhere have been identified as the agglutinated foraminifera *Bathysiphon* (cf. Moore 1988, Löwemark & Hong 2006).

Sinusichnus sinuosus Gibert, 1996

A (above) **B** (below)

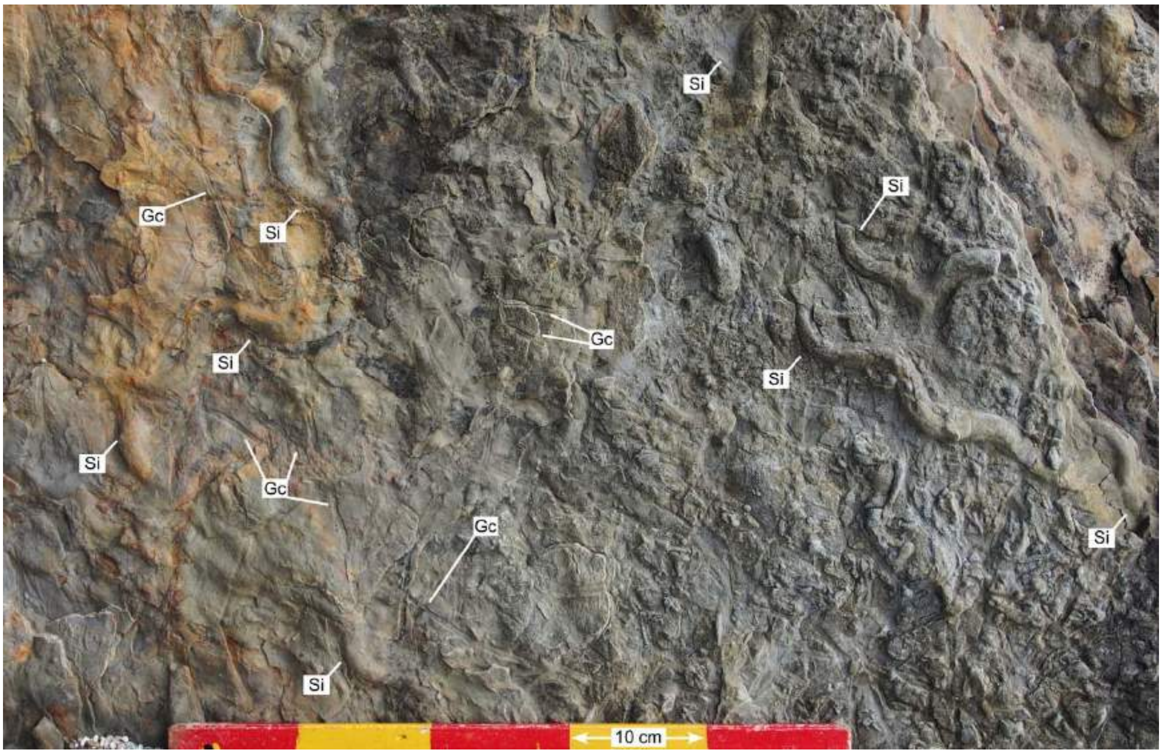


Fig. 29 Examples of *Sinusichnus sinuosus*, sub-horizontal burrow systems composed of sinuous branches, in Whakapohai Formation. (**A**) Whakapohai Beach exposure. (**B**) Otumotu Point. *S*. *sinuosis* is found in wavy bedded sandstone and mudstone close to the top of the tidal heterolithic-sandstone transition. *S. sinuosus* was first described from the Pliocene of Spain (Gibert et al. 1999), and also known from deepwater prodelta marine beds of Late Cretaceous age on James Ross Island, Antarctic Peninsula (Buatois et al. 2009).

Siphonichnus Stanistreet, Le Blanc Smith & Cable, 1980

A (above) **B** (below

Fig. 30 (**A**) Vertical exposure of *Siphonichnus* burrows in interbedded sand and mudstone. Sand beds frequently incorporate thin paired mud laminae (double mud drapes), each separated by a thin sand layer conceivably deposited during the subordinate tidal current phase. (**B**) Attributed to bivalves in upright life position, *Siphonichnus* displays elliptical, oval or sub-rounded sections in plan view. Following Zonneveld & Gingras (2013) the burrows are placed in Ichnogenus *Siphonichnus* rather than *Scalichnus.*

Skolithos Haldeman 1840

A (above) **B** (below)

Fig. 31 (**A**) Vertical exposure of moderately dense *Skolithos* (?)*linearis* burrows in sandstone. Scale divisions 10 cm. (**B**) Bedding plane assemblage. The *Skolithos* burrows are smoothly lined silty mud.

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