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Preservation of a Late Glacial terrestrial and Holocene estuarine record on the margins of Kaipara Harbour, Northland, New Zealand

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Abstract Subtidal to intertidal deposits from the margins of Kaipara Harbour in Northland preserve a c. 23 000 year incomplete sedimentary record of the transition from terrestrial to estuarine conditions. Cores are used to reconstruct the depositional setting for this transition, interpreted as a succession from dune and freshwater wetland to shallow estuarine environments. The fossil pollen record provides a proxy of Last Glacial Maximum and Late Glacial vegetation for the area. Stability of the Pleistocene dune landscape during the postglacial marine transgression is interpreted on the basis of strong dominance of tall forest taxa (*Dacrydium*) in the pollen record and soil development in dune sands, with preservation aided by location along the estuary margin. During the Holocene, reworking of the buried dune and wetland sediments has only reached to a depth of 1.5 m below the modern tidal flat. As such, the site provides a rare example of good preservation of Pleistocene deposits at the coast, where extensive reworking and loss of record are more typical.

Keywords ^{14}C dating; New Zealand; palynology; sediments; stratigraphy; transgression

INTRODUCTION

A key determinant of the completeness of depositional records in coastal sedimentary systems is the accommodation space available for storage of sediment. In an estuary, accommodation space equates to initial water depth at the time the estuary formed, with depth varying in accord with the inherited topography of the drowned valley. This antecedent topography will reflect local geological controls, but also the partial preservation of sediments from earlier episodes of valley infilling. Generally, for estuaries these earlier episodes will record infilling during past sea level highstands, notably the last interglacial highstand (oxygen isotope stage 5e) (Nichol & Murray-Wallace 1992; Roy et al. 1994). However, there is also the potential for accommodation space to be restricted by the preservation of deposits laid down during the last sea level lowstand (oxygen isotope stage 2) and which have survived reworking during the subsequent marine transgression (Zaitlin et al. 1994). Where this occurs, the sediment

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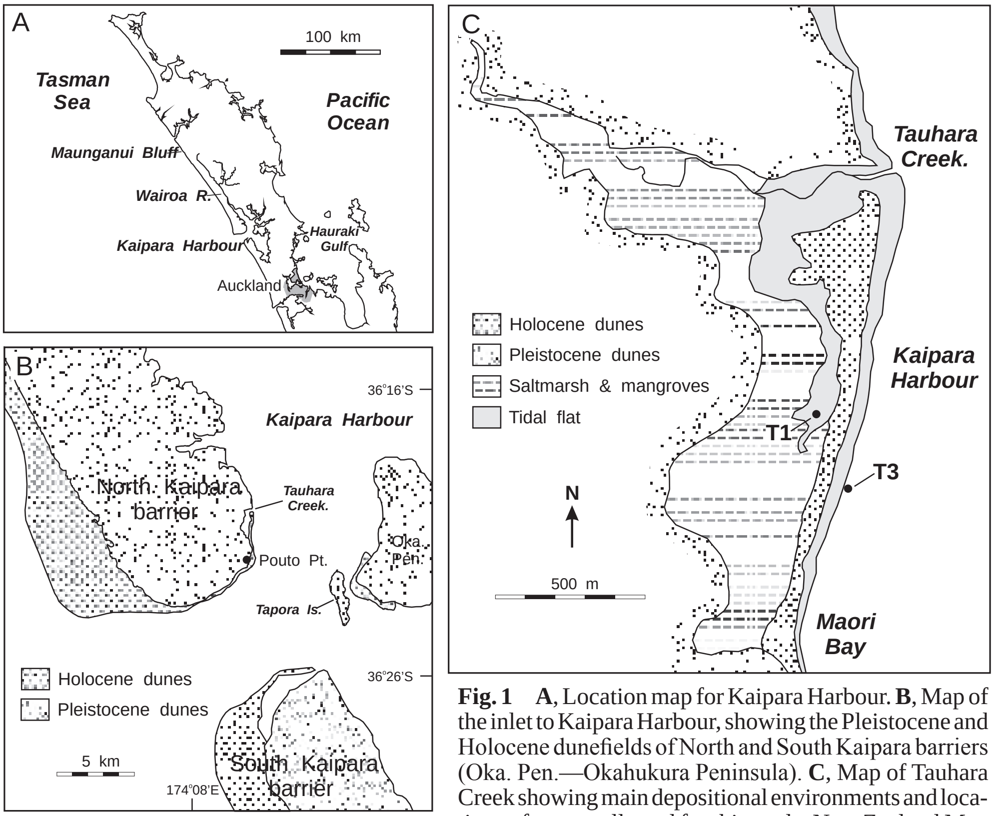

Fig. 1 **A**, Location map for Kaipara Harbour. **B**, Map of the inlet to Kaipara Harbour, showing the Pleistocene and Holocene dunefields of North and South Kaipara barriers (Oka. Pen.—Okahukura Peninsula). **C**, Map of Tauhara Creek showing main depositional environments and locations of cores collected for this study. New Zealand Map Grid (NZMS 260) co-ordinates for core sites: core T1 E2616220, N6539055; core T3 E2616337, N6538772.

record can yield information on climate-induced changes to local and regional environments that captures the glacial to interglacial transition.

For much of the New Zealand coast, estuarine evolution during the Late Quaternary was strongly influenced by tectonism (subsidence and uplift) and high sedimentation rates (Berryman & Hull 2003; Kennedy et al. 2008). For estuaries that have undergone uplift, such as along the east coast of North Island, Holocene depositional records are complex successions of estuarine and fluvial sediments raised above modern sea level (e.g., Pakarae River, Wilson et al. 2007). In contrast, estuaries formed on subsiding coasts are either unfilled (e.g., Marlborough Sounds) or preserve thick (>10 m) sub-tidal deposits of limited facies variability (e.g., Tauranga Harbour, Davis & Healy 1993). Neither situation is ideal for palaeo-environmental reconstructions that extend to pre-Holocene time. For tectonically stable sections of the New Zealand coast, notably the Auckland and Northland regions, previous studies of estuary stratigraphy have documented relatively thin (<5 m) Holocene deposits overlying Pleistocene deposits (e.g., Weiti River, Heap & Nichol 1997; Whangape Harbour, Nichol et al. 2000; Horrocks et al. 2001; Tamaki River, Abrahim et al. 2008). Due to the strongly weathered condition of the Pleistocene sediments at these sites, their utility for microfossil (pollen, foram, diatoms) analysis has been reduced. However, given the appropriate setting the potential remains for these Pleistocene to Holocene sediment successions to retain an accessible record of environmental change. In this study, we present evidence that such a record can be reconstructed using sediments from a sheltered tidal inlet on the margins of Kaipara Harbour.

KAIPARA HARBOUR

Located on the west coast of Northland, Kaipara Harbour occupies an extensive network of six drowned river valleys covering an area of 530 km^2 (Fig. 1). The largest freshwater inflow is from the Wairoa River which drains a catchment area of 3650 km^2 and exits to the Tasman Sea through a single tidal inlet that is 7 km wide and up to 35 m deep. Tidal range in the harbour is low mesotidal, with mean neap range of 1.9 m and mean spring range of 2.8 m at Pouto Point. The spring tidal exchange is approximately 1.99 billion m^3 (Hicks & Hume 1996) and drives large-scale sediment transport through the inlet. Annually, tidal flows deliver c. 2.6 million m^3 of sand into the harbour from the open coast (Hume et al. 2003) where deposits are accommodated in the extensive bars and islands landward of the inlet throat.

The harbour is enclosed on the seaward side by North Kaipara and South Kaipara barriers, each comprising fixed sand dunes and perched lakes that rise to 100 m elevation and a foreland of mobile dunes, less than 10 m high. The dune landscape of the Kaipara barriers has received little attention from Quaternary researchers, aside from the work of Brothers (1954) and Schofield (1970, 1975) on the coastal sands and dune belts of the west coast, geological mapping of the barriers (Brook 1989a,b; Richardson 1975, 1985) and surficial geological study of the dunes on Tapora Island (Smith 1999) and Okahukura Peninsula to the east of the harbour inlet (Balance & McCarthy 1975) (Fig. 1). These studies described and interpreted the general form and stratigraphy of the barriers and dunes, including delineation of the main sedimentary formations. Other palaeo-environmental research in the area includes the palynological work of Mildenhall (1985) who analysed 14 spot samples from lignite interbedded with dune sands along the North Kaipara Barrier, from Maunganui Bluff south to Kaipara Harbour and found a rich and varied palynoflora. He concluded that lignites west of the Kaihu and Wairoa rivers are at least as old as earliest Pleistocene.

For this study, we focus on the south-eastern shoreline of North Kaipara barrier, along the lower reaches of the Wairoa River and to the north of Pouto. This shore is characterised by a sandy shoreline of narrow pocket beaches, small tidal inlets and 20 m high cliffs. These cliffs expose unlithified sediments of the Pareotaunga and South Head Formations, recognised by Brothers (1954) and mapped by Richardson (1975). The Pareotaunga Formation comprises white to light buff, fine-grained quartzose sand interpreted as estuarine and dune deposits of Middle Pleistocene age (Richardson 1985). The South Head Formation consists of red-brown fine quartzose sand with up to 15% heavy mineral content. It is interpreted as an aeolian deposit that formed during a major sea level regression between 220 ka and 160 ka BP (Richardson 1985). Along the cliff at Tauhara Creek, 3 km to the north of Pouto, the South Head formation rests unconformably on the Pareotaunga Formation, with the latter extending below sea level.

Tauhara Creek forms a small tidal inlet that is incised into the Pareotaunga Formation with a catchment that drains dunes that belong to the South Head Formation. The inlet is characterised by a tidal flat with fringing mangrove and saltmarsh that is enclosed by a narrow sand spit (Fig. 1). The beach along the outer (eastern) side of the spit is 40 m wide with a low (<2 m) foredune and a continuous low tide terrace that is 100 m wide and fringes the Wairoa River channel. Across the surface of the terrace, peat is locally exposed, including *in situ* tree trunks and roots. Historical records and photographs for this section of shoreline, known locally as Maori Bay, show that in the early 20th century the intertidal terrace was occupied by a village (Fig. 2A). At that time, the shoreline was about 50 m further to the east of its present position (Parnell 2003).


A
1904
B
C

FIELD AND LABORATORY METHODS

Two vibracores were collected from the Tauhara Creek site. Core T1 was taken on the tidal flat to the west of the sand spit and T3 taken from the lower beach face of the spit (Fig. 1; Fig. 2B,C). Core sites were levelled relative to mean sea level and the amount of compaction was measured prior to core retrieval; depths reported here are unadjusted for compaction as it was less than 10% in each core. In the laboratory, cores were split lengthwise, photographed and described for textural composition and sedimentary structures. Pollen samples were taken from organic-rich horizons of each core at 5 cm intervals, yielding 13 samples from core T1 and 15 samples from core T3. Pollen preparation followed the standard acetylation and hydrofluoric acid method (Moore et al. 1991). Four samples of organic material (shell, peat) were submitted to the Radiocarbon Dating Laboratory at the University of Waikato for conventional dating and one sample of peat sent to the Rafter Radiocarbon Dating Laboratory for AMS age determination.

RESULTS

Sediment facies

Core T1 was taken from the sandy tidal flat of Tauhara Creek to 4.75 m depth and recovered a succession of three sediment facies (Fig. 3). The basal facies is 2.35 m thick (at least) and comprises well-sorted fine light grey-brown sand that is tabular-bedded below 2.4 m depth and massive above this depth. Within the upper metre of this sand unit, the sand is light brown and contains vertical roots. These roots extend down from the overlying facies, which comprises a soft silty peat. Contact between the sand and peat is sharp but not interpreted as erosional. The peat is 30 cm thick and includes small amounts of silt and very fine sand. Samples of peat from 1.36 m and 1.7 m depth yielded conventional radiocarbon ages of 12 554 ± 70 yr BP and 23 219 ± 177 yr BP, respectively (Table 1). The top of the peat is truncated by an erosion surface that is marked by a transition to the third facies, a 1.35 m thick massive bed of shelly sand and silt. In this unit, shells are concentrated below 0.8 m depth and form a 10 cm thick shell hash directly on the contact with the peat. A single whole cockle valve (*Austrovenus stutchburyi*) buried at 1.32 m within this shell lag yielded a conventional radiocarbon age of 3956 ± 114 yr BP (4270–3620 cal. yr BP). Above 0.7 m depth the sand is shell-free but rich in heavy minerals that form millimetre thick laminae to 0.3 m depth. Above this, the sand is massive and oxidised to the top of the core.

Core T3 was taken from the lower beach face of Tauhara spit at an elevation of 1.2 m below mean sea level. The core recovered 6.2 m of sediment comprising three facies. The basal facies is a 4.46 m thick bed of loose, fine- to medium-grained grey sand that is tabular-bedded and cross-bedded below 4.5 m depth and becomes massive with silt flasers up-core (Fig. 3). The upper 0.7 m of this sand bed is light brown, contains rootlets and is bioturbated. At 1.74 m depth the sand is overlain by a 0.5 m thick bed of soft silty peat. Two peat samples, at 1.23 m and 1.65 m depth, yielded conventional radiocarbon ages of 11 145 ± 150 yr BP and 17 656 ± 148 yr BP, respectively (Table 1). The top of the peat is defined by a sharp erosional contact at

◀ **Fig. 2** Photographs of Maori Bay and Tauhara Creek estuary, Kaipara Harbour showing: **A**, View in 1904 of the former village located at the southern end of Maori Bay. Reference point for photograph B is marked by the circle on the ridgeline. Original caption reads—A general view of the gathering during the addresses by the chiefs (source: Logan Forrest). **B**, View of Maori Bay in February 2001, looking south to Pouto Point at low tide. Sand dunes in the background are exposed as unstable cliffs along the shoreline and are not visible in the 1904 photograph. Arrow points to the location of core T3 and the dotted white line represents the 1904 shoreline. **C**, View of Tauhara Creek estuary at low tide. Arrow points to the location of core T1.

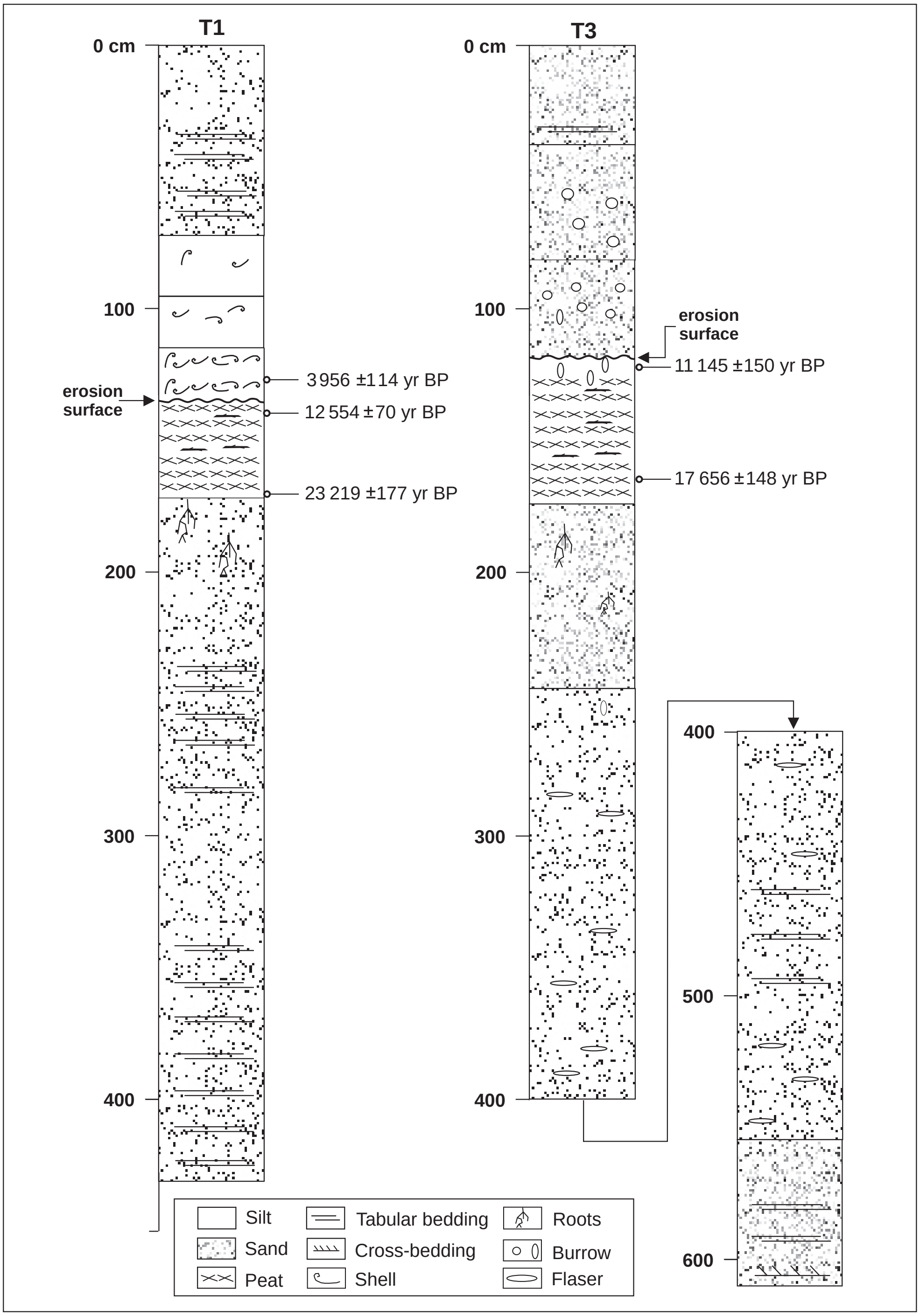

Fig. 3 Graphic log for cores T1 and T3 from Tauhara sand spit, drawn to the length of recovered cores. Core compaction was 40 cm on T1 and 6 cm on T3. See Table 1 for sample details of radiocarbon ages.

the transition to a 1.15 m thick bed of medium-grained sand that preserves abundant horizontal burrow traces below 0.5 m depth and is tabular-bedded in the upper 0.4 m. This sand bed extends to the modern beach face of Tauhara spit.

Pollen

In the sampled interval of core T1, the basal sand between 170 cm and 210 cm depth (Fig. 3) is dominated by pollen of tall trees (*Dacrydium*, *Prumnopitys ferruginea* and *Podocarpus*) and fern spores (*Cyathea* and monoletes) (Fig. 4). Small trees and shrubs are represented by *Coprosma*, *Leptospermum* and *Myrsine*. Within the peat unit, *Dacrydium* pollen are strongly dominant, with pollen from other tall trees (*Prumnopitys*, *Fuscospora* and *Metrosideros*) also present but in lower concentration. *Cyathea* fern spores maintain a strong pollen signal through the peat, while monolete fern spores decrease. Within the shelly sand above the peat, *Dacrydium* maintains high values, *Fuscospora* increases and fern spores decrease. The pollen profile from core T3 is broadly similar to that of core T1 (Fig. 5). Pollen from tall trees are dominant, particularly *Dacrydium*. Pollen from swamp plants (e.g., *Gleichenia*) and fern spores (*Cyathea*) maintain a strong signal throughout the peat.

FACIES CORRELATION AND INTERPRETATION

The three sediment facies in each core from Tauhara Creek are stratigraphically correlated in Fig. 6. Based on uniform grain size, sorting and sedimentary structures, the basal sand facies is interpreted as a dune deposit that is preserved beneath the modern low tide terrace, sand spit and enclosed tidal flat of Tauhara Creek. In core T3, silt flasers within the lower part of the dune sand are interpreted as evidence for settling of fine-grained sediment in a standing water body that once formed part of the dune field. Above this interval, the up-core transition in colour of the dune sand from light grey to brown with roots is interpreted as evidence for organic staining and soil development under vegetation cover. The pollen record shows that this cover comprised podocarp-hardwood forest, dominated by *Dacrydium* with some *Podocarpus* and *Prumnopitys ferruginea*, with *Cyathea* ferns common in the sub-canopy and *Leptospermum* in forest gaps. The subsequent decline of *Leptospermum*, coincident with the increase in monolete fern spore peaks in core T1, suggests patchy successional sequences of disturbance-related taxa. Given the proximity of cores T1 and T3 to cliff exposures of the Pareotaunga Formation and the similar colour of sands in the cliffs (as described by Richardson 1985) to the cores, it is likely that the lower part of the dune facies (below c. 2 m depth) in each core belongs to the Pareotaunga Formation. This is a tentative correlation, however, and requires additional core sampling for confirmation.

Table 1 Sample details and results for radiocarbon age determinations for Tauhara Creek cores, Kaipara Harbour. Samples marked as N/A are terrestrial and beyond the range of the Southern Hemisphere atmospheric calibration curve.

Core	Sample depth (cm)	Material	Conventional ^{14}C age (yr BP)	Calibrated ^{14}C age (yr BP)	Lab. code
T1	132	Single cockle valve[1]	3956 ± 114	4270–3620[2]	Wk-9631
T1	136	Sandy peat	12 554 ± 70	N/A	NZA-13689[3]
T1	170	Sandy peat	23 219 ± 177	N/A	Wk-17782
T3	123	Sandy peat	11 145 ± 150	N/A	Wk-9768
T3	165	Sandy peat	17 656 ± 148	N/A	Wk-17783

[1]*Austrovenus stutchburyi*.
[2]Calibration made with OxCal version 4.0 software (Bronk Ramsey 1995, 2001) using the Marine 04 calibration curve (Hughen et al. 2004) and a Delta-R value of 12 ± 15.
[3]This sample dated by AMS at the Rafter Radiocarbon dating lab.

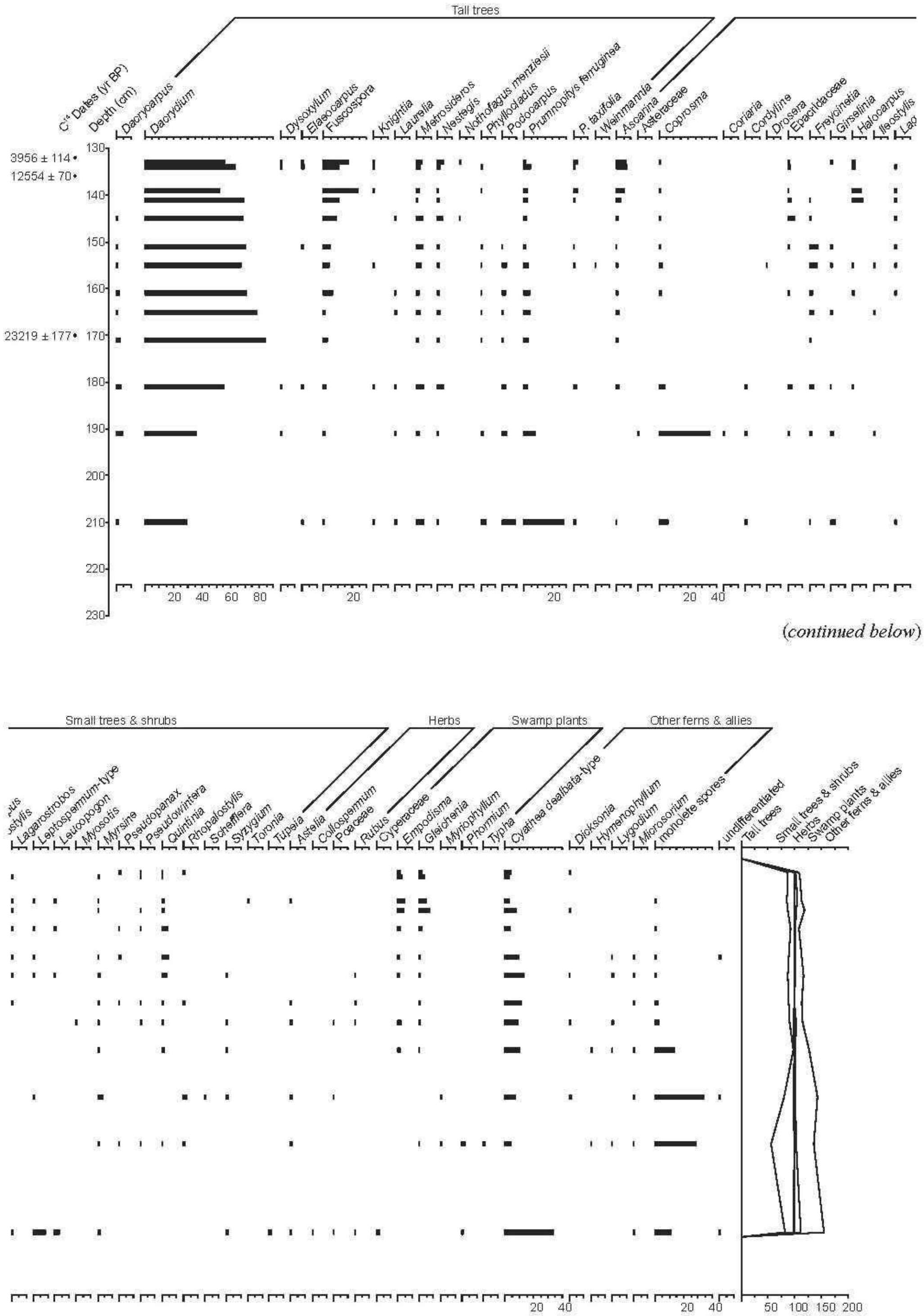

Fig. 4 Percentage pollen diagram for the sampled interval of core T1.

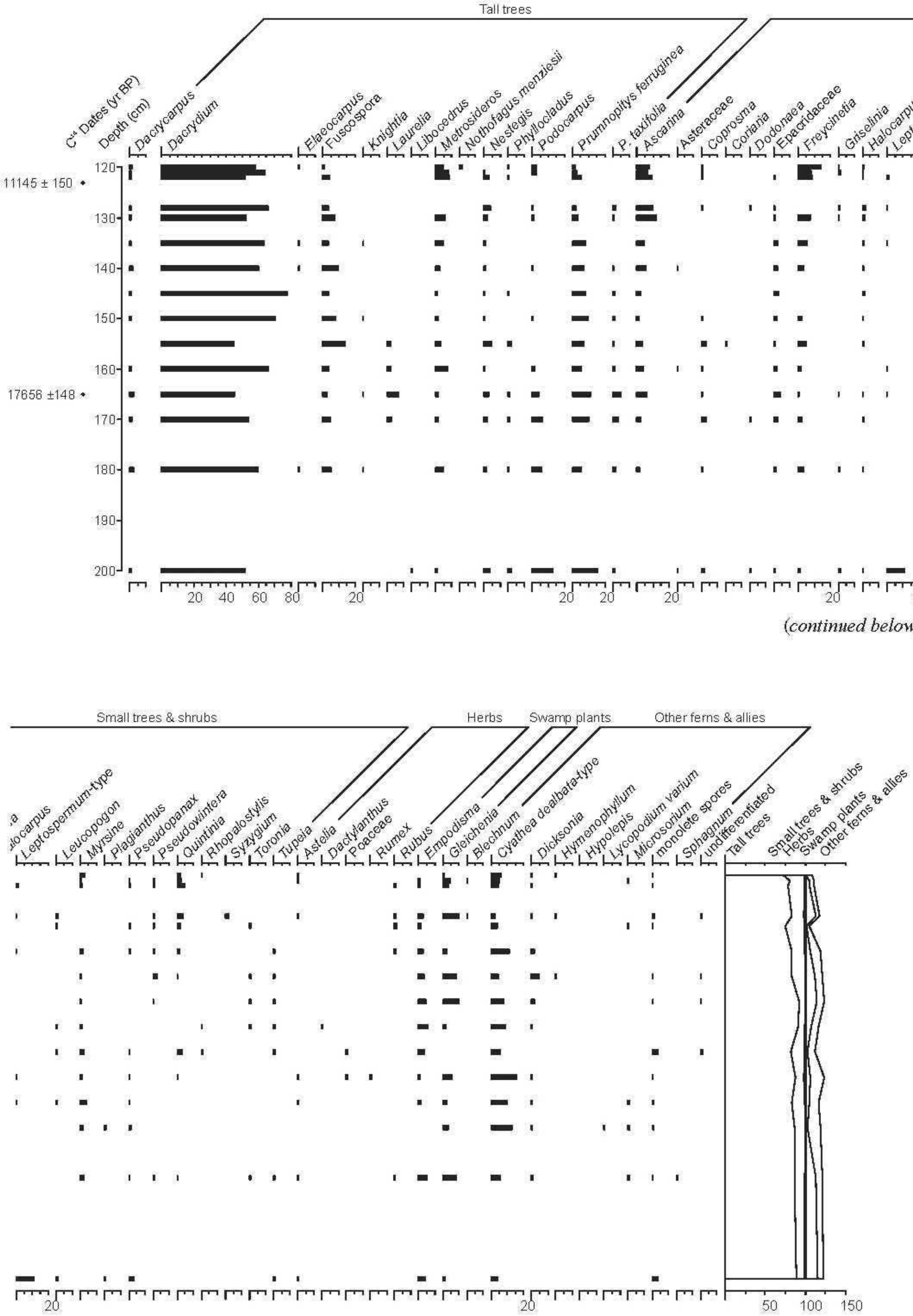

Fig. 5 Percentage pollen diagram for the sampled interval of core T3.

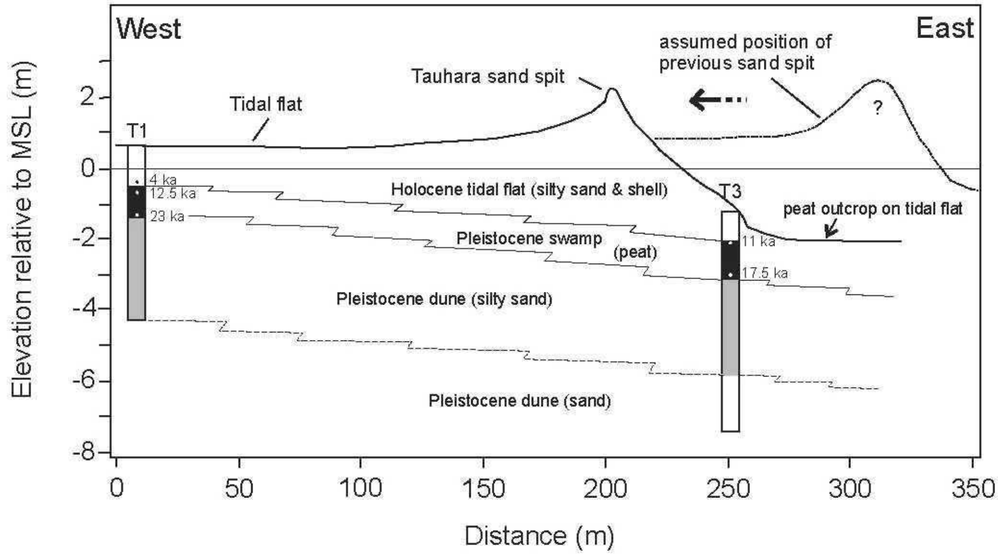

Fig. 6 Generalised stratigraphy of Tauhara sand spit and tidal flat, showing inferred former position of sand spit that has since migrated west. Ages shown are rounded uncalibrated radiocarbon ages for correlation purposes only. See Fig. 3 and Table 1 for details of ^{14}C results. MSL, Mean sea level.

The peat recovered in each core above the dune sand is interpreted as a continuous deposit beneath Tauhara sand spit. Peat formation most likely occurred in an inter-dune depression where drainage was impeded, thereby providing conditions suitable for swamp vegetation. While some of this was probably swamp forest (e.g., *Laurelia* in the early part of the T3 peat), much of it was sufficiently waterlogged to prevent tree growth in the swamp, being dominated by open herbaceous vegetation (i.e., *Empodisma* and *Gleichenia*). Our correlation between the cores suggests the palaeo swamp extended at least 250 m in the east-west direction. This dimension for an inter-dune lake/swamp is typical for the modern systems elsewhere on North Kaipara barrier.

Radiocarbon ages on the peat provide an age range of c. 23 000–11 000 yr BP for the period of swamp existence. We acknowledge that these ages are derived from bulk samples and therefore may contain reworked organic material, but we regard the potential for contamination to be low given the broadly consistent ages between the cores. Furthermore, given that our core samples and the pollen spectra do not suggest any stratigraphic breaks in the peat deposit, we suggest that the swamp remained undisturbed throughout the late glacial period until the post glacial marine transgression. The erosional contact between the peat and the overlying Holocene sand facies is interpreted as an unconformity produced by tide and wave scour during the transgression of the Kaipara Harbour. It follows that an unknown thickness of peat was removed during the transgression.

Depositional environments for the sand facies that forms the surficial deposits in cores T1 and T3 appear to differ. For core T1 the association of broken shell, silt and heavy mineral-laminated sand is interpreted as the product of sediment sorting in a shoaling tidal channel with a maximum depth of 1.5 m. The radiocarbon age on a single valve of the cockle *A. stutchburyi* provides a maximum calibrated age range of 4270–3620 yr BP for formation of the shell lag on the channel floor and for partial removal of the underlying peat. It is likely, however, that estuarine conditions pre-date this particular sample, as we would expect Tauhara Creek inlet and sand spit to have formed in association with postglacial sea level rise approximately 6500 yr BP (Gibb 1986). In contrast, the surficial sand facies in core T3 is interpreted as a modern beach deposit on the basis of its well sorted texture and tabular bedding, both of which are characteristic products of wave sorting. Below 0.5 m depth, the sand is clearly bioturbated with abundant horizontal (dwelling) burrows, indicating that regular wave-driven sediment reworking is limited to the upper 0.5 m of the beach face. Given that core T3 was taken from the lower beach face, we interpret the bioturbated sand as a nearshore bar deposit, which extends to an erosional contact with the peat at 1.15 m depth. As noted earlier, the present position of Tauhara spit was established only during the 20th century AD. It follows that the sand facies covering the peat in core T3 is modern and possibly ephemeral.

In summary, the shallow stratigraphy of Tauhara Creek and sand spit records the transition from a terrestrial to estuarine environment associated with the rise in sea level following the Last Glacial Maximum (LGM). This transition involved a shift from partly forested dunes and linked lowland swamps to an active beach face, sand spit and tidal flat system. In the following discussion we place this environmental transition into the context of controls on the preservation of these respective depositional records.

DISCUSSION AND CONCLUSION

A key finding from this study is the preservation of unconsolidated and unweathered Pleistocene deposits at shallow, intertidal depths in a relatively dynamic estuarine environment. In accounting for this preservation we concentrate on the depositional and erosion processes that operated during the glacial lowstand of sea level and the post-glacial marine transgression, as key factors. In doing so, we assume that the North Kaipara barrier has been tectonically stable during this time, experiencing neither major subsidence nor uplift. This assumption is supported by morphostratigraphic evidence at several sites on the Northland coast, including Kaipara Harbour, that tie the mid-Holocene sea level highstand to a common elevation of +1.2 to 2.1 m (Richardson 1985; Hicks & Nichol 2007), a range that is consistent with other tectonically stable sites in the SW Pacific (e.g., Woodroffe et al. 1995; Sloss et al. 2007).

The depositional and erosion processes associated with sea level regression and transgression are well understood (Curray 1964) and have been incorporated into a conceptual model for estuary evolution (Dalrymple et al. 1992; Zaitlin et al. 1994). In this model, the stratigraphy of an estuary is summarised for the main axis of the valley, showing key erosion surfaces and sediment successions produced during sea level regression and transgression. However, the model does not necessarily represent the stratigraphy along the margins of an estuary, for situations such as represented by Tauhara Creek. In general terms, the margins of an estuary valley are less exposed to large-scale incision during regressions and transgressions because erosive mechanisms (river flow, tidal flow, waves) are relatively weak along the valley sides. Thus, pre-existing deposits have a moderate to high preservation potential. Conversely, the potential for deposition along the valley margin may itself be limited, due to a lack of accommodation space during sea level highstands. In the case of Tauhara Creek, located at the point of maximum transgression, accommodation space at present sea level is less than 2 m. However, during the post-glacial lowstand, deposition in non-estuarine environments (e.g., dunes) was clearly possible. Hence the record of sub-tidal Pleistocene deposits overlain by thin Holocene deposits preserved at Tauhara Creek.

We also recognise two site specific factors that have contributed to the preservation of LGM and Late Glacial deposits at Tauhara Creek. First, the development of a forest cover on the dunes during the Late Glacial period would have helped maintain a stable dune landscape and allow a swamp to form as additional protection from stream or wind erosion. Second, the location of Tauhara Creek on the leeward side of the North Kaipara barrier with respect to prevailing winds means that exposure to wind and wave erosion during the Holocene has been limited. We expect a similar record exists at similar sites along the margins of Kaipara Harbour.

The aforementioned combination of physical setting and environmental conditions appears to be underutilised for the study of LGM to Late Glacial vegetation histories in Northland. Previous studies have mostly used inland wetlands of Northland to reconstruct the regional vegetation and landscape history (e.g., Newnham 1992; Elliot 1998; Horrocks et al. 2007). The pollen record from Tauhara Creek is generally consistent with this previous work in showing that vegetation in the Kaipara region during the LGM was podocarp-hardwood forest, dominated by *Dacrydium*, with *Podocarpus* and *Prumnopitys ferruginea* also common. Of note, *Fuscospora* (a cool climate indicator) shows a slight increase during the Late Glacial when the climate was presumably warming. Newnham (1992) also identified a Late Glacial increase in *Fuscospora* in a pollen record from Hikurangi (near Whangarei), but questioned the radiocarbon chronology and suggested an LGM increase. Further regional work on this species for the LGM period appears necessary.

In contrast to other regional pollen records, there is no evidence in the Tauhara sediments of an expansion of shrub/grassland into forest, as recorded at LGM pollen sites in Auckland (e.g., Sandiford et al. 2002). Another notable difference to other Northland studies is that *Agathis* (a local pollen disperser) seems to have been absent from vegetation around the Tauhara core sites during the entire period represented. Overall, Tauhara Creek provides a coherent pollen record that is a useful comparison to other Northland sites. It is also the most southern pollen site yet studied in Northland, thereby extending the known southern limit of the northern LGM-Late Glacial podocarp-hardwood forest.

At the global scale, the preservation of Pleistocene deposits along the margins of an estuary is not unique. For example, stratigraphic reconstructions in several estuaries on the Gulf of Mexico (United States) coast reveal buried Pleistocene fluvial terraces along the valley margins that extend onto the continental shelf (Thomas & Anderson 1994; Nichol et al. 1996; Rodriguez et al. 2005). Vibracore data from these estuaries show the Pleistocene terraces to comprise stiff, weathered mud overlain by soft estuarine mud of Holocene age (Rodriguez et al. 2005). This is in strong contrast to the Tauhara Creek record, where the Pleistocene deposits are loose dune sand and peat. We attribute this difference to the greater scale of dune development along the margins of Kaipara Harbour than along the margins of Gulf of Mexico estuaries. This in turn highlights the variability in facies character that can exist depending on local sediment supply conditions. Moreover, it emphasises the value of marginal estuarine environments for palaeo-environmental reconstructions that extend beyond the Holocene.

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