Taihoro Nukurangi

Preliminary Core Study – Upper Lyttelton Harbour

NIWA Client Report: CHC2005-151
December 2005

NIWA Project: ENC06501

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Prepared for

Environment Canterbury

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Executive Summary

Environment Canterbury contracted NIWA to determine summary changes in sediment accumulation rates and possible sources of sediment for Upper Lyttelton Harbour over the past 400 years or so. Results from this “proof of concept” include:

- A decadal to sub-decadal chronology for some periods since European colonisation.
- Data collated from a suite of chronological techniques that when used together produce a rigorous, and cross-correlated, chronology.
- A multidisciplinary interpretation of environmental changes (anthropogenic and natural) based upon sediment characteristics, chemistry, micropalaeontology, and geochronology.
- Evidence of the influence of at least three natural events – tsunamis – on sedimentation in the Upper Harbour. A finer resolution would undoubtedly identify additional events including storms.
- Evidence for at least one large pulse of “clean” sediment from the upper catchments.
- Evidence for a catchment wide increase in the concentrations of potential contaminants (but not to a level of contamination). This reflects a general increase that would be represented in some locations as point sources of contamination.
- Indications of the linkages between the Upper, Central, and Lower harbour sediment systems.
- Evidence for a complex change in Sediment Accumulation Rates related primarily to European land clearance, and the rapid infilling of available accommodation space in the Upper Catchment.
- Indications that Maori (Polynesian) colonisation had little or no immediate effect upon sediment input into the catchment.
- Observations that Upper Harbour sub-catchments appear to show a range of responses to Upper, Central, and Lower Harbour sediment sources. Where local sediment input is high this appears to dominate the sedimentary environment. This has implications for recent and future developments of small, Upper Harbour catchments.

It is recommended that a more comprehensive, multi-year, high resolution study of the sedimentary environment of the Upper Harbour should be undertaken. This should only take place once specific objectives have been discussed with Environment Canterbury and community representatives

1. Introduction

Environment Canterbury contracted NIWA to determine summary changes in sediment accumulation rates and possible sources of sediment for Upper Lyttelton Harbour over the past 400 years or so. The scope and nature of the services included:

- Using existing cores taken from the Head of the Bay and Charteris Bay with additional fieldwork if required.

- Co-ordinating fieldwork and core analysis:
  - Undertake sediment grain size, chemical (nutrients and trace elements), micropalaeontological (diatom), and geochronological (^{14}C; ^{210}Pb, ^{137}Cs, pollen) analyses.
  - Undertake stratigraphic interpretation of cores and place analyses in the context of the sedimentary environment.

- Provide a written report to the Council on the outcomes of the investigation.

2. Sites investigated

This project used sediment cores taken from Upper Lyttelton Harbour in November 2004. One additional (not required as part of the contract) core was taken in September 2005 to augment the existing collection. All core sites are shown in Figure 1. Sites were chosen to provide an overview of the sedimentary environment of Upper Lyttelton Harbour as opposed to focussing on specific catchments. With this sampling regime in mind, cores were taken from the periphery of the Head of Bay catchment and from the more sheltered environment of eastern Charteris Bay.

3. Results

Initial core examination indicated that the most useful data could be obtained from sites at or near the existing land-water interface. More landward cores were retained for later use and reference if required. The stratigraphy of two cores was logged, one each from the Head of the Bay and Charteris Bay, and both were sub-sampled for sediment grain size and micropalaeontology. The longest, and most useful sedimentary record was preserved in the Head of the Bay core. This was the focus of a more detailed geochronological and chemical analysis.

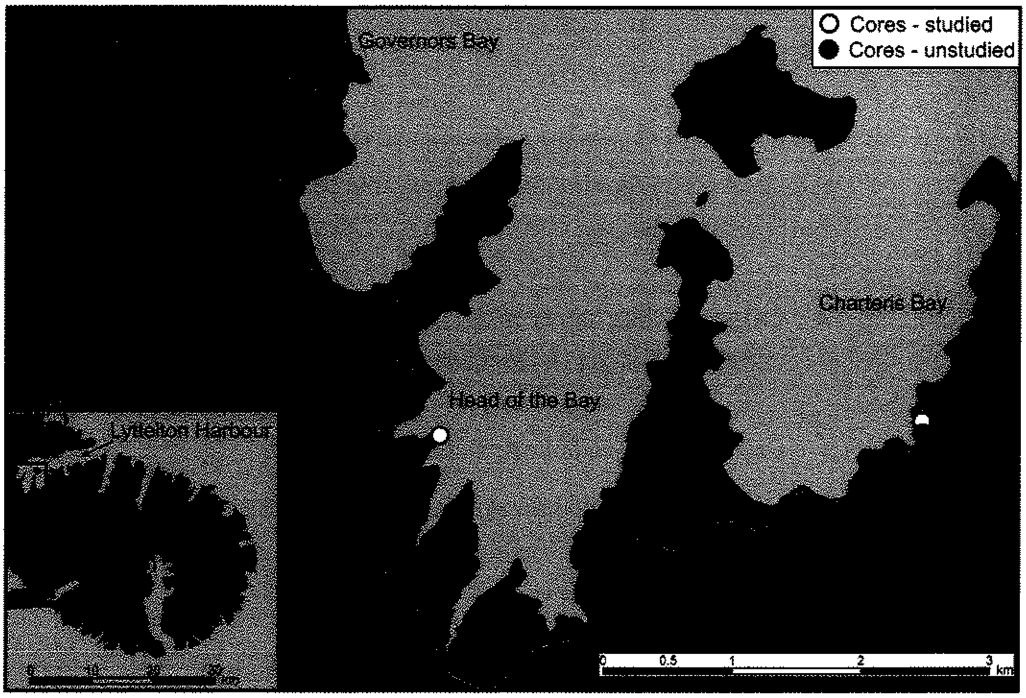

Figure 1: Upper Lyttelton Harbour: Location map of core sites

In summary, these analyses were chosen for the following reasons:

Stratigraphy/Sediment grain size: To give an indication of the changing sediment regimes – in this instance, one would expect changes in the sediment supply from the hills to be reflected in the changing sediment characteristics. 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.

Chemistry: Changes in the chemistry of the sediment will reflect differing sources and/or landuse. Chemical composition can, in the correct conditions, also act as an indication of European arrival – copper, lead or zinc for example often increase in concentration following European arrival. In conjunction with sediment characteristics it can help indicate sediment source areas.

Micropalaeontology: Pollen grains, spores and microscopic charcoal can all be used in great detail to chart landuse changes. In this instance however, pollen and spores have been used to identify two key time horizons – the arrival of Europeans (*Pinus* [pine] pollen and *Plantago lanceolata* [narrow-leaved plantain] are accepted marker horizons) and the arrival of Maori

(*Pteridium esculent* [bracken fern] and Anthocerotae [hornworts]) (e.g. Goff, 1997). While the intention of the project is to investigate changes over the past 400 years, we do not know where this date appears in the core and so we have to search for it using several techniques of which palynology is one.

European colonisation commenced in the early 19th century, but was fairly minor (with some exceptions) until large-scale immigration began mid-century. *Pinus pinaster* was naturalised in parts of New Zealand by the 1830's (Webb et al., 1988), and large-scale plantations of *Pinus*, mostly in the North Island, commenced in the first half of the 20th century. *Pinus* pollen is produced in great quantity and as such an early date of AD1830 for the first appearance in the sedimentary record has been adopted for this project. Polynesian/Maori colonisation is represented by forest disturbance and a proliferation of *Pteridium* spores in particular. The timing of this disturbance is usually in the area of 800-600 years Before Present (BP - AD1950 is the date used in this case). We use the oldest age of AD1250 to represent colonisation, although preservation in the sediment could be as late as AD1300. This work was undertaken by Microfossil Research of Auckland.

Diatoms can be used to interpret changing environmental conditions on land, at sea, and at the coast. They are single-celled plants (algae) that live in a range of conditions from saltwater to freshwater, from bottom dwelling to the water column to attached to plants. It was not the original intention to carry out diatom work for this project, but it was felt appropriate to undertake a limited study once the initial stratigraphic analysis had revealed several interesting units in each core. A study might also reveal environmental changes caused by variations in sediment supply.

Independent dating procedures: Radiocarbon dating – this can only be used on dead carbon (trees, shells etc.) and was be used to identify the older part of the core in order to fine-tune the analysis of the core to a time period of around the last 400 years. Lead-210 (^{210}Pb) and Caesium-137 (^{137}Cs) - Lead-210 can provide a fairly detailed indication of dates from sediment samples going back over about 150-200 years. Caesium-137 on the other hand gives the last 50-60 years and serves to cross correlate with Lead-210 over this time period (e.g. Goff *et al.,* 1998).

A reasonably detailed chronology of sediment accumulation and changing environmental conditions was achieved through a combination of ^{210}Pb, ^{137}Cs, ^{14}C, micropalaeontology, stratigraphy and sediment grain size. Results are shown in Table 1 and Figures 2-6. These are interpreted and discussed in the following section.

Table 1: Radiocarbon data for samples from Head of the Bay core

Laboratory No.[a]	CRA[b] (^{14}C yr BP)	$\Delta^{13}C$ (ppm)	(95%) Calibrated age range[c] (cal. yr BP)	Depth (m)	Material dated	Significance
WK-17477	1439±53	0.7±0.2	1140-890	0.16	Cockle (*Austrovenus stutchburyi*)	Uppermost shell in core
WK-17478	4336±52	0.3±0.2	4680-4310	3.42	Cockle - broken	Near base of core

[a]WK = University of Waikato radiocarbon laboratory
[b]Conventional Radiocarbon Age (Stuiver and Polach, 1977).
[c]Calibration data for marine shells from Stuiver and Braziunas (1993)

4. Discussion

Data from two cores form the basis for the discussion below. These cores were only studied in detail however, after an initial stratigraphic analysis of all available material. Of the two cores, the Head of the Bay (HOB) core provided the most comprehensive record of environmental changes over the past 400 years or more. Data from the Charteris Bay (CB) core however will be used to corroborate the findings. Cores were chosen as being representative of general Sediment Accumulation Rates (SARs) for the upper harbour and the discussion should be considered in this light. This point is discussed later.

One of the primary aims of this work was to ascertain whether a reasonable chronology could be achieved from sediment cores in Lyttelton Harbour. This is crucial to any further work that might be undertaken. We balanced the need for a detailed chronological record with that of determining which techniques can be applied to the sediments. In this context, the results discussed below are excellent.

4.1. Chronology

Radiocarbon dating is a fairly standard technique but as such it has also been widely misused, and results misinterpreted. We have two radiocarbon ages (Table 1). The older age, from a shell situated in relatively undisturbed estuarine sediments, provides a reliable maximum age for the HOB core (Figure 2). The younger age however comes from a shell lying on top of a coarse sediment layer subsequently identified as having been laid down by the 1960 tsunami. This shell has been reworked and while helping to identify tsunami inundation does not provide any useful chronological

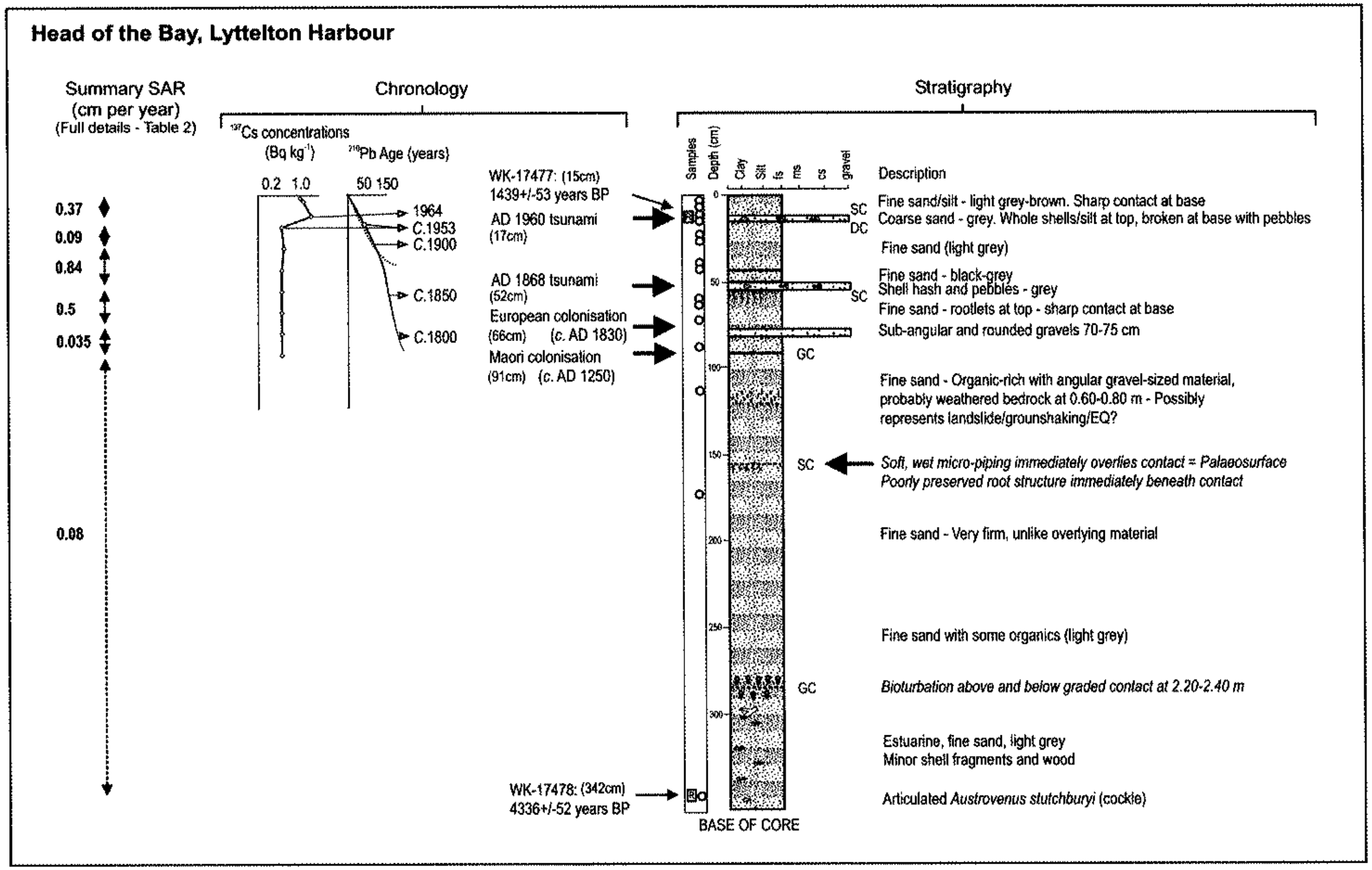

Figure 2: Head of the Bay: Stratigraphy, chronology and summary Sediment Accumulation Rates (SARs). The chronology comprises a combination of ^{14}C, ^{210}Pb, ^{137}Cs, pollen and spores, and stratigraphic interpretation aided by diatom data (see Figure 3). Summary SARs are discussed below (where required, the mid-point of the calibrated ^{14}C age range shown in Table 1 has been used to calculate the SAR). GC = gradational contact, SC = sharp contact, DC = deformed contact; the contact being the transition from one sediment unit to another)

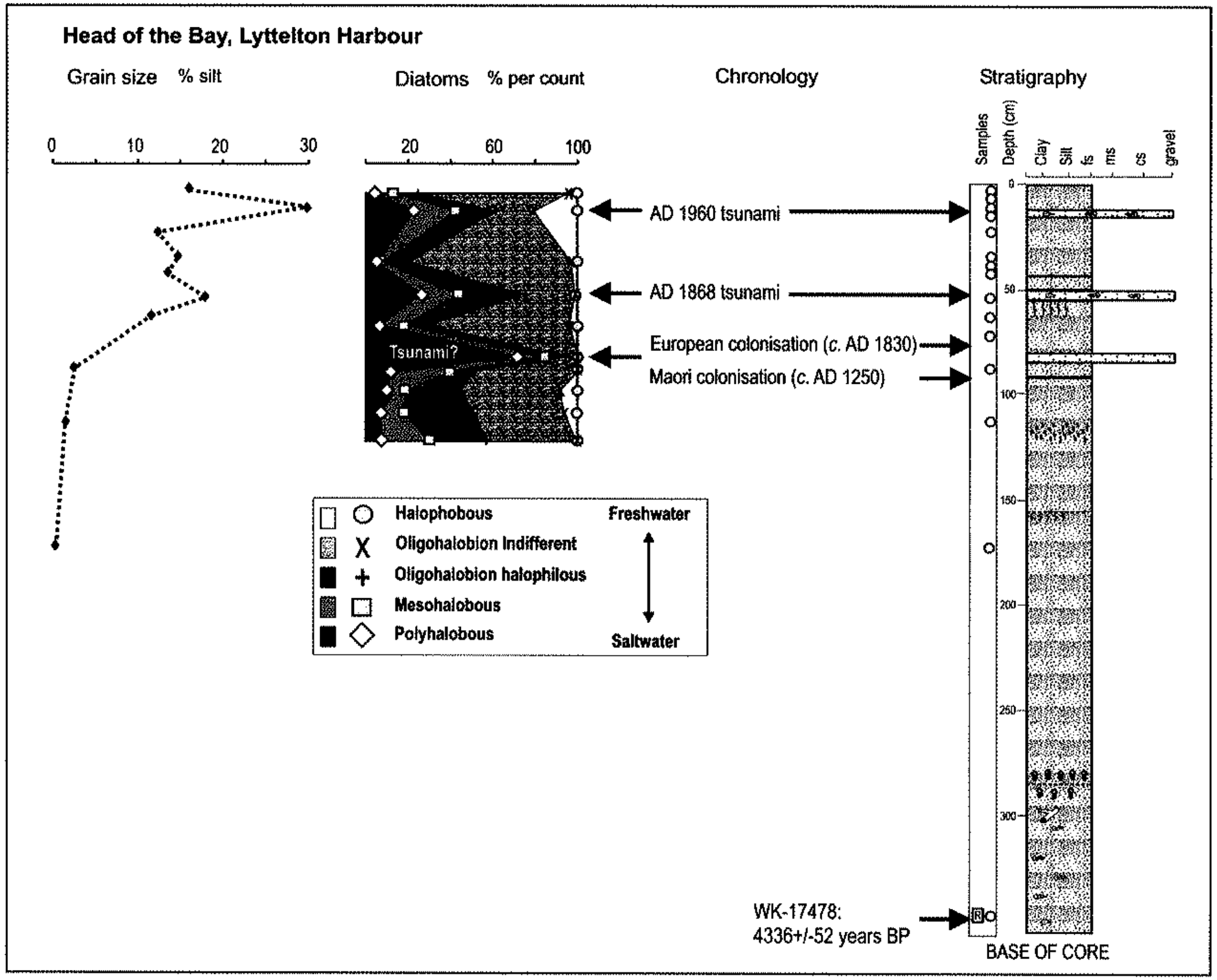

Figure 3: **Head of the Bay: Summary stratigraphy and chronology with sediment grain size and diatom data. Sediment grain size and diatom data are discussed below.**

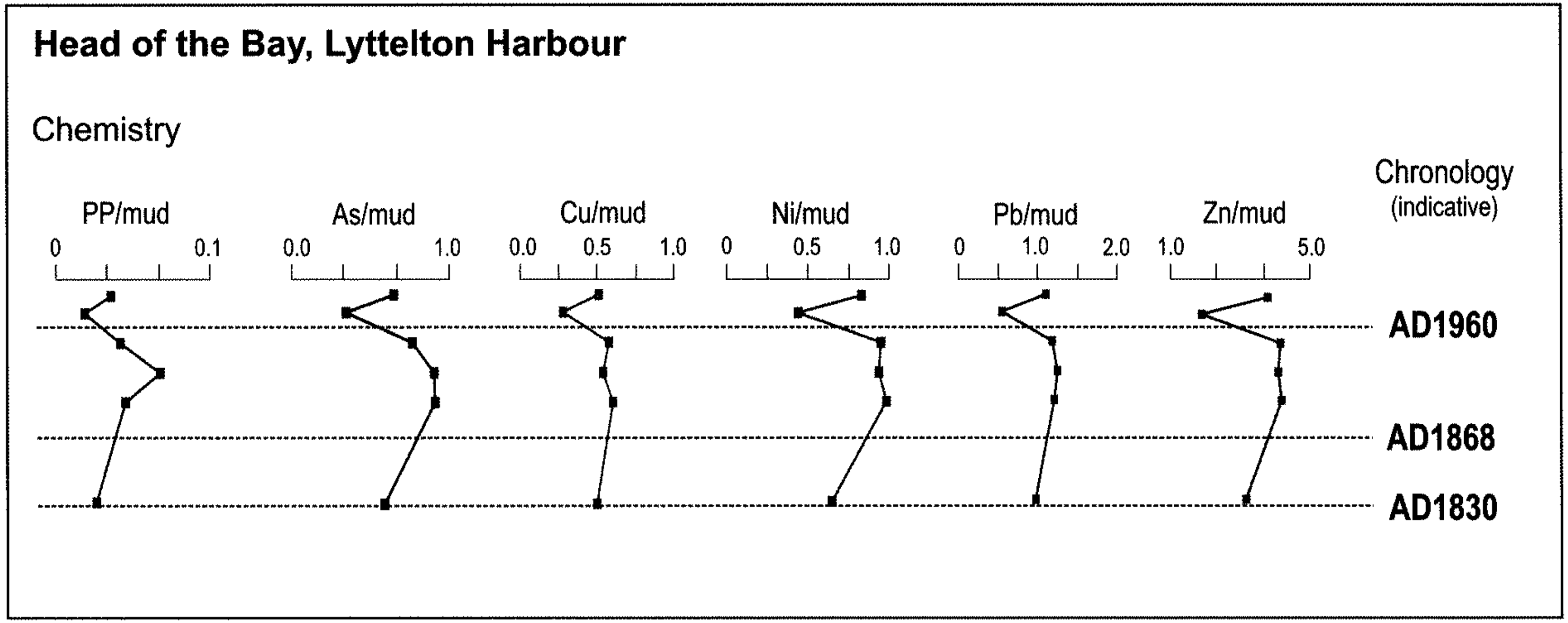

Figure 4: Head of the Bay: Summary chemical data for nutrients and trace elements (PP – Phosphorus, As – arsenic, Cu – copper, Ni – nickel, Pb – lead, Zn – zinc) shown against an indicative chronology for recent sediments. Data have been normalised to mud (less than 63 microns) content. Concentrations (on a dry weight basis) are low – up to 880 µg/g PP, 7.7 µg/g As, 8.9 µg/g Cu, 17.3 µg/g Ni, 20.8 µg/g Pb, and 7.7 µg/g Zn (1 µg/g = 1 part per million)

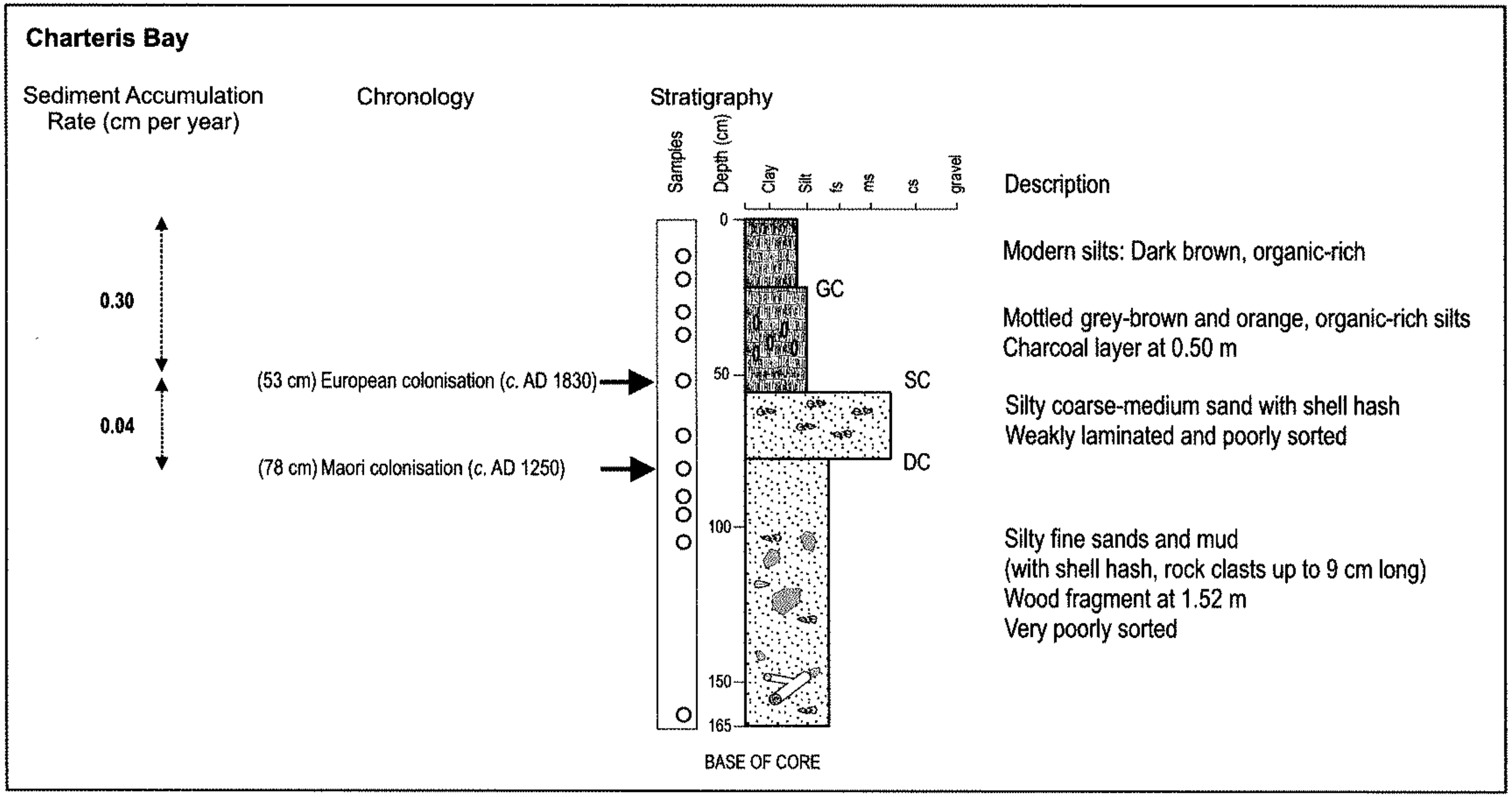

Figure 5: **Charteris Bay: Stratigraphy, chronology and summary Sediment Accumulation Rates (SARs). The chronology is based upon pollen and spores. Summary SARs are discussed below.**

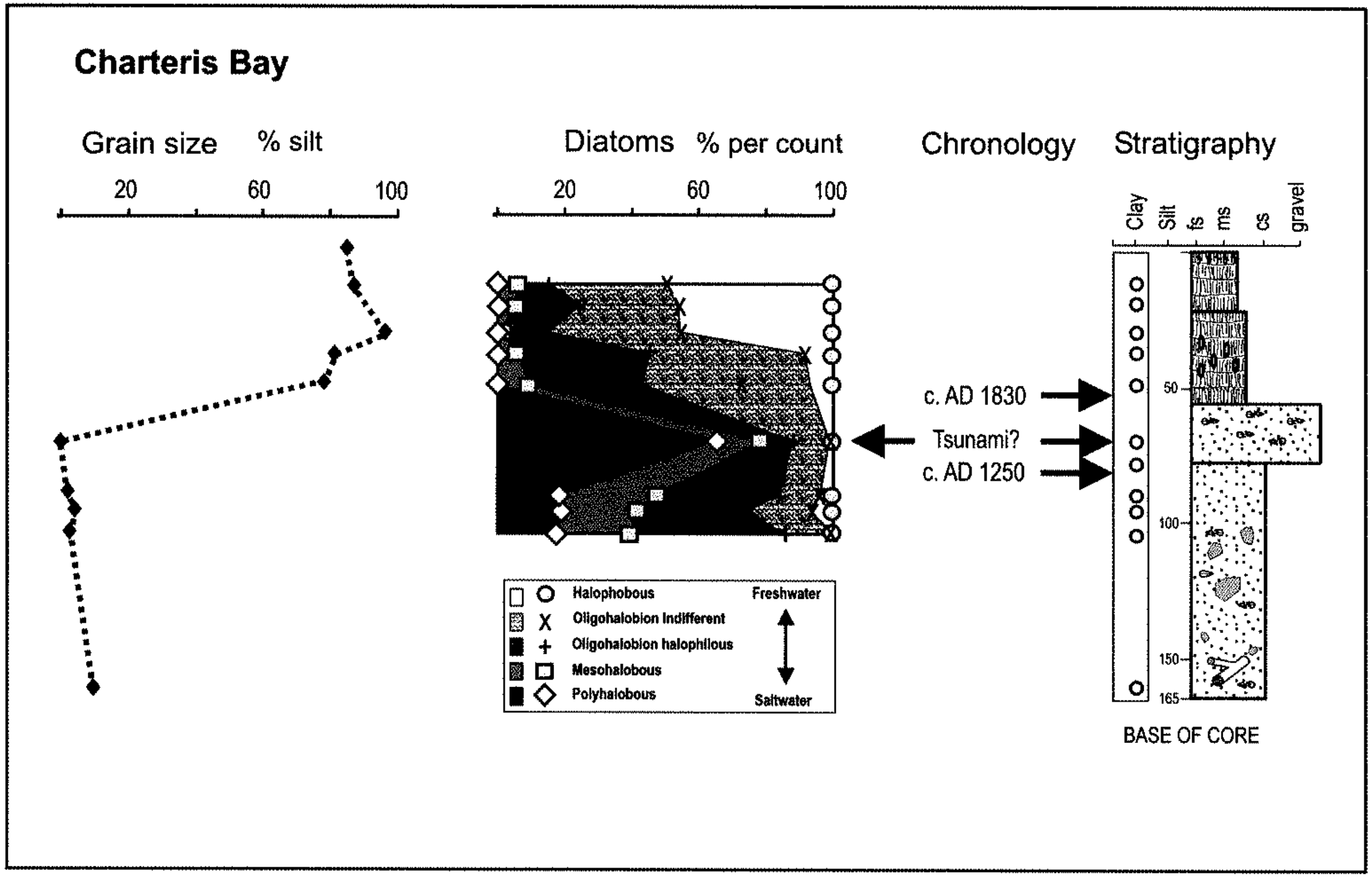

Figure 6: **Charteris Bay: Summary stratigraphy and chronology with sediment grain size and diatom data. Sediment grain size and diatom data are discussed below.**

information. ^{210}Pb and ^{137}Cs analyses are complementary (Figure 2). They both provide similar dates for the past 50 years of sedimentation in the upper harbour. This is useful for calculating SARs, and also indicates that the 1960 tsunami was depositional as opposed to erosional in the upper harbour. If erosion had taken place, the records would have been disturbed. ^{210}Pb extends down the core to around AD1800, a position that correlates with both the pollen and spore information (European colonisation = AD1830 and Maori colonisation = AD1250) (Figure 2). Stratigraphically this information concurs with the identification of two additional tsunami deposits, the AD1868, and another one believed to have occurred in the region around the 15th century, some time after Maori colonisation (McFadgen and Goff, 2005). This tsunami is indicated in Figure 3 as a peak in marine-based diatoms and a complex sediment layer in the core (additional criteria should be used for a more definitive interpretation, but we feel confident in our interpretation given the preservation of the deposit in the adjacent Avon-Heathcote catchment – refer to McFadgen and Goff, 2005).

4.2. Sediment Accumulation Rates, natural and human influences

Combining all the chronological information allows us to calculate SARs for the Head of the Bay Core. We corroborate these findings with data from the CB core. The chronology of the CB core however is rudimentary and based solely on pollen and spore data. The relative positions of European and Maori colonisation based upon pollen and spore data in the CB core appear to be reliable because they bracket what we have interpreted as the 15th century tsunami (this is identified solely by sedimentary characteristics and diatoms)(Figures 5 and 6).

Table 2 details the SARs calculated using the comprehensive chronological dataset for the HOB core. SAR data for the CB core are shown in Figure 5.

The SAR from the base of the core to Maori colonisation is low and decreases immediately afterwards. This decrease is unexpected and probably reflects erosion at the site as a result of the 15th century tsunami. This tsunami was considerably larger than both the AD1868 and AD1960 events (refer to McFadgen and Goff, 2005). The SAR at Charteris Bay is similar, suggesting that either the SAR did indeed decrease or that the tsunami caused similar erosion at both sites. The latter seems to be the most likely explanation.

There is some evidence for a possible signal of European colonisation and/or more extensive land clearance in the catchment, prior to AD1830 (Table 2). The SAR shows a marked increase over this time period presumably as a result of sediment runoff from the surrounding hills. This is not surprising since a European influence through sealing and whaling was moderately ubiquitous throughout New Zealand in the early 1800's. Chemical data are equivocal with low background levels prior to AD1830 (Figure 4). SARs continue to accelerate through the 1800's, reaching a peak of around 0.85 cm per year between 1868 and 1900. This is matched by a raised level of trace elements indicative of European colonisation such as zinc, lead, nickel and copper (Figure 4). It should be noted though that not surprisingly with a predominantly rural catchment, Upper Harbour sediments have relatively low levels of trace elements up to the present day.

Table 2: **Head of the Bay Core – Sediment Accumulation Rates in cm/yr. See Figure 2 for summary data *(SAR based upon radiocarbon age at base of core is calculated assuming a mid-point of 4495 cal yr BP – Table 1)*. The ^{14}C sample taken at 16cm has been ignored. In the SAR column, the rate on any one line relates to the amount of sediment accumulated in the time between the estimated age in the adjacent cell and the estimated age in the cell immediately beneath. Depths (cm) are the mid-point of the sediment thickness used for dating analysis (e.g. ^{14}C sample at 342 cm depth was a piece of wood taken from = 341-343 cm) and as a result SARs may vary by +/- ~10%.**

Depth (cm)	Dating method	Estimated age	SAR (cm/yr)	Comments
0	None	2005	0.37	Less accommodation space?
15	^{137}Cs	1964	0.5	
17	Sedimentology	1960	0.43	
20	$^{137}Cs/^{210}Pb$	1953	0.09	Marked decline – hiatus in development?
25	^{210}Pb	1900	0.84	
52	Sedimentology	1868	0.5	
60	^{210}Pb	1850	0.3	
66	Pollen	1830	0.2	European influence prior to pollen signal?
72	^{210}Pb	1800	0.035	Loss sediment due to tsunami inundation?
91	Pollen	1250	0.08	
342	^{14}C	4495 BP		

A marked decrease in SARs is recorded between 1900 and 1953. This is unlikely to be a function of imprecise chronological data and may signal a hiatus in development or land clearance, with the majority of the upper catchment being under a moderately stable landuse regime. Hart (2004), based on Curtis (1985), indicated that from 1903-1951 a large amount of accretion occurred at the harbour head and entrance, while a small degree of scour occurred in the central section. The correlation in dates indicates that this scour or absence of deposition may well have extended into the Upper Harbour.

From 1953 to the present day SARs have once more increased and have been sustained at levels similar to those experienced during the early stages of European colonisation. The noticeable decline in recent years in less a factor of a "real" decline in SARs, but rather it is the result of a decrease in the available accommodation space in the vicinity of the core. In other words, there is little room left for sediment to accumulate because the area around the HOB core site has been filled in.

The inference that there has been a marked reduction in accommodation space is borne out by the changing diatom assemblages at both core sites. Both cores were taken in an estuarine environment, influenced by both terrestrial and marine processes. There has been an increasing freshwater influence however in the upper part of both cores (Figures 3 and 6) reflecting this change. Prior to this the diatom assemblage has shown no response to anthropogenic influences such as contamination confirming the chemical record of low levels of potential contaminants (Figures 3, 4, and 6). The assemblage has however responded markedly to sudden, catastrophic natural events such as tsunamis. Similarly, elemental (chemical) concentrations in post 1960 sediments show a distinct decrease (Figure 4). In this case, however this is not as a result of tsunami inundation but rather it is most likely to have been caused by a significant pulse of relatively "clean" sediment that has little or no raised levels of trace elements and nutrients. Sediment sources could include; i) older sediments within the upper catchments that lie beneath the farmed soils or, ii) deep harbour sediments exposed during channel dredging operations. First, dredged harbour sediments could have been deposited at the site following increased storm activity and changes in the location of dumping ground (Hart, 2004). Second, a period of increased sedimentation and runoff from the catchment could have introduced relatively "clean", unfarmed material into the area. This latter event would normally be associated with the start of urban development in the area or changes in landuse practices such as land clearance for forestry (e.g. Goff, 1997). In this instance, the timing of the pulse closely approximates the occurrence of the Wahine Storm (10th April 1968) that caused a significant number of landslides on the surrounding hills. The second source is therefore the most likely because the dumping site for dredged sediments was moved further north and east from about 1969 onwards (Hart, 2004) and would have been less likely to contribute a marked pulse of material to the sediment budget at the core site.

As suggested, limited data from the CB core indicate that the area has slightly lower SARs, but it corroborates the overall record from the HOB core of a sustained, and order of magnitude, increase in SARs since European colonisation.

In general terms the Upper Harbour appears to be controlled by more immediate (proximal) sediment sources than the rest of the harbour. Extended periods of scour or accretion noted by Curtis (1985) in the central and lower sections do not necessarily correlate as expected. The hiatus between 1900 and 1953 correlates well, as do large amounts of accretion between 1953 and 1964 (Curtis' period was 1951-1976), but rapid sediment accumulation is found between 1850 and 1900, as opposed to an apparent period of scouring between 1849 and 1903 reported by Curtis (1985).

This variability in SARs at the head of the harbour is not entirely unexpected, although it was hoped to negate this through the choice of core sites. It is probable that the smaller CB catchment offers a better reflection of the average rates during this time period and this might warrant further investigation. The HOB core is on the periphery of a large catchment that supplied large quantities of sediment to the Upper Harbour during the period from 1850-1900. It is possible that scouring in Governors Bay, noted by Curtis (1985), was indicative of local conditions brought about by changes to the sediment transport regime at the start of harbour dredging in 1876. This provides some indication of the responses of individual bays to changing sediment dynamics within the harbour. It is worth considering dividing the Upper Harbour into three distinct areas, the southwestern (e.g. Head of the Bay), southern catchments (e.g. Charteris Bay), and northwestern (e.g. Governors Bay) sub-catchments.

On average, an estimated 44 300 t a^{-1} of loess and loess colluvium is eroded from the Lyttelton Harbour catchment (Curtis 1985). Much of this is deposited within the Upper Harbour through the HOB system. These sediment sources play a major role in maintaining high levels of SARs generally within the harbour, and in locations such as CB. More open sites such as the HOB are also exposed to storm wave transport of sediments from the Central and Lower Harbour sites (Hart, 2004).

5. Summary

A preliminary core study of the Upper Harbour has shown that detailed information can be gathered on the chronology of sedimentary change. The information gathered was the result of a coarse sampling resolution used as a "proof of concept" for future possible work and includes:

- A decadal to sub-decadal chronology for some periods since European colonisation.

- Collated data from a suite of chronological techniques that when used together produced a rigorous, and cross-correlated, chronology.

- A multidisciplinary interpretation of environmental changes (anthropogenic and natural) based upon sediment characteristics, chemistry, micropalaeontology, and geochronology.

- Evidence of the influence of at least three natural events – tsunamis – on sedimentation in the Upper Harbour. A finer resolution would undoubtedly identify additional events including storms.

- Evidence for at least one large pulse of "clean" sediment from the upper catchments.

- Evidence for a catchment wide increase in the concentrations of potential contaminants (but not to a level of contamination). This reflects a general increase that would be represented in some locations as point sources of contamination.

- Indications of the linkages between the Upper, Central, and Lower harbour sediment systems.

- Evidence for a complex change in Sediment Accumulation Rates related primarily to European land clearance, and the rapid infilling of available accommodation space in the Upper Catchment.

- Indications that Maori (Polynesian) colonisation had little or no immediate effect upon sediment input into the catchment.

- Observations that Upper Harbour sub-catchments appear to show a range of responses to Upper, Central, and Lower Harbour sediment sources. Where local sediment input is high this appears to dominate the sedimentary environment. This has implications for recent and future developments of small, Upper Harbour catchments.

6. References

Curtis, R.J. (1985) Sedimentation in a rock-walled inlet, Lyttelton Harbour, New Zealand. Unpublished PhD Thesis, Department of Geography, University of Canterbury.

Goff, J.R. (1997) A Chronology of Natural and Anthropogenic Influences on Coastal Sedimentation, New Zealand. *Marine Geology*, 138, 105-117.

Goff, J.R. Dunbar, G.B. and Barrett, P.J. (1998) Monthly to decadal sediment accumulation rates in a semi-enclosed embayment. *Journal of Coastal Research* 14, 461-471.

Hart D E, (2004) *Sedimentation in the upper Lyttelton Harbour*, Unpublished report to Environment Canterbury, 22pp.

McFadgen, B.G. and Goff, J.R. (2005) An earth systems approach to understanding the tectonic and cultural landscapes of linked marine embayments: Avon-Heathcote Estuary (Ihutai) and Lake Ellesmere (Waihora), New Zealand. Journal of *Quaternary Science*, 20, 227-237.

Stuiver, M. and Braziunas, T.F. (1993) Modelling atmospheric ^{14}C influences and ^{14}C ages of marine samples to 10,000 BC. *Radiocarbon,* 35, 137-189.

Stuiver, M. and Polach, H.A. (1977) Discussion: reporting of 14C data. *Radiocarbon*, 19, 355–363.

Webb, C.J., Sykes, W.R. and Garnock-Jones, P.J. (1988) *Flora of New Zealand. Volume IV.* DSIR, Christchurch.