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RESEARCH ARTICLE



Tectonic activity and the history of Wairau Bar, New Zealand's iconic site of early settlement

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ABSTRACT

Wairau Bar, possibly New Zealand's most significant archaeological site, is in a hazardous location. Since it was first settled, the site has several times been severely shaken by earthquakes and inundated by tsunamis. These events have impacted on the site's surroundings, on the archaeological remains in the site and possibly directly on the site's inhabitants. Observed impacts from the CE 1855 tsunami include demolition of buildings, scouring and fissuring of the ground surface, and stranding of fish. Inferred effects of the CE 1855 and earlier tsunamis include reworking and redepositing of archaeological material, and the possibility that some burials found on the site are of people killed by a tsunami. Judging from past earthquakes, and sea level rise from climate change, the site may not survive to the end of this century, an outcome that could be ameliorated by tectonic uplift.

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Introduction

Tectonic activity is now recognised as a potentially significant factor in the archaeological study of cultural change and human development (e.g. King & Bailey 2006; Force 2016). New Zealand, a relatively small group of islands in the southwest Pacific Ocean that sits across the boundary between the Pacific and Australian tectonic plates is, and has been for millions of years, subject to tectonic activity. Polynesians from tropical remote Oceania, ancestors of modern Māori, are thought to have arrived about 800 years ago (Anderson 2014, p. 16). Until European contact in CE 1769, Māori were a Neolithic people who recorded their history in song, legends, genealogy and other oral traditions. Such stories in Neolithic societies played the important role of preparing the youngest generation to survive in their environment (Kelly 2016), and in New Zealand there are similar stories that embody reference to tectonic hazards (King et al. 2007). This article examines the implications of an event recorded by Māori traditions for the interpretation of one of the earliest New Zealand sites occupied by Polynesians—the Wairau Bar archaeological site in Cloudy Bay (Figure 1).

Site location and history

In the Cloudy Bay area of Cook Strait, where the Wairau Bar site is located, the plate boundary between the Pacific and Australian tectonic plates is marked by the Hikurangi

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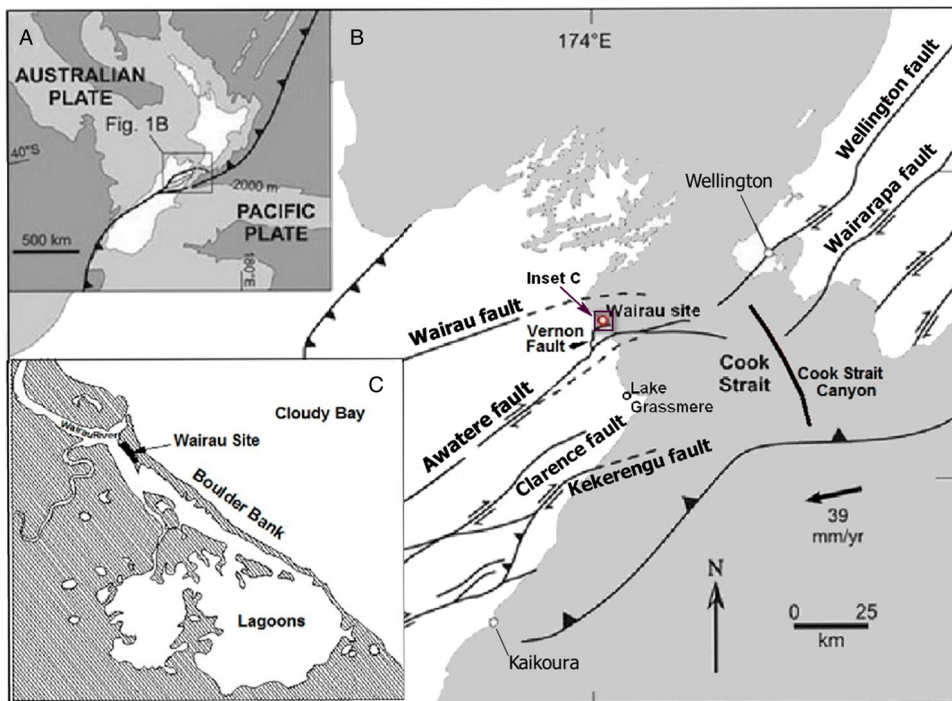


Figure 1. Cook Strait Faults (after Benson et al. 2001) and the location of the Wairau archaeological site. Hikurangi Trough shown by line with black triangles.

Trough and subduction zone, and earthquake fault lines (Figure 1). Some of these faults extend offshore, and vertical movement on them has caused significant earthquakes and tsunamis since human settlement. In addition, there is a deep canyon in the Cook Strait, which is a potential source of tsunamis generated by underwater landslides (Goff et al. 2001b; Lane et al. 2016). The impact of such events on the site and its surroundings has implications for interpreting the site's history, and for its future survival.

Māori traditions record large waves striking the coast of Cloudy Bay, particularly at Lake Grassmere and Wairau (Mitchell & Mitchell 2004). In one tradition Kupe, the 13th century Polynesian explorer who arrived in the Matahourua canoe, was annoyed by a local chief Haumia-nui-a-Kakaru, who had a village at the landward (southeastern) end of the Wairau boulder bank. In retaliation, Kupe is reputed to have called up a large wave that inundated Haumia's tribal lands, destroyed gardens and plantations, and created Lake Grassmere and the Wairau Lagoons (Mitchell & Mitchell 2004, pp. 32, 34, 45). Although there is clearly some embellishment consistent with Anderson's (2014, pp. 53–57) critique of voyaging traditions from Hawaiki to New Zealand here, there is no reason to doubt the general authenticity of a Māori record of a large wave in what would almost certainly have been a highly significant event in the lives of Māori in this region at the time. Indeed, Kupe's name is still memorialised in the Māori name for the Wairau Bar site today; Te Pokohiwi ō Kupe.

The site today sits at the northwestern extremity of the Wairau boulder bank where the Wairau River enters the sea (Figure 1C). Inland of the boulder bank, which rises to 4 m

above mean sea level, are shallow lagoons and a few small islands. Fossil faunas in lagoon cores suggest that a barrier existed between the lagoons and the sea, and that the lagoons formed, at least 1500 years ago (Hayward et al. 2010). The lagoons today are mostly less than 0.5 m deep at mid-tide, cover about 12 km², and are a source of cockle (*Austrovenus stutchburyi*), pipi (*Paphies australe*), mudsnail (*Amphibola crenata*) and the freshwater snail *Potamopyrgus estuarinus* (Knox 1990).

The boulder bank has been occupied since early prehistoric times. The find of a small chisel made from a tropical shell (*Acus crenulatus*), which is of tropical rather than New Zealand origin, suggests that the site may well be one of the pioneering sites of initial settlement directly from tropical east Polynesia (Davidson et al. 2011, p. 99). Dating of Polynesian occupation is based on radiocarbon, which depends on the reliability of the material dated. Dates for the site are determined on charcoal, human bone, moa bone, estuarine shells and moa eggshell (Higham et al. 1999; Jacomb et al. 2014). Charcoal dates are on unidentified species, and are thus likely subject to inbuilt age (McFadgen 1982; Anderson 1991; Higham et al. 1999). Human bone dates may be affected by the mixture of terrestrial and marine food eaten (Petchey 2005). In addition, the human bone and the moa bone samples were pre-treated using a method later considered to be unsuitable (Higham et al. 1999). The shell dates are on species that live in the tidal estuary of the Wairau River; they are consistent with the moa eggshell dates, although two of the four dated samples have a significantly older limit to their calibrated age range. The river passes through a landscape with calcareous rocks (Molloy 1993), and the shell dates have possibly been affected by old carbon. Moas were terrestrial birds that ate terrestrial plants (Wood et al. 2013), and the eggshell dates appear to give the most reliable results (Higham et al. 1999; Jacomb et al. 2014). From the radiocarbon ages on moa eggshell listed by Higham et al. (1999), recalibrated using SHCal13 (Hogg et al. 2013), and the radiocarbon dates on moa eggshell listed by Jacomb et al. (2014), early Polynesian settlers were occupying the Wairau site sometime between the early 13th century CE and the early 15th century CE. The dates analysed by Jacomb et al. (2014) are from a single feature. The dates listed by Higham et al. (1999) are from burials, and have a correspondingly wider spread. How much earlier or later the site was occupied has still to be determined—the analysed portions are a very small part of the original site location, which, as discussed below, was originally an island.

The early Polynesian settlers hunted and ate the now extinct large flightless moa bird, and they buried their dead on the site (Duff 1956). Wairau Bar is currently the only known site in New Zealand with the physical remains of people who, it is claimed, were apparently born in some other part of Polynesia (Kinaston et al. 2013) although a non-local origin from elsewhere in New Zealand has been suggested as another possible interpretation (Brown & Thomas 2015). European occupation of the boulder bank dates from the late 1840s; it included port facilities (Holdaway 2016), 'grog shops' and other shelters along the boulder bank, including a hotel in the vicinity of the site (Grapes 2000). More recently, the area on and around the site has been farmed and ploughed (Duff 1956). One of the first discoveries of moa remains on the site was in the CE 1840s when an almost complete skeleton was found during excavations for the foundations for an early house, roughly where the present farm house on the Wairau Bar is located (Nicholls 1973).

Tectonic context

Faults in vicinity of the site are the Wairau Fault, the Vernon Fault and the Awatere Fault (Figure 1). The Wairau Fault runs inland northwest of the archaeological site and river estuary, to within about 800 m of the coast (Grapes & Wellman 1986). It is thought to have last moved more than about 1800 years ago (Zachariassen et al. 2006). The Vernon Fault, which is a splinter of the Awatere Fault, runs inland southeast of the site, at the eastern end of the lagoon; it has probably not moved for 9000 years (Clark et al. 2011).

The Awatere Fault also runs southeast of the archaeological site, down the northwest side of the Awatere Valley. It last moved in CE 1848, causing an earthquake of estimated magnitude 7.5 that was widely felt (Grapes 2011). The earthquake severely damaged the new town of Wellington on the southern North Island (Grapes 2011, Grapes & Holdgate 2014; Holdgate & Grapes 2015), and resulted in significant subsidence and compaction of the sediments in and around the Wairau lagoons. Seven years later, the CE 1855 earthquake, which was on the Wairarapa Fault in the southern North Island, also severely damaged Wellington, and caused further compaction of the sediments in and around the Wairau lagoons (Grapes 2000, pp. 103–105; Grapes & Holdgate 2014, Holdgate & Grapes 2015).

Effects of the 1848 and 1855 earthquakes

The current geomorphological configuration of the site has existed for less than 170 years. The rupture of the Awatere Fault in CE 1848, and the Wairarapa Fault in CE 1855, caused the land around the site and lagoons to drop 1–2 m (Brown 1981; Grapes & Downes 1997). These two events resulted in considerable changes to the lagoons and boulder bank.

Before 1848 the lagoons and boulder bank were very different. In CE 1843 Frederick Tuckett, an early Surveyor, described the lagoons as having two entrances (Tuckett 1843). Old survey records, a CE 1880 cadastral plan, which shows the land boundaries at the time of the most recent survey (Budge's survey of 1844 for most of the land in and around Big Lagoon), are consistent with Tuckett's (1843) observation. The cadastral plan shows the location of the archaeological site as being an island, with the boulder bank a separate entity some distance seawards of the island (Figure 2). The lagoons were smaller and the islands in them larger than today (Figure 2 inset). In CE 1853 the Quaker Frederick Mackie referred to the Port of Wairau, at the entrance to the Wairau lagoons, as located on an island (Nicholls 1973). The associated settlement, which he illustrated in a sketch, shows at least eight buildings in the vicinity of the archaeological site (Nicholls 1973).

Following the earthquakes the location of the pre-CE 1848 boulder bank changed. Old survey records show the northwestern part of the boulder bank seawards of its present position and the southeastern part inland of its present position (Figure 2 inset). The only part of the pre-CE 1848 boulder bank remaining today is a small island in the lagoon (along cross-section C–D Figure 2 inset). In addition, along the seaward side of the island where the archaeological site was located, the shoreline encroached onto the island some 250 m, a result either of wave erosion or, if the island was previously low-lying, of inundation. Any archaeological remains that were on the affected area are today either destroyed or buried beneath the post-CE 1848 beach ridges that form the present boulder bank (Figures 2–3). On the lagoon side of the island, the shoreline

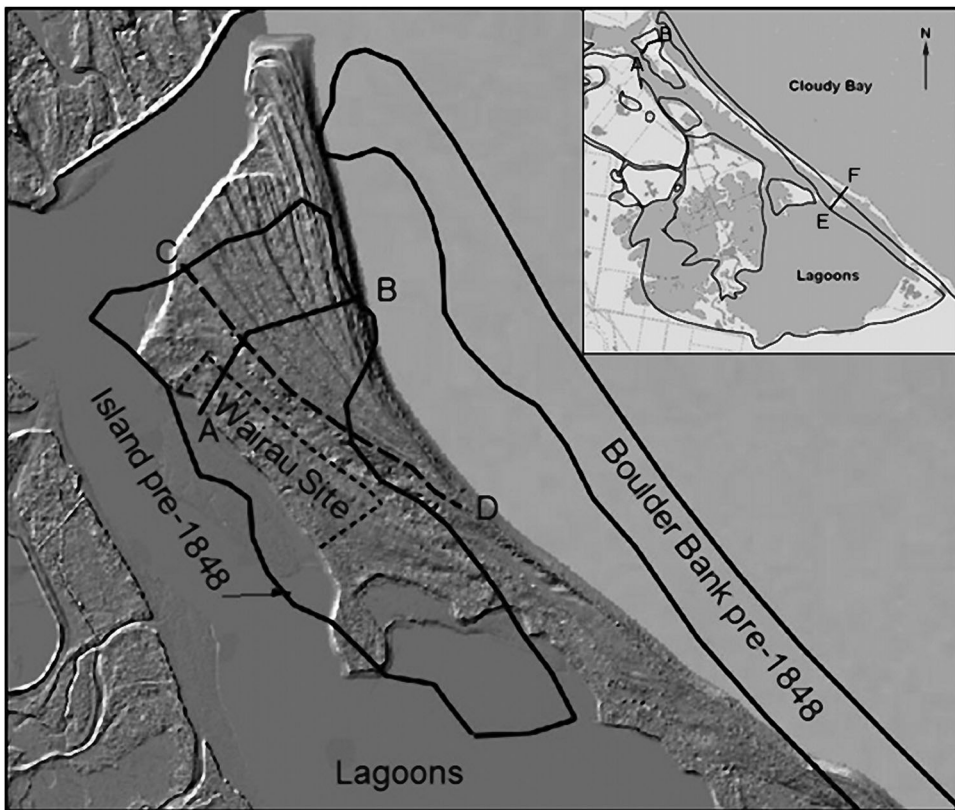


Figure 2. Lidar map of the north end of the present Wairau boulder bank (courtesy Marlborough District Council) showing the Wairau site, the pre-1848 island and boulder bank (outlined by black lines), and the innermost post-1848 beach ridge (dashed line C–D). A–B is cross section shown in Figure 3 (upper profile) across site and present boulder bank. Inset shows the lagoons and boulder bank today (courtesy Custom Software). E–F is cross section shown in Figure 3 (lower profile) across the present boulder bank and island in the southeast part of the lagoon. The pre-1848 configuration is compiled from: a plot of Budge’s 1844 survey field notes (Budge Field Book 9, LINZ); the Map of the Rural Sections of the Wairau Plains 1848 (Archives NZ Plan N8); and the cadastral map of the Clifford Bay Survey District 1880.

encroached onto the island by up to 120 m (Figure 4), either from erosion or inundation, affecting the occupation remains on this part of the island.

A cross section of the present boulder bank near the archaeological site, measured from Lidar images (Figure 3 upper profile), shows the height difference of the boulder bank following the CE 1848 and CE 1855 earthquakes. This amounts to a lowering of about 1.5 m due to earthquake compaction and subsidence. The lowering of the site was sufficient to put occupation remains below the lagoon water level, as noted by Owen Wilkes and Harold Wellman during archaeological excavations at the site in 1959 (Wilkes *n.d.*, p. 4; Brooks et al. 2011), and by Michael Trotter (1975).

In addition to the lowering of the site and subsequent erosion, at least three tsunamis have impacted the bar since human settlement, the most recent being in CE 1855 as a result of the Wairarapa earthquake (Grapes 2015). Historical accounts refer to the CE

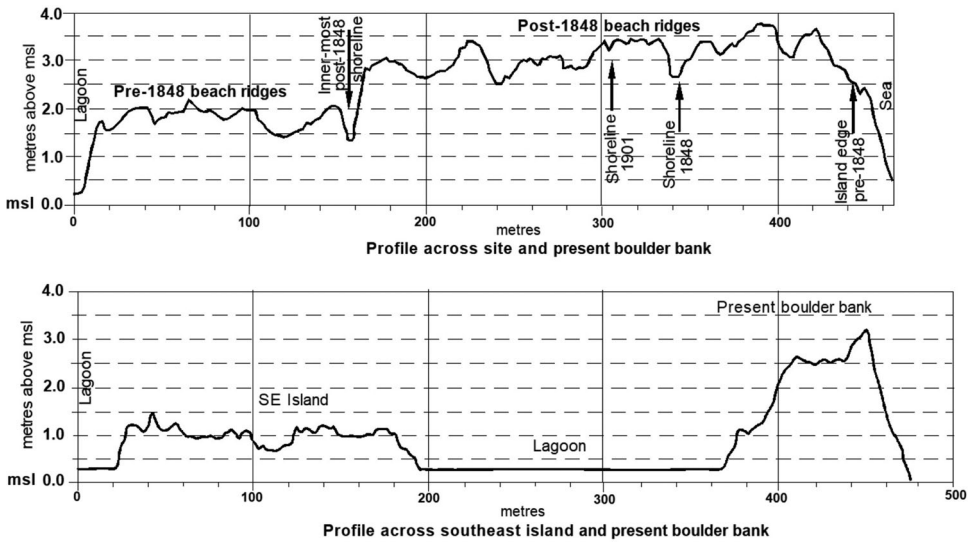


Figure 3. Profiles across the site, and the island in the southeast part of the lagoon, showing the post-1848 beach ridges (present boulder bank), and the height difference between pre- and post-1848 shorelines, measured from a Lidar image. Upper profile along line A–B [Figure 2](#), lower profile along line E–F [Figure 2](#) (inset). The height difference above mean sea level between profiles is probably due to differential exposure to wave action. For profile locations see [Figure 2](#).

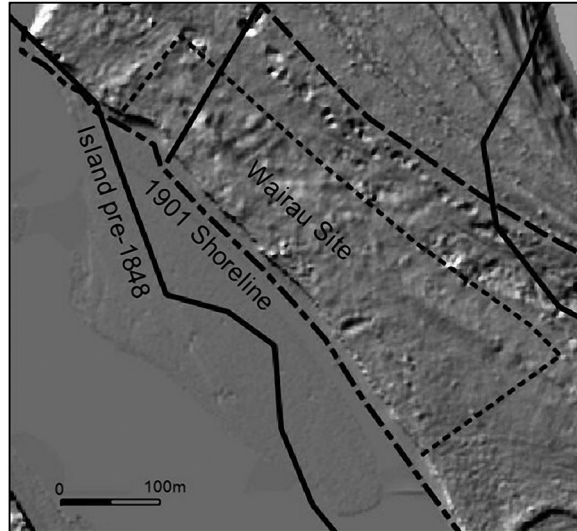


Figure 4. Shoreline of the site in 1901 compared with the shoreline of the island before the 1848 earthquake, and the modern shoreline recorded by Lidar. The 1901 shoreline is from LINZ survey plan SO621. Lidar courtesy of Marlborough District Council.

1855 tsunami as a ‘gigantic wave’ that swept the beach near the mouth of the Wairau River and inflicted considerable damage to the ‘grog shops’ and other shelters built along the bar (*Nelson Examiner and New Zealand Chronicle*, 14 February 1855, cited in Grapes [2000](#),

p. 52). According to Garin (1855, cited in Clark et al. 2015), the sea rose 14 feet (4.3 m) above high tide mark at Wairau Bar, caused scouring, uprooting, fissuring of the ground, and left fish on dry land. There was no tsunami associated with the CE 1848 earthquake.

Earlier earthquakes and tsunamis

The outcome of the event described by the Māori tradition echoes the effects of the CE 1848 and CE 1855 earthquakes, which deepened the Wairau lagoons, and in the case of the CE 1855 earthquake caused a tsunami to sweep the boulder bank.

Geological cores from the lagoon area record two earlier earthquakes and associated tsunamis in the last 1000 years (Clark et al. 2015; King et al. 2017). The first earthquake and tsunami (referred to here as Event 1) have a maximum radiocarbon date of about CE 1070; the earthquake caused subsidence of c. -0.45 m, and the accompanying tsunami, which had an estimated height greater than 3.5 m, washed inland some 360 m (Clark et al. 2015). The sediments in the cores show material deposited both by the incoming wave (offshore material), and by the outgoing wave (onshore material) (Clark et al. 2015; Hayward et al. 2015).

The second earthquake and tsunami (referred to here as Event 2) have a maximum radiocarbon date of about CE 1430, and the earthquake caused further subsidence of c. -0.25 m (Clark et al. 2015). The accompanying tsunami washed to a position at least 340 m from the present coast (King et al. 2017), but as the deposited sediments were from the lagoon, the tsunami is thought to have been a lagoon wave resulting from the subsidence rather than a wave from offshore (King et al. 2017). The subsidence during both events was too small to identify from the pre-1848 beach ridge profiles existing today (Figure 3 southeast island profile), if indeed the boulder bank at those times was the same as that existing just before the earthquake of CE 1848.

The compaction and subsidence from the CE 1855 earthquakes lowered the site in relation to sea level. Prior to the earthquakes, the site was between about 1.5 m and 2 m higher than today (Figure 4). Sea level during the time the site was first occupied is estimated to have been about 0.5 m to 0.6 m below that of today (Hayward et al. 2012). After the Event 1 subsidence, and allowing for the subsidence following Event 2 (-0.25 m) and the CE 1848 and CE 1855 earthquakes, the site was probably around 2.5 m higher than it is today, and the part now below lagoon level around 1.5 m to 2 m above lagoon level, at least near the present shore. How far occupation extended out into what is now lagoon, and the nature and age of the occupation, is not yet known.

As mentioned above, Polynesians arrived in New Zealand about 800 years ago (Anderson 2014). Except for the date assigned to the earlier event by Clark et al. (2015) (between about CE 1070 and CE 1150), Event 1 could have given rise to the Māori tradition described above—the subsidence possibly being enough to explain the reference in the Māori traditions to the creation of the lagoons (King et al. 2017). The dates for Event 1 are on samples that stratigraphically bracket the event. Dates measured to fix the younger age limit of Event 1, however, are on unidentified wood fragments (Clark et al. 2015), and thus have an unknown and possibly large inbuilt age, making them unsuitable for defining a minimum age (McFadgen 1982). Those for the older age limit are on peat, reeds and plant fragments from a peaty palaeosol stratigraphically just below the tsunami

deposit (Clark et al. 2015). The boundary between the tsunami deposit and upper surface of the palaeosol is a sharp contact, interpreted as probably a result of scouring removing the upper surface of the palaeosol (Clark et al. 2015), which would expose older organic matter in the soil. Furthermore, radiocarbon dating buried soil organic matter usually overestimates the true date of burial (Wang et al. 1996). It is likely, therefore, that the dates on the peat (NZA36394), the reeds (NZA53727) and the plant fragments (NZA55432) all therefore have inbuilt age (Figure 5), but how much inbuilt age is difficult to quantify. The radiocarbon dates for Event 1 thus provide a maximum date of about CE 1070 with an unknown inbuilt age for the event, but not a minimum date (Figure 5).

That the archaeological site was struck by the early tsunami after it was occupied is therefore possible. If the traditional stories are a guide, the tsunami would likely have been a significant event for the site's inhabitants, and may also have had the potential to disturb archaeological remains as described below. It is even possible that some of the burials on the site are of people killed by the tsunami. The dates on moa eggshell recovered from the burials listed by Higham et al. (1999) are not significantly different ($\chi^2 = 12.96$, $P > 0.1$), and do not rule out the possibility of deaths from a single event. These dates and the results, however, are influenced by calibration stochastic distortion (CSD effect), which is the extension of calibrated radiocarbon date ranges due to the changes of slope in the radiocarbon calibration curve (McFadgen et al. 1994), as are the dates

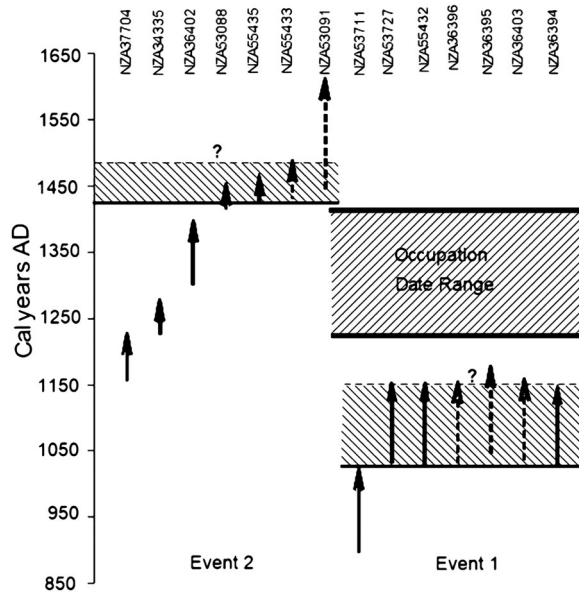


Figure 5. Plot of radiocarbon date ranges (95% probability) for Events 1 and 2 (after Clark et al. 2015), compared with the recalibrated radiocarbon date ranges (95% probability) on moa eggshell from Higham et al. (1999) (AD 1229–AD 1407), and the moa eggshell date ranges (95% probability) on moa eggshell from Jacomb et al. (2014) (AD 1291–AD 1417). For Events 1 and 2, upward-pointing arrows are maximum ages; dashed lines are samples stratigraphically younger than the earthquake evidence, measured on samples of unknown and possibly large inbuilt age. The maximum age for each event is the youngest maximum age measured on samples stratigraphically older than the event. The indicates an unknown minimum date for the age range. NZA references are for Events 1 and 2.

and result obtained by Jacomb et al. (2014). Better understanding of the dates of site occupation is likely to be obtained using archaeomagnetic dating in conjunction with the radiocarbon dates (Kinger 2017). If the big wave recorded by the Māori tradition is not related to Event 1, the archaeology of the site may provide more information as to what the event was. This, however, is a matter that future archaeological investigation of the site would need to address.

Implications of the tectonic events for the archaeological site, and its inhabitants

The effects of modern tsunami inundation show that tsunami waves are not just water, but, depending on their size and the nature of the beach and offshore seabed sediments, usually contain a mixture of other things such as stones, gravel, sand, silt, shells, fish and so forth picked up from the beach and offshore (Goff et al. 2001a; McFadgen 2007). When the wave recedes much of this material gets left behind onshore, mixed with additional material scoured from the ground, leaving behind holes and depressions. In a lagoon environment such as at Wairau, a wave coming through a river mouth can swing around and go back out to sea across the barrier (Dudley & Lee 1998). Such a wave going back out to sea over the site could potentially redeposit material picked up from the site. Not all tsunamis, however, necessarily leave a readily-identifiable sediment signature, and waves less than 5 m high can fall into this category (McFadgen 2007); nevertheless, waves of only 1 m high can still be lethal for anyone caught in them.

Tsunami effects on the site are only inferred at this stage from published descriptions and excavation notes; although as Garin (1855, cited in Clark et al. 2015) notes, the CE 1855 tsunami caused some of these effects (see above) and some evidence of these at least would be expected on the site. Possibly the evidence has been encountered but not recognised for what it is, and has been explained in archaeological terms as a cultural effect; an explanation that is common in the context of earthquakes in the eastern Mediterranean and Near East (Nur & Burgess 2008, pp. 1–31). The effect of tsunami inundation, however, is a hypothesis that can be tested during future excavations. This is important for two reasons. First, if a tsunami is shown to have affected the site, there are implications for the interpretation of the archaeological remains. Second, on a wider scale, New Zealand is exposed to tsunamis generated from nearby (e.g. the Kermadec Trench and Hikurangi Trough) and from some distance away (e.g. Chile), and some of these occurred in New Zealand during the prehistoric Māori period (New Zealand Palaeotsunami Database 2017). Archaeology therefore has the potential to add to the understanding of tsunami hazards in New Zealand by detecting, dating and assessing the impact of such events in an archaeological context, including their effect on prehistoric Māori society. Inferred effects on the Wairau site include (McFadgen & Goff 2007):

1. the spreading of occupation remains—oven stones and midden—over the main burial area, currently interpreted as the relocation of the cooking area towards the seawards side of the site;
2. the deposition of occupation remains in the holes and depressions formed along the beach ridge marking the CE 1848 shoreline;
3. scouring of some burials and removal of bones;

4. reworking of deposits, for example the adzes, ornaments and moa bones apparently mixed at random through the layer of oven stones and midden of Duff's (1956) second occupation;
5. redepositing of shingle derived from underlying base sediment as lenses lying on top of the first occupation layer (Wilkes *n.d.*);
6. mixing of occupation remains with redeposited shells and stones from the beach and offshore;
7. post butts in situ from posts that had been broken off;
8. formation of hollows, possibly by scouring along the boulder bank ridge just inland of the innermost post-1848 boulder bank ridge (Figure 2). The hollows contain moa bones, shells, burnt stones (Duff 1956; Brooks et al. 2011) and one with washed stones (Wilkes *n.d.*)—materials possibly washed in by tsunami waves.

In addition to tsunamis, and to the compaction and subsidence from the earthquakes exposing the site to erosion as described above, the resulting lower level of the site in relation to lagoon level also exposed it more readily to flooding, which may account for some of the silt deposits that Wilkes and Wellman found on the site (Wilkes *n.d.*; Brooks et al. 2011). There is also the layer of silt and estuarine shells noted by Wellman and Wilkes inland of, and above, the present lagoon shoreline (Wilkes *n.d.*; Brooks et al. 2011). Both Wellman and Wilkes were experienced geologists, and if their observation that the shellfish were in growth position is correct (Wilkes *n.d.*, p. 2), it would imply that the site had been covered by lagoon water for an extended time, long enough for the silt to be deposited and populated by shellfish. The silt contains vitrified glass (Brooks et al. 2011), indicating that at least some of the deposition is younger than European arrival on the site, which would be consistent with silt deposition after the CE 1848 and CE 1855 earthquakes and potential disturbance by flooding since CE 1855.

Earlier layers of silt, apparently deposited before and during occupation (Wilkes *n.d.*) when the site was higher than today, suggest inundation in earlier times from river flooding. This would have the potential to introduce material such as moa carcasses or other dead animals into the site, and to disturb archaeological remains. To what extent such inundation has affected archaeological remains since initial occupation, however, is something to be considered during future work on the site.

The post-CE 1848 lowering of the site would also enhance the effects of erosion. Of the c. 120 m retreat of the lagoon edge of the site since CE 1848, up to 85 m was before CE 1901 and up to 20 m since. Some of the retreat was probably a result of both river erosion during floods and tidal erosion, especially during extreme high tides. The section along the lagoon edge has been cut back exposing stratigraphic layers, and some of the retreat, at least since CE 1901, is almost certainly erosion in response to sea level rise since CE 1901, which is estimated to have been c. 0.2 m (PCE 2015). River erosion during floods, however, will almost certainly have declined as a result of the river diversion placed by Marlborough Regional Council in CE 1963 (McKinnon 2016).

The present height of the surface of the site above mean lagoon level (c. 2 m, Figure 3) is more than the expected rise in sea level by the end of this century as a result of climate change, estimated for New Zealand to be between about 0.2 m and 1.0 m (PCE 2015). How much the rise will be, however, depends on the response of the Greenland and

Antarctic ice sheets (IPCC 2013; Golledge et al. 2015; DeConto & Pollard 2016). Following the precedent of the last 170 years, the rise could be accompanied by reasonably substantial erosion, which could be further amplified by future major earthquakes on faults bordering Cook Strait. The CE 2016 Kaikoura earthquakes in November 2016 (up to magnitude 7.8), however, do not appear to have caused any compaction or subsidence of the Wairau coastline (Appendix 1)—the epicentres were probably too far away. Nevertheless, it is possible that the site may not exist by the end of this century. There is clearly a need here to monitor the erosion of the site lagoon edge, and Te Kawa a Māui, School of Māori Studies at Victoria University of Wellington, is currently exploring this possibility using drone technology. In addition, a planned research programme over the next few decades, carried out in conjunction with the Rangitane iwi and using appropriate sciences in addition to archaeology, would enable the gathering of data from the site before it finally disappears.

The effects of tectonic activity, earthquakes and tsunami inundation on the Wairau archaeological remains is only part of what needs to be examined further; there is also the possible impact of the events on the site's inhabitants. Archaeology has a role to play in this respect (not only at Wairau, but also elsewhere in coastal New Zealand), to examine the impact of such events on prehistoric communities and how those communities responded; indigenous knowledge of these events is here an important source of information. Earthquake archaeology and tsunami archaeology are both being developed as archaeological subdisciplines in Japan, to examine how people responded in the past to such events, as a guide to effects and responses to modern events (Barnes 2017). In a country such as New Zealand, which is subject to tectonic events and consequent environmental change, there is scope for a similar approach to add both to our understanding of prehistory, and to provide information relating to the study of tectonic hazards generally.

Conclusions

In the last 900 years the Wairau archaeological site has been struck by at least four earthquakes large enough to cause environmental changes to the site and its surroundings. These include changing the site setting, previously on an island, transforming it to become part of the existing Wairau boulder bank. In addition, the site has been subject to three tsunamis, the most recent of which was at least large enough to cause considerable damage to 19th century CE buildings on the site.

The archaeological significance of these events relates to their possible effects on the site's inhabitants, and on how the communities living on the site adapted to the earthquakes and tsunamis that impacted the site and local environs. The tectonic processes thus have implications for possibly enhancing the interpretation and understanding of the archaeology of the site, both for the remains that have already been recovered, as well as those that may be recovered during future work on the site.

The location of New Zealand across an active tectonic plate boundary means that earthquakes and tsunamis have a long history of affecting people in New Zealand, and many have been recorded orally by Māori. There is thus scope for earthquake archaeology and tsunami archaeology to be developed as subdisciplines in New Zealand: first, to examine how people responded in the past to tectonic events; and, second, to provide information relating to the study of tectonic events generally in New Zealand.

Considering the effects of past earthquakes, future sea level rise and the likelihood of further earthquakes, it is possible that the Wairau Bar site will not exist by the end of this century. This outcome, however, could be ameliorated by tectonic uplift in an earthquake event. There is need for monitoring of erosion of the site, and for a research strategy planned with Rangitane iwi to obtain data from the site before it disappears.

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Appendix 1

Differential GPS readings of Bench Mark AD7X 15 May 2017 compared with Land Information New Zealand (LINZ) values. Instruments used were a Trimble ProXT and a Trimble GeoXH6000.

Trimble ProXT			
Base station	Measured NZTM2000 mE	Measured NZTM2000 mN	Measured ellipsoid Hgt (m) NZVD2009
Wither Hills	1688204.883	5404874.550	13.733
Arapawa	1688205.067	5404875.260	13.939
Havelock/Mahakipawa	1688205.052	5404875.430	13.714
LINZ values	1688204.850	5404874.520	13.740
Trimble GeoXH6000			
Base station	Measured longitude	Measured latitude	Measured ellipsoid Hgt (m) NZVD2009
Wither Hills	174.0568570	-41.5029020	13.553
Arapawa	174.0568607	-41.5028961	13.790
Havelock/Mahakipawa	174.0568582	-41.5028926	13.685
LINZ values	174.0568565	-41.5029018	13.740

Within an error limit of +/-20 cm the elevation readings agree with those assigned to the Bench Mark by LINZ.