Large Earthquakes and the Abandonment of Prehistoric Coastal Settlements in 15th Century New Zealand

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This paper reports on the effects of large earthquakes and related events, such as tsunamis, on prehistoric coastal settlements in New Zealand. It is based on field observations at several well-established archaeological sites around the Cook Strait region and on literature reviews. We identify three broad periods of seismic activity in New Zealand since human occupation of the islands: 13th century, 15th century, and the 1750s to 1850s. The most significant, from a prehistoric human perspective, is the 15th century. Using examples from the Cook Strait region, we suggest that the abandonment of coastal settlements, the movement of people from the coast to inland areas, and a shift in settlement location from sheltered coastal bays to exposed headlands, was due to seismic activity, including tsunamis. We expect similar patterns to have occurred in other parts of New Zealand, and other coastal areas of the world with longer occupation histories. © 2003 Wiley Periodicals, Inc.

INTRODUCTION

Sea level has been at or near its present level for 16,000 of the last 150,000 years (Voris, 2000). The most recent stabilization of world sea levels during the last 6000 years, combined with modern climatic conditions, has created coastal habitats favorable to humans on a scale not matched since the previous interglacial maximum (Bailey and Parkington, 1988). The relative uniqueness of such highstands means that there have been only short periods of geological time available for scientists to understand the interaction of humans with the coastal environment. In particular, the effects of catastrophic events such as tsunamis on human occupation of the coast can only be studied within these short timeframes because generally, any previous evidence of human occupation will have been flooded by the highstands.

New Zealand is tectonically active, and within the period of human settlement several parts of the country have undergone tectonic uplift or subsidence (e.g., Grapes and Downes, 1997). Seismic activity has ranged from barely detectable earthquakes and tsunamis that cause no damage to large-scale land and sea movements capable of destroying cities and causing widespread regional disruption (e.g., earthquake: A.D. 1931, Napier [Hull, 1986]; tsunami: A.D. 1947, Gisborne [Eiby,

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1982]; Figure 1). Uplifted and subsided shorelines in coastal areas indicate local seismic activity, and, although such shorelines are not widespread, the entire coastline of New Zealand is nevertheless at risk from tsunamis generated by either local or distant tectonic or other events.

The first people to settle New Zealand were the Polynesian ancestors of today's Maori population who arrived about 700 years ago (Anderson, 1991; McFadgen et al., 1994; Higham and Hogg, 1997). They were mainly coastal people, and archaeological remains of many of their settlements are found along the country's coastal strip (Davidson, 1984). Europeans followed the Polynesians about 500 years later, and the present population of New Zealand occupies many coastal settlements.

International research into the impact of earthquakes and tsunamis on prehistoric coastal settlements is limited. Antonopoulos (1992) suggested the possible destruction of Knossos, Crete, by a tsunami (and, presumably, the subsequent abandonment of the city), although numerical modeling by Minoura et al. (2000) casts some doubt on this assertion. Hutchinson and McMillan (1997) report a 3000-year history of temporary and permanent village abandonment along 600 km of coastline in British Columbia, Canada, based on palaeoseismic and archaeological records, as well as native oral traditions. The hypothesis for village abandonment as a result of earthquake shaking and/or tsunami inundation has also been studied on the Oregon and Washington coasts in the United States (Woodward et al., 1990; Cole et al., 1996).

Bearing in mind New Zealand's position in the South Pacific Ocean, astride the boundary between two major tectonic plates, local earthquake-related events must have affected the prehistoric inhabitants. The Alpine Fault, more than 500 km long, runs almost the entire length of the South Island, and under the seafloor to the south (Bull, 1996; Barnes, 2000; Figure 1). Recent movements of the Alpine Fault have occurred at intervals of about 260 years, producing large earthquakes with magnitudes of approximately 8.0 M_w (Bull, 1996). At the northern end of the South Island, the Alpine Fault divides into many active faults (Bull, 1996). In the Wellington region of the North Island, on the north side of Cook Strait (Figure 1), 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; Table I), which are thought to be North Island continuations of the divided Alpine Fault (Carter et al., 1988).

Earthquakes related to tectonic activity in the Cook Strait region within the time of human settlement are grouped into three time periods by Goff and McFadgen (2001a): 13th century, 15th century, and the 1750s to 1850s. The earliest group was about the time New Zealand was colonized by humans and probably had minimal impact. The second group was well after human colonization, 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 A.D. 1855 Wairarapa earthquake, which produced widespread damage (Grapes and Downes, 1997).

Research over the last few years has broadly defined what constitutes deposits laid down by tsunamis as opposed to wind, storms, or humans. The diagnostic

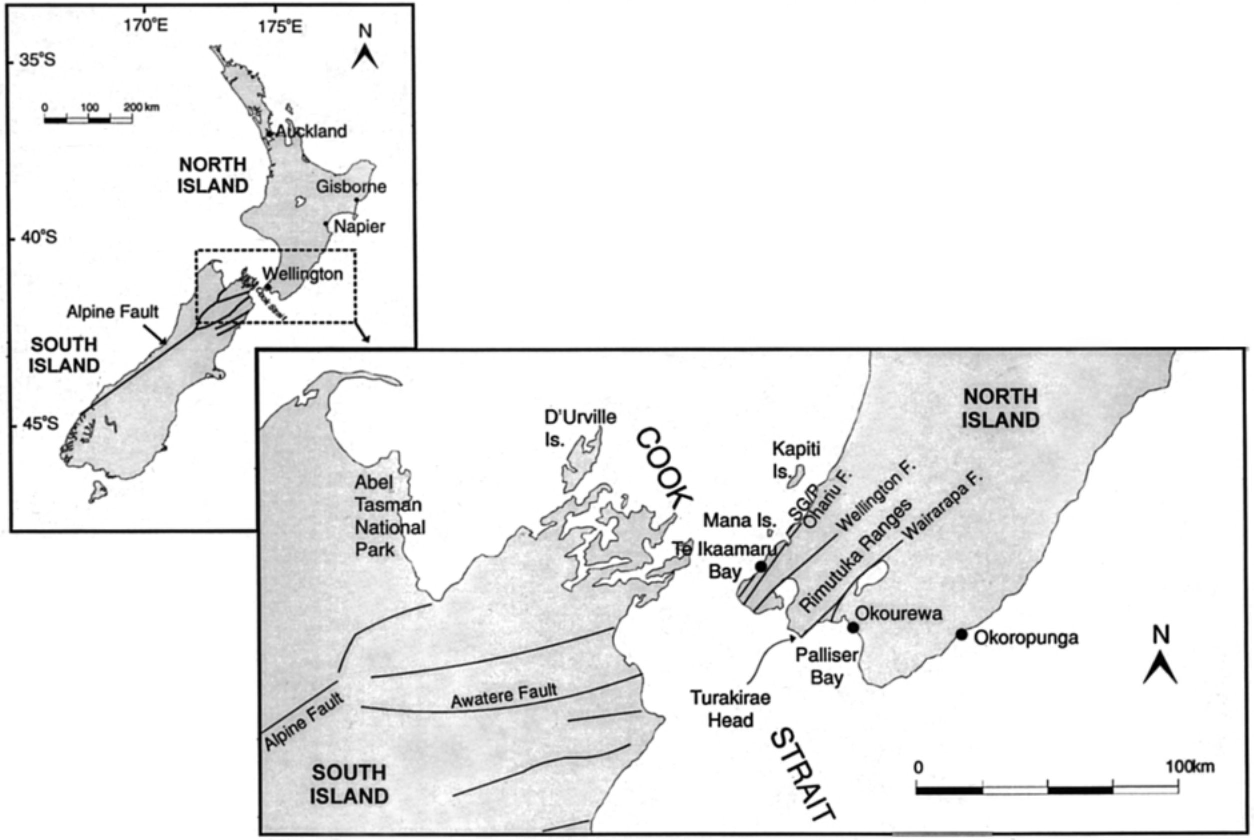

Figure 1. New Zealand with detail of Cook Strait region showing names mentioned in text. Fault lines have been simplified to show approximate locations in the immediate vicinity of Cook Strait (SG/P = Shepherd's Gully and Pukerua Fault).

Table I. Summary of fault rupture data.

Fault	Approx. Rupture Date (years A.D.)	Est. Magnitude M_w	Reference
Awatere	1848	~7.5	Grapes et al. (1998)
Wairarapa	1855	8.0 − 8.3	Van Dissen and Berryman (1996)
Ohariu	1290	7.6 ± 0.3	Van Dissen and Berryman (1996)
Wellington	1250, 1450	?, 7.6 ± 0.3	Van Dissen and Berryman (1996)
Alpine	1220, 1450, 1620, 1717	~8.0, ~8.0, ~8.0, ~8.0	Bull (1996), Yetton et al. (1998)

criteria used in New Zealand are briefly summarized in Table II. Such deposits from the 13th century, 15th century, and A.D. 1855 have been reported for the Cook Strait region from Abel Tasman National Park (Goff and Chagué-Goff, 1999) and Kapiti Island (Goff et al., 2000), and a 15th century event from Mana Island (Goff et al., 2000) and Okourewa, Palliser Bay (Goff et al., 1998; Goff et al. 2001a; Figure 1).

Table II. Summary of diagnostic characteristics for tsunami used in New Zealand (after Goff et al., 2001c).

Diagnostic Characteristics
• Particle/grain sizes range from boulders (up to 750 m^3), to coarse sand to fine mud. A tsunami will usually transport whatever size ranges are available, wind-blown deposits generally have a distinct grain size range
• The sediment generally fines inland and upwards within the deposit. Deposits often rise in altitude inland and can extend for several km inland and 10's of km alongshore. Deposits are generally far less chaotic than those of storms
• Each wave *can* form a distinct sedimentary unit
• Distinct upper and lower sub-units representing runup and backwash can often be identified. This is unlike storm or anthropogenic deposits
• Lower contact is unconformable or erosional
• Can contain intraclasts of reworked material, but these are not often reported
• Often associated with loading structures at base of deposit
• Generally associated with an increase in abundance of marine to brackish diatoms
• Marked changes in foraminifera (and other marine microfossils) assemblages. Deeper water species are introduced—this is unlikely in storm or anthropogenic deposits
• Pollen concentrations are often lower (diluted) in the deposit because of the marine origin
• Increases in the concentrations of sodium, sulphur, chlorine, calcium and magnesium occur in tsunami deposits relative to under- and overlying sediments—indicates saltwater inundation and/or high marine shell content
• Individual shells and shell-rich units are often present (shells are often articulated and can be water-worn). Intact shells as opposed to shell hash, and all age ranges are diagnostic of tsunami as opposed to storm or anthropogenic deposits
• Often associated with buried vascular plant material and/or buried soil
• Shell, wood and less dense debris often found "rafted" near top of sequence
• Often associated with reworked archaeological remains (e.g., middens). In some cases occupation layers are separated by a palaeotsunami deposit
• Known local or distant tsunamigenic sources can be postulated or identified

Based upon these events and other tsunami data reported for the area, tsunami wave heights within Cook Strait need to be at least 5 m high to leave a recognizable deposit (Lowe and de Lange, 2000). However, the deposit left by ancient tsunamis in the region depends 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 most recent event because the event tends to destroy or incorporate earlier deposits. A sheltered location, however, such as a coastal wetland, can preserve a record of multiple high-energy events because in such a passive environment, once a deposit has been laid down, there is little chance that a subsequent event will remove it.

Based upon the existing data, there is every reason to expect that the 15th century tsunamis affected prehistoric Maori coastal settlements in the Cook Strait region. In the past, however, little attention was given to the impact of seismic activity on such communities. Best (1923) and McFadgen (1980a) refer briefly to the impact of earthquakes, but the most comprehensive analysis is by Goff and McFadgen (2001a), 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 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, 2001a).

This paper discusses further evidence for the effects of large earthquakes and their aftermath on prehistoric coastal settlements in and around the Cook Strait region. We use the well-documented evidence of the A.D. 1855 Wairarapa earthquake (Grapes and Downes, 1997) as an analogue for evaluating the impact of seismic events.

COOK STRAIT REGION

At each location, we consider evidence for archaeological occupation and its age, earthquake activity, and tsunami inundation. Much of the evidence is from previous research, and, where possible, this is supplemented by our own observations.

Okoropunga

At Okoropunga, on the southeastern North Island, north of Cook Strait, there are prehistoric Maori gardens built on the Holocene coastal platform across uplifted beach ridges of gravel and cobbles mantled with sand (Figures 1 and 2; McFadgen, 1980b). Radiocarbon ages for the gardens indicate that they were in use by the late 15th century (McFadgen, 1980b; 1980c).

Between the inland and seaward gardens is a partly infilled borrow pit (from

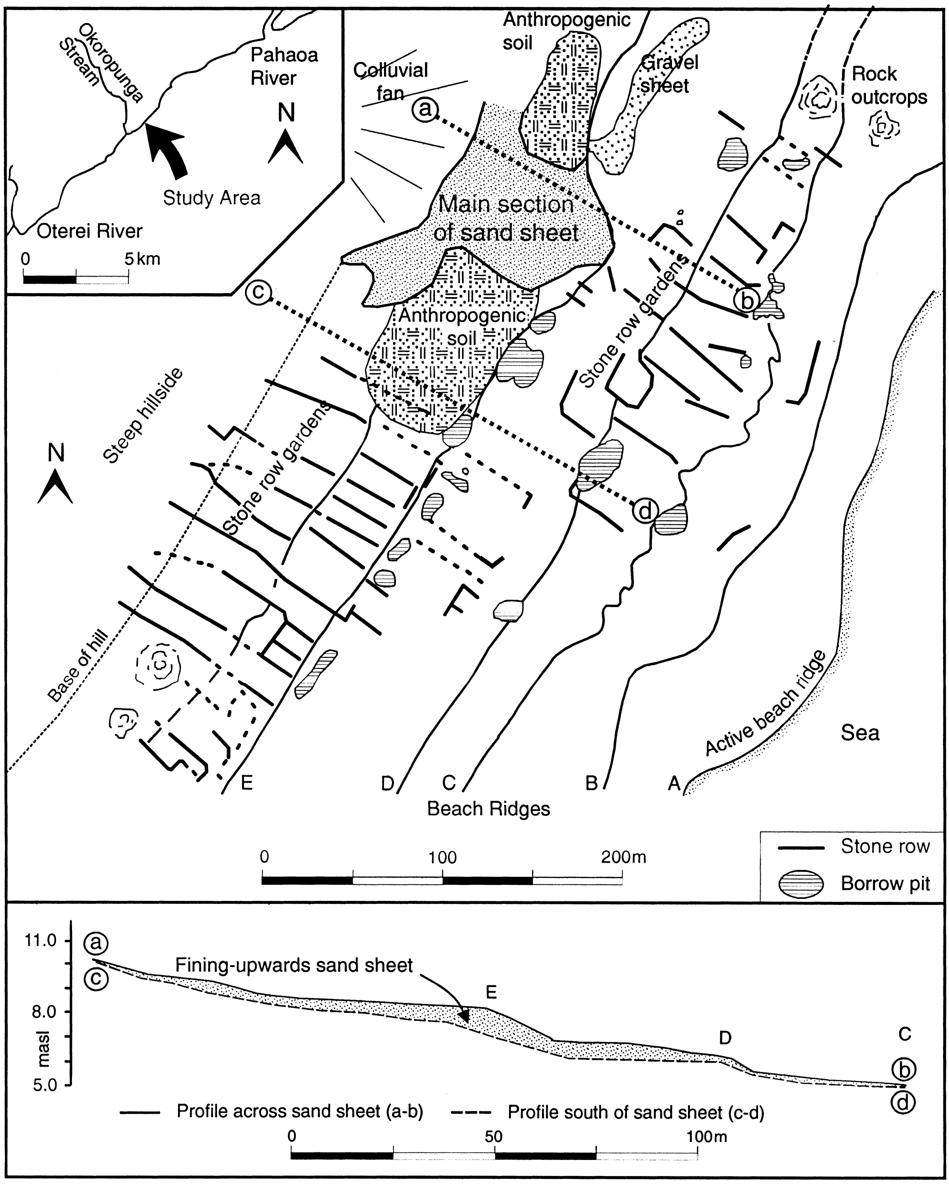

Figure 2. Okoropunga. Archaeological site with associated sand layer. Transects a–b and c–d are given at base of figure. Simplified after McFadgen (1980b).

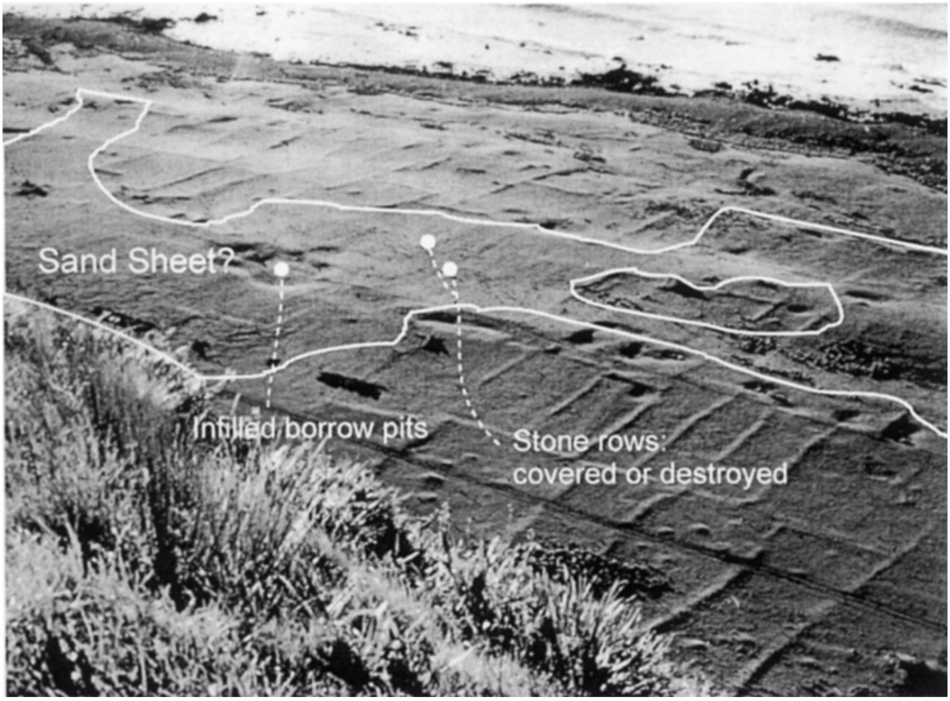

Figure 3. Okoropunga. Garden system and borrow pits on uplifted shorelines (Photo: Graham Billing). Geomorphological interpretation shown by white lines.

which garden material was mined) and stone row gardens that appear to have been partly or totally buried (Figure 3). Near the back of the coastal platform is a sheet of sand that is ca. 300–500-year-old based on soil profile development and radiocarbon dating (McFadgen, 1980c).

The sand sheet covers more than a hectare, is up to 70 cm thick, and has a minimum volume of at least 4000 m^3. It rises up to 10.5 m above present sea level where it pinches out (Figure 2). The sheet fines upwards and inland from a very coarse to a medium sand. Buried stone row gardens, infilled borrow pit, and sand sheet are consistent with tsunami inundation. An area of gravel to the northeast of the sand sheet was not studied in detail, and therefore its association with the tsunami is not known. This event probably took place sometime between the late 15th and early 16th centuries. While the sand sheet extends up to 250 m inland from the present beach, it is about 200 m inland from Beach Ridge C (5 m above present sea level), which was the shoreline at the time of deposition (Figure 2; McFadgen, 1980b).

The sand sheet is not extensive, although steep coastal bluffs have determined its landward extent and give rise to the marked lateral spread at the base of the hills (Figure 2). Its limited extent is thought to be due to the direction of travel of the tsunami. A tsunami generated in the vicinity of Cook Strait would be refracted around Cape Palliser and travel obliquely along the Wairarapa coast. During the Sissano Lagoon tsunami in A.D. 1998, such a wave came ashore only at places determined by the coastal configuration (McSaveney et al., 2000).

Palliser Bay

Palliser Bay is 40 km west of Okoropunga (Figure 1). 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). The oldest and highest shoreline is about 6000 years old and has a maximum elevation of about 10 m above present sea level (Ghani, 1978).

Prehistoric Maori extensively occupied the eastern coastal platform after 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 are all 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 (Goff and McFadgen, 2001a, 2002).

Te Ikaamaru Bay

At Te Ikaamaru Bay, on the western side of Cook Strait, 50 km northwest of Palliser Bay (Figure 1), are two prehistoric Maori hill forts, as well as middens and gardens (Davidson, 1976; Figure 4). Evidence for the beginning of prehistoric Maori occupation is poor, but occupation by the late 15th century is not unlikely based on a radiocarbon date for shells in a midden (NZ7754, listed in McFadgen [1997]).

Marine gravel, 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 (Figure 4). The gravel and cultural remains were interpreted by one of us (B.G.M.), 25 years ago, 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 (Figure 4). 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 A.D. 1855 and younger than Maori settlement. Sedimentologically, the gravel is strikingly similar to other tsunami deposits found in the Cook Strait region (e.g., Okourewa, Figure 1; Goff et al., 1998). The deposit is older than A.D. 1855 and younger than Maori settlement, so we infer that this event relates to the second grouping of seismic activity in the 15th century.

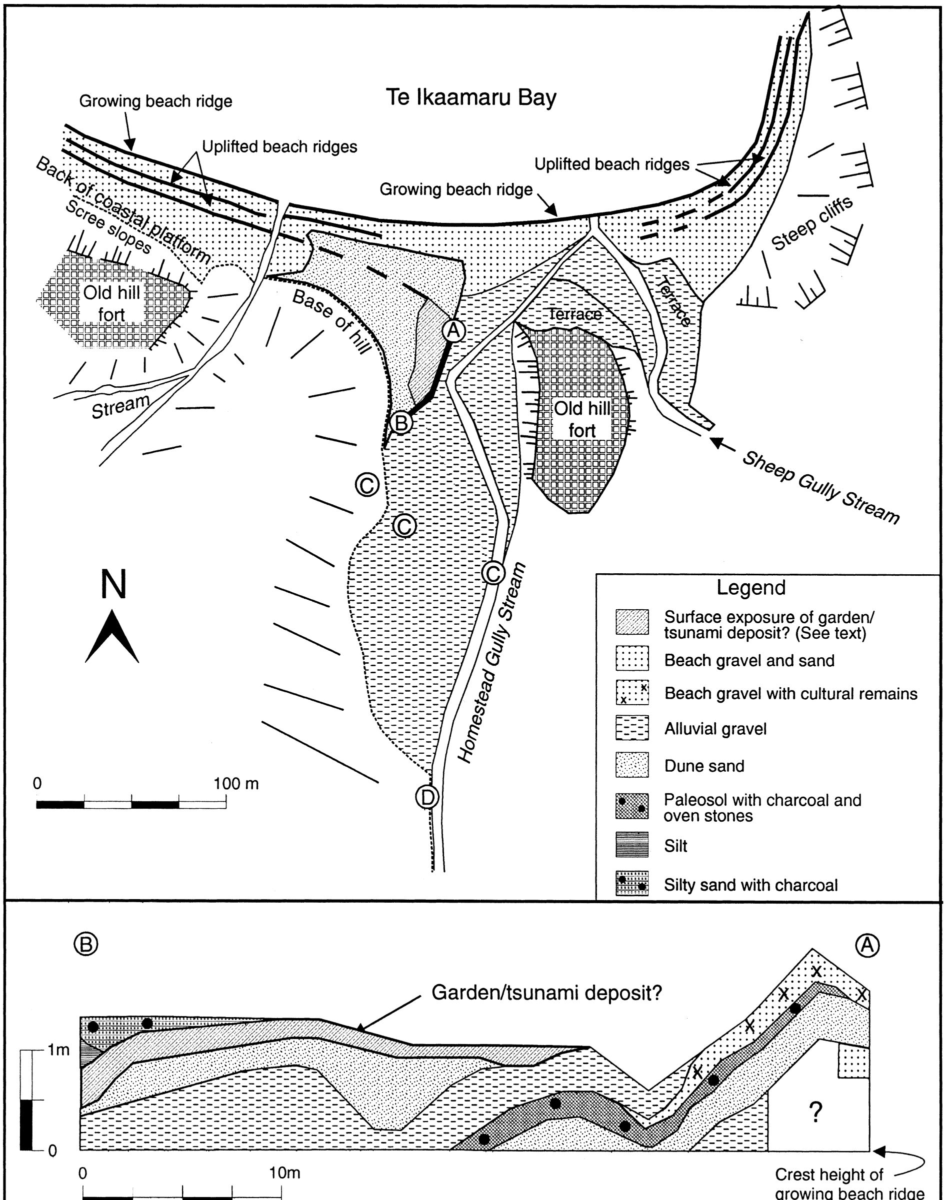

Figure 4. Te Ikaamaru Bay. Study site showing extent of archaeological remains and associated pebble/coarse sand unit. Simplified from field notes. A–B = generalized transect shown at base of figure, C = outcrops of beach gravel in stream sections, D = maximum inland extent of beach gravel.

D'Urville Island

There are two well-defined archaeological occupation layers on the western side of D'Urville Island (Figure 1); the older dates to between about A.D. 1300 and 1500, the younger to between about A.D. 1550 and 1800. Wellman (1962) reports a layer of pebbles at Greville Harbour (on the western side of the island) that, in places, underlies the older of the two occupation layers. It was thought that the pebbles had been dropped by Maori carrying gravel to their gardens (Wellman, 1962). An alternative hypothesis is that this is a tsunami deposit. The layer contains water-worn molluscan shells, with pebbles that range in size up to 5 cm in diameter, similar to those found on the beach (Wellman, 1962), and thins inland towards the hills behind the beach. The stratigraphic position of the pebbles (McFadgen, 1985) suggests probable deposition in about the 15th century.

IMPACT OF LARGE, 15TH-CENTURY EARTHQUAKES ON MAORI

Fault locations and the estimated earthquake magnitudes (Figure 1 and Table I) for faults in the vicinity of Cook Strait indicate that they could have generated significant tsunamis in the 15th century. This paper and previous research show that there is geomorphological evidence for one or more tsunami inundations on both sides of Cook Strait in the 15th century corresponding to the timing of the ruptures of one or both of the Wellington and Alpine faults. Furthermore, there is evidence for tsunamis at or about the same time in other parts of New Zealand (Table III): northeast of Auckland (Figure 1) (Nichol et al., 2003); on the West Coast of the South Island (Goff et al., 2001b); and other sites on the west and east coasts of both islands (Goff and McFadgen, 2001b). Beyond New Zealand there is possibly evidence for 15th century tsunami inundation in Australia (e.g., Bryant et al., 1997; Fullagar et al., 1999).

The available New Zealand evidence indicates widespread tsunami inundations that are most likely related to a cluster of closely grouped (in time), large earth-

Table III. 15th century tsunami data (see Figure 1 for locations).

Comments	References
• *Abel Tasman National Park*—up to 3.5 km inland, primarily mud in sand	Goff and Chagué-Goff, 1999
• *Archaeological sites*—common signal of inundation found throughout the country	Goff and McFadgen, 2002
• Canterbury region—up to 2 km inland, sand	J. Goff, unpublished data
• *North/Northeast of Auckland*—up to at least 350 m inland, runup over 32 masl, reworking of Maori ovens/midden sites	Nichol et al., 2002, 2003
• *Kapiti Is.*—over 200 m inland, runup over 10 masl, saltwater inundation of environment	Goff et al., 2000
• *West Coast, South Island*—over 2.5 km inland, runup over 5 masl, destruction of nearshore vegetation	Goff et al., 2001b
• *Palliser Bay*—over 3.5 km inland, cobbles up to 1 km inland	Goff et al., 1998

Table IV. Effects of the A.D. 1855 earthquake and tsunami (after Grapes and Downes, 1997).

- Earthquake occurred near Wellington—groundshaking felt as far afield as Auckland and Dunedin
- Landslides occurred over an area of 135,000 km^2 and up to 175 km away from the epicentre. About 33% of the hills up to 50 km away from the epicentre were stripped of vegetation
- Many rivers were dammed and later burst causing extensive flooding
- Groundshaking causes the liquefaction of soft sediments, fissuring of the ground, building collapse, river channel changes, and wetland drainage
- Sediment choked rivers, smothered shellfish beds in estuaries and along sandy shores
- Numerous lakes and lagoons were drained as a result of uplift leaving freshwater fauna stranded and dead
- Coastlines were uplifted up to 6 m, killing intertidal food sources
- Cliff collapse onto coastal platforms occurred at many places along the southeast coast of the North Island, burying vegetation/crops, and with fissuring of the ground this severely impeded travellers and communication
- Fish were stranded on shore by the tsunami. Many fish were seen dead in Cook Strait and are presumed to have been killed by rapid pressure changes
- Tsunami inundation destroyed coastal vegetation by saline poisoning
- At least one Maori village appears to have been destroyed in Palliser Bay by tsunami inundation

quakes (Goff and McFadgen, 2002). Tsunamis, however, are only one possible consequence of large earthquakes. Seismicity drives changes in geomorphology and ecology (Goff and McFadgen, 2002), and based upon the recorded effects of the A.D. 1855 earthquake and tsunami (Grapes and Downes, 1997), similar, and possibly larger, events occurring in prehistoric times would have had, in addition to tsunami inundation, earthquake-generated ground shaking, uplift, and increased sediment loads in rivers and near shore environments. The impact of these effects on coastal communities would have been catastrophic, even if no one was killed (Table IV).

There would have been a loss of terrestrial, lacustrine, and marine food sources, the destruction of vegetation, drying up of lakes and lagoons, sediment infilling of streams and rivers, and smothering of shellfish beds. Settlements and gardens at the foot of cliffs would have been vulnerable to landslides, and travel either on foot or by canoe would have been seriously impeded in the short term as a result of landsliding, fissuring, and destruction of vegetation. Tsunami inundation is likely to have destroyed settlements and canoes, and rendered coastal gardens and soil unproductive for at least one growing season (Goff and McFadgen, 2001a). In some coastal areas, the after-effects of such large earthquakes, or, as proposed here a cluster of large earthquakes, would have continued to be felt for many years. In other areas, for a short time at least, settlement sites would have been unsafe and food resources unreliable.

The preservation of tsunami deposits in association with prehistoric coastal settlements provides the first indication that the suite of seismic-related events described above may have precipitated the abandonment of some coastal settlements.

The timing of the 15th century clustering of events coincides approximately with a movement by Maori from bays to headlands (Wellman, 1962; Jacomb, 2000) and from the coast to sites many kilometers inland (Leach and Leach, 1979). The occupation of headlands has variously been linked to changes in fishing practices (Anderson, 1981) and to the need for protection in an increasingly war-like society (Wellman, 1962). Wellman (1962) inferred that during the early occupation period on D'Urville Island people lived in bays, choosing convenient and sheltered rather than defensive and exposed locations, whereas, in the later occupation period, they lived on exposed headlands to guard themselves against surprise attack. The move to inland sites has been related in part to a slight deterioration in climate that coincided with the Northern Hemisphere's "Little Ice Age" (Leach and Leach, 1979), although such a climatic deterioration has yet to be proven for New Zealand.

In our opinion, an important factor which should be considered in both of these changes in settlement location is catastrophic seismic-related disturbances, which are now known to have taken place at about the same time (e.g., Van Dissen and Berryman, 1996). A move from bays to headlands in response to seismic-related events that included tsunami inundation has been suggested for British Columbia in the 13th century (I. Hutchinson, personal communication, 2001).

The changes in settlement location would help to reduce the problems caused by seismic-related ground shaking, coastal uplift, landslides, and tsunami inundation. It is significant that, on the Palliser Bay coast, food storage pits were located within early settlements on the coastal platform and would have been subject to tsunami inundation with consequent loss of their contents, while later storage pits were often located on higher ground and in more inland situations (Leach, 1979). Such a change in location would ensure continuity of food supply following a catastrophic seismic event. Warfare and depopulation following catastrophic events that deplete food supplies are known from Tropical Polynesia (Kirch, 1994), and a move to headlands *and* the construction of fortified sites would serve to guard the people and their severely depleted food stores against surprise attack from neighboring groups similarly affected.

CONCLUSIONS

Understanding the processes that have operated during the last 6000 years is crucial to the study of human occupation of the coastal zone throughout prehistory. During the relatively short occupational history of New Zealand, catastrophic events such as tsunamis are likely to have had a significant effect upon coastal settlements. From a human perspective, three broad periods of seismic activity have been identified, with the most widespread impacts those of the 15th century.

During this period, we attribute to seismic activity and tsunamis the abandonment of settlements around the Cook Strait coast, the movement of people from the coast to inland areas, and shifts from sheltered coastal bays to exposed headlands. Similar patterns may well be expected to have occurred in other parts of New Zealand, and other coastal areas of the World with longer occupation histories.

Further research needs to be carried out to investigate the extent and return period of such catastrophic events, their effects on prehistoric human populations in the coastal zone, and the possible effects they will have in the future.

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