Avon-Heathcote Estuary (Ihutai): Palaeoenvironmental changes project – Final stage report

NIWA Client Report: CHC2007-026
May 2007

NIWA Project: CCC07501

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Prepared for

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Contents

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Executive Summary

The final stage report details the results of a coring programme undertaken over the last year or so in and around the Avon-Heathcote Estuary (Ihutai) (AHE(I)). Sediment cores were taken from Brooklands Lagoon, South New Brighton Park, Estuary Park, Charlesworth Reserve, and Taylors Mistake. These were analysed using an assortment of techniques including stratigraphic analysis, sediment grain size, chemical analysis, microfossils (diatoms, pollen, spores), and radiocarbon dating.

Several possible tsunami deposits have been identified and placed in the context of earlier work. A combined total of five events have been identified, three through coring and two from an earlier trenching project. Approximates dates for these events are: 6460-6250 years BP, 5230-4830 years BP, 4100-4400 years BP, 3400-3700 years BP, and AD 1300.

The historic record and modelling work give us some idea of traditional sources for Christchurch such as South America (distant) and the Cook Strait/Kaikoura Canyon areas (regional/local). In reality though, these produce only small tsunamis, with waves possibly up to 2-3 metres high. The sedimentary evidence reported here is most probably related to larger waves, in the order of 4-5 metres or more. Our current state of knowledge means we are not aware of all possible sources and we are unable to speculate further. However, it is worth noting that all the events reported in this study would have inundated AHE(I) at a time when South New Brighton Spit was either not present, or offered only moderate protection to sites such as Estuary Park. This is important because it means that not only does the spit protect the landward shores of AHE(I) from tsunamis, but that a considerable amount of sedimentation has taken place in the area. This has fundamentally altered nearshore bathymetry and will have helped to reduce the size of incoming tsunami waves. In other words, the type of event we have recorded in the sediments in and around AHE(I) is unlikely to recur. What we do not know therefore, beyond modelling, is the likely effect that the next tsunami will have on South New Brighton Spit.

1. Introduction

This is the final report in a reconnaissance series of three planned stages. It builds upon the work outlined in Goff and McFadgen (2004), Goff (2005a) and Goff and Chagué-Goff (2006).

The work developed from the discovery in 2004 of two possible tsunami deposits inside the Avon-Heathcote Estuary (Ihutai) (AHE(I)) (Goff and McFadgen, 2004). It has culminated in this report that details the broad brush analysis and interpretation of a series of sediment cores taken from around the AHE(I) and surrounding area. Cores were taken from South New Brighton (one core), Charlesworth Reserve (two cores), Estuary Park (three cores), Taylors Mistake (one core), and Spencerville – Brooklands Lagoon (one core) (Figures 1, 2, 3). Full details are given in Goff and Chagué-Goff (2006).

Figure 1: Aerial photo of Avon-Heathcote Estuary (Ihutai) showing main core sites (Photo © GNS Science) (1 = Charlesworth Reserve, 2 = Estuary Park, 3 = South New Brighton)

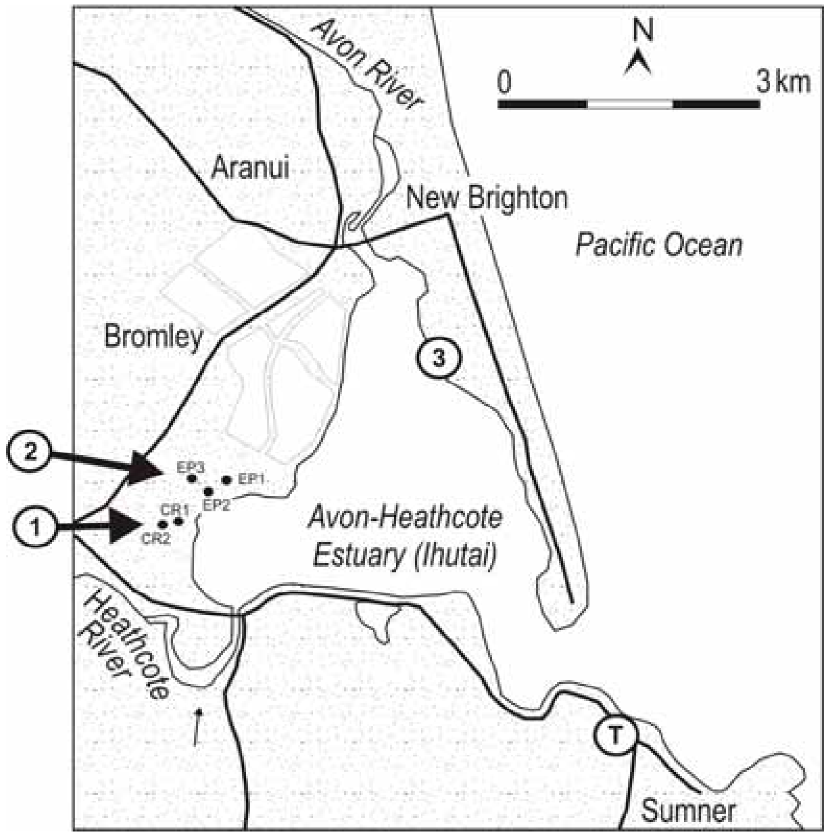

Figure 2: Map view showing main core locations (1 = Charlesworth Reserve: CR1 – Core 1, CR2 - Core 2; 2 = Estuary Park: EP1 - Core 1, EP2 – Core 2, EP3 – Core 3; 3 = South New Brighton) and the Sumner trench site (T)

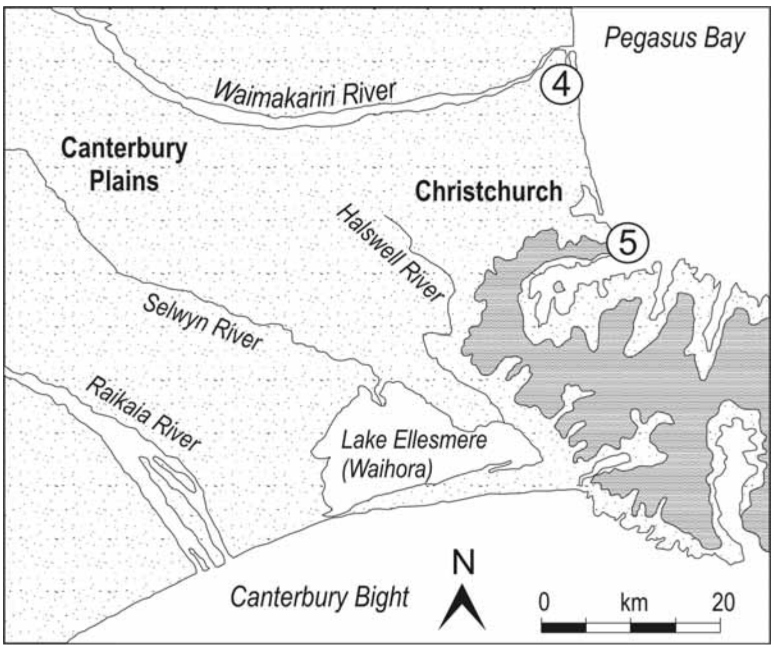

Figure 3: Map view showing outlier sites (4 = Spencerville – Brooklands Lagoon, 5 = Taylors Mistake)

2. Core analysis

All seven cores were opened in the laboratory, logged – their stratigraphy noted, sampled for sediment grain size, microfossil and geochronological analyses. Selected samples from two of the cores were also sampled for chemical analysis. Photographs were taken at approximately 30 cm intervals along the length of each core and details are used in this report where appropriate.

2.1. Stratigraphy/Sediment grain size

This analysis is undertaken to give an indication of the changing sediment regimes. A combination of a stratigraphic analysis – changing sediment regimes noted in the core – coupled with grain size helps to provide the underpinning data on top of which a more detailed construction of environmental change can be built. Grain size was measured using a laser particle sizer system that determines particle size based on the time of transition principle.

2.2. Chemistry

Changes in the chemistry of the sediment can reflect differing sources of the material – marine/terrestrial and/or changing land use. Sulphur (S) and sodium (Na) for example have previously been used as proxies for palaeosalinity in lagoon environments (e.g. Chagué-Goff *et al.*, 2002), because of the relatively high S and Na contents of seawater compared to freshwater. Chemical composition can, in the correct conditions, also act as an indication of European arrival – copper, lead or zinc concentrations for example often increase following European arrival. In conjunction with sediment characteristics it can help indicate sediment source areas. Total elemental analysis was undertaken using XRF spectrometry.

2.3. Microfossil analysis

Marked changes in pollen and spore assemblages have been used by researchers to identify two key time horizons. The arrival of Europeans is associated with the appearance of pine (*Pinus*) pollen, which is produced in great quantity soon after the trees are planted. A date of around AD 1830 is used for the first appearance in the sedimentary record in the region (e.g. Goff, 2005b), although this can vary around the country and estimates range from AD 1800 to AD 1870. The arrival of Maori is normally associated with an increase in the number of bracken (*Pteridium*) spores (e.g. Goff, 1997). The timing of Maori arrival is generally placed around 750 years ago and we use AD 1250 to represent this event horizon.

Diatoms can also be used to interpret changing environmental conditions. They are single-celled plants (algae) that live in a range of conditions from saltwater to freshwater. A high-resolution study was prohibitively expensive for this work, however we felt it important to use as much available time as possible to produce a record of environmental change that could be compared and contrasted with other data. To this effect we concentrated on placing diatoms into key groupings associated with relevant environmental conditions ranging from freshwater to marine.

2.4. Radiocarbon dating

This can only be used on dead carbon (trees, shells etc.). There was a paucity of good dateable material but we have managed to successfully match up chronologies between cores using a combination of radiocarbon data and stratigraphic correlation.

A reasonably detailed chronology of sediment accumulation and changing environmental conditions was achieved through a combination of radiocarbon, microfossil, palaeontology, stratigraphy and sediment grain size (Table 1). These are interpreted and discussed in the following section.

Table 1: Radiocarbon data for samples from this study

Laboratory No.[a]	Core	CRA[b] (^{14}C yr BP)	$\Delta^{13}C$ (ppm)	(95%) Calibrated age range (cal. yr BP)	Depth (m)	Material dated	Significance
WK-19655	EP1	3158±62	-29.3±0.2	3140-3460	1.56	Organics	Immediately above fining-upward sequence
WK-19656	EP1	3707±65	-27.5±0.2	3760-3800	1.84	Wood, twig	Immediately above fining-upward sequence
WK-19657	CR1	1856±71	-28.4±0.2	1550-1890	0.85	Wood, branch	Top of fining-upward sequence
WK-19658	CR1	1335±30	-27.6±0.2	1140-1300	1.12	Rootlets	Beneath upper fining upwards sequence

[a]WK = University of Waikato radiocarbon laboratory
[b]Conventional Radiocarbon Age (Stuiver and Polach, 1977)

3. Data by site

3.1. Taylors Mistake

Several attempts were made to take cores at this site with little success. One core was retained for opening and examination. Upon opening (Figure 4) the core was found to contain a massive medium to fine sand with a thin soil cover. This appears most likely to be the result of considerable human disturbance and the redistribution of windblown sand in the bay. No further work was carried out. This was unfortunate given that the Taylors Mistake is an outlier site, outside the existing sheltered environment of AHE(I).

Figure 4: Taylors Mistake – upper part of core

3.2. Sumner

Trench work by March Construction along Nayland Street parallel to the coast provided an opportunity to view subsurface sediments. The trench was approximately 300 metres inland from the sea and immediately seaward of the seacliffs. No useful data were acquired at this site. A combination of past human disturbance along much of the trench and the piling up of windblown sand against the old cliff have masked or destroyed any useful record of past catastrophic events.

The infilled sandy embayment of Sumner, like Taylors Mistake, is not the perfect environment for preservation of tsunami deposits. There is always, however, the possibility that evidence will be present in the interdune depressions. The most likely location for any deposits will likely be between the existing trench and the coast – an area that is due to be trenched in the near future.

3.3. Spencerville – Brooklands Lagoon

Peaks in pine pollen and bracken spores were identified. There was no suitable material for radiocarbon dating and therefore the chronology is based solely upon the microfossil data (Figure 5). Sediment grain size samples match the stratigraphic

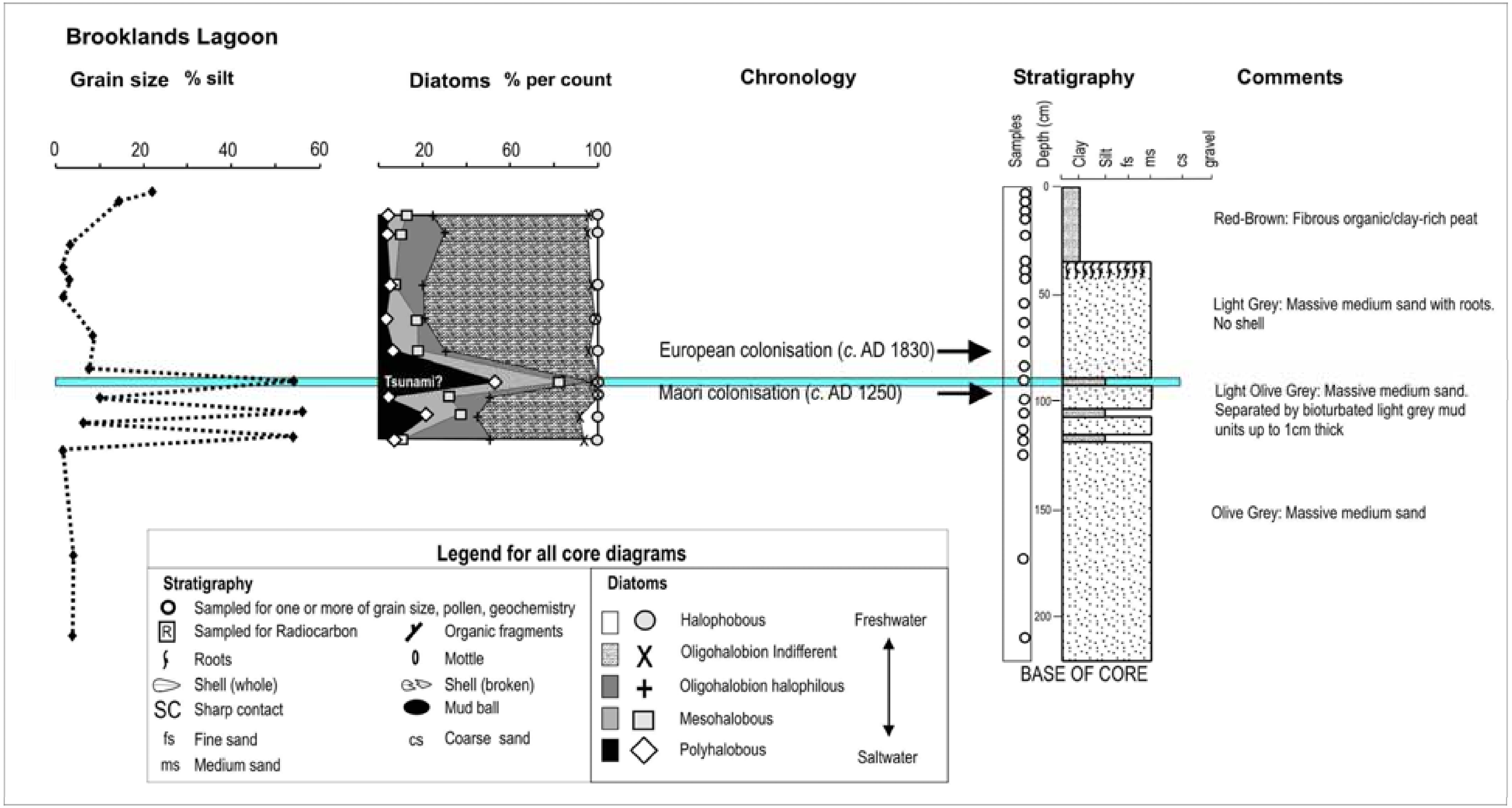

Figure 5: Brooklands Lagoon: Summary core data. Light blue box delimits section of the core – and associated analytical results – that are interpreted as tentative evidence for tsunami inundation.

interpretation, indicating a fibrous peat overlying a predominantly sandy environment with rare mud laminations (Figures 5 and 6). The upper mud lamination at 88 cm depth, which was laid down immediately after Maori arrival, has a marked marine signal as indicated from the diatom record. Other mud laminations show no such peaks and are assumed to represent fine material washed into the lagoon during river floods. The site is approximately 500 m from the sea and we therefore tentatively assign the uppermost mud unit to tsunami inundation. It should be noted however that the Kairaki sands between the lagoon and the sea were not present at the time of Maori arrival (Goff and McFadgen, 2004). This would have placed the area closer to the sea in a more exposed site with a lower barrier separating it from the sea. Interpretation of the stratigraphy confirms this interpretation. Furthermore, the lagoon exit has migrated over the past few hundred years, more so when the Kairaki sands were absent. This peak though still represents an unusual event in the stratigraphy of the site, an event that probably occurred soon after Maori arrival around AD 1300. However, the interpretation is tentative at best.

Figure 6: Brooklands Lagoon: Poorly preserved, heavily bioturbated, upper mud laminations

3.4. South New Brighton Park

The site was on the landward side of the spit, or seaward side of AHE(I). The site was chosen in an attempt to find if there was evidence for any catastrophic saltwater inundation that might have occurred over the last 500 years or so. McFadgen and Goff (2005) reported that, in the last 4000 years, the South New Brighton spit has formed at least twice. By the mid to late 14th century, the spit has reformed after a gap of approximately 1400 years.

Pollen and spore data provide an indication of European and Maori arrival (Figure 7). The latter is recorded in a sediment layer that fines upwards at about 145 cm depth. The layer contains broken shells (primarily fine shell hash, identifiable fragments included *Dosinia lambata* – a shallow subtidal shellfish) and organic material. Unfortunately this was not particularly photogenic, and no diatom information was collected. This unit contains appropriate diagnostic criteria for tsunami inundation in that the sediments fine upwards, they contain marine macrofauna and reworked organic material. However, the interpretation is tentative because a more comprehensive suite of criteria needs to be examined. A way to incorporate this tentative interpretation is to consider it in the light of additional data from other sites examined as part of this study. In other words, does one find a similar "type" of event around the same time in other cores? This is one of the benefits of stratigraphic correlation between sites. Chronologically this event occurs after Maori arrival, but apparently soon after, since any evidence for arrival is incorporated into the fining-upwards sequence. This probably places the event between about AD 1250 and 1350, or at about the same time as the tentative inundation noted in Brooklands Lagoon (around AD 1300).

3.5. Estuary Park

Estuary Park is adjacent to the Bromley sewage treatment facility (Figure 2). This area was chosen because it represents one of the most unspoilt sites on the landward periphery of AHE(I). It is a moderately altered dune sequence that was levelled to create usable pasture land. However, it remains largely undisturbed beneath the ground surface of the old dune slacks/swales. Several test cores were taken to ensure that the most suitable sites were sampled. Cores 1 and 3 were the deepest cores with radiocarbon dates indicating that a sedimentary record for about the past 4000 years was retrieved. Once the cores had been examined in the laboratory it was decided that Core 1 offered the most useful record for a detailed study. An initial stratigraphic correlation between all three cores indicated that they had a remarkably similar sedimentary sequence, with Core 2 being shorter and less complete. Core 1 however offered the best opportunities for radiocarbon dating specific units, with additional chronological control achieved through the use of pollen and spore data to determine European and Maori arrival. Matching up of different events between cores can be achieved through cross-correlation of the stratigraphy.

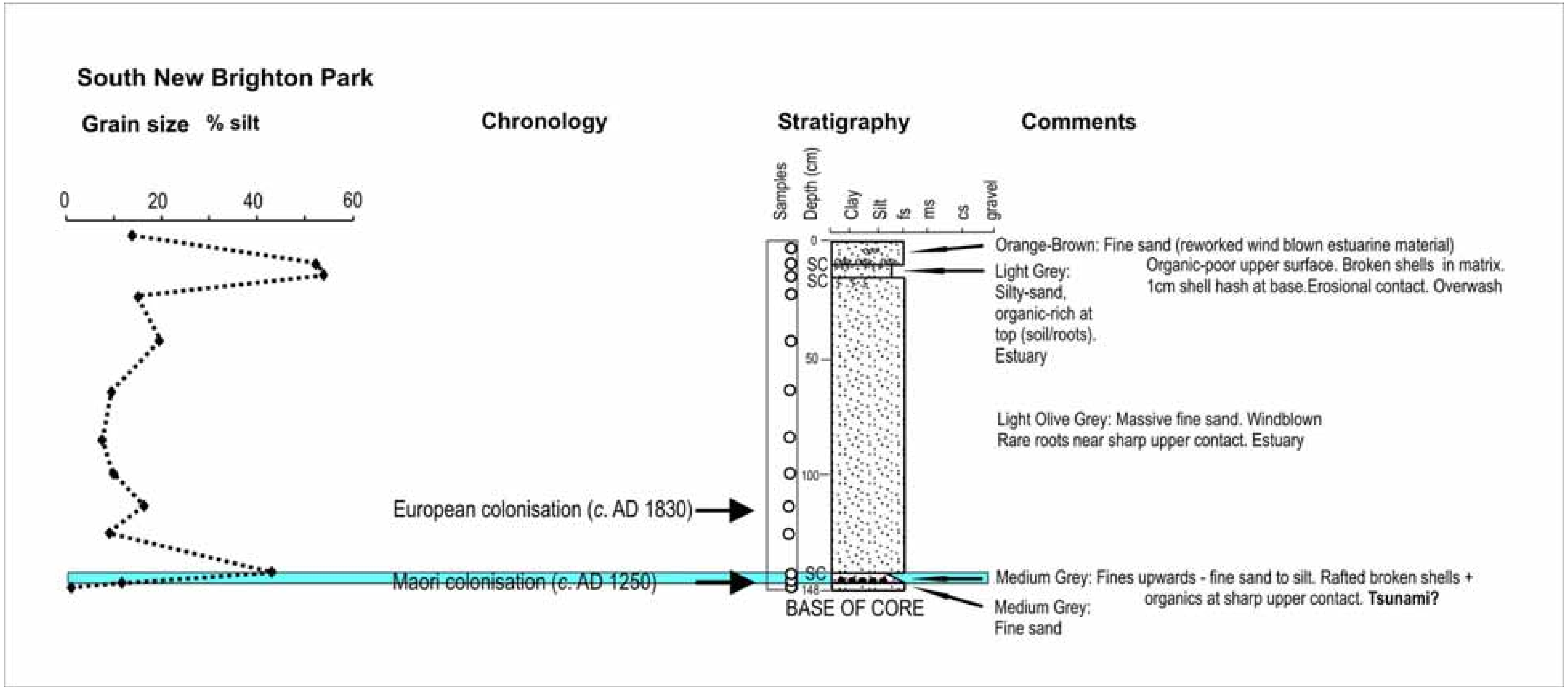

Figure 7: South New Brighton Park: Summary core data. Light blue box delimits section of the core – and associated analytical results – that are interpreted as indicating evidence for tsunami inundation. See Figure 6 for legend

European and Maori arrivals were recorded in all three cores (Figures 8, 9 and 10). European arrival was associated with a marked charcoal layer that appears to record a period of burning in the area. This was not noted in the cores from other sites.

In Core 1, the upper 1.5 m contained little of interest, which in itself is interesting given the evidence for possible tsunami inundation around the time of Maori colonisation in the Brooklands Lagoon and South New Brighton Park cores (Figures 5 and 7). Beneath 1.5 m core depth there are two fining upward sequences. In reality, the uppermost sequence consists of coarsening upward followed by a fining upward segment (Figure 8 and 11). Diatoms indicate a distinct marine incursion and chemical data are also consistent with this finding (Figures 8 and 12). This unique assemblage of coarsening and then fining upwards was only found in Core 1 and seems most likely to represent deposition by a traction carpet at the base of a tsunami wave (Moore *et al*., in review). As wave speed decreases the traction carpet can no longer be sustained and deposition occurs by weight as speed decreases – a fining-upward sequence is laid down. If traction carpets form they are usually only found close to the coast where a tsunami wave first advances over the land. This may also help to explain why only fining-upwards sequences are found in Cores 2 and 3 in a similar stratigraphic position (Figures 9 and 10), as the traction carpet terminated soon after passing over the land. The diatom record from Cores 2 and 3 however confirms that the sequence has a marine origin and as such we link this event across all cores. A radiocarbon date from immediately above the uppermost sequence gives a minimum age of somewhere around 3140-3460 years BP (WK-19655, 3158 ±62 ^{14}C yr BP).

About 15 cm further downcore in Core 1, at about 175 cm depth, is a simple fining-upwards sequence (Figure 8). Like the upper sequence however, it also has a marked marine diatom and chemical signature. This is also interpreted as a tsunami deposit (Figures 8 and 12). The sequence is not present in the shorter (younger) Core 2, but appears again in Core 3 slightly further inland (Figures 2, 9, and 10). The sequence in Core 3 also contains mud balls and rip-up clasts. These are becoming increasingly recognised as distinctive features of tsunami, not storm, deposits (A. Moore, pers. comm., August 2006). Dating of this event horizon is constrained by a twig immediately overlying the deposit, which is believed to offer a minimum age of 3760-3800 years BP (WK-19656, 3707±65 ^{14}C yr BP) (Table 1). Acknowledging that the tree species (for the twig) is not known, it is possible that there is some inbuilt age (inbuilt age refers to how much time has passed between the death of the material and the event dated) – growth age combined with storage age. A twig overlying the sequence would normally be considered to have little inbuilt age, but would still require sediment deposition to occur above the sequence prior to deposition.

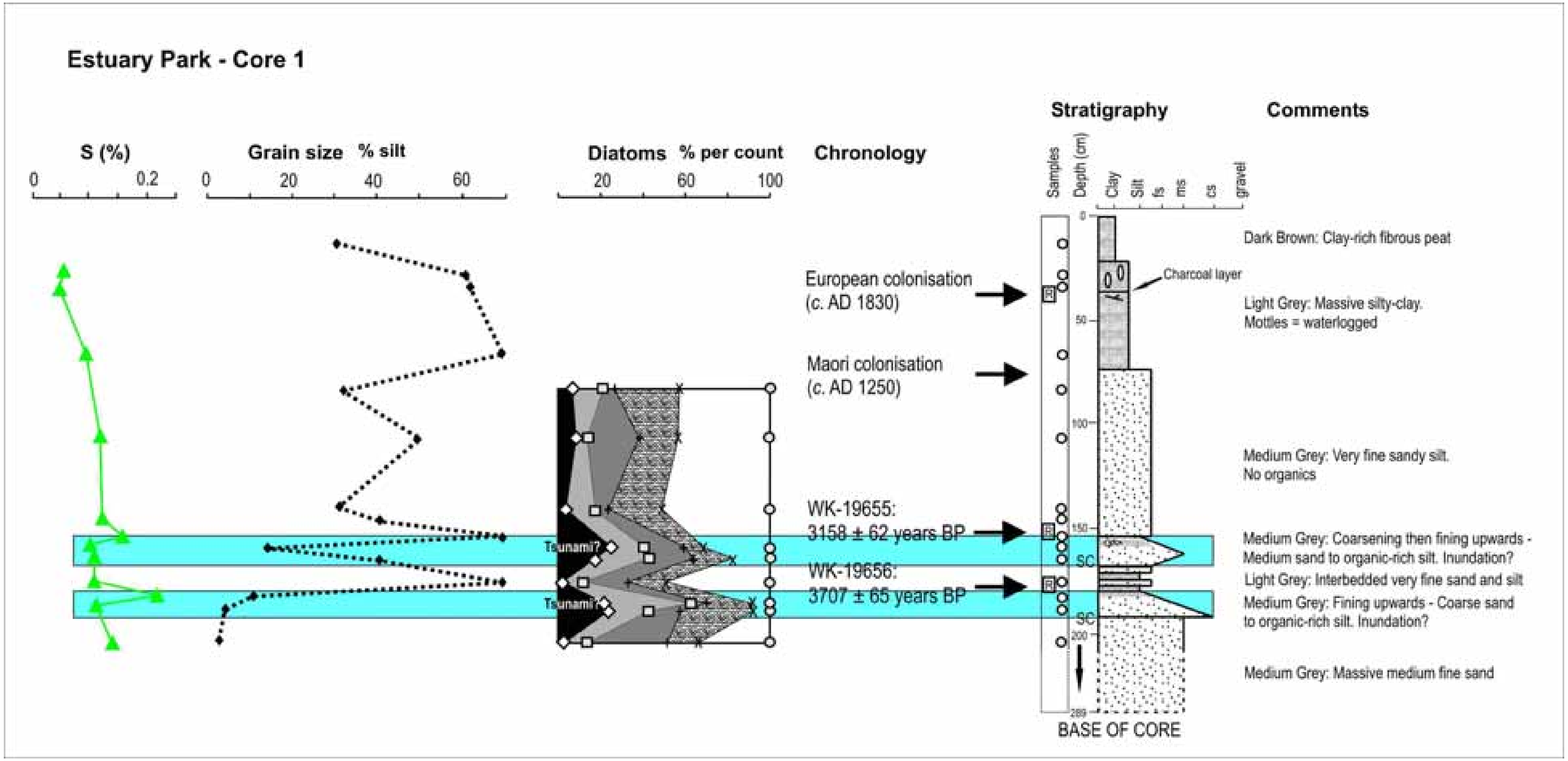

Figure 8: Estuary Park: Summary of Core 1 data including stratigraphy, sediment grain size, chronological information, diatoms, and partial chemical data (the latter links to a comprehensive elemental analysis shown in Figure 12). Light blue boxes delimit sections of the core – and associated analytical results – that are interpreted as indicating evidence for tsunami inundation. (Note change in scale of core length at base). See Figure 6 for legend.

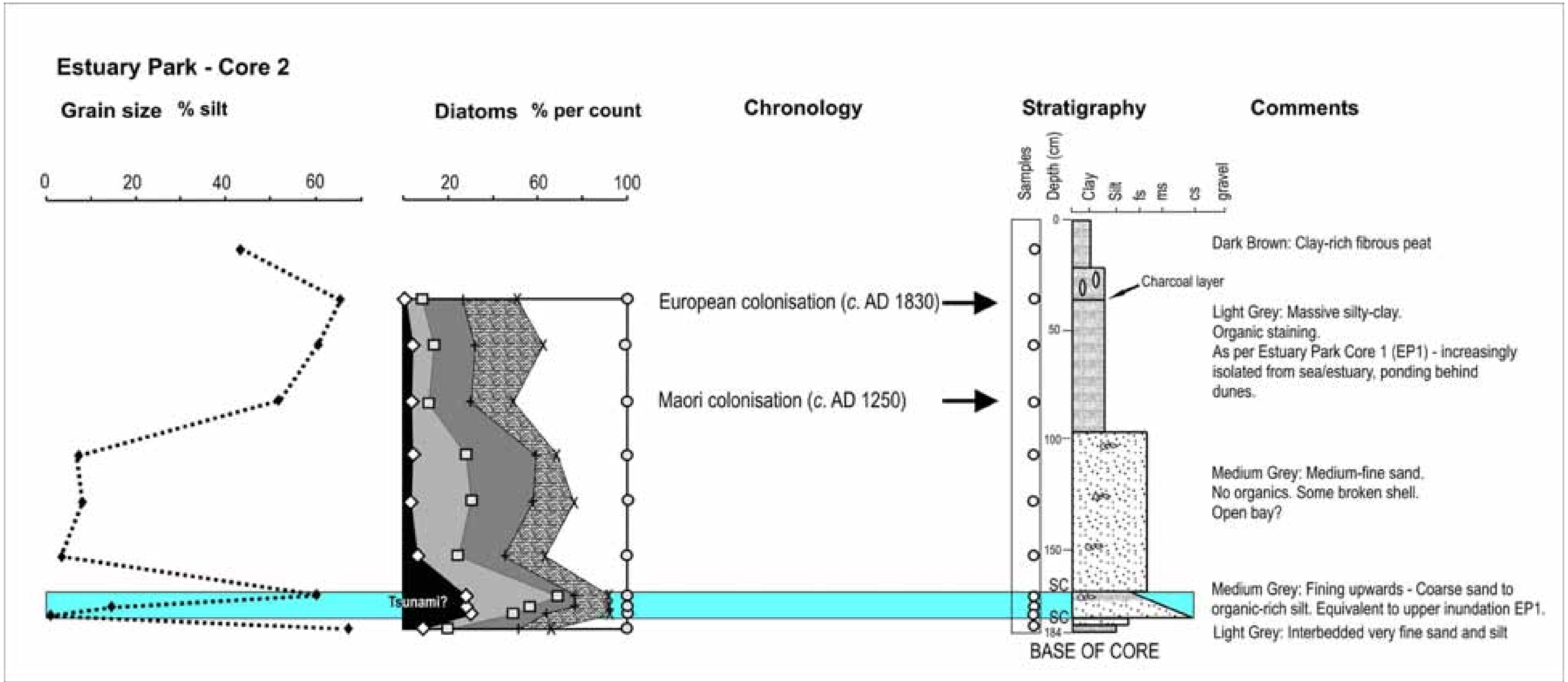

Figure 9: Estuary Park: Summary of Core 2 data including stratigraphy, sediment grain size, chronological information and diatom data. Light blue box delimits section of the core – and associated analytical results – that are interpreted as indicating evidence for tsunami inundation. See Figure 6 for Legend.

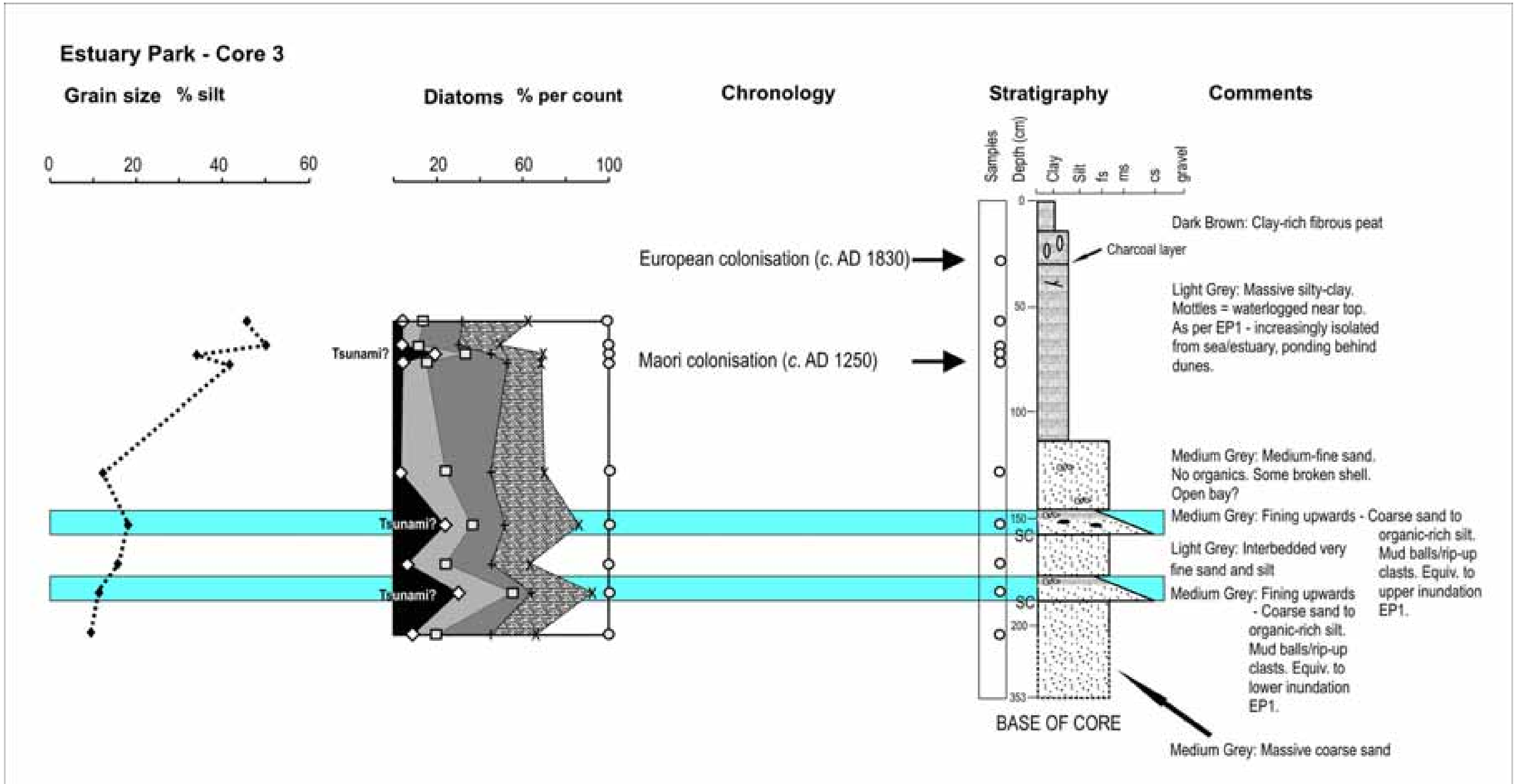

Figure 10: Estuary Park: Summary of Core 3 data including stratigraphy, sediment grain size, chronological information and diatoms. Light blue boxes delimit sections of the core – and associated analytical results – that are interpreted as indicating evidence for tsunami inundation. See Figure 6 for Legend.

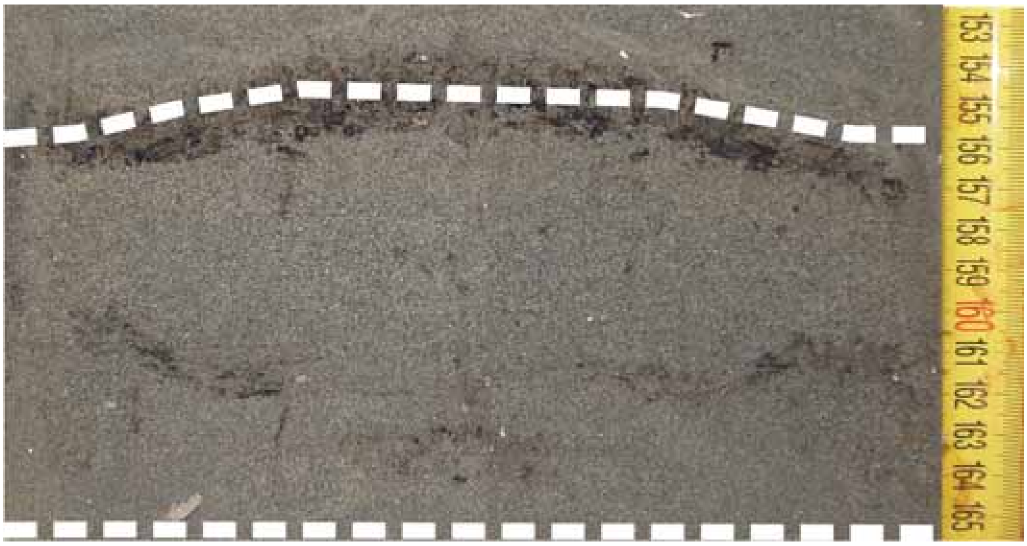

Figure 11: Estuary Park: Core 1 detail of upper tsunami that coarsens upwards to about 160 cm, then and fines upwards to rafted organics at top.

3.6. Charlesworth Reserve

When compared with other potential coring sites around the periphery of AHE(I), the Charlesworth reserve site was considered to be the most reasonable for acquiring good cores for analysis. It is situated only a short distance southwest of Estuary Park (Figure 2) and the original geomorphology would have been similar. In this case however there has been more invasive disturbance of the site with a small constructed wetland, power line and pipeline being the most obvious recent changes (Figure 13).

Careful site selection ensured that reasonably undisturbed cores were acquired because like Estuary Park much of the underlying sediments remain intact. Two cores were retained for analysis and once opened in the laboratory it was decided to focus most attention on Core 1 for the chronology and use stratigraphy to cross-correlate with Core 2. Core 2 however was sampled for chemical analysis.

European and Maori arrivals were once again picked up in both cores using microfossil data. Core 1 contained a distinct charcoal layer, which unlike Estuary Park appears to be linked to a period of Maori occupation well before European arrival (Figure 14). The point in the core where Maori arrival is first noted however underlies a branch that has been radiocarbon dated to around 1550-1890 years BP (WK-19657, 1856±71 ^{14}C yr BP) (Table 1). The branch occurs within a fining-upward sequence that is similar to others reported above. The sequence is linked with a distinct peak in

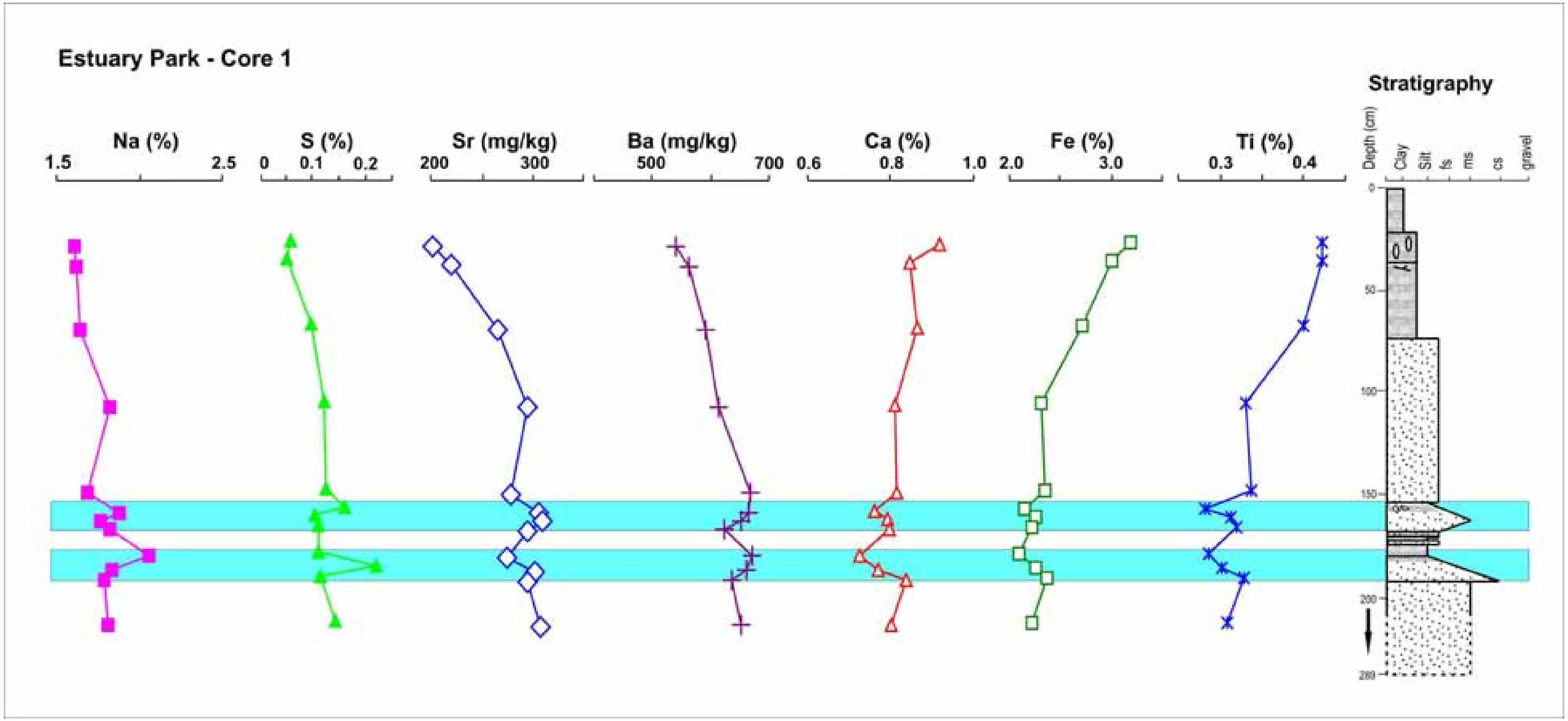

Figure 12: Estuary Park: Summary of Core 1 chemical data. Light blue boxes delimit sections of the core – and associated analytical results – that are interpreted as indicating evidence for tsunami inundation. See Figure 6 for legend.

Figure 13: Charlesworth Reserve: Site photo looking south – note overhead power lines.

marine diatoms and is tentatively interpreted as representing tsunami inundation. It is not present in Core 2 (Figure 15). The reasons for this tentative interpretation are three-fold:

i) It has appropriate sedimentary and diatom signatures.

ii) It is, like those found in the other cores studied for this project, a moderately unique event. No more than two similar sequences have been found in all cores. Given the relatively large historic record of large storms, one would expect to find numerous storm deposits throughout the core – one finds none because storms are rarely big enough to leave geologically significant deposits and while storm waters can penetrate inland great distances, deposits tend to be restricted to a narrow (10's of metres) band at the coast (e.g. Goff *et al.*, 2004).

iii) It correlates stratigraphically with similar sediments in the Brooklands Lagoon and South New Brighton Park cores. Chronologically it also appears to correlate with the other cores. The radiocarbon date of 1550-1890 years BP is from material incorporated in the deposit. It appears likely to be older material reworked by the tsunami. The radiocarbon date can therefore be discarded and the event can be correlated stratigraphically from three sites as occurring soon after Maori arrival.

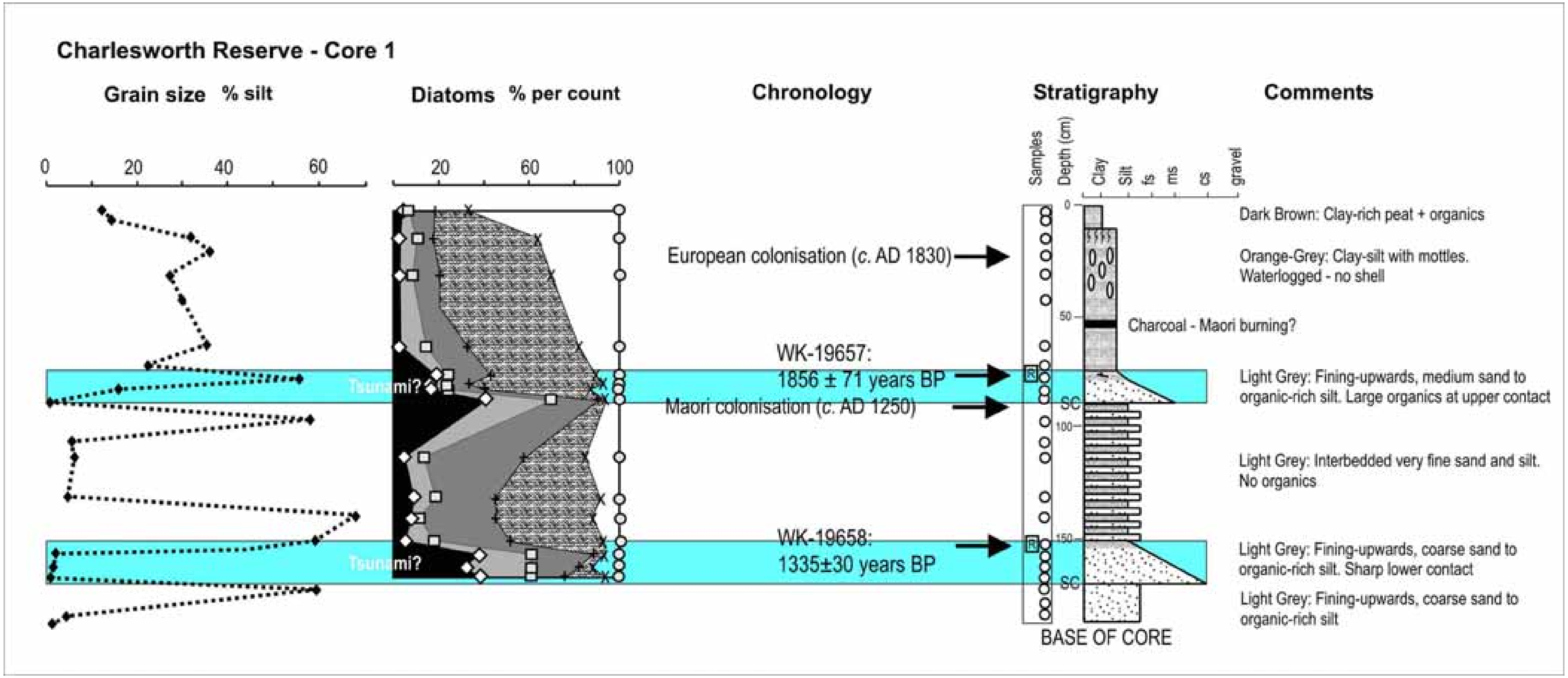

Figure 14: Charlesworth Reserve: Summary of Core 1 data including stratigraphy, sediment grain size, chronological information and diatom data. Light blue boxes delimit sections of the core – and associated analytical results – that are interpreted as indicating evidence for tsunami inundation. See Figure 6 for Legend.

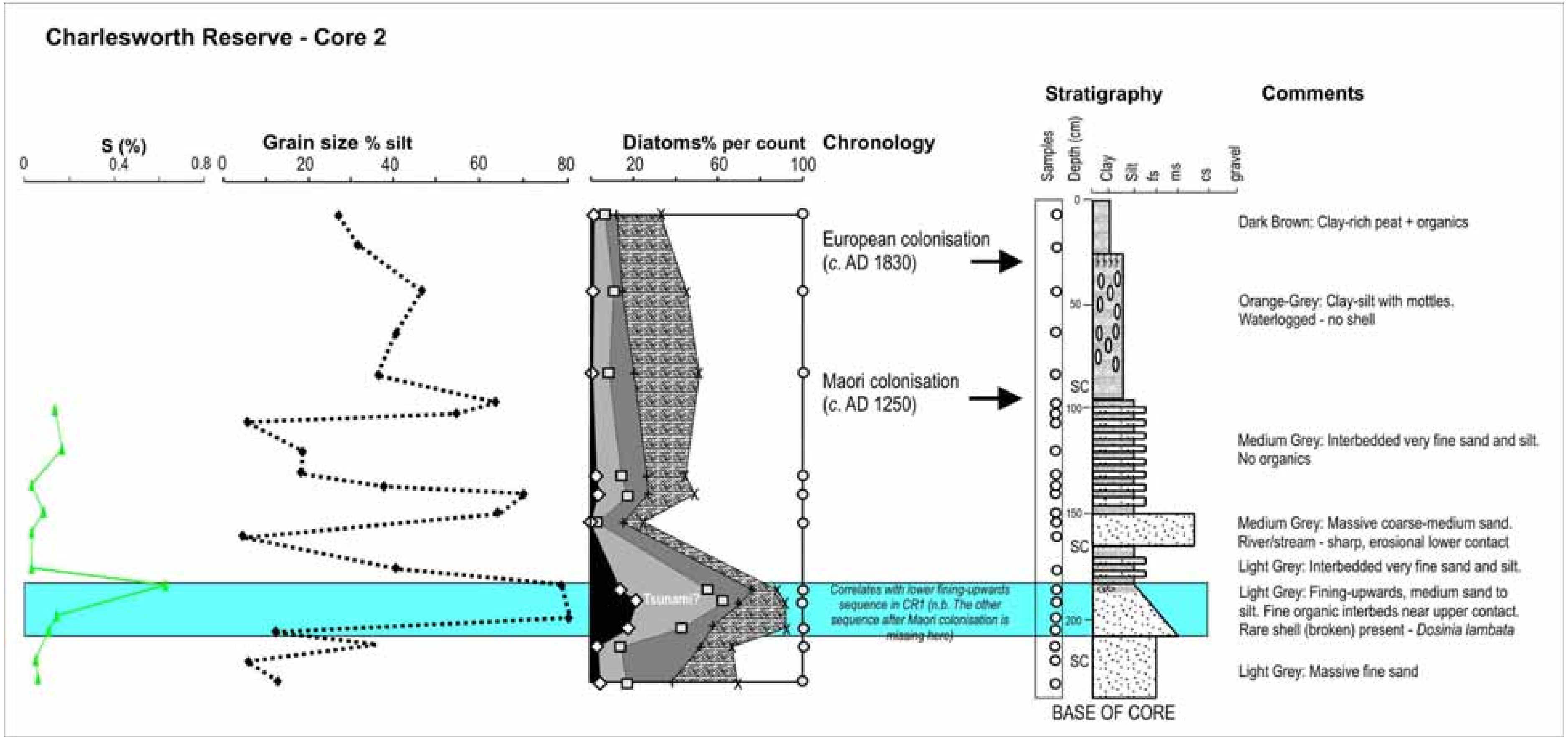

Figure 15: Charlesworth Reserve: Summary of Core 2 data including stratigraphy, sediment grain size, chronological information, diatoms, and chemical data. The light blue box delimits section of the core – and associated analytical results – that are interpreted as indicating evidence for tsunami inundation. See Figure 6 for Legend.

Further downcore, at 150 cm depth, another fining upwards sequence is apparent (Figure 14). It has similar sedimentary characteristics to the upper sequence and again it is marked by a peak in marine diatoms. Stratigraphically, we correlate this with a similar sequence in Core 2 (Figure 15). In Core 2 the sequence contains broken subtidal *Dosinia lambata* shells (see South New Brighton Park core – Section 3.4), and while some chemical data are equivocal there is a marked peak in sulphur content, which is indicative of saltwater inundation. It is more difficult to put a date on this event because of a lack of material for radiocarbon dating. Material well above the sequence dates to 1140-1300 years BP (WK-19658, 1335±30 ^{14}C yr BP) (Table 1, Figure 14). Given that this fining-upwards sequence occurs in both cores, and at some depth beneath the dated horizon in Core 1, it seems most likely that it closely approximates the upper event recorded in all Estuary Park cores (dated as older than 3140-3460 years BP, see Section 3.5).

4. Discussion

Cores taken from around the AHE(I) and two outlier locations have been analysed for evidence of tsunami inundation. Several possible tsunami deposits have been identified and need to be placed in the context of the development of AHE(I) and earlier work.

Goff and McFadgen (2004) identified a number of possible tsunami deposits around the AHE(I) area related to events over the past 6000 years or so. These are summarised in Table 2 with a summary of the findings of this report.

Table 2: Summary of inferred tsunami data for AHE(I) and the surrounding area (BL = Brooklands Lagoon, SBP = South Brighton Park, CR = Charlesworth reserve, EP = Estuary Park)

Evidence	**Approx. age** (cal years BP unless stated)	**This study** (core sites in brackets)
Environmental changes in Redcliffs area	2100-2400 to AD 1250-1300	c. AD 1300 - post Maori arrival **(BL, SNBP, CR1)**
Basal deposits in Bill's cave	3400-3700	Older than 3140-3460 **(CR1, CR2, EP1, EP2, EP3)**
Shell fragments in Bill's cave	4100-4400	Older than 3760-3800 **(EP1, EP3)**
Heathcote River deposits	5230-4830	
Heathcote River deposits	6460-6250	

There are several points to note:

i) The dating could be improved but as it stands there are no new events, those recorded in the sediment cores match with ones previously noted at other sites.

ii) In general terms, the absence of data does not mean that a tsunami did not inundate a particular area. In other words, the absence of evidence at Charlesworth Reserve for the oldest event could be because:

   (a) We did not retrieve sufficient core material.

   (b) The sedimentary record has been lost.

   (c) The tsunami was too small to leave a significant deposit.

   Most importantly it should be noted that Charlesworth Reserve was probably under shallow water at the time and the absence of a deposit compared with Estuary Park may simply be that the latter was possibly slightly more sheltered or closer to sea level. This also applies to the absence of evidence from South New Brighton Park – there was no spit at the time of the two earlier events (McFadgen and Goff, 2005) and this would have been deeper water than Charlesworth Reserve or Estuary Park.

(iii) Given that the c. AD 1300 event is recorded in Charlesworth reserve, the absence of evidence at Estuary Park has three possible explanations.

   (a) The tsunami was too small or did not inundate this area because the general geomorphological context for the Estuary Park site will have varied little since Maori arrival. It has generally been the landward side of some type of moderately sheltered coastal embayment over the past 500 years or so. The degree of development of the estuary is a moot point since this site would have been reasonably protected whatever the stage of spit development (cf. Goff and McFadgen, 2004; McFadgen and Goff, 2005).

   (b) The tsunami had a northern source and dissipated rapidly as it moved south leaving no marked evidence at Estuary Park.

   (c) The sedimentary record has been lost.

Five tsunamis have been identified (Table 2). These cover a period from about 6300 years BP to date. Coring was unable to penetrate to depths equivalent to 6300 years BP and we were therefore unable to add further to data from the Heathcote valley. This is not a particular concern given that all the sites would have been underwater and none would have been at or near sea level at that time. It is highly unlikely that a deposit would have been preserved under those circumstances.

The tsunami around 3500 yrs BP seems to have been rather more significant than originally suggested in Goff and McFadgen (2004). Their comments were based upon one record from the floor of Bill's Cave, but no evidence was found in the Heathcote valley. The answer to this is again most probably provided by one of the points raised above under Point ii. The event occurred around the time of the mid-Holocene highstand, when sealevel was around a metre or so higher. It is therefore not surprising that this event was rather more significant than originally suggested. Most interestingly, the immediate post Maori arrival event has become more ubiquitous. It is worth considering taking a study of this further by investigating the database of Maori oral traditions for the region.

A discussion would not be complete without consideration of potential sources. Ongoing work at NIWA to identify tsunami sources for the Christchurch area is providing little relevant data for this study. The historic record and modelling work give us some traditional sources such as South America (distant) and the Cook Strait/Kaikoura Canyon areas (regional/local). In reality though, these produce only small tsunamis, with waves possibly up to 2-3 metres high. The sedimentary evidence reported here is most probably related to larger waves. Our current state of knowledge means we are not aware of all possible sources and we are unable to speculate further. However, it is worth noting that all the events reported in this study would have inundated AHE(I) at a time when South New Brighton Spit was either not present, or offered only moderate protection to sites such as Estuary Park. This is important because it means that not only does the spit protect the landward shores of AHE(I) from tsunamis, but that a considerable amount of sedimentation has taken place in the area. This has fundamentally altered nearshore bathymetry and will have helped to reduce the size of incoming tsunami waves. In other words, the type of events we have recorded in the sediments in and around AHE(I) is unlikely to recur.

What we do not know therefore, beyond modelling, is the likely effect that the next tsunami will have on South New Brighton Spit.

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