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Tsunamis in the New Zealand archaeological record

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Abstract

Historical and geological records both indicate tsunami inundation of New Zealand in the 700 years since the first human settlement. In addition, Maori oral traditions refer to unusual waves that might have been tsunami waves, although the accounts are open to other interpretations. Tsunami evidence has rarely been proposed from archaeological sites, primarily because of a limited understanding of the requisite evidence and environmental context. We list a criteria suggesting possible tsunami inundation of archaeological sites based upon geoarchaeological data, and use them in a case study from the Archaic Maori occupation site at Wairau Bar. The list is possibly incomplete, but indicates that archaeological investigations can gain from assessments of changing environmental conditions through time at any individual site. Our intention is not to prove tsunami inundation; rather, it is to point to archaeological sites as possible sources of information. We highlight the potential of the Wairau Bar site for further investigation.
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Keywords: Archaic; Tsunami; Maori legends; Wairau Bar; Archaeological sites

1. Introduction

New Zealand is a group of islands in the southwest Pacific Ocean that sits across the interface of two major tectonic plates (Fig. 1). It is exposed to tsunamis from local and distant sources (de Lange and Healy, 1986). Tsunamis greater than 12 m high have inundated the coast in historic times, and have run up to heights above 30 m since post-glacial sea level reached its present height about 6500 years ago (de Lange and Healy, 1986; Bell et al., 2004; Nichol et al., 2004). It is one of many places in and around the Pacific with a long record of tsunamis affecting coastal communities (e.g. Hawaiian Islands — Atwater et al., 1999; Burney, 2002; Papua New Guinea — McSaveney et al., 2000; Canada — Hutchinson and McMillan, 1997; Pacific Northwest, USA — Cole et al., 1996; Japan/Chile/Peru — Atwater et al., 1999).

Europeans arrived about 200 years ago and while written history provides an extensive record of tsunami events, albeit many of them small, there is no such record for the prehistoric period. The first people to settle New Zealand, the Polynesian ancestors of today's Maori population, arrived about 700 years ago (Anderson, 1991; McFadgen et al., 1994; Higham and Hogg, 1997). They were primarily a coastal people (Davidson, 1984), and they have oral traditions that describe unusual waves. The causes of the waves are equivocal. It is not always possible to rule out a tsunami event, and in such cases, the traditions provide a reason to look

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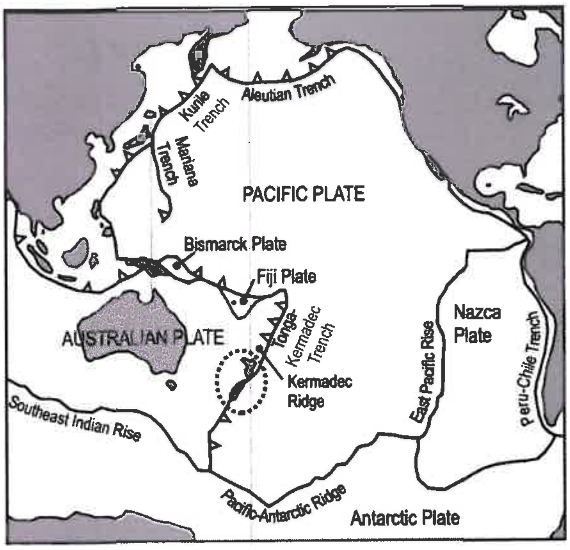

Fig. 1. New Zealand's position in the Pacific Ocean with relation to the major lithospheric plate boundaries.

more closely at the archaeological record as a possible source of additional information.

Archaeological remains of prehistoric coastal settlements are a potential source of information (Goff and McFadgen, 2001, 2003). In this paper, we discuss the sort of evidence that archaeological sites might contain, and we illustrate the evidence with a case study.

2. Context

2.1. Distribution of archaeological sites and tsunami risk

For more than 200 years following Polynesian settlement, the population centred on the drier eastern side of the main axial ranges, close to the source of large birds and sea mammals, in what Anderson (2002) calls the *leeward province* (Fig. 2). Of all archaeological sites dating from the first few hundred years of Polynesian settlement about three-quarters are in the *leeward province* (Anderson, 1997). People lived mainly along the eastern seaboard of the two main islands, in small communities located just a few metres above high water mark, on beaches and spits often sandwiched between the sea and lagoons (e.g. Figs. 3 and 4).

The coastal communities were well positioned to exploit coastal foods and other resources, and where the climate and soils were favourable (mainly in the north), they established gardens on the coastal strip. The coastal focus of their settlements and gardens exposed them to the risk of tsunamis.

About a third of all shallow earthquakes in New Zealand are underwater and a major risk contributor (e.g. Berryman and Hull, 2003). Along the east coast, the Hikurangi Trough, and Cook Strait and Kaikoura canyons lie only a short distance offshore, and tsunamis triggered by underwater debris avalanches and flows (Lewis et al., 1998) may enhance the risk. Adding further to the risk are tsunamigenic eruptions of volcanoes just north of New Zealand along the southern section of the Kermadec Ridge (e.g. Nichol et al., 2003; Wright et al., 2003), and possibly gas releases from clathrate deposits along the edge of the Hikurangi trough (Pecher et al., 2004). In addition, distantly generated tsunamis especially from South America periodically reach the New Zealand coastline, although in the historic period these have produced either only local inundation or none (de Lange and Healy, 1986). In short, prehistoric New Zealand coastal communities were exposed to tsunamis from several sources, sources that are likely to initiate tsunamis of varying degrees of severity.

2.2. Modern analogue — Sissano Lagoon, Papua New Guinea

The December 26th 2004 Indian Ocean tsunami illustrates the widespread impact a major tsunami can have. The effects on coasts distant from the source are less intense but spread over a longer stretch of coast (e.g.

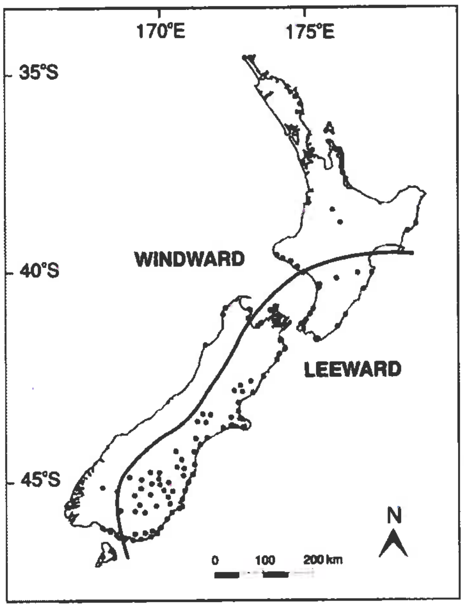

Fig. 2. New Zealand showing Windward (west) and Leeward (east) provinces (after Anderson, 1997). Dots represent significant Archaic archaeological sites.

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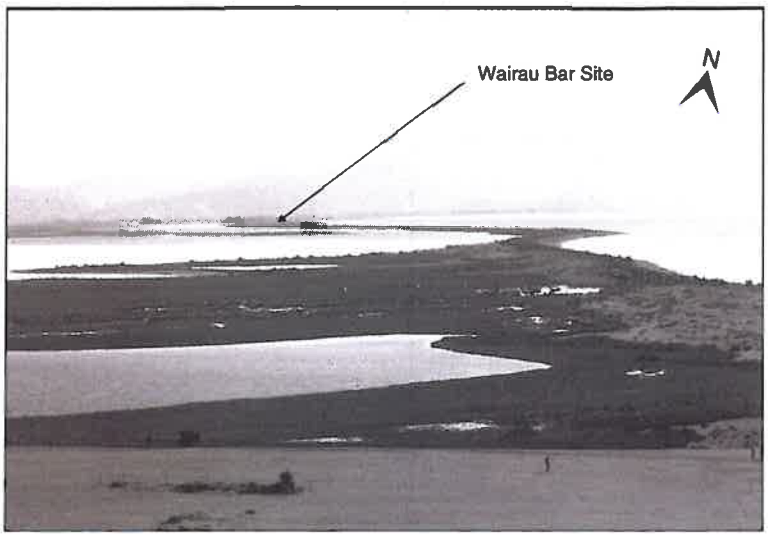

Fig. 3. Wairau Bar – looking northwest across Wairau Lagoons – an example of the exposed nature of an Archaic (early) Maori coastal site (see Fig. 4. for site location).

Sri Lanka, Maldives) than the effects on coasts near the source, which can be remarkably catastrophic over a relatively short stretch of coast (e.g. Aceh Province, Indonesia). From an archaeological perspective, the catastrophic effects on communities near the source provide a simpler record to interpret. With this in mind, we briefly discuss a modern analogue of a local event — the 1998 Sissano Lagoon tsunami.

The cause of the Sissano Lagoon tsunami is still open to debate (it may involve elements of both earthquake and underwater mass failure (McSaveney et al., 2000)), but whatever the trigger, the tsunami came ashore in the early evening as a wave up to 17 m high travelling at about 70 km an hour (McSaveney et al., 2000). The wave came ashore as sand-laden water, and as it crossed the ground, it demolished buildings and stripped vegetation, picking up the debris and carrying it inland.

The tsunami, which was unexpected, caused severe damage along about 20 km of coast, destroying entire villages, less severe damage along a further 20 km of coast, and it killed more than 2000 people. It struck low-lying villages on beaches and sand spits and bars between the sea and lagoons — very similar to the locations of settlements and gardens in New Zealand during the early prehistoric period. Sissano Lagoon is in an area of active tectonics and although it has an unverified historical record of previous catastrophic tsunami inundations possibly during last century (McSaveney et al., 2000), there seems to have been no community memory of past events (de Lange, 1999).

If tsunamis of this magnitude had happened within the time of human occupation in New Zealand, then given the exposure of prehistoric Maori coastal sites to large waves, the expectation is for some evidence preserved in the prehistoric record.

2.3. Maori legends

There is a largely untapped source of data embodied in Maori oral records. Some of the stories that European ethnographers recorded describe or allude to large waves that were flood-like events, possibly tsunamis. We briefly discuss one of these below.

The story relates to Wellington Harbour where, in 1855 A.D., shortly after European settlement, a large earthquake uplifted the land around the harbour between 1 m and 2 m, and triggered a tsunami that inundated the shores on each side of Cook Strait (Grapes and Downes, 1997; Grapes and Goh, 1998). According to a tradition of Ngati Ira, a tribe who occupied the land around Wellington Harbour when Captain Cook visited New Zealand in the late 18th Century A.D., there had been a similar event some centuries earlier. About 18 generations ago, a huge earthquake called the Hao-whenua uplifted the land around the harbour (Best, 1919). Before the earthquake, Miramar Peninsula was an island separated from the mainland; the Rongotai Isthmus now joins it (Pillans and Huber, 1995). Why the Maori called the earthquake Hao-whenua or "land swallower" seems strange considering that land apparently came up out of the sea, and the name may refer to a tsunami generated by the earthquake. Maori is a contextual language, and an alternative meaning of Hao-whenua is "to sweep the land clean" (Williams, 1957).

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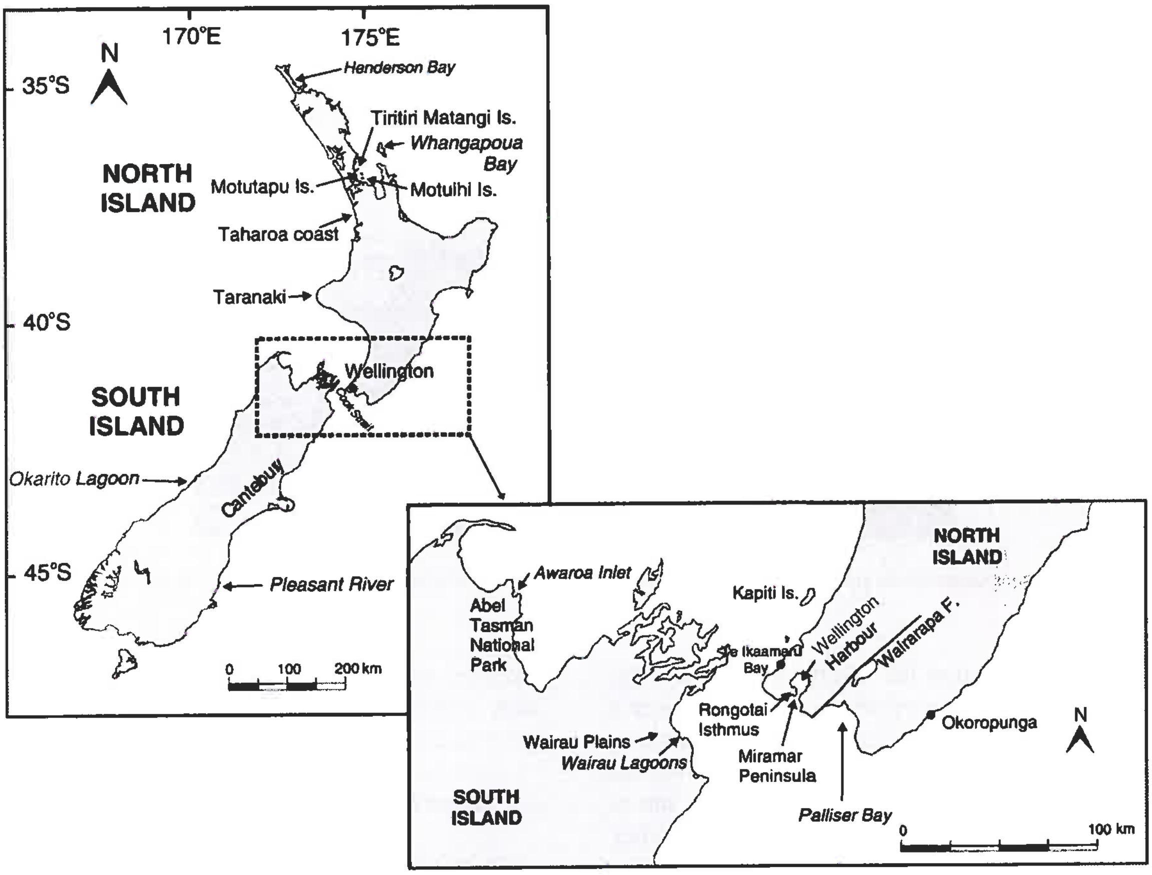

Fig. 4. Map of New Zealand showing locations mentioned in the text.

Stories such as this are an element of Polynesian mythology that helps to identify a tribe with a region, in much the same way as Europeans identify with their place names. The interpretation of the story given here infers an event with a modern analogue in the same area. The next sections consider the archaeological record.

3. Archaeological record

The identification of tsunami deposits in New Zealand uses analytical and stratigraphic techniques to identify biological, stratigraphic, and chemical signatures (Goff et al., 2001). On low-lying sites, the techniques can apparently distinguish between sediments left behind by a tsunami, and those left behind by a storm surge (Goff et al., 2004). The application of the techniques to archaeological sites is uncommon, partly because the study of palaeotsunamis is very recent in New Zealand.

Existing geological work on or near archaeological sites in New Zealand identifies primary and secondary locations with evidence of tsunami inundation. Primary sites have been studied in some detail and published (e.g. Henderson Bay — Nichol et al., 2004; Whangapoua Bay — Nichol et al., 2003; Okoropunga — Goff et al., 2004; Kapiti Island — Goff et al., 2000) (Fig. 4). Secondary sites are those where the evidence is unpublished (e.g. Motuihi Island — Mather, 2004), or where physical evidence has been recorded from on-site visits and, pending further investigations, has been noted as perhaps related to tsunami inundation (e.g. Tiritiri Matangi Island, Motutapu Island, Taharoa coast, Palliser Bay, Te Ikaamaru Bay, Awaroa Inlet, Pleasant River). Many of the latter sites have been the focus of past archaeological investigations, but geoarchaeological studies are still required.

Large tsunamis can affect parts of the coast beyond a single archaeological site, and their stratigraphic signatures should replicate at several locations, including in the wider landscape. Such signatures in archaeological sites might be breaks in occupation, layers of gravel, and so called *sterile layers*, which are layers with no apparent cultural content, or sometimes with reworked cultural content. Where these occur on more than one site and in

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the wider coastal landscape, they represent an environmental event, such as might potentially follow tsunami inundation. From a geoarchaeological perspective, sterile layers are not just sediment layers that happened to accumulate on sites while people were absent — they may link closely to *why* people moved.

Tsunamis, however, do not necessarily leave deposits, and when they do leave them, the deposits may be easily confused with those from other processes; for example, Maori gardening and tsunamis can both leave layers of gravel (Goff and McFadgen, 2001).

Among the sediments, archaeological deposits may contain middens, the content of which may contain proxy information for past tsunamis. Middens are the repositories of food refuse left over from the consumption of animals, by far the greater part of which will be the remains of food collected nearby. Tsunamis can create new environments, erode existing sandy environments, and change the depth and extent of coastal lagoons and estuaries, and as such, they can eliminate or severely curtail some animal species, and enhance the availability of others. There are sites where the animal species in middens change over time, for example Cross Creek in Whaorei Bay (Sewell, 1984), and Palliser Bay (Anderson, 1981). Such sites may possibly be sources of information about the impact of tsunamis on both the site environment, and the human community that occupied it.

Tsunamis, however, are only one possible reason for change. In Palliser Bay, for example, the numbers of a shallow intertidal gastropod decline in middens, at the same time as the numbers of a deeper water gastropod increase. The Palliser Bay shoreline is tectonically uplifted. The cause of the change in shellfish has been explained by over-collection of shellfish for food (Anderson, 1981), and by localised co-seismic uplift of the shoreline, or alternatively the destruction of near shore biota with tsunami inundation causing rip-up and removal (Goff and McFadgen, 2001).

Keeping in mind the effects of the Sissano tsunami and the foregoing discussion, we propose a list of criteria in Table 1 that we reasonably expect might follow a

Table 1
Potential geoarchaeological criteria suggesting possible tsunami inundation in the archaeological record of low-lying archaeological sites close to the coast, as applied to the Wairau Bar archaic site

Criteria	Example	Wairau Bar	Alternative explanations for criteria
1. Oral traditions (*Taniwha* or other legend referring to inundation) from the locality	D'Urville Island (Mitchell and Mitchell, 2004)	√	Storm surge, unusual sized waves.
2. Middens: change in shellfish species/ absence of expected species	Palliser Bay (Goff and McFadgen, 2001)	√	Cultural selection of species, overfishing, environmental change for reasons other than tsunami.
3. Structural damage: damage to buildings/ foundations at site	Sissano Lagoon (McSaveney et al., 2000)(M) This paper (A)	√	Natural deterioration, wind.
4. Geomorphological change:			
i) Evidence for uplift of site/locality	Wellington region (Grapes and Downes, 1997) (M) Okoropunga (McFadgen, 1980a)(A)	X	
ii) Evidence for subsidence/compaction of site/locality	Hawaii (Tilling et al., 1976)(M) Okarito Lagoon (Goff et al., 2001)(A)	√	Change in lagoon level because of blocked entrance, large flood.
iii) Scour/erosion/reworking of sediments at site/locality	Papua New Guinea (Gelfenbaum and Jaffe, 2003) (M) Henderson Bay (Regnauld et al., 2004)(A)	√	Storm surge.
iv) Gravel deposition/gravel pavements	Peru (http://walrus.wr.usgs.gov/peru2/index.html) (M) Whangapoua Bay (Nichol et al., 2003)(A)	√	Addition of sand and gravel for gardening, storm surge.
v) Sediment layer separating or overlying anthropogenic deposits (refer: Goff et al., 2001 for specific geological criteria)	Japan (Sato et al., 1995)(M) Okoropunga (Goff et al., 2004)(A)	√	Storm surge, addition of sand and gravel for gardening.
5. Reworking of anthropogenic deposits at site:			
i) Occupation layers/shell middens	Sri Lanka (Liu et al., 2005)(M) New South Wales (Fullagar et al., 1999)(A)	√	Human activity, storm surge.
ii) Burials	Sri Lanka (http:/www.newsday.com/mynews/la-fg-quake29dec29,0,5050721.story.html) (M) This paper (A)	√	Interference by humans or animals (e.g. dogs).
6. Replication at more than one site or in off-site deposits	Sri Lanka (Liu et al., 2005)(M) Wellington region (Goff and McFadgen, 2003)(A)	√	Errors of correlation and dating.
7. Geological context shows areas influenced by after effects of local and distant tectonics	Lower Wairau Plains (Grapes and Goh, 2000) Canterbury region (McFadgen and Goff, 2005)(A)	√	

Ticks and crosses indicate presence and absence respectively. Examples refer to occurrences of the criteria at other sites and localities. For criteria 3 to 7, we give modern (M) and archaeological/prehistoric (A) examples. Alternative explanation column gives other possible reasons for the criteria as seen on the Wairau Bar site.

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tsunami inundation of coastal sites. The criteria are not conclusive, and individually there are other explanations for them. The more criteria that are present, however, the more we consider a search for more positive geological evidence is worthwhile. We illustrate the criteria with a case study from the well-known Archaic (early) Maori archaeological site at Wairau Bar. The site is on the southern shore of Cook Strait, which separates the North Island and South Island of New Zealand.

4. Wairau bar — case study

Occupation of the Wairau Bar site was between about 1280 A.D. and 1300 A.D. (Higham et al., 1999). The site is located on the Wairau boulder bank near the present mouth of the Wairau River, and is best known for the large number of burials (43), many with rich grave goods, principally adzes, moa eggs, and ornaments found there (Duff, 1956). The site covers more than 4 ha, although the original area may have been twice this (Anderson, 1989). Many of the burials and much of the distribution of archaeological remains were found by ploughing; scientific excavation covers less than 2% of the site (Figs. 3 and 5).

The boulder bank is an 8 km long ribbon of gravel that separates the Wairau Lagoons from Cloudy Bay (Fig. 5). Today, the site forms part of the boulder bank. The region, however, is tectonically active, and the present geomorphology may be misleading as a guide to what the bar was like during the occupation of the site. Furthermore, strong winds, often gale force, and storms are common in Cook Strait, and can cause very large waves. Subtropical cyclones periodically affect the area, and can inundate the coast depositing gravel and other debris. The outcomes of these events can locally change the coastline, and leave signatures that are easily confused with tsunami signatures.

Frederick Tuckett, a Surveyor with the New Zealand Company, describes the lagoons in 1843 as having two entrances (Tuckett, 1843). According to an early cadastral map of the Clifford Survey District published in 1880 (LINZ, 1880), the two entrances were on either side of an island which, today, is the where the moa hunter site is located, and the bar was further seawards. Owen Wilkes (n.d.), from a brief study of the shoreline ridges near the moa hunter site, suggests that during occupation, there was an exit to the sea to the southeast of the site.

The boulder bank and lagoons probably only attained their present configuration after the 1848 A.D. Marlborough earthquake. This was the first of two major earthquakes that struck the area soon after the European settlement. The second earthquake, in 1855 A.D. generated a tsunami that swept the beach at the mouth of the Wairau River (Grapes and Goh, 1998) (Table 1, Point 7). The earthquakes, of magnitude 7.4 and 8.1 respectively (Eiby, 1973), through a combination of tectonic subsidence and

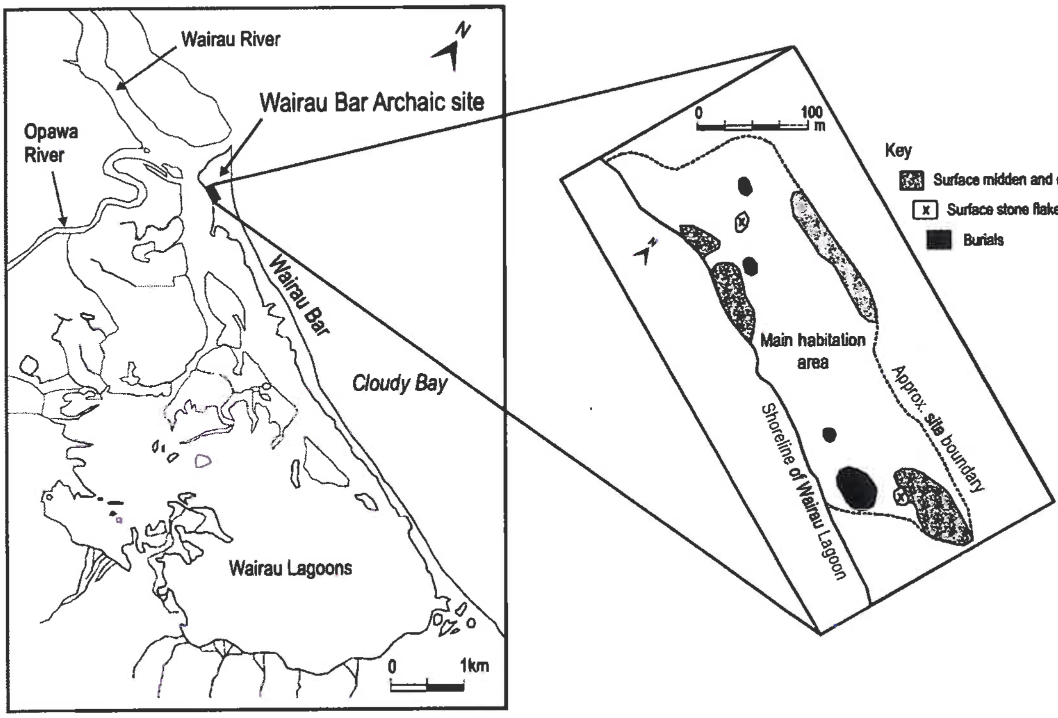

Fig. 5. Map of Wairau Bar and detail of archaeological site (after Anderson, 1989).

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sedimentary compaction, between them caused the lower Wairau Plain and parts of the adjoining coast, to subside between about 1.5 m and 2 m (Brown, 1981; Ota et al., 1995; Grapes and Goh, 1998) leading to enlargement of the lagoons. These descriptions and events indicate that the bar and lagoons are in a changing environment, of which tsunamis are only one of a range of active natural processes.

During the first occupation of the site, which Wilkes (n.d.) correlates with the seven oldest and richest burials, cooking was concentrated along the lagoon edge. During the second occupation, the inhabitants relocated the cooking area to the seaward side of the site. Wilkes (n.d.) correlates the second occupation with the "main" occupation of Duff (1956); he notes that it grades into a silt layer containing cockles, and infers that the relocation was due to a rise in water level. The change in water level is not great, and it is debatable whether it was the result of a tectonic change in land level, or a change in lagoon level caused by the outlet blocking for an extended period (Table 1, Point 4ii). That it probably depleted shellfish beds near the site we infer from an abundance of mud snails in the later occupation middens, a shellfish not normally preferred by Maori (Anderson, 1989) (Table 1, Point 2).

Some archaeological remains show signs of reworking. These include adzes, ornaments, and moa bones apparently mixed at random through a layer of oven stones and midden from the second occupation (Duff, 1956) (Table 1, Point 5i). Furthermore, oven stones and midden from the second occupation overlie the main burial area of the first occupation (Duff, 1956; Wilkes, n.d.), which is strange considering that the two occupations appear to be no more than a reorientation of the site by the same people (Wilkes, n.d.). According to Higham et al. (1999), the span of occupation was less than 20 years, and the graves within the main burial area would have been dug within the living memory of people who deposited the second occupation layer. Overlying the graves of persons of rank with food refuse would appear to be an extraordinary mark of disrespect; unless some natural event such as a storm surge or tsunami spread the food refuse over the site.

Other features on the site that might relate to such an event are missing bones including skulls from some burials (Duff, 1956). This might possibly be a result of scouring (Table 1, Points 4iii and 5ii), although post-burial removal of skulls for ritual purposes is probably more likely. Re-deposition of scoured material could account for shingle lenses derived from the underlying base sediment found lying on the top of the first occupation layer (Wilkes, n.d.) (Table 1, Points 4iii–4v), providing that people digging pits and holes can be excluded as a cause. In several parts of the site, *in situ* post butts were found up to about 12 cm in diameter. Where stratigraphy was recorded, the posts had apparently broken off at the top of the first occupation layer, and been buried by the second (Wilkes, n.d.) (Table 1, Point 3).

Concentrated along the inland side of a beach ridge immediately seaward of the site are *artificial-looking* but apparently, purposeless hollows (Wilkes, n.d.). The largest dimensions cited by Duff (1956) are about 12 m long, 7 m wide and 0.75 m deep, with other pits about 6 m by 4 m by 1 m, and 4.5 m by 3 m by 0.5 m, although in the past the areas were probably somewhat smaller, and the depths greater. Storm over wash or some similar process seems the most likely explanation for the pits. Scour pits 1–2 m deep, however, were formed by strong lee vortices behind the barrier fronting Sissano Lagoon during the 1998 tsunami inundation (Bryant, 2001), and similar scour might account for the Wairau Bar hollows (Table 1, Point 4iii). Some Wairau Bar pits contained occupation debris including midden, charcoal, and oven stones (Duff, 1956), and at least one contained *washed* oven stones (Wilkes, n.d.) and muddy sandy gravel (Table 1, Points 4iv and 5i).

Occupation of the site was around 1300 A.D. (Higham et al., 1999). There is evidence for a tsunami in wetlands on Kapiti Island and in the Abel Tasman National Park at about this time (Goff and Chagué-Goff, 1999; Goff et al., 2000). Although the evidence at Wairau Bar is far from conclusive, it is possible that this tsunami struck the Wairau Bar Archaic site between the first and second occupations (Table 1, Point 6).

If a tsunami did strike between the first and second occupations, it does not seem to have deterred people from reoccupying the site. The original inhabitants, however, may have been absent from the site as part of their seasonal round of activities, or the second occupants might possibly have been a different group of people.

5. Distribution of sites showing possible evidence of tsunami inundation

The Wairau Bar site is one of several prehistoric Maori coastal sites on which there is one or more of the criteria suggesting tsunami inundation (Table 2, Fig. 6). Gravel deposits are common, and range from layers only a few metres above high water mark extending 200 m inland (Te Ikaamaru Bay), to layers 30 m or more above high water mark, covering hundreds of square metres, and extending inland more than 200 m (e.g. Tom Bowling Bay). Along the West Waikato coast, large expanses of scattered pebbles covering up to several hectares are a distinctive feature of the coastal dunes. There are at least 36 pebble sheets, mainly in destabilised sand dunes, and nearly always

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Table 2
Selected archaeological sites showing one or more of the criteria listed in Table 1 suggesting possible tsunami inundation

Locality	Middens: change in shellfish species/absence of expected species	Structural damage to buildings/foundations at site	Evidence for uplift of site/locality	Evidence for subsidence/compaction of site/locality	Scour/erosion/sediment reworking of sediments at site/locality	Gravel deposition/gravel pavements	Sediment layer separating or overlying anthropogenic deposits	Reworking of occupation layers or shell middens	Reworking of burials	Approximate Age	Reference
North Island											
Te Ikaamaru Bay			√			√				Prehistoric	Goff and McFadgen (2001); Pers. Obs.
Koangaumu			√			√				–	Best (1918), Walton (1991), McFadgen (1980b)
Waitori					√					15th–17th C	Cassels (1979)
West Waikato coast						√				Archaic?	Wilkes (1995), Pers Obs (JRG).
Tauroa Head	√					√	√	√		14th–15th C	http://www.arts.auckland.ac.nz/ant/Tauroa_, 2003, Brook (1999b), Pers Obs.
Twilight Beach						√				–	Pers Obs.
Te Werehi					√	√		√		–	Brook (1999a), Pers Obs.
Spirits Bay						√				–	Pers Obs (JRG).
Tom Bowling Bay						√		√		–	Pers Obs.
Houhora					√					14th C	Furey (2002)
Henderson Bay						√		√		14th–16th C?	Nichol et al. (2004)
Mangawhai	√					√				16thC	Pearce (2001), Pers Obs (JRG).

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Tiritiri Matangi Is						√				15th–17th C	Brassey, pers. com; Pers. Obs.
Motutapu Is					√					14th–16th C	Nichol (1988)
Whangapoua Bay						√		√		14th–16th C?	Nichol et al. (2003)
Whaorei Bay	√									14th–15th C	Sewell (1984)
Okoropunga			√				√			16th–17th C	McFadgen (1980a), Goff et al. (2004)
Palliser Bay	√		√							15th C?	Anderson (1981), Goff and McFadgen (2001)
South Island											
Wairau Bar	√	√		√	√	√	√	√	√	~1300AD	This paper, Table 1.
Long Beach						√				–	Pers Obs (JRG).
Salt Water Lagoon				√						–	Brunner (1952)
Golden Bay	√			√						Late Archaic	Brooks (2002), Pers Obs (BGM).
Awaroa Inlet	√			√	√					Late Archaic	Barber (1994), Pers Obs (BGM).
Greville Harbour						√				Archaic	Wellman (1962)

Ticks indicate presence. Approximate ages based on radiocarbon dates and cultural association. "Archaic" indicates evidence is probably pre-1500 A.D. — indicates age uncertain. For site locations, see Figs. 4 and 6.

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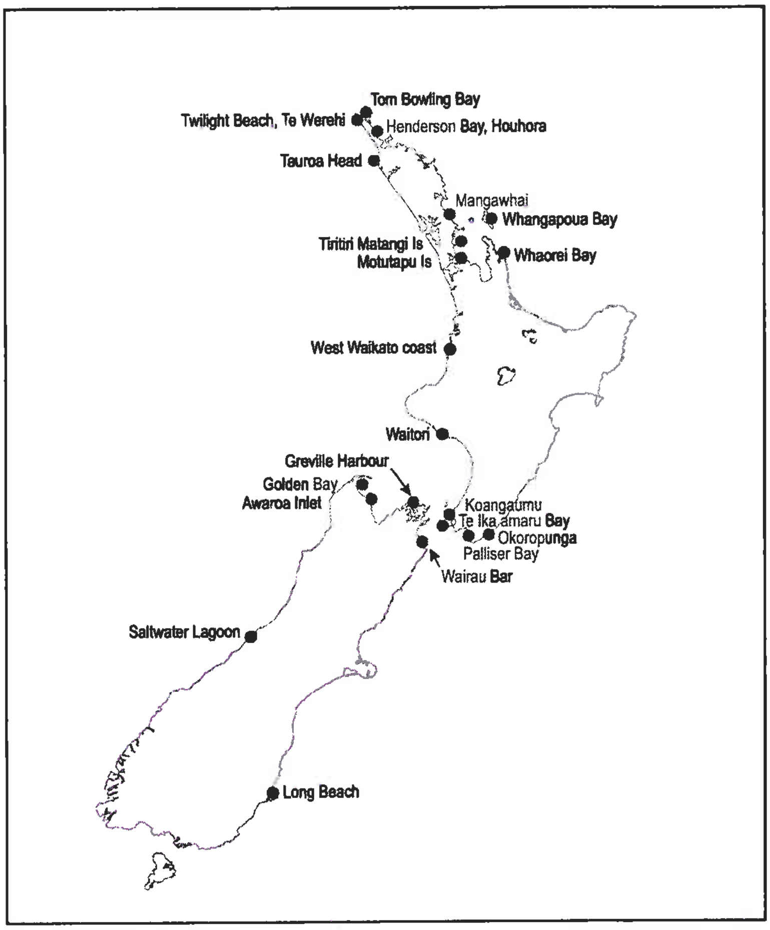

Fig. 6. Distribution of selected archaeological sites showing one or more of the criteria listed in Table 1 suggesting tsunami inundation. For details of evidence and age, see Table 2.

associated with human occupation, which is often archaic (Wilkes, 1995; pers. com 2004).

Where there is an indication of age, the chronological distribution of the evidence on sites is usually between the 14th and 17th centuries A.D. If the evidence is confirmed as coming from tsunamis, then the middle of the prehistoric period saw widespread and sometimes severe tsunami inundation, on many parts of the coast.

6. Conclusions

A list of criteria for possible tsunami inundation based upon geoarchaeological data has been drawn up and applied to a case study of the Wairau Bar. Occupation of the site was around 1300 A.D. (Higham et al., 1999). There is apparent evidence for a tsunami in the wetlands on Kapiti Island and in the Abel Tasman National Park at about this time (Goff and Chagué-Goff, 1999; Goff et al., 2000). Although the evidence is inconclusive, it is not unreasonable to expect that such an event might have also struck the Wairau Bar moa hunter site between the first and second occupations. If a tsunami did strike Wairau Bar between the first and second occupations, it did not deter people from reoccupying the site soon after. Beyond Wairau Bar, there is evidence that suggests tsunamis on the coasts of both the North and South Islands. If further research confirms the origin of the evidence as tsunamigenic, then there was widespread, sometimes severe tsunami inundation on many parts of the coast during the middle of the prehistoric period.

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References

Anderson, A.J., 1981. A model of prehistoric collecting on the rocky shore. Journal of Archaeological Science 8, 109–120.

Anderson, A.J., 1989. Prodigious Birds. Moas and Moa-hunting in Prehistoric New Zealand. Cambridge University Press, London. 238 pp.

Anderson, A.J., 1991. The chronology of colonization in New Zealand. Antiquity 65, 767–795.

Anderson, A.J., 1997. Prehistoric Polynesian impact on the New Zealand environment: Te Whenua Hou. In: Kirch, P.V., Hunt, T.L. (Eds.), Historical Ecology in the Pacific Islands. Yale University Press, New Haven, pp. 271–283.

Anderson, A.J., 2002. A fragile plenty. Pre-European Maori and the New Zealand environment. In: Pawson, E., Brooking, T. (Eds.), Environmental Histories of New Zealand. Oxford University Press, London, pp. 19–34.

Atwater, B.F., Cisternas, V.M., Bourgeois, J., Dudley, W.C., Hendley II, J.W., Stauffer, P.H., 1999. Surviving a tsunami — lessons from Chile, Hawaii, and Japan. USGS Circular 1187 18 pp.

Barber, I.G., 1994. Culture Change in Northern Te Wai Pounamu. Unpublished PhD thesis, Department of Anthropology, University of Otago.

Bell, R.G., Goff, J.R., Downes, G., Berryman, K., Walters, R.A., Chague-Goff, C., Barnes, P., Wright, I., 2004. Tsunami hazard for the Bay of Plenty and eastern Coromandel Peninsula: stage 2. Environment Waikato Technical Report 2004/32.

Berryman, K., Hull, A., 2003. Tectonic controls on Late Quaternary shorelines: a review and prospects for future research. In: Goff, J.R., Nichol, S.L., Rouse, H.L. (Eds.), The New Zealand Coast. Dunmore Press, Palmerston North, pp. 25–58.

Best, E., 1918. Shell-middens of the Porirua District. New Zealand Journal of Science and Technology X, 212–217.

Best, E., 1919. The land of Tara and they who settled it. Polynesian Society, New Plymouth.

Brook, F.J., 1999a. Stratigraphy, landsnail faunas, and palaeoenvironmental history of coastal dunefields at Te Werahi, northernmost New Zealand. Journal of the Royal Society of New Zealand 29 (4), 395–405.

Brook, F.J., 1999b. Stratigraphy, landsnail faunas, and palaeoenvironmental history of Late Holocene coastal dunes, Tauroa Peninsula, northern New Zealand. Journal of the Royal Society of New Zealand 29 (4), 361–393.

Brooks, E. 2002. Selectivity Versus Availability: Patterns of Prehistoric Fish and Shellfish Exploitation at Triangle Flat, Western Golden Bay. Unpublished MA thesis, Department of Anthropology, University of Otago.

Brown, L.J., 1981. Late Quaternary geology of the Wairau Plain, Marlborough, New Zealand. New Zealand Journal of Geology and Geophysics 24, 477–490.

Brunner, T., 1952. The Great Journey: an Expedition to Explore the Interior of the Middle Island, New Zealand, 1846–1848. Pegasus Press, Christchurch, New Zealand. 107 pp.

Bryant, E.A., 2001. Tsunami: The Underrated Hazard. Cambridge University Press, London. 320 pp.

Burney, D.A., 2002. Late Quaternary chronology and stratigraphy of twelve sites on Kaua'i. Radiocarbon 44, 13–44.

Cassels, R., 1979. Early prehistoric wooden artifacts from the Waitore Site (N136/16), near Patea, Taranaki. New Zealand Journal of Archaeology 1, 85–108.

Cole, S.E., Atwater, B.F., McCutcheon, P.T., Stein, J.K., Hemphill-Haley, E., 1996. Earthquake-induced burial of archaeological sites along the southern Washington coast. Geoarchaeology 11, 165–177.

Davidson, J.M., 1984. The Prehistory of New Zealand. Longman Paul, Auckland.

de Lange, W.P., 1999. Tsunami Lessons. NZ Science Monthly 6–8 (September).

de Lange, W.P., Healy, T.R., 1986. New Zealand tsunamis 1840–1982. New Zealand Journal of Geology and Geophysics 29, 115–134.

Duff, R.S., 1956. The Moa-Hunter Period of Maori Culture. Canterbury Museum Bull. No. 1. Govt. Printer, Wellington. 400 pp.

Eiby, G.A., 1973. A descriptive catalogue of New Zealand earthquakes. Part 2 Shocks felt from 1846 to 1854. New Zealand Journal of Geology and Geophysics 16, 857–907.

Fullagar, R., Head, L., Bryant, E.A., Beaman, S., 1999. Tsunami disturbance on coastal middens. McCauleys Beach, New South Wales. In: Hall, J., McNiven, I. (Eds.), Australian Coastal Archaeology. ANH Publications, Department Archaeology and Natural History, ANU, Canberra, pp. 235–238.

Furey, L., 2002. Houhora. A fourteenth century Maori village in Northland. Bulletin of the Auckland Museum 19. 169 pages.

Gelfenbaum, G., Jaffe, B., 2003. Erosion and sedimentation from the 17 July 1998, Papua New Guinea tsunami. Pure Applied Geophysics 160, 1969–1999.

Goff, J.R., 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.R., McFadgen, B.G., 2001. Catastrophic seismic-related events and their impact on prehistoric human occupation in coastal New Zealand. Antiquity 75, 155–162.

Goff, J.R., McFadgen, B.G., 2003. Large earthquakes and the abandonment of prehistoric coastal settlements in 15th Century New Zealand. Geoarchaeology 18, 609–623.

Goff, J.R., Rouse, H.L., Jones, S., Hayward, B., Cochran, U., McLea, W., Dickinson, W.W., Morley, M.S., 2000. 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.

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

Goff, J.R., McFadgen, B.G., Chagué-Goff, C., 2004. Sedimentary differences between the 2002 Easter storm and the 15th Century Okoropunga tsunami, southeastern North Island, New Zealand. Marine Geology 204, 235–250.

Grapes, R., Downes, G., 1997. The 1855 Wairarapa, New Zealand, earthquake — analysis of historical data. Bulletin of the New Zealand Society for Earthquake Engineering 30, 271–368.

Grapes, R., Goh, A., 1998. Marlborough: one hundred and fifty years of earthquakes. Family Histories of the Marlborough Area. Marlborough Historical Society.

Higham, T.F.G., Hogg, A.G., 1997. Evidence for late Polynesian colonization of New Zealand: University of Waikato radiocarbon measurements. Radiocarbon 39, 149–192.

Higham, T.F.G., Anderson, A.J., Jacomb, C., 1999. Dating the first New Zealanders: the chronology of Wairau Bar. Antiquity 73, 420–427.

http://walrus.wr.usgs.gov/peru2/index.html.

http://www.newsday.com/mynews/la-fg-quake29dec29,0,5050721.story.html.

http://www.arts.auckland.ac.nz/ant/Tauroa_2003.

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Hutchinson, I., McMillan, A.D., 1997. Archaeological evidence for village abandonment associated with late Holocene earthquakes at the northern Cascadia Subduction Zone. Quaternary Research 48, 79–87.

Lewis, K.B., Collot, J.-Y., Lallemand, S.E., 1998. The dammed Hikurangi Trough: a channel-fed trench blocked by subducting seamounts and their wake avalanches (New Zealand–France GeodyNZ Project). Basin Research 10, 441–468.

LINZ, 1880. Cadastral Map of Clifford Survey District.

Liu, P.L.-F., Lynett, P., Fernando, J., Jaffe, B.E., Fritz, H., Higman, B., Synolakis, C., Morton, R., Goff, J., 2005. Observations by the International Tsunami Survey Team in Sri Lanka. Science.

McFadgen, B.G., 1980a. 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., 1980b. 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., Goff, J.R., 2005. An earth systems approach to understanding the tectonic and cultural landscapes of linked marine embayments: Avon–Heathcote Estuary (Ihutai) and Lake Ellesmere (Waihora), New Zealand. Journal of Quaternary Science 20, 227–237.

McFadgen, B.G., Knox, F.B., Cole, T.R.L., 1994. Radiocarbon calibration curve variations and their implications for the interpretation of New Zealand prehistory. Radiocarbon 36, 221–236.

McSaveney, M., Goff, J., Darby, D., Goldsmith, P., Barnett, A., Elliott, S., Nongkas, M., 2000. The 17th July 1998 Tsunami, Sissano Lagoon, Papua New Guinea — evidence and initial interpretation. Marine Geology 170, 81–92.

Mather, N.S., 2004. Coastal sedimentation on the east coast of Auckland: Evidence for tsunami. MSc Thesis. The University of Auckland, New Zealand.

Mitchell, H., Mitchell, J., 2004. Te Tau Ihu O Te Waka: a History of Maori of Nelson and Marlborough. Te Tangata me te Whenua: the People and the Land, vol. 1. Huia publishers, Wellington. 499 pp.

Nichol, R., 1988. Tipping the feather against a scale, archaeozoology from the tail of the fish. Unpublished PhD thesis, Department of Anthropology, University of Auckland.

Nichol, S.L., Lian, O.B., Carter, C.H., 2003. Sheet-gravel evidence for a late Holocene tsunami run-up on beach dunes, Great Barrier Island, New Zealand. Sedimentary Geology 155, 129–145.

Nichol, S., Goff, J.R., Regnauld, H., 2004. Sedimentary evidence for tsunami on the NE coast of New Zealand. Geomorphologie 1, 35–44 (Relief, Proc., Env.).

Ota, Y., Brown, L.J., Berryman, K.R., Fujimori, T., Miyauchi, T., 1995. Vertical tectonic movement in northeastern Marlborough: stratigraphic, radiocarbon, and palaeoecological data from Holocene estuaries. New Zealand Journal of Geology and Geophysics 38, 269–282.

Pearce, P., 2001. Mangawhai sandspit excavation 1978. Archaeology in New Zealand 44 (4), 294–303.

Pecher, I.A., Henrys, S.A., Zhu, H., 2004. Seismic images of gas conduits beneath vents and gas hydrates on Ritchie Ridge, Hikurangi margin, New Zealand. New Zealand Journal of Geology and Geophysics 47, 275–279.

Pillans, B., Huber, P., 1995. Interpreting coseismic deformation using Holocene deposits, Wellington, New Zealand. Quaternary International 26, 87–95.

Regnauld, H., Nichol, S., Goff, J.R., Fontugne, M., 2004. Maoris, tsunami, middens and Dune front accretion rate on the northeast coast of New Zealand: resilience of tsunami driven coastal features. Maoris, dépôts alimentaires et taux d' accrétion du front dunaire sur la côte nord est de la Nouvelle Zélande: adaptabilité d'accumulations cotières liées à un tsunami. Geomorphologie 1, 45–54 (Relief, Proc., Env.).

Sato, H., Shimamoto, T., Tsutsumi, A., Kawamoto, E., 1995. Onshore tsunami deposits caused by the 1993 Southwest Hokkaido and 1983 Japan Sea earthquakes. Pure Applied Geophysics 144, 693–717.

Sewell, B., 1984. The Cross Creek site (N40/260) Coromandel Peninsula. Unpublished M.A. thesis, Department of Anthropology, University of Auckland.

Tilling, R.I., Koyanagi, R.Y., Lipman, P.W., Lockwood, J.P., Moore, J.G., Swanson, D.W., 1976. Earthquake and related catastrophic events island of Hawaii, November 29, 1975: a preliminary report. USGS Circular 740, 1–33.

Tuckett, Frederick, 1843. Report of His Exploratory Journey to Wairau. Alexander Turnbull Library, NZC 3/13/#51.

Walton, A.J., 1991. Excavation of terraces at Titahi Bay, Porirua. New Zealand Archaeological Association Newsletter 34 (2), 105–111.

Wellman, H.W., 1962. Maori Occupation Layers at D'Urville Island, New Zealand. New Zealand Journal of Geology and Geophysics 5, 55–73.

Wilkes, O., n.d. Further work at Wairau Bar. Typescript, Canterbury Museum.

Wilkes, O., 1995. Site recording, site types, and site distribution on the King Country coastline. Archaeology in New Zealand 38 (4), 236–256.

Williams, H.W., 1957. A Dictionary of the Maori Language, 6th Edition. Government Printer, Wellington.

Wright, I.C., Gamble, J.A., Shane, P.A.R., 2003. Submarine silicic volcanism of the Healy caldera, southern Kermadec arc (SW Pacific): 1 — volcanology and eruption mechanisms. Bulletin of Volcanology 65, 15–29.

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