GeoEnvironmental Consultants

Paleotsunami investigations – Okoropunga and Pukerua Bay

Prepared for

Wellington Regional Council

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In Association with

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Prepared for

Wellington Regional Council

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EXECUTIVE SUMMARY

Possible paleotsunami sites were investigated in the Okoropunga and Pukerua Bay areas. A late 15th Century tsunami deposit is reported from Okoropunga, and its association with an overlying gravel soil is discussed. The argument for this being a tsunami as opposed to a storm deposit is addressed with use being made of the 3rd April 2002 storm deposit that was laid down in the area. Material was also taken from a site at Te Oroi, where it was noted that recent storm activity had exposed a considerable length of coastal sediments, providing a rare opportunity for future work. The tsunami deposit is linked with other evidence from around the region and elsewhere. Bearing in mind the general rule of thumb that tsunami of 5 m or more are needed to produce visible tsunami deposits in the Cook Strait area, it is noted that the Okoropunga deposit does not mark the limit of tsunami inundation. It represents a small fraction of the area of inundation that would probably have included the entire Wairarapa coast and other parts of the region.

In the Pukerua Bay area, evidence for tsunami inundation was equivocal. However, a series of uplifted beach ridges, similar to those found on Mana and Kapiti Islands, and around Pauatahanui Inlet, indicate that possible tsunamigenic, region-wide, uplift events have occurred. The exact nature, dates and sources of these uplift events are unknown and further research is recommended.

It was noted that other additional future work could include a study of suitable coastal wetland environments on the eastern and southern coast of the Wellington region. This would help produce a long term record of tsunami inundation because wetlands tend to preserve records of several previous events, not just the last one.

Another key point raised by this study is that without suitable expertise the presence of a tsunami deposit in either exposed coastal platforms or low-lying wetland-type environments is likely to be overlooked. It is suggested that any future developments must investigate the physical evidence (sediments) for such hazards either prior to application for resource consent or that it be made a condition of the consent.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The Wellington Regional Council contributed towards the costs of a paleotsunami investigation of selected deposits in the Wellington Region.

The investigation involved a combination of reconnaissance work and hand and trench digging at sites of potential paleotsunami deposits. Samples were taken for microfossils and geochemical analyses, although these will not be part of the report. This research report provides a summary of the results (including maps, photos and figures) and describes how the findings enhance the overall understanding of tsunami hazard in the Wellington Region.

1.1. Caveat

This report is written on the basis of the contemporary scientific knowledge about tsunami and tsunami hazards. We have made every attempt 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 tsunami indicate that the effects along a coastline are extremely variable.

2. CONTEXT

The data discussed below add some additional information to the Wellington Regional Tsunami Hazard Scoping Project (Wellington Regional Council Publication No. WRC/RP-T-01/23) undertaken by GeoEnvironmental Consultants in 2001. The reader is referred to that document for much of the region-specific data pertinent to this report.

In the Wellington region there are at least five active faults: the Wairarapa, Wellington, Ohariu, Shepherd's Gully, and Pukerua faults (Van Dissen and Berryman, 1996; Goff et al., 1998) which are thought to be North Island continuations of the divided Alpine Fault (Carter et al., 1988). Many others exist but their activity is poorly understood. However, earthquakes related to tectonic activity in the Cook Strait region within the time of human settlement can be grouped into three main time periods (Goff and McFadgen, 2001): 13th Century AD, 15th Century AD, and the 1750s to 1850s.

- The earliest group occurred about the time of human colonisation but are not discussed here in any detail.
- The second group was well after human settlement at a time when the Cook Strait coast had been settled by prehistoric Maori (e.g. Leach and Leach, 1979).
- The third group contains the magnitude 8+M_w 1855AD Wairarapa earthquake, the tsunami effects of which are discussed in the GeoEnvironmental Consultants (2001) report.

Previous research in New Zealand has already identified some tsunami deposits in and around the Cook Strait region that were laid down during the two earlier periods mentioned above. 13th Century AD, 15th Century AD, and 1855AD tsunami deposits have been reported from Abel Tasman National Park (Goff and Chagué-Goff, 1999) and Kapiti Island (Goff et al., 2000), and a 15th Century AD event from Mana Island (Goff et al., 2000) and Okourewa, Palliser Bay (Goff et al., 1998; Goff et al. 2001) (Fig. 1). Based upon these and other tsunami data reported for Cook Strait it is now generally accepted that tsunami wave heights within Cook Strait need to be at least 5 m high to leave a recognisable deposit (Lowe and de Lange, 2000). However, the deposits left by ancient tsunami in the region depend upon the nature of the coastline and whether it is in a more 'exposed' or 'sheltered' location (Goff et al., 1998). An exposed site normally preserves evidence only of the latest event, whereas a sheltered location can preserve a record of multiple events.

Based upon the existing data, there is every reason to expect that prehistoric Maori coastal settlements in the Cook Strait region would have been affected by 15th Century AD tsunami. In the past, however, little attention has been given to the impact of seismic activity on such communities even though this type of information is extremely relevant to on-going development of the region's coast. There is passing reference to the impact of earthquakes by Best (1923) and McFadgen (1980a) but the most comprehensive analysis to date has been by Goff and McFadgen (2001) who reinterpreted data collected from Palliser Bay in the early 1970s (Leach and Leach, 1979). Environmental changes and changes in prehistoric occupation, including site abandonment, were originally explained in terms of human impact on the landscape and a climate change from a relatively calm, warmer period to a stormy cooler period

(Leach and Leach, 1979). Using an improved understanding of the effects of seismic activity (e.g. Grapes and Downes, 1997), the environmental and cultural changes described by Leach and Leach (1979) were reinterpreted as being the result of human impact and seismic-related activity (Goff and McFadgen, 2001).

This report discusses further evidence for the effects of large earthquakes and their aftermath in two places, the Okoropunga and Pukerua Bay areas. The impact upon prehistoric Maori coastal settlements is particularly relevant to the former. All the sites discussed are in generally exposed sites, and therefore one would expect to find evidence for the latest event only.

3. OKOROPUNGA AREA

3.1. Okoropunga

Okoropunga is situated in the southeastern part of the Wellington Region, between the Oterei and Pahaoa rivers. Here there are prehistoric Maori gardens built on the Holocene coastal platform across uplifted beach ridges of gravel and cobbles mantled with sand (Figs. 1 and 2; McFadgen, 1980b). A similar situation is found along much of the Wairarapa coast. Many of these coastal platforms along the Wairarapa coast are either being developed or are under consideration for future development as new road end sub-divisions.

Radiocarbon ages for the gardens indicate that they were in use in the 15th Century AD (Table 1). Between the inland and seaward gardens is a partly infilled borrow pit (from which garden material was mined) and stone row gardens that appear to have been partly or totally buried (Fig. 3). Near the back of the coastal platform is a sheet of sand estimated from soil profile development and radiocarbon dating to be between 300 and 500 years old (McFadgen, 1980c; Table 1), in other words it was laid down at the time of Maori occupation.

Ten trenches were dug within the sand sheet, with great care being taken to avoid any known archaeological sites. At all trench sites the tsunami deposit was initially difficult to distinguish as it was similar to the underlying material. One trench (I) showed a small amount of gravel in the top of the tsunami deposit. The gravel is possibly the edge of the Anthropic soil described by McFadgen (1980c), although apart from gravel there were no other distinguishing criteria. Subsequent cleaning and preparation of sections of trench wall allowed the tsunami deposit to be identified and studied in detail. Two trench sites were selected for examination in greater detail.

- At Trench I (21.0 m x 0.6 m), the top of the tsunami deposit contains gravel (Figs. 2, 4 and 5). The lower contact was abrupt but uneven suggesting an element of erosion but also of a marked change in depositional environment. The upper contact with the gravelly deposit was uneven and shows that the gravel was mixed into the upper parts of the tsunami deposit and a subsequent tsunami inundation, a second wave or an inundation possibly generated by the historic 1855 AD Wairarapa earthquake, cannot be ruled out.

Sediment samples were taken from the surface to base of the trench at several places. While sample analysis does not form part of this report, initial observations indicate that the sediment characteristics are not favourable for microfossil preservation or for retaining a good geochemical signal. However, a detailed sedimentological analysis will be undertaken and comparisons will be made between all sediments to ascertain different depositional environments. This is discussed in more detail below.

- Trench II (11.0 x 0.6 m) was dug through the main section of the sand sheet (Fig. 6). The deposit is thicker here, but more difficult to distinguish because of the lack of contrast between the under- and overlying material. Unlike tsunami deposits reported from other areas of the Wellington region (e.g. Kapiti Island, Okourewa) the tsunami deposit consists largely of material that is sedimentologically *similar* to that in which it is found and therefore marked visual differences are difficult to distinguish without careful study. This is a key point because without suitable expertise the presence of a tsunami deposit in these types of exposed coastal platform is likely to be overlooked. Identification of a tsunami deposit based upon sediment characteristics alone is problematic (Goff et al., 2001), although in this instance the use of archaeological data from the surrounding area provides useful additional information (e.g. Goff and McFadgen, 2001). Samples were also taken from the surface to the base of the trench and have been prepared for detailed sedimentological analyses.

Figure 2 indicates the areal and vertical extent of the deposit. The sand sheet covers more than a hectare, is up to 70 cm thick, and rises up to 10.5 m above present sea level where it pinches out (Fig. 2). The sheet fines upwards from a very coarse sand to a medium to coarse sand and fines inland between sites A and B (Goff and McFadgen, in press) (Fig. 2). The buried stone row gardens, infilled borrow pit, and sand sheet are consistent with tsunami inundation.

The gross sedimentological information indicates catastrophic saltwater inundation. The deposit rises to an elevation of at least 10.5 masl, well above the elevation of other possible generating mechanisms. While the coast is likely exposed to considerable storm surge and cyclonic activity, the absence of any other significant deposit at or near this elevation indicates that tsunami inundation is the most likely explanation. However, because this is an exposed coastline it is probable that this, the latest catastrophic inundation, destroyed the evidence of earlier events of similar magnitude thus making the tsunami inundation hypothesis equivocal.

n.b. It should be noted that the maximum lateral and vertical extent of a tsunami deposit does not represent the maximum extent of tsunami inundation. At present there are no clearly defined relationships between actual tsunami run-up and the extent of the resulting deposit. In New Zealand we have reached the point where we can say that these sediments probably represent tsunami waves of 5 m or more, and it is therefore likely that tsunami inundation would have covered a considerably larger area. Tsunami of 0.5 m or less can cause widespread destruction (e.g. some inundations associated with the 1946 and 1960 tsunami, Hawaii) and it would not be unreasonable to assume that tsunami inundation related to this deposit would have affected all of the Wairarapa coast and probably much more of the region.

For comparative purposes it was fortunate that during the period of study this stretch of coastline suffered from a storm surge equivalent to a 30-50 year event, similar in size to the Wahine Storm. We were fortunate enough to be able to study the resulting storm surge deposits laid down along the coast (Fig. 7). The maximum inland extent of inundation from MHW was 36 m, with the deposit rising to a maximum possible elevation of 2.5 masl. A maximum clast size of 100 cm was recorded 20 m inland. Samples of sand were taken for analysis, and grain size measurements were made. Initial indications show that like the tsunami deposit, the sediment characteristics are not favourable to the preservation of microfossils or a geochemical signal. However, even cursory observations indicate that there are fundamental differences between the nature of each deposit. The storm deposit indicates chaotic deposition by varying levels of energy, whereas the tsunami deposit indicates a waning energy with distance inland - a far greater distance, to a far greater elevation.

Comparisons will be made between the sediments of both deposits and these will be reported in due course. Detailed sedimentological techniques are being developed that can be used to differentiate between the mode of deposition of high energy events. Distinct zones of sedimentary characteristics are being defined for tsunami and storm surge, but at present researchers are dealing with a limited database. The Okoropunga data provide a unique New Zealand dataset for such comparison, and world-wide it is one of only two sites where both tsunami and storm surge deposits have been sampled from the same area. Copies of any publications relating to this work will be made available to the council.

No additional radiocarbon dateable material was found within the tsunami deposit at any of the Okoropunga sites over and above those dates reported in Table 1. It was therefore decided to examine other localities nearby in an attempt to find useful dateable material associated with tsunami inundation. The existing dates indicate that the tsunami probably took place sometime around the late 15th to early 16th centuries AD.

3.2. Te Oroi

At Te Oroi, on the coast about 25 km southwest of Okoropunga, the Oroi Stream cuts through the coastal platform leaving vertical sections exposed on the true left bank (Fig. 8). Earlier work by McFadgen (1985) identified three distinct depositional “chronozones” of deposition, the Hoatan (c. 150 years BP to present), the Ohuan (c. 450-150 years BP) and the Tamatean (c. 1800-450 years BP). The tsunami sand lies above the Tamatean and is part of the Ohuan sediments giving an approximate age for the event. In addition, a group of Paua (*Haliotis iris*) shells within the deposit were sampled for radiocarbon dating. A radiocarbon age of 759+/-42 years BP was obtained, yielding a calibrated age of between 1480-1660AD at a 95% probability. This age is consistent with the deposit at Okoropunga, suggesting that this was a regionally extensive event. No other sampling was undertaken, although it was noted that recent storms have eroded and exposed at least 1 km of coastal sediments adjacent to the Te Oroi stream. A brief examination of the exposure was of limited success due to fading light, but this extensive exposure represents a rare chance to carry out further work along part of the Wairarapa coast. The authors note that the last time such an exposure was available for study was approximately 30 years ago.

3.3. Palliser Bay

Palliser Bay, about 40 km west of Okoropunga (Fig. 1), was not visited during this work, but existing evidence is useful from a regional perspective. Like both Okoropunga and Te Oroi, the Palliser Bay coastline is tectonically uplifted as shown by the presence of six uplifted shorelines on a coastal platform up to 1 km wide (Ghani, 1978). Prehistoric Maori extensively occupied the eastern coastal platform about 700 years ago. Settlements and gardens were established on friable soils at stream mouths and up stream valleys. Birds, fish, shellfish, and gardening were the basis for the subsistence economy (Leach and Leach, 1979).

Increased colluvial fan activity and severe river flooding, dramatic changes in shellfish numbers and the apparent loss of filter feeders from coastal waters, have all been interpreted as evidence of seismic activity that occurred during occupation and precipitated the rapid abandonment of the Palliser Bay coast by human communities in the 15th century AD (Goff and McFadgen, 2001).

It seems likely that the same event was responsible for the geological evidence found at all sites.

4. PUKERUA BAY AREA

4.1. Pukerua Bay

Brief examination of the Pukerua Bay site indicated that this was unlikely to reveal any useful data and that any deposits previously noted were no longer present. We therefore took the opportunity to look further south in the vicinity of Titahi Bay for evidence of possible tsunami inundation.

4.2. Titahi Bay

Access to the narrow coastal platform was by foot and therefore the ability to dig extensive trenches was limited. However, a series of uplifted beach ridges was identified and measured. It was felt that the uplift events that generated these ridges would have been sufficient to generate tsunami, but the timing and regional extent of these could not assessed within the scope of this present study. We are aware of similar uplifted ridges on the adjacent island of Kapiti and Mana, and in the Pauatahanui area. Some of these have been dated, and a 15th Century event is documented at both Kapiti and Mana, as is one around 3200 years BP (Goff et al., 2000). However, further work is needed to assess the regional extent of these uplifted beach ridges, and to produce a detailed chronology that can be fitted with all available paleoseismic and paleotsunami data.

A reconnaissance study of the area revealed numerous well-rounded marine gravels in sediments up to an elevation of approximately 30 masl (Fig. 9). They appeared to have been reworked from further uphill, but we were unable to locate any source deposit. It seems unlikely that they were emplaced by tsunami, although this cannot be ruled out. A more likely source would appear to be prehistoric Maori garden terraces. Several terraces were found in the general vicinity, but not immediately uphill of the marine pebbles.

There was insufficient time available for a more extensive study and therefore the evidence for tsunami inundation along this particular stretch of the region's coast remains equivocal. However, there is evidence from both Mana and Kapiti Islands, and also from Te Ikaamaru Bay, approximately 20 km south of Titahi Bay.

4.3. Te Ikaamaru Bay

At Te Ikaamaru Bay, marine gravels, mixed with cultural remains including obsidian flake tools, is exposed on the surface of an old sand dune on the west side of the Homestead Gully Stream. 25 years ago the gravel and cultural remains were interpreted by one of us (BGM) as having been added to a garden soil. Further study has shown that the gravel is, however, part of a poorly stratified unit of marine pebbles, coarse sand and alluvium that overlies sand and alluvium for more than 200 m inland. The unit also overlies cultural remains consisting of charcoal-blackened sand and oven stones. Without precluding the possibility that parts of the layer were later gardened, our interpretation now is that the marine gravel represents tsunami inundation that is stratigraphically older than 1855AD and younger than Maori settlement. Sedimentologically the gravel is strikingly similar to other tsunami deposits found in the Cook Strait region (e.g. Okourewa, Fig.1) (Goff et al., 1998). Since the deposit is older than 1855AD and younger than Maori settlement we infer that this event relates to the second group of seismic activity in the 15th Century AD.

5. REGIONAL PERSPECTIVE

GeoEnvironmental Consultants (2001) discussed the broad regional picture for tsunami hazard. Here we have investigated two broad areas, Okoropunga and Pukerua Bay, where there were believed to be possible tsunami deposits.

Work at both sites has revealed evidence showing that one or more events occurred around about the 15th Century AD. At Okoropunga, a Maori garden site, the work indicates that tsunami inundation probably occurred in the late 15th Century after which the site was reoccupied and new gardening techniques were possibly adopted. Further south, a similarly timed event inundated Te Oroi. Whether or not this was also experienced further north at Flat Point, we are unable to say from these data. However, in Palliser Bay, settlement abandonment appears to have been the result of seismic-related events including tsunami and this suggests that tsunami inundation was widespread around the Wairarapa coast at this time.

Similarly, on the west coast of the region, while Pukerua Bay proved to have no suitable sites, a reconnaissance of the coast further south around Titahi Bay revealed that there are several uplifted beach ridges that may well be of similar age to those found on Mana and Kapiti Islands. While beyond the scope of this study, the authors are aware of several dated beach ridges in the area, but the nature of the association between sites is yet to be established. It seems likely that they are probably all related to synchronous events, in which case there were quite likely tsunamigenic. Rounded marine pebbles found at elevations up to 30 masl may be tsunami related, but are more likely to have worked their way downhill from prehistoric Maori garden terraces, although we were unable to find any in the immediate vicinity.

Recently, Goff and McFadgen (in press) have reported the seismic driving of nationwide changes in geomorphology and prehistoric settlement as a result of a cluster of large earthquakes in the 15th century. There may well have been other tectonic-related driving mechanisms but these were not discussed. They reviewed a suite of environmental outcomes including tsunami, rapid coastal dune building, and river aggradation, as well as the abandonment of prehistoric Maori coastal settlements. The evidence from Okoropunga, Te Oroi and Palliser Bay fit within this model for nationwide change. In brief, seismic activity immediately generates tsunami and landslides. Sediment flow down rivers causes an increase in fine material reaching the nearshore zone and a period of rapid coastal dune building takes place, while coarser material forms river aggradation surfaces. Prehistoric coastal Maori settlements suffer from tsunami inundation, sediment smothering of shellfish beds, and loss of land due to landsliding and aggradation (Goff and McFadgen, 2001).

The 15th Century event (or events – they cannot be differentiated based upon radiocarbon dates) in the Wairarapa is part of this nationwide pattern. The environmental outcomes appear to have taken place over an extremely short time frame, in the order of a few decades whereas previous clusters of large earthquakes appear to have had a more drawn out aftermath. Goff and McFadgen (in press) identify an unfortunate coincidence with a catastrophic El Niño event at the same time that may well have accelerated the movement of sediment from the mountains to the sea. From the available data, a broad grouping of such events seems to occur about once every 500 years or so (Goff and Chagué-Goff, 2001), although usually not as rapid and catastrophic as the 15th Century event. However, tsunami are an immediate aftermath of many large earthquakes, and it is not necessary for other environmental outcomes to follow to cause a catastrophe. Therefore it is interesting to note that these events may occur about once every 500 years. The last one seems to have caused region-wide tsunami inundation of the Wellington region, and it is therefore likely that other evidence exists for earlier events. Indeed, the 13th Century event has already been reported from Kapiti Island and also Abel Tasman National Park (Goff and Chagué-Goff, 1999; Goff et al., 2000). The evidence for several previous events are found on Kapiti Island, but little or no work has been undertaken elsewhere in the region to add to this database.

The suggestion is that large, catastrophic tsunami affect the whole region at least once every 500 years or so as a result of locally-generated events. This sits outside any other evidence for distantly-generated events, their return period and their destructive ability. Similarly, there will most likely have been other locally-generated events that were more locally focussed.

6. FUTURE WORK

Based upon the findings of this study, we would suggest that there are three main areas of future tsunami research in the immediate future:

a) A study of the uplifted beach ridges on the west coast of the region to determine synchronicity and likely fault sources.

b) A study of suitable coastal wetland environments on the eastern and southern coast of the Wellington region to complement work already undertaken on Kapiti Island. This would help produce a longer term record of tsunami inundation since wetlands tend to preserve records of several previous events, not just the last one.

c) A study of the exposed coastal land in the vicinity of the Oroi Stream. The erosion caused by recent storms offers a rare opportunity to examine an extensive stretch of coastal sediments.

Another key point raised by this study is that without suitable expertise the presence of a tsunami deposit in these types of exposed coastal platform is likely to be overlooked. Similarly, in areas where there might be multiple events recorded (e.g. in or adjacent to wetlands), then an appropriate systematic approach should be adopted (Goff et al., 2001) for the investigation. We would therefore like to to suggest 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 the particular site will be destroyed forever.

REFERENCES

Best, E. 1923. Miramar and its history: How Motu-kairangi was discovered and settled by Polynesians and how in times long past it became Miramar Peninsula. Transactions of the New Zealand Institute, 54, 779-791.

Carter, L., Lewis, K.B. and Davey, F. 1988. Faults in Cook Strait and their bearing on the structure of central New Zealand. New Zealand Journal of Geology and Geophysics, 31, 431-446.

Ghani, M.A. 1978. Late Cenozoic vertical crustal movements in the southern North Island, New Zealand. New Zealand Journal of Geology and Geophysics, 21, 117-125.

Goff, J.R. and Chagué-Goff, C. 1999. A Late Holocene record of environmental changes from coastal wetlands: Abel Tasman National Park, New Zealand. Quaternary International, 56, 39-51.

Goff, J., Chagué-Goff, C. and Nichol, S. 2001. Palaeotsunami deposits: A New Zealand perspective. Sedimentary Geology, 143, 1-6.

Goff, J.R., Crozier, M., Sutherland, V., Cochran, U. and Shane, P. 1998. Possible tsunami deposits of the 1855 earthquake, North Island, New Zealand. In: Stewart, I.S. and Vita-Finzi, C. (eds.) Coastal Tectonics. Geological Society Special Publication No. 133, 353-374.

Goff, J.R. and McFadgen, B.G. 2001. Catastrophic seismic-related events and their impact on prehistoric human occupation in coastal New Zealand. Antiquity, 74, 155-162.

Goff, J.R. and McFadgen, B.G. in press. Seismic driving of nationwide changes in geomorphology and prehistoric settlement – a 15th Century New Zealand example. Quaternary Science Reviews.

Goff, J.R., Rouse, H.L., Jones, S., Hayward, B., Cochran, U., McLea, W., Dickinson, W.W. and Morley, M.S. 2000b. Evidence for an earthquake and tsunami about 3100-3400 years ago, and other catastrophic saltwater inundations recorded in a coastal lagoon, New Zealand. Marine Geology, 170, 233-251.

Grapes, R. and Downes, G. 1997. The 1855 Wairarapa Earthquake, New Zealand, Earthquake – Analysis of Historical Data. Bulletin of the New Zealand Society for Earthquake Engineering, 30, 271-368.

Leach, B.F., Leach, H.M. (Eds.). 1979. Prehistoric Man in Palliser Bay. Bulletin of the National Museum of New Zealand, 21, 272p.

Lowe, D.J. and de Lange, W.P. 2000. Volcano-meteorological tsunamis, the c. AD 200 Taupo eruption (New Zealand) and the possibility of a global tsunami. The Holocene, 10, 401-407.

McFadgen, B.G., 1980a. Age relationship between a Maori plaggen soil and

Moa-hunter sites on the west Wellington coast. New Zealand Journal of Geology and Geophysics, 23, 249–256.

McFadgen, B.G., 1980b. A Stone Row System at Okoropunga on the southeast Wairarapa coast and inferences about coastal stone rows elsewhere in central New Zealand. New Zealand Journal of Science, 23, 189–197.

McFadgen, B.G., 1980c. Maori Plaggen Soils in New Zealand: their origin and properties. Journal of the Royal Society of New Zealand, 10, 3-18.

McFadgen, B.G., 1985. Late Holocene stratigraphy of coastal deposits between Auckland and Dunedin, New Zealand. Journal of the Royal Society of New Zealand, 15, 27–65.

Van Dissen, R.J. and Berryman, K.R. 1996. Surface rupture earthquakes over the last ~1000 years in the Wellington region, New Zealand, and implications for ground shaking hazard. Journal of Geophysical Research, 101 B3, 5999-6019.

FIGURES

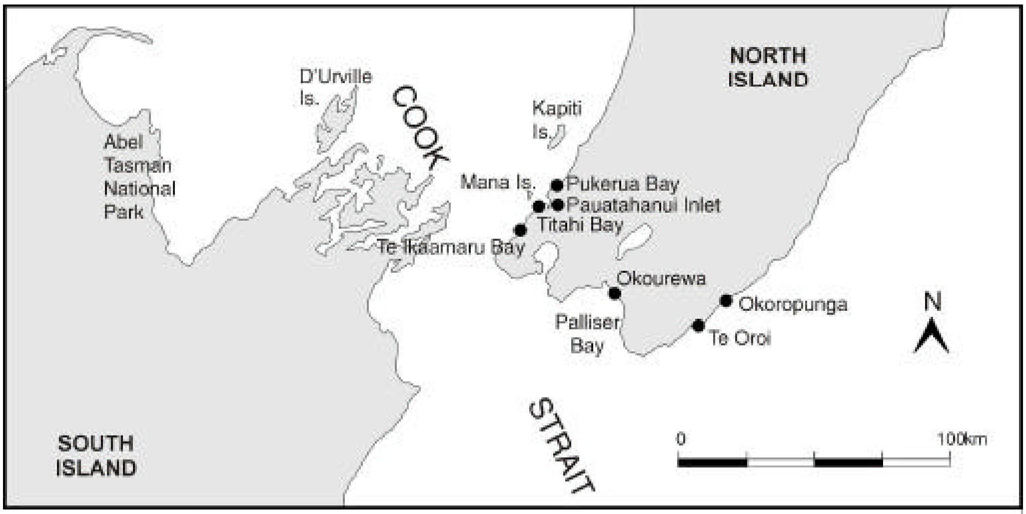

Figure 1: Map showing locations discussed in the text

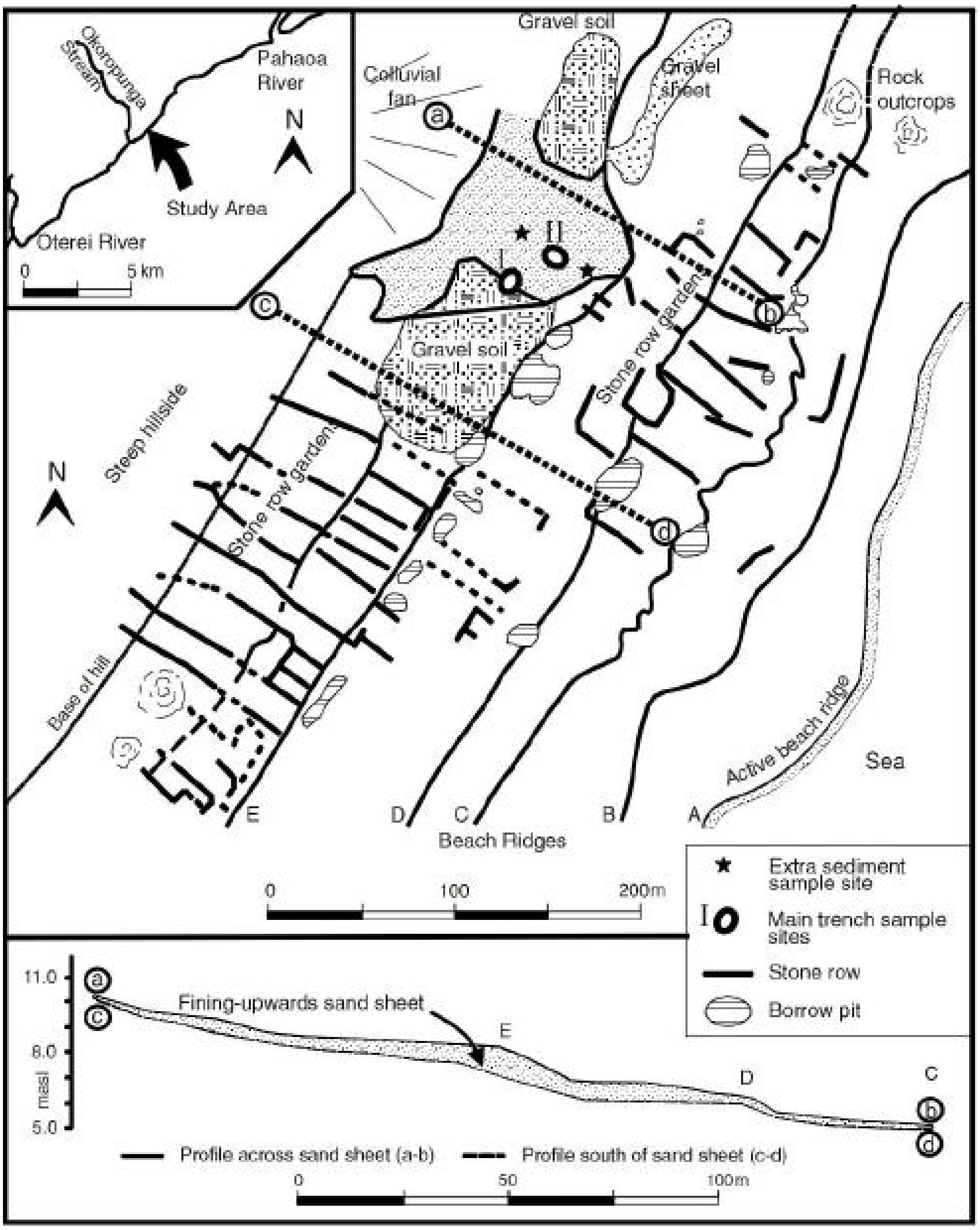

Figure 2: Okoropunga. Archaeological site with associated sand layer. Transects a-b and c-d are given at base of figure. Simplified after McFadgen (1980b)

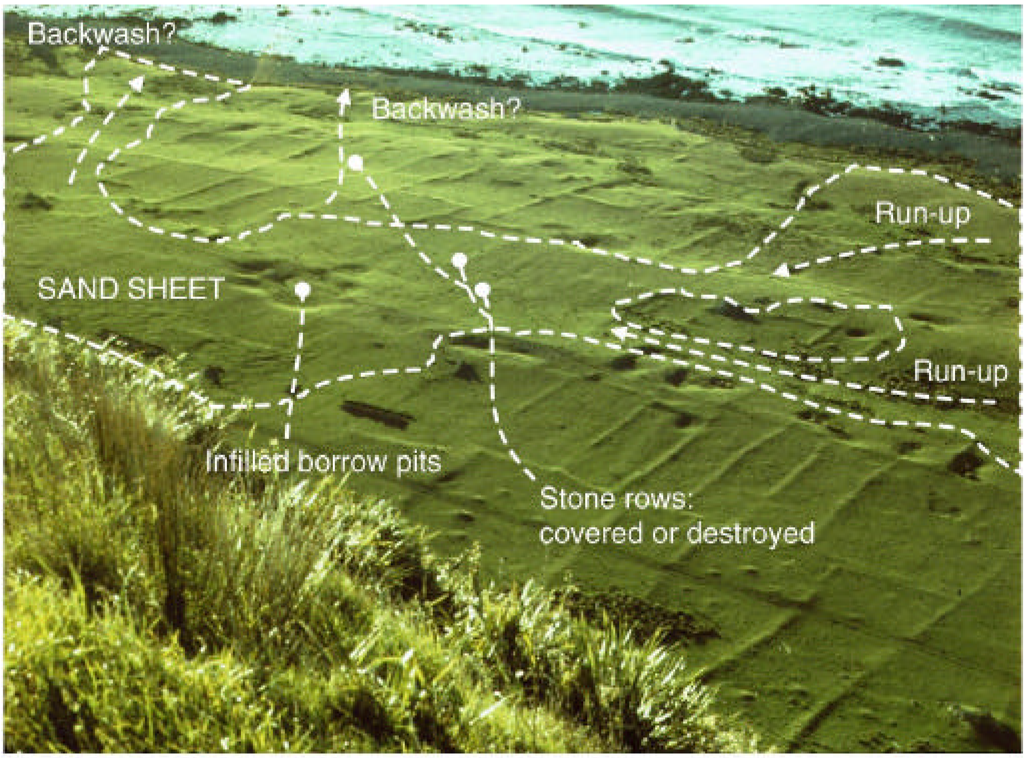

Figure 3: Okoropunga. Garden system, covered stone rows and infilled borrow pits on uplifted shorelines (Photo: Graham Billing). Geomorphological interpretation shown by dashed lines

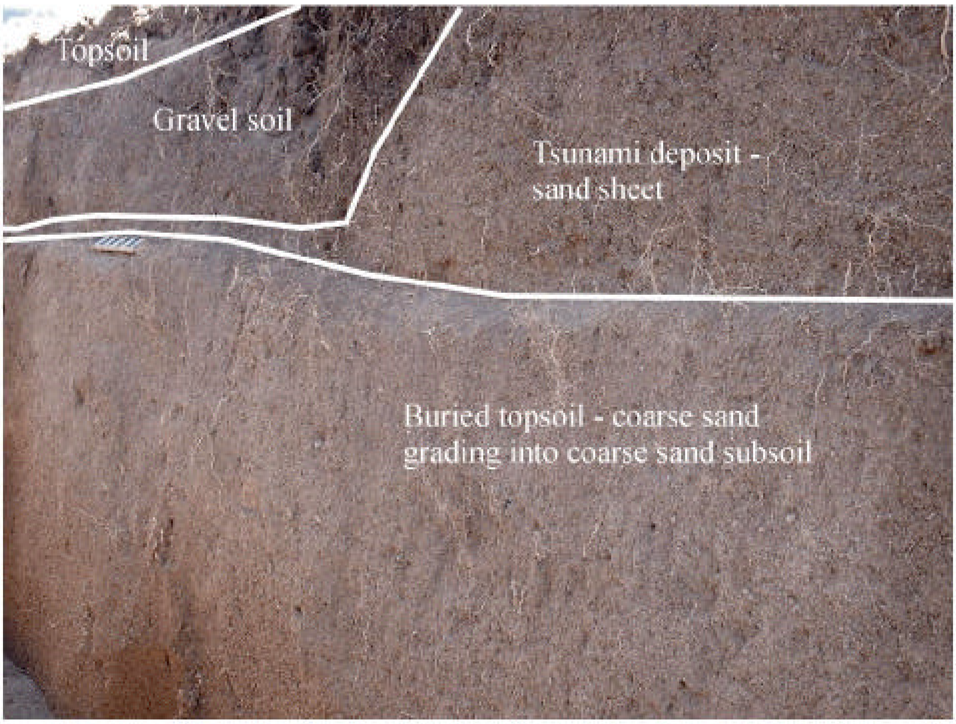

Figure 4: Okoropunga, Trench I. Tsunami deposit abuts up against the gravel soil

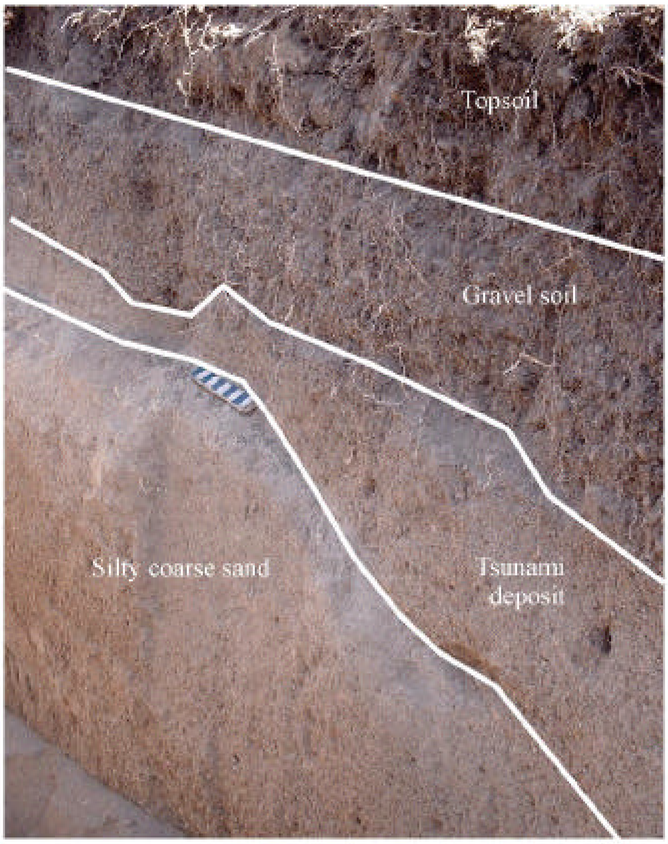

Figure 5: Okoropunga, Trench I. Detail of tsunami deposit abutting gravel soil

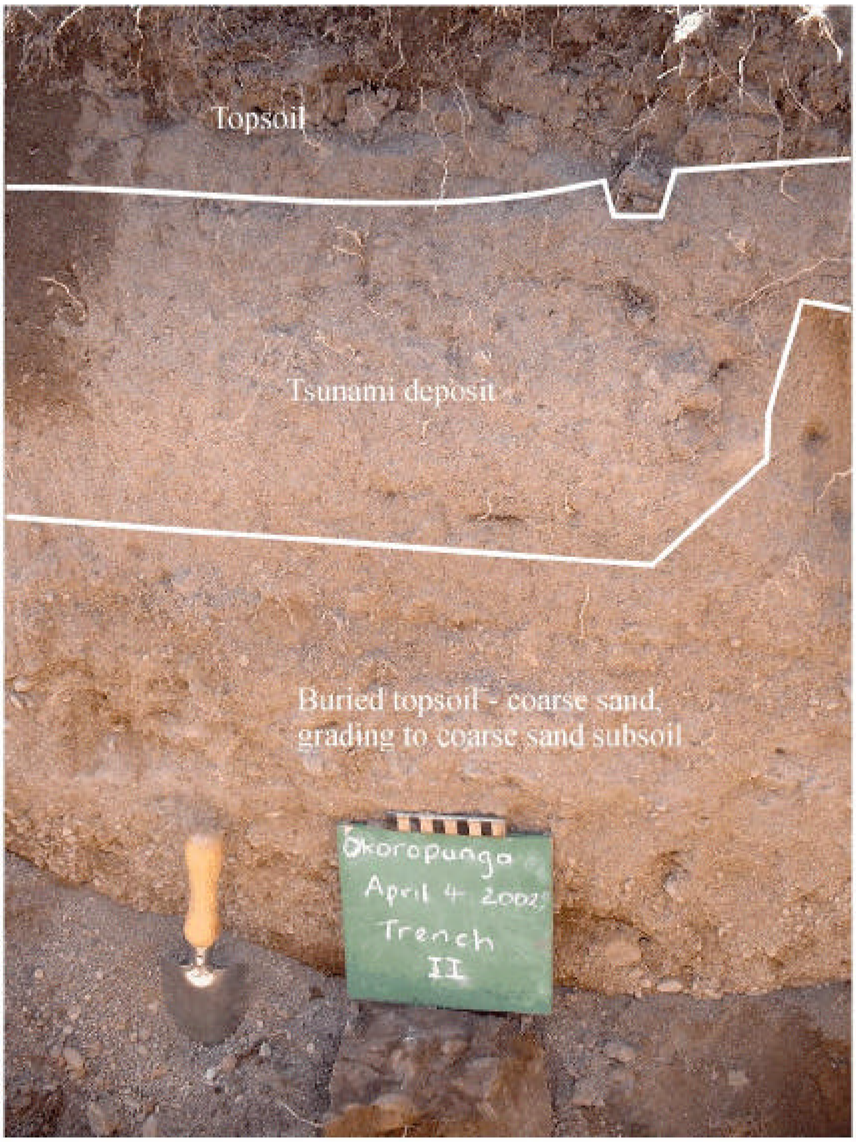

Figure 6: Okoropunga, Trench II. Tsunami deposit overlain by present-day topsoil.

Figure 7: Storm deposit, Te Awaiti, 3rd April 2002.
Top photo - note chaotic nature of deposit, no indication of fining-inland. People are standing on the road, the sea is behind the camera. Bottom photo - note all clast sizes from both boulders to sand were deposited, smothering vegetation

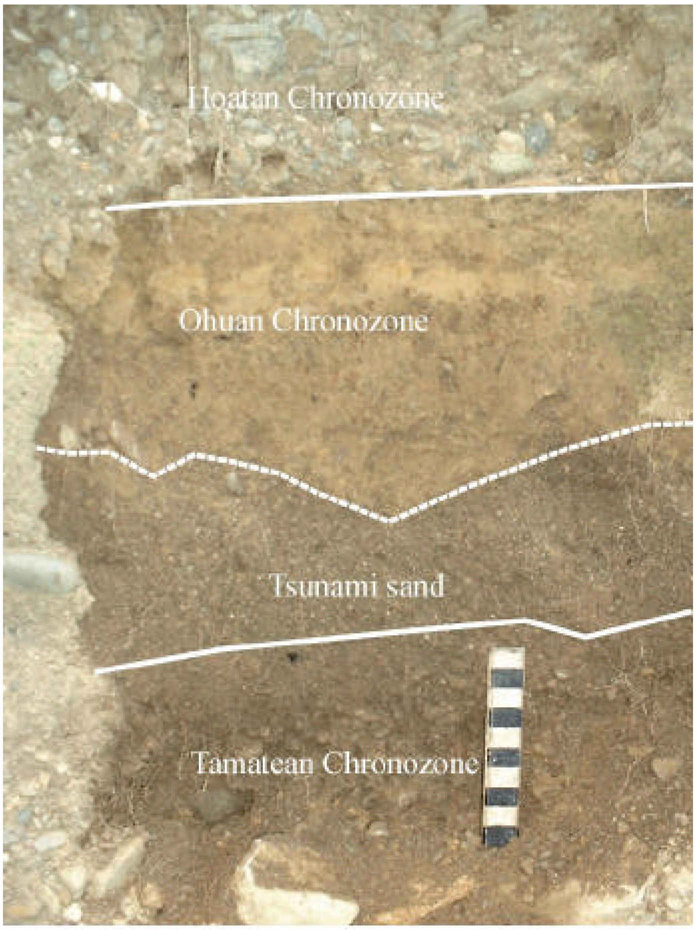

Figure 8: Te Oroi - left stream bank

Figure 9: South of Titahi Bay. Rounded marine pebbles up to 30 masl.

TABLES

Table 1: Summary of radiocarbon data

Lab. No.	Location	Material	Radiocarbon age BP
NZ3114A	Okoropunga: Soil around stones in stone rows	Charcoal: *Coprosma* sp., *Hebe* sp., *Podocarpus spicatus*	340+/-60
NZ3115A	Okoropunga: Buried topsoil, immediately beneath NZ3114A	Charcoal: *Coprosma* sp., *Podocarpus totara-hallii* group	530+/-60
Wk-10880	Te Oroi: Immediately beneath tsunami sand	Shells: Paua (*Haliotis iris*)	759+/-42