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Tsunami Hazard for the Bay of Plenty and Eastern Coromandel Peninsula : Stage 1

Prepared by:
GeoEnvironmental Consultants In association with
Dr Scott Nichol (University of Waikato)

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

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Approved by:

James Goff, PhD

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Executive Summary

This report details the results of Stage One of a tsunami study of several key sites identified in an earlier reconnaissance of the Bay of Plenty. Five broad chronological periods of potential activity were identified. These are:

A) Post-Kaharoa (c. 500-600 yrs BP) - probably related to submarine volcanic activity.
B) Kaharoa (c. 750 yrs BP) - immediate post-eruption.
C) Pre-Kaharoa/Post-Taupo (c. 800-1800 yrs BP) – most probably associated with significant amounts of coastal subsidence, possibly as a result of large, subduction earthquakes to the east.
D) Taupo (c. 1850 yrs BP) - immediate post-eruption.
E) Pre-Taupo: (i) Waimahia (c. 3200 yrs BP)? (ii) Whakatane (c. 4800 yrs BP)? groundshaking (and local subsidence?) – the dating is currently somewhat arbitrary but these events relate to one or both of known sub-aerial volcanic eruptions and/or large, subduction earthquakes to the east, and/or local seismic sources.

A tentatively tsunami magnitude (high to low) hierarchy is suggested based on the limited data obtained to date: Event C, A, E(i), D/B, E(ii). The relative significance of the Taupo eruption (D) is difficult to estimate because of the sheer magnitude of the event and the resultant surfeit of tephra in the nearshore zone. However, from the perspective of the greater hazard, tsunami inundation in this instance seems to be less of a concern. There are currently too few data to be able to estimate magnitude and frequency with any reliability, but there would seem to be about six large (unknown magnitude at present) events in the last 5000 years or so. It is important to note though that the absence of visible deposits does not mean the absence of events. BUT the presence of high magnitude (>5m), low frequency events is a good indicator of the occurrence of many lower magnitude, higher frequency ones.

Three recommendations for possible additional work are highlighted as a result of the work to date:

- A detailed, site-specific analysis is needed of the Korapuke site.
- Other islands in the Mercury group such as Red Mercury, Ohinau, Motukoruenga, Double and Stanley should be visited.
- A detailed, high-resolution study of the Ohiwa Harbour, Jacobs Creek core is recommended. A Masters student project should be considered.

1 Introduction

Environment Bay of Plenty (EBOP) and Environment Waikato (EW) contracted GeoEnvironmental Consultants to undertake Stage 1 of the Joint Tsunami Research Project. This is a palaeotsunami investigation for the Bay of Plenty.

Palaeotsunami investigation work was to be undertaken between October 2002 and March 2003. Fieldwork was to involve a study of a maximum of four mainland sites and no fewer than three. These sites were to include Otama Beach, Waihi Beach, and Waiotahi estuary, and additional sites chosen during fieldwork. The necessary permissions or approvals (e.g. DOC permits, Consents) were the responsibility of the appropriate Regional Council. Details of the work to be undertaken were:

a) A maximum of FIVE cores will be taken from each wetland site using a vibracorer. These will be taken in a transect or transects pertinent to the site-specific geomorphology.
b) Where appropriate, site surveys and Ground Penetrating Radar will be used to augment core data and to tie in any associated surficial (surface) deposits of relevance to this study with core sites.
c) A reconnaissance AND coring (possibly hand coring only, although the option to vibracore will be retained) survey of selected islands will be undertaken. This work is dependent upon permissions and logistics organised by the relevant Regional Council but as a minimum it is suggested that the islands of Slipper, Great Mercury and Koropuki be examined. The exact regime will be determined at the time of reconnaissance and could include but not be limited to:
    i Vibracoring of sites on each island - up to three cores from each site.
    ii Hand augering of sites and collection of material for analysis.
    iii Studies of surficial deposits and possible surveying and GPR of key locations.
    iv Study of near-surface deposits by shallow trench.

Fieldwork was to commence during October with subsequent laboratory analysis continuing into 2003.

Cores were to be returned to the laboratory for opening, logging, and further examination. One core from each site was to be studied in detail, with analyses to include all or some of, radiocarbon dating, sedimentological, geochemical, micro- and macro-palaeontological investigations. Much of the laboratory analysis is to be undertaken in Year Two, but the aim was to obtain initial dating control using radiocarbon dates in Year One.

This report represents the output required by the two Regional Councils. It details the fieldwork undertaken and the preliminary results of laboratory analyses and interpretations. The report includes relevant data from a Preliminary Study of the Tsunami Record on Coromandel East Coast undertaken in mid-2002, and an Ancillary Tsunami Project completed in December 2002.

1.1 Caveat

This report is written on the basis of the contemporary scientific knowledge about tsunamis and tsunami hazards. Every attempt has been made to provide as comprehensive an interpretation of available data as possible, although there is always the possibility that some data have been missed. In many instances much of the interpretation is based upon professional intellectual property and as such this type of information cannot be referenced. Studies of tsunamis indicate that the effects along a coastline are extremely variable. Therefore, where necessary, a general approach has been adopted acknowledging that, for example, while runup height is controlled by many variables, a general runup is chosen based upon known site-specific conditions.

2 Context

2.1 Summary of related work

The results of two recent pieces of work relevant to Stage 1 are summarised below, these are the "Preliminary study of tsunami record on Coromandel East Coast" undertaken for both EBOP and EW, and the "Ancillary Tsunami Project" carried out for EBOP.

The former report preceded part of Stage 1 by investigating possible sites for further work along the BOP West Coast/Coromandel East Coast and the following summary information was produced:

> *Based upon the findings of this study, it is suggested that there are three main areas for immediate future palaeotsunami studies:*
>
> *Sediment coring and surficial sediment studies of Waikawau Bay and **Otama Beach** areas.*
> *Sediment coring at Whiritoa and **Waihi Beach**.*
> *A reconnaissance with possible sediment coring and surficial sediment studies of the **Mercury Islands** and Slipper Island.*
>
> *Bearing in mind the rapid urban development of many of the eastern Coromandel beaches and the inevitable loss of sedimentary evidence is it suggested that consideration be given to the proposal that either prior to an application for coastal development (e.g. residential, industrial) or as a condition on a resource consent, specific requirements be laid down to ensure that the physical evidence (sediments) of past coastal hazards be properly investigated. Depending upon the nature of the coastal site, such conditions may require coring or trenching to investigate the area. Such conditions are immensely valuable since they serve to provide hazard information that would otherwise be unavailable. Furthermore, if construction proceeds, any physical evidence at any particular site will be destroyed forever.*

The highlighted names represent sites from the western BOP that were investigated during Stage 1. It should be noted that while Slipper Island is mentioned in the contract brief, time and logistical constraints prohibited any visit to the island. Not all the sites listed above were investigated in detail, and there were also several other locations that while appearing less suitable for research do actually offer future opportunities for study. The full site list is given in Table 1. These are pertinent because the final paragraph in the statement above raises the crucial issue of loss of evidence caused by ongoing urban development. This Stage 1 report does find evidence for past tsunami inundation and this evidence can only be supplemented with data from relatively undisturbed coastal sites.

The second report focuses specifically on the Tauranga-Maketu area with particular reference to identifying the causes and timing for known deposits of fallen trees. The results are summarises as follows:

> *A study of possible tsunami inundation in the western Bay of Plenty was undertaken following the recent discovery of fallen trees, all apparently lying in the same direction in the Kopurereroa Stream area. The apparent similarity of the trees with another site in the Maketu area suggested a region-wide catastrophic event, possibly a tsunami. Accordingly, to investigate the possibility of such an event,*

trenches were dug to examine the geological stratigraphy at several locations including Maniatutu Road, Poplar Road, Hopping Farm, Bell Road, the Hickson Property and Parton Road.

As many as seven ***possibly catastrophic events*** *were identified, three of which appear to represent periods of forest destruction:*

Post-Kaharoa volcanic eruption (Event A) – groundshaking, probably associated with other seismic-related events.
Pre-Kaharoa-post-Taupo eruption (Event B) – groundshaking, probably associated with tsunami inundation near the coast (as shown by Ohiwa Harbour to the east).
Pre-Taupo eruption (Event E) – groundshaking, localised forest destruction in the Wairoa River valley, probably caused by compaction or subsidence of valley sediments. This event appears to be associated with others caused by compaction, subsidence, or tsunami inundation elsewhere in the Tauranga-Maketu area.

While these events seem to have been relatively widespread, only Event B appears to have been region-wide. Events A and E appear to have been more localised than Event B. Recent research indicates that submarine volcanoes are more numerous than previously reported and events during the last 500-600 years provide strong evidence for widespread tsunami inundation. The volcanoes, known submarine faults, known large subduction earthquake, and near-surface volcanoes, indicate a high likelihood of tsunami inundation.

A key point of this study is that the resolution used is only capable of identifying tsunami events larger than about 5m. ***It is therefore important to note that the absence of visible deposits does not mean the absence of events.***

Catastrophic tsunamis between 1 and 5m can only be identified through high-resolution analyses using micropalaeontology and geochemistry. While this can be undertaken at the locations studied, there is a relative paucity of useful sites close to the immediate shoreline because of on-going coastal development. A possible solution would be to study a sheltered, offshore sedimentary environment for data concerning past tsunami inundations.

Once again, the summary identified the paucity of "good" coastal sites, but it also raises the possibility of considering the offshore environment. With respect to possible tsunamigenic events, the report identifies three main time periods, identified with reference to known tephras found at the sites, Pre-Taupo (pre *c*1800 years BP), Pre-Kaharoa –Post-Taupo (*c*800-1800 years BP), and Post-Kaharoa (post *c*750 years BP). The tephras provide important chronological markers in the coastal sediments of the area, data that can be supplemented with calibrated radiocarbon dates.

The important point of the size of a catastrophic tsunami is raised in the summary. While there are some scientific debates associated with the interpretation of what constitutes the "height" of a tsunami, it should be understood that a tsunami of 1m should be considered catastrophic although it will most likely not leave any visible sedimentary evidence. Tsunamis of 5m or more seems to be the general "Rule of Thumb" at present for leaving visible deposits. However, it may be possible to use some of the evidence from more inland sites studied in the Ancillary Report to supplement data from Stage 1. With this in mind, Table 2 details the evidence for the seven possibly catastrophic events reported in the Ancillary Tsunami Report.

2.2 General tsunami information

In order to provide a somewhat stand-alone document, some of the background text given in the reports mentioned above will be repeated.

Tsunami is a Japanese word meaning ‘harbour wave or waves’ (the word is both plural and singular in Japanese, but the plural ‘s’ is now used in English). Tsunamis are a series of long period waves generated by an impulsive source that produces a sudden displacement of the water column, and thereby the water surface, which develops into a tsunami. Tsunamis are not in the strict sense of the words ‘tidal waves’. Tidal waves are primarily caused by the gravitational pull exerted by objects in the Solar System, mainly the Sun and Moon, on the Earth’s surface, although the extremely rapid rise and fall of a tsunami could be seen as representing such a tidal “wave”.

The displacement causing a tsunami is normally generated by a submarine earthquake, landslide (into or under the water), volcanic eruption, or a bolide impact (e.g. asteroid) (de Lange, 1998; in press). If locally-generated, they may come onshore within minutes, but more distantly-generated ones can takes hours. For example, it can take about 14 hours for a tsunami to travel from South America to New Zealand, allowing sufficient response time to issue warnings from the Pacific Tsunami Warning Service (Gilmour, 1960; Downes et al., 2000).

Tsunamis are fast-moving and unlike wind-generated waves where the energy rapidly decreases with depth, the energy associated with a tsunami is distributed throughout the whole water column irrespective of depth, and the energy moves at the same velocity as the waves. In shallow water (10’s of metres) a tsunami slows down and wave height increases. They may be up to 10’s of metres high at the coast, although most are less than 1 m in height. Normally tsunami come onshore as non-breaking waves like a rapidly rising tide that inundates the land. This is normally preceded by a negative wave, the trough between two waves, and the sea is seen to rapidly recede from the coast, stranding fish and going out way beyond normal low tide levels. Sometimes a tsunami comes onshore as a breaking or broken wave such as seen in Papua New Guinea in 1998 (Goldsmith et al., 1999). Under certain conditions tsunamis can persist for several days, supplemented by local seiching and resonance, such as might occur between Motiti Island and the mainland. It is normally not the first wave that is the highest or most destructive, but rather the second or third, except perhaps in locally-generated events (Ridgway, 1984; Goldsmith et al., 1999; de Lange, in press).

2.3 Tsunami sources

The two main sources for tsunamis are classified as distant and local. Distantly-generated tsunamis are generated beyond the New Zealand continental shelf, and have the potential to affect most of the New Zealand coast (de Lange and Fraser, 1999). e.g. The 22 May 1960AD Chile earthquake produced runup heights of about 2.5 m at Whitianga, 2.3 m in Mercury Bay, 1.4 m at Mt. Maunganui, 1.2 m at Tauranga, 2.3 at Maketu, 0.5 at Whakatane, and 1.5 at Opotiki. Locally-generated tsunamis are generated on or from the New Zealand continental shelf. Such tsunamis do not last long and normally only affect a regional section of the coastline, but are likely to have localised peak runup heights well in excess of any distantly-generated tsunamis (de Lange and Fraser, 1999).

Locally-generated tsunamis currently comprise all of the prehistoric (palaeo) record. Most information is known about events that occurred in the 15th Century, although Holocene palaeotsunami inundations can be dated as far back as 6300 years BP (Chagué-Goff et al., 2002). The tsunamis that inundated the coast in the 15th Century show great variability around the country, but in the relevant north-eastern section of the North Island of New Zealand (Walters and Goff (in press) refer to this region as the Tsunami Crescent) there are several sites that give us an indication of the nature of the event. The primary indication of tsunami inundation in this region is a discontinuous pebble/gravel layer or veneer overlying coastal dune systems. Underlying sand is far older than the overlying material and a hiatus in deposition indicates signs of erosion, while overlying sand often fails to stabilise on this “armoured” layer. Evidence was first reported from the east coast of Great Barrier Island, where pebbles rise up to 14.3 m above mean sea level (Nichol et al., 2003). Subsequent deposits have been found further south on the island. The maximum elevation of such a deposit unfortunately provides only a minimum runup height for the water. In most cases though tsunami deposits are found in low-lying wetlands and elevations are close to sea level, so the unusual coincidence of sand dunes overlain by a pebble veneer is most helpful. Therefore, the elevation of pebbles on Great Barrier Island is rather impressive, although it is somewhat insignificant when compared with elevations up to 32 m above mean sea level at Henderson Bay in the Far North (Nichol et al, 2002). The Henderson Bay deposit is the highest published record so far, although recent findings on Korapuke Island (Figure 1) detailed below indicate runup to 60 masl or more.

The contemporaneous deposits of the tsunami crescent must have been laid down by a tsunami with a local source sufficiently distant and large to affect the whole area. A logical source is submarine volcanism and/or associated earthquake activity in the vicinity of the Hikurangi trough, east of the southern Kermadec arc and 360 km east–southeast of Great Barrier Island. This is a seismically active area that has experienced a minimum of 21 large (Mag. 7.3 or greater) palaeoseismic events during the past 2.5 ka (Berryman et al., 1989). An equally logical source is the southern Kermadec arc that is comprised of at least 13 modern submarine volcanoes between 34^{o}50’S and 36^{o}50’S (Wright and Gamble, 1999). Of these volcanoes, the Healy caldera is a strong candidate for tsunami generation. A probable 15th Century eruption (contemporaneous with the palaeotsunami deposits) was pyroclastic and the associated caldera collapse in 550-1000 m water depth was catastrophic and possibly tsunamigenic (Wright et al., in press).

Confirmed or possible palaeotsunami deposits that are probably related to the Healy caldera collapse have been found in the Far North (Nichol et al., 2002), Great Barrier Island (Nichol et al., 2003), north of Whangarei Heads (J. Goff, unpublished data), and in the Bay of Plenty (Waikawau Bay, Otama Beach) (Goff, 2002)(Figure 1). Conversely, possible erosion generated by tsunami inundation has been found on Matakana Island (B. McFadgen, pers. comm., 2002) (Figure 1). Interestingly, runup elevations appear to decrease southwards towards Tauranga. The last known deposit is a discontinuous pebble veneer about 7 masl at Otama Beach. This elevation is approaching the minimum runup height (5 metres) believed necessary to generate a visible deposit (Lowe and de Lange, 2000).

The decrease in elevation with distance south is suggestive of a tsunami generated from a point source, such as a landslide or submarine volcano to the northeast. Normally these dissipate quite rapidly away from the source and will not be hazardous after propagating for more than 1000 km or so.

2.4 Tsunami-related hazards

To a large extent the hazards related to each tsunami are different because they are generated differently. The hazards created are site specific and can realistically only be dealt with in general terms.

The initial measure of potential tsunami hazard is the runup. As a “rule of thumb” the runup height on land approximates the vertical wave height at the shore, although in reality this varies considerably depending upon nearshore bathymetry and onshore topography (Morgan, 1984). Therefore, the runup is the height of the tsunami above a specified datum, which is normally the tidal elevation at the time of the tsunami. The maximum potential runup provides an indication of the hazard - the higher the runup, the greater the hazard. According to de Lange (in press), any runup exceeding 1 m is considered to be potentially catastrophic. However, the maximum elevation of runup is dependent upon the sea level at the time of inundation. A small tsunami arriving at high tide may be more damaging than a large tsunami at low tide (de Lange and Hull, 1994).

When a wave comes onshore, it is normally as a non-breaking wave, or rapidly rising tide, forming bores only within rivers and estuaries. A shallow onshore slope may encourage friction and reduce runup height, and vice versa for a steep slope (e.g. Synolakis, 1991). Tsunami sometimes come onshore as breaking waves that are turbulent and as such may have a higher runup, but because of rapid energy loss they are unlikely to penetrate as far inland (Downes et al., 2000).

While breaking waves and their associated turbulence are more damaging, the runup and backwash associated with non-breaking waves induces strong currents that are extremely destructive and life-threatening (Downes et al., 2000). Therefore, both components of tsunami inundation, runup and backwash, can be destructive. Since the energy is distributed throughout the water column, the runup is extremely destructive irrespective of the nature of the wave. Similarly, the backwash is equally or more destructive and life-threatening because the water contains an assortment of loose debris ranging from houses to small artifacts (e.g. Goff and McFadgen, 2001).

Interactions between runup and backwash are complex. Both have high velocities and as such can be highly erosional. While frequently it is one of the first few waves that is considered most destructive, they may all appear to have erosional and depositional attributes (Goff et al., 1998). During runup, at the shore and immediately offshore, material is picked up, but almost immediately it starts to deposit again, possibly behind the eroding wave front. The high flow velocities are difficult to interpret because on-going erosion during the runup changes the onshore topography and therefore changes the response of the runup and subsequent backwash for each wave (de Lange, in press). However, the backwash generally travels down the path of least resistance, such as through low-lying topography, much of which has been recently recontoured by the incoming wave (e.g. Goldsmith et al., 1999). Flow velocities of both runup and backwash can be high, varying from estimates of 10 to 70 km per hour (Shuto and Matsutomi, 1995; McSaveney et al., 2000).

The runup is therefore fast-moving and sediment laden, and causes death and injury by sandblasting, crushing (against more resistant objects such as trees and buildings), and dismemberment. On the other hand, the backwash is generally associated with drowning as people are swept into deep water by the return flow, and injury by floating debris (Butcher et al., 1994; Goldsmith et al., 1999). For example, in the 1993 Hokkaido-Nansei-Oki tsunami, 71% of the deaths were due to the impact of floating debris (Butcher et al., 1994).

Much of the study of floating debris has focussed on the effects in ports. However, when a tsunami enters a harbour, estuary or river, it may well interact with the geometry and dimensions of these semi-enclosed areas to produce seiches. This excitation of the water inside a semi-enclosed area such as a harbour depends upon the time interval between the peaks of each wave (the wave period) which is normally 15 to 60 minutes. These wave periods can induce a sort of sympathetic (or in this case 'forced') oscillation because they interact with the natural oscillations of the area, thus enhancing the height of tsunami at some locations. This has two effects; it serves to amplify the size of the individual waves in a tsunami, and it normally extends the effects of the tsunami by continuing to "slosh" around for many hours after the arrival of the first wave. However, if the tsunami has a wave period that does not 'match' the natural modes, this may serve to dampen their height and produce no forced oscillations (Downes et al., 2000).

The effects of tsunami in estuaries and rivers are two-fold. Firstly, they can generate rapid changes in water level, inducing strong currents, eddies and seiches that break moorings, and scour and redeposit sediment, often necessitating the resurvey of shipping channels (de Lange, in press). Secondly, tsunami can form bores. These are particularly destructive because they are generally at their strongest at the upper limit of the tidal influence where the opposing currents of river and sea may result in the greatest steepness of wave (Tsuji et al., 1991), and which is also where most road and rail bridges are built (de Lange, in press).

Tsunami inundation introduces saltwater into the coastal area. This can kill all types of coastal vegetation that in itself has serious knock-on effects. There is a paucity of research into the long and short term effects of saltwater contamination and the effects on coastal farmlands and stressed natural ecosystems are unknown, although the responses of these types of environment are probably dependent upon the salt tolerance of individual plants. In the case of monoculture farming or forestry, the effects could be catastrophic. For stressed natural ecosystems, there is clearly the potential for weed invasion following die-off (Goff et al., 2001). There is a need to further understand several aspects of saltwater contamination by tsunami. What are the long and short-term effects of small, more frequent and large, less frequent tsunamis on:

- Buildings and structures? Are there problems with structural integrity?
- Natural ecosystems – stressed, sensitive, or apparently robust? How does one manage the ecosystems to mitigate damage?
- Agricultural/horticultural land? Which crops are more susceptible?

There are clear long and short-term economic issues embedded in this lack of knowledge and there is a pressing need to understand more about the impacts of saltwater contamination caused by tsunami.

3 Sites Investigated

Locations for the sites discussed below are shown in Figure 1. The relevant figure numbers for each site are given at the beginning of each sub-section. Sites are discussed in order from northwest to southeast.

3.1 Mercury Islands

3.1.1 Korapuke Island (Figures 2-4)

This island was visited because of the possibility of finding similar discontinuous pebble veneers to those reported by Nichol et al. (2003) on Great Barrier Island, Nichol et al (2002) at Henderson Bay in the Far North, Goff (2002) at Waikawau and Otama Bays, and by de Lange (pers. comm., 2002) at Port Jackson adjacent to Cape Colville (unfortunately, evidence at Port Jackson appears to have been obscured by rapid vegetation growth). In a brief visit to the island in 1990, McFadgen (unpublished data) reported the almost ubiquitous presence of pebbles and gravels on the north/northwest-facing slope of the south side of the island, with some found beneath large boulders. There was also an associated scatter of archaeological artifacts. The island is fully vegetated and is the breeding ground for burrow-dwelling seabirds.

The main northwest facing beach has a fully vegetated backshore area with sandy soils containing abundant rounded pebbles on the surface up to an elevation of approximately 5masl. Further up the northwest facing slope towards the southern high point of the island, there are large boulders (e.g. 1.5m x 0.65m x 50 cm) with well-rounded fossil boreholes, fossil abrasion grooves or hollows, and fossil "rock pools" scattered across the slope to the cliff edge. These have a maximum estimated elevation of about 60 masl.

At the southwest end of the island there is a discontinuous pebble "sheet" deposited across the broad, flat top of the main ridge. Pebbles are smooth, well rounded with a range of local lithologies. They have a density of about 10-20 pebbles per m^2 and they rest on and within a sandy soil containing coarse sand and gravel. Clusters of large boulders are also scattered across the hilltop, some of which are markedly angular, *in situ* regolith, others of which appear to have been transported onto the hillside.

Several test pits were dug, pebbles were sampled and two soil samples were taken for micropalaeontological analysis.

<u>Discussion:</u>

A pebble/boulder veneer rises to about 60 masl on the southern side of Korapuki Island. Many of these clasts bear the indication of a marine provenance and can be clearly distinguished from *in situ* material. Given that the island is fully vegetated and there are many petrel burrows some caution in the interpretation is warranted. However, the ubiquitous nature of the deposit, and the characteristics and size of many clasts prohibits an interpretation of significant reworking. While the main slope faces NW, there appears to be a general clast fining to the WNW suggesting emplacement from the ESE, although this may not be the case. This degree of structure to the deposit implies an non-anthropogenic source, one within the Bay of Plenty with the *only realistic*, if improbable, cause being tsunami deposition possibly from a volcanological tsunami caused by eruptions of either Major or White islands or from local fault rupture. If a tsunamigenic source is responsible, it is possible that it may be linked with other deposits discussed above, in which case the source may well be outside the Bay of Plenty and associated with either the collapse of the Healy caldera, or one of many other submarine volcanoes in the southern Kermedec arc, or from seismic activity in associated with the Hikurangi Trough about 350 km to the east (Berryman et al., 1989; Nichol et al., 2003; Wright et al, in press). Based upon a geochemical similarities between Healy and Loisels pumice, the date of the Healy caldera collapse has been placed tentatively at around 1290–1440AD (Wright et al., in press), which matches well with the age (1390-1670AD) of reworked prehistoric Maori middens on Great Barrier Island (Nichol et al., 2003). The presence of “scattered” prehistoric Maori artifacts on Korapuke Island (McFadgen, unpublished data) suggests a similar association.

A detailed, site-specific analysis is needed of the Korapuke site. The geological importance of this site cannot be overstated, and the need for a more comprehensive investigation is paramount.

3.1.2 Great Mercury Island (Figure 5)

A brief survey was undertaken at Rocky and Coralie Bays. Rocky Bay is a narrow sandy beach about 100 m wide on the NE shore of the island, backed by steep slopes cleared of vegetation for pasture. Two shallow gouge auger samples were taken from a narrow wetland behind the beach. The stratigraphy was primarily slopewash material and no obvious marine deposits were found. The wetland was to narrow and shallow to be of any use. Coralie Bay was also a narrow beach on the NE side of the island, with steep grassy slopes behind it, and bare soil especially at the southern end. The southern end of the beach was also devoid of sand, with weathered bedrock exposed in the intertidal zone. Grooves had been incised into the weathered volcanics, with pebbles and cobbles lined up in these grooves. This indicates that there is a supply of coarse marine material, although no evidence for any marine incursion as found in the narrow wetland behind the beach.

<u>Discussion:</u>

It would be expected that some evidence of tsunami inundation would be found here because of its proximity to Korapuke Island. However, the surface environment has been heavily altered by human occupation, and there were no suitable sites for the preservation of past tsunami deposits.

It is possible that some sites on the NW side of the island may be more suitable, but at present no further action is recommended. However, other islands in the group such as Red Mercury, Ohinau, Motukoruenga, Double and Stanley should be visited.

3.2 Otama Beach (Figures 6-10)

This is a north-facing beach on the mainland (in the lee of Great Mercury Island). It is about 2km long and backed by sand dunes that rise up to about 8masl, extending inland for about 200m. The surrounding hills are drained by the Otama River which exits to the sea at the eastern end of the beach. The river is partially constrained by the dunes and forms an extensive wetland behind them to the south. This wetland has been heavily modified by farming, roading and drainage.

Ground survey, Ground Penetrating Radar, GPS and coring were undertaken at this site. A discontinuous pebble veneer was present on the second dune phase about 110m back from the beach, with elevations above sea level ranging from 4-7m. Some reworked oven stones were also present. Patches of pebbles and spot GPS heights were taken, and a survey line perpendicular to the shore was run through the largest exposure of pebbles through to the wetland behind. Cores were taken from the wetland, but there is a considerable fluvial influence here and it seems unlikely than any significant data will be forthcoming. A GPR line was run adjacent to the ground survey and a strong reflector was identified about 1.00-1.20m below the surface. Subsequent investigations revealed this to be a series of strongly laminated heavy mineral layers in a medium sand. The strongest concentration was at about 1.00m depth, correlating with the GPR signal. The reflector can be traced under the dunes to the wetland behind and may represent a former erosional surface, or a sea level highstand.

There appear to be two phases of dune construction with the pebbles deposited on the palaeo-beach face of the second dune phase. The most recent dune phase has formed since the gravel was deposited, with the interface between the two phases suggesting a “rapid” progradation, implying a high sediment supply.

OT1 was one of two cores retained for further analysis in the laboratory, these were taken from the wetland about 250m inland behind the dune system. This was opened in the laboratory and sampled for micropalaeotonology, radiocarbon, and grain size. The core is composed almost entirely of medium sand with rare organic-rich units, some sharp contacts between units, and rare radiocarbon datable material.

Discussion:

The geomorphological evidence indicates that there have probably been at least three key phases of significant activity, the first forming the heavy mineral rich layers that lie beneath the dunes, the second depositing a discontinuous pebble veneer on the second dune phase, and the third creating two marked phases of dune construction subsequent to pebble emplacement.

The core adds little to this interpretation, but there appears to have been a relatively recent period of flooding (0.12m below surface), and a much earlier event that appears to have buried an organic-rich layer similar to that seen today (2.23m). This may well represent a marine incursion, possibly associated with emplacement of the pebbles or heavy mineral-rich layer. In the absence of any chronological information it is difficult to infer any relationships, however, preliminary analysis shows that the sediment below the inferred subsidence/marine incursion there are no diatoms present whereas above it a mixture of marine and other diatoms are present. The presence of marine diatoms above the contact is not unexpected given that the area is subject to storm flooding from the sea, but while this is inconclusive a significant environmental change has taken place. A wood sample has been submitted for radiocarbon dating from the unit – a depth of 2.23m.

Looking at the wider context of palaeoenvironmental changes in the region it is difficult not to associate the discontinuous pebble veneer with similar sites elsewhere. This association is strengthened by similar geomorphological evidence from sites where discontinuous pebble veneers are also found on the second phase of dunes back from the sea, and also in association with reworked Maori artifacts. A subsequent rapid supply of sand to the nearshore zone suggests that there may be an association between the two events. This again may probably relate to 15th Century tectonic or seismically-related activity reported by Goff and McFadgen (2002). The after effects of such activity includes a logical sequence of events with tsunamis following immediately after the tectonic event, followed for some years after by a rapid increase in the supply of sediment to the coast by rivers and landslides (Goff and McFadgen, 2002). If this is indeed the case, then the most recent dune phase is linked to the whole process and post-dates the emplacement of the pebble veneer. It seems unlikely that the inferred subsidence in the core is related to this event, although it is possible that it might be associated with the heavy mineral-rich layer identified underlying the sand dunes. While the GPR line does not extend into the wetland this linkage is tentatively made in the absence of any supporting chronological information. However, the absence of any other significant changes in sediment characteristics tend to support this inference.

It is inferred that the pebble layer is most likely contemporaneous with those reported by Nichol et al., 2003 and others discussed above). To explain why Great Mercury Island has no such deposit and yet Otama Beach in the lee of the island preserves some, albeit at a far lower elevation that Korapuke Island, is open to conjecture. If a tsunami was approaching from the NE, there would have been considerable interference to the wave patterns by the Mercury Islands, and tsunami inundation of Otama Beach would not be unexpected. As mentioned above, the absence of such a deposit on Great Mercury Island may merely be a function of human activity, poor preservation, or because the most suitable sites have not been investigated.

3.2.1 Opito Bay (Figure 11)

Opito Bay is situated about 2km east of Otama on a NE facing coastline. This was investigated because there had been insufficient time during the reconnaissance survey to study the whole beach. The dunes at the southern end were largely undisturbed and contained a considerable quantity of Maori artifacts, but no pebble veneer was evident. The central part of the Bay has been developed, but areas to the north are still largely undisturbed. Once again, there were numerous Maori middens and oven sites but no pebble veneer. However, at Papatai Point a large section of the rocky shore platform (approx. 4m x 3m) has been deposited on top of the existing shore platform. Bedrock fractures, abrasion groves and hollows are consistent with the existing shore platform although the precise source of this clast could not be determined. While no further work was carried out at the site, it is interesting to note that a considerable amount of energy would have been required to erode, entrain and transport this section of shore platform. Investigations of the timing and the mechanism involved are beyond the scope of this study.

3.3 Waihi Beach (Figures 12-15)

A detailed survey of the area between Bowentown and Waihi Beach indicated that the wetland immediately to the east of Emerton Road and landward of the dune system was, as indicated in the reconnaissance report, the most appropriate location for coring. The wetland forms part of the estuary of the Waiau River draining the hills to the west.

In the interests of obtaining a range of past environmental conditions cores were taken in a transect extending landward from opposite the Sea Air Motel (in a paddock/drained wetland 450m inland and dominated by exotic grasses and *Leptocarpus similis*) to a DOC wetland (just over 1km from the sea dominated by *Isolepsis nodosa* - GPS locations are available). Two cores, WAI 1 and WAI 2 were retained for further examination, one from each end of the transect.

Core WAI 1 was opened in the laboratory and sampled for radiocarbon, micropalaeontological and sediment analyses. While still dominated by sandy material, the core is more heterogeneous than the Otama Beach ones, containing frequent shell and shell hash units (dominated by *Austrovenus stutchburyi*), as would be expected in an estuarine environment such as this.

<u>Discussion:</u>

The stratigraphy of the core indicates two key units, one at 1.05m, the other at 3.08m below the surface. The uppermost unit is marked by a buried or eroded soil at the lower contact and is composed primarily of coarse gravel and sand. This is most likely (and common in estuarine sediments) a channel-changing event showing where the river has changed its course and reworked sediments at the site. It may however represent subsidence and burial of the soil (with possible associated tsunami) and samples have been taken to assess this possible scenario. The lower unit, at 3.08m immediately underlies what we have termed a “chaotic unit” that is composed of shell hash mixed with poorly sorted sand and silt with frequent intact shells. This underlying unit has a sharp lower contact with an underlying medium sand, although it is composed of silty fine sand with abundant pumice. The unit also contains a markedly different macrobiota to the almost ubiquitous *A. stutchburyi* found throughout the rest of the core. Here there is a mix of mussels, limpets, turretella and other unidentified species. This distinct change in sediment characteristics and macrobiota immediately underlying a “chaotic unit” suggests that something more that a simple period of channel change has taken place. A shell sample from 2.77m depth, within the chaotic unit, has been submitted for radiocarbon dating. Initial micropalaeontological analysis indicates that there are no diatoms within the thin unit at 3.08m, however other samples are awaiting further analysis. These association of exotic shell species and a chaotic stratigraphy are indicative of a higher energy regime introducing the material into the site, although it is interesting to note that the sediment is distinctly finer. If a possible tsunami inundation is to be inferred, it must be reconciled with this apparent juxtaposition.

Similar sedimentary features have been found in tsunami elsewhere in New Zealand. A tsunami represented as a mud layer with a coarse sand has been reported from Abel Tasman National Park (Goff and Chagué-Goff, 1999). The site was situated 3.5km inland from the coast and is believed to near the most landward extent of tsunami inundation, where sediments have fined inland to a point where they have almost pinched out. If one assumes that the was shoreline in approximately the same place as it is today, and that a tsunami breached several sections of the dune belt (several large overwash deposits are present along the sand spit between Waihi Beach and Bowentown) and entered via the estuary, then sediments would have been transported a considerable distance from the sea (at least 450m). Remembering that to leave a recognisable deposit we are looking at an initial wave height of at least 5m, this site may be near the landward end of the runup. Core WAI 2 may help to prove or disprove this hypothesis. The association of this chaotic unit with others from cores taken further to the east of the Bay of Plenty could be used to suggest that the event may be related to coastal disturbances generated by the Kaharoa (or Taupo?) eruptions.

3.4 Ohiwa Harbour

While no reconnaissance had been undertaken along the eastern side of the Bay of Plenty, we were aware of several suitable sites in and around Ohiwa Harbour. As opposed to taking five cores from one site we took several cores from a number of sites, and by supplementing this with hand augering to check what the cores contained, were able to select the most appropriate cores to be retained for further work. Three sites were selected, one on the western side of the Nukuhou River, Stoney Brook on the NE side of the harbour, and Jacobs Creek east of Waiotahi Estuary. An additional advantage of this arrangement is that work undertaken by Marra (1997) in Waiotahi Estuary can be compared with the data collected for this study. Three cores were retained for further work, one from each site, with Core OH 2 taken from Stoney Brook opened for further work. However, the details of a hand auger taken adjacent to Core OH 3 from Jacobs Creek are also included in this report.

3.4.1 Nukuhou River (Figure 16)

The Nukuhou River area was used by Vucetich and Pullar (1964) to describe the tephra stratigraphy of the region, and has been correlated with sites extending from Taupo to Gisborne. These tephras, found in the estuarine sediments of the Nukuhou River and all core sites in the Ohiwa Harbour area, provide excellent initial chronological control. The site was located in the western corner of the wetland, E. of Burke Road and N. of Wainui Road in an area that appeared to be relatively sheltered from and undisturbed by the main river channel. It comprises a small sub-catchment of the main river and as such is unlikely to have been exposed to high river flows at any time. The vegetation is predominantly *Isolepsis nodosa*. 100% core recovery was achieved with no compaction and a total length of 6.24m. A hand auger adjacent to the core indicated the presence of at least two tephras and a buried peat horizon at about 2.00m below the surface. Core OH1 has been retained in the laboratory and will be opened during Stage 2 of this work.

<u>Discussion:</u>

We tentatively correlate the buried peat horizon with Marra's (1997) subsidence event that she places around the time of the Kaharoa eruption, but we would place it between the Kaharoa and the Taupo eruptions based upon a correlation with data from Core

OH2. However, this may represent a separate local catchment-wide subsidence (Ohiwa Harbour) adjacent to, and slightly earlier than, that of the Waiotahi Estuary.

3.4.2 Stoney Brook (Figures 17-19)

The Stoney Brook core site is situated 2.5km S. of the Ohiwa Holiday Camp on Reeves Road. It is a small tidal wetland estuary with a catchment less that $1km^2$. The vegetation is a mix of *Juncus krausii* and mangrove. Cores were taken at about the hide tide mark and one, core OH1, was retained for further analysis in the laboratory.

The core was sampled for tephra, radiocarbon, grain size and micropalaeontology, and examined in detail. At least two, possibly four tephras were identified, including the Kaharoa and Taupo. Several other interesting units were identified including two “chaotic units” that appeared to be associated with tephras – possibly the Waimahia and Whakatane and with a subsidence/groundshaking or volcano-tsunami. In addition there was a marked buried peat horizon (2.09m) representing a subsidence of 2.00m located between the Taupo and Kaharoa tephras. The buried peat was overlain by a unit of mixed sand, peat and shell hash interpreted as a subsidence-generated tsunami. This unit may extend for some 50cm upcore but further work is required to establish the exact nature of the stratigraphy. The Kaharoa tephra is overlain by a series of marked coarse units that are indicative of significant fluctuations in the coastal energy environment. This may be storm-related instabilities created by the eruption or to tsunami inundation, or to more than one high-energy event. Interestingly though, there is no similar unit found on top of the Taupo tephra, a much larger, and presumably more disruptive event, although some deformation is noted.

<u>Discussion:</u>

The core has provided a wealth of data on changes in the coastal environment and provides ample opportunity to correlate with other coastal sites in the region. Initial interpretations suggest as many as five possible events. Working from the base of the core upwards, there are two closely-spaced “chaotic units” at about 3.55 and 3.85m that appear, like the Kaharoa event higher up, to be associated with volcanic activity. While no tephra layers are present, there is a considerable amount in these units. There are also marked erosional contacts at the base of these units suggesting a marked, one-off event. Tephra samples have been taken for analysis to help with interpretation, but we tentatively suggest that these are tsunami deposits, although they may indicate storm activity. Given the extremely sheltered nature of the site inside Ohiwa Harbour, and the protection of a 2-3.00m high sand barrier, the latter seems unlikely.

Further upcore (2.73m) there is a significant deposit of Taupo tephra. The lack of any significant environmental response to this catastrophic event is initially surprising, although we infer this as showing that the ash generated by the Taupo eruption was somewhat overwhelming for the coastal environment producing an effect similar to pouring oil on stormy water. By overloading the rivers and nearshore waters with ash it effectively dampened most of the effects caused by atmospheric disturbance this close to the eruptive centre. A less fall of ash from a smaller eruption may well not have such an effect (e.g. Kaharoa).

The buried peat horizon at 2.09m allows us to calculate a 2.00m subsidence primarily because we achieved 100% core recovery with no compaction. This is markedly similar to the Nukuhou Site and that of neighbouring Waiotahi estuary (Marra, 1997), however further detail is added by the presence of what we infer to be a tsunami deposit overlying it. This quite probably represents the suitability of this sheltered site for retaining the sedimentary record of such events. It seems likely that the sedimentary record from Stoney Brook will prove to be the most useful long-term database from this study, and will allow data from other sites within the Bay of Plenty to be compared with, and added to, this record.

At 0.90m the Kaharoa tephra also forms a marked unit that is overlain by interbedded tephra and marine sediments. As suggested above, the higher energy marine environment represented by these marine sediments may well be related to volcanic activity. Whether they are tsunami or storm-induced is as yet unclear, although the former seems more likely given the location.

Chronologically, there appear to be at least three broad periods of activity, pre-Taupo, post-Taupo and pre-Kaharoa, and post Kaharoa. As opposed to dealing with these at length here, there will be addressed in the main discussion below since they form the main chronology around which the other data can be fitted in.

3.4.3 Jacobs Creek (Figures 20 and 21)

Jacobs Creek is a small, narrow valley (about 4km long and 0.5km wide) about 1km east of Waiotahi Estuary. The valley sides are composed of uplifted Quaternary marine sediments and, as opposed to the adjacent Waiotahi and Ohiwa basins, appears to have been relatively tectonically stable during the Holocene. Sediments in this valley may well prove to be a useful “control” for comparing and contrasting the tectonic activity of adjacent basins, and assist in the interpretation of tectonically related events such as tsunamis.

Geomorphologically, the valley floor was evidently a small wetland ponded behind an approx. 3m high sand barrier. Today, the wetland has been drained and used for pasture, and the sand barrier is overlain by the main highway. Some modification of the barrier has taken place reducing the height by approximately a metre. Wetland drainage has caused surface shrinkage which is marked by a terracette around the periphery of the valley floor about 0.50-1.00m about the present pasture level.

One core, JC1, was taken from the pasture about 130m inland from high water mark. Surface shrinkage means that the present pasture surface is about 5cm below the high water mark. A total core length of 4.94m was obtained including compaction of 1.54m. We therefore took a hand auger adjacent to JC1 to provide stratigraphic comparison and to adjust for the effects of compaction. Examination of the hand augered core indicates that this site is markedly different from others in the Ohiwa Harbour area. In order to avoid unnecessary desiccation of the peat and loss of core integrity, the core is being held in the laboratory unopened until Stage 2 of the project is underway. However, details of the hand augered core are briefly discussed below.

Core stratigraphy is primarily composed of peat and organic-rich silts (gyttya) interspersed with rare tephra units and associated sediments. The base of the core is composed of a medium sand that may be either a windblown or washover deposit. At least three, possibly four, tephra units were identified, the most marked being the Taupo(?) which is overlain by a mixture of reworked silts and tephra in an overwash unit. A cursory examination of the core did not show any similar associated sediments with the other tephras. If this is indeed the case, then this may provide some indication of the relative size of coastal disturbances following eruptions, both from the point-of-view of wave height and the local/regional extent of inundation.

<u>Discussion:</u>

There appears to have been no previous research undertaken in this area which is surprising given the tectonic evidence reported from the adjacent Waiotahi Estuary and Ohiwa Harbour environments. The geomorphology of Jacobs Creek indicates a more benign, stable environment, that may well offer a suitable control site to help unravel the story of events from adjacent basins.

While the site is within 130m of the sea, it seems to have been rapidly impounded by a sand barrier during sea level rise probably around 6500 years ago. There appears to have been only a small, temporary ponding of water allowing for the gradual accumulation of peat and organic-rich fine sediments in a nearshore swamp. This provides an extremely unusual coastal environment indicative of stable conditions for thousands of years, surrounded by a region of marked tectonic instability. The potential palaeoenvironmental record retained in this wetland cannot be overstated but because of slow peat accumulation rates it will require detailed, high-resolution analysis to produce the data.

Cursory observations during this work indicate the presence of up to four tephras, and every indication is that this valley has received the same ashfalls as other sites in the area. This will provide excellent opportunity for stratigraphic correlation with other Ohiwa Harbour cores, giving the opportunity for estimating the regional significance of events without the added complications of a subsidence or uplift signal. For example, there appears to be little environmental disturbance associated with most of the tephras indicating perhaps that any coastal inundations may have been confined to low-lying estuaries, or larger outlets to the sea.

Resolution of the tephra stratigraphy during Stage 2 will enable a more robust interpretation of the significance of this site to be made. However, it seems likely that a detailed, high resolution of this core would reveal much about nearshore conditions during the Holocene, however Stage 2 will essentially use a coarse resolution that deals primarily with visible stratigraphic changes. It is recommended that the councils consider funding a Master project aimed at producing a higher resolution analysis of core data from this site.

4 Discussion

The following point is reiterated from recent work for EBOP.

A key point of this study is that the resolution used – the identification of visible changes in the stratigraphy – is only capable of identifying larger events, whether they are subsidence, groundshaking, tsunami, or something else. In the case of tsunamis, de Lange (in press) indicates that a tsunami over 1m should be considered catastrophic. Lowe and de Lange (2000) suggest that inundation by a wave of 5m or more is required to leave a visible deposit, which means that catastrophic tsunamis between 1 and 5m can only be identified through high resolution, microscopic analysis, if at all. Similarly, subsidence events of less than 50cm are extremely difficult to identify, and yet a 30-50cm subsidence was partially responsible for the 15+m Papua New Guinea tsunami in 1998 (Goldsmith et al, 1999). ***It is therefore important to note that the absence of visible deposits does not mean the absence of events***. ***BUT the presence of high magnitude (>5m), low frequency events is a good indicator of the occurrence of many lower magnitude, higher frequency ones.***

From a local volcanic perspective, de Lange and Healy (1986) note that the major tsunami hazards should be expected from volcanic eruptions of Major Island, White Island, and the Okataina Volcanic centre, and from movement of submarine faults. It is important to add to these the submarine volcanic area of the Kermadec trench (Wright et al., in press). In the case of most of these volcanic sources, the hazard associated with the primary eruption event may outweigh that of any subsequent tsunami (de Lange and Healy, 1986).

A tentative summary assessment of the data collected during the current work is given in Table 3 (relevant sites reported in the Ancillary Tsunami Report are shown in italics). We have initially defined five broad chronological units based upon a tentative tephrostratigraphy with the oldest unit sub-divided on this basis: Post-Kaharoa (*c*. 500-600 yrs BP); Kaharoa (*c*. 750 yrs BP); Pre-Kaharoa/Post-Taupo (*c*. 800-1800 yrs BP); Taupo (*c*. 1850 yrs BP); Pre-Taupo: Waimahia (*c*. 3200 yrs BP)?, Whakatane (*c*. 4800 yrs BP)?

4.1 Post-Kaharoa (*c*. 500-600 yrs BP)

The most recent event may possibly be two or more events as indicated by a series of interbeds of sand and silt in the Stoney Brook (OH2) core. It may not be preserved at other sites (e.g. Jacobs Creek) because of more recent human disturbance, or it may be difficult to differentiate it from other events (e.g. Otama Beach) because of the sedimentary environment, or the event may only have been of local significance. The latter acknowledges that local variations in runup occur and in some instances would have undoubtedly been less than the minimum wave height necessary to leave a recognisable deposit.

Evidence for coastal inundation in the region around the 15th Century includes:

a) Matakana Island – post-Kaharoa erosion surface at southern end (Shepherd et al 1997).
b) Deposits related to tsunamis possibly generated by Healy caldera collapse or other submarine volcano (Ian Wright, pers. comm., 2002; Wright et al., in press; Nichol et al., 2003; Goff, 2002; Goff and McFadgen, 2002).
c) Large subduction earthquakes recorded in coastal sediments from the Bay of Plenty to Gisborne in approx. 300 and 600 years BP (Berryman et al., 1989; Ota et al., 1992).
d) Prehistoric coastal village abandonment, separation of occupation layers by tsunami layers, and anomalous pebble layers (Goff and McFadgen, 2002; McFadgen, 1985; 1996; Wellman, 1962; Smart and Green, 1962; Kahotea, 1993).

e) McFadgen (1985) reports a period of rapid dune building in the 15th Century – the Ohuan Chronozone – that has subsequently been linked with a series of post-seismic “knock-on” effects at that time (Goff and McFadgen, 2002). They are also considered to be post-volcanic in part as well.

4.2 Kaharoa (*c*. 750 yrs BP)

As mentioned in the section above, McFadgen (1985) reports a period of rapid dune building in the 15th Century – the Ohuan Chronozone – that has subsequently been linked with a series of post-seismic “knock-on” effects at that time (Goff and McFadgen, 2002). These are also considered to be post-volcanic after-effects and, such as tsunamis, are more immediate. An immediate post-Kaharoa subsidence has also been recorded in cores taken from Waiotahi Estuary (Marra, 1997) although this may have been locally tsunamigenic and separate to the event proposed here. Atmospheric disturbances and meteorological tsunamis can often be generated by volcanic eruptions (e.g. Lowe and de Lange, 2000), and this appears to be evidence in this study from the numerous associations of “chaotic layers” with those of ashfalls.

4.3 Pre-Kaharoa/Post-Taupo (*c*. 800-1800 years BP)

There is a marked subsidence event in Ohiwa Harbour, with possible events at Waihi and Otama Beaches. The subsidence event at Ohiwa Harbour is overlain by what appears most likely to be a tsunami deposit. Similarly, what appears to be contemporaneous subsidence is reported in the Ancillary Tsunami Project at the Maniatutu, Poplar Road and Parton Road sites (Goff, 2002). Both Ota et al. (1992) and Berryman et al. (1989) report the effects of large subduction earthquakes to the east, about 900-1200 years BP.

Whether the events at all sites are contemporaneous or not is at present unclear although this seems likely. However, there was another large subduction earthquake to the east between 1600-2000 years BP (Ota et al., 1992), an age gap that spans some of this time period.

4.4 Taupo (*c*. 1850 yrs BP)

The Taupo eruption is believed to have generated a volcano-meteorological tsunami (Lowe and de Lange, 2000). While this appears less obvious than earlier or later events in the coastal sites studied, it may simply be a function of the sheer size of the event and the rapid emplacement of vast quantities of ash in the nearshore zone in relatively close proximity to the eruption, thus mitigating the effects of the subsequent tsunami.

4.5 Pre-Taupo: Waimahia (*c*. 3200 yrs BP)? and Whakatane (*c*. 4800 yrs BP)?

Until there has been a formal identification of the tephras associated with the “chaotic units” of Ohiwa Harbour these association of dates and tephras should be considered tentative and speculative, Indeed, there is wealth of evidence for other pre-Taupo events that could be equally tsunamigenic. It seems unlikely that both eruptions would have been sufficient to generate significant tsunamis around the Bay of Plenty, in which case it is pertinent to look elsewhere for possible pre-Taupo sources. Large subduction earthquakes in the eastern Bay of Plenty and as far away as Gisborne have been reported around 1600-2000, 2100, 2300 and 2500 years BP (Berryman et al., 1989; Ota et al., 1992). Interestingly, these dates (several of them) coincide with fluctuations in vegetation growth (Newnham et al., 1995) and a sudden die-off of trees in coastal wetlands near Tauranga sometime between 2100 and 2700 years BP (Campbell et al., 1973). There are no apparent subsidence events recorded from coastal areas elsewhere in the region and we infer that these vegetations changes and chaotic layers are a result of tsunami inundation. It is suggested that at least two (maybe more) large, possible subduction earthquakes or local submarine faults generated tsunamis (and possibly some local subsidence) that inundated much of the low-lying coastline. The age of these events is yet to be determined, but a more comprehensive examination of Ohiwa Harbour cores should provide better information about the extent and magnitude of these disturbances.

5 Summary

The discussion considers five broad chronological units for tsunami activity based upon a tentative tephrostratigraphy and pending the results of initial radiocarbon analyses. These are:

F) Post-Kaharoa (*c*. 500-600 yrs BP) - probably related to submarine volcanic activity.
G) Kaharoa (*c*. 750 yrs BP) - immediate post-eruption.
H) Pre-Kaharoa/Post-Taupo (*c*. 800-1800 yrs BP) – most probably associated with significant amounts of coastal subsidence, possibly as a result of large, subduction earthquakes to the east.
I) Taupo (*c*. 1850 yrs BP) - immediate post-eruption.
J) Pre-Taupo: (i) Waimahia (*c*. 3200 yrs BP)? (ii) Whakatane (*c*. 4800 yrs BP)? groundshaking (and local subsidence?) – the dating is currently somewhat arbitrary but these events relate to one or both of known sub-aerial volcanic eruptions and/or large, subduction earthquakes to the east, and/or local seismic sources.

While the evidence for these has primarily been sourced from the eastern Bay of Plenty, there is sufficient correlation between events studied here and also those of the Ancillary Tsunami Report to suggest that there are varying degrees of regional significance and magnitude. However, a decrease in the number of sites recording the earlier events does not mean that these were less significant, but rather that they were either not retrieved from or not preserved in the sediments cored. In general terms, we tentatively suggest the following hierarchy of magnitude from the point of view of tsunami inundation (high to low):

C
A
E(i)
D/B
E(ii)

It is difficult to place the significance of the Taupo eruption (D) because the surfeit of tephra appears to have masked most of the effects of tsunami inundation in the areas studied. However, from the perspective of the greater hazard, tsunami inundation in this instance seems to be less of a concern.

There are two points to make here. Firstly, the above rating is extremely tentative and should be seen as indicative only – they may be more events as yet undiscovered but probably of lesser magnitude, and there are several cores as yet unopened that will reveal more about these events listed. There are currently too few data to be able to estimate magnitude and frequency with any reliability, but there would seem to be about six large (unknown magnitude at present) events in the last 5000 years or so. It would seem probable that there will be several intermediate events as yet unclassified by this report and others that will not be identified because the events are too small. ***It is important to note that the absence of visible deposits does not mean the absence of events***. ***BUT the presence of high magnitude (>5m), low frequency events is a good indicator of the occurrence of many lower magnitude, higher frequency ones.***

Secondly, there is a considerable quantity of on-going research related to submarine volcanoes off the Bay of Plenty coast and to the north. This work continues to identify more possible tsunamigenic sources and past caldera collapses. It is possible that using these (and other) data we will be able to extend the record of possible tsunami events in the Bay of Plenty back further in time, and also fill in some of the intermediate events that have either been destroyed or poorly preserved in the sediment studied.

Three possible areas of additional work to be considered were raised and these are noted below:

- *Korapuke*
  A detailed, site-specific analysis is needed of the Korapuke site. The geological importance of this site cannot be overstated, and the need for a more comprehensive investigation is paramount.

- *Other Mercury islands*
  Other islands in the group such as Red Mercury, Ohinau, Motukoruenga, Double and Stanley should be visited.

- *Jacobs Creek*
  Resolution of the tephra stratigraphy during Stage 2 will enable a more robust interpretation of the significance of this site to be made. However, it seems likely that a detailed, high resolution study of this core would reveal much about nearshore conditions during the Holocene, however Stage 2 will essentially use a coarse resolution that deals primarily with visible stratigraphic changes. It is recommended that the councils consider funding a Master project aimed at producing a higher resolution analysis of core data from this site.

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Figures

Figure 1: Study area in a regional context – showing access roads used and coastal portion of Bay of Plenty rivers. Main study sites are marked with an asterisk.

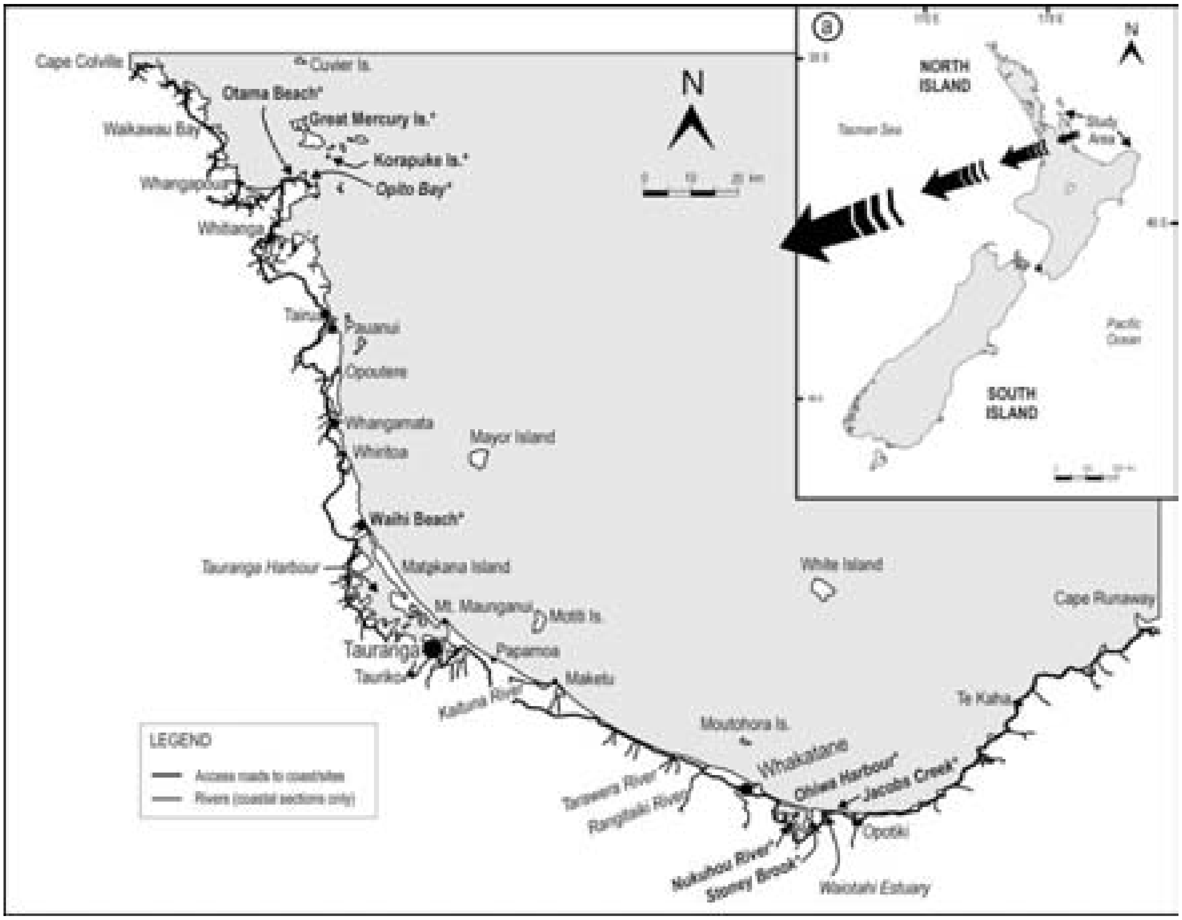


Figure 2: The southern section of Korapuke Island viewed from the northeast. This section rises to c. 60 masl.

Figure 3: Forest floor on hilltop at southern end of Korapuke Island. Note the discontinuous pebble veneer.

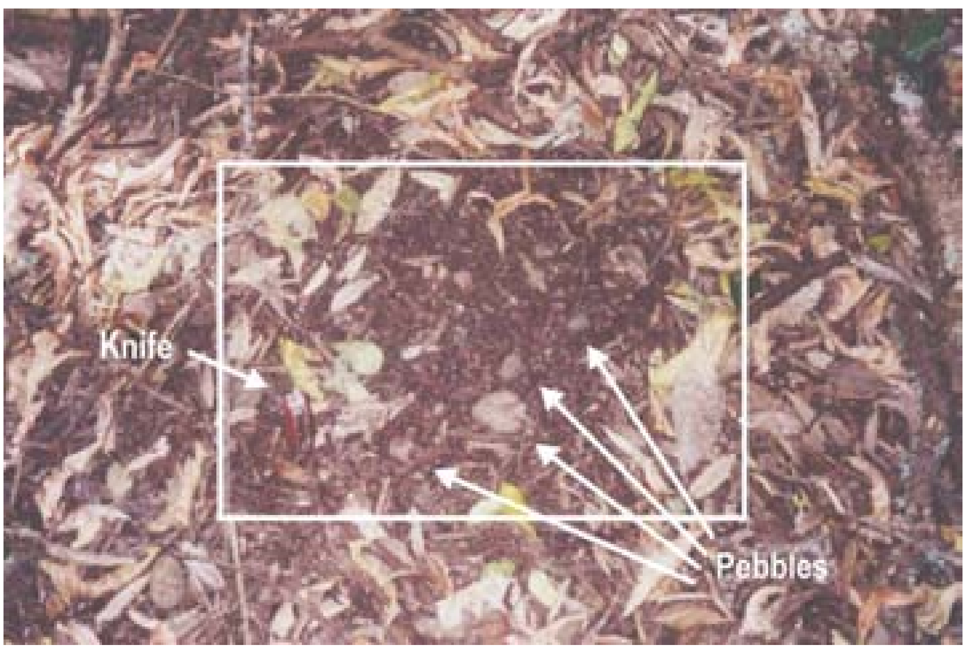


Figure 4: Korapuke Island: a) Large boulder near hilltop at southern end of Korapuke Island. Fossil abrasion hollow is indicated by the circle, and there is part of a fossil abrasion groove at the upper end of the boulder. b) Other large, well rounded boulders at crest of hill.

Figure 5: Great Mercury Island: Pebble lineations on beach at low tide.

Figure 6: Otama Beach – view looking east. The discontinuous pebble veneer is found at various sites along the beach face of the second dune phase.

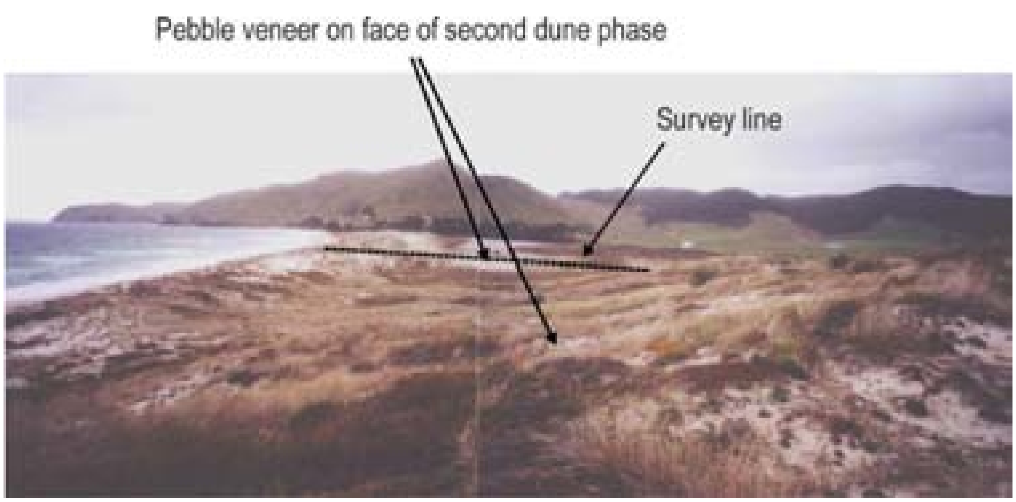


Figure 7: Otama Beach – Looking west. Core site OT 1 showing wetland behind dunes and the end of transect line.

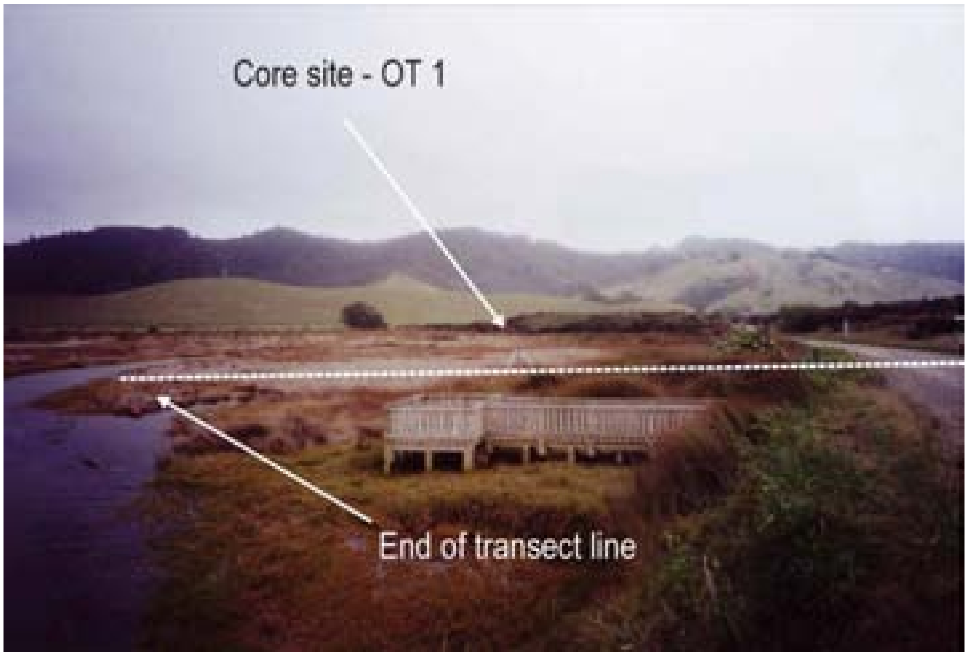


Figure 8: Otama Beach – exposure of pebble veneer. This is the more distant of the two sites shown in Figure 7. Ellipse marks the approx. area of main concentration in the photo.

Figure 9: Otama Beach – Core OT1 stratigraphy showing possible subsidence and flood (refer to Figure 14 for legend of core stratigraphy).

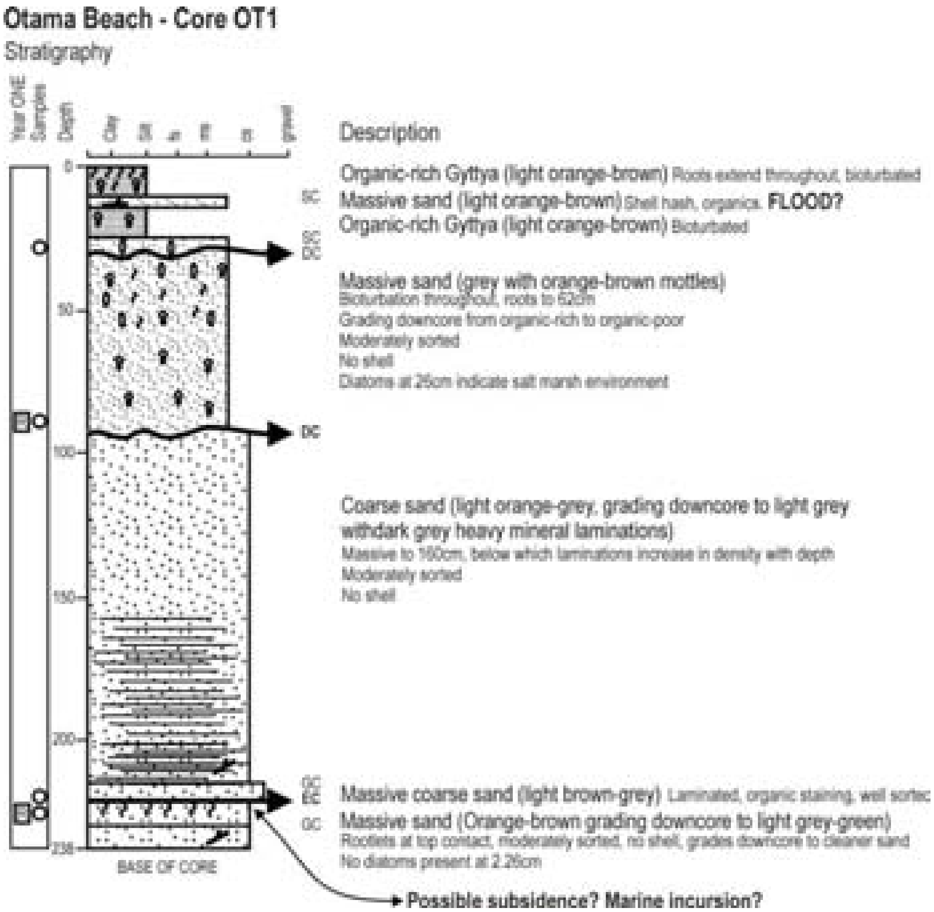


Figure 10: Otama Beach – ground survey and GRP line showing position of pebbles, core OT1 and the strong reflector of heavy minerals.

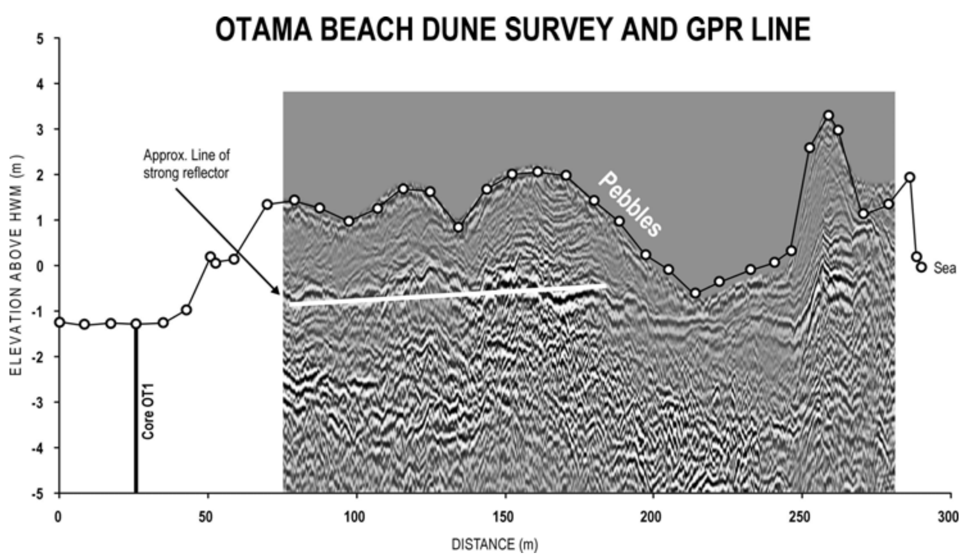


Figure 11: Opito Bay – Papatai Point with large boulder of transported shore platform overlying existing rocky shore platform.

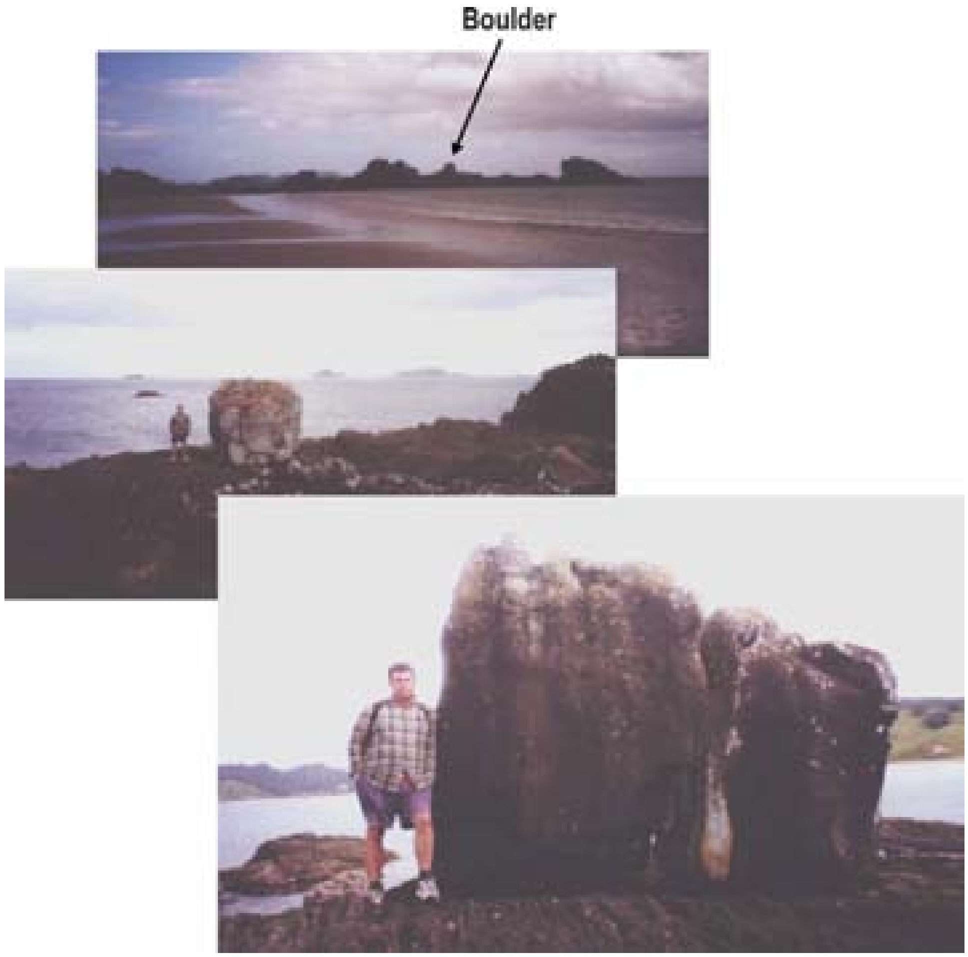


Figure 12: Waihi Beach – Study area viewed from Bowentown to the east.

Figure 13: Waihi Beach – Transect along east side of Emerton Road. Photo looking towards the sea. Wetland formed in estuary of Waiau River.

Figure 14: Waihi Beach – Core WAI 1 stratigraphy showing “Chaotic Unit” and possible subsidence.

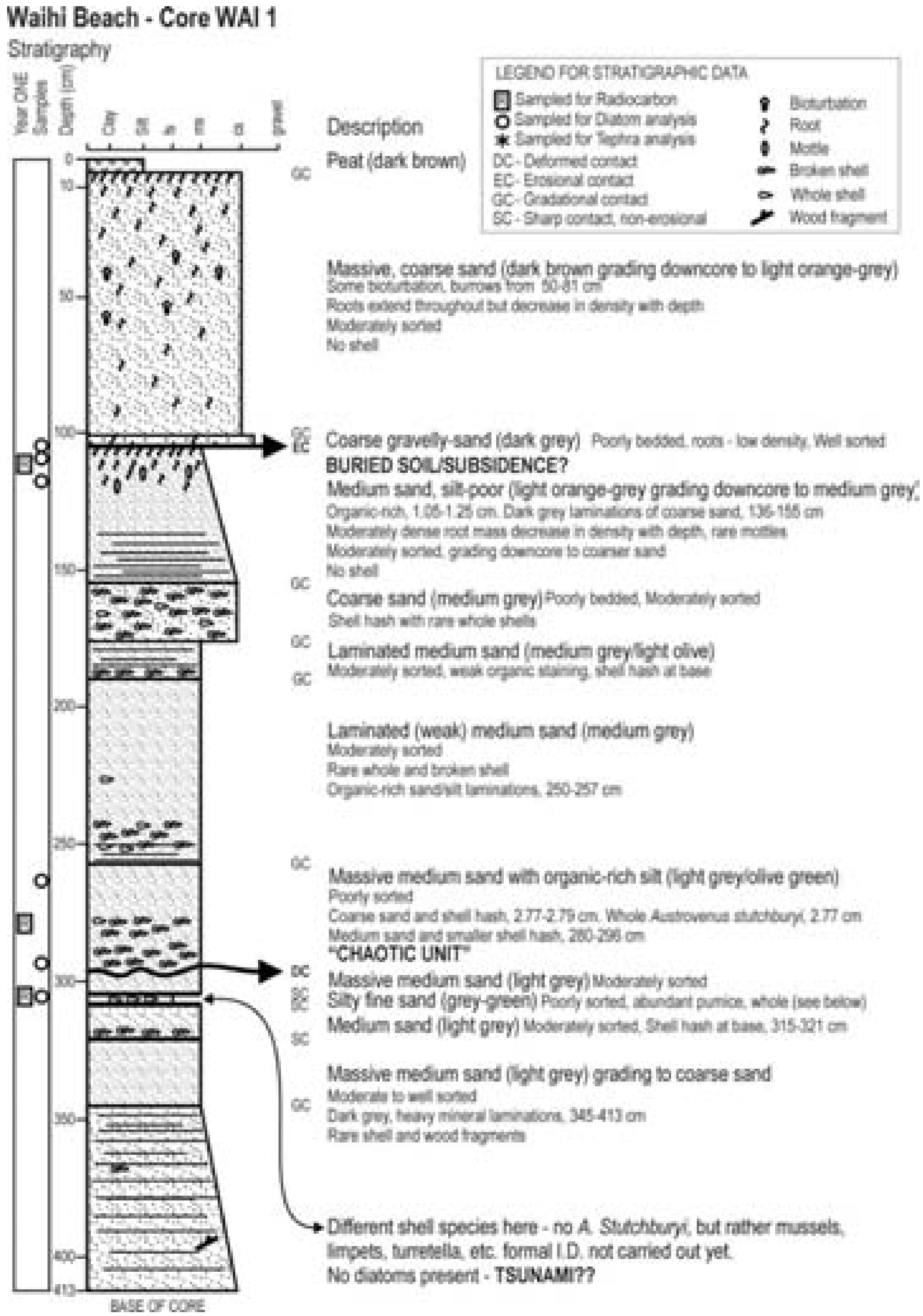


Figure 15: Waihi Beach – Detail of Core WAI 1 from approx. 2.50-3.10 m showing chaotic layer and possible tsunami deposit (unclear in photo) – refer to Figure 14 for details.

Figure 16: Nukuhou River core site: Panoramic view looking east – van for scale.

Figure 17: Ohiwa Harbour – Stoney Brook study site adjacent to Reeves Road.

Figure 18: Ohiwa Harbour – Stoney Brook: Core OH1 stratigraphy showing "Chaotic units", subsidence, tephras, and possible tsunamis units.

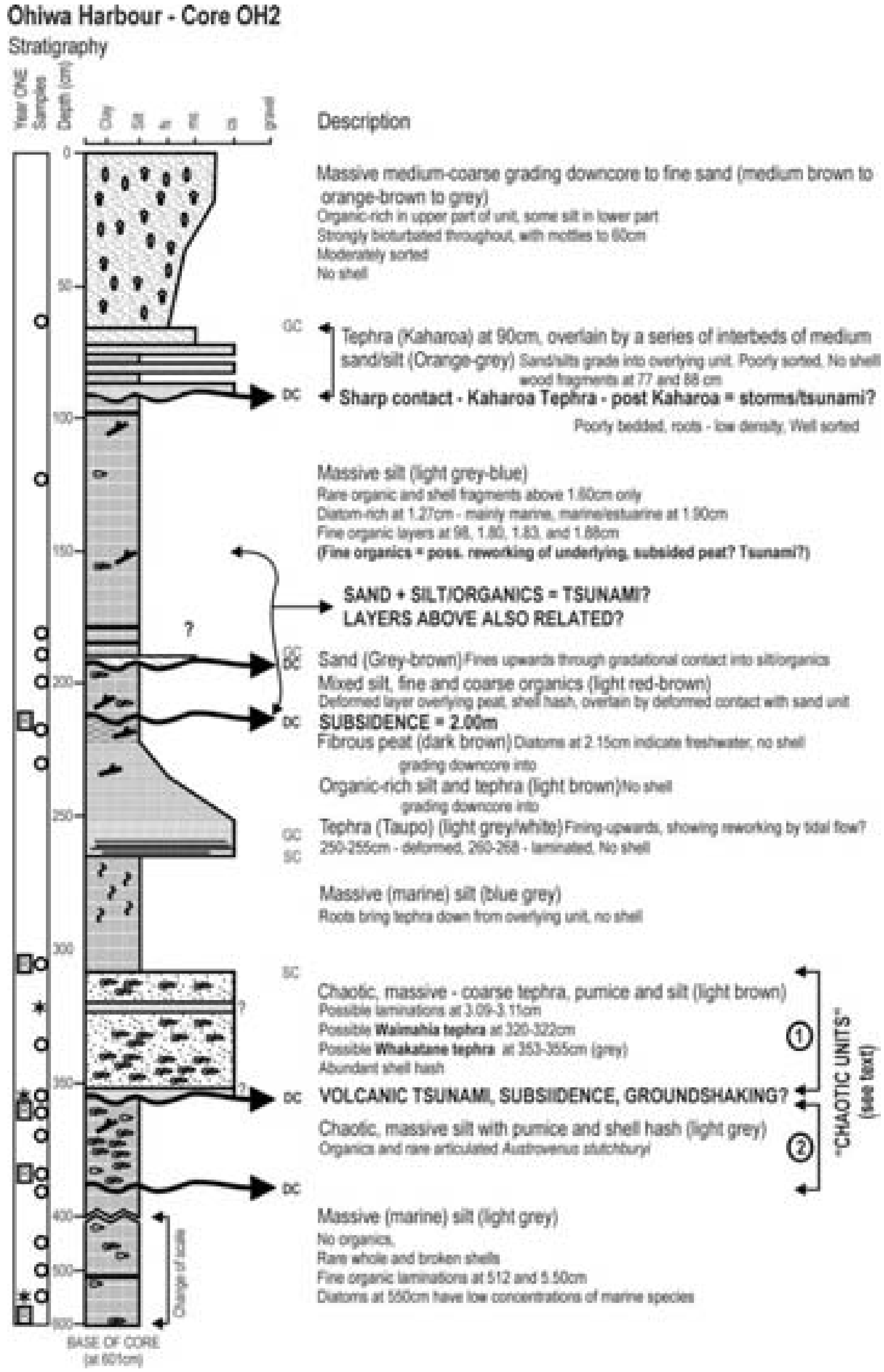


Figure 19: Ohiwa Harbour – Stoney Brook: Photographs of sections of Core OH1 showing; contact with Kaharoa tephra, subsidence event, and contact with the Taupo tephra.

Figure 20: Ohiwa Harbour – Jacobs Creek: Top picture, view from west; bottom picture, view from east. Approximate location of Core JC1 is shown.

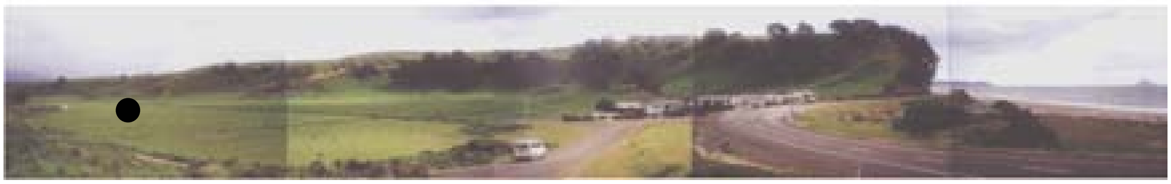
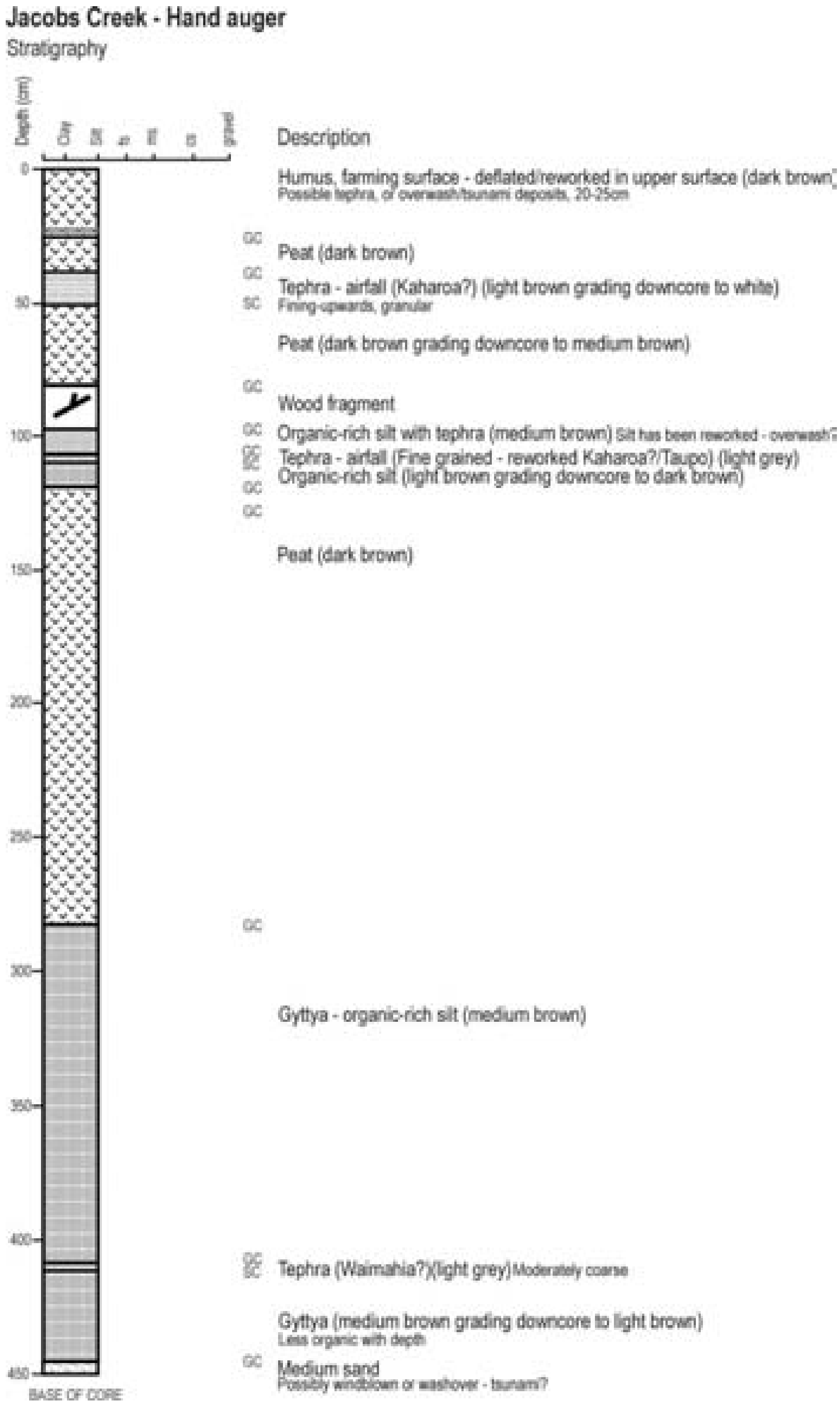


Figure 21: Ohiwa Harbour – Jacobs Creek: Stratigraphy of hand auger taken adjacent to Core JC1.



Tables

Table 1: Summary of reconnaissance survey results.

Location	Grid Reference	Suitability for study*
Fletcher Bay	S09 247223	B
Kennedy Bay	T10 & U10 385000	B
Maketu	V14 147770	B-C
Mercury Islands	U10	**A-B**
Ohui	T12 667546	B
Onemana	T12 660460	C
Opoutere	T12 667510	B
Otama Beach	T10 & U10 565955	A
Papamoa Beach	U14 025824	B
Pauanui	T12 655700	B
Port Charles	T10 & U10 324158	C
Port Jackson	S09 210220	B
Sandy Bay	T10 & U10 307164	B-C
Slipper Island	U11, U12 & U13 720570	**A-B**
Stoney Bay	S10 275182	C
Tauranga Harbour	U14 855873	B
Waihi Beach	U11, U12 & U13 715140	**A-B**
Waikawau Bay	T10 & U10 366080	A
Whangapoua	T10 & U10 440950	B
Whiritoa	T12 677313	**A-B**
Whitianga, Cooks Beach, Hahei Beach, Tairua	T11 515820; T11 555810; T11 604808; T11 645630	C

*A (most suitable), B (moderately suitable), C (unsuitable)

Table 2: Approximate chronology of events from EBOP Ancillary Tsunami report (Goff, 2002).

Event	Approx Age	Cause	Site
A	Post-Kaharoa (<750 years BP)	Groundshaking?	Maniatutu
B	Pre-Kaharoa and post-Taupo(c. 800-1800 years BP)	Possible subsidence *c*.50cm (induced tsunami closer to coast?)	Maniatutu, Poplar Road
		First event: subsidence – either regional or local, or another form of tsunamigenic event	Parton Road
??	Pre-Loisels	Tsunami linked with subsidence reported at other sites or be old estuarine sediments of the Kaituna River	Hickson Property
C?	Pre-Kaharoa and post-Taupo	Second event: subsidence either regional or local, or another form of tsunamigenic event	Parton Road
D?	Taupo eruption or pre-Taupo?	Tephra, but on the other hand may well be related to tsunami	Bell Road
E	Pre-Taupo (TPL), 2500 years BP?	Groundshaking	Hopping Farm
F?	Possible pre-Taupo, 3200 years BP??	Possible Waimahia ash or tsunami?	Parton Road

Table 3: A tentative assessment of the chronology of possible tsunami events from Stage 1 (relevant sites from Ancillary Tsunami Project shown in italics).

Approx Age	Cause	Site
Post-Kaharoa **(*c*.500-600 yrs BP)**	Healy? Or similar submarine/island volcano. Possibly with associated earthquake(s)/subsidence	• Korapuke • Waihi Beach (1.05m) • Otama (0.90m) • OH2 -Stoney Brook (0.75m)? More than one event? • Maniatutu
Kaharoa **(c. 750 yrs BP)**	Kaharoa eruption – meteorological/tectonic?	• OH2 -Stoney Brook (0.75-0.90m)? One event only? • Jacobs Creek (0.20m) • Waiotahi (Marra, 1997)
Pre-Kaharoa/Post-Taupo **(c. 800-1800 yrs BP)**	Subsidence – up to 2.00m (inducing tsunami at coast?)	• Waihi Beach (3.08m) • Otama (2.23m) • OH2 -Stoney Brook (2.09m) • *Maniatutu, Poplar Road, Parton Road, Hickson Property*
Taupo **(c. 1850 yrs BP)**	Taupo eruption	• OH2 -Stoney Brook (2.55m) • Jacobs Creek (1.05m) • *Bell Road*
Pre-Taupo: **Waimahia** **(c. 3200 yrs BP)?**	Waimahia eruption?	• OH2 -Stoney Brook (3.50m) • Jacobs Creek (1.05m) • *Parton Road*
Whakatane **(c. 4800 yrs BP)?**	Whakatane eruption?	• OH2 -Stoney Brook (3.85m) • Jacobs Creek (4.50m)?