THE 1855 WAIRARAPA, NEW ZEALAND, EARTHQUAKE - ANALYSIS OF HISTORICAL DATA

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ABSTRACT

Nearly 200 historical accounts have been examined and analysed in order to determine the effects of the magnitude 8+ 1855 Wairarapa, New Zealand, earthquake. The documents examined include contemporary diaries, letters and journals, newspaper reports and articles, archives, memoranda and reports of the Wellington Provincial Government as well as later reminiscences, extracts from published scientific papers, books and other articles. Other than the published accounts of Sir Charles Lyell, who, in 1856, first recognised the importance of the earthquake as causing the greatest deformation and surface fault rupture then known, there has been no comprehensive account of the effects of the earthquake in the scientific literature until now.

Much of the data is presented with extensive quotations from the source material, especially where conflicting accounts on important aspects have been found. All material is analysed with an understanding of the geographical, social and political conditions at the time. The reliability of the material is taken account of so that first-hand accounts, that have been recorded no more than several years after the earthquake, and in which there are no obvious inconsistencies or confusion with other earthquakes, are valued most highly.

Using the historical accounts as the primary source of data, but also taking into account the results of more recent geological, geomorphological and seismological investigations of the deformation, many aspects of the earthquake are discussed in detail. These are mainshock magnitude and epicentre; felt intensity distribution; descriptive account of the effects of the mainshock on people (including casualties) and man-made structures by location throughout New Zealand (including a resumé of contemporary building techniques); effects on the environment from strong shaking such as fissuring, liquefaction, spreading, subsidence and landslides, and from tectonically produced uplift, subsidence and faulting; biological effects; tsunami and seiche; aftershock occurrence and social response and recovery.

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INTRODUCTION

On the evening of 23 January 1855 a large earthquake shook almost the whole of New Zealand. Historical evidence analysed in this paper shows that the earthquake was severely damaging to settlements in the southern half of the North Island, particularly Wellington and Wanganui, and in the northern part of the South Island, reaching a maximum intensity of MMIX, possibly MMX. Surface rupture occurred on the now recognised Wairarapa Fault and about 5,000 km^2 of land to the west of the fault was uplifted and tilted. Uplift of about 2.7m was recorded at several locations on the south coast of the North Island to the east of Wellington. Historical descriptions also indicate that the earthquake resulted in other ground damage with widespread occurrence of landslides, expulsion of water and sand, lateral spreading, differential settlement and possibly tectonic subsidence. Seismic seiches were generated in a number of rivers, lakes and harbours by earthquake shaking in the North and South Islands. A large tsunami washed the shores of Cook Strait, and tidal disturbances were reported reaching as far north as Otaki and possibly Dunedin in the south. Waves up to 9-10m high were observed in Palliser Bay. The water level in Wellington Harbour oscillated for 8-12 hours after the earthquake which may be explained as a response to tsunami generated external to the harbour and to seiching generated by differential uplift across the harbour and possibly by sudden horizontal displacement of the harbour perimeter accompanying right lateral slip on the Wairarapa Fault. Horizontal movement on the fault was not recognised in any contemporary account of the earthquake. Numerous aftershocks were experienced, with up to two or three daily for six weeks. Several aftershocks can be identified from descriptive accounts as large events but the only signifcant damage which can be related to particular aftershocks occurred near Kekerengu on the northeast coast of the South Island. At this location several shocks were regarded as larger than the first and main shock.

By early 1856, the significance of the earthquake as being associated with uplift and faulting to the greatest extent then known was recognised by the eminent British geologist, Sir Charles Lyell. His inferences were based on information supplied to him from three New Zealand eye witnesses, Walter Mantell (son of the prominent geologist, Gideon Mantell), Edward Roberts (a Royal Engineer) and Frederick Weld (a Marlborough landowner). Lyell's publications (Lyell 1856a, b; 1868), together with a memorandum of Edward Roberts (1855), provide the only authoritative contemporary scientific information on the faulting, uplift and subsidence that accompanied the earthquake.

Although the 1855 earthquake has long been recognised as a "great" earthquake (Hayes 1953; also catalogues of Hogben (1891); Milne (1911); Bastings (1935); Hayes (about 1935, unpublished)), historical accounts of the earthquake have apparently been considered too incomplete for a comprehensive scientifically based account of it to be written. Hayes (1936) comments on the limitations imposed by lack of reports, especially poor in areas away from the main settlements, although by this time the Seismological Observatory had accumulated a number of accounts of the earthquake in addition to the well known reports of Lyell and Roberts (Hayes 1935, 1936; Seismological Observatory files). The accounts included Mallet (1858, eyewitness account of an engineer, W. Bennett); Taylor (1855), whose book *Te Ika a Maui* includes some Wellington newspaper extracts as well as the Roberts memorandum; Davie (1870, tsunami observations); A. McKay (1890, faulting); W.MacKay (1902, raised beaches); Field (1891, general description of effects in Wanganui and elsewhere); Hector (1891; description of nature of the earthquake shaking); Henderson (1932; summary of current knowledge); the Mills & Carter Report (1855, a Government commissioned report on building damage in Wellington); *Life and Recollections of a New Zealand Colonist* (Carter 1866, the same Carter who contributed to the previous report); the recollections of Alfred Matthews* (c1925), a Wairarapa station owner; the diary of Frederick Trolove (1855), a northeast Marlborough settler; and a small number of newspaper reports. Based on these, Hayes (1936) produced the first isoseismal map of the earthquake, assessing intensities on the Rossi-Forel scale. The magnitude of the earthquake is first listed as about 8 by Hayes (1953), clearly recognising the 1855 earthquake as larger than the earthquake in Marlborough in 1848 (M7.1; Eiby 1980) and the largest since written records had been available.

By 1989 the historical source material had been greatly extended by George Eiby with the addition of many previously unknown contemporary accounts, sufficient for Eiby to be able to present a summary of its effects (Eiby 1989) at the Workshop on Deformation in the Wellington Region. At this time Eiby had the intention of publishing a comprehensive paper. Unfortunately, he died in 1992 without having written it. The Workshop had provided the focus for proposing projects which were most important for assessment of the seismic hazard of the region. A full analysis and publication of the existing data on the 1855 earthquake was identified at the Workshop as having the highest priority of the projects proposed. This paper is produced in response to the recommendation of the Workshop. Independently of Eiby, one of the authors of this paper, Rodney Grapes, had also collected accounts of the earthquake. Although amalgamation of the source information collected by Grapes and Eiby resulted in a considerable database, it has been possible to extend it with further historical accounts, maps, charts, sketches and photographs.

Extracts from diaries, private journals and notebooks, family papers and letters, reminiscences, newspaper articles (sourced and unsourced), Government papers, published books (which for the most part are original material, not interpretations), survey maps and hydrographic charts are used as the basis for the analysis of geological, seismological, biological and social aspects of the earthquake presented in this monograph. Relevant background information on important locations and on people who have described the earthquake's effects forms part of the source material.

In addition to descriptions of the earthquake, geomorphological and geological evidence for the uplift, faulting and subsidence

* **Note:** *References to unpublished source material (letters, diaries, journals etc.) and published source material (including newspaper articles that are italicised) are distinguished by being underlined and not underlined respectively, in addition to being listed separately under the appropriate headings in the references section.*

accompanying it, has been investigated and described in a number of papers since 1900. These include: Bell (1910; raised beach, Wellington south coast); Aston (1912; uplifted beach at Turakirae Head); Adkin (1921; uplift in Porirua Harbour area); Ongley (1943; 1855 fault break); Stevens (1956; 1969; 1973; 1989; uplifted coastline of the Wellington area); Wellman (1967; uplifted beach at Turakirae Head); Grapes (1988; 1855 landslide and revegetation); Dellow (1988; landslide); Robbins (1958; landslide and revegetation); and Eiby (1990; changes in Porirua Harbour). In addition, Darby & Beanland (1992) have used elastic dislocation modelling to investigate possible sources of the 1855 earthquake, Fairless & Berrill (1984) have tabled liquefaction reports, and tsunami and seiche effects in Wellington Harbour have been modelled by Barnett *et al.* (1991). The data from a number of these papers have been incorporated into, but are secondary to, our interpretation of the historical material.

Little from the many published popular accounts of the earthquake (for example, Grayland 1957; Rodgers 1996) has been found of use, as they rely on limited information. A number repeat unsubstantiated stories from folk history. The particularly persistent tradition of considerable uplift at Pauatahanui has been shown to be without historical foundation by Eiby (1990). Numbers of family histories (e.g. Bidwill & Woodhouse 1927; Sutherland 1947; Manson 1981) have been published also. It is not always clear whether descriptions contained in them are accurately based on family diaries, other written records or "family stories". Few, if any, of these types of publication have been written with any seismological and/or geological expertise. Nevertheless, several have proved useful.

When analysing historical material on earthquakes it is important to have an understanding of its reliability, and of the social, political and economic conditions of the period that may have contributed to the manner in which the material was written. Further, it is desirable that publication of any analysis be in the form which is unbiased and allows interpretations by other researchers at a later date. These are the principles for the analysis of historical earthquakes suggested by Ambraseys *et al.* (1983). The extent of the source material on the 1855 earthquake (over 250 typed pages) precludes its general publication. It has, however, been keyworded and will soon be available to other researchers in a searchable database. There is no doubt that further material will be found in future and may already be known to others who, we hope, will consider adding it to the existing database. In order to obtain the material that we have, many times more possible sources have been fruitlessly examined.

Although most of the sections can be read independently, a better understanding of the earthquake will be obtained by reading the manuscript more fully. A table of contents is given to help the reader understand the layout. As the political and social conditions in New Zealand in 1855 are particularly relevant to the way in which accounts were written a brief historical section has been included. Throughout the paper we quote extensively from the source material not only to present our interpretation but at the same time we try to ensure that all relevant information is given, especially where there are conflicting accounts or questionable effects. With the wealth of data being presented in this format the paper should encourage discussion and should lead to further modelling of the 1855 earthquake deformation, tsunami and seiche effects, ground and building damage, and hence contribute to better hazard models for the region.

HISTORICAL BACKGROUND

Organised European settlement of New Zealand began in 1840. Before this time there had been scattered outposts of Europeans at whaling stations and at mission stations. By 1855 not only had the missions expanded from their earliest settlements north of Auckland to other more southerly North Island locations but, following on from the initial major European towns established in 1840 in Wellington and Auckland, settlements had been initiated at Christchurch (1853), Dunedin (1848), Nelson (1841), New Plymouth (1841) and Wanganui (1840). From these centres small numbers of settlers moved further afield to take up the open plains of the Wairarapa, northeastern Marlborough, and Canterbury for running sheep and cattle. Wellington was the oldest of the settlements initiated by the New Zealand Company. Auckland, the only settlement established independently of the New Zealand Company, was the centre for British administration of New Zealand. All settlements were small and wished to attract larger populations and all had a vested interest in success of colonisation.

Within months of arriving in Wellington the settlers had been frightened by their first experience of a small earthquake. Much more frightening were the October 1848 earthquakes (mainshock M7.1; Eiby 1980) in which many of the brick and clay structures of the town were badly damaged. The epicentre of the principal earthquake was in northeastern Marlborough (Eiby 1980). One of the larger aftershocks was responsible for three deaths in Wellington. Other large earthquakes had affected the settlements of Wanganui (1843) and New Plymouth (1853) (Eiby 1968). Those who were associated with the local administration of the settlements or who were strong advocates of immigration were concerned that news of another damaging earthquake would further deter prospective immigrants in England.

Evidence of social and political influences resulting in stifling of information can be found in a number of the historical accounts. Alfred Ludlam (1855 letter in Ward 1928) comments, "It appears to me that the papers in the different provinces are anxious to keep the affair quiet." Certainly the Wellington *Independent*'s first report on January 24 creates this impression, "On Tuesday evening a little before ten o'clock, the community were alarmed by a smart shock of earthquake, which lasted several seconds, and was succeeded at intervals by tremors of less violence ... At the time of our going to press, there is every appearance of all commotion having ceased". The February 10 issue of the same newspaper tells a somewhat more realistic story but still with overtones that others, in particular the *Spectator*, had exaggerated the effects. The editor of the *Spectator* had, on January 27, censured the *Independent* with "We cannot help noticing in terms of strong reprobation, the short paragraph in Wednesday's *Independent* referring to this visitation, the falsehood and flippancy of which has excited very general disgust. Possibly the writer of it thought by this manner of treating this subject, to do away with any unfavourable impression out of the colony which such news was likely to produce; if so, like most cunning but shallow persons, he has overshot his mark, and will, we think, create a very opposite feeling, an utter want of confidence in anything the Independent may say, and a disposition to believe any exaggerated accounts from private sources which fear and despondency may dictate". There was obvious acrimony between the two editors (Carter 1866), but one correspondent (*Australian and New Zealand Gazette* June 2 1855) suggests a more sinister reason — that "the Provincial Government having one of the papers in their pay are trying to make it appear that it is only a very slight shock, but such a proceeding must defeat its own end — the truth must come out".

The contents of the account of the earthquake written by Byron Drury, the commander of the survey ship *Pandora* anchored in Wellington Harbour at the time of the earthquake, was much criticised by the politicians when it was published in the Nelson papers and later in the *Spectator* (Feb 7 1855). No doubt it was thought, quite correctly, that the report would be sent back to England. At a public meeting that was called "to consider different public questions arising out of the recent earthquake" (*Spectator* Feb 10 1855) Jerningham Wakefield, son of Edward Gibbon Wakefield, whose theories on colonisation were put into practice in New Zealand, remarks that "Captain Drury's hasty account would convey false impressions to distant readers", but "he felt sure from the high character of that officer that he had intended to give a true account, but had been betrayed by haste into expressions which he would probably have modified on further examination and reflection". Wakefield maintained that "Captain Drury's actual words were correct in most instances, but it was the absence of explanation which produced false impressions". The opinion that Drury's account was exaggerated is reiterated by William Fox, a member of the Wellington Provincial Council, in a letter to J. Godley (Fox 1855). He suggested that Drury was ashamed of it. Commander Drury's letter to Captain Washington of the British Admiralty in mid-February (Drury 1855) does not admit this. He remarks that the account which he enclosed "appears to be acknowledged as the most accurate account yet in Wellington"! It appears that it is Drury who first recognised the benefits of the earthquake, - that the road to the Hutt and around the coast had been removed above the reach of the tide and that reclamation of the land around Lambton Harbour had become easier.

Even in 1862, Sir Julius von Haast remarks that "there is not a year in which some slight shocks are not felt in Wellington, but as generally they do not do any damage, even the newspapers do not speak of them, principally under the apprehension that it would deter people from coming here to settle" (Haast 1862).

The government commissioned report on the building damage in Wellington from the earthquake (Mills & Carter 1855) is one of the more important pieces of historical source material. Both Charles Mills and Charles Carter were builders. Little is known about Mills but Carter was a leader in the trade and a well known and influential figure in early Wellington. According to the Dictionary of NZ Biography (Vol. 1, p74) he was "a strong advocate of emigration, particularly to New Zealand" and emigrated himself in 1850. In 1849, he expressed his opinion of the 1848 earthquake in a letter (Carter 1849) to the *New Zealand Journal*, a journal published in London whose main purpose was as a mouthpiece for the New Zealand Company informing on the progress of the colonies. Despite not having any personal experience of New Zealand or earthquakes, he remarks in the letter that the earthquake, "or rather, earth tremor" was "unworthy of the name of earthquake" and that the "recent accounts from New Zealand show the whole affair to have been absurdly exaggerated". He implies that the earthquake damage was due to poor building materials and techniques. Given Carter's views in 1849 and his strong advocacy of emigration it is possible that he let these influence the contents of the official report of building damage (Mills & Carter 1855). The Report tends to concentrate on the quality of the buildings and specific successes or failures of building techniques and in this way fails to provide an unbiased overview of the damage in Wellington.

Another influence affecting the reporting of damage in Wellington, in particular, was a decision, yet to be made, on the location of the future centre of the New Zealand government (in contrast to administration from England). Wellington was in strong competition with Christchurch and Auckland. Charles Bowen, of Lyttelton, a prominent political figure, was sure of the outcome, "the question of the seat of Government is settled. Everyone has given up the idea of Wellington" (Bowen 1855). Similarly Henry Sewell (McIntyre 1980) writes, "the political effect of the earthquake will I think be suspension at all events and the removal of the seat of Government. There will be no Government House in Wellington, and nobody will propose building one there". Sewell has more to say on Wellington's position, "It is beyond doubt a calamity to that place [Wellington] and I am afraid to New Zealand generally. The damage in Wellington is two-fold; loss of property and loss of good repute. The loss of property is considerable, buildings destroyed, and goods damaged. More than that: the whole place has undergone a depreciation of marketable value.... A septennial calamity of this sort is of course utter condemnation to a place for residence".

With this political and social background in mind the important parameters of mainshock origin time, magnitude and epicentre, and the effects of the 1855 earthquake sequence have been extracted from the historical accounts.

MAINSHOCK

The first earthquake on January 23 1855 was the most widely felt of the earthquakes experienced on this day and in following weeks, and almost without exception it was reported as the most severe earthquake. Contemporary reports from two locations only, both on the northeast coast of the South Island, record other earthquakes of equal or greater strength within several days after the first shock. They appear to be local shallow shocks of moderate to large magnitude or possibly, the result of the observers' misjudgement of the intensity of shaking. They are discussed in the section on Foreshocks and Aftershocks. There were no identifiable foreshocks.

At Wellington, Nelson and Wanganui, newspapers and other accounts record that there were two or more separate events identifiable within the first and principal earthquake. This was not an unprecedented observation on New Zealand earthquakes, the same observation having been made about the 1848 earthquake. It is not unusual to be able to detect instrumentally the occurrence of one or more large sub-events within the mainshock of a large earthquake. When people report feeling an earthquake, the P and S arrivals, or perhaps the arrival of the surface waves, are often mistakenly identified as two earthquakes. However, this does not appear to fit the 1855 comments and it is possible that the wide recognition of several events within the mainshock in 1855 represents a real occurrence.

(a). Origin time

Contemporary newspaper reports and the majority of diaries and letters establish January 23 1855 (Tuesday), the second of two days of festivities celebrating the founding of Wellington, as the date of the principal shock. The time, as well as the day and year, are often incorrectly recalled in reminiscences but for the most part there is little doubt that the various reports refer to the same event. Even in accounts regarded as contemporary, i.e. written within several weeks of the earthquake, the times given for the principal shock vary from about 8 pm (Hall 1855) until 11pm (Colenso 1855). These can only be the result of poor memory as others at the same or similar locations are approximately correct. Confusion of minutes before and after the hour is common. Limited access to accurate time and time pieces resulted in many approximations.

The exact origin time is not only of academic interest but might be required to identify the arrival of the tsunami generated by the earthquake on overseas records. This paper accepts Eiby's (1989) preferred origin time of the principal shock as 1855 January 23 2111 Wellington Civil Time (WCT), this time being that given by Drury (*Spectator* Jan 27 1855). Drury, as hydrographer and Commander of the survey ship HMS *Pandora* which was anchored in Lambton Harbour at the time of the earthquake, was the most likely to have had access to accurate time and he had the training to record it in the ship's log. A time ball was not installed in Wellington until 1864 (New Zealand Historic places Trust 1979). Previously Wellington Civil Time has been accepted as 11 hours 30 minutes in advance of the civil time of Greenwich meridian, and hence approximately Universal Time (UT) (Eiby 1980). However, Eiby (1989) adopts a time difference of 11 hours 39 minutes which seems to have its basis in King (1902). King records that prior to 1868 each location adopted mean local solar time and Wellington's position to the east of the longitude defining 11.5 hours in advance of Civil Time at Greenwich, requires the addition of a further 9 minutes. The origin time of the mainshock of the earthquake is therefore given as 1855 January 23 2111 WCT; 0932 UT.

(b). Magnitude

Comparison of the isoseismal map for the 1855 earthquake (Fig.1) with those of the earthquakes of 1931 Hawke's Bay (1931 Feb 02 M_s7.8) (Downes 1995) and 1929 Buller (1929 Jun 24 M_s7.8) (Dowrick 1994), indicate that the areas enclosed by MMIX, MMVIII and MMVII isoseismals of the 1855 earthquake greatly exceed those of the 1929 and 1931 earthquakes (Fig.2). The major axis of the elliptical MMIX isoseismal of the 1855 earthquake is twice that of the 1929 earthquake, indicating a considerably higher magnitude (Fig.2).

Attenuation of intensity expressions for New Zealand earthquakes have been derived by Dowrick (1992) and Smith (1995 a,b). Dowrick (pers. comm.) calculates a magnitude of M8.3-8.4 from the isoseismal map given here although he prefers a more conservative interpretation of isoseismal lines that gives a magnitude of M8.1. Smith (pers. comm.) estimates a magnitude of M8.1 (using the "upper crust" model), but notes that there is a substantial discrepancy from one isoseismal line to the next. Eiby's (1989) isoseismal map of the 1855 event is the only magnitude 8+ earthquake in the historical record and has been used in deriving the intensity attenuation expression of Smith (1995 a,b). Dowrick (1992), on the other hand, has used only earthquakes from the instrumental period (maximum magnitude M_s7.8) and hence estimation of a magnitude for the 1855 earthquake requires extrapolation of his expression beyond the magnitude range on which the equations were based.

Parameters of fault length, fault plane dimensions and duration can be estimated. Expressions relating these to magnitude are approximate but can be useful in estimating magnitudes of pre-instrumental earthquakes and yield magnitudes of about M8-8.2 ±0.5.

Table 1

Wairarapa Fault only	Mw7.9
Wairarapa Fault + subduction interface from 40 km to 10 km depth	Mw>/=8.4
Wairarapa Fault as a "listric" fault.	Mw8.2-8.4
Flexed fault model approximating a 8 km side step in the Wairarapa Fault near the coast	Mw7.9

More reliably, estimates of the moment magnitude (M_w) can be found using dislocation modelling. Using the technique of forward elastic dislocation modelling, Darby & Beanland (1992) produced four source models for the 1855 earthquake which attempted to explain the deformation data then known. More accurate deformation data, and a maximum uplift now recognised to be twice that known previously (McSaveney & Hull, 1995), will necessitate further modelling. Nevertheless, Darby & Beanland's work provides insight into plausible mechanisms and estimates of magnitude. The four model types and their calculated moment magnitudes are summarised in Table 1.

The listric fault models involved various lengths of the subduction interface to the west of intersection with the fault from 25km to

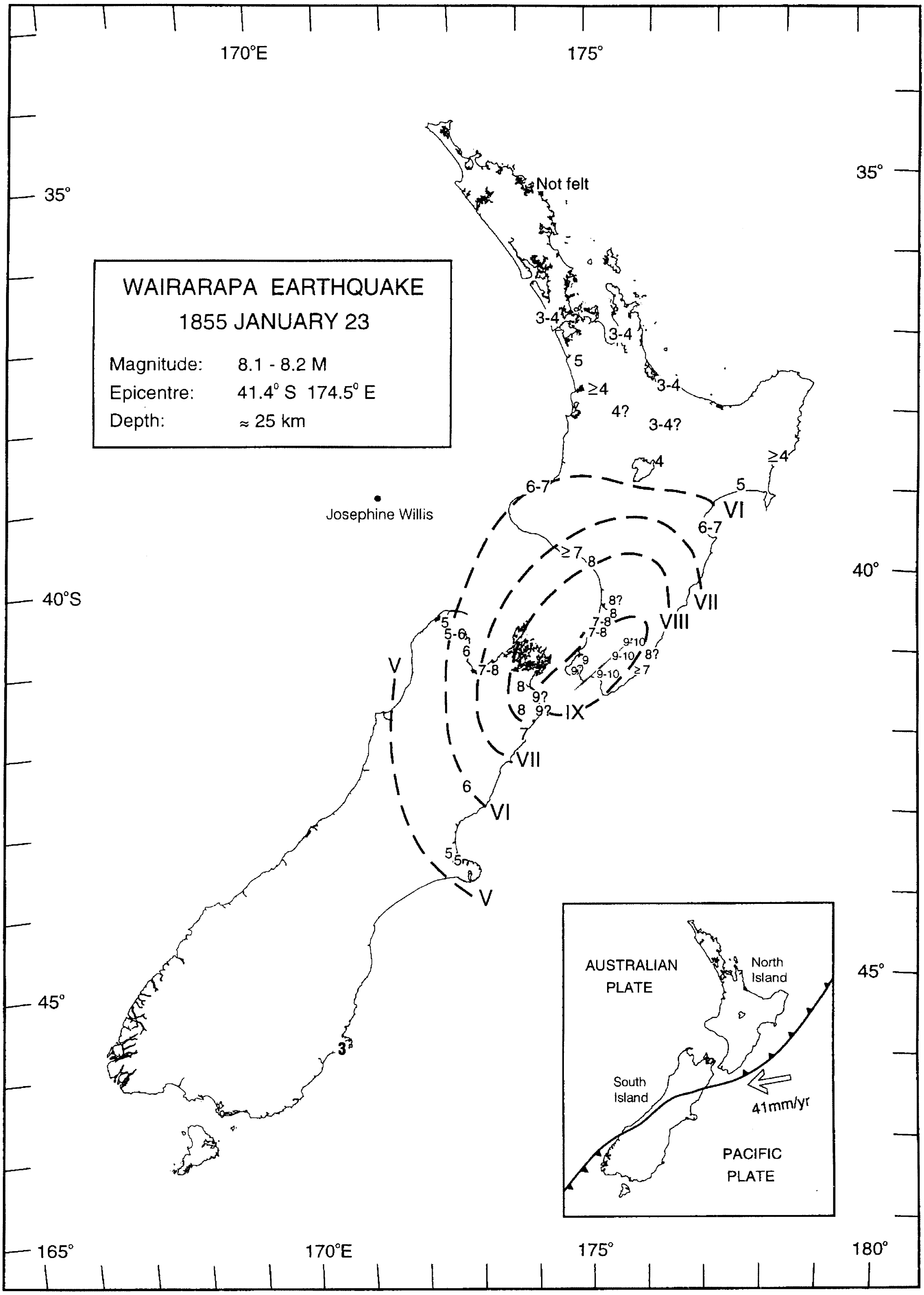


Fig.1. Isoseismal map of the January 23 1855 earthquake. Approximate position of the Josephine Willis *when the earthquake was felt. Line of 1855 rupture along the Wairarapa Fault shown in area of highest intensity. Inset shows tectonic setting in terms of the present day plate margin through New Zealand and convergence rate.*

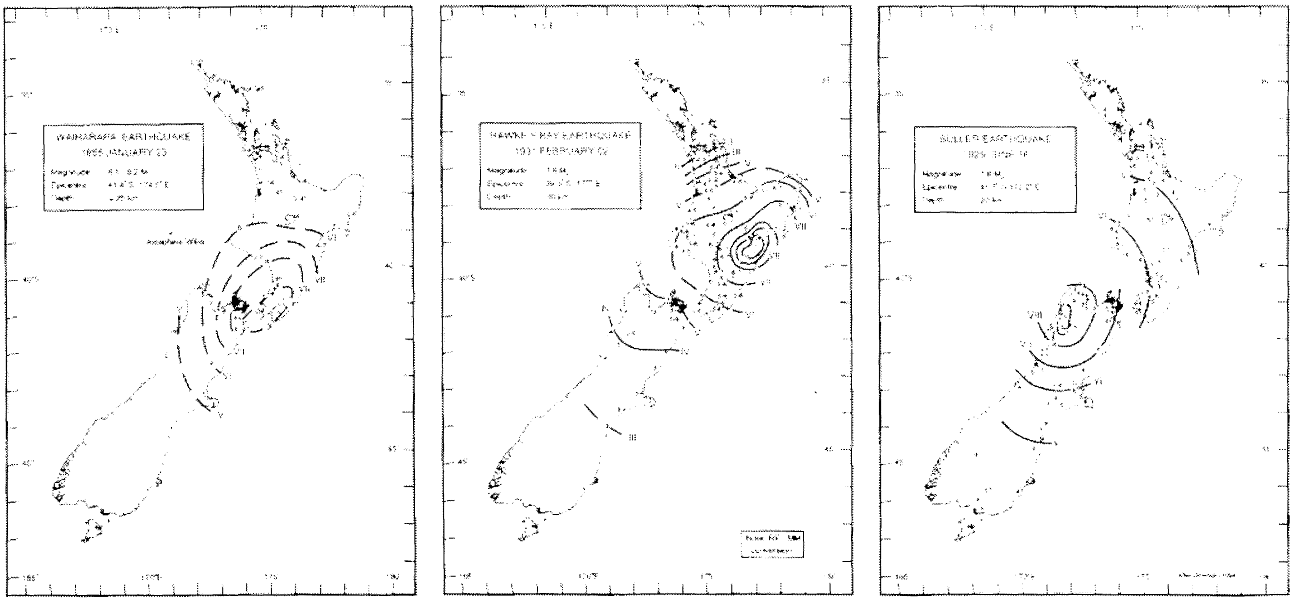


Fig.2. Comparison of isoseismals for the 1855 (Wairarapa), 1931 (Hawke's Bay), and 1929 (Buller) earthquakes. Isoseismal maps of the Hawke's Bay and Buller earthquakes are from Downes (1995).

a maximum at 40 km depth (with moment magnitudes in the range 8.2 - 8.4). These models were considered by Darby & Beanland (1992) to best approximate the deformation.

The magnitude of the 1855 mainshock is estimated to be M8.1-8.2.

(c). Epicentre

Frequently the epicentre assigned to a pre-instrumental historical earthquake merely satisfies the need to have co-ordinates for a database. Generally the nearest half degree of latitude and longitude within or close to the highest intensity area are chosen. In a large earthquake such as occurred in 1855 this area can be large and encompass a number of possible "locations" for the epicentre. Identifying an epicentre more accurately from descriptive accounts is speculative but it is considered worthwhile to examine what insight the contemporary records of the 1855 earthquake give as to where in the 140 km x 30 km (approx.) fault plane the rupture may have initiated.

The isoseismal map (Fig.1) shows that the greatest damage to structures and to the environment was concentrated around the eastern part of Cook Strait, although this observation is limited by the lack of intensity data in northern Wairarapa. Descriptions of the shock in Wellington, Wairarapa and Marlborough fairly consistently indicate a short S-P interval, provided that the first shock was the largest shock or at most was preceded by a small or moderate event at the same location. Descriptions include Coote (1855), who records that "we were startled by a rumbling noise, followed instantly by a tremendous shaking" and similarly in the *Australian & New Zealand Gazette* (June 2 1855) a correspondent writes " we heard a rumbling sound, followed instantly by a most violent rocking of the house". John Jolliffe (1855), the surgeon on board H.M.S. *Pandora*, was ashore at Te Aro when he "distinctly heard a slight rumble" but before his companion could answer his question as to what it was " the whole earth trembled". Elsewhere he comments that "the great shock came with only a half second's warning in the form of a low rumbling noise". Matthews (1901; 1913) also suggests that the earthquake struck without any warning, while Pilcher (1855) recognises a slight motion for a short time before the strong shaking. Bennett (1855) is in the minority suggesting that there was a little time before the violent rocking commenced: "we suddenly felt a most unusual rocking and loud rumble.... [We] just had time to get into the garden when the ground commenced shaking in so violent a manner that I could scarcely keep my feet.... The shaking was first a lineal motion in a NNW and SSE direction". However, his later account (in Mallet 1858) suggests the shaking was strong before he had managed to exit the house, "I felt the house ... give a very extraordinary shake, which seemed to continue, and was accompanied by a fearful noise. I at once jumped up, rushed, as well as the violent motion would permit me to, into the front garden, the motion increasing in violence". Hort (1855) and Richardson (1855) similarly refer to the short time from detection to onset of strong shaking.

From the Hutt Valley and the Wairarapa only a few accounts are useful. Alfred Ludlam (1855 letter in Ward 1928) of the Hutt Valley, records that: "the first shock, the vertical one, threw it [the house] in the air and shook it. The second, in a moment, shook all the chimneys off their foundations and brought them into the rooms". In the Wairarapa, Anon 4 (1855), whom we believe to be the Charles Borlase referred to by Lyell (1856b; 1868) writes that, "without the rumbling notice which earthquakes generally give us, the shock commenced". Individual observations are often unreliable and perhaps Meredith's (1898) comments serve to illustrate the need to have many accounts to be able to judge consistency. At *Orui* on the east Wairarapa coast, he does not appear to recognise any motion prior to the strong shaking; "without any warning the ground under our feet seemed to be struck with tremendous violence" seems to imply a short S-P interval or perhaps merely lack of observation of the P wave. At Kekerengu, northeast Marlborough, Trolove (1855) observes also that the shock was "so sudden and severe".

While only one account from the Wairarapa and one from Marlborough indicate a short S-P interval, the consensus in Wellington was that there was a short time interval between detecting the coming of the earthquake and the arrival of violent shaking, which is assumed to indicate a short S-P interval. In contrast, at Wanganui, a Mr. Bates (Allen 1855) records that, "suddenly an extraordinary motion was felt, which I had scarcely noticed before an exclamation ... was uttered ... I now heard the jingling of the bottles in the bar and instinctively made my escape from the house ... Now outside of the building, I cautiously eyed the position of the chimneys, and making the necessary circuit to avoid them, stood in the drenching rain to notice more collectively the fearful convulsion. The chimneys fell just after I had cleared them and the rocking of the house was violent and continuous.... In a few moments I was wet to the skin; but the shake continuing I did not like to venture into the house. The violence of the shock abated for a little, succeeded shortly by a greater convulsion, differing in nature from the commencing one, the first great one being rotary, the other undulatory". At Waitotara, Field (1891) "heard a very loud earthquake explosion, which was followed by a sharp upheaval and violent shakes, accompanied by loud rumbling. I at once lighted a candle to see what was happening, and found everything rocking in a most alarming manner. There seemed to be three shocks joined together. Twice the motion slackened, and then became more violent again. The third time the motion was so violent that my table ... was turned completely upside down". These extracts seem to indicate a somewhat longer time interval to the arrival of the S waves in comparison to Wellington and the Wairarapa, with the most severe shaking also occurring much later within the principal shock.

Recognition of more than one event during the mainshock is recorded in several other extracts, for example the *Nelson Examiner* (Jan 27 1855) records that the earthquake appeared "to come from a NE direction and [it] is believed to have lasted from three to four minutes, but not with the same uninterrupted violence, for it rose and fell several times, and instead of being one shock was probably a succession of shocks, but so closely following one another as not to be distinguishable". And in the *Spectator* (Jan 27 1855), "the first shock, which proved so destructive ... occurred at 17 and a half minutes past nine o'clock p.m., and its duration was 50 seconds. It was followed so closely by another, that the two shocks, by common observers, have been confounded together. The shock is also stated by the same authority to have proceeded from ESE towards ENE describing an arc of about 40 degrees". Of note in this extract is the implication that the first shock was immediately destructive in Wellington, in contrast to Wanganui and Waitotara.

In addition to descriptions of the nature of the shaking, many observers attempt to ascribe a direction to either the shaking or to the origin of the earthquake. Significant among these is Drury, who comes to the conclusion, without stating reasoning, in his Remarks Book (written on Jan 27 1855 and printed in the *Spectator* Feb 7 1855) that the mainshock was centred in Cook Strait between the termination of the Rimutaka Range and Cape Campbell. Hochstetter (1867) adopts the same position at a latter date. Interestingly, Allen (1904) attributes Archdeacon Stock with the theory that the earthquake "emanated from a large submarine crater off Palliser Bay" and that "its centre was at the letter "R" of "Palliser" as the word was printed on the Admiralty chart of the day"! On the Admiralty chart of Cook Strait published in July 1855 that letter is remarkably close to the offshore extension of the Wairarapa Fault determined by Carter & Lewis (1988). While a number of observers in Wellington also suggest directions for the motion experienced as from northwest to southeast, nearly as many suggest the opposite, i.e. northeast or southwest. William Bennett even changes the direction from his 1855 diary (Bennett 1855) to his account in Mallet (1858). Hence this source of identifying an epicentre is considered unreliable although it is tempting to accept the position given in the *Spectator* quoted above especially when it so nearly fits the concept of rupture of the Wairarapa Fault northeast from its southern end.

To summarise, an epicentre close to Wellington is in accord with the macroseismic epicentre suggested by the isoseismal map and with the majority of observations of a short S-P interval in Wellington and a longer interval in the Wanganui area. To locate the epicentre more accurately than "close to Wellington" from observational data is not possible. However the source models of Darby & Beanland (1992) and the structures both within the subducting Pacific Plate (Robinson 1989) and in the overriding Australian Plate (Carter & Lewis 1988) provide some constraints on the earthquake location and its likely depth.

Seismological studies of the location and mechanism of earthquakes recorded on the Wellington seismograph network (1978-1982) indicate a NW-SE trending vertical offset of the Pacific-Australian plate (A-A' in Fig.3) in the Cook Strait region (Robinson 1989). Robinson considers that the offset might limit the depth of rupture of the faults in the overriding Australian Plate in events such as the 1855 earthquake and might provide a focus for possible precursory activity. Interpretation of the seismic reflection data indicates that the major dextral faults in the Cook Strait region, with the possible exception of the Wairau Fault, do not appear to be continuous across the strait; the Wairarapa Fault extends about 20-30 km into Cook Strait (Carter & Lewis 1988). Deformation of the sea bed in Cook Strait in the 1855 earthquake is suggested by the occurrence of a significant tsunami (see section on Tsunami and Seiche).

The preferred forward elastic dislocation model of the 1855 earthquake rupture of Darby & Beanland (1992) is that of a listric fault representation of the Wairarapa Fault, the structure having a steep dip at the surface, the dip decreasing with depth to become tangential to the subduction interface. The model rupture involves part of the interface as well as the Wairarapa Fault. The best-fit model indicates that the rupture could have initiated at least 30 km to the west of the surface expression of the Wairarapa Fault at a depth of at least 25 km This depth corresponds with apparent change in dip of the downgoing Pacific Plate.

Given these constraints the epicentre of the 1855 earthquake is assigned a location of 41.4° S 174.5° E ±0.5°. The location reflects the southwestern limits of the probable earthquake source zone, i.e. it lies close to the probable offset in the subducting Pacific Plate below Cook Strait and close to the observed change in dip of the plate, and at a depth approximately corresponding to the intersection of the Wairarapa Fault (Fig.3). The depth of the plate interface at this location is about 25 km (Robinson 1989). Better definition of the plate interface and its relationship to the major dextral faults in the Cook Strait area as well as further dislocation modelling with new deformation data presented in this paper and in McSaveney & Hull. (1995) may necessitate refinements to the epicentral location and the probable earthquake source zone.

The preferred location of the 1855 earthquake epicentre is consistent with several factors. The Wairarapa area appears to have experienced the highest intensities. The Rimutaka Range,

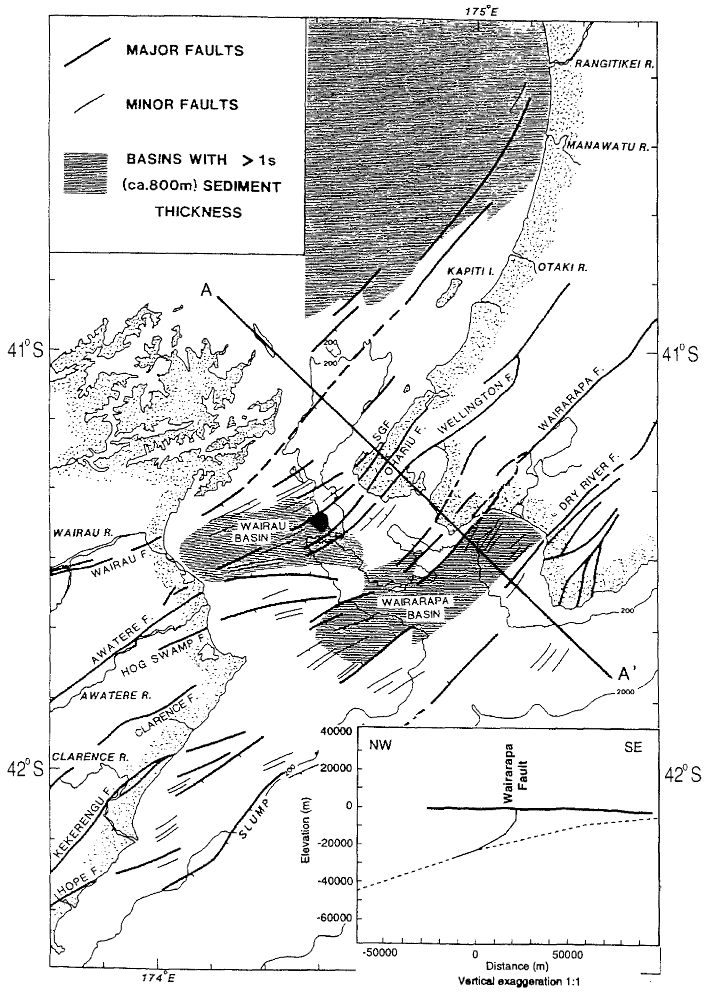


Fig.3. Map showing major active faults in the Cook Strait area (after Carter & Lewis 1988) together with inferred location of epicentre (large black dot) of the 1855 earthquake together with constraints on location:- surface projection of offset in the Pacific Plate beneath Cook Strait region (line A-A'), (Robinson 1989); offshore extension of Wairarapa Fault (Carter & Lewis 1988). Inset shows preferred dislocation model (listric Wairarapa Fault) along line A-A' of Darby & Beanland (1992). Dashed line delineates upper surface of the Pacific Plate.

to the west of the Wairarapa Fault, and the ranges to the east of the Wairarapa Valley were extensively damaged with landslides, more so apparently than around Wellington. Admittedly slopes are steep on the Rimutaka Range but according to Heaphy (1879) there were no landslides on the hills about Wellington in 1839. This information could be interpreted as indicating a directivity effect in the propagation of the earthquake upwards along a listric Wairarapa Fault and towards the Wairarapa. Hence an epicentre some twenty or thirty kilometres west or southwest of Wellington is not at variance with the maximum intensity occurring in the Wairarapa rather than in Wellington. Such directivity is also consistent with higher intensities being experienced in the lower Wairau and Awatere valleys than on the northeast (Kaikoura) coast of the South Island.

The long duration in Wellington (most accounts suggest close to a minute to 2-3 minutes; see *Spectator* extract above) is also consistent with a predominantly unilateral rather than bilateral rupture initiating closer to the southern end rather than the northern end of the fault plane. Although the occurrence of the strongest shaking towards the end, rather the beginning of the principal shock, in the Wanganui area could be interpreted as a shaking enhancement on alluvium, directivity of the propagation of the rupture or a subevent closer to this area than to Wellington could produce the same effect.

(d). Felt intensity distribution

The isoseismal map for the principal earthquake is shown in Fig.1. The distribution of the intensity observations provides a good constraint on the isoseismal lines around Wellington and Cook Strait only. The earthquake was felt almost over the whole of mainland New Zealand, from at least Auckland to Dunedin and was strongly felt (MMVI and greater) with structural damage to buildings and chimneys at least as far north as New Plymouth and extending south to approximately Cheviot in North Canterbury. Damage to household goods (MMV and greater) was experienced from at least Napier to Christchurch. Within the highest intensity areas damage was extensive, many masonry buildings and some wooden buildings being seriously damaged and some collapsing. The effects of strong shaking on the environment within the same areas were severe with ground damage from liquefaction, fissuring, lateral spreading, differential settlement, landslides and ridge renting (see section on Ground Deformation).

The isoseismal map differs significantly from the preliminary map of Eiby (1989; also in Downes 1995). In particular the MMIX isoseismal results from a better distribution of intensity observations that has allowed a more complete interpretation. Eiby had less data available to him when the map was drawn in 1984 and some intensities were based on environmental effects, for example landslides. It is now well recognised that there are insufficient data for New Zealand earthquakes on such effects to be able to identify other than a range of intensities at which they can occur (Study Group of the New Zealand National Society for Earthquake Engineering 1992). Hence a number of MMX intensities indicated on Eiby's map are difficult to justify.

In contrast to Eiby's near circular isoseismal line, the MMIX isoseismal exhibits the strong elongation in the northeast-southwest direction. It is well constrained south and west of Wellington but lack of significant European settlement in northern Wairarapa and southern Hawke's Bay means the northeast extent of the MMIX isoseismal is uncertain. An elongation paralleling the regional trend of major structural features is common to many North Island east coast earthquakes (Smith 1995), reflecting factors such as depth, extent and orientation of the earthquake source zone and directivity of fault rupture and/or regional propagation characteristics.

Isoseismal lines other than the MMIX isoseismal do not show the same trend, some enhancement of strong shaking occurring in the northwest direction. The earthquake was surprisingly strongly felt in the eastern Waikato and Taupo districts. The Central Volcanic Zone characteristically exhibits strong attenuation (Smith 1995). Attenuation in this area is less obvious for (shallow) earthquakes originating on the west coast of the South Island, an example being the 1968 Inangahua earthquake (Downes 1995), or to the west of the main axial ranges. Earthquakes whose epicentres lie to the east of the main axial ranges of the North Island are rarely felt strongly in the Central Volcanic Zone or in eastern Waikato although they can be well felt to the west of these areas. Examples can be found in Downes (1995). The higher than expected intensities in the high attenuation areas perhaps lends support to the location of the epicentre to the west of the main axial ranges.

(e). Intensity assessment

It is particularly important to understand that the reporting of earthquake damage in both newspapers and Government papers in New Zealand's major settlements in 1855 was very much influenced by political and social pressures, particularly with respect to Wellington. The evidence in the historical accounts is that many persons, political figures in particular, realised that full recognition of the damage from a second large earthquake in seven years would not only discourage prospective immigrants to the New Zealand Company's settlements but also limit Wellington's chances of becoming the seat of future government in New Zealand. These influences are discussed more extensively in the Historical Background section, but here it is sufficient to say that the written accounts of damage in Wellington present conflicting images. Also of relevance in the assessment of intensity is an understanding of common building types and modes of building. A brief resume of information contained in the source material and from other general reading is given here but it is by no means comprehensive.

(i) 1855 building types

"Throughout Wellington's first 40 years, most of the buildings were built of timber" (Cochran 1990). This factor was undoubtedly significant in limiting the extent of severe damage and casualties in Wellington in the 1855 earthquake. The first cottages in the new settlements in the early 1840's used readily available materials. Some were built as the Maori built their whares, not infrequently by the Maori themselves (Ward 1928; Cochran 1990). "Trolove's first hut at Woodbank [on the Kaikoura coast] typified an early kind of homestead which could be thrown together in a matter of a day or two. Having chopped posts to a set length, he had them dragged to the chosen site where they were set upright with butts three feet in the ground, rough cross-beams and a ridge pole were hoisted into place, and a lattice work of light branches run between the uprights. The walls were then completed by lacing on bundles of toi-toi stalks and leaves, the same material serving as thatching for the roof. A wide clay chimney [was] built across one end of the rectangular hut..." (Sherrard 1966). Later, cob, brick and timber sheathed houses were introduced, some of very high quality using local and imported timbers (Cochran 1990). Where there was not the abundance of timber, "cob" cottages were common. Not all were of the standard rammed earth or mud brick type. "Wattle and dab" was apparently considered to be "cob" also, as described by Mrs Bidwill on her arrival in Dunedin: "there were very few houses built of sawn timber, nearly all being made of wattle and dab or cob" (Bidwill & Woodhouse 1927). It should be explained that "wattle and dab" means a building erected of small posts cut in the bush and placed every two feet in the ground, saplings nailed longitudinally on either side of the posts, at intervals of a foot, the space between being filled with clay. Saplings were used as rafters for the roof which was covered with native grass. The bare ground sufficed as a floor. In many cases chimneys were erected with slabs split from a tree, with clay built around the base to a height of four or five feet. This was the "ordinary hut or dwelling that many early settlers dwelt in" (Bidwill & Woodhouse 1927).

The immense damage done to a great number of brick, clay and cob buildings in the earthquakes of 1848 (Eiby 1980), centred about 70 kilometres from Wellington in northeastern Marlborough, soon convinced the early settlers around Cook Strait of the merits of building in wood, although most settlers in the Awatere and Wairau valleys apparently continued to build cob cottages (Kennington 1978). In Wellington and the Wairarapa only a few cob houses are described with several others partly built of clay. Widespread awareness of the earthquake resistant qualities of wood is indicated by contemporary comments such as: "there [Wellington]- since the last severe shocks, six years ago - they have built what they imagine to be earthquake-proof wooden houses, and though some of them are much damaged and much property destroyed, only one or two are down" (Anon 4 1855); "the amount [of damage in Wellington] in 1855 was very much less than in 1848. This may easily be accounted for from the fact that there were not so many brick houses, and those that were are all strongly bonded with wood and iron" (Ludlam; 1855 letter in Ward 1928).

Ludlam's comment perhaps recognises another influence on the methods of house construction in 1855, that of Charles Carter. In a letter to the editor of the *New Zealand Journal* (Carter 1849), published in London to provide information on the colonies (mainly for the purpose of attracting immigrants), Carter offered his advice as an experienced builder on techniques of building in brick and in timber. Besides recommending horizontally and diagonally reinforcing brick walls with hoop iron and bracing and dovetailing of timber framed houses, he called the "attention of the public ... and the local government, to the necessity of making some local building act as a guide for workmen, builders and architects", as he considered that "the greatest part of the damage [in 1848]... occurred from the discreditable and very inferior description of material used in their construction" and that "the two principal things ... which contribute most to stability, are good material and good workmanship". Although Carter's advice on the introduction of building regulations was not heeded for 30 years (Cochran 1990), it is evident from Ludlam's letter that some houses may have been built in the manner advocated by Carter. By 1855 Carter had been in Wellington for over four years in business as a builder "soon becoming a leader in his trade" (Dictionary of New Zealand Biography 1933). It is interesting to note that Carter's own house at the corner of Bowen Street and the Terrace (north side) "rode out the earthquake with chimneys intact " and only "one or two bottles containing wine, a little crockery, and two or three chimney ornaments broken, and no other damage done". Perhaps his call for good workmanship was well-advised. However, the site of Carter's house lies in Zone 2 of the Ground Shaking Hazard Map for Wellington (Wellington Regional Council 1992) in which Zone 1 represents least ground hazard and Zone 5 the greatest. Carter's expertise in the building trade obviously led to his being appointed as one of the Commissioners (with Charles Mills and Edward Roberts) to report not only on the damage caused in 1855 earthquake, but also on "the materials and mode of building, best calculated to resist the effects of the earthquake peculiar to New Zealand" (Mills & Carter 1855).

As to the style of wooden buildings in Wellington, Carter's comments on the housing he encountered on arrival in Wellington again prove useful; "the houses of the majority of the inhabitants ... were in a style of genuine simplicity - a long, narrow, but very large box: the sides fronting the streets were about eight feet in height and from 20 to 24 feet in length; they had a door in the middle, and a window ... on each side of the door. The house was divided into two rooms ... and was frequently supplemented with the fashionable and useful lean-to, sometimes constructed at one

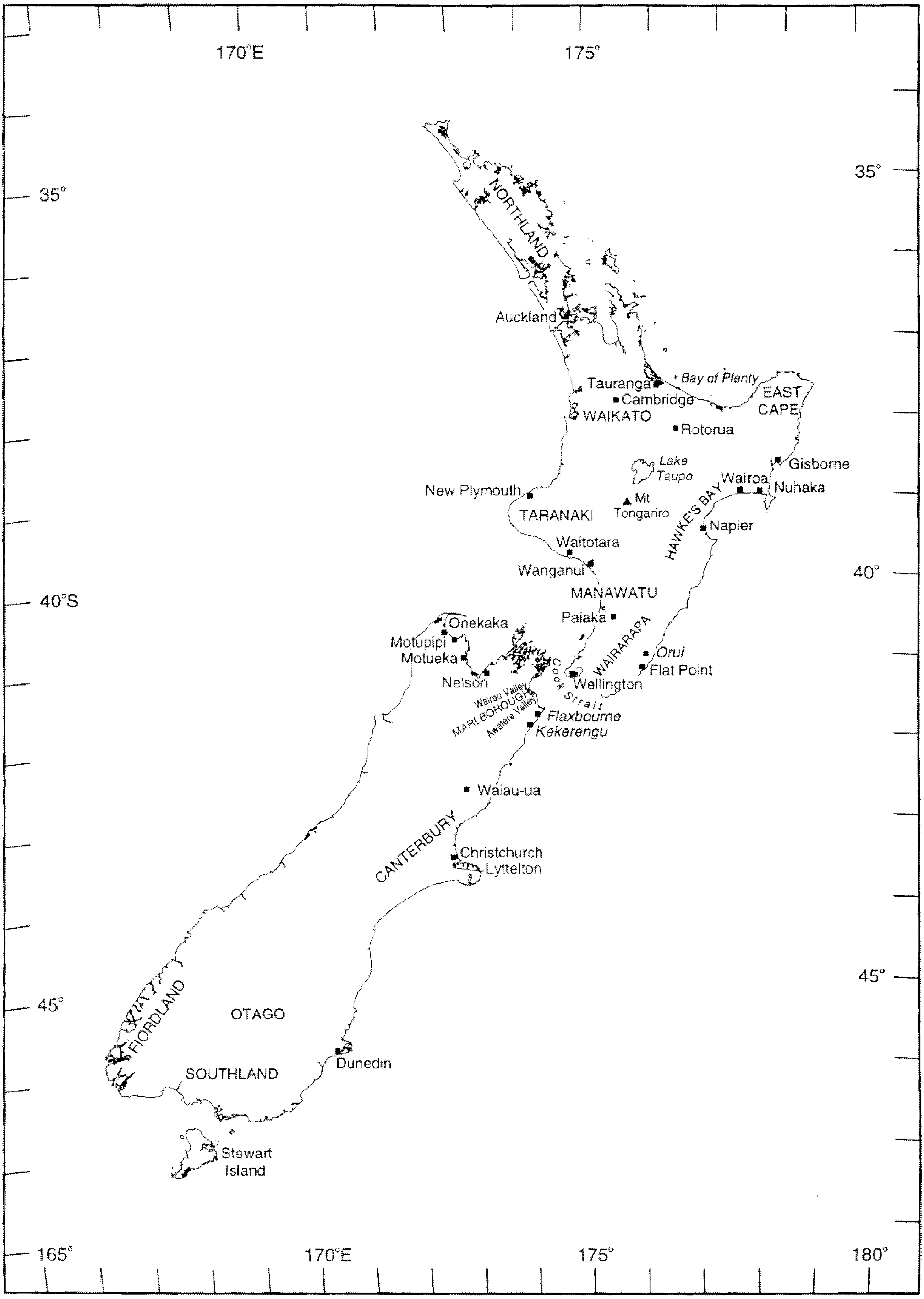


Fig.4. Location map showing areas and settlements where earthquake intensity has been deduced (see Fig.5 for detail of the Cook Strait area).

end, but oftener in the rear of these truly convenient and comfortable colonial cottages" (Carter 1866). Another type of house with "wooden walls with iron posts" was obviously available in Wellington as Mrs Coote (1855) records that on its arrival in New Zealand, such a house "was pronounced to be of all kinds the most suitable to stand the shock of earthquakes". Both this and the simple box-like wooden structures described by Carter would be least likely to be severely damaged even at high shaking intensities.

Although most of the newer settlements and country districts were without masonry or brick buildings Wellington was not, but numbers were probably more limited than they might have been without the experience of the 1848 earthquake. The main reasons for building in brick were the danger of fire and the impressive appearance. Locally made and imported bricks and lime and mortar were readily available, although the quality of the lime and mortar was not regarded very highly by Mills & Carter (1855), mainly because of the materials, such as clay, with which it was mixed. Mills & Carter also refer to cement structures and many brick structures, some of which had survived the earlier earthquake. Brick was still commonly used in chimney construction although there were attempts to design them in such a fashion to prevent their falling. In a proposed house design for John Pearse (Alexander Turnbull Library: date unknown, but probably before 1856) the chimneys are sketched in several positions. Appended to the drawing is a note: "proposed alteration of chimneys to puzzle the earthquakes". The problem was obviously being considered before and after the 1855 earthquake.

In a letter to the editor of the *Wellington Independent* (Jan 24 1855), William Fox, a prominent member of the Wellington community, artist, politician, explorer and trained lawyer, suggests the "American practice of portable stoves with a cylindrical pipe carried through the wall" should be used instead of brick. It is clear that these and iron sheets were already available in the stores as Thomas Pilcher (1855) wished that he "had 20 tons at the present moment of Sheet Iron for chimneys - Patent Stoves that were at discount before were all sold two days after the shock". The report by Mills & Carter (1855) also mentions the use of iron in building construction.

Apparently not all agreed that sufficient lessons had been learned from the 1848 earthquake and that "since the last earthquake, all kinds of flimsy prettinesses have sprung up in the architecture of the place, as though the earthquake had left assurance that it would not return" (*Australian & New Zealand Gazette* May 26 1855) and "the damage done by this one [earthquake] was occasioned by the absence of proper forethought and judgement: for if people, knowing they are in a country subject to earthquakes, will build houses of brick and other material not securely braced ... they run the risk of the accident that has befallen them" (letter signed Observer, *Nelson Examiner and New Zealand Chronicle* (Jan 31 1855). The attitude expressed by this writer introduces another aspect relevant to the reporting of the 1855 damage in which poor construction techniques were blamed rather than an admission that the earthquake was severe. Damage reports for Wellington suffer most from this source of distortion of the facts (see Historical Background section).

(ii). Felt intensity

In this section the basis of intensity assessment using the Modified Mercalli Scale (Study Group of the New Zealand National Society for Earthquake Engineering 1992) is given, beginning with observations in North Auckland and progressing south through both Islands. Emphasis is on the effects on people and man-made structures, with only brief remarks on environmental effects as they are described fully in the section on Ground Deformation. Locations are shown in Fig.4 (New Zealand) and in detail around Cook Strait in Fig.5. Intensity assessments are consistent with Dowrick (1996) who proposes modifications to the 1992 scale.

It is well known that shaking enhancement in areas underlain by deep soft soils can occur and can result in considerably more damage to buildings on susceptible sites than on nearby firm ground. As dense forest still covered much of the New Zealand countryside in 1855, settler's houses in remote areas and at least part of many towns were located near river mouths or harbours and hence often on ground susceptible to shaking enhancement. This may have resulted in artificially high intensities at some locations, for example Wanganui, but they cannot be eliminated as, for the most part, the historical data allow no comparison between firm and soft sites.

NORTH AUCKLAND

The *Southern Cross* (March 1 1855, quoted in *The Maori Messenger* (*TeKarere Maori*)), an Auckland newspaper, records that the earthquake "did not extend so far north as the Bay of Islands at all".

AUCKLAND Intensity: MMIII, possibly MMIV

In Auckland, the earthquake was regarded as slight or as a slight tremulous movement. Those in motion did not notice it but some who were at rest were able to give duration (1 minute, *Spectator* Feb 7 1855; a few seconds, *Southern Cross* Mar 1 1855) and suggest a direction, but many were unaware of the earthquake. Brodie (1864), although he did not feel the earthquake himself as he was walking outside, records that his children "asked me what I had been doing on the roof of the house", clearly indicating a noise associated with the earthquake, possibly from creaking of the house frame.

TAURANGA Intensity: MMIII, possibly MMIV.

The Reverend Brown (1855), a missionary, merely records in his diary "an earthquake this evg", apparently in no doubt as to the source of the disturbance. A letter to the *Maori Messenger* (March 1 1855) reports only that "the tribes at Maketu heard the noise".

WAIKATO DISTRICT Intensity: Not less than MMIV at Kitotehe; MMV at Kohanga

In a day to day record of his journey from Auckland to Wellington, Johnstone (1855) felt the earthquake at Kitotehe, just south of Cambridge, and notes that a number of others whom he met *en route* to Taupo also felt the earthquake. Because the author refers to the effects of the earthquake in Wellington before he can have had any knowledge of them, it is clear that the account was not written at the time in its present form but at some time later from what must have been copious notes. The date and time of the earthquake in the account are incorrect although Johnstone assumed that the earthquake was the same one that had affected Wellington. He records that "at about 8 o'clock ... [we] were all sat round a table ... when the house began to move to and fro. I sang out ... and had scarcely got the words out of my mouth when the whole earth and place seemed as if about to turn topsy turvy, and the natives outside cried out 'he ru he ru' meaning the shaking of the earth. We all rushed outside rather alarmed that

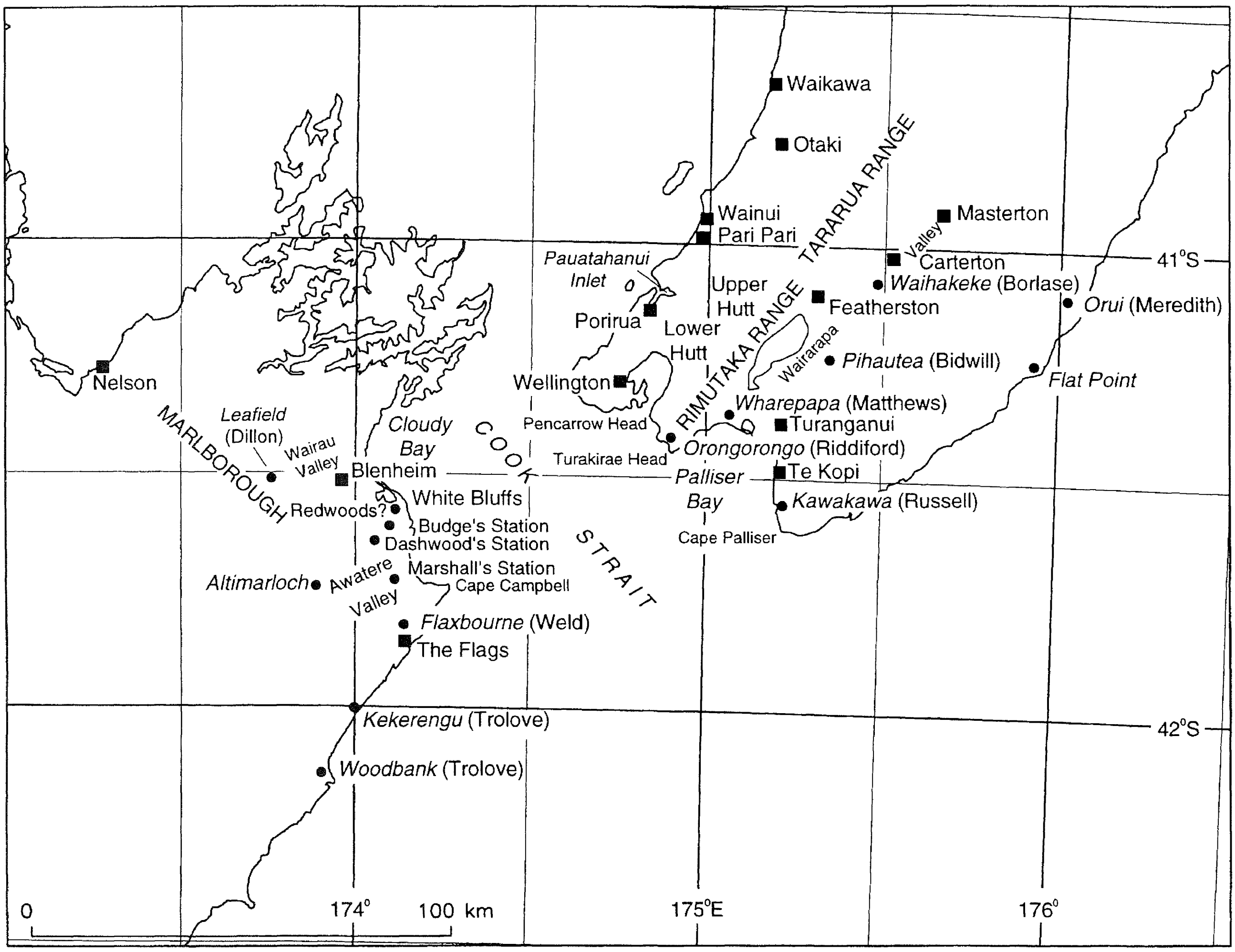


Fig.5. Map showing geographic features and some homestead locations for which earthquake intensity information etc. are available in the Cook Strait area.

the house was coming down. It lasted about 3 or 4 minutes.... I should think that no brick building could possibly have stood ... ". However, at Kohanga, near the mouth of the Waikato River, Canon J. W. Stack (1956) records that "our houses being made of wood or thatch did not suffer, but the chimneys were all cracked". Stack also observed seiching of the river.

The *Maori Messenger* (Mar 1 1855) published an account, sent to the Editor, of the effects of the earthquake at (Mount) Maungatautari, a volcanic cone. There are several locations and tribes mentioned in the extract, of which only a few can be identified. These point to a location east of Te Awamutu and south of Cambridge. The report reads, "on the 23rd January, in the middle of the night, came the shaking of the earth. When the shaking had ceased, a great noise was heard ... like the report of great guns.... On the following morning a man came to our settlement, and informed us that a portion of the mountain of Maungatautari had been cleft asunder, and carried to the stream of Mangahoe, blocking up the source of the river". Landslides usually occur at an intensity of at least MMVI.

The accounts in the *Maori Messenger* and of Johnstone indicate that the earthquake was felt quite strongly in the Waikato District, more strongly than expected perhaps from an earthquake near Wellington. However there is no evidence to suggest that another earthquake of local origin may have been responsible for the strength of shaking as it was widely felt in both the Waikato and Taupo areas and the reported duration indicates an earthquake of distant origin.

CAMBRIDGE TO MOUNT TONGARIRO Intensity: at least MMIV.

As Johnstone travelled to Taupo over a period of three weeks others reported to him that they had felt the earthquake; Hay from the Thames District; Simpson from Whakapaeu, near Ngaruawahia (seiche also observed); Vicar from near Rangiawahia?, who also heard loud reports after the earthquake; and Spencer from near Taupo, who felt the earthquake very severely (Johnstone 1855). At the latter place, the Spencers informed Johnstone that Tongariro was said by the natives to be "in volcanic motion, and had burst out, lava flowing down its sides". Hochstetter (1859) mentions that one of the cones on Tongariro fell in at the time of the earthquakes and that there was also some volcanic activity and later (Hochstetter 1867), "an ash eruption is said to have taken place here ..." at a location he identifies as Ketetahi although Red Crater is more probable.

While individual intensities cannot be assessed, it is clear that the earthquake was widely felt and from that we must assume an intensity of at least MMIV. That such a distant earthquake was felt so widely, and reportedly, so severely, is unusual because of high attenuation in volcanic areas (Smith 1995). However, west of a line from Tongariro to Tauranga attenuation is much less than in the Central Volcanic Region, so that earthquakes are better felt in this area (e.g. the 1968 Inangahua earthquake). (E. Smith, pers. comm.).

GISBORNE Intensity: Not less than MMIV.
At about the same latitude, on the east coast of the North Island, Jane Williams (1855), wife of William Williams, both missionaries at Turanga near Gisborne, wrote to a friend, "we have had some rather severe shocks of earthquakes this summer, one on the 23rd Jany which lasted several minutes and really alarmed us; happily our buildings are neither brick nor stone". No damage was done but clearly the earthquake was strongly felt. They also noted several aftershocks. MacKay (1949) mentions that heavy jolts accompanied by rumbling were felt in the Poverty Bay area.

WAIROA Intensity: MMV?
The Rev. James Hamlin (1855) and his family at Wairoa were also well aware of the earthquake and several aftershocks, recording in his journal that "the earthquake commenced first slight then increasing in severity - it lasted 5 to 7 minutes. The motion was as though we were aboard ship ... The water in the river was dashing on the bank two or three yards about its usual height from the motion. It was the longest we have ever felt and only exceeded in severity by one". The house and chimney received no damage however.

The earthquake was felt also at Tahaenui and Nuhaka, the Maori there upon feeling the earthquake and hearing "a severe discharge of musketry" had come to see if their friends, the Hamlins, had been buried in their house during the earthquake, or to determine whether there was a fight between two warring parties (Hamlin 1855).

NAPIER Intensity: At least MMVI, possibly MMVII
The Rev. William Colenso (1855), well known missionary and traveller, was stationed at Waitangi on the banks of the Ngaruroro River and Waitangi Stream (Colenso refers to it as a river), a swamp-surrounded location in 1855. Colenso wrote to Joseph Hooker at Kew in England on February 23 that they had been visited by a series of earthquakes, the first of which occurred at 11 p.m. on January 23 and was very severe. The description he gives is quite lengthy but to summarise: the house reeled and creaked, bookshelves and their entire contents of 4500 books, specimens, a writing case, jars, etc. fell, but the chimney apparently did not. Furniture was flung about. Colenso escaped the house during the earthquake and once outside, he clung to the ground watching the willows being tossed about and listening to the post and rail fence clattering noisily. The nearby rivers rose and fell (presumed to be seismic seiching). Colenso indicates very clearly that a number of aftershocks were still being felt late in February, although some of these may have been of local origin (see section on Foreshocks and Aftershocks).

In his notebooks, Henry Hill (c1897), a good friend of Colenso in his later years, recalls him talking of this earthquake (and others) and referring to extensive rents and landslides at Cape Kidnappers (see section on Ground Deformation). However, Hill (1888) seems to confuse some of the effects of the 1863 earthquake with the 1855 earthquake giving rise to doubt as to when the landslides occurred. The only reference to Hawke's Bay in the newspapers is a comment by Commander Drury (*Spectator* Feb 3 1855) that the earthquake was "comparatively mild" from accounts he had heard. The area for the new settlement of Napier had only just been purchased and surveyed and the European population was very sparse.

The environmental effects suggest the intensity could have reached MMVII, but the damage described by Colenso is more appropriately MMVI.

NEW PLYMOUTH AREA Intensity: MMVI and MMVII
The *Taranaki Herald* (Jan 24 1855) reports New Plymouth experienced a sharp shock, which "for a time created considerable alarm but which fortunately was not attended with any consequences more serious than the damaging of a few chimneys". The shaking continued with some severity for 5 minutes and a number of aftershocks were felt. A letter written by Jane Atkinson (1855) mentions that their household had experienced the longest and strongest earthquake ever felt at New Plymouth, lasting about two minutes and accompanied by five or six explosions like the discharge of heavy artillery as the shaking was subsiding. Other than several damaged chimneys, smashed crockery and spilt milk, no other damage was done to the town, but Frances Porter (1989), in her biography of Jane Atkinson, writes that C. W. Richmond (the Richmonds and Atkinsons were related by marriage) reported that the shape of Mount Taranaki had been altered by the earthquake. Richmond (1855) does not mention this in a letter to J. Chamberlain, only referring to a "few defective chimnies" being brought down and some crockery broken. The chimney at the Colonial Hospital (Colonial Surgeon 1855) was also cracked and required rebuilding. John Blackett (1855) mentions at least two chimneys which came down (Mr Allen's and Mr Nash's) during 1 1/2 minutes of shaking and William Messenger (1855) records that several others fell (Mr Blake's and Dr Sealy's) at Omata, about 6 km south of New Plymouth (his estimation of the duration of shaking being 3 minutes).

WAITOTARA Intensity: not less than MMVII
Information on the effects of the earthquake at Waitotara seems to come from the one source, H. C. Field. An extract found in the papers of J. J. Burnet (c. 1904) was undoubtedly written by Field. It appears to be one of a series of articles, perhaps for a newspaper, and possibly instigated by an earthquake in August 1904 that was quite strongly felt in Wanganui (Downes, unpublished data). Field wrote several papers on earthquakes, in particular the 1897 Wanganui earthquake (Field 1898), and he had obviously maintained an interest over many years, communicating with Archdeacon Stock, Reverend Richard Taylor and, at least through the New Zealand Institute, with Sir James Hector.

On January 23 Field was in a large toitoi hut at Waitotara finishing a mill for the Maori. The only damage he records is the upsetting of a small table (Field 1891). After the earthquake, Field hastened a short distance to his neighbours, the Reverend Stannard and his family, but their house had also withstood the shock with no recorded damage. At daylight the alluvial flat nearby was found to be extensively fissured and sand fountains were evident. At Te Hupuku Pah on the banks of the Waitotara River further ground cracks were found and next morning these were observed to move during aftershocks. Along the sea beach track from Waitotara to Wanganui, Field found evidence of landslides with further rock falls occurring with aftershocks.

There are few elements other than environmental effects on which to base an intensity (light huts would not fall until a much higher intensity, if at all) but the occurrence of fissures and sand fountains suggests that the intensity cannot have been less than MMVII, although this intensity may only have occurred in areas of alluvium.

WANGANUI Intensity: MMVIII

In 1855, the town of Wanganui (or Whanganui) was situated on the river flats of the Wanganui River, close to the site of the present commercial area. The 65th Regiment had barracks on small sandhills (Downes 1915). Their construction is described in Downes (1915, pp234-239). York Stockade is now the site of Cook's Gardens and Rutland Stockade is now Queen's Park (Figs.6, 16). Most houses were built of wood and single storied (Allen 1904). Several commercial buildings were two storied with tall chimneys (Fig.6).

The earthquake was very strongly felt in Wanganui. Nearly all the chimneys were thrown down and it was difficult to stand (*Spectator* Jan 31 1855). As in Waitotara, 30 km to the northwest, the mainshock was regarded by some as two or more events, W. Bates (Allen 1904) commenting that "the violence of the shock abated for a little, succeeded shortly by a greater convulsion, differing in nature to the commencing one.... The first two shakes are termed, par excellence, the great shakes". Although Field's house was uninjured there was an "immense" amount of damage in stores and hotels, and all brick chimneys except for two low double chimneys built into the framework of Field's house were destroyed (Field 1891; Burnett 1904). Some chimneys made of squared pumice did not fall, nor the one house built entirely of pumice (Burnett 1904). At Putiki, the brick church with 2.4 m high walls and heavy roof, and a nearby brick wall, were totally destroyed. The brick-nogging, i. e. the space between the studs infilled with brick, of many houses disintegrated or was so shaken as to require rebuilding. Other brick buildings were badly cracked. The Block Houses, the Rutland Stockade and the York Stockade "were extensively injured. In the York Stockade, the arms and accoutrements of the soldiery were buried in the ruin. The Guard and Cook houses were much injured, but happily no loss of life took place" (*The New Zealander* Feb 28 1855).

The effects on the environment in and around Wanganui were considerable. Landslides, sand fountaining, fissuring, lateral spreading and differential settlement occurred (see section on Ground Deformation).

An intensity of MMVIII is well justified. The environmental effects more accurately fit MMIX descriptions but damage to structures probably does not justify assignment of the higher intensity. No wooden buildings were apparently damaged or shifted off their foundations, except possibly at the stockade. Most houses would have been situated on alluvium and possibly susceptible to shaking enhancement.

MANAWATU DISTRICT

Ground damage in the form of liquefaction, fissuring and landsliding was extensive throughout the Manawatu district (see section on Ground Deformation) indicating environmental effects no less than at Wanganui. It is probable that MMVIII was experienced over a large part of the Manawatu.

PAIAKA Intensity: MMVIII, possibly MMIX

At Paiaka, a small township situated close to the Manawatu River about 20 kilometres upstream of present-day Foxton, there was so much destruction that the site was abandoned (Buick 1903). Many of the "rude" houses were thrown down, while others were "left so inconveniently angular" that demolition was the only

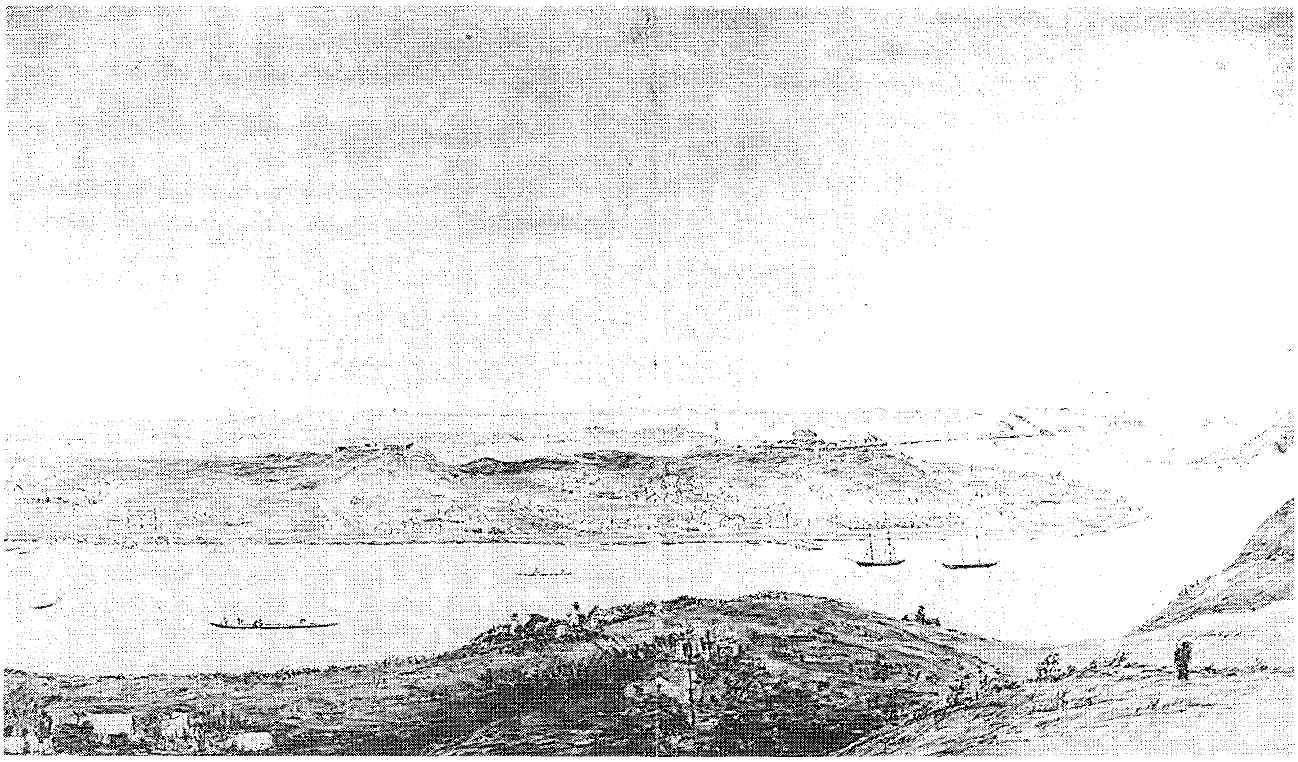


Fig.6. Sketch of the settlement of Wanganui in the 1850's showing location of houses and the York (left) and Rutland (right) stockades upon small hills. Shakespeare Cliff can be seen at centre right. A portion of this cliff collapsed during the 1855 earthquake. Ink and watercolour by John Pearse (Album 1851-56). (Ref. No. 62064 1/2, Alexander Turnbull Library, NLNZ

option. According to Buick, the Kebbell's flour mill, a long irregular building, was extensively damaged, the building becoming distorted, pipes broken and machinery upset. Thomas Bevan (1905) records that it was levelled to the ground. The township was relocated to Foxton, all that could be retrieved from the ruins being moved. The Kebbells erected a new mill in Wellington with whatever machinery could be rescued from Paiaka. The town had been planned as the nucleus of the future European settlement of the Manawatu.

The intensity cannot be less than MMVIII and could be higher. There is no information on the structure of the buildings, although they were probably wooden and Buick's reference to "rude" houses indicates simple and utilitarian, or perhaps roughly built, structures. The township reportedly suffered more damage than places further downstream and its approximate location suggests that it may have been located on ground susceptible to shaking enhancement, although no liquefaction or ground damage are described. The nearby area of Opiki has shown evidence of liquefaction in other earthquakes (Fairless 1984; Fairless & Berrill 1984)

WAIKAWA Intensity: MMVII, possibly MMVIII
At the accommodation house of Thomas Bevan, several kilometres from the mouth of the Waikawa River, two chimneys, one a large double chimney, were demolished (Bevan 1905). Some doors were jammed. Bevan also remarks on the cracking of the surrounding hills (sandhills?) and the draining of the Manga-pirau lagoon. As elsewhere, the environmental effects seem to suggest a higher intensity than the damage to structures. The absence of any masonry other than in the chimneys makes assessment of intensity difficult.

OTAKI Intensity: MMVII, possibly MMVIII
At Otaki, Reverend Arthur Stock and family suffered little damage to household goods although one chimney was thrown down and another badly cracked (Stock 1855). Stock refers to demolished chimneys at four other properties but mentions that their "beautiful wooden church" was undamaged. Reverend Hadfield's chimney was also damaged (Hadfield 1855). Stock remarks in his diary on January 23-24 that the area was severely fissured and showed evidence of sand fountaining. The remarks on intensity at Waikawa apply equally at Otaki. Further south there was a landslide at Wainui or the Pari-pari, close to present-day Paekakariki.

WAIRARAPA Intensity: from MMVII to MMIX, and possibly MMX.
Since the settlers had arrived in Wellington in 1840, the Wairarapa Plains had attracted those searching for good grazing land on which to run their sheep. In 1855 large properties had been established, by purchase, lease or merely occupation, over a large part of the Wairarapa Valley and north along the coastal strip to Hawke's Bay. Several inns were to be found along the main tracks. The Small Farm's Association had been formed by Joseph Masters and Charles Carter (after whom present day Masterton and Carterton are named) and had received approval from the Government to subdivide land but few had yet moved to the area. The European population of the whole area including the coast amounted to 500 (NZ Government Gazette 1855), but few have left accounts of their experiences. Locations are shown in Fig. 5.

At the southwestern end of the valley, Alfred Matthews' house, to the east of Wharepapa Stream, Palliser Bay, was shaken down but the cowshed remained standing and served as accommodation after the earthquake (Matthews 1901). It should be noted that there are at least three versions of Alfred Matthews' memoirs and two or three of Charles Matthews' so that they must be consulted with care although this part of the story seems consistent. The recollections of Thomas Zillwood (1923) refers to Mr. Hume's house (probably "Tauhenui" in the lower part of the Wairarapa valley) where "the first 'quake left nothing of the house standing". In both cases an intensity of at least MMVIII is indicated.

On the eastern side of Lake Wairarapa, at Turanganui, Thomas Mason (1855) records two Maoris killed when a house collapsed. According to Drury (1855) the house was a "mud" hut. A number of other extracts clearly refer to the same incident although the location is given only as the "lower valley" and may refer to one of several pas along the Turanganui River. An intensity of at least MMVIII is implied.

The house of Charles Bidwill at "Pihautea" was east of Lake Wairarapa on a small hill surrounded by river flats often subject to flooding from the Ruamahanga River (Crawford 1880). The house itself, although thrown off its piles with all the doors jammed and the chimneys collapsed, was considered habitable, at least after two or three days of cleaning up (Bidwill & Woodhouse 1927). Nearby there were many deep fissures and sand fountaining occurred. An intensity of MMIX is probable.

Burling's Hotel at Featherston only lost its chimneys and a large amount of crockery (Iveson 1954 quoting from the recollections of Henry Jackson published in the 1880's) implying an intensity of at least MMVII.

The writer of a letter (Anon 4 1855) printed in the *Times* (London) on July 18 1855 is not identified but several factors lead us to believe that the letter was written from the Wairarapa and that the writer is possibly Charles Borlase (presumed to be the same Borlase referred to by Lyell (1856b; 1868)) who lived at Waihakeke to the east of present-day Greytown, close to the confluence of the Ruamahanga and Waiohine rivers. He writes, "the house waved to and fro, rocked and jumped, as you might fancy a ship would when she strikes a rock; the lights were dashed off the table, books, glass, china &c, on the shelves round the room, came down, together with the chimney, part of which fell inside and mixed with the ruins of the furniture, &c. Our friend jumped out of the window, and clung to a post outside, but was thrown down then and obliged to lie on the ground.... I was thrown down, and could not rise on my legs till the shock was over, which lasted about three minutes, although trying my utmost to get up for the purpose of bringing out the family. No house, but one built with posts let into the ground, and wooden houses put together like a box, as the houses in this country are built, could have outlived such a rattling. Ours, though somewhat out of the perpendicular, is not down; the roof, however, is entirely dislodged". The house was apparently rendered uninhabitable as the family moved into a tent (until it was burnt down several days later), as did many other people in the Wairarapa valley. The country nearby was extensively fissured and sand fountaining widespread. As intensity of at least MMIX is indicated.

In accord with Borlase's observation, some simply designed wooden structures withstood the earthquake with no reported damage (recollections of the Eaton family in *Evening Post* Aug 5 1961). The Eaton's house near Masterton was indeed simple as according to Bagnall (1976), it was a "hasty shell 20'x10'", with a "loosely laid floor and a chimney not built until some time after. The windows were of calico, and it was unlined".

At *Orui* just south of the Whareama River (Fig. 4), the cottage of Edwin Meredith was violently shaken, but being constructed of raupo and thatched with toi toi, he records no damage, although the occupants were thrown about inside (Meredith 1898). Meredith also reports a prominent ridge rent in the nearby hills and that a chimney fell at Flat Point further to the south. An intensity of at least MMVIII is probably needed for ridge renting to occur.

No locations are given for a cob house of "clay & straw" in the Wairarapa being shaken down (Lyell1856b) or for two Maori huts in which Anon 4 (1855) knew of fissures opening which "nearly smothered the inmates with water, besides bringing their light buildings down on them". At least MMVIII is indicated.

Descriptions of environmental damage, liquefaction, ground cracking, differential settlement and sand fountaining, and landsliding are a feature of most accounts of the effects in the Wairarapa (see section on Ground Deformation).

Most of the elements for an intensity of MMIX are evident, i.e. some wooden buildings were shifted from their foundations or otherwise seriously damaged, several cob buildings destroyed and environmental effects were very conspicuous and widespread. Because of the Wairarapa's inaccessibility it is unlikely that houses were built of materials other than that locally available, e.g. wood, thatch and clay or mud. It is difficult to determine from damage to these types of structures whether MMX was reached but the environmental effects suggest that it was. However, most homesteads would have been built on alluvium.

HUTT VALLEY, WAINUIOMATA AND EASTERN BAYS OF WELLINGTON HARBOUR Intensity: MMVIII; possibly MMIX.

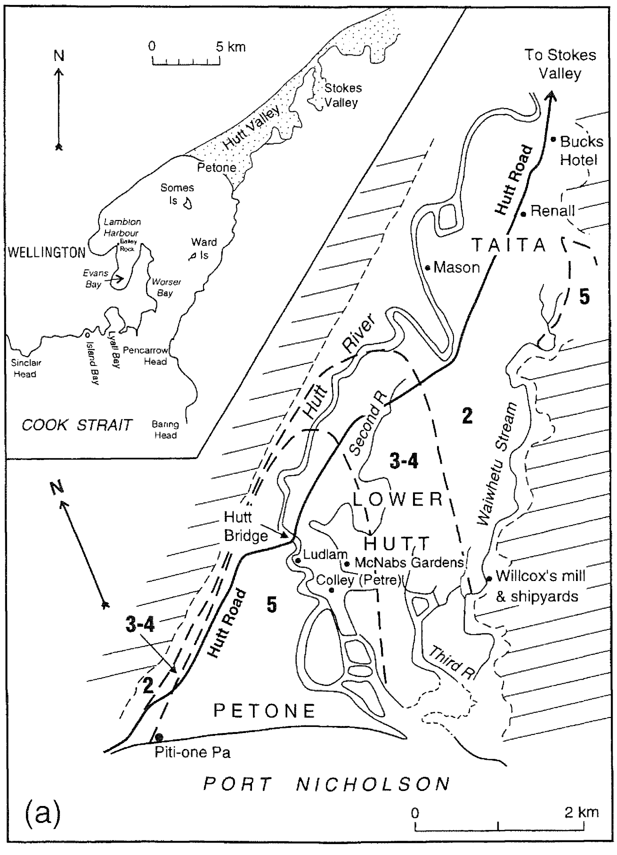
Although the European population in the Hutt Valley was about 1600 (NZ Government Gazette 1855), slightly less than half that in Wellington, first hand accounts are much fewer and it is difficult to get a good understanding of the extent and nature of the effects of the earthquake. Damage to houses seems comparable to Wellington, although ground damage was far more widespread with many wide fissures and large sand boils reported. As in Wellington, many abandoned their houses for days and even weeks after the earthquake, living in tents or outbuildings in preference to returning to their damaged houses. Fig.7a shows the locations of some early residents mentioned in the text.

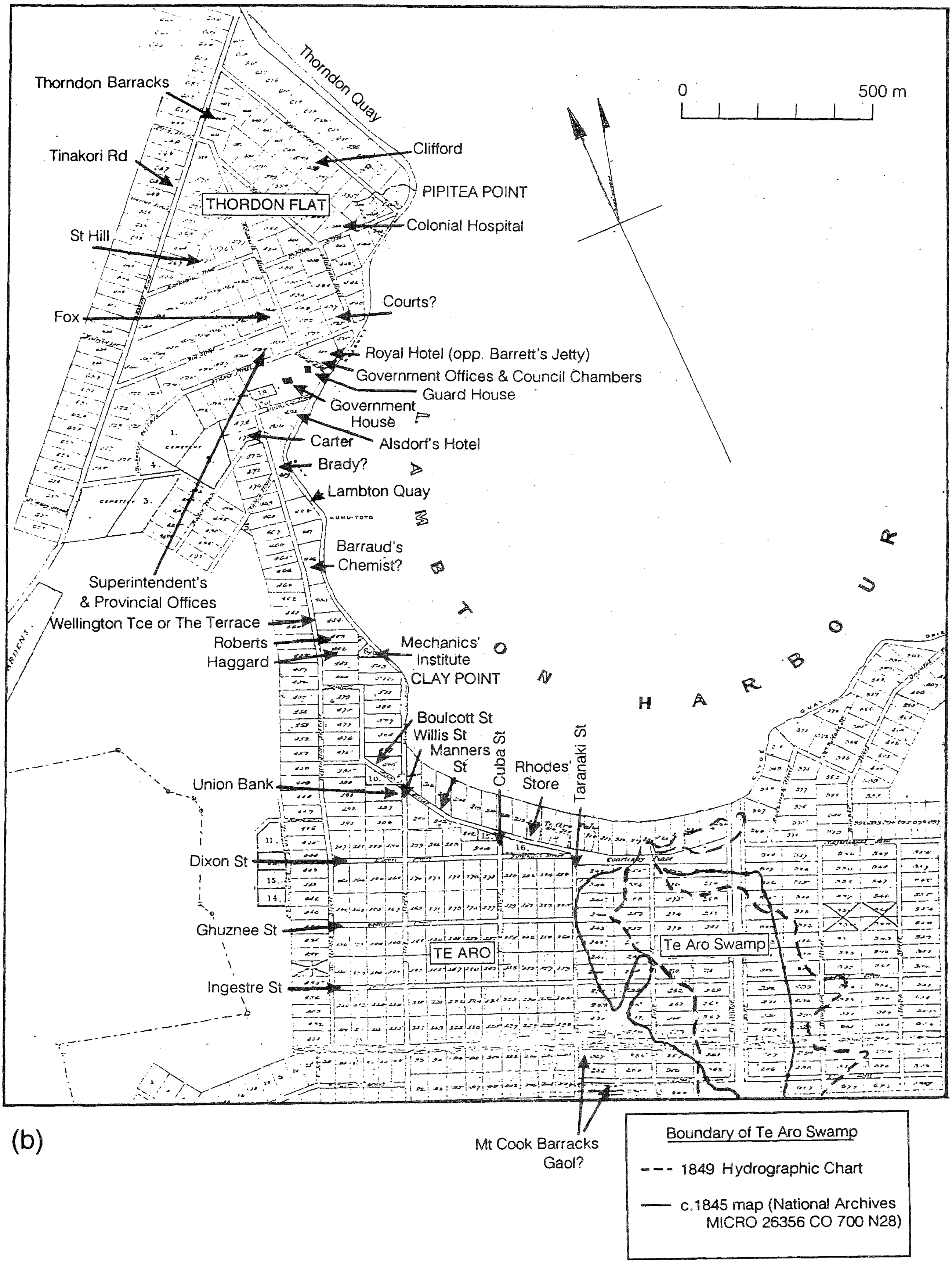
According to Willray (*Spectator* Feb 3 1855), "the visible effects of the shock on the roads and country in general presented stronger manifestations on entering the [Hutt] valley; as a rule the chimnies are down along the whole line; mills reported as damaged, houses damaged internally rather than externally". Alfred Ludlam's house was extensively damaged, as described in an 1855 letter from him (printed in Ward 1928); "the destruction of my house was momentary ... [the earthquake] shook all the chimneys off their foundations and brought them into the rooms" and "completely destroyed my house and a great deal that was in it". Henry Jackson (recollections in Iveson (1954)) regarded Ludlam's house as completely "wrecked". It would seem, however, that the greater part of the damage was caused by the chimneys falling. According to Ludlam the 1848 earthquake had done little to his then new house in comparison. Bassett (1925), Deane (1855) and Mason (1855) also refer to fallen and damaged chimneys but no other structural damage. However a newspaper clipping (Fildes Collection, date unknown) states that Udy's house in Petone "was in a state of collapse", Mrs Udy having escaped to a neighbour's through a window.

Another structure that was irreparably damaged was the wooden bridge over the Hutt River (Fig.8). Henry Jackson (*Wairarapa Standard* Sep 10 1883) recording that it was "both a durable and fine-looking bridge. The earthquake of 1855 lifted it clean up, causing the right end to slide back on the abutments for 10 feet, and the left end to drop into the river without breaking anything ... it could not be lifted, so had to be broken up". This description is much the same as that of Willray (*Spectator* Feb 3 1855): "the swing bridge over the river is gone, broken, and the ground burst up at each abutment, lower end fallen into the water, the whole aslant upstream", while Mason (1855) comments that the bridge was "broken in two". The *Spectator* (Jan 25 1855) suggests that the tsunami (see section on Tsunami and Seiche) contributed to its collapse. Willray records that other smaller bridges throughout the valley had also collapsed.

In addition to damaged and fallen chimneys a number of extracts record that furniture was thrown about, doors jammed and household goods destroyed. Although Mason (1855) records little damage to household articles in his house, Elizabeth Hollard (reminiscences 1842-1930) at Taita mentions that there was "great destruction to household treasures". Hollard and Hill (Anon 2 1884) "found everything breakable smashed, clocks, crockery, etc., were in fragments and tables, chairs and other articles of furniture were upside down and otherwise damaged".

At Taita the foundations of the Renall's water-driven flour mill (Fig.7a) were damaged, the machinery thrown out of gear, and the mill was considered a wreck (McIntosh 1986). It took a month





(b)

Fig.7. Maps showing locations of settlers for which earthquake intensity information etc. are available in the Wellington-Hutt Valley area. (a). The Hutt Valley-Petone area. (b). Detail of Wellington shows landmarks referred to in text and buildings listed in Table 2. Ground shaking hazard zone assessment relative to bedrock (after Van Dissen et al. *1992) in (a) is shown for reference. Zone 2 - low to moderate amplifications of shaking of compact gravel and gravely sand (up to 200m thick); Zones 3-4 - shaking amplifications intermediate between those of Zone 1 and Zone 5 in areas underlain by 5-10m of soft and/or loose sediment; Zone 5 - high to very high amplifications of shaking of soft, unconsolidated, fine-grained sediment.*

Table 2 **WELLINGTON BUILDING DAMAGE**

Owner/Occupier	Location	Section No. from map in Ward (1928). Some locations are marked in Fig.7b.	Construction	Damage	Source
Allen's store	Old Customhouse St; opposite Post Office		iron & wood	damaged	Mills & Carter 1855
Alzdorf's Hotel	Lambton Quay	between 513 & 484	"lath & plaster with brick chimneys and no bond between them trimming them up inside"	"north side is rather out of the straight and the building is twisted 2 or 3 degrees off the brick foundation"	Pilcher 1855
			2 storey, lath and plaster	"nearly destroyed"	Bennett 1855
				"much shaken and part has fallen down"; "the owner was killed by the falling in of a chimney as he sat by the fire"	Jolliffe 1855
Anon	?		new wooden building, chimneys outside	chimneys down	*Australian & NZ Gazette* 1855
Anon	Lambton Quay		"old wooden houses"	"several old wooden houses were level with the ground", "chimneys universally -the brick houses Those of lathe & plaster were also much rent & shaken. Nearly all the shop fronts had fallen out"	Jones 1855
Barracks	Thorndon Flat			all brickwork down but "neither the troops nor buildings attached suffered to any great extent"	Wynyard 1855b
Bennett	Nairne St, Oriental Bay			chimney toppled through roof	Bennett 1855
Bethune & Hunter Store	Dickson St		brick encasing wood	brickwork torn away from frame	Mills & Carter 1855
Blake	Lambton Quay?			chimney down, demolishing outside stairs	Blake 1909
Bonded stores				"partly down, and the rest must be pulled down for safety"	*Australian & NZ Gazette* 1855
Bowler			new brick offices	"quite sound"	McIntyre 1980
Cameron	Miramar		whare	undamaged	Cameron (date unknown)

Capt Rhodes store	Manners St?	215	brick encasing wooden frame, frame decayed, possible 2-storeyed	side walls out of perpendicular (7-8 ft) & partially separated from rest of building	Mills & Carter 1855
Carter	cnr Bowen St/Wellington Terrace	473		no structural damage, intact chimney	Carter 1866
Civil hospital	Thorndon Flat			chimneys fallen onto beds, water tank split	Jolliffe 1855
Clifford	Hobson St	599	new wing: timber framed, battened & plastered externally & internally	no damage to new wing	Mills & Carter 1855
				"he had a nice house but the dining room is in perfect ruins, the walls having fallen in"	Jolliffe 1855
				"only one room safe"	Coote 1855
				dining room & chimney down	Jones 1855
Colonial Bank of Issue, Strong Room, Offices				"whole of masonry and brickwork was so entirely fractured that it was necessary to rebuild the vault in toto". Two chimneys required rebuilding	St Hill 1855a
Council Chambers	cnr Lambton Quay/ Mulgrave St	514/515	wooden structure -imported from England	lower storey collapsed, rotten ground plates	Carter 1866
			"very slightly and cheaply built ... the upper story ... loaded with brick nogging"	"upper storey completely severed from the lower"	*Spectator* 1855
			"rickety 2-storeyed building"	"fallen to ground"	Jones 1855
D'Arcy	Te Aro Flat		small wooden house, 4 rooms & garret	chimney down	Jolliffe 1855
Eades store	Lambton Quay		well constructed, on rock	"almost no injury"	Mills & Carter 1855
Fox	Molesworth St	about 564	pise	brick chimney & wall fell	Fox 1855
Gaol	Mt Cook?		massive stone base, cornerstones and window surrounds.	Minor cracking. Top heavy decorations were damaged	Mills & Carter 1855
			" a substantial building of brick & stone and supposed to be earthquake proof"	"rent in several places"	Jones 1855
			brick	much damaged, guard &	Wynyard 1855b

				prisoners removed	
				"nearly as bad [ly damaged as the Bank]"	*Australian & NZ Gazette* 1855
Gold				chimneys down	Jones 1855
Government House	Kumutoto st (now Bowen st)			"much damaged"	Coote 1855
				"complete wreck'	*Australian & NZ Gazette* 1855
				chimneys down, roof injured, older building not worth repairing, new building: plastering & brickwork "much shaken and destroyed"	Wynyard 1855b
Government Offices	cnr Charlotte St/Mulgrave St	513/514		"interior ... a perfect wreck, every room being filled with rubbish of falling chimneys"	Jones 1855
Guard House (at Government House)	Charlotte St			much injured, the building requiring propping up, chimneys down, foundation "much shaken at one end"	Wynyard 1855b
				bricks of chimney fell into room	Jolliffe 1855
Harrison, Mrs	Happy Valley		stone house	"all the house down"	Ward 1928
Henton	?		well constructed	"almost no injury"	Mills & Carter 1855
Hervey's warehouse Farish St				completely shaken down	Carkeek 1855
Hickson	Ingestre St		well constructed, on concreted clay foundation	"almost no injury"	Mills & Carter 1855
Hoggard	Wellington Terrace	482		extensive damage to household goods only	Jolliffe 1855
Holdsworth	Tinakori Road		well constructed	"almost no injury"	Mills & Carter 1855
Hort	Abel Smith St		brick house lined with wood	all chimneys down, outer cladding of house "greatly shaken & cracked'. Greenhouse shattered	Hort 1855
Hurley				no damage	Pilcher 1855
Laing	Lambton Quay		2 storey, plaster front, large brick oven, & chimney, good foundation?	little damage	Mills & Carter 1855
Lower Barracks	below Mt Cook			"the destruction was tremendous"	Jolliffe 1855

				all chimneys down, one breaking through floor of a Hospital ward	Wynyard 1855
Loxley's store	Manners St		brick	"so shaken as to render it quite impossible to abstract goods"	Carkeek 1855
Major Murray	Ingestre St?			chimneys down, tremendous destruction of household goods	Jolliffe 1855
Matthews	Thorndon Quay			chimney through roof, "half of the house came down"	Matthews 1901
McCleverty	Tinakori Rd??			chimney down	Jones 1855
Mechanics' Institute	Lambton Quay,	near 513	good natural foundation	little damage	Mills & Carter 1855
Military Chest	lower Mount Cook?			"cracked & displaced throughout"	Wynyard 1855
Mill (Hoggard's?)	Te Aro (east of Te Aro Swamp)		?	"terribly shook one side out - it will take at least £200 to make it good"	Pilcher 1855
New Church	Willis St		good natural foundation, 2ft high brick foundation walls	no damage	Mills & Carter 1855
Ordinance store	lower Mount Cook?		lathe & plaster	lath & plaster almost completely stripped off	Wynyard 1855
Pilcher	lower slopes Mount Victoria?			several chimneys down, one iron chimney not down. All other brickwork cracked.	Pilcher 1855
Prendergast, Dr				chimney down, plaster fallen	Jolliffe 1855
Richardson, G.	Mulgrave St			chimneys down only	Richardson 1855
Royal Hotel	Mulgrave St near Government Offices	525		"much shattered so that the doors could not be closed"	Jolliffe 1855
St Hill, Henry	Hawkestone St	about 575		chimneys down	Jones 1855
Supreme Court & Offices	Mulgrave St?			repairs, rafters, weatherboards, glass, roof, chimneys. Total cost £72/12/-	St Hill 1855c
Sutherland	Sutherland Rd, Lyall Bay		wood and clay	kitchen, built of clay, collapsed	Sutherland 1947
Union Bank	cnr Willis & Boulcott St (now Manners)	198	new & handsome building with slate roof & stone coping	porticco fallen, inside wrecked from falling chimneys. Iron store at back not damaged.	Jones 1855
				"much damaged"	Coote 1855
				"so much shaken that it will have to be pulled down"	*Australian & NZ Gazette* 1855

				"whole of ornamental portico down"	Jolliffe 1855
			"brick & stone portico ... tied to the building by iron rods"	"pillars snapped ... would not had had so much damage if the portico had not been tied to [the main building]	Pilcher 1855
Upper Barracks	Mount Cook			"tolerably free of injury'	Jolliffe 1855
				two chimneys down, others needed demolition, outer wall of Magazine cracked	Wynyard 1855b
Waterloo Hotel	S side of Kaiwarrawarra Stream			"shaken to pieces" but building on N side of stream "not a chimney was damaged"	Matthews 1901
Watkin			wooden, unbraced	racked & distorted	Mills & Carter 1855

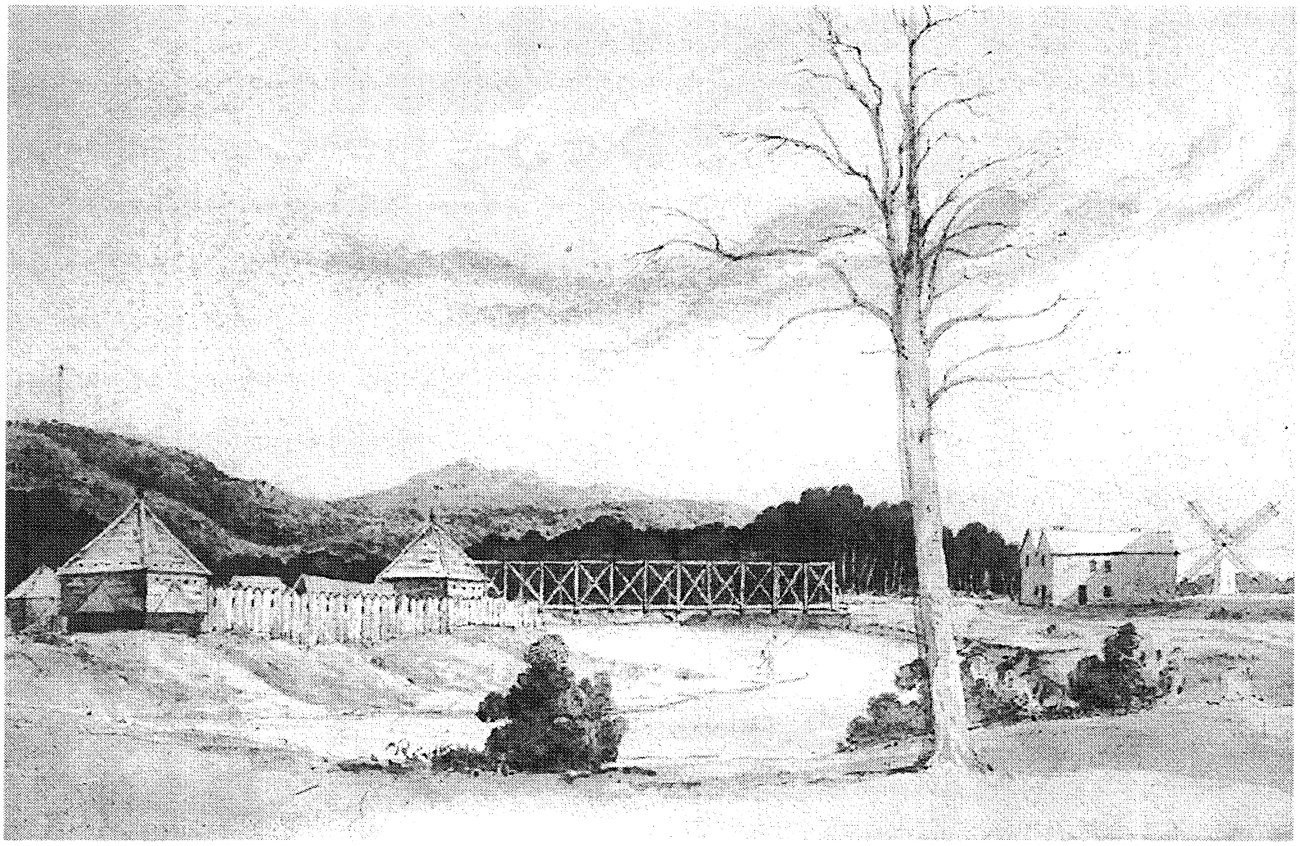


Fig.8. Sketch by William Smith (c.1847) of the bridge (second) over the Hutt River that collapsed during the 1855 earthquake together with Fort Richmond. Also shown are the Aglionby Arms (second site) and Moleworth's windmill opposite. Location of the bridge is shown in Fig.7a. (Ref. No D-P034029-A -CT; Alexander Turnbull Library, NLNZ).

for a gang to repair the machinery and restore the water races with the expenditure of £176. In Stokes Valley where Mr Hart Udy operated a sawmill, "the whole structure was razed to the ground" (Fildes Collection, extract 3; date unknown). There is no building damage information from Upper Hutt, and Willray (*Spectator* Feb 3 1855) also indicates little environmental damage, at least in the vicinity of the road from Upper Hutt to Pakuratahi.

Throughout the Lower Hutt Valley ground cracking, settlement, lateral spreading, and sand fountaining were widespread, particularly near rivers and streams (Mason 1855; Ward 1928; *Spectator* Feb 3 1855), (see section on Ground Deformation).

The above information clearly justify an intensity of MMVIII over most of the lower part of the Hutt Valley. There are few criteria by which to assess MMIX. Damage to wooden houses appears to be related to the collapse of chimneys rather than frame or foundation damage, and few masonry structures are mentioned. However, given the extensive nature of the environmental effects, an intensity MMIX is possible.

There were two European families resident along the coast east of Wellington, the Bennetts at Pencarrow lighthouse and the Riddifords near the mouth of the Orongorongo River (Fig.5). According to Thomasina Hewett (nee Riddiford) the Riddiford family moved to "Woburn" in the Hutt Valley because of the feeling of isolation the earthquake gave them, the house being severely damaged with "gaps made in the walls and other damage" (Riddiford family 1939). Staying at Pencarrow Lighthouse on his way round the coastal route to the Wairarapa, Graham Speedy records only that barrels of flour and oil rolled in front of the door of the lighthouse making their exit difficult (Speedy 1855). The lighthouse was little more than a shed that was neither wind nor water proof (Furkett 1953).

WELLINGTON Intensity: MMIX.

From a population of about 3200 Europeans (NZ Government Gazette 1855) about forty accounts (as well as contemporary newspapers) of the earthquake and its effects in Wellington have been found. Because of Wellington's aspirations of becoming the seat of Government and because of the New Zealand Company's desire to promote the settlement to prospective immigrants, some accounts show a distinct bias in the reporting of damage (see Historical Background section).

After the 1848 earthquake a very useful inventory of the damage in Wellington (Miles 1849) was produced. In 1855, no doubt as a result of a public meeting called to address several matters, among them a "petition for regulations governing building construction" (*Spectator* Feb 10 1855), the Provincial Secretary appointed a Commission "to enquire into the amount of damage sustained by the City of Wellington and suburbs by the late earthquake" (Mills & Carter 1855). Charles Mills, Charles Carter and Edward Roberts were appointed as Commissioners, although Roberts was not able to carry out his part as he was recalled to England. In addition to reporting on the damage, Mills and Carter were also asked to report "on the material and mode of building, best calculated to resist the effects of earthquake peculiar to New Zealand". This latter task they took very seriously. In the Report damaged and undamaged buildings are cited as examples of unsuccessful or successful building techniques, and much of the damage was attributed, perhaps correctly in some cases, to poor materials, foundations and structural technique. While the report shows a remarkable understanding of the necessity to have good workmanship, good materials, strong bracing, and sound foundations it cannot be considered to provide a complete inventory of damage, as had been the result of the 1848 inquiry, and in fact some information is quite misleading.

The Mills & Carter report cites Charles Clifford's house as a good example of how a new wing could be added with the result that neither "the weather or earthquake has injured the plastering or cornice internally or externally". No mention is made of any other damage, yet Trolove (1855) writes that "Clifford's house is shaken except two rooms" and Jolliffe (1855) adds,"at Mr Clifford's (the speaker) ... he has (or had) a nice house but the dining room is in perfect ruins the walls having fallen in", together with Jones (1855) "his dining room and chimney, wine, china, etc. smashed"! Eight months later when Henry Sewell was in Wellington on a visit, he records that "[Clifford's] house was shaken to pieces by the earthquake and is all in the confusion of repair" (McIntyre 1980).

Additionally, the Commissioners were not appointed until March 15, nearly two months after the mainshock, and many extracts record that clearing of debris was in progress well before this date. Carter (1866) in his recollections writes that "the very day after this awful night ... repairs were effected, business was resumed, the newspapers were published as usual", while Jolliffe (1855), on February 11, records that "people are busy clearing away the fallen houses, etc. from the first great shock but very few have commenced rebuilding their walls or chimneys". An account written on January 27 (*Australian and New Zealand Gazette* June 2 1855) mentions that "fatigue parties of soldiers are busy pulling down a number of houses and stores in the principal street" [i.e. Lambton Quay]. Several weeks later, Fox (1855) writes that the chimneys are "nearly all rebuilt" and Pilcher (1855), in early March, reports that "chimneys [are] being rebuilt and repairs going on as fast as they can". Hence it would have been difficult after two months for Mills and Carter to produce an inventory of all the damage, although they were, as builders, probably much consulted over clearing debris and rebuilding. Perhaps this is the reason that some damage has not been recognised. Carter was also known to be strongly in favour of immigration (Dictionary of New Zealand Biography, 1993) and some bias on account of this may have been present when he and Mills wrote their report. Despite some inadequacies the Mills & Carter report is the only document which identifies structural techniques and materials and their performance as related to specific buildings. With this background in mind, that is, the social and political influences and personal biases, the structural damage and other effects of the earthquake in Wellington have been assessed. As far as possible building locations have been identified (Table 2; Fig.7b) using a number of resources (primarily Ward 1928) and the 1855 electoral role (NZ Government Gazette 1855).

Damage to brick and masonry structures

"Every chimney or erection of brick in the town except a few built in cement was levelled to the ground; many wooden houses ruined" (Bennett 1855) and "though some of them [i.e. wooden houses] are much damaged and much property destroyed, only one or two are down. All the brick and mortar ones, however, and all the chimneys are down" (Anon 4 1855) are typical of the comments in many extracts. According to Mills & Carter (1855), of the total number of chimneys in Wellington, 20% were totally demolished, 60% had their tops thrown down or were so "dislocated" as to require demolition and 20% were uninjured. Captain Chesney's Report (Thomson 1859) differs somewhat; viz. that 53% chimneys were down and 39% much damaged. As Chesney was a Royal Engineer with the 65th Regiment, his report may have been very interesting but we have had no success in locating it. Neither report records the percentage of chimneys that were constructed of brick.

Other than chimneys many brick and masonry structures received damage but few, it seems, collapsed during the earthquake, although many were so damaged as to require subsequent demolition. Some brick structures were not damaged, "Bowler's new brick offices are quite sound" (McIntyre 1980), but others were. Mills and Carter's report (1855) records that "the whole of the brickwork of this building [the Gaol], is with the exception of a trifling crack, uninjured; the massive stone base, the stone quoins, and the window stone dressings, are not injured in the slightest degree; the stone entablature was injured and was taken down". In contrast, Jones (1855) writes in his Journal that "the Wellington Jail, a substantial building of brick and stone and supposed to be earthquake-proof, has been rent in several places; the roof has also suffered" and in the *Australian and New Zealand Gazette* (June 2 1855) a correspondent writes " the new Bank is so much shaken that it will have to be pulled down - the gaol is nearly as bad", an observation echoed by the *Spectator* (Jan 25 1855), "the Gaol has also received considerable damage". A dispatch from R. H. Wynyard (1855b), acting Governor and senior military officer of the Colony, mentions that "the men of the main guard and prisoners in their cells were removed, as the buildings occupied by them were much damaged in their brickwork". Walls were thrown out of plumb, for example at Rhodes and Bethune's & Hunter's bonding stores (Mills & Carter 1855; *Australian & New Zealand Gazette* May 6 1855), and Hort's house in Abel Smith St. (Hort 1855), or were much cracked and rent ("the houses built of brick had also suffered much being rent and many portions displaced" (Jones 1855)). Mills & Carter point out that some of the brick buildings which had been built after the 1848 earthquake were heavy two storeyed structures which had a timber framing (imported?) that had become rotten thus contributing to their collapse. Some brick foundations were damaged, for example, the Guard house at Government House and the Magazine at Mount Cook (Wynyard 1855b), although Mills & Carter suggest that damage was very dependent on the material on which the foundation was built. The joining of the foundation to the upper structure was another contributor to damage, both in timber-framed brick and wooden houses.

Damage to wooden structures

The lower storey of the Council Chambers, a two-storey wooden building on Lambton Quay, collapsed, but several writers note the fact that prior to the earthquake it had been a dilapidated building, particularly Carter (1866) who in his recollections, writes "well might this building fall [the Council Chambers] ... I found the ground plates on the brick foundation, entirely rotted away, as were also the lower end of the studs.... It was one of the oldest buildings in Wellington and imported from England". The adjoining Government Offices also collapsed, apparently from similar causes; "[the Government Offices] was a very slight building, of inferior construction, 12 or 13 years old, and of which the uprights were, and had long been, perfectly rotten at the level of the ground" (*Spectator* Feb 10 1855).

Jones (1855) comments that along Lambton Quay he found "several old wooden houses were level with the ground", while Mason (1855) writes "that many wooden buildings also were thrown down". Commander Drury (*Spectator* Feb 7 1855) mentions that "the most substantially wooden buildings of one storey, with the exception of the chimnies, are mainly standing". Chimneys falling through roofs or demolishing walls or staircases contributed to damage to wooden buildings (Blake 1909; Matthews 1901). In particular, the only verified death in Wellington, that of Baron Alzdorf, was attributed to the collapse of his chimney into the interior of the room he was in. There is evidence that a few wooden houses were cracked and distorted and many structures, both wooden and brick, were rotated on, or thrown from their foundations. Pilcher (1855) writes that "the building [Alzdorf's Hotel] is twisted two or three degrees off the brick foundation - which every house upon brick foundations have [sic] more or less".

Damage to structures made of other materials

Lathe and plaster houses were also reported damaged, for example, Alzdorf's Hotel (Jones 1855 and others). The chimney and a brick wall in William Fox's pise (rammed clay) house were demolished forcing the family to live in a calf pen (Fox 1855). At Lyall Bay the Sutherland's clay kitchen was destroyed while the adjoining wooden house was undamaged (Sutherland 1947). A stone house in Happy Valley was completely demolished (Ward 1928).

There was widespread, but not universal damage, to household goods, china, furniture, etc. and many windows were smashed, doors jammed, and interior and exterior plaster cracked and fallen in houses and stores. However, some householders received no damage other than to the odd ornament or bottle of wine. Contrasts such as this are difficult in evaluating intensities but occur within the epicentral area of any major earthquake. For example, the inner isoseismal for the 1964 Alaska earthquake encompasses intensities from MMVII - MMXI (Cloud & Scott 1972), with some reports from the Anchorage area, where many buildings collapsed, recording the loss of a cup or two only. Mills & Carter (1855) "after careful inspection of the whole of the buildings in Wellington, beg to report that, they estimate the loss sustained from injuries to buildings of every description, (including merchandise and household effects, as near as they can ascertain) at the sum of £15,408". In the days immediately following the earthquake others had made estimates of £70,000, a figure which was disputed by the editors of both the *Spectator* and the *Independent*. Many suggested that the cost of replacing their damaged structures and household items was of the order of a hundred to several hundred pounds.

Microzone effects on buildings

The lack of precisely known building damage at well located sites in Wellington makes it difficult to relate the damage distribution to sub-surface geology. The highest hazard regions (Zone 5) on the Ground Shaking Hazard Map Sheet 1 (Wellington Regional Council 1992) encompass areas of alluvium and reclamation but by 1855 there had been only one reclamation, a small area to the southeast of the Willis Street/Manners Street intersection. There was no building on it, but mud extrusion was reported. On the southwest corner of the same intersection the portico of the Union Bank which "stood in part upon made ground" collapsed. Many Zone 5 areas, such as the Te Aro swamp (Fig. 7b) were not built upon in 1855.

Wellington's earliest houses were situated close to and on the beach from Thorndon Quay, along Lambton Quay, to Willis Street and along Courtenay Place (Fig.7b). Buildings in some of these areas seem to have been fairly heavily damaged, but whether because of age, or because of the nature and depth of the underlying material on which the foundations were laid, is difficult to determine. Mills & Carter (1855) comment on this subject, saying that "in the course of their enquiries and inspection two things have invariably presented themselves, in those parts of the town where the most damage occurred, namely dilapidated buildings and defective foundations; buildings erected on loose gravely, or swampy foundations; buildings with ground plates partially or entirely decayed, or destitute of braces - have suffered severely while both houses, and stores, where the timbers were sound and the foundations good, have escaped without almost any injury, even brick houses, on a good foundation have escaped material injury.... From Mr Bowler's Office to Kumutoto Stream [from about the Willis Street/Manners St. intersection to the Willis St./Lambton Quay corner] good buildings have really suffered very little, the foundations along here being rock, cropping out, or within three or four feet of the surface". Similarly, Drury (1855) comments that "it appears to be generally established that the lower ground has been most disturbed, that elevated houses - on rock or solid base has had comparative exemption" and Jones (1855) also recognises that "buildings on high ground appear to have suffered much less than those in lower situations". Many accounts recognise the differential effects of the earthquake from one location to another; "it is rather remarkable that in some localities houses were shaken to pieces, and others in the immediate vicinity scarcely suffered at all. One notable instance was that of the old Waterloo Hotel, just on the Wellington side of the Kaiwarra Stream. This building was shaken to pieces, while on the Kaiwarra side not a chimney was damaged" (Matthews 1901).

Ground deformation in Wellington was not as extensive as in the Hutt Valley and was rather localised (see section on Ground Deformation). An intensity of MMIX is well justified, but MMX does not seem to have been reached.

NORTHWEST NELSON Intensity: MMV, MMVI at Motupipi. Although European settlement in the Golden Bay area of northwest Nelson began in 1845, it developed slowly until the discovery of gold in the Aorere Valley brought in several hundred persons in 1857. Hence to have three reports from this area is excellent. As the West Coast had not been developed by 1855 it is not surprising that there are no reports from this area.

At Onekaka, near Collingwood, Mrs Caldwell (Washbourn 1970), writes in her diary that "the motion though frequent, was not violent enough to be apparent, but our sensations were not agreeable" and that she was thankful that their house was a Maori-built whare "for a brick or stone house might have been shaken to pieces". To William Rout and friends, camped near Takaka, the earthquake "seemed to heave in waves like a boat rolling on the swell of the sea, and as a very large tree was close to us we were in fear it might fall and crush us, for we were too paralysed to move" (Miller 1943). According to the reminiscences of Mrs Harwood,written at age 90, she was thrown to the ground by the earthquake at Motupipi to the east of Takaka and in the house "ornaments and kitchen utensils were displaced from their hooks and all the goats' milk in the wide, flat pans ... were spilt" (Halket 1943). Seiching is also described. The date of the earthquake is not given but no other known event could fit the time of day.

There is little to establish an intensity in Golden Bay but it was probably no less than than MMV and probably MMVI at Motupipi.

MOTUEKA Intensity: MMVI.
Enga Washbourn (1970) recalls her grandfather talking of the earthquake when the earth at Motueka shook violently and the furniture was moved about, all accompanied "by noise and confusion". Little damage was done however.

NELSON Intensity: MMVII; MMVIII at some locations.
The settlers of Nelson regarded the earthquake to be comparable to that which occurred in 1848. As in Wanganui, Otaki and Wellington, the mainshock, which lasted 3-4 minutes, was considered to be a succession of strong shocks (*Nelson Examiner and New Zealand Chronicle* Jan 27 1855). The newspaper reports indicate that in addition to widespread breakage of household and shop goods, several chimneys were damaged or destroyed and a few brick buildings (four were named, three of which were 2-storied buildings) were seriously damaged, but implies it was only those buildings not repaired after previous damage in 1848. In the case of one building at least, the Wesleyan Chapel, this is disputed in a letter to the editor, also suggesting that another adjacent building was damaged more seriously. A pise house was damaged but with no detail on extent, but many houses of brick and cob construction, as well as those of wood and lath-and-plaster, were apparently undamaged.

John Jolliffe (1855), the ship's surgeon on the *Pandora*, which arrived in Nelson three days after the earthquake, records that "a good deal of injury has been done to the houses in the town chiefly those about the Waikaki? Hotel suffered most - at the Port and other places the shocks were comparatively light". Next day after landing he further notes that the shocks "could not have been as severe here as at Wellington, two or three brick houses are much shaken and must be taken down" and that "several chimneys only were thrown down, while some parts of the town suffered little building damage". Morton Jones (1855), another officer on board the *Pandora*, suggests that although the earthquake was felt severely in Nelson, some residents gave "a most exaggerated account of what had happened". It is probable some debris had already been cleared by the time that Jones and Joliffe arrived. An intensity of MMVII with MMVIII occurring at some locations, is indicated.

WAIRAU VALLEY Intensity: MMVIII in the lower part of the valley.
The *Nelson Examiner* (Jan 31 1855) reported that the earthquake "was felt very severely at the lower end of the Wairau Valley, where several buildings were more or less damaged, but ascending the valley, the shocks became less severe as the distance from the sea increased". Fissuring and sand fountaining occurred near the present town of Blenheim. Several contemporary reports refer to subsidence in the lower part of the Wairau Valley (Mason 1855; Roberts 1855; Lyell 1856a; Lyell 1856a,b) which is discussed in the section on Ground Deformation. According to McIntosh (1940) "nearly every mud whare in the Wairau came down", but the information is unsourced and damage seems somewhat more than that reported in the *Nelson Examiner* . There was, however, extensive damage to cob buildings in the Awatere Valley with which McIntosh may have been confused. It is worth noting here that prior to the early 1850's the Awatere River was known as the Wakefield River, the flat lands of the valley were known by the Maori name Kaiparatehau (Reed's index of place names; Alexander Turnbull Library, NLNZ), and the whole of the district, Wairau and Awatere Valleys, was referred to as "The Wairau".

Sir David Monro (1855) records in his diary that Dillon's house (*Leafield*) in the Waihopai Valley, about 20km from the sea, was "very much shaken" but Joseph Ward (1855) finds "all pretty well, much better than expected" on his return home to Omaka, near Blenheim.

It is difficult to justify an intensity of more than MMVIII, assuming that McIntosh's statement referring to the Wairau Valley is incorrect.

AWATERE VALLEY Intensity: MMVIII; possibly MMIX.
In the Awatere Valley "nearly all the cob buildings, within twenty miles of the sea, were more or less damaged, but beyond this the force of the shocks sensibly diminished" (*Nelson Examiner* Feb 21 1855). Situated about 30 kilometres from the mouth of the Awatere River the sod house of the Mowat family, *Altimarlock*, was rendered uninhabitable by the earthquake and required extensive rebuilding (Mowat 1855; Kennington 1978). There was also extensive damage to household goods. Frederick Trolove (1855) records in his diary in March that the owners of *Redwoods* (lower part of the Awatere Valley) had found it necessary to abandon their house and that the house of the Marshall family had been "shaken down". Cob or sod seems to have been the most common method of building (Kennington 1978).

FLAXBOURNE and KEKERENGU Intensity: MMVIII-IX? at Flaxbourne; MMVII at Kekerengu
Flaxbourne, situated on the northeast coast of the Marlborough district, was the home of Frederick Weld, who was one of Sir Charles Lyell's informants on the effects of the earthquake. The homestead stood about 800 metres from the beach and was a prefabricated wooden house brought from England (Kennington 1978). Unfortunately there are no known contemporary descriptions of the effects of the earthquake specifically at the homestead among Weld's personal papers or diary. However, Frederick Trolove, a neighbour of Weld's to the south at Kekerengu, refers to Flaxbourne Station in his diary, having received news via his brother. He records that "16 houses (all new, having been built this summer or last) are either flat to the ground or so shattered that they are beyond repair. The houses built under the large hills have suffered the least. Those on the flat ground are levelled with it" (Trolove 1855). Two months after the earthquake the effects of the strong shaking, landslides and cracked hills, were still visible to Sir David Monro at Lake Flaxbourne (now Lake Elterwater). Monro also passed by the "ruins of the clay cottages", most of the houses being "down level with the ground" (Monro 1855) and presumably those referred to by Trolove. In mid February, Trolove rode to the Awatere and Wairau, commenting that he thought the earthquakes "have not been so severe in the Awatere and Wairau as at *Flaxbourne* and *Woodbank*". *Woodbank* was situated on the north side of the Clarence River.

There is some difficulty in assigning intensities at Flaxbourne and Kekerengu, primarily because of possible confusion with the effects of a large aftershock felt by both Weld and Trolove within a few hours of the mainshock (see section on Foreshocks and Aftershocks). Weld apparently informed Sir Charles Lyell (1856b) that "at 3:00 [am] he felt a shock, supposed to be local, which had the same strength as the first one", while Trolove also seems to consider the second shock to be of greater intensity, with his chimney toppling and walls being rent and torn by this shock, although he is not very clear on this point (Trolove's diary is quoted extensively in the section on Foreshocks and Aftershocks). It was this aftershock that convinced him to move to his woolshed. Several further severe earthquakes completed the demolition of Trolove's house at Kekerengu, which is assumed to have been a cob construction, and of his shepherd's cottage, *Woodbank*, "made of toitoi and posts in the ground three feet with a clay chimney". It is impossible to know whether the houses at *Flaxbourne* were demolished in the first severe shock, or even in the first two shocks. An intensity of at least MMVIII, possibly of MMIX if all the damage was done in the first earthquake, can be assumed at *Flaxbourne*. At Kekerengu an intensity of only MMVII in the first shock seems likely with MMVIII in the subsequent event. In the Awatere Valley, however, Alexander Mowat at *Altimarlock* recognised the first earthquake as the most severe.

NORTH CANTERBURY Intensity: MMVI.
In a letter to J. Godley, J. Hamilton (1855) refers to the effects of the earthquake on "the Plain" being sharper than at Christchurch where some household crockery was damaged, but that no damage had been done "nearer than Lee's station - at Waiau-ua 80-90 miles north of this [Christchurch] - where a chimney was shaken down". The name "Wai au uwha" is the Maori name for the Waiau River.

CHRISTCHURCH AND LYTTLETON Intensity: MMV (Christchurch); MMV (Lyttleton).
The settlements of Christchurch and Lyttelton were well established by 1855 and producing a local newspaper. Several contemporary letters record the effects of the earthquake at both settlements.

The mainshock was certainly widely and strongly felt, but a letter by Sir John Hall written in June 1855 (Hall 1855) states that the earthquake did "no damage in Canterbury beyond breaking a few teacups". Others (Lean 1881; McIntyre 1980) comment upon the creaking of their houses. Edward Chapman (1855) felt it was difficult to stand steadily during two minutes of very strong shaking, while John Aldred (1855) was alarmed by the several severe shocks that he felt.

At Lyttelton, Charles Bowen (1855) considered the earthquake to be very slight, but William Smith (1855) was much more alarmed as "the timbers of the house creaked, the pictures swung from the walls, the floor heaved up underneath us, the bells rung". He records also that aftershocks during the night caused further creaking of the house and jingling of the crockery. Hannah Caverhill (1855) considered the shock very severe and about two minutes duration.

DUNEDIN Intensity: MMIII.
The *Otago Witness* (Feb 17 1855) records that only a very few persons felt the earthquake.

CASUALTIES

Casualties of the earthquake are variously put at between 5 and 10. Thomas Mason (1855) mentions the deaths of two people in a fissure in the Manawatu, about 65 kilometres north of Lower Hutt (possibly Levin or Otaki?). It is interesting that neither Thomas Bevan (1855) at Waikawa nor Reverend Stock (1855) at Otaki mention any deaths in the area so that the report of Mason, the sole source of this information, cannot be verified. B. Iorns reminiscing in the *Wairarapa Times Age* (Sept. 24 1932) claims knowledge of one Maori who was the sole survivor of seven. The other six were killed when their whare near the Turanganui River in southern Wairarapa collapsed. The survivor suffered a broken leg. Anon 4 (1855) alludes to five persons killed in one "Maori hut". Mason (1855), referring to the same, notes only two people killed "by collapse of their whare", while the *Spectator* (Feb 21 1855) reports the deaths of four Maori. In Wellington, the *Spectator* (Feb 21 1855) also reports the death of "one old colonist, Baron Von Alzdorf, who was unable to get out of the way of a falling chimney". Henry Sewell is more specific; "the only life lost was that of poor baron Alzdorf, whose Hotel (where we were staying) is a ruin. He was standing by the chimney piece when the side of the wall fell in, carrying with it a looking glass, which broke, the pieces cutting him, dividing the femoral arteries. He died of exhaustion from bleeding. It is quite marvellous that there should have been no other life lost but his. They say that some Maoris in the Wairarapa were killed by the fall of a home: and one poor girl in ill health was terrified to death" (McIntyre 1980). This last casualty is not mentioned by any other available source. Trolove (1855) records that several Wellingtonians "have got their legs and arms broken", one of whom suffered a broken leg after a chimney fell on her. John Jolliffe, surgeon onboard the *Pandora* visited this woman in the Civil Hospital (Jolliffe 1855). Morton Jones records the fracture of the skull of one women and the arm of another, a soldier with some ribs broken, and noted the death of Baron Alsdorf, "who dangerously ill in bed, was struck by a portion of falling chimney" (Jones 1855). In Nelson the only casualty appears to have been the baby son of a Mr. A. McDonald of the Union Bank, who "while lying in his cot was slightly struck by some falling brickwork" (*Nelson Examiner* Jan 27 1855).

The small number of casualties can be related to building techniques (see section on 1855 Building types) and to the time of the mainshock, — "the hour, too, was favourable to the escape of adults, who seized the children from beneath tottering chimneys, themselves not generally retired to bed" (extracts from Drury's Remarks book in *Spectator* Feb 7 1855).

GROUND DEFORMATION

(a). Fissuring, liquefaction, landslides.

The 1855 earthquake caused severe ground disturbance in areas underlain by alluvial gravel and sediment (river valleys; coastal plains) and on adjacent hill sides in the form of fissuring, subsidence, lateral spreading, sand fountaining, and landslides. The area over which such damage was reported is about 135,000 square kilometres and the maximum area of most extensive ground damage appears to have been about 52,000 square kilometres (Fig.9). Reports of ground damage refer to Wellington and the Port Nicholson area, the Hutt Valley, Rimutaka Range, Tararua Range, Wairarapa Valley and coast, Hawke's Bay, the road from Wellington to the Manawatu, the Horowhenua - Manawatu area, Wanganui-Waitotara area, Mount Taranaki, Mount Tongariro, Mount Mangatautari, and the Napier area in the North Island, and the Wairau Valley, Awatere Valley and Kaikoura coast in the South Island.

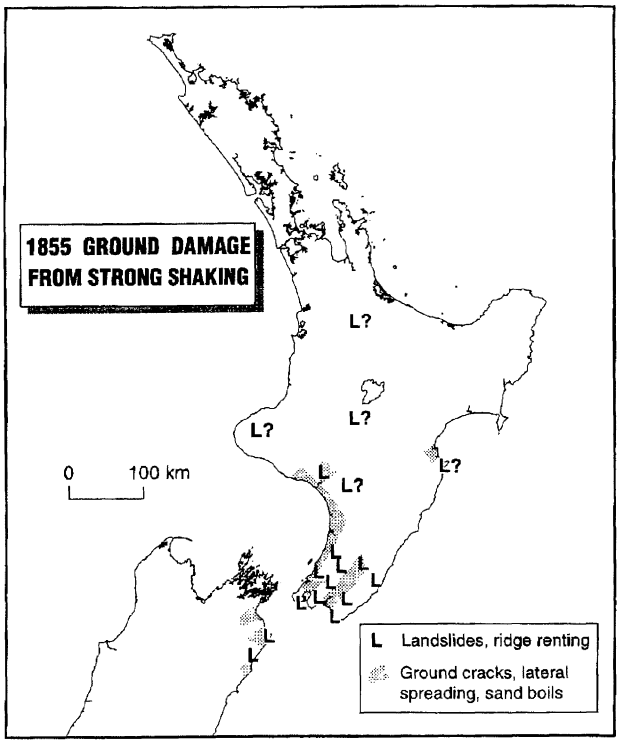


Fig.9. Map showing reported locations and areas throughout New Zealand of ground damage from strong shaking for the 1855 earthquake.

WELLINGTON

Ground deformation in the vicinity of Wellington (Fig.10) consisted of some fissuring and mud extrusion. "Large quantities of mud were ejected in parts of the City of Wellington ... more especially opposite the Union Bank in Willis Street" (*The New Zealand Magazine* 1862). A letter by Thomas Pilcher (1855) describes, "slate-coloured clay bubbling up [from fissures]- but only in the places that are swampy" and "at the corner of Willis and Manners streets on reclaimed ground a shallow fissure was made from which white mud issued and ran down Willis Street". The reminiscences of A. Blake (1909) make further mention of "numerous small muddy excrescences" that could be seen at "various places along the foreshore beyond low-water mark, which has now changed to high-water mark". Blake states that only one of these springs, that referred to above near the corner of Boulcott Street and Willis Street, "caused anxiety or trouble". He describes it as "of a pale bluish colour [that] oozed forth as though being forced by a pugmill, and slowly continued its course seaward. As repeated endeavours to gauge its depth had failed, it was at length stayed by placing a totara slab of very substantial dimensions over the outlet". This same fissure is also described by Jolliffe (1855) as "a large crack in the earth thirty yards (27m) long and from the upper end of it was issuing a quantity of thin grey or bluish mud and there is none like it anywhere in the vicinity. It must have come up from some considerable depth below. Some say it came up from about 30 feet (9m)". In his official memoranda on the earthquake, Edward Roberts (1855) considered the majority of the mud extrusions in Wellington as more of "a mechanical effect than anything else, the liquid mud pre-existed and been forced out at fissures formed during the vibration by superincumbent masses of more solid material". A letter from James McDowell (c1910) to the *Evening Post* relates information obtained from a Mr. John Valentine of Oriental Bay (then nearly 90 years old) about this prominent fissure which he describes as extending "from behind the Oriental Bank now the Albert Hotel, across Willis Street and through where the Duke of Edinburgh Hotel now stands, and on into the harbour as far as the eye could trace it. It was wide, and long planks had to be placed across". The fissure and mud extrusion referred to in the above abstracts appear to have originated near the intersection of a sediment-filled stream course and the Lambton Fault (Fig.10).

Yet another fissure is described by Blake (1909), "abreast of Government House" where Blake and a companion suddenly found themselves "sprawling in a crevice of about three feet (0.9m) wide and two feet (0.6m) deep, which had opened right across the road-way" (Fig.10). Another fissure of significant length in the Thorndon area (Fig.10) could be related to movement on the Wellington Fault (see section on Faulting).

In 1855 much of the Te Aro area of Wellington consisted of swamp through which a "deep boggy stream wound its sluggish way". The swamp extended inland for several kilometres (Fig.10) and was described as "a morass of flax, raupo and tussock grass ... impassable in winter, where horses and cattle sometimes perished miserably, and where the first surveyors, jumping from tussock to tussock, occasionally slipped, plunging into mud sometimes up to their armpits" (Ward 1928). An unsourced reference quoted by Ward (1928) states that "the earthquake ... disintegrated the swamp, and small islands of flax and toi-toi were floating about the harbour and interfering with the passage of small coasters in the vicinity". The "small islands" of flax and toi-toi may have been dislodged by the sudden rise in the water level of the harbour immediately following the first and greatest shock of the earthquake (see section of Tsunami and Seiche). Uplift of the area that occurred in 1855 (see section on Uplift and Subsidence) lowered the water table of the swamp and put a stop to plans to establish a canal and inland dock. It was not until 1863 that work commenced using prison labour to drain the swamp in order to create the Basin Reserve recreation ground (Ward 1928).

OTHER PARTS OF WELLINGTON HARBOUR

Allan Cameron (undated) living above the cliffs of Worser Bay near the entrance to Wellington Harbour, was kept awake by the noise of rocks crashing down nearby cliffs. He mentions that "a number of roads and tracks were blocked with rocks, slips and fallen trees along the cliffs facing the sea". James McDowell (c1910) recalls some 44 years after the earthquake the changes that occurred in the "wooded appearance" of the hills around the harbour with the hills being "split open ... and the front parts [falling] into the harbour".

The road from Wellington to the Hutt Valley was then, as it is today, a vital link between the two areas. The earthquake caused several landslides that in some places almost blocked the road (Smith 1855). R. Willray (*Spectator* Jan 27 1855) on his damage assessment trip to the Wairarapa, mentions "only one [landslide] of any size, and, that at present [the day after the earthquake] but a slight obstacle to the communication into the Hutt, a road now being rapidly pushed around its base". This reference to the only landslide "of any size" was noted by Sir Charles Lyell (1856b) during an interview with Edward Roberts in 1856 as "a land slip of about 3 acres (1.2 hectares)". The landslide covered the Wellington - Petone road 2.7 km NE from the Ngauranga Gorge entrance and is the subject of a sketch by Charles Gold (Fig.11).

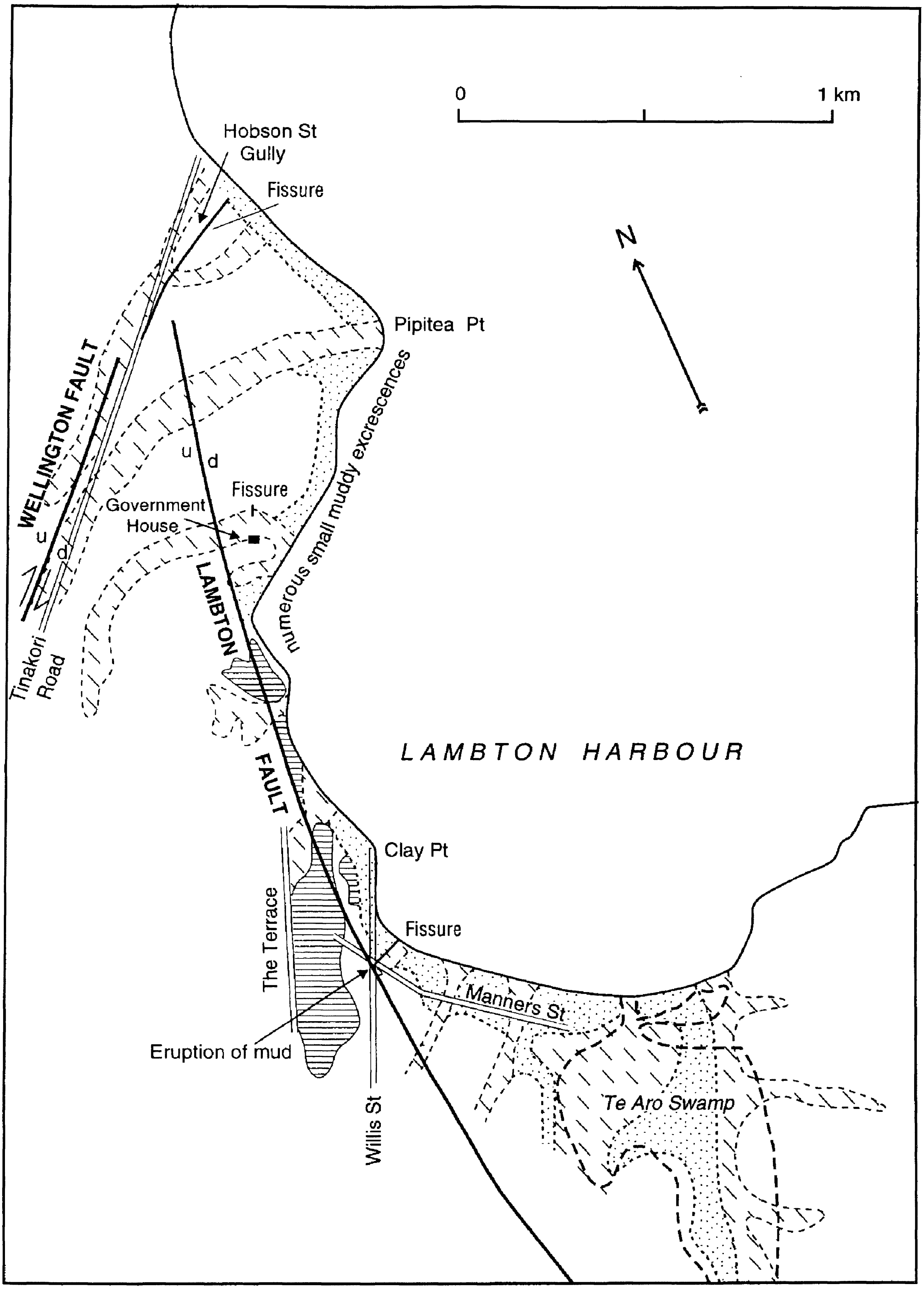


Fig.10. Map showing locations of reported 1855 ground damage in Wellington. Position of the Lambton Fault from Grant-Taylor et al. *(1974). Position of the mapped trace of the Wellington Fault after Ota* et al. *(1981), u and d refer to upthrown and downthrown sides respectively. Arrows on Wellington Fault indicate direction of horizontal movement. Subsurface sediment distribution and basement greywacke outcrops after Perrin & Campbell (1992); horizontal lined areas - greywacke basement; dotted areas - mainly beach and stream deposits; diagonal hatched areas - stream fill.*

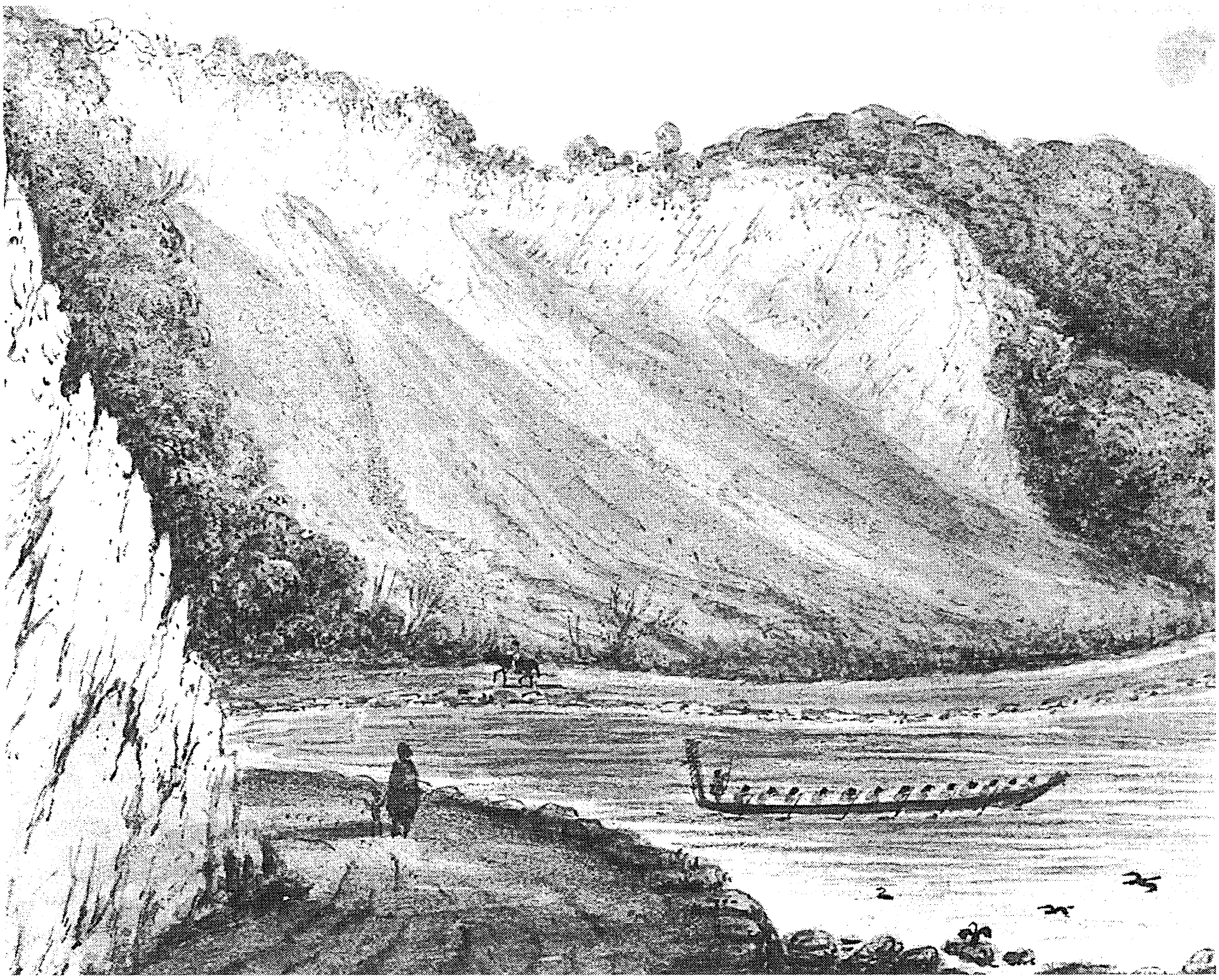


Fig.11. Sketch of an 1855 landslide that covered the Wellington - Petone road by C. E. Gold (see text). (Ref. No. F53309- 1/2, Alexander Turnbull Library, NLNZ.)

HUTT VALLEY

The Hutt Valley was particularly badly affected by the earthquake and suffered extensive ground damage, more so than at Wellington. Willray (*Spectator* Feb 3 1855) reports that the "visible effects of the shock on the roads and country in general presented stronger manifestations on entering the [Hutt] valley", and the "road, for seven miles (11.3km), that is, up to three miles (4.8km) the other side of Buck's Hotel [Taita], (Fig.7a), considerably injured; many of the smaller bridges gone at the lower gorges [Taita Gorge], several considerable landslips occur, impassable for carts; from this point, for thirteen miles (21km), as far as Hodder's [Pakuratahi], the roads are all right.... From the damage done to roads caused by the slips and falls of bridges, the communication, except on horseback or foot is completely cut off from the country" and "the fine bridge across the Hutt is completely smashed, the land on each side having sunk and let it bodily down and the road up the valley of the Hutt is rent into continued chasms".

Thomas Mason (1855), mentions that large fissures formed "mostly along the banks of the rivers and creeks: the roads were rent, and in some places large landslips came down from the hillsides" while in the lower part of the valley, Edward Roberts (1855) noted the presence of "numerous hillocks of sand [that] were thrown up, forming cones, varying from two (0.6m) to four feet (1.2m) in height, and in many parts of the valley large fissures were formed, with partial subsidences in many places". According to a Edward Withers (c. 1901), Mr. Henry Sanson (an old and respected settler of the Hutt), related that "a woman living near him rushed out at the first shock of the earthquake, but stopped at the door, remembering her baby in a back room. When she ran back with it, there was a chasm of some 50 or 60 feet [!] (15-18m) at her doorstep, which partially closed up and would have no doubt swallowed her if she had not stopped when she did". Another account of one of the fissures in the Hutt Valley is described by T. Bassett (1925). During the earthquake he, in the company of a 'servant girl', attempted to climb out a window to escape their quaking house but "on looking through [the window] ... found a great fissure had opened in the ground below it ... The crack in the ground was so wide that they were unable to cross it, so they followed it down the road towards the river [presumably the Hutt River]. While crossing the garden [he] fell into the crack some feet deep and was unable to get out. The girl went down and assisted him up and, lying full length on the ground, she was just able to reach his fingers and pull him up, smothered in mud".

RIMUTAKA HILL ROAD AND RIMUTAKA RANGE

By 1855 the road through the Hutt Valley had reached the summit of the Rimutaka Range linking with a bridle track on the

Wairarapa side. According to Judge Chapman (1847) the road ascending the Rimutakas was a narrow cutting with a one in twenty five gradient. Seven years later in 1854 Thomas Kempton described the road over the hill as a "dangerous bridle path with high rocks above and below with thousands of dead trees hanging down, a danger in windy weather". The Rimutaka road was almost completely destroyed by the earthquake, broken "away altogether in places and in other places the hills [coming] down and completely [blocking] the road which was difficult to find" (Kempton 1901) and was obstructed "with trees, clay and broken rock, all in the greatest confusion" (Masters 1871). Charles Bidwill, trying to return to his home at Pihautea in the lower part of the Wairarapa Valley from the Hutt the day after the earthquake, was forced to walk the whole distance, jumping the fissures, threading his way among the great landslides and cracks in the quaking hillside (Bidwill & Woodhouse 1927). A Mr Jackson going in the opposite direction, found that the "road was damaged more or less until [he] got to Drake's Elbow. Beyond that the road had clean slipped away for chains together, and [he] had to climb over the broken edges as best [he] could, and the stones kept rolling down. [He] was five hours getting to the saddle" (Iveson 1954).

A trip from Wellington to the Wairarapa to inspect the damage was made by R. E. Willray the day after the earthquake and his first-hand description of the state of the Rimutaka road was published in the *Spectator* (Feb 3 1855). From "Hodder's Hotel" at Pakuratahi in the upper part of the Hutt Valley, "... on the ascent up the Rimutaka gorges, for upwards of seven miles, the landslips and crevices are both numerous, dangerous, and almost impassable, even on foot. Barricades of the largest trees, stumps, and rocks, avalanches of earth, underwood, decayed trees, and boulders, bar your progress, and conceal your line of road, while loose logs and stones hang in threatening positions far above your head, so that a steady hand and cool head are necessary to carry you safely over the precipices that sweep down below you to the bottom of the valley; no sort of conveyance can pass; all horses are left at Hodder's Hotel". According to Thomas Kempton (1901) the road "was blocked for weeks before you could get a pack animal over it", although the Government soon "placed men upon the line to clear a good bridle path" (Masters 1871).

The official memorandum of Edward Roberts states that the Rimutaka Range as a whole "was very much shaken in its elevation, and a great many large slips occurred, laying bare the western side as well as on the eastern" (Roberts 1855). A similar observation was made by Commander Drury; "the lofty Rimutakas - as seen from Wellington - whose flanks, from the summits, are chequered with land slips" (*Spectator* Feb 24 1855) and recalled by James McDowell; "the high mountains behind Wainuiomata [Rimutaka Range] were split, the fronts falling, all the trees and bush being covered up, leaving an almost perpendicular face in many places and very ugly scarred and rugged faces. The writer remembers how ugly and desolate they looked 44 years ago [1866?]" (McDowell c. 1910).

Landslides were particularly severe in the southern part of the Rimutaka Range in the vicinity of Palliser Bay where, in the words of Alfred Matthews (1901; and also related in the memoirs of his son Charles Matthews (c.1925)), "Parts of the mountain range were torn to pieces, and big slips came down the sides of the mountain. The traces are apparent today as at the time of the visitation. Some of the slips were hundreds of feet long and many chains across ... Great rents, caused by the earthquake, are still visible on the mountain side". Several of these rents are very evident today on the slopes above the northwest corner of Palliser Bay, several being permanently water filled (Fig.12). The rents are continuous with a prominent zone of faulting extending to the NW (Fig.12). In 1901, McKay (1901) described the "vast landslips" that had occurred in 1855 on both sides of the Rimutaka Range, and considered that they were much greater on the western slope (Orongorongo River side) than on the eastern side, "The slips have come down from the highest points, and the uppermost part of most of the slips must be at least 2,600ft.(792m) above the sea. In all, there must be thousands of acres, for they descend to the river-bottom in most cases at a height of only 500ft. (152m) above the sea". Similarly, Heaphy (1879) asserts that, "the landslips on the Orongo Range, to the eastward of Port Nicholson, were not existing in 1839; they are said, and I believe correctly, to have been caused by the great earthquake in 1848 [it was in fact 1855].... There were no such slips anywhere about Port Nicholson in 1839". The catastrophic effect of the earthquake on the vegetation covered western slopes of the Rimutaka Range, with particular reference to Green's Stream that drains into the Orongorongo River, was studied by Robbins (1958). Robbins describes extensive slips, some 20m in length and 10m wide that expose shattered greywacke fault pug and brecciated rock, with long and wide screes or fans and clay beneath the slip scarp.

WAIRARAPA VALLEY AND COAST

William Bennett, a civil engineer, described the extensive fissuring that occurred all over the Wairarapa Plain, "the ground having opened in many places 8 or 9 feet (2.4 or 2.7m), and sunk in one place for 300 yards (274m) equal to a depth of 8 or 9 feet. The cracks are very frequent, and at first were of a considerable depth (deemed unfathomable, because people could not see their depth), perhaps 15 or 20 feet (4.6 or 6.1m) in depth, and extending for many hundreds of yards. Ploughed ground and mud, dry river or pond-beds were thrown up into all sorts of undulations like a short choppy sea, the ridges in some cases 2 feet (0.6m) in height, the prevailing direction of cracks and ridges being generally at right angles to the apparent line of force, NE-SW" (Mallet 1858).

Eight years after the earthquake (March 1863), the Opaki Plain, north of Masterton, was observed by the Wellington Provincial geologist, James Crawford, and described as, "severely fissured with numerous landslides on adjoining hills to the east" (Crawford 1870). At Kopuaranga, in the northern part of the Opaki (or Pairau) Plain, Vennell (1891) records that a "mountain (Bruce's Hill) near Masterton was literally rent in twain, and remains to be seen to this day". This same locality was described and sketched by Crawford (1870), as "a Tertiary hill having been split in two, the western part having slipped down towards the river bed [Ruamahanga River]", (Fig.13). In 1866, the area of the landslide was purchased by Alexander Bruce and is shown on the Survey Office Plan (1866, S.O.10799) where a high, steep scarp with a small hill in front of it are separated by an "earthquake rent". Charles Bannister (1940) relates information given by Hamura Paora concerning the landslide caused by the earthquake that " split Bruce's Hill asunder, one half going into the river, blocking it up and causing a large lake". This blocking of the river [Ruamahanga] caused it to go dry and a large flood occurred when the river broke through the landslide barrier. However, Bannister places the landslide event at about 1838 and not 1855, based on his informant's age and the date of occupation of Te Ore

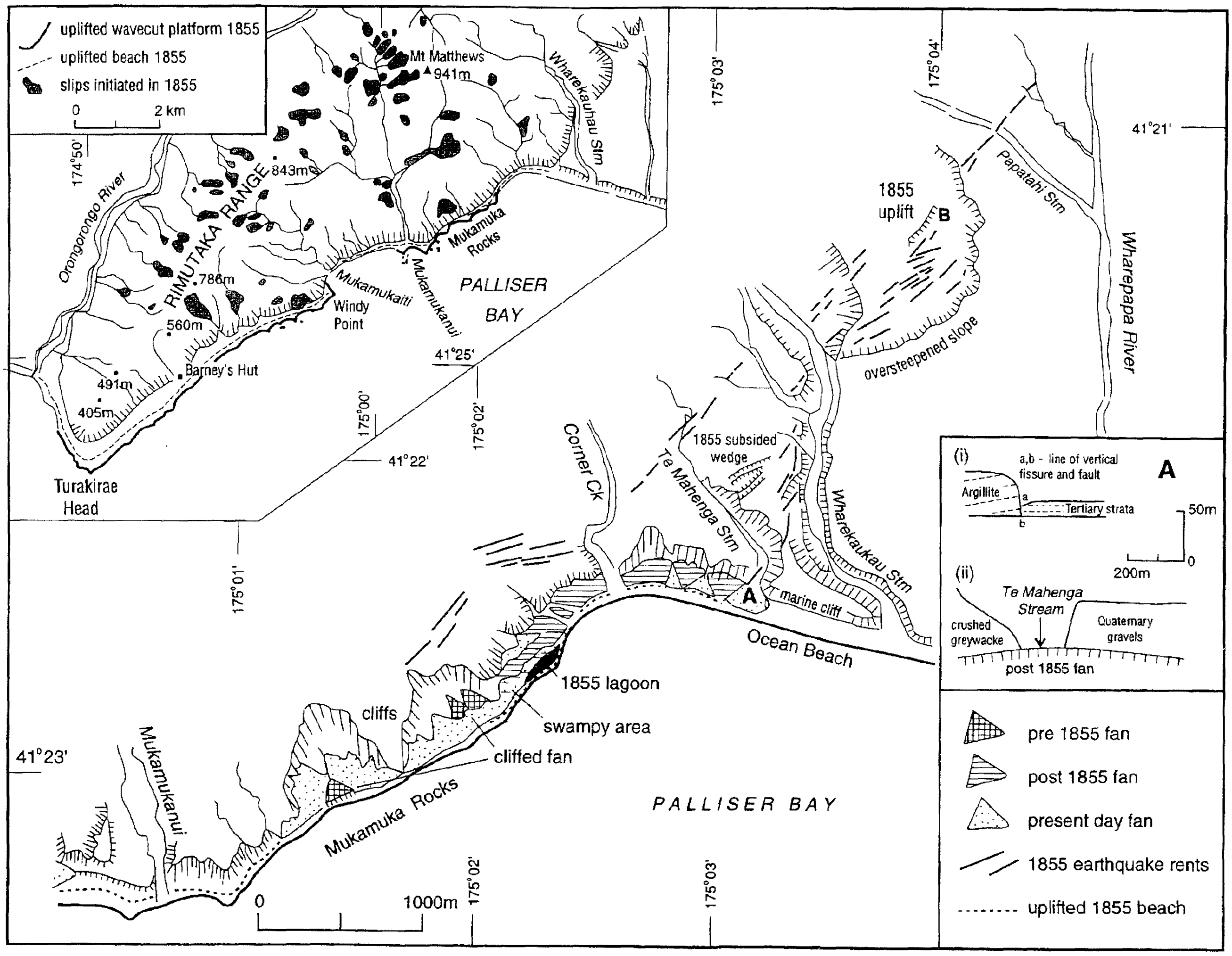


Fig.12. Maps showing extent of 1855 landslips and rents in the southern Rimutaka Range - NW Palliser Bay area. (A) Junction between greywacke and Pleistocene sediments at Te Mahenga Stream; (i) - explanatory diagram after Lyell (1868) and, (ii) - as the locality appears today.

Ore station by Richard Collins in 1849-50. This is at variance with the information given by Crawford (1870) and Vennell (1891) suggesting that Bannister's account may be a confusion between the 1855 landslide and an earlier, possibly earthquake-triggered event. The Survey Office plan on which the "earthquake rent" is featured, shows that the course of the Ruamahanga River was further to the east just north of the landslide than at any time since, and that the river swung further towards the true right bank just downstream from the landslide than is shown on the first aerial photographs of the area taken in 1943. The position of the river in 1866 just downstream from the landslide lends support to the temporary damming of the river which eventually broke through the lowest part of the slip, i.e. on the true right side of its course. The geology and revegetation history of the landslide at Kopuaranga is described by Grapes (1988). The landslide is roughly circular in plan with an area of about half a square kilometre, and consists of a number of rotated blocks containing two lakes below a single primary failure plane that forms a curved crown scarp 100m above the present day flood plain of the Ruamahanga River (Fig.14).

At Waihakeke, near the confluence of the Waiohine and Ruamahanga rivers, Anon 4 (1855) describes that the area, "for many square miles, is rent in every direction: cracks in the ground of many feet in length, and from a few inches to several feet deep, exist over very large spaces, at short intervals from each other; our horse track to the river, which is about half a mile off, has more than twenty such across it, twelve of which opened and shut with violence during the shock, and threw water to a considerable height over the surrounding bushes. I saw the water, cracks, sand and mud, which were thrown up, the morning after, and glad I was that no fissure had opened nearer to our house than 200 yards (183m), or it must have come down on us". Further south, Vennell (1891), recalls that the Moroa (stony) Plain between Greytown and the Tauwharenikau River, "was rent for several miles, one part subsiding about two feet" and that the road, "being of made ground, sank nearly three feet where the ground opened, leaving one part so much higher than the other."

In the lower part of the Wairarapa Valley at Pihautea, at the homestead of Charles Bidwill near the Ruamahanga River, "fissures in the ground were sometimes three or four feet in width and Mrs. Bidwill walked about examining these cracks but was unable to reach the bottom of them with the longest flax stick" (Bidwill & Woodhouse 1927).

Along the south and east Palliser Bay coast, rockfalls occurred at Kiriwai on the south-western shore of Lake Onoke where a cave used to store wool prior to it being shipped to Wellington collapsed (Matthews 1901; Iveson 1954) and from the mudstone

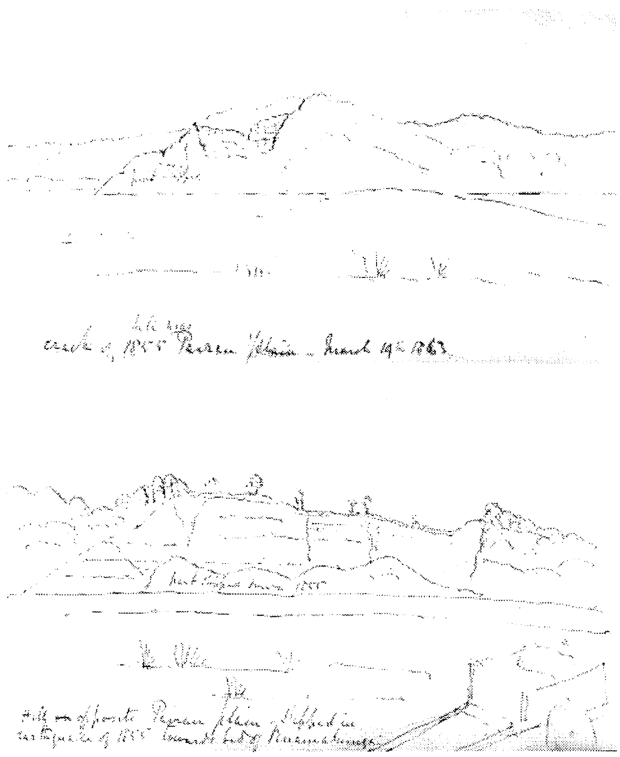


Fig.13. Sketches by J. C. Crawford in March 1863 of the landslide at Kopuaranga, Wairarapa. a. Landslide viewed from the south; b. sketch of the landslide scarp looking east across the Ruamahanga River. (Ref. Nos. (a) F147860-$^1/_2$, (b) F-147529-$^1/_2$, Alexander Turnbull Library, NLNZ)

cliffs to the east of Lake Onoke at Whatarangi (Fig.15a). Landslides shown in the November 1855 William Mein Smith sketch of J. P. Russell's station, *Kawakawa*, on the eastern side of Palliser Bay (Fig.15b) may have been caused by the earthquake. Along the east Wairarapa coast, Thomas Mason (1855) records that "heavy landslips and large fissures are to be seen". At *Orui*, on the east Wairarapa coast, not far south of Castlepoint, Edwin Meredith (1898) found that the main range running north and south through his run', "was rift open by a crevice or crack running along the apex of the ridge for several miles and rent open into deep fissures at a point where the range turns at an abrupt angle". This most probably represents ridge-renting, a topographic effect.

HAWKE'S BAY

The notebook of Henry Hill (c.1904) containing records of meetings with the Reverend William Colenso from 1897-1900 refers to the effects of the 1855 earthquake, "In Hawke's Bay, Mr. Colenso said that the Kidnappers underwent a great shaking and the deep canyon-like openings appeared as a result of the shake ". Hill later elaborated on these effects in an article on artesian wells (Hill 1888), where he states that, "It was during this earthquake that the Kidnapper conglomerates were riven and torn in many places. These rifts may still be seen, and they can be distinguished by an observer standing on the Napier hills by the circumstance of the conglomerate falling in sections towards the north-west, and by the greater slope of the north-east side of each rift than of the south-east side".

A letter from William Colenso (1855) written soon after the earthquake (February 23) to Joseph Hooker at Kew in England,

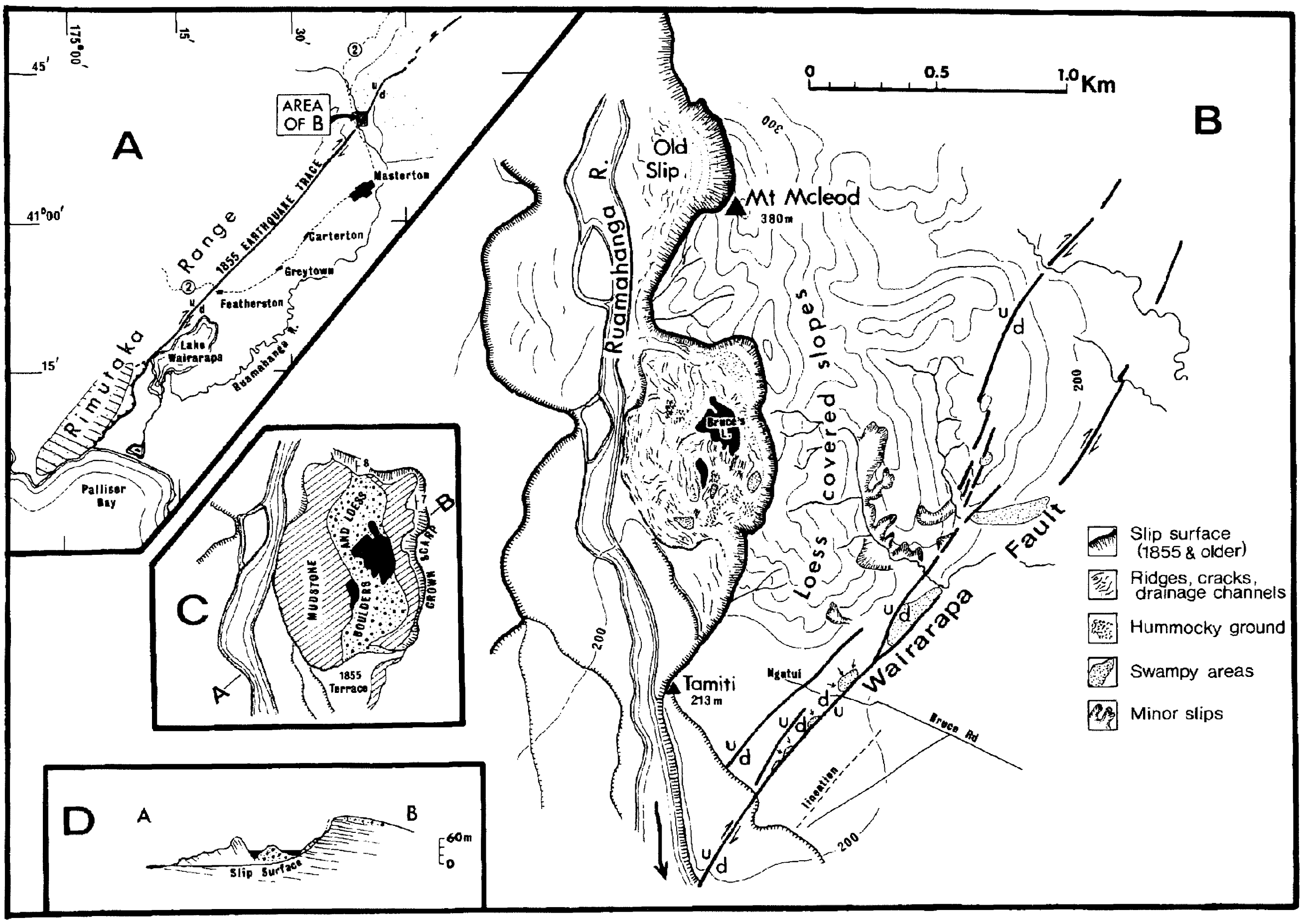


Fig.14. Maps and cross section of the 1855 landslide into the Ruamahanga River, Kopuaranga, Wairarapa (after Grapes 1988).

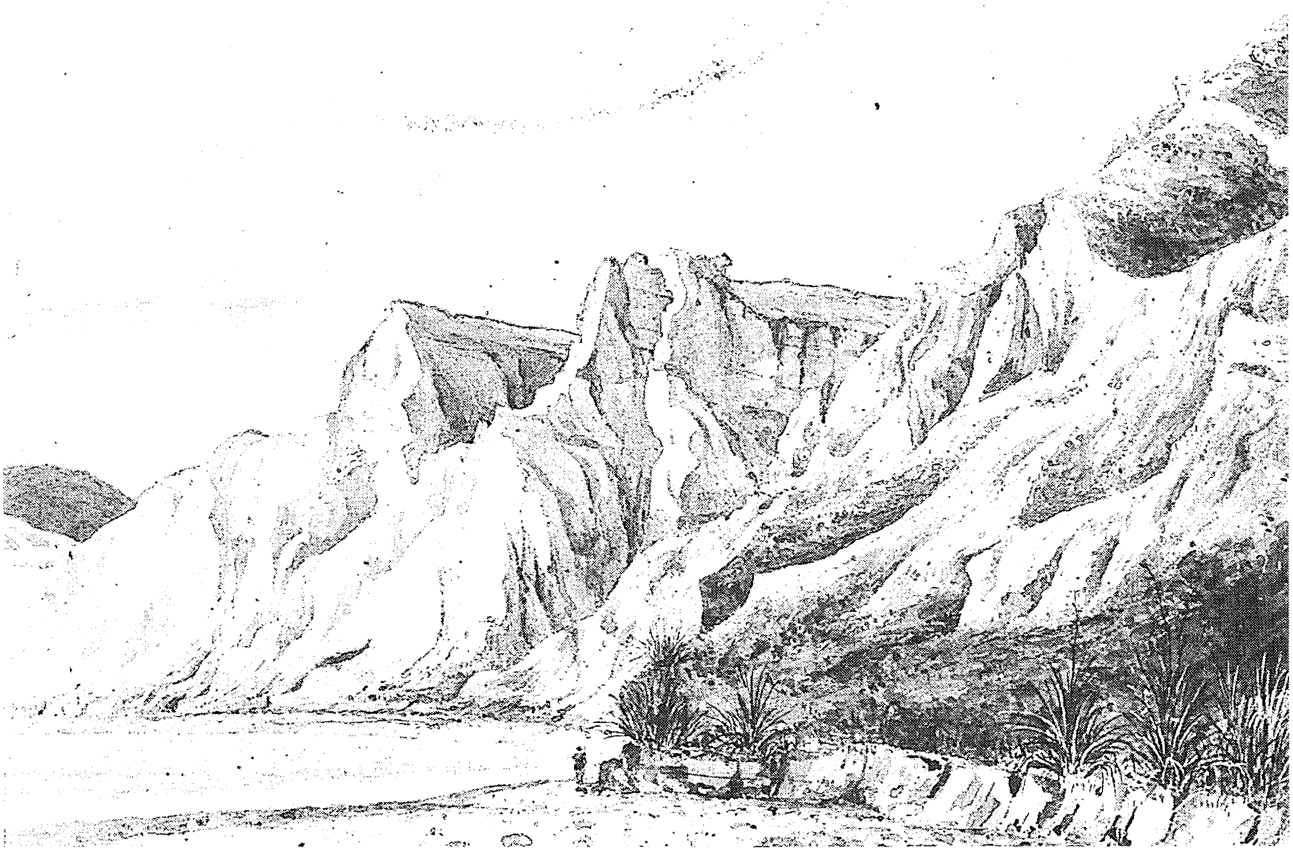
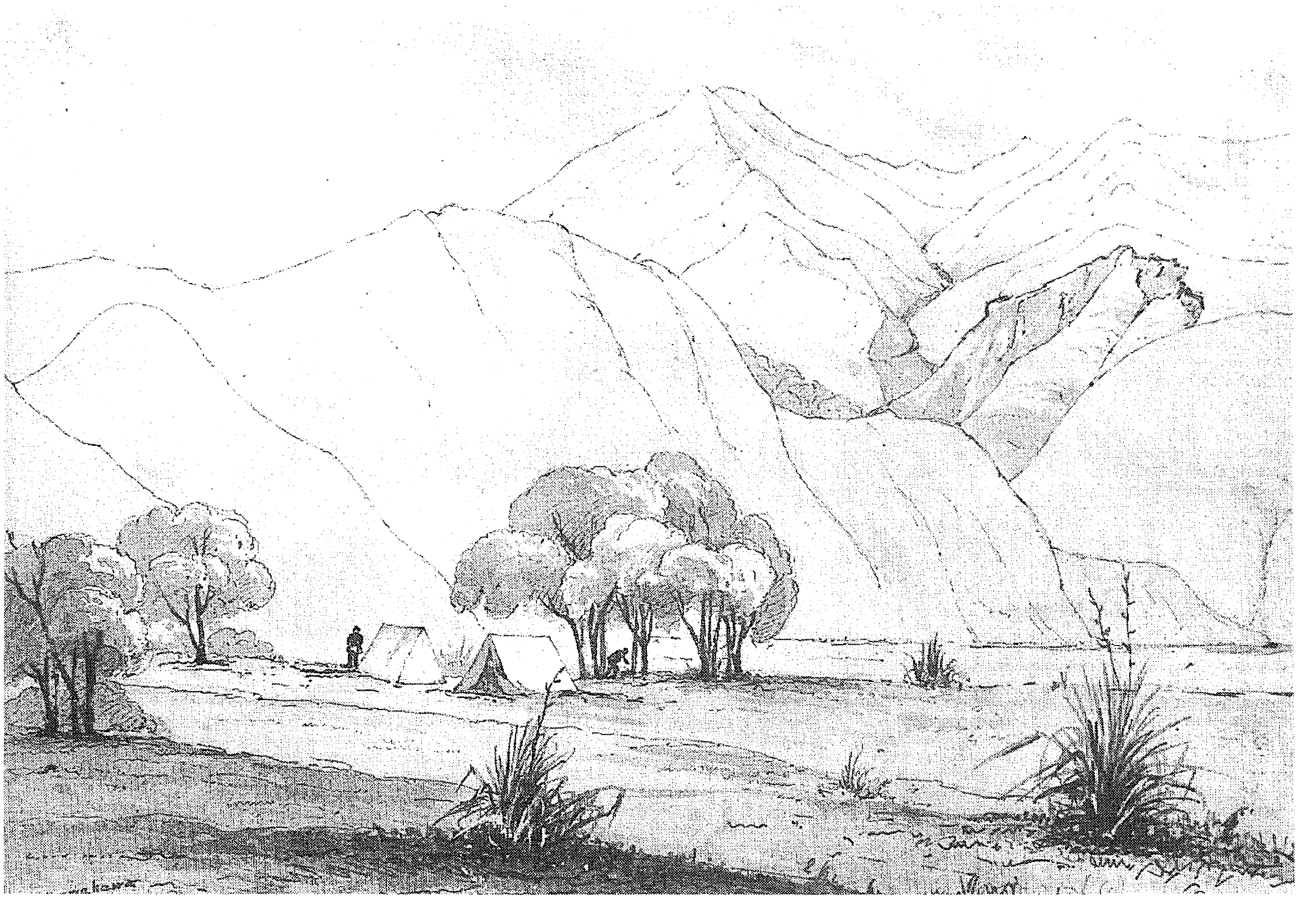


Fig.15. a. Sketch of the badly eroding mudstone cliffs between Whatarangi and Te Kopi, eastern side of Palliser Bay, from which landslips occurred in 1855 (William Mein Smith, date unknown, but possibly November 1855. Ref. No. F42990-1/2, Alexander Turnbull Library, NLNZ). b. Sketch of J. P. Russells station "Kawakawa", east Palliser Bay coast showing possible 1855 landslide scars (William Mein Smith, November 1855. Ref. No. F53347-1/2, Alexander Turnbull Library, NLNZ). The location of "Kawakawa" shown in Fig. 5.



makes no mention of any ground deformation although Hill (1888) records that "the ground showed a rift 10 in. to 12 in. wide, running north-west and south-east across the plain" [presumably the Heretaunga Plain]. Hill also mentions that "disturbances were also noticed at Pakipaki and the land in some places raised several feet in height." What these "disturbances" were is not stated, but it is interesting to note that fissuring is also recorded to have occurred at Pakipaki during a later earthquake in 1863 (Downes unpubl. data) and it is possible that Hill could have confused at least some of the effects of the two earthquakes. The fissure running across the Heretaunga Plain mentioned by Hill is in the opposite direction to the trend of active faults in the area which strike NE-SW, so that it must have been a superficial product of the shaking in alluvial sediments. However, the fissure appears to have been a notable feature that apparently extended for a considerable distance.

THE ROAD FROM WELLINGTON TO MANAWATU

The *Spectator* (Jan 27 1855) reports a "heavy land slip that covered the coast road near Wainui [just north of Paekakariki]" and Commander Drury (*Spectator* Feb 7 1855) was "informed that the Porirua road is sunk in places". The *Taranaki Herald* (Feb 14 1855) reports that "in the road between Wanganui and Wellington there were cracks eight feet (2.4m) wide rendering it impassable, and in other places where the ground had been quite dry the water was for miles two feet (0.6m) deep". The surface water could have been the result of inundation by the tsunami that accompanied the earthquake (see section on Tsunami and Seiche). The *Taranaki Herald* report was later criticised in the *Wellington Independent* (Feb 28 1855), "We have conversed with persons who travelled from Wellington to Wanganui and back again, immediately after the earthquake on the 23rd January, and who solemnly declare that they never saw anything of the kind. The mail has always been received regularly, and we have never heard before of the road being impassable" (but see Historical Background section).

MANAWATU DISTRICT

Extensive ground cracking and liquefaction occurred throughout the Manawatu Plain. In comparison with the Hutt Valley the "plains of the Manawatu" were affected "to a much greater degree" (Roberts 1855). According to Buick (1903), "huge gulches were torn in hillsides, and long fissures were opened on the flats, in some cases a few inches and in others a few feet wide, which today may be traced as blind watercourses with no entrance and no outlet. Many of these gaping holes were seen upon a few cleared spaces, others were well within the bush and not discovered for many years afterwards". This account lends support to the *Taranaki Herald* claim that the Manawatu-Wellington road was deeply fissured.

At the mouth of the Rangitikei River, "the ground was extensively and very deeply fissured, and that a sulphurous smell was distinctly perceptible" (Field 1891), and on his return from England in 1856, Reverend Richard Taylor found "several deep fissures still remaining" at Rangitikei (Taylor 1856). Between the Rangitikei and Turakina Rivers several lakes were drained (Burnett 1904). While travelling down the Manawatu River in 1863, James Coutts Crawford "was informed that at a place called Ekipi, the cliff being thrown down by the earthquake of the year 1855, had blocked up the river for two days, during which time a lake had formed and the river became dry below" (Crawford 1880). The location of Ekipi has not been identified.

At Waikawa, Thomas Bevan found the sand hills "cracked in all directions" and that a lagoon (Adkin (1948) asserts that it was the Manga-Pirau Lagoon) situated a little south of the former mouth of the Waikawa River, was drained because of cracking of the underlying iron pan so that "all that remained of it were hundreds of eels, high and dry, where the beautiful expanse of water had been only a few hours before" (Bevan 1905). Some 5km to the south at Otaki, Reverend Stock (1855) observed after he had travelled the district on January 25, that "the ground is rent in every direction" and that in "one place the cracks reached to water, which seems to have boiled up". He was also informed, "that our river's [Otaki] bed had opened, and for some time the river was dried up: but I do not quite believe this, as the Maoris almost always exaggerate". However, it is possible that a landslide in the hills behind Otaki dammed the river for a short time.

WANGANUI AND WAITOTARA

The Reverend Richard Taylor (1856) describes the effects of the earthquake at Wanganui where "in various places parts of the ground opened, so that some places appeared as though they had been ploughed up in furrows [cf. Bennett's 1858 description of the Wairarapa in Mallet (1858)]; large quantities of gas and water were ejected from many circular apertures, around which, mounds several yards high were formed; the ground so intersected with deep ravines, as actually to stop all travelling for a time". After returning to Wanganui in October 1856, Taylor "was surprised to find how the features of the country had changed since the great earthquake. Many of the lakes being quite dried up", again caused by the cracking of the iron pans underlying them (Taylor 1856).

W. W. Bates (Allen 1904) who was living at Wanganui at the time of the earthquake, recalls that, "on the morning after the great shakes, the features of some parts of the river's [Wanganui River] bank were completely altered. The beach immediately opposite my own door I could hardly recognise, crack after crack appearing. And in one place particularly the effects were visible, one portion of the bank having been elevated, or the whole bed of the river having sunk five or six feet (1.5 or 1.8m). A portion of Shakespeare Cliff came down" (Figs. 6, 16). According to Field (in Burnett 1904), "the whole foreshore of the river from Taupo Quay (Fig.16) to low-water mark looked like an ill-ploughed field, there being cracks parallel with the water at every few inches, while the whole had evidently slipped outwards." Extracts of a letter published in the *Spectator* (Jan 31 1855) refer also to the foreshore, suggesting that the intervening high tide may have "helped fill up the fissures made" but "still presenting an ugly appearance". The article goes on to say that "Taylor and Watt's wharf is a wreck nearly, warped and bent up and down all along, and the extreme end sunk obliquely". About 8 km upstream at Aramoho Pah (Fig.16) near a place called Sutherland's Flat, "two cracks about 20 ft (6m) apart, had opened from the river into the flat, and the space between them had sunk down several feet" (Burnett 1904). A slightly different version (Field 1891) states "two cracks, fully 100 yards (90m) long, and from 30ft (9m) to 50ft (15m) asunder, extended from the river bank into the flat, and the interval between them had sunk down fully 6ft (1.8m), so that at high water boats could be taken into the flat". Field also considered that "a certain amount of good was done by the shock in draining swamps. These had been formed by layers of ironsand becoming rusted together and forming a pan, which prevented the surface-water from soaking downwards. The shock cracked these pans, and enabled the water to escape". Another, very similar

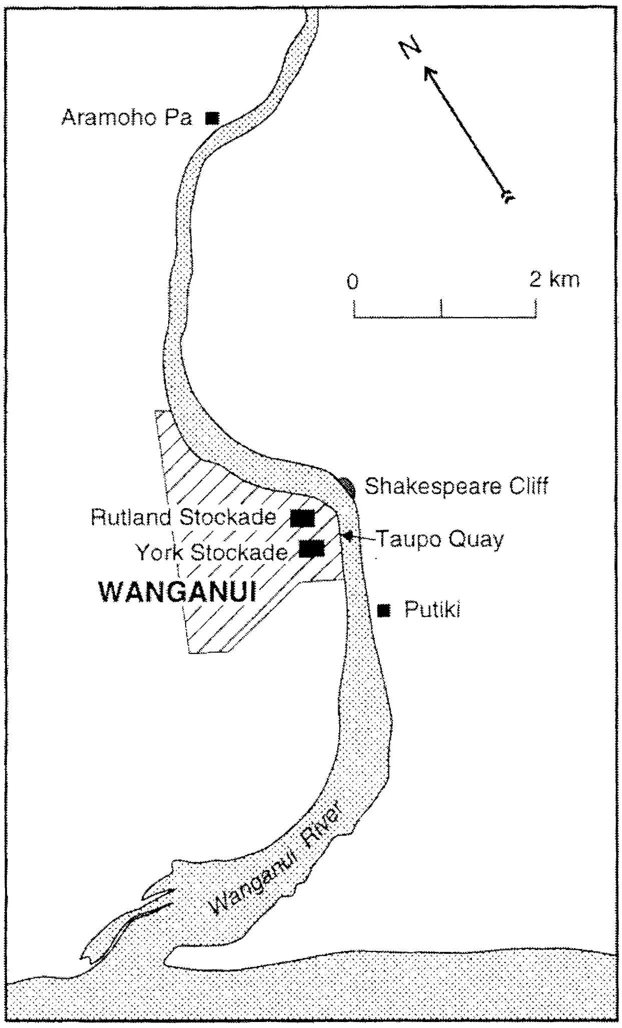


Fig.16. Sketch map of the Wanganui River area showing locations of 1855 earthquake damage mentioned in the text.

account from the scrapbook of J. J. Burnett (1904) records that "at Alma Farm, beyond the racecourse [at Wanganui], there was a deep swamp, caused by a seam of ironsand, which being rusted together, formed a pan. This pan was cracked by the shock, and the water sank down and disappeared".

Further up the coast at Waitotara, Field (1891) found that, "the ground was cracked in all directions, and that on the alluvial flat just in front of Rev. Stannard's house there was a crack fully 50 yards (46m) long, through which sand and water had been thrown up from a depth of 15ft or 20ft (4.6 or 6.1m) and scattered on the surface to a width of about 20ft (6.1m), and to a depth of several inches". Where the track to Wanganui crossed the Waitotara River, "the ground was cracked in all directions, and as the slight shocks passed along, the cracks could be seen to open and close". At the coast, "the whole face of the cliff [was] thrown down, and that further small slips were constantly occurring [with aftershocks]. An isolated mass of shell-rock, called "Te Ihonga", similar to the Pulpit Rock at the Isle of Wight, which had stood at the top of the cliff for ages ... has been thrown down and dashed to pieces".

MOUNT TARANAKI

Residents of New Plymouth "at some distance to the south ... heard explosions like the discharge of heavy artillery" that may have been caused by slips from Mount Taranaki (Porter 1989) as according to a C. W. Richmond, many New Plymouth settlers thought the earthquake had altered the shape of the mountain (Richmond 1855).

MOUNT TONGARIRO

In a report on his field trip in the central North Island, Hochstetter records that "... the shape of the cone [part of Mount Tongariro] is changing; the western side, for instance, having fallen in at the last earthquakes" (Hochstetter 1859). It is presumed he is referring to 1855.

MAUNGATAUTARI (SOUTH OF CAMBRIDGE)

At Maungatautari (a residual volcanic edifice 2616m high), the *Maori Messenger* (March 1855) reports that "a portion of the mountain of Maungatautari had been cleft asunder, and carried to the stream of Mangahoe, blocking up the source of that river". A loud noise was heard at the time. "When the shaking of the earth had ceased, a great noise was heard from the earth like the report of great guns. The natives supposed that some of the people were fighting; but the minds of the Ngatihaua were not certain on this point, as the noise was similar to that of thunder."

WAIRAU AND AWATERE VALLEYS

Extensive fissuring and liquefaction occurred in the Wairau and Awatere valleys in Marlborough. The *Nelson Examiner* (Jan 31 1855) reported that "intelligence has been received from the Wairau, and we find that the shock of the 23rd was felt very severely at the lower end of the valley ... but ascending the valley, the shocks became less severe as the distance from the sea increased", and that the ground was cracked with "sand and mud thrown up there in places". Hochstetter (1864) relates the observations made by Dr. Julius von Haast in 1859, that "in the Wairau Valley ... near the river bed, numerous systems of earthquake fissures can be observed, which always trend parallel to the course of the river and are intersected at various angles by abrupt bends in the river" and Thomson (1859) records that "several fissures in the earth, four feet (1.2m) deep, and sufficient to admit a man, yawned".

According to Hochstetter (1867), in the Awatere Valley, "the soil received large fissures and crevices. One such fissure was traced full forty miles (64km), and as late as 1859 my friend Dr. Haast found some of these fissures three feet (0.9m) wide and several feet deep". The 40 mile (64km)-long fissure mentioned by Hochstetter was probably formed along the line of the Awatere Fault. It is also reported by the Atkinsons of Burtergill Station in the lower Awatere Valley (Woodhouse 1940), but whether it was the one remaining from the 1848 earthquake or a reopening of the Awatere Fault in 1855 is a moot point (see section on Faulting).

KAIKOURA COAST

A few days after the first great shock the coastal section from Kekerengu to Woodbank was traversed by Trolove (1855). Between Kekerengu and "The Flags" he found "the hills are very much shaken and split" and, between Kekerengu and Woodbank, "the overhanging hills along the beach are now bare of vegetation as can be well imagined owing to the slips". At Kekerengu itself, Trolove, after several strong aftershocks during the night of January 25/26, checked to see "whether the hill [behind the house] had slipped any more". Hochstetter (1867) mentions that, "near Cape Campbell parts of the mountain fell exposing white rocks" , and further south along the coast, Lyell (1856b) states that, "in a place called "The Flags", between Cape Campbell and Waipepo [Waipapa], on the second day after the first earthquake of the 23rd

January, several men employed to load logs on a ship distinctly saw an earthquake approaching them from a point called White Rocks, situated 3 miles (4.8km) northward. It approached them in a NW-SE direction, and was made visible by stones rolling from the top of the cliffs, by landslides, clouds of dust and a sea wave". At Flaxbourne Lake (now Lake Elterwater) Monro (1855), in March, observed that "in many places the ground is very much cracked and the sides of the hills have slipped".

(b). Uplift and Subsidence

The 1855 earthquake was accompanied by the sudden uplift of some 5000 square kilometres of the south western part of the North Island and subsidence of the coastal area of the Wairau Valley, Marlborough. Uplift is recorded to have occurred westwards from the south western side of Palliser Bay to as far north as Wanganui and extending to nil uplift on the west coast of the North Island, just north of Paekakariki. Several reports mention that a small amount of uplift occurred on the eastern side of Lake Wairarapa, and along the east Wairarapa coast as far north as Castle Point. Another account reports that the east Wairarapa coast and the eastern side of Palliser Bay subsided. Evidence of uplift or subsidence as a result of the earthquake was provided by elevation changes with respect to sea level (mean low tide springs), and in the case of Lake Wairarapa, to normal lake level. Subsequent investigations of uplift are based on emergence height of the uplifted 1855 beach with respect to the crest of the present day forming beach or to mean sea level and the elevation height of rock platforms above mean sea level. In areas susceptible to settlement due to strong shaking as well as tectonic deformation it is difficult to determine the contribution due to each effect. In such areas the observed tectonic uplift can only be a minimum as in the Hutt Valley, for example, and the observed tectonic subsidence, or settlement due to shaking, a maximum, as in, for example, the Wairau Valley.

The best known and most reliable evidence for uplift and subsidence as a result of the 1855 earthquake is that reported by Edward Roberts of the Royal Engineers (Roberts 1855);

> "A tract of land of 4,600 square miles (11,914 square kilometres) in extent was elevated to a height varying from one to nine feet (0.3 to 2.7m), the greatest elevation being a range of hills called the Rimutaka (a spur from the Tararua mountains), which terminates abruptly at the sea coast in Cook's Straits. This range, which appears to have been in the direct line of the subterranean action, was elevated nine feet (2.7m), while the whole country as far as Wai-nui, about two miles (3.2km) northward of the foot of the road leading down the Pari-pari [near Paekakariki], was elevated with it, though the elevation at the last named point was on the sea coast very slight....
>
> The valley of the Wai-rau, on the middle island (which appears to have formed part of a continuous basin with the Wairarapa), together with parts of the adjoining coast, subsided, during the shock, about five feet (1.5m); so that now the tide flows eight miles (13km) further into the Wairau river than it formerly did. The harbour of Port Nicholson, together with the valley of the Hutt, is elevated from four to five feet (1.2 to 1.5m), the greater elevation being on the eastern side of the harbour, and the lesser on the western. A rock, known as the "Ballet Rock," a short distance from one of the points of Evans's Bay, which was formerly two feet (0.6m) under water at the lowest tides, and over which was placed a buoy to mark its position, is now nearly three feet (0.9) above the surface at low water. Very little tide now enters the Hutt river, in consequence of the elevation. Large portions of land can be easily reclaimed from the harbour for the extension of the town."

This evidence, including further details, was given by Sir Charles Lyell in 'The Proceedings of the Royal Institution' (Lyell 1856a) and in the 'Bulletin of the Geological Society of France' (Lyell 1856b) based on information given to him in person by Edward Roberts on his return to England from New Zealand following the earthquake, and by Walter Mantell and Frederick Weld who were also eyewitnesses to the earthquake and were in London at the same time as Edward Roberts (Fig.17a,b).

> "The shocks of this convulsion extended over an area of land and sea three times as large as the British Isles: after it had ceased, it was found that a tract of land, in the immediate vicinity of Wellington, comprising 4600 square miles (11,914 square kilometres), or nearly equal to Yorkshire in dimensions, had been upraised from one to nine feet (0.3 to 2.7m), and a range of hills, consisting of older rocks, uplifted vertically, while the tertiary plains to the east of it remained unmoved: so that a precipice, nine feet (2.7m) in perpendicular height was produced, and is even said to be traceable for 90 miles (145km) inland, from north to south bordering the plain of the Wairarapa [see section on faulting]. In consequence of a rise of five feet (1.5m) of the land on the north side of Cook Strait, near Wellington and Port Nicholson, the tide had been almost excluded from the river Hutt, while on the south side of the same straits on the Middle Island, where the ground had sunk about five feet (1.5m), the tide now flows several miles further up the Wairau than before the earthquake.
>
> ... These [memoranda] were furnished by Mr. Edward Roberts, of the Royal Engineers Department, who has since (March 1856), on his return to London, communicated other particulars to Sir C. Lyell. Mr. Walter Mantell, also now in London, and who was in Wellington (New Zealand) during the shocks of last year, besides confirming the statements of Mr. Roberts, has supplied valuable information respecting the geological structure of the country upraised or depressed during the catastrophe. The upheaval around Wellington was only from a half to four feet (0.15 to 1.2m), but went on increasing gradually to Muka Muka Point, 12 miles (19.3km) distant, in a direct line to the south-east, where it reached its maximum, amounting to nine feet (2.7m), and beyond, or eastwards of which, there was no movement. Mr. Roberts was enabled to make these measurements with accuracy as a white zone of rock, covered with nullipores just below the low tide, was upraised...
>
> Among other proofs of subsidence experienced on the opposite side of Cook's Straits, or in the northern part of the Middle Island, contemporaneously with the upheaval above mentioned, Mr. Roberts states, that settlers have now to go three miles (4.8km) further up the river Wairau to obtain supplies of fresh water, than they did before the earthquake of January 1855." Lyell (1856a).

Lyell's later account (in French) was read by Mr. de Verneuill before the Geological Society of France in 1856 (Lyell 1856b).

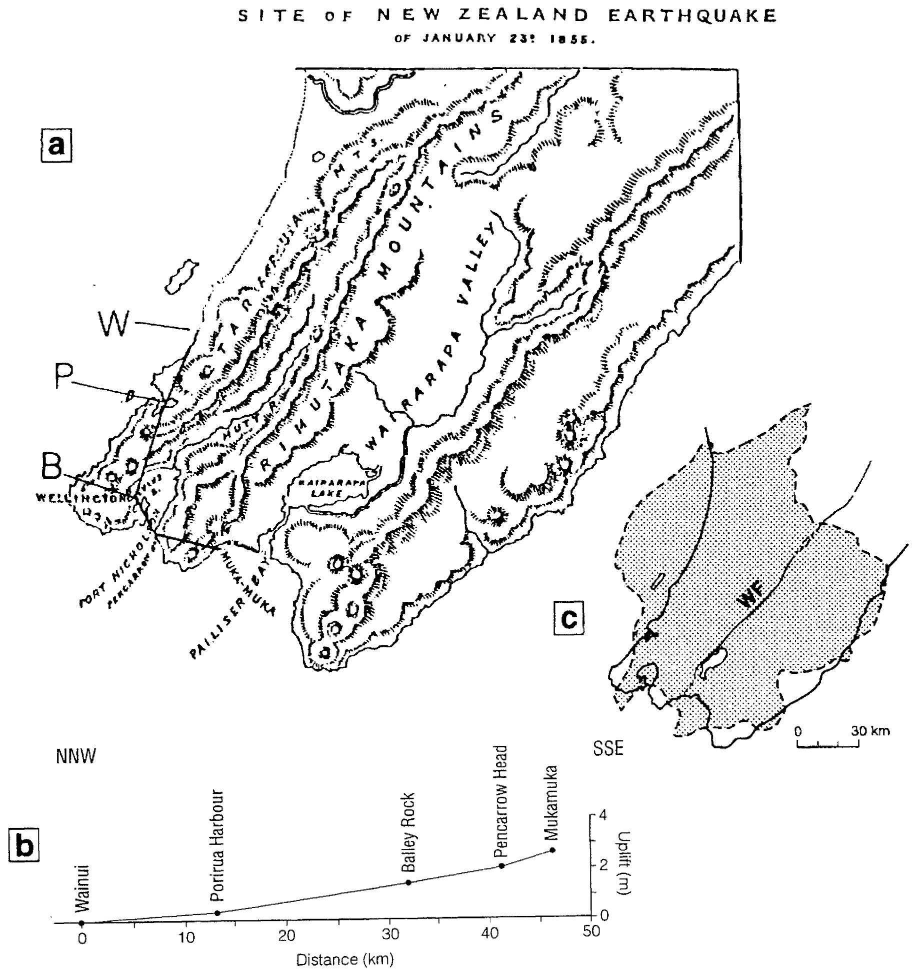


Fig.17. a. Locations where 1855 earthquake uplift was recorded in the accounts of Roberts (1855) and Sir Charles Lyell (1856a,b; 1868), W = Wainui; P = Porirua; B = Balley Rock (map after Lyell 1868). b. Plot of uplift versus location along the traverse line shown in a. c. The boundaries of Yorkshire in the 1850's (dotted line), i.e. equivalent to the area of the southern North Island purported to have been uplifted during the 1855 earthquake by Roberts and Lyell (see text). WF = inferred length of 1855 rupture along the Wairarapa Fault.

"In the vicinity of Wellington (in the North Island) Mr. Roberts believes 4,600 square miles (an area just smaller than Yorkshire) was raised permanently from 1 to 9 feet. There was no noticeable rise of the coast 16 miles (25.7km) N. of Wellington. From this point to Pencarrow Head, the eastern headland of Port Nicholson, the extent of the upheaval varied gradually from 1 to 7 feet (0.3 to 2.1m). This continued to the eastern side of a range of hills called the Rimutakas, which form an arm of the Tararua ranges. Here the amount of upheaval reached 9 feet (2.7m). At this point the motion suddenly stopped, not affecting the lower land extending further east, called the Wairarapa Plain. The points of minimum and the maximum elevation just mentioned, are almost 23 miles (37km) apart, in a NW direction.

Around the time of the 23rd January, Mr Roberts was working on various projects for the government, in Port Nicholson harbour and on the coast. Thus he had the opportunity to precisely observe changes in the level of the land which affected several points including the cliffs of Muka-Muka. This is 12 miles (19.3km) SE. of Wellington, where the eastern side of the Rimutaka Range reaches Cook Strait. Here, he observed a very distinct fault line; on one side of the line, the rocks had been raised vertically to a height of 9 feet (2.7m); on the other side there had been no movement of any sort.

According to Mr. Mantell the risen mass consists of old stratified argillites, with the normal composition of argillaceous schists, but without schistosity. This mass forms a several hundred foot high cliff towards the sea, whereas the tertiary marine strata, which are exposed to the east, next to the shore, form another relatively low cliff which would not be higher than eighty feet (24m). These tertiary strata did not rise. Mr Roberts was able to accurately measure the amount of the uplift of the old rocks at Muka-Muka Point due to the altered position of a white band of millipores [the 1868 account calls these nullipores] which covered the surface of the rocks to just below low tide level. On the morning following the earthquake, he found this white zone 9 feet (2.7m) higher than it was before the shock. Previously, it was not possible to pass between the sea and the bottom of this perpendicular cliff except during a short time at low water. Shepherds were forced to wait for low tide in order for stock to pass the promontory. Since the upheaval, a gently sloping beach in excess of 100 feet (30m) wide has been laid dry so that settlers have been able to form a track which follows the shore....

On the day after the earthquake [23rd January] Port Nicholson Harbour and the Hutt Valley were found to be uplifted by 4 to 5 feet (1.2 to 1.5m). Minimum elevation was on the western side and maximum elevation on the eastern side of the harbour. Balley Rock, not far from Evans Bay, was formally 2 feet (0.6m) under water at lowest tides, and because a vessel had touched it, a buoy had been placed to show its position. This rock is now 3 feet (1.2m) above low tide level. Since the earthquake the tide hardly goes up the Hutt River....

In short, it appears that the area involved [in the Wairau] was not as important as that which was upheaved around Wellington. Moreover it seems that south of the strait, the direction of movement was reversed. That is, almost everywhere there was a downward movement. The Wairau Valley and part of the adjoining coast, subsided about 5 feet (1.5m) in such a way that now the tide flows several miles further up the Wairau River than it did before. Now the settlers are forced to walk three miles (4.8km) further up the river to get fresh water than they did before the earthquake....

I will conclude this account of changes produced by the 1855 earthquake by pointing out that some have asked whether the land having risen several feet around Port Nicholson in January would not have sank again during the following 6 to 8 months, or before September. On this point witnesses are somewhat contradictory but not irreconcilable. Mr. Mantell believes that there was a partial sinking before he left New Zealand in September, an opinion shared by two other reliable witnesses, Captain Sharp, head of the port and Mr. R. Park, a government civil engineer and land surveyor. Their conclusions were mainly based on the fact that high-tide levels seemed higher in September and low-tide levels lower than just after the January shock.

Mr. Roberts left New Zealand three months after the earthquake and hence was unable to give evidence on the September conditions. He returned [to England] certain that there had been no sinking before his departure. He feels that he could not have missed any slight change of level because he was still being employed in the same work by the government. We have already said that the tides were very irregular for several weeks following the earthquake. Thus it is necessary to make accurate measurements to establish any likely collapse, by taking into account any upheaval and subsequent collapse. This is especially important in Port Nicholson Harbour because of the 18in inch (0.46m) difference between spring tides and summer tides. Those rocks exposed at low tide depend on when observations were made."

Lyell's article in the *Bulletin of the Geological Society of France* was repeated in English, together with a map, twelve years later in the 10th edition of his *Principles of Geology* (Lyell 1868). To date, Lyell's accounts of the 1855 earthquake have provided the only authoritative source of contemporary information regarding the 1855 earthquake.

It should be pointed out that area of 4,600 square miles (11,900 square kilometres) purported to be uplifted by Roberts and repeated by Lyell, is improbably large . From locations mentioned by Roberts, the area uplifted is less than half this amount as indicated by comparison of the area of Yorkshire mentioned by Lyell (Fig.17c).

Letters and diary entries by those who experienced the earthquake and subsequent coastal observations by and large tend to confirm Roberts' official memorandum and the information given to Lyell by the three New Zealand eyewitnesses.

On his return to Wellington in January 1858 James Coutts Crawford (1858) who was later appointed Wellington provincial geologist found that "the rise of land as described to me by Mr. Park (Surveyor General of the Province) is greatest at the end of the Rimutaka Range where it runs into Palliser Bay about the Muka Muka rocks. The land was there risen about 9 feet (2.7m). From there in a slope to a rise of about 4ft (1.2m) in Port Nicholson and the rise extending to the Gorge of the Manawatu where it seems to cease". First accounts of uplift in the vicinity of the town of Wellington (Lambton Harbour), the Hutt Valley and Palliser Bay appeared in the *Spectator* and were repeated in letters and diaries of Wellington residents.

(i). Lambton Harbour (Port Nicholson)

Because of the greater number of people in Wellington than elsewhere, there are numerous estimates and measurements available of the amount of uplift that occurred during the earthquake, particularly with respect to the area around Lambton Harbour. An eyewitness account in *The Australian and New Zealand Gazette* (June 7 1855) records that "the tides are at least six feet (1.8m) lower since the first shock so that it is evident there has been an uplifting of the land" and "from measurements which have since been made, it has been ascertained that the land has been raised to a height of from three feet six inches (1.1m) to four feet (1.2m)" (*Spectator* Feb 7 1855). The writer mentions that "Balley Rock, off Point Jerningham (Fig.17a), which was formerly 18 inches (0.46m) below low water (spring tides) is now two feet (0.6m) above low water". A similar account was published in *The Australian and New Zealand Gazette* (May 26 1855): "The present earthquake gives evidence of having raised the land several feet, even raising rocks in the harbour [presumably a reference to Balley Rock], which were formerly submerged at low water, one or two feet (0.3 or 0.6m) above the surface".

Reference to the elevation of Balley Rock on the eastern side of Lambton Harbour in these newspaper accounts is inexplicably different from that given by Roberts (1855) and Lyell (1856b) i.e. "formerly 2 feet (0.6m) under water at lowest tides" and after the earthquake, " 3 feet (0.9m) above low tide level". However, the notebook of Sir Charles Lyell (1856b) where he recorded an interview with Edward Roberts about the earthquake states that Balley rock "had 3ft (0.9m) of water over it and it is now 2ft (0.6m) above low water mark a month after the earthquake", although the amount of uplift of 5ft. remains unchanged. The *Wellington Almanacs* of 1846-1857 offer no help. Issues prior to 1857 all state that Balley rock is about 100 yards (91m) off Point Jerningham and has 6ft (1.8m) of water over it at high tide while the *1857 Almanac* states that Balley Rock has 6ft (1.8m) of water over it at low tide! - this is clearly a major inconsistency and one that could have proved hazardous to shipping. *The New Zealand Pilot* (1849) published by the Hydrographic Office of the British Admiralty states that, "Point Jerningham, (its western point, as also the NE entrance of Lambton Harbour) has a rocky patch of 9 feet (2.7m) lying nearly a cables length (185m) from it, in a NE direction", and in a footnote mentions, "It is reported that the

Earthquake of 1855 has raised this shoal patch, and that a rock is visible at low water". On Stokes' detailed map of Lambton Harbour (1849) this shoal is referred to as "Harbour reef".

Despite these inconsistencies, the uplift of Balley Rock of 5ft (1.5m) stated by Roberts and Lyell is probably reliable. Lyell, however, was concerned about the amount of uplift in relation to whether it referred to spring or neap tides level as stated in a letter to Walter Mantell (Lyell 1856a), "I am in the hope of getting Mr. Roberts to re-measure the Balley Rock as a difference between spring and neap tides could make some inches, if not feet in the amount of emergence of the Balley Rock" and in his account published in the Bulletin of the Geological Society of France quoted above. On p. 83 of Lyell's interview notebook (Lyell 1856b) he had been able to acquire this information from Edward Roberts, "low water at neap tides does not show so great an elev^{n}, as low water at Spring tides — there is a difference of 18 inches (0.46m) - ordinary tides about 4ft. 6" (1.4m)". Unfortunately, Roberts did not return to New Zealand and there is no record of re-measurement made at this important locality. However, Lyell's 1868 account of the earthquake in his 'Principles of Geology' (Lyell 1868) repeats his statement that Balley Rock "... was formerly 2 feet (0.6m) under water at the lowest tides" and that "This rock projected after the shock nearly 3 feet (0.9m) above the water at low tide" implying that the 5ft (1.5m) of uplift at this locality was measured with respect to the lowest or neap tide level.

Other accounts are in general agreement that in the vicinity of Lambton Harbour fronting the town of Wellington uplift was in the order of 3 - 4ft (0.9 - 1.2m). The journal of William Bennett, (1855) a civil engineer, states that a few days after the earthquake he was "walking about looking at the effects of the earthquake ... at the shore of the Bay [Lambton Harbour] which had been exposed for a considerable distance, the land appearing to have been upheaved 4ft (1.2m) at least". In a later communication to the English seismologist, Robert Mallet, Bennett (in Mallet 1858) reported that the, "ebb and flow [of the tide in Wellington Harbour] is the same as before the earthquake" and "that it does not come at high water within 3 or 4 feet (0.9 or 1.2m) of its former height". Similarly, Thomas Pilcher (1855) states that "the tide was so low that I walked round Noah's Ark when at the lowest tide known there was three feet (0.9m) of water, [so that the] the land has risen about 3 feet (0.9m)", and William Smith (1855) who arrived at Wellington from Lyttelton the day after the earthquake was astonished to see "the number of vessels [that] lay canted over on their sides in shallow water and some smaller ones had been left high and dry on the beach".

These estimates of the amount of uplift in Lambton Harbour are corroborated by extra information in the notebook of Sir Charles Lyell (1856b) recording his interview with Edward Roberts; "About three years ago an English vessel broke from her moorings in Wellington Harbour and was driven on shore at [the] S.E. end of the harbour [Oriental Bay] where she remained when Mr. Roberts came away [returned to England] three months after the earthquake of 1855. Before the earthquake at low water there was generally 3ft (0.9m) [of] water round her and after the shocks she was high and dry at low water - one could walk around her". The same 3ft (0.9m) or more of uplift is also mentioned in an official report recorded in the Governor's Letterbook by J. Wynyard (1855a) "Shores of the Harbour (Wellington) and coast had been upheaved by 3 feet (0.9m) judging from the past and present high water mark". Other non-contemporary sources mention greater uplift; "At Wellington, the harbour is stated to have been raised full four feet and a half (1.4m)" (Taylor 1855); "Geologically, I found the town risen about 4ft (1.2m) and the harbour bottom raised to a corresponding height, a shallow bank extending off from Thorndon Quay making it impossible for boats to land at low water and the Hutt road raised beyond the reach of damage from the waves" (Crawford 1858); and "The Te Aro flat was raised three or four feet (0.9 or 1.2m) making habitable land out of a bog" (unknown source quoted by Ward 1928). The oldest known photographic view of Wellington taken in circa 1857 shows the amount of seaward progradation of the shoreline off Te Aro on the eastern side of Lambton Harbour (Fig.18).

The uplift caused a noticeable seaward extension of the beach in the vicinity of Lambton Harbour as noted by Alfred Matthews (1901); "We were astonished to notice that the tide receded a considerable distance so that the foreshore, owing to the raising of the land, was dry for some distance", and by William Fox (1855); "It is true that the level of the harbour here is elevated probably 4 feet (1.2m); and the rise of high and low water is very different to the eye, the former not coming up on the beach by eight or ten yards (9.1m) of its old mark". The Reverend Henry Sewell (McIntyre 1980) notes in his diary (July 29) when he visited Wellington that the town "looked much as usual, though I observed a decided difference in the elevation of the land. The water on the beach was shallower - jetties which before stood out in deep water (Fig.19), now were dry at low water, and there was a palpable rise in the whole coast, the effect of the earthquake". Progradation of the beach by the earthquake uplift is clearly revealed by comparison between the position of low tide level shown on the hydrographic map of Port Nicholson made by the *Acheron* in 1849 (Hydrographic Dept. of the British Admiralty1856) and the position of high tide surveyed in September 1856 in connection with land claims consequent on the uplift (Fig.20a). Also, A comparison between the bathymetry of Lambton Harbour as determined by Stokes in 1849 and a resounding made in Lieutenant G. Richards in 1877 (inset map on the 1903 bathymetric map of Port Nicholson made by the H.M.S *Penguin*), clearly shows a seaward shift in the 1 fathom contour line as delineated in both surveys (Fig.20b).

Commander Byron Drury of the H.M.S. *Pandora* that was anchored in Lambton Harbour at the time of the earthquake, sounded the area of Lambton Harbour after the Pandora returned from Nelson (February 10) and found "the extent of upheaving not to exceed two feet, and came to this conclusion upon the supposition that the ocean, where the convulsion is not felt, maintaining its level, must, when the local cause is removed, return everywhere to the same. Having discovered there is no tidal variation, but that the springs rise and fall as usual to the proper time, the difference between the height at mean tide now and formerly should give us the height this part of the land has risen. Our boats having sounded round that part of Port Nicholson - Lambton Harbour - we find, on comparing with the Acheron's chart, no changes beyond the two feet (0.6m) mentioned [It should be mentioned here that all depth values less than 1 fathom on the 1849 hydrographic chart are given in feet], ... It is well known that there is a flat extending around Lambton Harbour for a considerable distance beyond low water mark, and from which it suddenly shelves into deep water. And it is a matter of congratulation to the inhabitants that they have gained, or can easily redeem a large tract of building ground. I do not think there is any reason to apprehend its subsiding, for in viewing

Fig.18. Photograph by F. J. Denton (c.1857) looking east towards Mt. Victoria and the Te Aro foreshore, Wellington, and showing the widened area of beach exposed by about 1.5m of uplift during the 1855 earthquake. The post-1855 high tide mark can clearly be seen (see text). (Ref. No. F145534½, Alexander Turnbull Library, NLNZ).

this country geologically we perceive there has been at intervals similar upheavings, we find shells and marine deposits at various levels, and the present generation of oysters and other shells now left above the high water level will add another strata to the growing formation of this country" (*Spectator* Feb 24 1855).

The chart of Port Nicholson published by the *Hydrographic Office of the British Admiralty* in 1856 from the survey made by Captain Stokes of the H.M.S. *Acheron* in 1849 includes a margin inscription based on information supplied by Drury; "Since this survey (1849) the shoal facing the Town of Wellington has risen two feet from the effects of the 1855 earthquake". The 2ft (0.6m) of uplift, as opposed to the 3 to 4ft (0.9 to 1.2m), is also repeated by others. Mills & Carter (1855) in their report on the earthquake damage in Wellington to the Provincial Secretaries Office, state that the Wellington area had been raised two feet during the earthquake. Thomson (1859) in his book, "The Story of New Zealand" of 1859 states that "the country around Wellington was elevated two feet ... and that the low-water mark had become the limit of high water", and Hochstetter (1864) writes; "the elevation

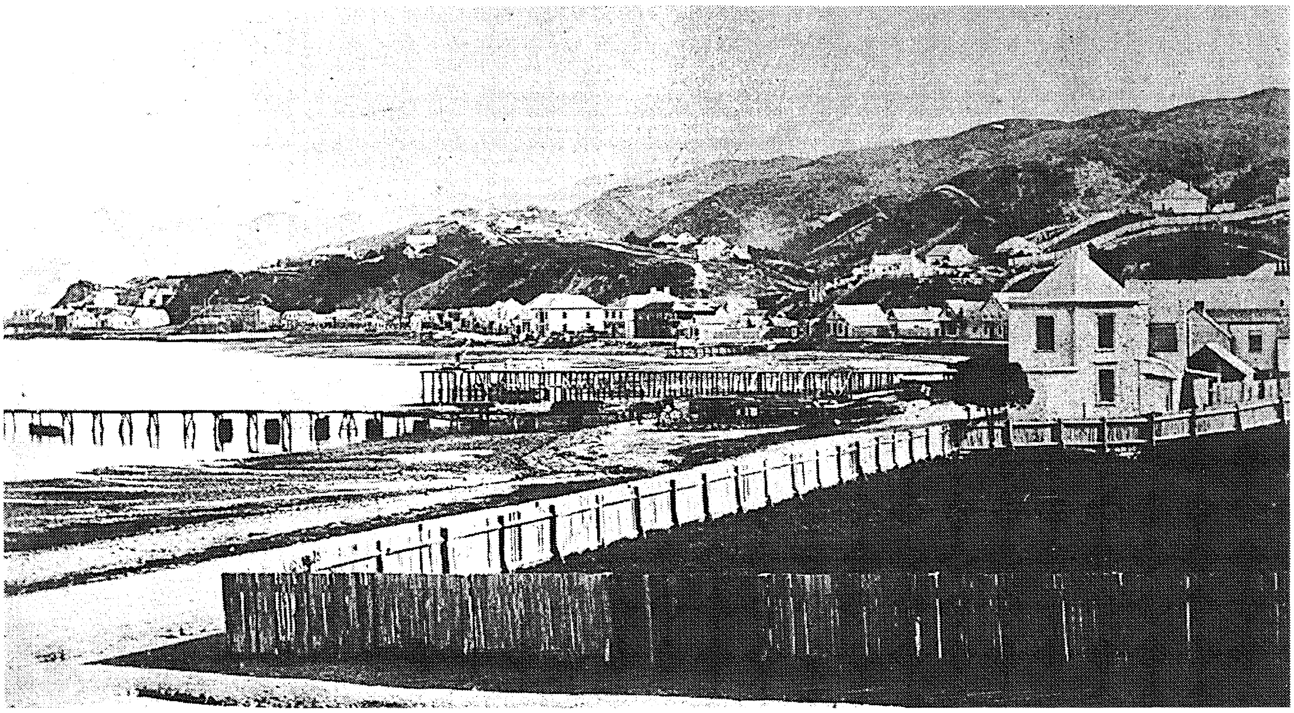


Fig.19. A photograph looking south along Lambton Quay from Brandons Corner, Wellington, showing the 1855 uplifted beach and "stranded" jetties (see text), (1860 photo by William James Harding). (Ref. No. G3924-1/2, Alexander Turnbull Library NLNZ).

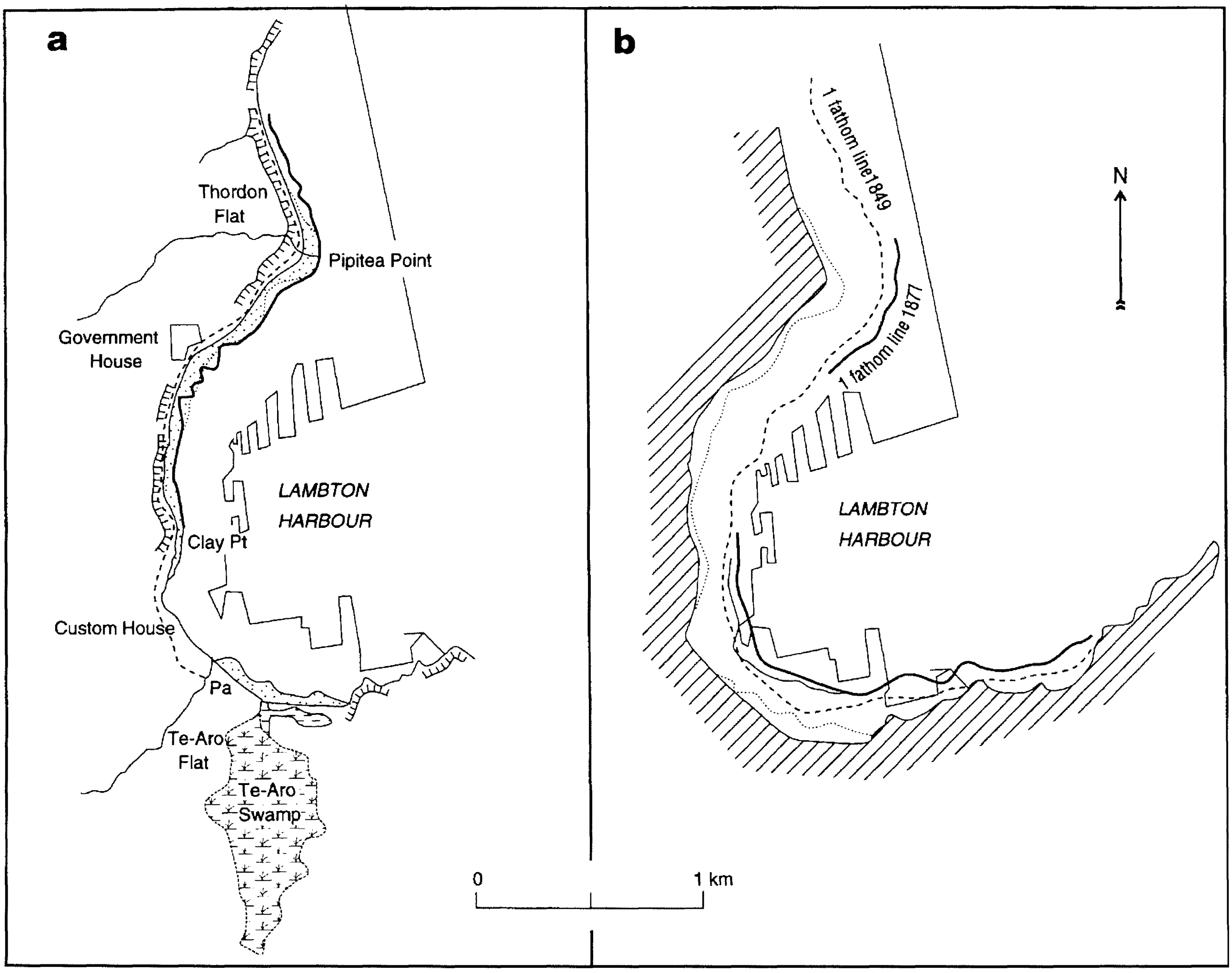


Fig.20. a. Position of high tide in part of Lambton Harbour before (thin line) and after (thick line) the 1855 uplift (see text for details). b. Comparison between the 1 fathom contour of Lambton Harbour before (dashed line) and after (solid line) the 1855 uplift (see text for details). In both diagrams the extent of the present day reclamation and wharves in Lambton Harbour is shown for reference.

in the town itself [Wellington] was only two feet". Although these authors are secondary sources that may have quoted the 2ft (0.6m) uplift estimate published by Commander Drury, the fact remains that there is a notable discrepancy between this and the 3 - 5 ft (0.9 - 1.2m) of uplift quoted by others.

Drury's estimate was made by sounding in Lambton Harbour and comparing the values with the chart made by Captain Stokes of the *Acheron* six years previously in 1849. As stated by Drury (*Spectator* Feb 24 1858), "It is well known that there is a flat extending around Lambton Harbour for a considerable distance beyond low water mark, and from which it suddenly shelves into deep water". A report from the Harbour Office, Wellington, dated 29th December 1852 (S. Carkeek [Collector of Customs] & C. Sharp [Harbour Master]) in relation to construction of two wharves at Port Nicholson, describes that part of Lambton Harbour (from the Custom House to Pipitea Point) as "extremely shallow close to the shore, the nearest approach to deep water being at Clay Point, but even there a depth of 18 feet (5.5m) at low water spring tides is not obtained at a less distance than 800 feet (244m) from the shore, and immediately after it increases to 4 and 5 fathoms. The shore shelves off gradually from low water mark to the above mentioned depth with a soft muddy bottom". If, during the earthquake, the mass of loose sediment overlying the shelf area moved outwards (a subaqueous landslide) as a result of the shaking (see section on Tsunami and Seismic Seiche), then the amount of measured uplift would be reduced in the area of Lambton Harbour in comparison with more reliable measurements made on rock or foreshore uplift.

(ii). Evans Bay

Evidence for the amount of uplift occurring on the eastern side of Evans Bay comes from the elevation of a tunnel excavated by James Crawford to drain Burnham Water (or Para Lagoon), that occupied the central part of the Miramar flat, into Evans Bay. It is interesting to note that in an abridged version of a lecture given by Crawford in May 1848 entitled the 'Geology of Port Nicholson District, New Zealand', Crawford (1855) mentions that "fluctuations in the height of the land ... is to be looked for ... for earthquakes are extremely frequent" and that "A tunnel which he cut horizontally from high-water mark to drain Burnham Water in the [Miramar] Peninsula, near Wellington, will form a good mark in that locality". Returning to Wellington in January 1858, Crawford (1858) comments that "my tunnel is now 4ft and 9/10ths above the level of high water in Evans Bay". In the following April, he contracted to lower the tunnel by 3ft (0.9m) (2ft (0.6m) at the Burnham Water end and 3ft (0.9m) at the Evans Bay end) so that he resumed drainage of the lagoon. Another foot was to be removed at a later date. The tunnel was situated about 3.2km SSE of Balley Rock and the implied uplift of about 5ft (1.5m) is the same.

(iii). Wellington Harbour Entrance

A comparison of the hydrographic surveys of Port Nicholson made in 1849 (*Hydrographic Department, British Admiralty, London, 1:24 000*) and a resurvey of the harbour entrance and the south coast from the harbour entrance to Lyall Bay in 1903 (*Hydrographic Department, British Admiralty, London, 1:24 000*) show important differences that can be attributed to the uplift in 1855 (Figs.21a,b). The 1903 survey clearly shows the emergence of beaches and rock platforms, the emergence of a shoal (the Falconer Shoal) just inside the harbour entrance, shallowing in the vicinity of Barret Reef (spelt Barrett on post-1903 charts) at the entrance to Wellington Harbour and between Ward Island and the Eastbourne area. From a study of sand transport in the area of the harbour entrance, Carter (1977) considered that these three areas have been the important depositional sites of sediment. The reason that they are so can be probably be attributed to the 1855 uplift. Comparison between the 1849 and 1903 surveys in the vicinity of the harbour entrance suggests that if the 1855 uplift is recorded it is about 6 ft. (1 fathom), although precise matching of sounding localities between the two surveys is tenuous in addition to factors such as sediment deposition and erosion within the 54 year interval between the surveys. In contrast, comparison between the 1903 and 1950 surveys shows that shallowing in the harbour entrance was a little less than about 1m.

The uplift of Barret Reef near the Harbour entrance described as a "cluster of rocks principally standing well out of the water" (*The New Zealand Pilot* 1849), was clearly noticeable from the stranded line of coralline algae (the nullipores mentioned by Lyell (1856a,b)), "a part of Barret's reef (outside of it) was quite white whereas other rocks of the same reef had only a zone of white rising above the water - several feet above their base" (Notebook 213 of Lyell 1856b). Lyell's statement implies that the outer (most southern) rock of Barret Reef was covered at low tide whereas the 1849 Hydrographic chart (also The New Zealand Pilot 1849) indicates that it was 10ft (3.0m) high and that it was a "black rock". Confusion with respect to estimating the amount of uplift is compounded by the fact that the 1903 resurvey (Fig.21b) shows the outer rock to be 7ft (2.1m) high! That some of the rocks showed a lower limit of the algal encrustation "several feet above their base", presumably above low tide level, implies several feet of uplift.

(iv). South Coast of Miramar Peninsula

The 1855 elevated beaches along the south coast of the Miramar Peninsula between Lyall Bay and Seatoun were first described 55 years after the earthquake by James McIntosh Bell of the New Zealand Geological Survey; "They stretch for miles along the wild shore, elevated about 5ft (1.5m) above the present high tide level. In places the surface of the beach bordering the steep marine-denuded cliffs is so flat, and is composed of such fine gravel, that it resembles an artificial embankment. Elsewhere occur flats, 5 or 6 chains (100 or 121m) wide or even more, surmounted by skerries [small rocky outcrops] which until very recently were washed by the waves. Here and there along the seashore fishermen have taken advantage of the recently raised beaches to erect their huts thereon" (Bell 1910). Photographs taken in 1919 of Eve Bay, Flax Bay and Reef Bay by Sir Charles Cotton (Fig.22) and of Reef Bay by G. L. Adkin in 1923, (Fig.23a), along the southeast coast of the Miramar Peninsula clearly show the pristine nature of the 1855 uplifted gravel beach.

Adkin made detailed surveys of this beach in 1923 (Adkin 1923; Notebook 5). He describes the area as being accessible only by foot and being famous for "exhibiting the magnificent vestiges and memorials of the abruptly uplifted sea-margin of the great earthquake of A.D. 1855. With the march of 'progress', rumours were current that a vehicle road was to be constructed round the coast linking Lyall Bay and Seatoun, with the inevitable result of wholesale destruction or obliteration of scenically and scientifically priceless shoreline features". Adkin describes the shoreline of the eastern headland of Lyall Bay - Hue-te-taka Peninsula, as a raised shore platform with numerous stacks. He mentions that this rock platform "carries the shingle ridge of the

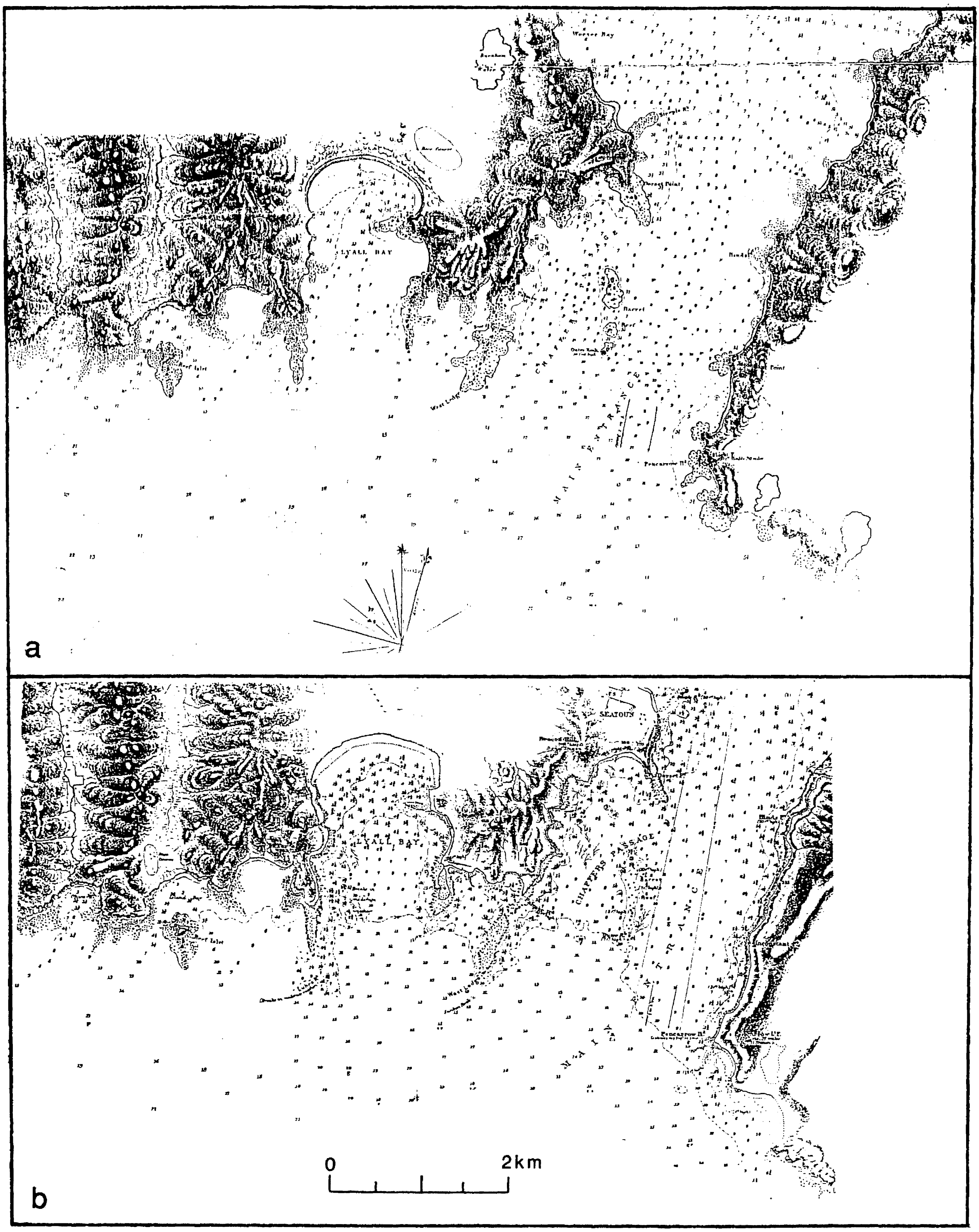


Fig.21. Comparison of the British Admiralty hydrographic surveys of 1849 (a) and 1903 (b) of part of the south Wellington coast and entrance to Port Nicholson with the 1903 chart showing, in particular, 1855 uplifted rock platforms east of Lyall Bay and the prograded beach at Lyall Bay in (a) (see text).

Fig.22. Photo taken by Sir Charles Cotton in 1919 of Reef Bay, south Wellington coast, showing the 1855 uplifted beach. Photo taken at extreme low tide showing uplifted rock platform. (Geography Department, Victoria University of Wellington).

pre-1855 shoreline as a fine (shingle) raised beach of bare cobbles and pebbles, annular in ground-plan at about 5ft (1.5m) (plus accretion by wave piling) above present sea level. At a slightly lower level are discontinuous accumulations of a modern storm beach, also of wave-worn shingle, and closely resembling in appearance the 1855 raised beach. At the shoreward end of Hue-te-taka Peninsula a fine exposure of the 1855 beach lies on the mainland shore, backed by the inland sea cliffs, and from the seaward side this beach stands up as a massive wall-like embankment partly hiding the fishermen's cottages at its rear." At Palmer Head, Adkin refers to the "grand scale" of the uplifted pre-1855 shoreline that included "the massive beach deposit, beautifully graded transversely and sweeping in superb curves round and just-within the perimeter of the projecting raised shoreline platform of the Palmer Head foreland" (Fig.23b).

The emergence of raised beaches and surrounding rock platforms at Hue-te-taka Peninsula on the eastern side of Lyall Bay and Palmer Head about 800m to the east are also clearly shown by the 1903 resurvey of the harbour entrance area (Fig.21b). Height differences between the crests of the modern storm beach and 1855 storm beach at both localities constructed from unpublished observations of Adkin (notebooks; 1947; 1955; 1956) and Stevens (1973) indicate an uplift of about 1.8m (Fig.24). A recent precise level survey of the area by Huber (1994) indicates a height difference between the crest of the 1855 beach and modern storm beach of 1.35m.

Along the western shore of Chaffers Passage, the 1855 beach extended continuously from Palmer Head to the western end of Breaker Bay (Fig.24). At Eve Bay, Adkin (1923) records that "the southerlies had piled up the great pre-1855 beach to its maximum extent and there the great coarse deposit stands at a height of the 5ft (1.5m) of uplift perhaps another 4ft (1.2m) of wave accumulation". At the head of Breaker Bay, "the 1855 raised beach and the modern storm beach have been packed into a single blended bank with its inner edge lying against the hill-face and its seaward side sloping to the present high tide line and level".

(v). Lyall Bay

"Soon after the earthquake, a phenomenon occurred which the two families [Sutherland and Dougherty] remembered all their lives. An island rose up in the middle of Lyall Bay.... the adventurous Robina [Dougherty] had rowed herself out to explore it. Just in time, as soon it subsided and vanished without trace" (Manson 1981). The 1903 hydrographic map shows several small rocky shoals in the western part of Lyall Bay that are not shown on the 1849 hydrographic map (Fig.21) although the soundings are considerably more numerous on the former chart. It is therefore possible that the reference to a temporary "island" might refer to one of these which are all within reasonable rowing distance from the shore. The account is interesting but just too vague to be of much importance.

The sand beach at Lyall Bay is notably broader on the 1903 map in comparison to that in 1849 suggesting that uplift created a more gently sloping beach profile (Fig.21). A photograph of Lyall Bay beach taken only 15 years after the earthquake in 1870 shows a wide, gently sloping beach which appears to have moved little since the early 1900's. This implies that progradation of the beach following uplift occurred within 50 years of the earthquake.

(vi). Wellington - Petone Road.

Prior to the 1855 earthquake the only land route between Wellington and the Hutt Valley lay along the western edge of the harbour. According to Ward (1928), the road was a narrow track

Fig.23. Photos taken by G. L. Adkin in the early 1920's showing the 1855 uplifted beach, south Wellington coast; a Reef Bay (same locality as shown in Fig. 22; taken at half tide); b Palmer Head. (Neg. Nos. B21094 and B20937, Hector Library, Museum of New Zealand, Wellington).

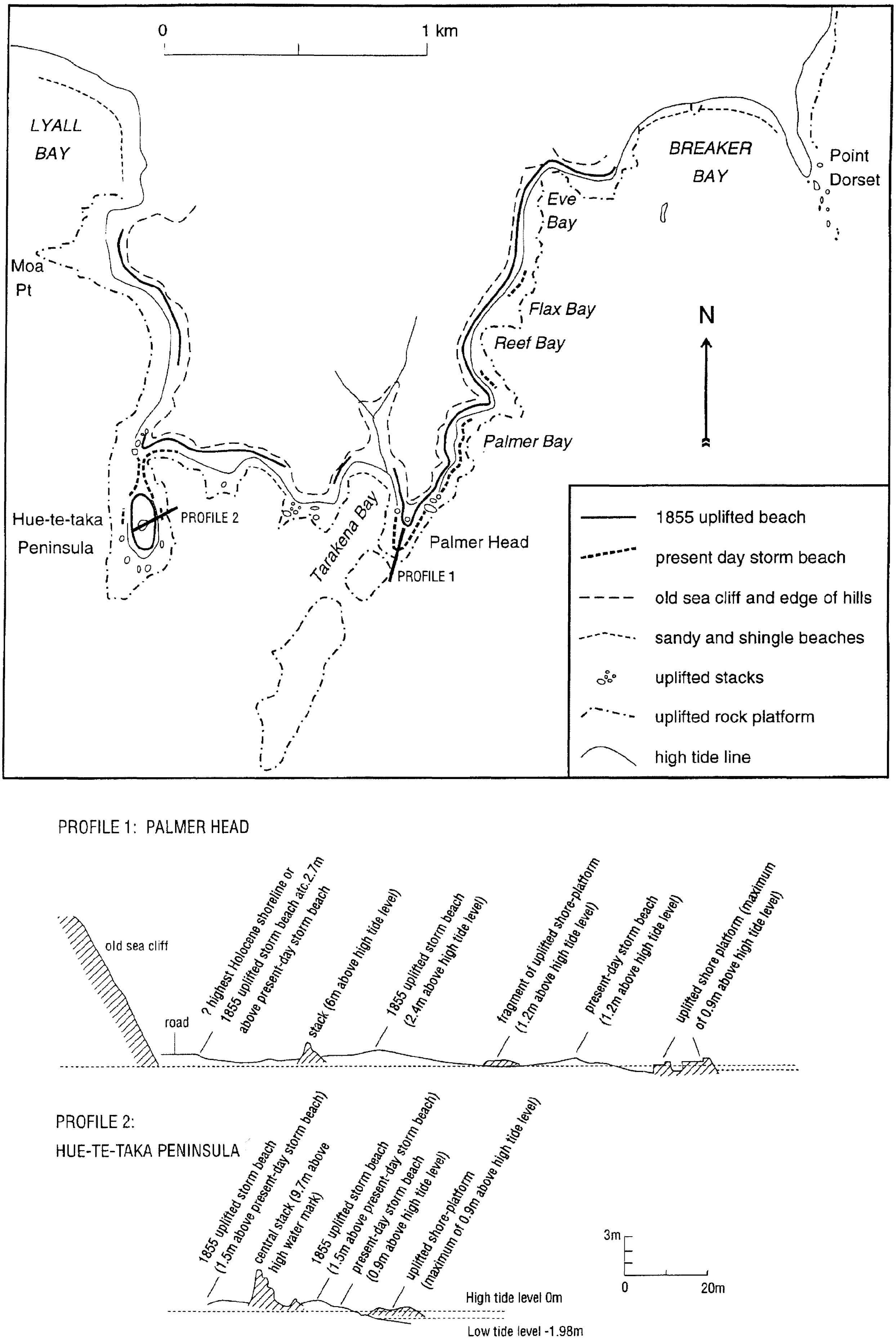


Fig.24. Map and section profiles of the 1855 uplifted beach ridge, stacks and rock platform between Breaker Bay and Lyall Bay, south Wellington coast (after Adkin, unpublished notebooks 1957, 1955, 1956).

along the base of steep cliffs, barely above high tide level and travellers were frequently in danger from waves during a southerly making travelling a risky business. In places the road had to be retained by a sea wall. A somewhat more flattering description of the road is given in a report to the New Zealand Company directors in London by Colonel Wakefield (May, 1842) who describes the road as "nearly six miles (9.6km) in length with sufficient width the whole way for two carriages to pass. The distance may appear small, but the difficulties to contend with were considerable. The road which follows the beach line is, throughout its whole extent, built far above the influence of the tide, and consequently walls of rough masonry were necessary on the side next to the sea while the other side had to be cut out from the hills". Several circa 1840 paintings and sketches (e.g. Swainson 'Sketches' 1843; Alexander Turnbull Library) clearly show that the road ran along a raised rock platform at the base of the cliffs.

The uplift that occurred in 1855 on this (western) side of the harbour during the earthquake was sufficient to "escape the damage of the one [waves] and the expense of the other [sea wall], (Roberts 1855). Although the exact amount of uplift is nowhere recorded, Roberts mentions 4ft (1.2m) of uplift on the western side of the Harbour.

(vii). Somes and Mokopuna Islands; Ward Island.
Raised arches and rock platforms around Somes and Mokopuna islands indicate an 1855 uplift of about 1.5m (Stevens 1956; 1973). The 1855 shoreline forms a conspicuous feature around Somes Island and according to Hull *et al.* (1981) is marked by notches at the same height above the present day storm beach, caves and a marine-cut platform. Measured heights above mean sea level (tidal variation at time of measurement was 1.4m) for all three features averaged 1.7m although the average of marine cut platform values is 1.4m above mean sea level and lies within the 10-20% error margin of all heights measured. More recent measurements made at the northwestern tip of Somes Island gave consistent marine platform/notch uplift values measured relative to the high tide mark of 1.1m (R. Grapes, Jan. 1996).

Ward Island was investigated by Adkin in 1957 (Adkin; unpublished Notebook 41) who noted the presence of stranded beaches on the east side of the island; "... the outer and most recently formed of these is of fine, loose gravel forming a high-tide beach-ridge about 2ft (0.6m) above that level. Inside this is a second beach-ridge, also of quite unconsolidated similar detritus, standing about 4ft (1.2m) above present high-tide level and fairly obviously a storm beach-ridge related to present sea level. The third innermost beach-ridge rises to about 5 1/2ft (1.65m) above present high-tide level and is noticeably more consolidated and of older accumulation; it can be correlated with the pre-1855 beach-ridge, the uplift on that date at this point being 5ft (1.5m)."

(viii). Hutt Valley.
Pre-1855 survey plans of the Hutt Valley (shown on the 1849 British Admiralty chart of Port Nicholson; and in Nicholson (1940) and Hall & Toomath (1941)) show that much of the Hutt delta was swamp and tidal inlets. The Hutt River and Waiwhetu Stream were navigable for some distance as indicated by the position of shipyards (Wilcox's Shipyards on the Waiwhetu Stream and Oxenham's Shipyards on the southern part of what is now called Gear Island). The Hutt River was navigable to as far as Maoribank (about 22km from the river mouth) for smaller craft and according to *the New Zealand Pilot* (1849), the Hutt River was navigable for "nearly 2 miles, or as high as the bridge [Hutt Bridge], for large cargo boats".

The 1855 uplift considerably shallowed the Hutt River and Waiwhetu Stream making them unsuitable for navigation; swamps were drained and the shoreline was extended southwards. Comparison of the Hydrographic survey maps of 1849 and 1903 shows that the width of the beach at the western end of Petone foreshore was greater in 1903 than in 1849 and a possible consequence of the 1855 uplift. A painting by Samuel Brees in 1843 (Fig.25) clearly shows the 1855 beach ridge positioned just seaward of Te Puni's Pa and Colonel Wakefield's quarters (the site of the first landing of immigrants on 21 September, 1839) on the western side of the Hutt Valley, i.e. running along the present day Esplanade of Petone as shown on the 1849 Hydrographic Chart of Port Nicholson (Hydrographic Office of the British Admiralty 1856). In contrast, Stevens (1973) and Stirling (1992) mistakenly put the position of the 1855 beach along Adelaide Road, nearly 200m inland from The Esplanade. On the basis of the historic evidence this has to be an earlier beach ridge (possibly earthquake stranded) so that the record of Holocene earthquake uplifts that have affected the Hutt Valley requires revision.

Sediment changes in a core taken off Petone Wharf relating mud content to depth indicates a major decrease in mud content at a depth of 240cm. Taken together with beach profiling and grain size distribution, this corresponds to a sudden depth change of 1.1m and is inferred to represent the uplift in 1855 (Irwin 1993). The present day beach is about 70-90m south of the 1855 beach line. An 1855 uplift of between 2 - 2.5m for the Petone area suggested by Stevens (1973) and Stirling (1992) appears to be far too high.

The effects of uplift on the southern (Petone) end of the Hutt Valley are mentioned by several people. Roberts (1855) states that "the whole of that valuable valley (Hutt) will be rendered, if possible, more healthy from greater facility of drainage arising from the elevation". According to Crawford (1858), "The Hutt Valley was raised so much that the tide ceased to run into the river." An unknown source cited in Nicholson (1940) states that the 1855 earthquake "raised the level of much of Petone by several feet, and in particular extended the eastern foreshore a further chain depth into the harbour. The western, or Korokoro, end was not greatly affected. The raising of the level of the land was beneficial to Petone as land which had been swampy was now high and dry". Brightwell (1917) recollects two schooners that were stranded where the "old racecourse now is at the Lower Hutt. These schooners were well out in the harbour at the time, and as a boy I and my schoolmates were able often at low water to wade out close to those schooners. The earthquake left them high and dry, and the beach where they were lying became dry and was later ploughed and laid down into paddocks: all the then deep rivers being left as mere streams compared with what they were before the earthquake. Wellington Harbour and the Hutt side shrank very much in area in consequence of the earthquake. In fact all around the harbour the water receded never to return. It was most noticeable all along the Hutt Valley frontage [Petone] because of the shallow, sloping beach. I well remember sea-fish being caught daily up beyond the Hutt Bridge and sea-fish visited that part with every tide. The same applied to the second river, past McNab's Gardens (Fig.7a).... Now that river is only

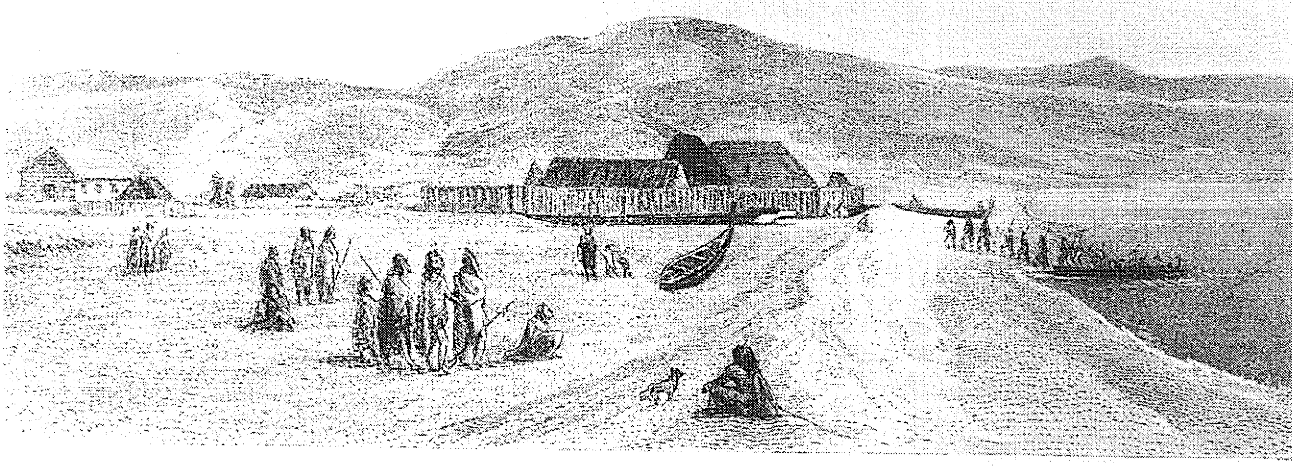


Fig.25. An engraving after an original drawing of S. C. Brees showing the pre-1855 beach ridge at Petone (c.1843) and "Pitone Pa" (see Fig.7a for locality). (*In: *Brees, S. C. 1847.* Pictorial Illustrations of New Zealand. *J. Williams, London.) (Ref. No. B1904½, Alexander Turnbull Library, NLNZ).

a small stream and the settlers had then to cut a channel for more than a mile (1.6km), I should say, to lead its dribble of water into the harbour".

Additional information with respect to Waiwhetu Stream comes from an unsourced newspaper clipping in the Fildes Collection. "The Waiwhetu river had a large mud bank on each side of it next morning after the earthquake ... in the early days fair-sized craft used to sail up the Waiwhetu river, and one small schooner, which was at anchor in the river at the time of the great [1855] earthquake, was found high and dry on a mud bank next morning, the water in the river having receded through the land being thrown up". Ben Iveson (1954), a personal friend of Alfred Matthews of Waiorongomai (southeast Wairarapa Valley), and Henry Eglington of Wharekaukau (Palliser Bay) records that these men told him that after the earthquake, "the Waiwhetu River became a comparatively shallow stream on the banks of which the writer [Iveson] saw some 56 years ago the remains of a trading boat which he was told became stranded there during the earthquake", although the stranding could have been the effect of the tsunami following the earthquake. Florance (1858) adds that "about 20 acres (8 hectares) or more were added to the seaboard side of farmer Braithwaite's land in the Wai-awai-tou [Waiwhetu] district", and that further up the valley, "the great Mungaroah [Mangaroa] Swamp in the Upper Valley of the Hutt was raised to an altitude of not less than 20 feet (6m) [very clearly written!] above its old level by the great earthquake of 1854 [1855]. An elevation of the same extent took place at the same time in and about the harbour of Port Nich[olson]". The 20ft (6m) of uplift mentioned is clearly a gross error. As the uplift of the Mangaroa Swamp is stated to be the same as that at Wellington, a value of 2ft (0.6m) would appear to be what the writer meant (corresponding to the estimate made by Commander Drury (*Spectator* 1855)). This amount of uplift would have been enough to have caused a noticeable amount of drainage of the swamp.

Comparison of survey maps of the Hutt Valley in 1852 and 1865 show no notable changes in the position of the Hutt River over this period. Significant changes in the course of the river occurred between 1843 and 1852, presumably as a result of flooding. Nevertheless, the uplift of c.1.5m would have caused a notable increase in the river gradient especially in the lower part of the valley and this concern was raised by Edward Jerningham Wakefield in 1857 (Acts of the Wellington Provincial Council 1857) when he requested that a survey be made of the river depth and course to ascertain what changes had taken place since a survey made by Edward Roberts in 1854, although this does not appear to have been carried out. In addition, Wakefield introduced the Hutt Park Act in 1856 claiming the land raised by the earthquake, including Fetherly Island in the delta area of the Hutt River and Waiwhetu Stream, for public use.

(ix). Eastern side of Wellington Harbour

At Point Howard, "caves and stacks were raised above sea level, and the cliffs remain conspicuously undercut in many places. Before the earthquake, travellers did in fact find Point Howard impassable at high water" (unsourced reference in Stevens 1956) and the track climbed through the bush above the rocky point because passage via the beach was not safe at high tide (Bagnall 1972). An account entitled, "Notes of a Journey to the Wairarapa with a Flock of Sheep" by Northcote & Tiffen (1848) who made the journey to the Wairarapa in August, 1845 with 762 sheep, states that after leaving Waiwhetu in the Hutt Valley they were obliged to cross the hill at Lowry Bay (Point Howard being impassable) and that along the remainder of the coast route to Okiwi ("Okiwi-nui"; south side of the Eastbourne foreland salient), several rocky points could only be passed by those driving sheep at low tide. Beyond Okiwi there was "one point to go around at low water" before the road climbed up from the beach at Robinson's Bay (just south of "Muritai"). Further access along the 7 kilometres stretch of coast from this place to Pencarrow Head, at least with mobs of sheep, was not possible prior to the earthquake. The track followed along the top of the hills overlooking the coast to Pencarrow and then descended to the beach.

According to Stevens (1956), a gravel bar was present at Lowry Bay, enclosing a swamp, known as "The Marsh", and implied by the Maori name "Whiorau" ('the place of many blue duck'). The swamp is now drained and built upon and the present road to Eastbourne has been sited along the 1855 uplifted gravel bar. Stevens also considers that a similar swamp - raised gravel bar occurred at Days Bay. "The morning after the earthquake the Jackson family who resided at Lowry Bay were amazed to see that the sea had receded - the shore line had risen about four feet (1.2m) - " (Bagnall 1972). The uplift also meant that there was no longer any necessity to wait for the tide to pass Point Howard.

(x). Pencarrow Head - Baring Head

The amount of 1855 uplift at Pencarrow Head is given by Lyell (1856b) as 7ft. (2.1m). The question of whether or not this was "permanent" uplift is recorded in his interview notebook (Lyell 1856b); "Mr. Roberts made a report on the lighthouse [Pencarrow Head] - & they ascertained that there was no sinking of a few inches after the rise".

East of Pencarrow Head in Fitzroy Bay are the fresh water lakes Kohangapiripiri and Kohangatera that occupy the lower ends of drowned valleys (Cotton 1921) (Fig.26). In the 1840's, Lake Kohangatera was apparently a salt water (most probably brackish water) lake whereas Lake Kohangapiripiri contained fresh water (Northcote & Tiffen 1848). This may have been simply a function of the greater amount of fresh water input from Gollans Stream into Lake Kohangapiripiri. Uplift during the earthquake resulted in some drainage of side valleys of the lakes (Fig.26). Unfortunately, the uplifted 1855 and older beaches fronting the lakes have been considerably modified by removal of gravel. Nevertheless, from air photos taken in the 1940's it is clear that the outlet channel of lake Kohangatera has cut through the 1855 beach ridge and it is now blocked by the modern storm beach so that drainage is by seepage through present-day beach gravels. A map of Lake Kohangatera made by Adkin in 1956 (Fig. 26) shows the position of the stranded pre-1855 outlet channel that originally ran parallel to and behind the 1855 beach ridge. The bottom of this outlet channel is at approximately the height of the present storm beach crest. Adkin's observations at Lake Kohangatera (see also Stevens 1973) indicates that the crest of the 1855 beach was about 2m above that of the modern storm beach thus confirming the 7ft. uplift mentioned by Lyell at Pencarrow Head.

Prior to the earthquake uplift it was not possible to continue around the beach past Baring Head with sheep except at low tide. The beach route ended at Parangararu (a Maori fishing settlement) near the north east corner of Fitzroy Bay and from there the track led over a low saddle into the Wainuiomata Valley and thence once again to the beach and on to the Orongorongo River (Fig.26).

(xi). Turakirae Head - Mukamuka, Palliser Bay

Northcote & Tiffin (1848) noted that the route from the Orongorongo River around Turakirae Head to Waimarama (Barney's Hut) was very rough and rocky. The 1855 earthquake

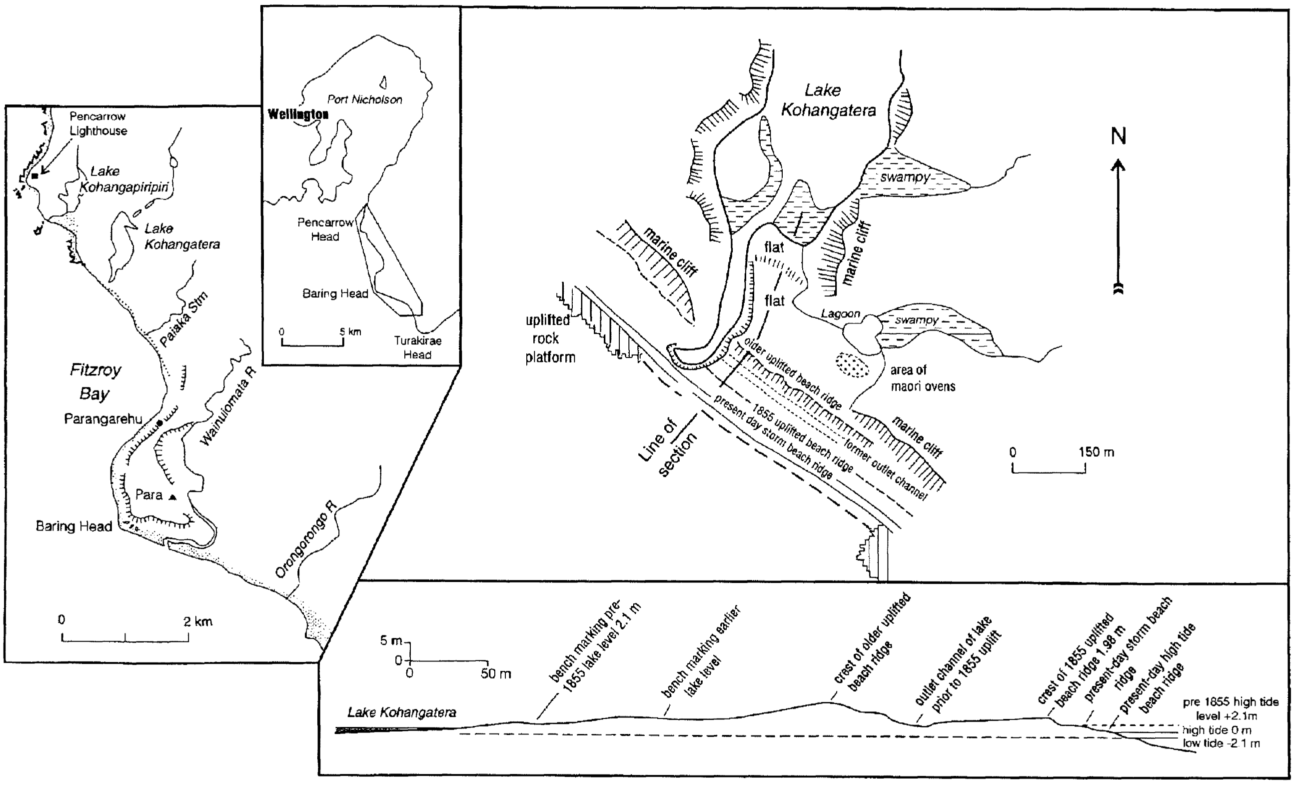


Fig.26. Map and cross section showing the uplifted 1855 beach ridge at Lake Kohangatera, Fitzroy Bay, Wellington (see inset maps for location). (After G. L. Adkin, unpublished notebook 41, 1956).

caused uplift of the entire beach line. W.A.McKay (1901), (son of the celebrated geologist Alexander McKay), provides the first description of the uplifted beach around Turakirae Head; a "very fine example of the effects of the 1845[1855] earthquake is the raised beach stretching without a break from a point three miles and a half (7.2km) eastward of Cape Turakirae to the mouth of the Wainuiomata River, fully four miles (6.4km) to the westward. In width it varies from 200ft to 300ft (61 to 91m) on the eastern and western extremities to three quarters of a mile (1.2km) at Cape Turakirae.... the effect of the earth-movements has been to throw up a ridge (the old beach) of large boulders and gravel, between which and the hills or high ground is found a lagoon and swamp, which is scarcely above the tideway. In this raised beach at Cape Turakirae the whole surface from end to end is littered with big boulders from 2 ft (0.6m) to 6ft (1.8m) or 8 ft (2.4m), together with the small water-worn gravels of the old beach. Besides this, there are exposures of the water-worn rocks *in situ* projecting through the boulder-beach. The old beach-line keeps near to the hillsides, at a distance of about 300 yards (274m) to half a mile (0.8km). Of a necessity the line of the old beach of these raised gravels forms the boundary of the dry ground that was elevated and of the sea-bottom that was raised to its present position. On both sides of the cape the boulders get smaller and smaller as this is left behind, and on the western side of the Orongorongo the character of the beach changes very much, the size of the boulders being much less" (Fig.27).

The raised beaches at Turakirae Head have attracted the attention of several scientists (Aston 1912; Cotton 1969; Stevens 1956; 1969; 1973) and were the subject of a detailed survey by Wellman (1967). Until recently, the lowest beach ridge was considered to represent the 1855 uplift of 9ft. (2.7m) mentioned by Roberts (1855) and Lyell (1856a,b;1868) at Mukamuka Rocks some 7km northeast of Turakirae Head. Recent work by McSaveney & Hull. (1995) have confirmed that the 2.5m beach is actually the present-day storm beach and that the 1855 uplifted beach is the one considered by these previous workers to represent an uplift about 450 years ago (the so-called Haowhenua earthquake of Best 1923; Stevens 1969; Moore & McFadgen 1978; Moore 1987). This beach stands at between 4 and 6m above the present-day forming beach. Based on the revised interpretation, the amount of uplift in 1855 along the western side of Palliser Bay varies from 2.7m (Mukamuka) to 6m (where the fold axis of the Rimutaka Range intersects the coast (Wellman 1967), (Fig.28a). The new interpretation of the beach ridges at Turakirae removes one earthquake uplift event and necessitates a re-evaluation of the paleoseismic record with the recognition of 4 rather than 5 earthquake uplifts within the last 6.5 to 7 ka. The McSaveney & Hull. (1995) interpretation is consistent with the 1901 description of McKay and, more importantly, with a previously undiscovered 1868-69 survey map of the coast from Fitzroy Bay around Turakirae Head to Windy Point, Palliser Bay (Survey map "Orongorongo, Wellington", 20 chains = 1 inch: Lands and Survey, AAFV 997 W131, National Archives, Wellington). This map shows the line of the 1855 uplifted beach, labelled "High Water Mark previous to Earthquakes of 1848 & 55" (Fig. 28b). The position of the 1855 beach line on the map is identical to that of the pre-1855 uplifted beach ridge designated by Aston (1912; beach ridge "2"), Wellman (1967) and Stevens (1973 (beach ridge "C") and Moore (1987, beach ridge "BR2").

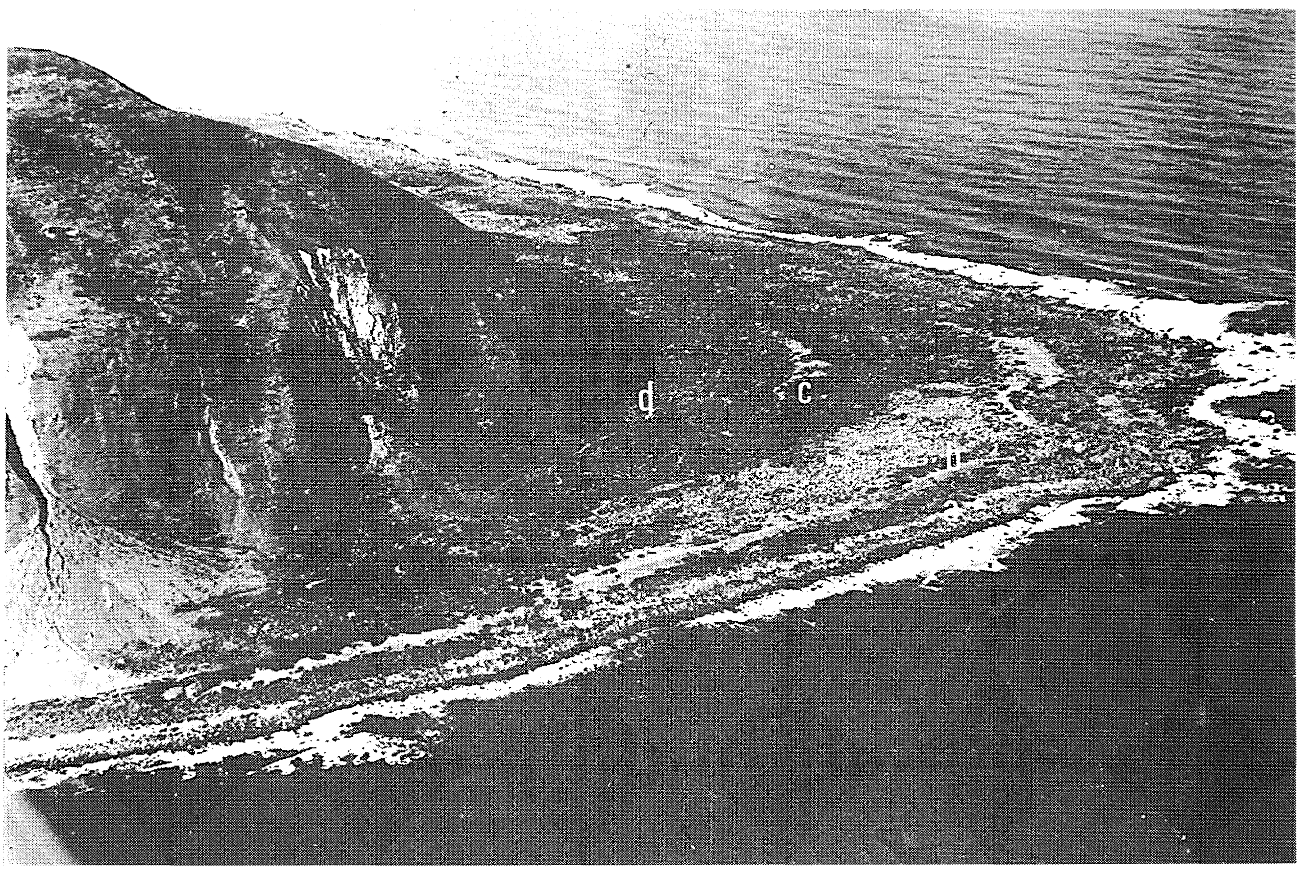


Fig.27. Oblique aerial photo looking SE across Turakirae Head showing extent of the 1855 uplifted beach ridge (labelled** b**);** a **= present day beach ridge;** c **and** d **= older earthquake uplifted beach ridges.

The most hazardous part of the coastal route between Wellington and the Wairarapa was passing the Mukamuka rocks near the northwest corner of Palliser Bay (Fig.12; 17a) and advice was given to those driving mobs of sheep, to reach the rocks half an hour before low water, or "half ebb to about a quarter flood" (Chapman 1847), when there would be little difficulty in getting past the rocks, and indicating to those without sheep that the rocks could be easily passed at half tide. As a result of uplift during the earthquake, Edwin Meredith (1898) reports that "the dreaded 'Muku-Muku' rocks literally had to take a back seat, as by the upheaval they were left many chains above high-water, and a fine sandy beach formed about their base, affording the settlers a fine driving road for their stock, where previously so much delay and loss had prevailed."

Uplift of the Mukumuka rocks was recorded by Edward Roberts (1855) who was in the process of constructing a road to safely bypass them at the time. As related by Sir Charles Lyell (1856b); "Mr. Roberts was able to accurately measure the amount of the uplift of the old rocks at Muka-Muka Point due to the altered position of a white band of millipores which covered the surface of the rocks to just below low tide level. On the morning following the earthquake, he found this white zone 9 feet (2.7m) higher than it was before the shock. Previously, it was not possible to pass between the sea and the bottom of this perpendicular cliff except during a short time at low water. Shepherds were forced to wait for low tide in order for stock to pass the promontory. Since the upheaval, a gently sloping beach in excess of 100 feet (30m) wide has been laid dry so that settlers have been able to form a track which follows the shore".

A graphic account of the changes that took place in the western Palliser Bay area are given by Charles Matthews (c.1925). "My father Alfred spent some days in making his wrecked house habitable [in Wellington] and then left for "Wharepapa" [on the cliffs overlooking Ocean Beach, Palliser Bay]. He was astonished to see the changes that had taken place. The Muka Muka rocks, where I had known parties of men, large mobs of cattle and sheep, to be held up for several days waiting to get round, were no longer an impediment to travellers - the earthquake having left them high and dry.... The sea in Palliser Bay had receded at least two chains (40m) - in our place there was actually a shallow lagoon between the sea and the shore at high tide". With respect to the Mukamuka Rocks, Alfred Matthews (1901) stated that "the land was raised to such an extent and the sea forced so completely back that nowadays one can travel over this route at any time without one's journey being delayed. At high tide the sea does not come within two chains of where the Muka Muka rocks were".

In examining the geology of this part of the coast, McKay (1901) records, "At a point about two miles (3.2km) north of the Mukamuka River a small length of raised beach is seen. It continues for about half a mile (0.8km), and in width it is about 200 yards (183m). It covers the rocks of the main range, the mountain-side rising abruptly from the beach to heights of 2,000ft (610m) or more.... The height above the tide is about 10ft (3m)".

(xii). Porirua - Paremata - North Island West Coast

The account of the 1855 earthquake given by Lyell (1856b) mentions that "there was no noticeable rise ["perceptible elevation" in Lyell's 1868 version] of the coast 16 miles (26km) N. of Wellington", i.e. on the coast north of Porirua Harbour. Roberts (1855) states, "the whole country as far as Wai-nui, about

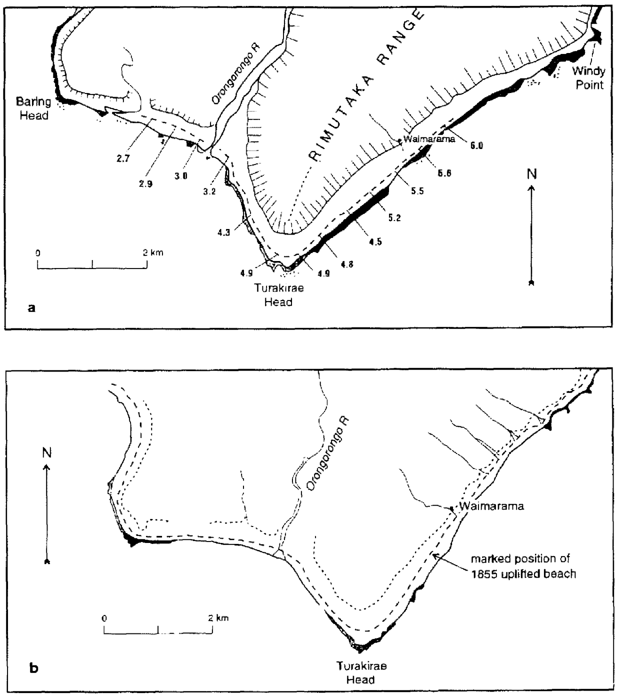


Fig.28.** a. **Map showing line of 1855 uplifted beach ridge around Turakirae Head (dashed line) and measured heights (in meters), (from Beach ridge C of Wellman 1967 that is now considered to be the beach ridge stranded in 1855). The highest value of 6m approximates the position of the Rimutaka Anticline where it intersects the coast. Shaded areas denote area of uplifted rock platform.** b. **Tracing after an 1868-69 survey map of the coast from Fitzroy Bay around Turakirae Head to Windy Point, Palliser Bay, showing the line of the uplifted 1855 beach, labelled on the original map as "High Water Mark previous to Earthquakes of 1848 & 55". (See text) The scale is close to that of Fig28a.

two miles (3.2km) northward of the foot of the road leading down the Pari-pari, was elevated ... though the elevation at the last named point was on the sea coast very slight". "Wai-nui" was just north of the present township of Paekakariki and about 16km NNE of the entrance to Porirua Harbour (Fig. 17). Lyell also mentions that according to Roberts the area of land permanently uplifted varied from 1 to 9ft (0.3 -2.7m). From the point of no, or "very slight" uplift, 16 miles (26km) north of Wellington, Lyell (1868) describes that the uplift, "went on increasing somewhat gradually", to the east so that the 1ft (0.3m) of uplift probably refers to the area of Porirua Harbour (Fig.17b). This is south of Wainui and therefore within the area considered by Roberts as being "elevated". A contrary claim made by Sir James Hector simply states, "the vicinity of Porirua Harbour not being affected" (Hector 1891). One account (unknown source, Fildes Collection) records that some subsidence occurred, "at Paramatta [Paremata], there was a subsidence of parts of the harbour, boats that had been pulled up on the sand [were found] floating over several feet of water".

In this last extract the state of the tide is not referred to and although partial subsidence of "several feet" seems excessive, the environment of Pauatahanui Inlet is not dissimilar to the lagoonal area in the lower part of the Wairau Valley where there was differential subsidence caused by compaction of soft sediment of between 2 and 5 ft. (0.6 - 1.5m) in 1855 (Roberts 1855; Lyell 1856b,1868; McIntosh 1940). The hydrographic map "Cook Strait" made from soundings of the *Acheron* between 1849-1851 (Hydrographic Dept. of the British Admiralty 1878) and the Porirua Harbour chart of 1850 (Hydrographic Dept. of the British Admiralty 1858) which includes part of Pauatahanui Inlet, shows two large sand banks between two channels "navigable for boats only" in the western part of the inlet. Allowing for inaccuracies in the position of the coastline on these maps, parts of the area covered by the sand banks, particularly the more eastern one, have subsequently been deepened (Healy 1980). These areas may have been those "parts of the harbour" that subsided during the earthquake. Today, the most extensive area of banks are located at the western end of the Inlet. These banks show a variable rate of change in their morphology and position, although over the period 1942-1972 this has generally been small. The stability of the banks is largely maintained by the growth of eel grass which filters out sediment and accelerates silting. Similarly, the charts also show two extensive sand banks aligned along the centre of Porirua Harbour that are bordered by channels labelled "navigable for boats only". These sand banks are not apparent today, even at low tide. Possible subsidence during 1855 could be suggested although the erosive action of changing currents might also be responsible.

The question of partial subsidence in Porirua Harbour also appears in the notebooks of Sir Charles Lyell (1856b) in which he recorded his interviews with Edward Roberts and Walter Mantell; "The old post of a native village according to Mantell indicates subsidence under the low water — Mr Roberts has been there, knows the place well and saw nothing to indicate it". An early painting by Samuel Brees of the Maori settlement near the entrance to Porirua Harbour and Pauatahanui Inlet shows several such "posts" partially immersed in the harbour and these would have afforded good markers of any uplift or subsidence.

The Porirua coast shows evidence of uplift in the form of a raised rock platform (Adkin 1921) and at the entrance to Porirua Harbour and within Pauatahanui Inlet elevated rock platforms, beaches and spits are recorded by Adkin (1921) and McFadgen (1980). The last uplift in the area has been ascribed by these authors and others (e.g. Best 1914; Leamy 1958; Healy 1980) to the 1855 earthquake and is stated to have been 3ft (0.9m). Adkin (1921) quotes a Mr. James Jones, an 'old Pauatahanui settler', who stated that an area of at least 100 acres (40 hectares) of the tidal flats of Pauatahanui was raised above sea level and his estimate of the amount of uplift was 3ft (0.9m) and that there was shallowing of the Pauatahanui Stream as mentioned by Bell (1910). This uplift is contrary to inferences from the statements of Roberts and Lyell that uplift was only about 1ft (0.3m).

Legal proceedings in 1902 (N.Z Law Reports, pp. 464-483) concerning rights to land bounded by high water mark at the head of Pauatahanui Inlet which had been "removed several chains to westward" as a generally accepted belief that this was "one of the effects [uplift] of an earthquake in 1855". However, the Chief Justice, Sir Robert Stout, suggested the possibility that "the land ... has been formed by a gradual accretion caused by deposit of silt etc.", although conceding that this had occurred since the earthquake. The idea of shallowing due to accelerated silting after 1855, mainly due to clearance of the bush rather the tectonic uplift has been argued by Quennell (1938) and Eiby (1990). Four main streams enter the inlet, Pauatahanui, Horokiwi, Duck Creek and Kahao Streams. The largest streams, the Horokiwi and Pauatahanui, enter the inlet at its eastern end so that it might be expected that accelerated sedimentation that may have occurred subsequent to the 1855 earthquake would have been largely confined to the delta areas of these streams. Deforestation of the area is probably the main cause of any siltation of the inlet.

South of Porirua Harbour, at Smiths Bay just north of Makara Beach and at Te Ikamaru Bay some 6.1 kilometres south of Smiths Bay, McFadgen (1980) has determined the uplift height (i.e. emergence height) of the 1855 beach as 0.8 and 1.1m respectively although he also records the presence of 6.2Ka driftwood in estuarine muds at almost the same height above present high water level at Smiths Bay.

(xiii). Wanganui

William Bennett (in Mallet 1858) considered that the 1855 uplift extended from Wanganui around the coast to Castle Point on the East Wairarapa coast. That slight uplift occurred at Wanganui is supported by two other claimants; "Hereabouts (Wanganui) we are upheaved about a foot (0.3m), but the upheaval was greater inland, as the tide which at high spring used previously to reach Karatia, has since only extended to Parakino" (unsourced reference in the 'scrapbook' of J. J. Burnett 1904), and "Wanganui was upheaved by the shock to the extent of from 1ft. to 15 inches (0.3 - 0.4m): but all but about 6 inches (0.15m) was gradually lost afterwards" (Field 1891). Such precise measurements could only have been made at the coast and it is unfortunate that Field, a careful observer, who published accounts of other earthquakes as they affected Wanganui, e.g. Field (1898), does not elaborate as to what features were used to determine of this uplift and subsequent sinking.

(xiv). The Possibility of Uplift East of the Rimutaka Range

There are several reports suggesting that some uplift may have occurred east of the Rimutaka Range and specifically east of the Wairarapa Fault during the 1855 earthquake. The presence of Holocene uplifted beach ridges along the east side of Palliser Bay (e.g. Ghani 1978) on the eastern flank of a growing anticline (Pounui Anticline with an uplift rate of 1.4m/ka) just east of the Ruamahanga River connection between Lake Wairarapa and Lake Onoke (Heath 1974) and the western deepening of Lake Wairarapa, are both indicative of earthquake related tectonic uplift, with uplift increasing eastwards towards the Aorangi Range. In terms of the evidence for Holocene uplift of the area, the possibility of tectonic uplift in 1855 is not unreasonable.

The report of Edward Roberts and reminiscences of Alfred Matthews concerning the changes that took place at Palliser Bay during the earthquake, specifically mention that there was no uplift to the east of the Rimutaka Range; " This valley and plain remain on the same level as before [the earthquake], the range of hills [Rimutaka Range] having gone up alone," (Roberts 1855) and "The eastern side of Palliser Bay was not affected to any great extent in the way the features of the country being changed" and "On the Whatarangi side of the bay [east side of Palliser Bay] there was no upheaval, if anything a slight sinking. After the shake the cliffs caused a lot of trouble, and several tracks along the face had to be cut, on account of the sea encroaching" (Matthews 1901).

McKay (1901) mentions that "the earthquake of 1845[1855] which was the cause of the raised beaches along this coast [western side of Palliser Bay] according to the old settlers, did not affect the spit [the area between the Lake Onoke outlet and Kirawai]. The height of these raised gravels is considerably lower than the adjoining bar of Onoke Lake, parts of it being barely above the tide".

Available evidence of possible uplift east of the Rimutaka Range is reviewed below.

According to Charles Matthews, (c. 1925), at Kiriwai, situated at the southwest corner of Lake Onoke, "great changes had taken place - the backwater, as we called it - where probably the lake at one time or another had flowed out to sea, was wholly changed. The connecting channel from the Lake, which was a considerable depth before the shake was practically dry." While this could be interpreted in terms of tectonic uplift, it could also be due to lateral spreading of the sand and gravel that make up the bar as a result of earthquake shaking. This would account for the disappearance of the 'deep' connecting channel between the 'backwater' mentioned by Matthews, and Lake Onoke (Fig.29). There is no evidence of tectonic uplift in this area as the height of the highest Holocene beach is less than the height of the present day beach ridge, an observation also made by McKay (1901).

Alfred Matthews (1901) also recalls that "a lot of the Lake lands, which previously lay so low, so as to be practically useless, were shaken up and became fairly useful land." In 1891, a government commission was convened to consider Maori ownership claims to this land "uplifted during the 1855 earthquake" (McKay 1891). The case put was that, "In 1855 heavy earthquakes raised the land, and the lakes were lowered, leaving large strips of land between their borders and the previous high-water mark, which can be easily defined to this day by logs and other land-marks. The boundaries of the sales can also be proved by living witnesses". Evidence given at the inquiry relative to this allegation was conflicting. Some witnesses testified that all the low-lying land between the margin of the lake and the flood-line had been raised, while others stated that it had only been raised in parts, and that the lake, when closed for any length of time, flooded the same extent of country as before the earthquake. The Commissioner's conclusion was that, "The allegation is not clearly expressed, as it creates an idea that large strips of land on the margin of the lake have been reclaimed through the action of the earthquake, which is not the case, although it is generally admitted that some places were raised by its action; but the area upheaved in this manner is insignificant when compared with the extent of low-lying land in the vicinity of the lakes".

The area referred to as being "raised" by the earthquake is in the vicinity of Kumenga near the south-east corner of Lake Wairarapa where deltaic sediments deposited by the Ruamahanga River occur (Fig.30). It seems highly likely that liquefaction and movement of these unconsolidated sediments into the lake could account for the "uplift" and/or that there was accelerated silt deposition following the earthquake. In any event, due to the low lying nature of the area, and the extreme shallowness of the lake, the apparent uplift would not have amounted to any more than 0.3m.

Several writers, (Heron 1928; Carle 1945; Carter 1982) have repeated the assertion that after the 1855 earthquake the Te Kopi anchorage in Palliser Bay "was dewatered"; "the anchorage at Te Kopi was rendered useless owing to lack of depth of water"; "The anchorage at Te Kopi was lost". The source of this

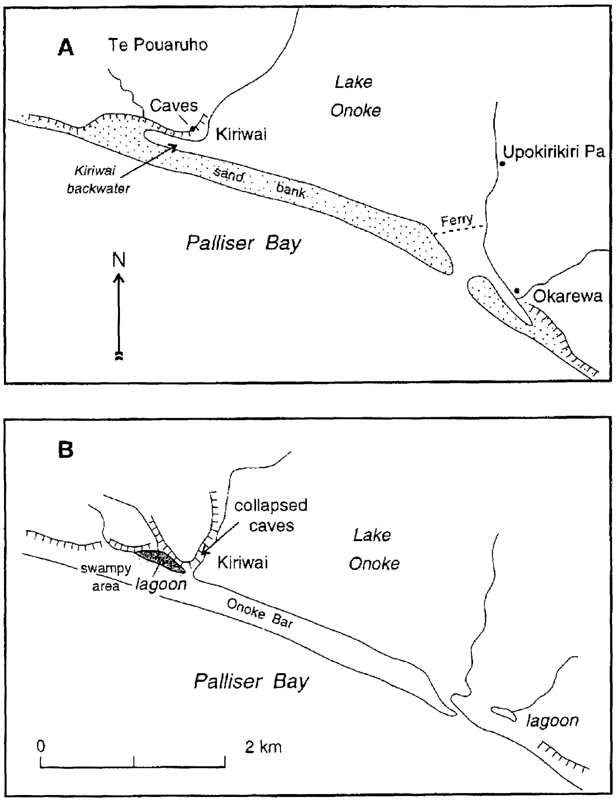


Fig.29. Pre-1855 (A) and post-1855 (B) sketch maps of the Lake Onoke area, Palliser Bay, showing possible changes resulting from lateral spreading of the Onoke Bar during the 1855 earthquake (see text). At this locality no tectonic uplift is evident. (A) is drawn from an 1849 survey map of "Valley of Wairarapa and Ruamahanga" by William Mein Smith (SO 10468. Land Information New Zealand Wellington). (B) is drawn from NZMS 260 Sheet R28 Turakirae, 1:50 000 1979, Department of Lands and Survey, New Zealand.

information is nowhere cited, but it is certain that following the earthquake Te Kopi was no longer in use. Te Kopi was a small 'harbour', formed by a slight indentation in the coast line about 4.3 kilometres south of the north-east corner of Palliser Bay where ships up to 400 tons could shelter (Fig.31). It was an important anchorage for the transport of supplies and produce between the Wairarapa and Wellington prior to the 1855 earthquake. Te Kopi was, and still is, sited in an area of Tertiary mudstone which forms cliffs north and south of the anchorage. If shallowing of the Te Kopi anchorage after the 1855 earthquake was not due to tectonic uplift then it may have been caused by landsliding. The mudstone cliffs fronting the sea near Te Kopi are subject to extensive erosion and gullying so that vegetative cover was and is scarce (Fig.15a). It seems highly likely that landsliding and consequent increased sedimentation from this unstable area in 1855 could have resulted in a shallowing of the Te Kopi anchorage. There is no record of sudden landsliding into the sea from the cliffs in 1855, although Alfred Matthews (1901) does mention that "the cliffs caused a lot of trouble" on the eastern side of Palliser Bay, near Whatarangi just south of Te Kopi (Fig. 31), and that ".. several tracks had to be cut, on account of the sea encroaching". Similarly, Iorns (1932) mentions that many landslides occurred along the coast east of Lake Wairarapa.

There are two contradictory statements with respect to the situation on the east Wairarapa Coast. Mason (1855) states that,

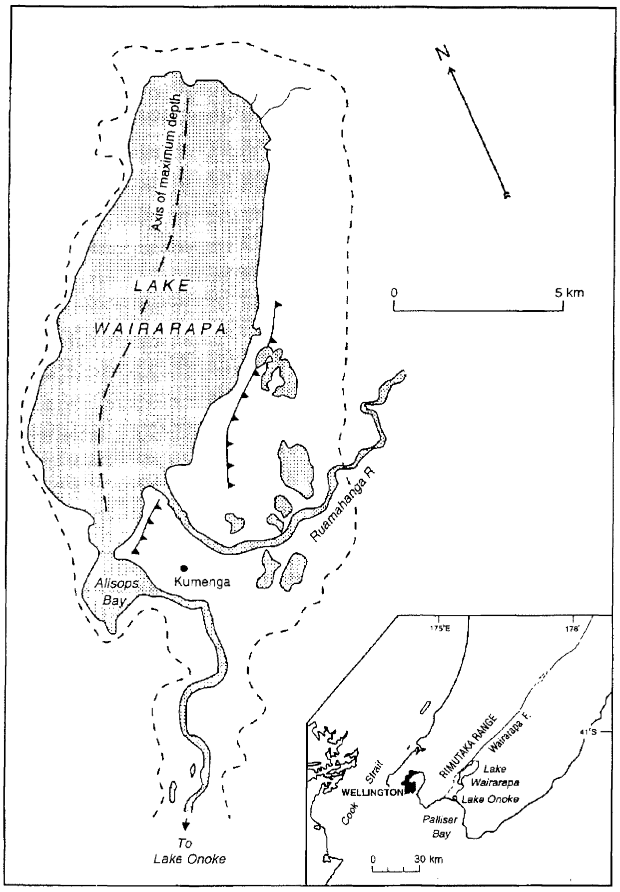


Fig.30. Map of the Lake Wairarapa area (after McKay 1891). Dashed line denotes the flood-mark of the lake that was claimed by the Maoris as representing the boundary of "solid" land. Areas within this boundary were said to have been uplifted by the 1855 earthquake (see text). Barbed lines indicate position of possible ?3.8ka sand dune. Any change in land surface level (i.e. by earthquake uplift or siltation/lateral spreading of soft deltaic sediment) presumably occurred west of the sand dune lines.

"On the east coast [i.e. the Wairarapa coast] the land is not upheaved", whereas, William Bennett (in Mallet 1858) states that the coast was uplifted as far north as Castle Point. Raised beaches occur along the east Wairarapa Coast that record tectonic uplift since 6.5ka (e.g. Wellman 1971; Singh 1971; Ota *et al.* 1990). The lowest and most recent uplifted beach ridge varies in height from 1-2m above the modern storm beach. If this amount of uplift occurred in 1855 it would almost certainly have received mention.

(xv). Wairau Valley

In the lower Wairau Valley there are many reports of subsidence having occurred during the 1855 earthquake. McIntosh (1940) records that William Budge, who was living at Budge's Island near the mouth of the Wairau (Fig. 32) records in an 1855 letter to the Superintendent of Nelson (letter has not been found) that "the subsidence of the whole district at the time of the last severe earthquake [1855] to the extent of at least eighteen inches (0.5m)" forcing Budge to leave the island because it had become waterlogged. Buick (1900) quoting an unnamed source, states that "the land which is now covered by the Vernon Lagoons was

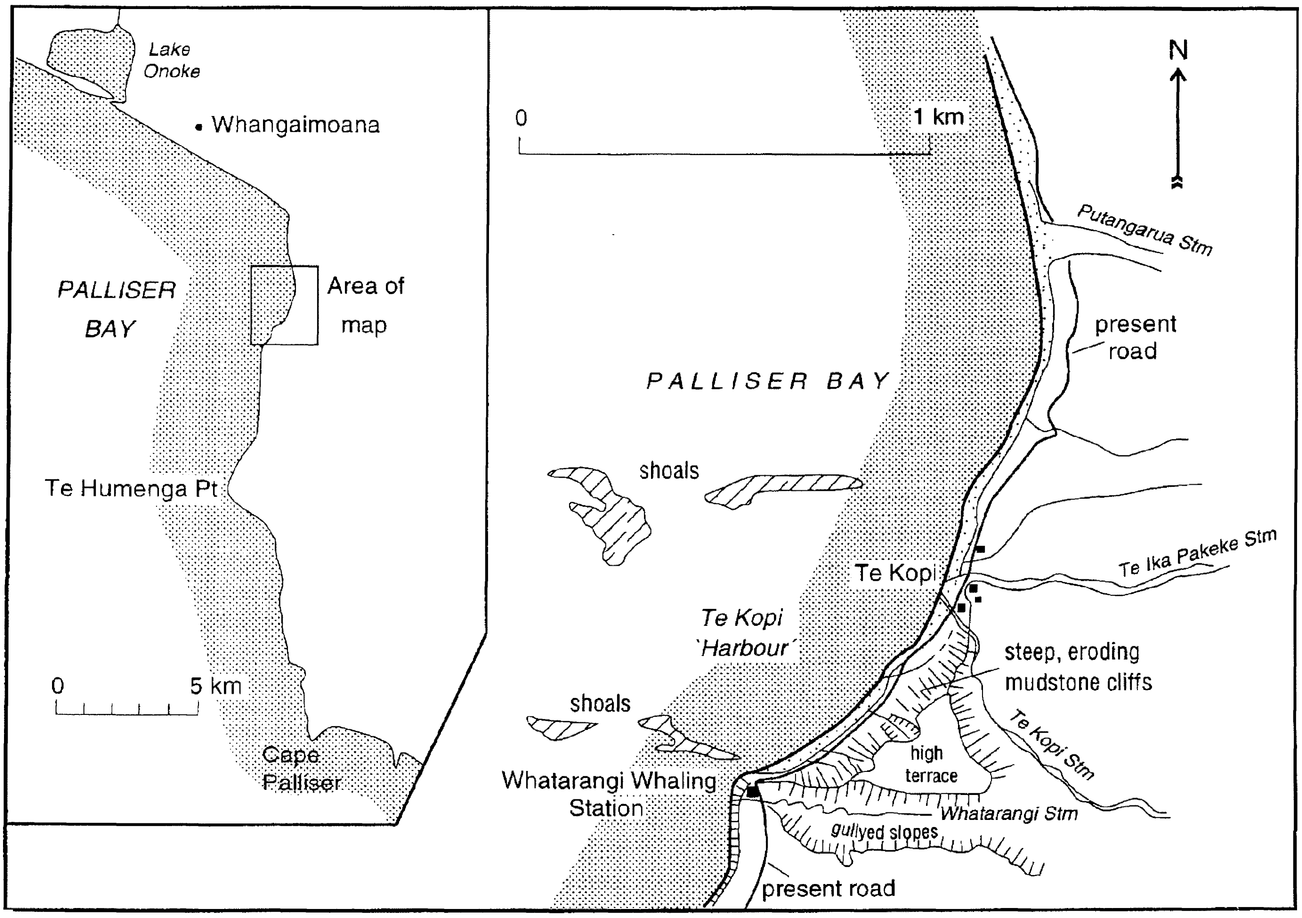


Fig.31. Map of the Te Kopi area, Palliser Bay (see text). The area of the "steep, eroding mudstone cliffs" was sketched by William Mein Smith and is shown in Fig.15a.

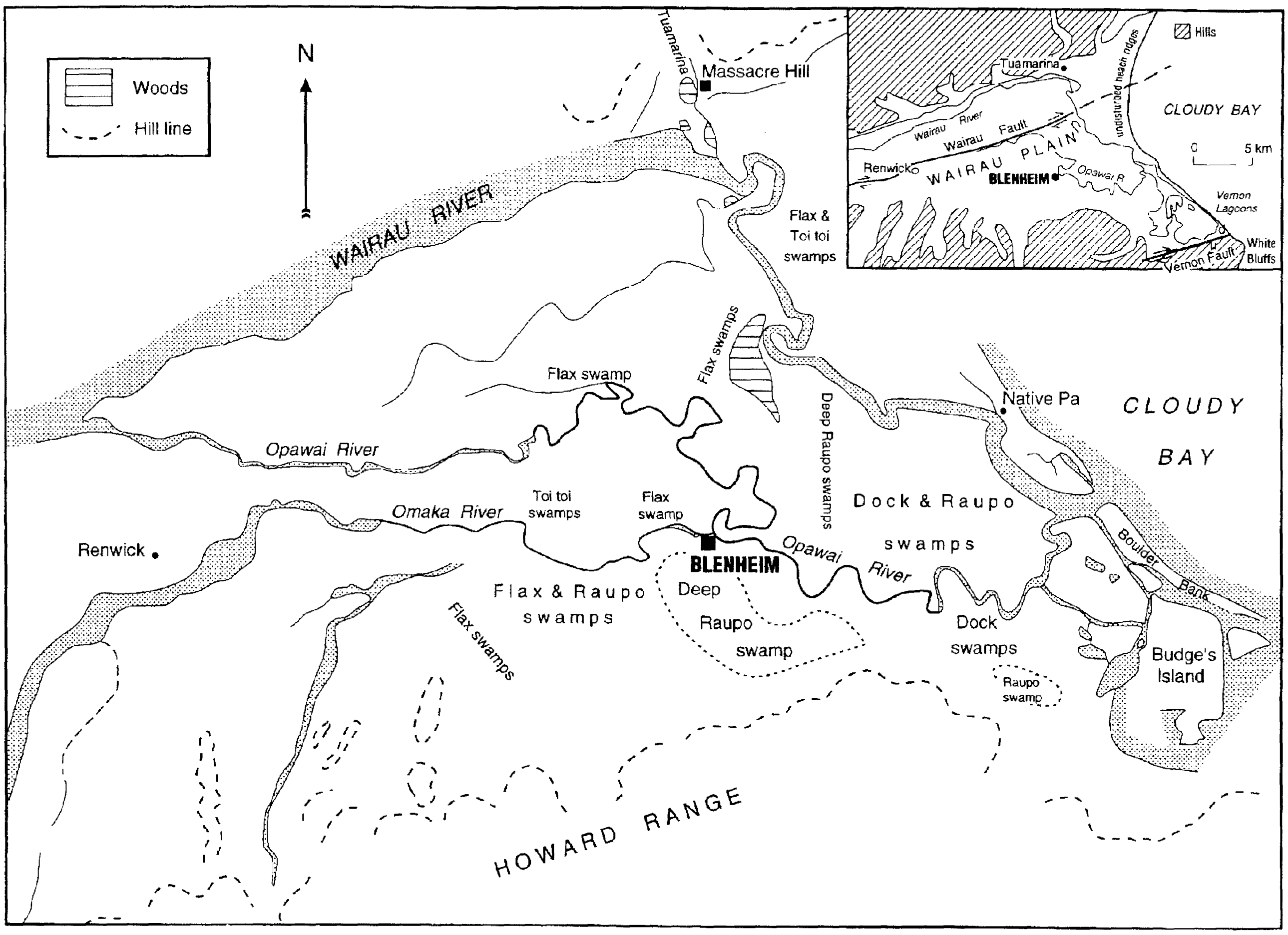


Fig.32. Sketch map of the lower Wairau Valley showing areas mentioned in the text and the distribution of swamps. The map is drawn from an 1848 New Zealand Company map entitled "Rural lands in the Wairau and Wakefield (i.e. Awatere) Districts, Settlement of Nelson, Middle Island of New Zealand" probably after an 1847 survey made by William Budge (Alexander Turnbull Library, NLNZ). Inset map shows line of the Wairau and Vernon faults with arrows indicating dextral sense of movement and "u" and "d" indicating upthrown and downthrown sides respectively.

lowered at least 24 inches (0.6m)", and a letter from Thomas Mason (1855) also records that, "At Wairau the land appears to have fallen about 2 feet (0.6m)". In a scrapbook of J. Burnett (1904) an undated newspaper article records that those "people whose houses stood on the flat in the Wairau Valley had to shift to higher ground to avoid being flooded out". According to McIntosh (1940), the Opawa River was deepened by the earthquake and "it was soon discovered that small schooners could navigate the bar [at the mouth of the confluence of the Opawa and Wairau rivers] and sail almost up to the tidal limits, which were just beyond the railway bridge over the Omaka", which is 18.5km inland from the coast (Fig.32).

The estimates of about 2ft. (0.6m) of subsidence given above are about half the amount of subsidence reported by Roberts (1855) and Lyell (1856a,b;1868) for the lower Wairau Valley. In Roberts' account, "The valley of the Wai-rau, on the middle island (which appears to have formed part of a continuous basin with the Wairarapa), together with parts of the adjoining coast, subsided, during the shock, about five feet (1.5m); so that now the tide flows eight miles (13km) further into the Wai-rau river than it did formerly". Lyell's accounts add little to that of Roberts; "... Mr. Roberts states, that settlers have now to go three miles (4.8km) further up the river Wairau to obtain fresh water, than they did before the earthquake" (1856a); "it seems that south of the strait [Cook Strait] the direction of movement was reversed, that is, almost everywhere there was a downward movement. The Wairau Valley and part of the adjoining coast, subsided about 5 feet (1.5m) in such a way that now the tide flows several miles further up the Wairau River than it did before" (1856b). The difference in estimates of subsidence in the lower Wairau Valley could be explained by differential subsidence, a conclusion also supported by Furkett (1953) who was involved in engineering work to divert the Opawa River in 1919. Furkett writes;

> "In April, 1861, the overflow of the Wairau River into the Opawa caused alarm (and well it might).... It had been the writer's opinion that the prevalence of the flooding in the lower Wairau Plain, including Blenheim, was due in part to the lowering of the alluvial lands by the shaking of the 1855 earthquake, the river from the Omaka Junction seawards having become navigable after that earthquake, but William Budge, a surveyor giving evidence on the question of a bridge site, stated that in a flood of 1854 he had seen two feet (0.6m) of water over the town site. On 22nd September, 1860, Dobson had referred to the Opawa 'having been flowing out of the Wairau for some years'. It seems probable that the earthquake of 1855 caused so much compaction of the deltaic and fluviatile material in the lower reaches that the river's banks became lower than they had been, thus

facilitating overflow towards the Opawa. Navigational evidence shows clearly that the seaward 12 miles (19km) of the Opawa was considerably lower after this earthquake".

The area is question contained innumerable swamps as shown on a New Zealand Company survey map of 1848 (Fig.32) making subsidence through compaction highly likely during earthquake shaking.

It should be mentioned here that according to Cotton (1954) and Eiby (1980) the amount of subsidence in the Wairau during the 1855 earthquake reported by Roberts (and subsequently by Lyell) is incorrect. This claim is unfounded and rests on no better evidence than a supposition that Roberts confused the dates because of "a belated report of the events of 1848" (Cotton) or that Roberts's informant confused subsidence with "some of the transitory 'tidal' phenomena that undoubtedly occurred" (Eiby). Available historical evidence indicates that the subsidence that occurred in 1848 was probably localised. A journal entry of Frederick Weld (November 2 1848; Weld 1846-52) mentions that, "In the Wairau the surface crust of dry land has in some places sunk 10ft (3m) the water spouting up through diminutive craters from the swamp subsoil". This implies that he observed instances of local subsidence related to "sandblows", a phenomena that was also widespread throughout the lower Wairau in 1855. More specific is the information provided by Judge Chapman (1849), "A report that there has been some subsidence of land at the Wairau Plain (where the Nga-ti-toas massacred their prisoners in 1843), creating a swamp where the land was dry before, and draining another place hard by". The area referred to by Chapman is Tuamarina, site of the well-known Wairau massacre (Fig.32). It may be significant that this area lies on the boundary between Pleistocene alluvial gravels and the estuarine sediments of the Dillons Point Formation that represent the maximum post-glacial inland transgression (Brown 1981). It is therefore possible that the subsidence referred to by Chapman was the result of differential compaction across this boundary during the 1848 earthquake. We have been unable to find any accounts of more general subsidence in the lower Wairau Valley in 1848. From the evidence presented above it appears that significant subsidence of the lower Wairau Plain, and in particular the Vernon Lagoons area occurred in 1855 and not in 1848. Key supporting evidence comes from William Budge and Budge's Island. The lower Wairau area was surveyed by Budge (a New Zealand Company Surveyor) in 1847. Subsequently, Budge occupied and grazed the area of Budge's Island (Fig.33) until the 1855 earthquake when it became so sodden through subsidence that he was forced to leave. If significant subsidence of this area had occurred in 1848, it seems hardly likely that Budge would have been able to graze it.

Vertical deformation at any locality is the net result of tectonic movement plus settlement. On rock or firm ground settlement should be negligible but in areas underlain by soft, waterlogged sediment significant compaction would be expected in addition to any tectonic deformation. The lower Wairau Plain is such an area and it underscores the difficulty of resolving the relative contributions of tectonic movement versus compaction to the reported subsidence in 1855.

A recent study of regional subsidence in the Marlborough area has been made by Ota *et al.* (1995) and shows that over the last c. 6ka the total subsidence rate in the lower Wairau Plain has been c. 4.6 mm/yr of which c. 60% may be tectonic and the remainder by compaction. Several bore holes from the Vernon Lagoons area behind the Boulder Bank (Figs. 32, 33) indicate the presence of between about 0.5 and 3m of silt and sand overlying the shallowest horizon where marine shells, C^{14} dated at between 860 and 1.950ka, are found (Dillons Point Formation) thus providing compelling evidence of long term differential subsidence. However, the possibility that some tectonic subsidence affected the lower Wairau Plain during the 1855 earthquake is strengthened by the fact that the area had already been severely shaken by a large earthquake just seven years before in 1848 (same MM intensity as in 1855) when some compaction undoubtedly occurred (e.g. Eiby 1980). The evidence cited by Roberts, Lyell and Furkett above relating to encroachment of sea water for several miles up the Wairau River and the improved navigability of the Opawa River following the earthquake, suggests that subsidence affected a significant part of the lower Wairau Valley and strongly implies a tectonic component. North of the Wairau River is an extensive area of beach ridges that extend inland from the coast for a maximum of about 2km. There is no progressive change in elevation of the ridges inland from the coast (Pickrill 1976) suggesting that there has been no appreciable compaction of the gravel or that the beach ridges are the result of uplift stranding. The beach ridges extend across the Wairau Fault that is downthrown on the SE side (Grapes & Wellman 1986), (Fig.32). The youngest ridges are not offset indicating that there has been no movement on the fault for about the last 800 years that could account for tectonic subsidence (Grapes & Wellman 1986). Furthermore, the coastal route between the Wairau and Awatere valleys around White Bluffs does not appear to have been affected by subsidence during the 1848 or the 1855 earthquakes as it would have almost certainly been commented upon if it had (e.g. Kennington 1978). Therefore, if 1855 subsidence in the lower Wairau Valley had a tectonic component as we believe, it was apparently restricted to the area north of the Vernon Fault that forms the southern margin of the Vernon Lagoons (Fig. 32) and probably included the area on both sides of the Wairau Fault. It is interesting to note that the regional vertical deformation predicted by the listric Wairarapa Fault model of Darby and Beanland (1992) indicates between 0.2-0.4m tectonic subsidence of the Marlborough coastal area.

(xvi). Possible Uplift of Kaikoura Coast

A letter [dated January 7, 1949] from E. Weld (1949), son of Sir Frederick Weld and the last manager of Flaxbourne Station situated between Cape Campbell and Kekerengu on the Kaikoura Coast, implies that some uplift or shallowing may have occurred during the 1855 earthquake, "Flaxbourne River was deep enough for small craft to come up as far as the old boiling-down plant, and that was the reason that the original homestead [that of Sir Frederick Weld] was established a short distance further up the river. The big earthquake [1855?] of which you speak in your letter [letter by E. Roberts] was responsible for the alteration [a shallowing?]. The cutter which was used for trading with Wellington used the river which in those days acted as a harbour". Unfortunately the letter of E. Roberts is not archived. The river harbour referred to was the landlocked estuary of the river "where there was six to seven feet (1.8 to 2.1m) of water at low tide" and the river entered it for about "a mile (1.6km) between hills of considerable height" (Journal 1846, Weld 1846-52). As with Te Kopi at Palliser Bay, the presumed shallowing of the river "harbour" could have been caused by landsliding from these "high hills" or accelerated siltation as a result of the earthquake.

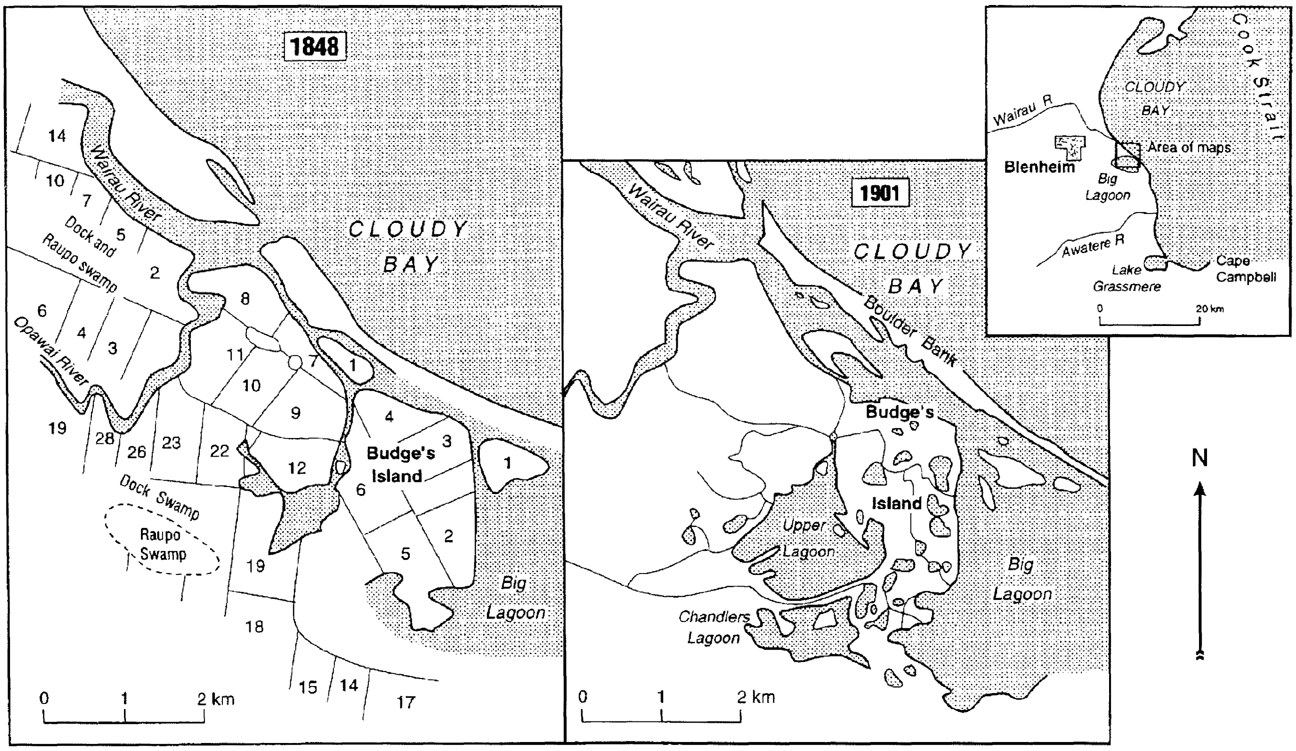


Fig.33. Comparison of surveys of the lower Wairau Valley, Marlborough in 1848 and 1901, showing evidence of subsidence (particularly in the vicinity of Budge's Island) inferred to have occurred during the 1855 earthquake (see text). The 1848 map is the New Zealand Company map referred to in Fig. 32. The 1901 survey map is entitled "Topographic plan of part of the Clifford Bay Survey District (20 chains to an inch) by J. L. D. Irvine. (Map - 621, Land Information New Zealand).

Certainly, the hills in the area were clearly prone to landsliding during the earthquake as reported by Monro (1855) and Trolove (1855) (see section on Ground Deformation). It is interesting to note also that a personal communication in an article by Cotton (1914) on the uplifted east coast of Marlborough from the same E. A. Weld of Flaxbourne mentioned above, states that the bed of the Flaxbourne River had been "perceptibly raised" as a result of aggradation. Cotton concludes that the aggradation was the result of man-induced destruction of original vegetation cover but earthquake landsliding is also a possibility as occurred in 1855. Nevertheless, the presence of well-preserved remnants of an uplifted wave-cut platform a few kilometres north of the Flaxbourne River (Plate XI of Cotton 1914) attest to the fact that this area of the Kaikoura coast had undergone earthquake uplift prior to 1855.

(c).Faulting

(i). Wairarapa Fault

The 1855 earthquake provided dramatic proof that earthquakes are associated with faulting in addition to changes in the elevation of the land. Sir Charles Lyell's (1856a,b; 1868; Lyell 1856a) accounts of the earthquake emphasise the appearance of the fault that ruptured in 1855 in a cliff at Palliser Bay and along the western side of the Wairarapa Valley and states that his informant, Edward Roberts "observed a very distinct fault line (Fig.12); on one side of the line, the rocks had been raised vertically to a height of 9 feet; on the other side there had been no movement of any sort", and that along the Wairarapa Valley the boundary between old argillaceous and "Tertiary " rocks seen at Palliser Bay are "marked inland by a continuous north-south escarpment along the Rimutaka Mountains (Fig. 34). The eastern side is escarped and looks down on the Wairarapa Plain formed of tertiary deposits. According to a witness, Mr Borlase who lives in the Wairarapa Valley about 60 miles (97km) north of Cook Strait, the course of the fault direction produced by the upheaval was rendered visible by the formation of an almost vertical wall (Fig.35). This contains the mark of the recent rupture of 9 feet (2.7m) and can be followed for the amazing distance of 90 miles (145km). Moreover, the fault is marked in many places by an open fissure into which cattle fell, and sometimes from which no-one could pull them out. At other places there are fissures, from six to nine feet (1.8 to 2.7m) wide, that are filled with mud and top soil" (Lyell 1856b).

The locality of the fault at Palliser Bay described and figured by Lyell (1868) appears to have been a noteworthy feature even before the earthquake and was described by Durmont D'Urville on the 28 January 1827 when he was anchored in Palliser Bay at a place "where the bed of a torrent had made a most extraordinary cleft in the cliff" (Wright 1950); the stream (Te Mahenga) apparently running along the fault contact between the "old argillaceous and tertiary rocks" described by Lyell (Fig.12). In Roberts' (1855) official memoranda of the earthquake, he does not specifically mention the word *fault* but states that the Rimutaka Range was uplifted relative to the Wairarapa valley and plain "forming a perpendicular precipice of nine feet in height which has been traced to a distance of ninety miles inland". It would appear that only after his meeting with Lyell in 1856, was Roberts aware that his "perpendicular precipice" represented a fault and that the length to which it could be traced was "extraordinary".

Despite the fact that the fault could be traced "for an amazing distance of 90 (145km) miles" along the eastern foot of the Rimutaka Range, there is little reference to it other than Robert's

report. Iveson (1954) quotes from reminiscences (c1890, the original cannot be located) of a Mr. Jackson of Stonestead [between Featherston and the Tauwharenikau River] who travelled over the Rimutaka Range to the Hutt Valley the day following the earthquake; "When I got to the ascent of the [Rimutaka] hill behind the Hotel [Burling's Hotel at Featherston] I found the road over the Rimutaka hill broken in two and one part raised six feet (1.8km) above the other". The locality described by Jackson is about where the trace of the Wairarapa Fault occurs west of present-day Featherston (Grapes & Wellman 1988). Another reference to the trace of the fault rupture comes from *Newstead* situated at the foot of the Rimutaka Range just north of Featherston where the hills behind the homestead "were slashed across by large fissures" (Joblin 1975). The locality described lies within the most recent, i.e. 1855, break along the Wairarapa Fault mapped by Grapes & Wellman (1988). The only other possible reference to faulting comes from Vennell (1891) who recalls how the Moroa (stony) Plain between Greytown and the Tauwharenikau River ... ''was rent for several miles, one part subsiding about two feet (0.6m)''.

No further information concerning the fault could be traced to Charles Borlase, the "settler" mentioned by Lyell who presumably informed Roberts that the fault was rendered visible by the "formation of an almost vertical wall" some 60 miles (97km) inland from the coast. This is an overestimate; Borlase's house

Fig. 34. Aerial photograph looking SW along the line of the 1855 rupture along the Wairarapa Fault, south of Featherston with Cross Creek in the lower part of photo. (Photo by Lloyd Homer, Institute of Geological and Nuclear Sciences).

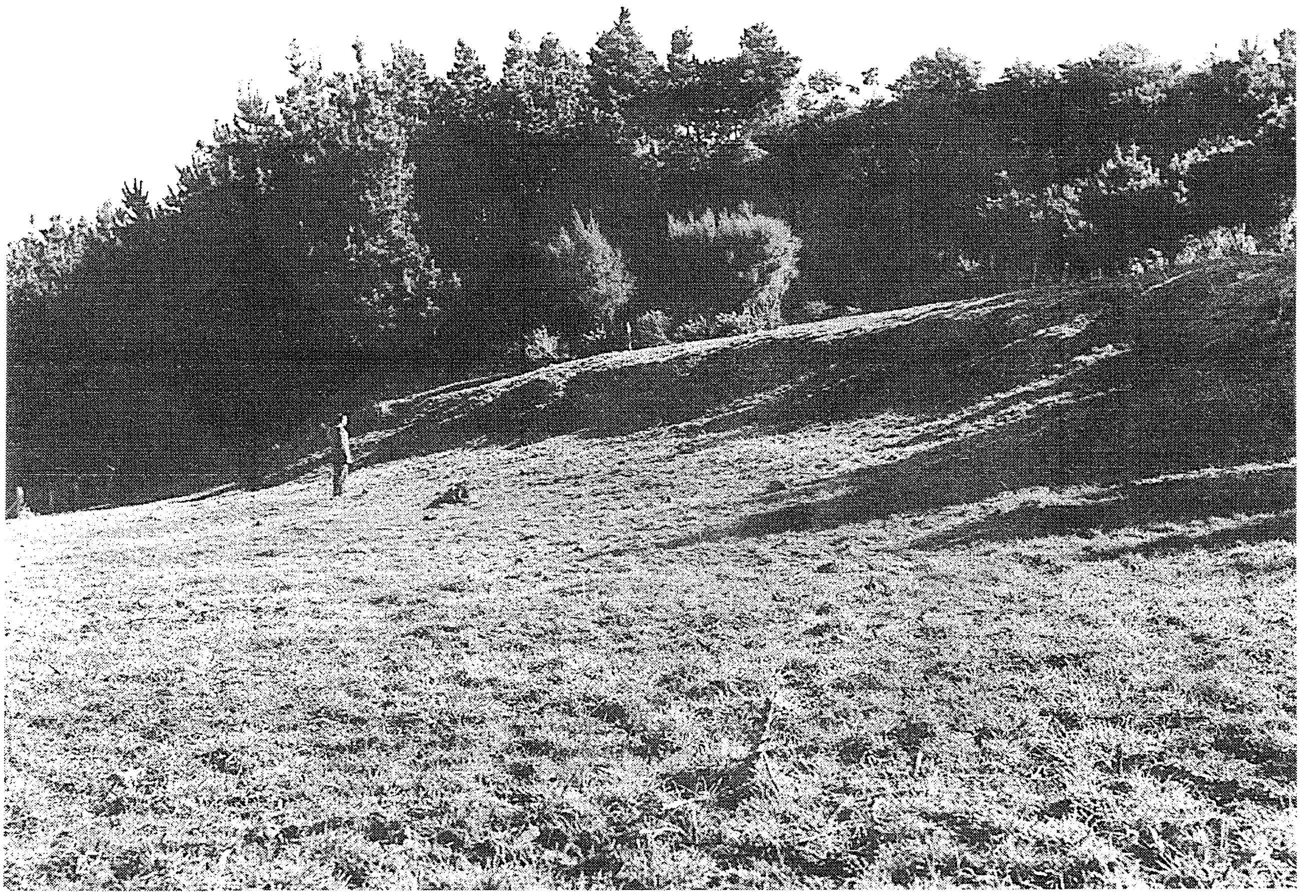


Fig. 35. The c.1.6m high scarp of the 1855 uplift viewed from the east near Pigeon Bush, south of Featherston, Wairarapa. (Photograph by Professor E. L. McKenzie, Victoria University of Wellington, 1959).

was situated 29 miles (47km) from the coast at Palliser Bay. A letter, published in the London *Times* in July 1855 that is almost certainly from Borlase (Anon 4), makes no mention of the newly-formed fault suggesting that at the time of writing he did not know that it existed. This is perhaps not surprising because in 1855 the foothills of the Rimutaka Range were largely covered by forest and Borlase's house situated near the confluence of the Waiohine and Ruamahanga rivers was 11km east of the nearest part of the fault break. Borlase was, however, in a good position to receive, albeit second-hand, descriptions from travellers who passed by. According to Bagnall (1976, p.143) he was a welcoming host.

In 1863, J. C. Crawford (1880) observed the fault just south of the Waiohine River and his description provides independent confirmation of Lyell's account: "Here the split or fissure may be observed which was caused by the earthquake of 1855 and the western side of which, or that nearest the mountains, stands at a height of several feet above the rest of the plain. The fissure may be observed all along the western side of the Wairarapa Valley for a distance of 60 miles [97km], and was clearly produced by the rise of the main range and not by the sinking of the plain".

The first person to show the Wairarapa Fault on a map was Alexander McKay (1892). The fault is depicted as a perfectly straight "rent" extending NE from Palliser Bay for 56km (far short of the 145km mentioned by Lyell). McKay mentioned that historical (presumably 1855) movement could be traced from Featherston to the sea on the west side of Palliser Bay and he recognised that there had undoubtedly been earlier movements on the fault. The Wairarapa Fault was first mapped in reasonable detail from the coast to just beyond Mauriceville by Ongley (1943) who considered the fault scarp to be the result of successive earthquakes, the last being in 1855 (Fig. 36). According to the fashion of the time he recognised the vertical but not the horizontal displacements. Ongley disputes Lyell's positioning of the fault at Palliser Bay "in a sea cliff, called Muka-Muka" because he erroneously restricted the location to the area of the Mukamuka rocks "two miles south of the bay-head down the west side", where there is no fault junction between the "argillite" and "tertiary rocks" described by Lyell. In the 1850's, "Mukamuka" generally referred to the line of sea cliffs that comprise the eastern flank of the Rimutaka Range where it meets the coast at Palliser Bay. He considered that the 1855 break did not reach the coast and that the most southerly evidence of the fault was a "fault wedge with two breaks on either side" (Fig.12) situated about 1 mile (1.6km) from the coast. Ongley also examined the site of Lyell's fissure in the Holocene marine cliff at the Te Mahenga Stream site and considered that it did not represent the line of the 1855 movement. He described the contact as a low angle thrust dipping to the west, rather different than the vertical fissure figured by Lyell. Nevertheless, the stream has undergone considerable aggradation since the earthquake, and what Roberts observed the morning after the event is now buried by several tens of metres of gravel (inset in Fig. 12). There is no doubt, however, that the Te Mahenga Stream exposure represents the easternmost contact between crushed greywacke of the Rimutaka Range and Pleistocene sediments of the Wairarapa Plain. For several hundreds of metres west of this contact, the greywacke contains rents (some of which are permanently water-filled) that can be traced along strike for hundreds of metres, are characterised by fault pug indicating recent, presumably 1855, movement over a wide zone (Fig.12).

Historical data and recent investigation indicates that vertical uplift along the Wairarapa Fault during the 1855 earthquake progressively decreases northeast from Palliser Bay, i.e. from a maximum of 6m a few kilometres NE of Turakirae Head to about 0.3m at Mauriceville, a distance of about 75km (Grapes & Wellman 1988), (Figs.37, 38). Along the western side of Palliser Bay the amount of uplift is given by the stranded pre-earthquake beach ridge; inland from Palliser Bay, uplift is shown by near vertical soil and alluvial gravel walls developed along the fault scarp especially where there is forest cover. The fault vertical displacement data coupled with that of coastal uplift allow a regional uplift map across the Wellington Peninsula to be constructed as shown in Fig.39.

Although vertical movement on the fault caused by the 1855 earthquake was recognised at the time, the much greater right lateral shift was not. In fact it was to be another 99 years before the dominant dextral displacement on the Wairarapa Fault was realised (Adkin 1954; Wellman 1955). The most obvious evidence of horizontal movement on a fault is where it displaces man-made features such as fences and roads, e.g. displaced fence lines across the Hope Fault at Glynn Wye during the 1888 earthquakes (McKay 1890). In 1855 the only man-made feature that crossed the line of the fault rupture was a bridle track that ran down the escarpment mentioned by Lyell at an oblique angle near Burling's Hotel on the site of the future town of Featherston, thus rendering any horizontal movement difficult to see although the vertical break was noted by Henry Jackson (Iveson 1954) the day after the earthquake. Although the significant amount of right-lateral horizontal movement along the Wairarapa Fault during the 1855 earthquake went unnoticed, the effect of this movement can, in

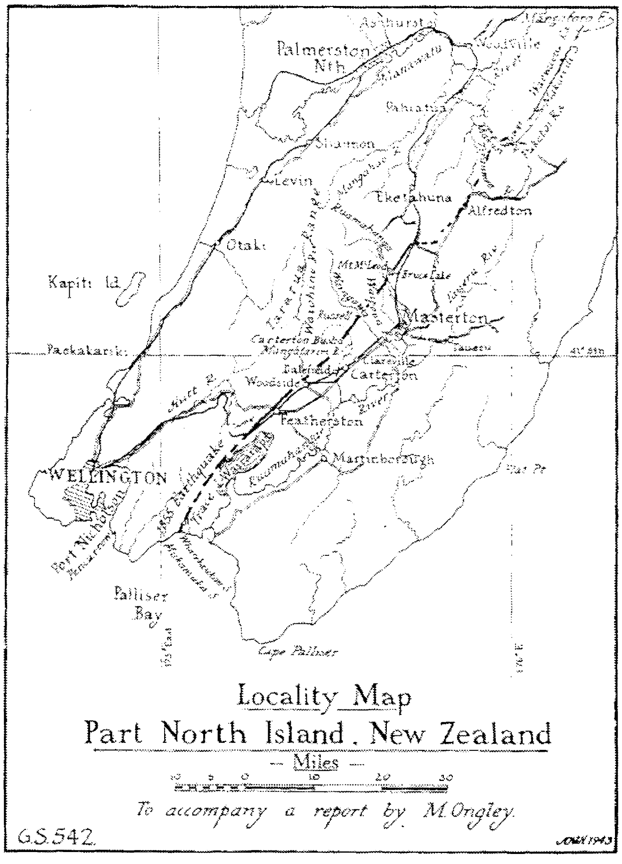


Fig.36. The line of the 1855 earthquake rupture as mapped by Ongley (1943).

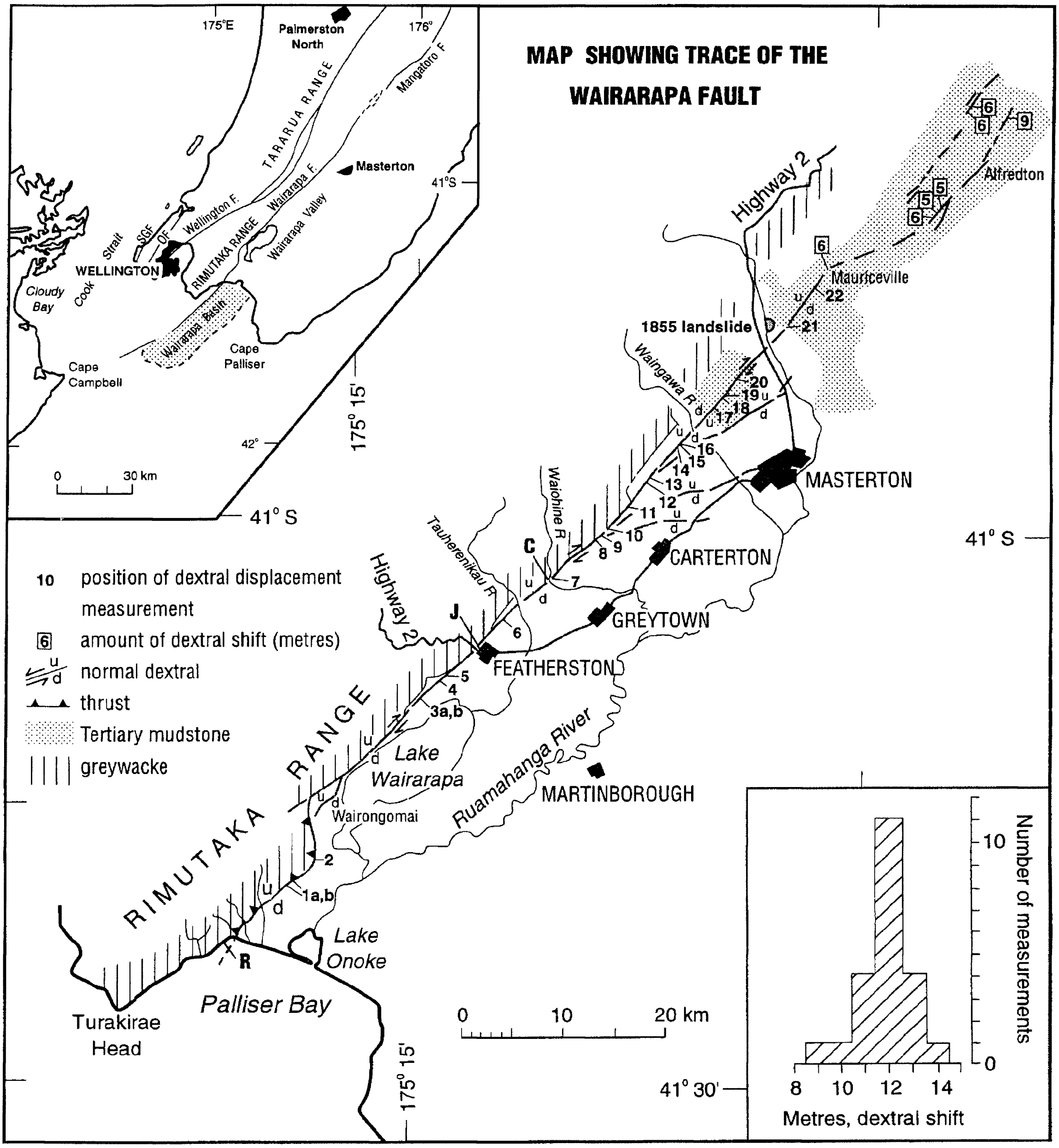


Fig.37. Map showing trace of the Wairarapa Fault (after Grapes & Wellman 1988). Numbers along the fault are sites where inferred 1855 horizontal and vertical displacement has been measured. A histogram of the horizontal displacement at 22 sites (26 measurements) is given in the inset. R, J, and C refer to localities of vertical displacement noted by Edward Roberts, Henry Jackson and James Crawford, respectively (see text). The segmented fault traces extending NE of Mauriceville to Alfredton and beyond are from Lensen (1970). T he boxed numbers refer to sites on these fault traces where the smallest and freshest-looking horizontal displacements have been measured by Lensen (1970). In the locality map SGF = Shepherds Gully Fault; OF = Ohariu Fault.

part, be inferred from the formation of an immediate wave in Lambton Harbour at the time of the earthquake as described by Jolliffe (1855) Jones (1855) Meredith (1898) and Brady (Fildes collection, date unknown) and from the movement of the *Pandora* described by Drury (see section on Tsunami and Seismic Seiche).

Adkin (1954) described the fault from Dalefield to the Waipoua River, 50 - 70km from the Palliser Bay coast. He distinguished between the eastern slope of the Tararua Range which he supposed to be the inactive Wairarapa Fault and the active (1855) trace already mapped by Ongley (1943) about 200m to the SE. Although Adkin recognised some large dextral displacements on the fault he did not consider this movement to be representative of the fault as a whole. The importance of horizontal displacement along the Wairarapa Fault was recognised by Wellman in 1955. At Waiohine River, he suggested (Recent Crustal Movements Conference 1970) that the smallest horizontal displacement of 12m and vertical movement (up to the west) of 1.5m of a river

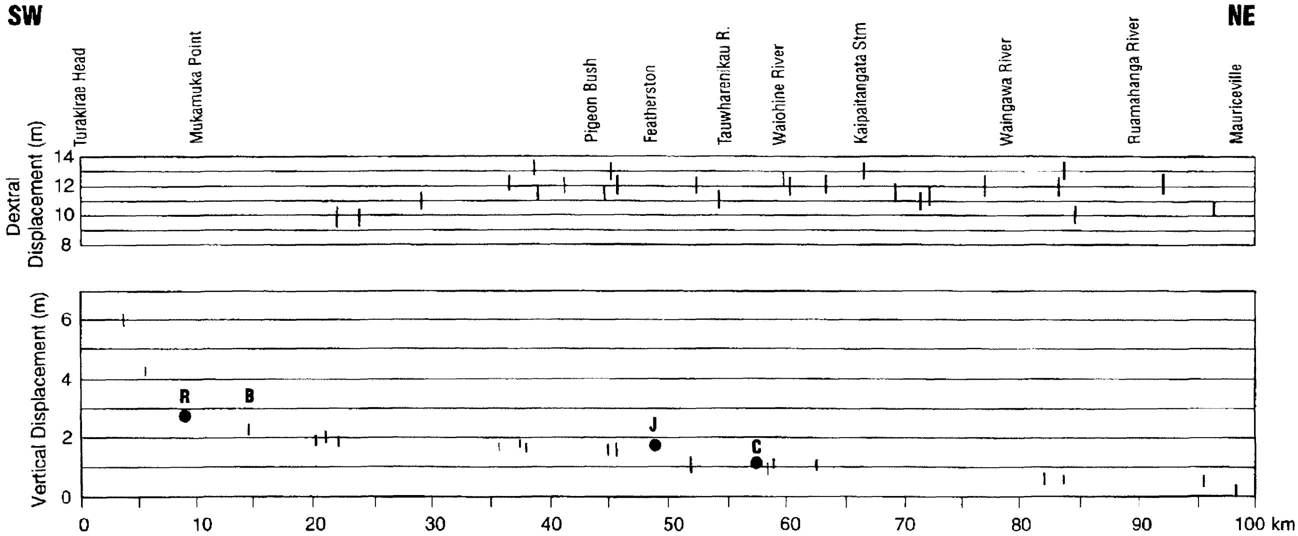


Fig.38. Plots of inferred 1855 dextral and vertical displacement along the Wairarapa Fault from Turakirae Head in the SW to Mauriceville in the NE. For solid dots labelled R, J, and C see caption to Fig. 37. For localities see Fig.37. Locality of B is shown in Fig. 12.

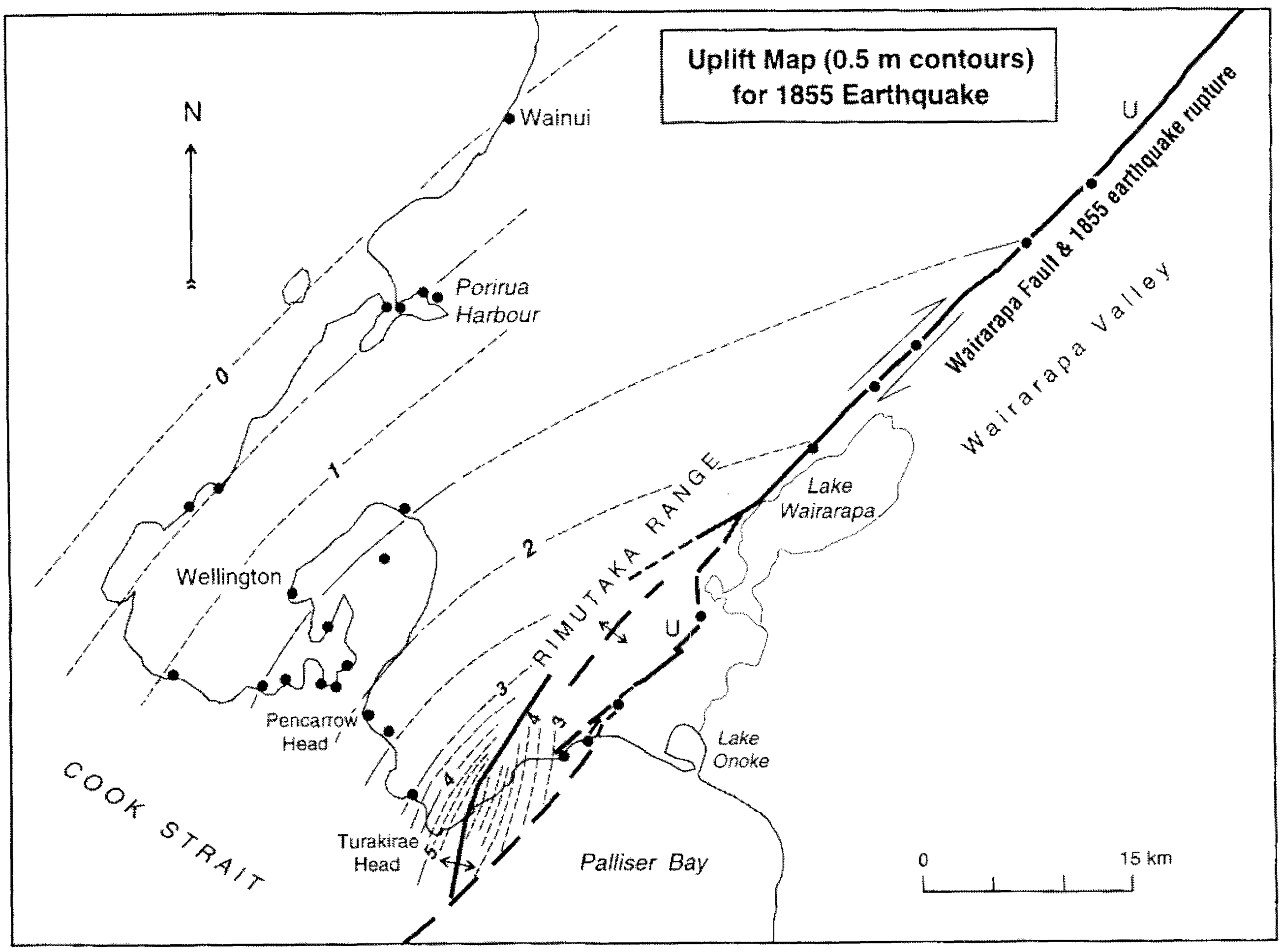
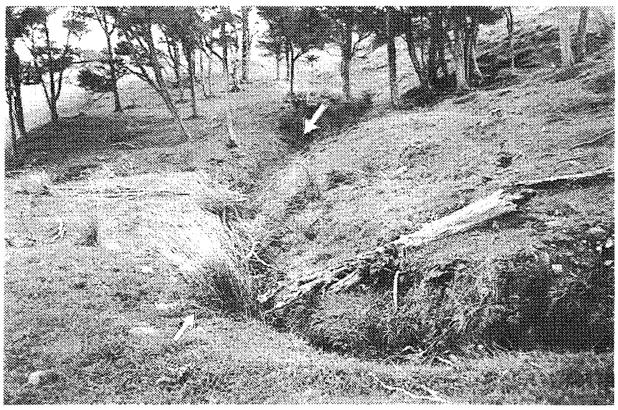
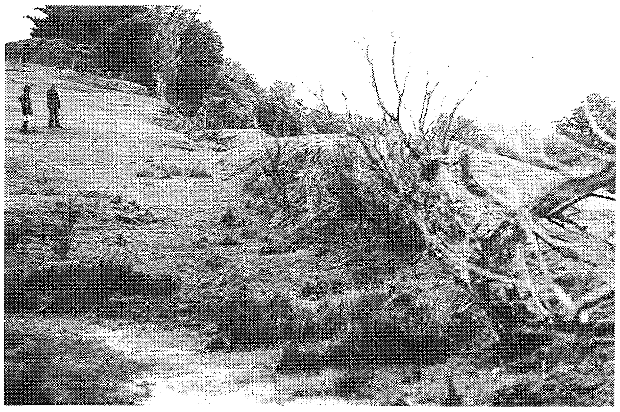


Fig. 39. Inferred uplift contour map (0.5m contour interval) for the 1855 earthquake. Solid dots = position of vertical uplift measurements along the Wairarapa Fault and coastal uplift measurements. Near Turakirae Head the uplift contours are closely spaced due to detailed measurements (see Fig. 28) and are constrained by the axis of the Rimutaka Anticline determined by Wellman (1967). "U" denotes upthrown side of the 1855 rupture along the Wairarapa Fault.

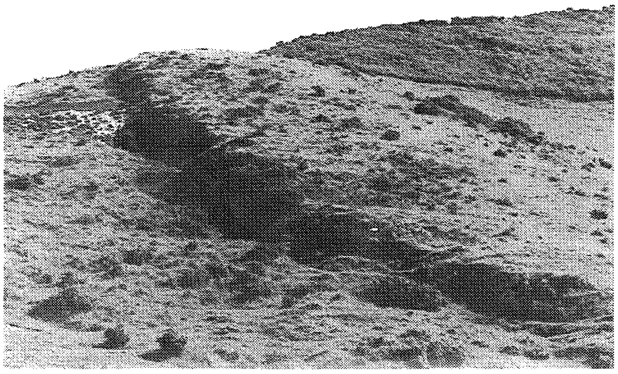
Fig.40. a. Photograph looking west with near vertical scarp of the Wairarapa Fault in the background and two stream channels beheaded at the fault scarp (Pigeon Bush, locality 4 in Fig. 37). The channels were the continuation of the bushclad stream cut in the upthrown (west) side of the fault scarp (right side of photo). The channels illustrate dextral displacement as a result of two earthquakes, the last in 1855 which resulted in the stream channel in the centre of the photograph being displaced to the left (southwest) by 12m relative to its incised continuation on the NW side of the fault. (Photo by R. Grapes 1990).



b. Photograph looking SW along the line of the 1855 rupture (arrowed) and showing dextral displacement of a stream by about 12m (Pigeon Bush, locality 5 in Fig.37). (Photo by R. Grapes 1988)



c. Photograph looking NE along the line of the Wairarapa Fault and showing an example of a protruding half-scarp caused by dextral displacement in 1855. Two figures are on the upthrown (west) side of the fault trace and the ridge on the right (east) side of the fault has been moved dextrally, i.e. towards the observer resulting in an apparent reversal of vertical displacement (i.e. on the east side rather than the west side of the fault). Matching the end of the ridge slope (partly covered with dead wood) on the east side of the fault with its equivalent on the west side of the fault (about where the figures are standing) indicates that the 1855 dextral displacement was about 12m (south of Tauharenikau River, locality 6 in Fig. 37). (Photo by R. Grapes 1988).



d. Photo looking southwest showing a prominent 1855 rent with vertical displacement (up to the west) of about 2.5m, Wharekauhau, Palliser Bay (locality B in Fig.12; also figured by Ongley 1943). (Photo by R. Grapes 1986).

channel in the lowest degradation terrace represented the movement in 1855. However, Lensen & Vella (1971) in their study of the faulted terraces at Waiohine River, adopted a horizontal value of 3m for the 1855 movement as judged from other historical earthquake displacements in New Zealand, rather than accepting the smallest recorded horizontal displacement of 12m. Previously, Lensen (1968) had mapped a 20km length of the fault from 66km to 86km from the Palliser Bay coast on a 1:63,360 scale and listed 70 sites with dextral and/or vertical displacements. Detailed mapping of the Wairarapa Fault by Grapes & Wellman (1988) located 22 sites (including re-measurement of some of those listed by Lensen (1968)) at which the horizontal displacement varied between 9 and 13m (Figs.37, 38). These represent the smallest and freshest looking displacements along the fault and are inferred to indicate the 1855 movement. Examples are shown in Fig.40 a,b,c and are represented by displaced river channels, doglegged streams, protruding half-scarps and slope rents. In rare cases, slickensides show a shallow (c.10°) dip to the SW indicating a predominant horizontal component of movement (Grapes & Wellman 1988).

The 1855 fault break is a single well defined and continuous trace from the southern end of Lake Wairarapa to just north of Mauriceville, a distance of 72km (Grapes & Wellman 1988), (Fig.37). From the southern end of Lake Wairarapa to the coast at Palliser Bay, a distance of about 19km the trace of the earthquake rupture is marked by a series of discontinuous scarplets, fissures and hill rents (Fig.40d). It has the same appearance over a 48km stretch from Mauriceville to just north of the Makuri River as described by Ongley (1943) and mapped by Lensen (1970), (Fig.37). The smallest and freshest horizontal displacements on these subparallel fault strands vary between 5 and 9m and could also represent the 1855 movement. If so, this gives a minimum on land distance of 140km for the fault rupture, in agreement with the 90 miles (145km) stated by Lyell. Nevertheless, it seems extraordinary that this information was available prior to the departure of Lyell's informant, Edward

Roberts from New Zealand within three months of the earthquake, because much of the rupture length would have been covered by forest at the time.

(ii). Awatere Fault

There is some evidence to suggest that movement in the form of a fresh opening was made along the Awatere Fault in Marlborough during the 1855 earthquake. Hochstetter (1867) records that one fissure "was traced full forty miles (64km)" and this strongly suggests that the fissure was along the line of the Awatere Fault. The Atkinsons (Cameron in Woodhouse 1940) of Burtergill Station in the lower Awatere Valley mention that in 1855 "a great crack opened up in the ground, the remains of which can be seen today". Similarly, J. Burnett (1904) mentions that, "The earthquake crack in Marlborough was much enlarged, the ground east of it subsiding several feet". Buick (1900) records that a writer [not identified] describing the effect of the 1855 earthquake upon the upper Awatere says, "On Fairfield Downs (near Upcot Station), a fissure was opened as far as the eye could reach, and perfectly straight".

Alexander McKay was the first person to investigate the Awatere Fault in any detail during his 1886-7 and 1888-89 surveys of the Marlborough and Amuri districts. His observations of "earthquake rents" were published by Hector (1890) in the progress report of Geological Explorations of 1890 where he states that, "Mr. McKay came to the conclusion, both here (at Altimarloch Station) and further up the [Awatere] valley obtained distinct proof, that the earthquakes of 1848 and 1855 did but open afresh an old line of dislocation, and produced meagre results compared with the total movement which has taken place along this line [Awatere Fault]". Unfortunately, Hector did not elaborate further regarding this "distinct proof". Nevertheless, Hector also relates the McKay was informed by Mrs. Mouat (actually Mowat) of Altimarloch Station that, "the open rents and fissures yet seen on the surface along the line of fracture were not produced by the disturbances of 1855, but were caused by the earthquakes of 1848" - information that McKay appears to have disregarded.

The information at hand suggests that some rupture may have occurred along the Awatere Fault in 1855 but to what extent is unknown. It is clear, however, that some of the statements appear to confuse the effects of the 1848 earthquake in that the fault trace was an obvious feature that existed before the 1855 earthquake.

(iii). Wellington Fault

Two extracts describe a fissure that extended along what appears to be the active trace of the Wellington Fault in the Thorndon area of Wellington. McDowell (c1910) mentions a fissure that extended "beyond Pipitea Point, and went up Tinakori Road and on into the harbour. This fissure appears to be the same as that described by Edward Withers (1901), Quartermaster of the 65th Regiment stationed in Wellington at the time of the earthquake; "one [fissure] remains in a gully crossed by a suspension bridge now a stream at the bottom and sides covered with ferns, etc." The suspension bridge referred to is that illustrated by Ward (1928; Fig.93, p.234) which connected Tinakori Road to Hobson Street (Fig. 10). In 1853 it was crossed by a "very hazardous footbridge" (Sewell 1853; McIntyre 1980). The gully along which the fissure ran was a precipitous-sided, V-shaped ravine about 25m wide at the top, some 330m in length and appearing as a deep cleft in the sea cliff at Thorndon (Adkin, Notebook 5, 25/5/1923), (Fig.10). Although now covered by the Wellington Motorway, the gully has formed along the Wellington Fault from the end of its mapped extension parallel to Tinakori Road (Ota *et al.* 1981) to where it enters the harbour, and is on line with the fault trace mapped by Lewis (1989) in harbour sediments off Kaiwharawara. The length and position of the reported fissure strongly suggest that movement on the Wellington Fault may have occurred during the 1855 earthquake, possibly in response to regional northwest tilting of the Wellington peninsula (see section on Uplift and Subsidence).

EXPULSION OF GAS

There are a few reports of the expulsion of gas during and after the earthquake. At Waitangi, Hawke's Bay, William Colenso (1855) states that he saw "a stream of pale lambent fire gliding along, only a very few feet from me ... This fire was very peculiar: in it and through it I could plainly see the [bottom of page - text lost] trees in the garden; the sheet or body of flame did not rise higher than 3 or 4 feet (0.9 or 1.2m) from the ground and its edges were blue and ragged (flame pointed); it momentarily affected my sight, as for a few seconds after it had passed I was in total darkness". In the same area Henry Hill (c.1904) records that "lambent flame appeared along the swamp areas from Waitangi towards Poraite". Both these accounts presumably refer to the ignition of marsh-gas or methane from nearby swamps.

In Wellington, near Lambton Quay, "a number of cracks had opened up and were ejecting steam and nasty smelling gases" (Cameron, date unknown), although an unnamed source in *The New Zealand Magazine*, (1862) recalls that although he was "... not aware from his own experience of the evolution of gaseous vapour [in Wellington], he had heard reports that such were observed in places in the Ahuriri District [e.g. Hawke's Bay]. The gases were stated in this case to be of a sulphurous nature". Similarly, from extensively fissured ground at the mouth of the Rangitikei River, "... a sulphurous smell was distinctly perceptible. A similar smell was said to have been perceived at Wanganui" (Field 1891) and Taylor (1855) notes that large quantities of gas, together with sand, were expelled from sand "boils".

EFFECT ON SPRINGS

There are a few reports of wells and springs drying up during the earthquake. Thomson (1859) claims that "one of the Taupo geysers dried up" and Lyell (1868) states that "the natives allege that the temperature of the Taupo hot springs was sensibly elevated, just before the catastrophe". Trolove (1855) records that the springs at Waipapa south of the Clarence River had stopped flowing, while Withers (1901) at Miramar also comments on wells drying up, although other parts of this manuscript suggest some confusion with the effects of the 1848 earthquake.

TSUNAMI AND SEISMIC SEICHE

Harbour have been modelled by Barnett *et al* (1991). The data on the tsunami and seiching effects throughout New Zealand presented here are more extensive than were available to De Lange *et al.* or Barnett *et al.*

The occurrence of seismic seiches at a number of locations in the North Island and at several locations in the South Island has not been recognised previously. Seiching of rivers, lakes and harbours at great distances from large earthquakes, has been observed in many great events, well known examples being the 1755 Lisbon, the 1950 Assam (Richter 1958) and 1964 Alaska earthquakes (McGarr & Vorhis 1968).

Fortunately no deaths or injuries resulted from the tsunami in Cook Strait and property damage seems to have been confined to the loss of several sheds at Te Kopi on the shores of Palliser Bay and to the flooding of shops along part of Lambton Beach (now Lambton Quay). At Te Kopi where the waves seem to have been highest, the deaths of several people were reported as having prevented by a sailor who recognised the potential of the large, white-crested waves from his experiences in South America.

The distribution of seiche and tsunami observations is shown in Fig 41.

(a).Seismic seiche

The term "*Seismic Seiche*: was first used by Kvale (1955) in discussing oscillation of lake levels in Norway and England caused by the Assam earthquake of August 15, 1950. McGarr & Vorhis (1968), in describing the seiche effects of the 1964 Alaskan earthquake at teleseismic distances, extended its usage to apply to standing waves set up in rivers, reservoirs, ponds and lakes at the time of passage of seismic waves from an earthquake. Their usage is adopted here. A number of contemporary reports describe water movement on inland waterways during the earthquake shaking which is interpreted as indicating seismic seiching. Because seiching in Wellington Harbour occurred in conjunction with the tsunami generated external to the harbour both effects are described under a separate heading [Seiche and tsunami effects in Wellington Harbour].

NORTH ISLAND

The Waipa River, probably near its junction with the Waikato River, "rushed from side to side" (Johnstone 1855?); at Maketu, possibly referring to one of the nearby estuaries, "the waves of the sea were dashing one against the other, and lifting themselves high in the air" (*Maori Messenger* 1855); at Lake Rotorua "the people of Mokoia fled to the summit of the hill, and the people of Ohinemutu went inland to the heights of Pukeroa ... all the shellfish was [sic] thrown on the land by this earthquake" (*Maori Messenger* 1855); Lake Rotoiti "appeared ... as if it were sinking into the earth" (Thomson 1859); the water in the Wairoa River, Hawke's Bay, "was dashing on the bank two or three yards (1.8 or 2.7m) above its usual height" (Hamlin 1855); the Waitangi and Ngaruroro Rivers "instantaneously rising and falling several feet "(Colenso 1855). Several lakes near Wanganui, one "a small but deep lake ... surged backwards and forwards many times ...and was covered next morning with masses of raupo" and another "broader and shallower ... spread so suddenly over the low flat land" (*New Zealand Magazine* 1862). Near Turakina the water was "violently agitated at the sides and then rushed to the centre of the lake where it was forced up to a great height like a huge pillar of water" (Taylor 1856). As Reverend Taylor was on his way to England at the time of the earthquake this description was probably given to him over a year later, being recorded in Taylor's diary in October 1856. It seems rather extreme but may indicate a unimodal standing wave, fountaining associated with liquefaction or possibly slumping of sediments, particularly as Turakina lay within the area of extensive ground damage from strong shaking.

The most distant locations at which clearly recognisable seismic seiches were reported, the Waipa River and Lake Rotoiti are about 400km from the source. Although the waters of Lake Wairarapa and Lake Onoke would be expected to respond to the earthquake similarly no reports have been located.

SOUTH ISLAND

Mrs Harwood (Millar 1948) remembers from her childhood that the Motupipi River, near Takaka, "slapped from side to side against the banks". In the Christchurch area, Sewell (1855 in McIntyre 1980) records that "a man who lives at Kaiapoi, on the banks of the Waimakariri, says that the river rose in a few minutes 6 feet (0.9m). I think that must be a mistake; the oscillation of the river bed probably washed the banks to an unusual height". A similar story is told by J. Hamilton in a letter to Commander Drury (printed in the *Spectator* Feb 24); "the water in the Courtenay suddenly rose 'six feet' - say, however, four. It fell again immediately. ["The Courtenay" was the south branch of the Waimakariri River. "Here the river was broad, possibly up to a quarter of a mile (0.4km). It is a tidal stream with a sandy shore." Sewell (1855).] At the Heathcote ferry, a fresh wet mark was found up the sloping road, to about four or five feet (1.2 or 1.5m) from the water's edge. Now, in that case, the water would not have risen vertically above eight inches or twelve inches (0.2 or 0.3m), so that I fancy the Courtenay rise is exaggerated". A letter by J. W. Hamilton (1855) to J. R. Godley gives more information: "the Courtenay rose in our first shock (the one which did all the mischief at W. [Wellington])". The association of the rise in the Waimakariri River with shaking is clear. It is not so obvious for the Heathcote River nor for the Avon nearby, where "a wave came up the Avon to within two miles (3.2km) of Christchurch ... about one foot (0.3m) in height" (Davie 1870). Davie "was at the time living close to the river, and heard the rushing sound of the water' but he "did not know what it was until the next morning", that is, the time is unknown. He notes

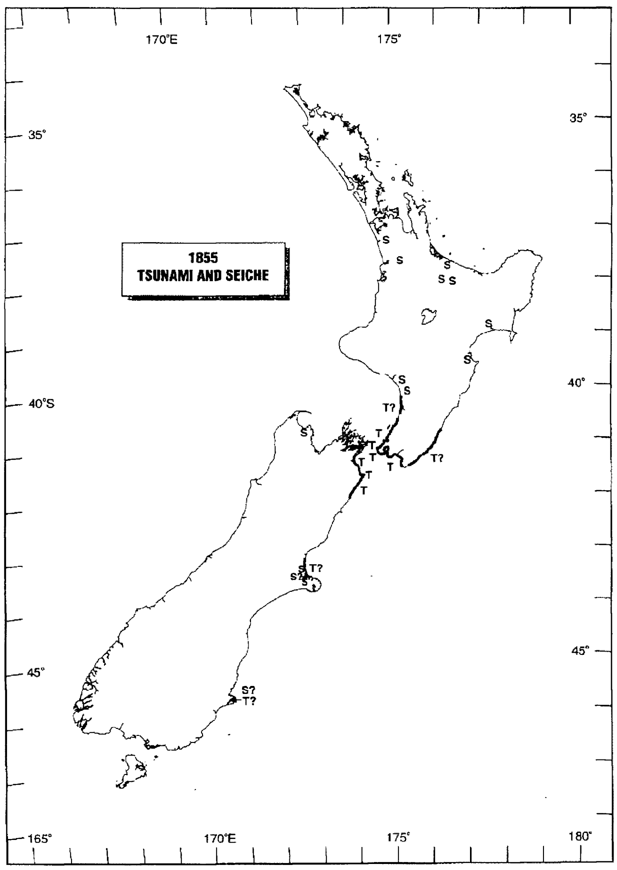


Fig. 41. Map showing areas where seismic seiching (S) (lakes and rivers) and tsunami (T) were experienced during the 1855 earthquake.

also that heavy rain fell in the northwest on the day of the earthquake, implying that this may been the reason the Avon rose. De Lange *et al.* (1986) attribute the effects in the Avon to a "bore", presumably tsunami generated. The rise at the Heathcote Ferry site (time unknown) might be interpreted similarly, both rivers emptying into the same estuary. Davie (1870), however, states that he was not aware of any reports of a tsunami on the Canterbury sea coast. As it seems certain that seiches were observed in the Waimakariri River and at Lyttelton (see below and extensively in the North Island it is possible that a seismic seiche, rather than a tsunami, was generated in the estuary and the effects transmitted to the Heathcote and Avon rivers, or that seismic seiches were generated in the rivers themselves. The estuary would have been a large body of water as the tide was high at the time of the earthquake (reference to tidal charts indicate the high tide would be expected at Lyttelton at much the same time as in Wellington).

A short distance from Christchurch, at Lyttelton, William Smith and his family "[during the earthquake] rushed out of the front door in time to see the sea, which all day had laid in molten stillness, arise in one mighty wave and break with a sudden roar against a wall not many yards from where we were standing" (Smith 1855). Further south, Crawford (1875), citing Mantell as the source of the information, records that a large sea wave was observed in Otago, time unknown. A seismic seiche in Otago Harbour or perhaps Blue Skin Bay, where there was a small community, is again suggested as a possibility worth considering, although Heath (1974), in studies of the response of Otago Harbour to the tsunami from the 1960 Chilean earthquake, found that Otago Harbour was not a good resonator and any oscillations induced in the harbour were severely damped. In contrast, in 1960 a seiche with a maximum amplitude of 3m was generated in Lyttelton Harbour and the 1964 Alaskan earthquake tsunami also produced a strong response (Heath 1974). Under certain circumstances this harbour seems susceptible to seiching.

(b). Tsunami

Tsunami occurs as a result of massive disruption of the sea floor, caused either by earthquake induced ground deformation (faulting, uplift, subsidence), large submarine landslide, occasionally a coastal landslide displacing a large volume of water, or a volcanic eruption. Conditions for any one of the first three possible sources exist in the Cook Strait area. Although landslides are known to have occurred along the Kaikoura Coast (Trolove 1855; Lyell 1868), from White Bluff between the Awatere and Wairau valleys (Hochstetter 1867) and in the Palliser Bay area (Matthews 1901), they are considered to have been of insufficient size to generate the tsunami although they may have contributed some energy locally.

The bathymetry of Cook Strait is such that submarine landsliding would not be unexpected and possibly did occur as indicated by the deaths of pressure sensitive bottom dwelling fish in Cook Strait (see section on Biological Effects). In Alaska in 1964 very large waves were thought to have been generated by extensive submarine slumping in the Whittier Passage and a mechanism for this is suggested in Kachadoorian (1965). However, while submarine slumping may have occurred, the faulting and uplift that accompanied the 1855 earthquake are alone sufficient to account for the generation of the tsunami (Barnett *et al.* 1991). The occurrence of further "tidal disturbances" around Cook Strait for up to a week after the mainshock may, however, be accounted for by further deformation or submarine slumping generated in already unstable sediment by aftershocks. Reflections of the original tsunami off South America and Antarctica are also possible as such reflections were recorded around the Pacific after the 1960 Chilean tsunami (A. Barnett, pers. comm. 1996).

The effects of the tsunami and seiching in Wellington Harbour are discussed separately in the next section. Other than at Wellington, the tsunami, or rather its effects, were observed near Otaki, where the next morning it was found that the "tide" had risen almost to the houses and left fish stranded on the sand (Bevan 1905). Porirua Harbour experienced the effects of the tsunami as Hort's (1855) diary records that "the mouth of the [Wellington] Harbour being too small to admit its [i.e. the tsunami's] full force ... but from this impediment it divided itself, the greatest force entering the next, or Porirua Harbour". Disappointingly, details of the effects in Porirua Harbour are not recorded by Hort and we have found no evidence elsewhere. Adkin (1921) refers to the recollections of Mr James Jones, an old Pauatahanui resident, who claimed that the tidal flats "were for a time noisome on account of putrefying shell-fish and other marine matter" that may in part be the result of the tsunami stranding fish (see section on Biological Effects). At Lyall Bay near Wellington, the sea washed inland a considerable distance, some saying it completely covered the sand between Lyall and Evans Bays (Brightwell 1917; Sutherland 1947), the *New Zealand Magazine* (Oct 1862) being quite specific recording that the water was about 3 feet (0.9m) deep. Keys (1919) states that the water rushed as far as Burnham Water, a lake on which parts of Miramar are now built, and into the gullies beyond. An extract from Sir Charles Lyell's (1856b) notebook refers to the "tidal wave [that] flowed inland near Wellington and left fish wh[ich] died near Wellington —it came in over the race course [at Burnham Water], the races being held in afternn. of [the] day before the earthquake". It is not clear from any account from which bay, Lyall or Evans, that flooding had originated. Reminiscences of the Sutherland family (Sutherland 1947), pioneer residents of Lyall Bay, also mention that the tides were so irregular the morning following the earthquake that use of the beach track to the Pilot Station near Palmer Head was thought inadvisable.

At Palliser Bay the waves from the tsunami, particularly at Te Kopi, were observed and recognised as being dangerous and to be avoided (Davie 1870; Hort 1855; Mason 1855). The loss of several houses or sheds and their contents, including bales of wool, at Te Kopi as the result of a large wave, over 9m high, was recorded in many contemporary accounts, no doubt because of reports in the newspapers. In addition, Mason (1855), apparently in receipt of information from a source other than the newspapers, records that "immediately succeeding the first shock three large waves came up, the last higher than the first two, and at Te Kopi ... four houses were washed away - but the inmates had retreated in time each succeeding wave being some minutes after the one preceding it". It is not clear whether the sheds where settlers' wool was often stored were on the cliffs overlooking the little harbour of Te Kopi or were part of the little settlement on the beach. The loading of wool was apparently accomplished by lowering the bales over an 8m cliff onto boats waiting below (Matthews 1913). Estimates of the tsunami wave height (about 30 ft (9m) (Davie 1870); 30-40 ft (9-12m) in Cook Strait and Palliser Bay (Fox 1855); over 30 ft along east coast (Hector 1868); about 30 ft (*New Zealand Magazine* Oct 1862) are fairly consistent and were almost certainly estimated by comparison with the height of the wool-loading area and hence fairly reliable. Mantell and Pharazyn, both of the Wairarapa Valley, apparently remember the wave "as having done much injury along the east coast [of the Wairarapa]" (Hector 1868), but they may only mean the eastern shore of Palliser Bay. There is only one other account which might possibly refer to coastal inundation north of Cape Palliser although numbers of European settlers lived on the east Wairarapa coast and were able to make observations. At Mahia Hamlin (1855) comments on abnormally high water levels apparently following a local earthquake on February 12 (see section on Aftershocks). He may have mistakenly associated the effect with the wrong earthquake as the report was second hand.

No extracts have been found which mention any effects north of Otaki which can be attributed conclusively to the tsunami. The *Taranaki Herald* (Feb 14 1855) mentions that some parts of the road between Wellington and Wanganui were inundated with water for some miles (see section on Ground deformation). As much of the track was close to the beach the tsunami could have been responsible. Field (1891; Burnett 1904) traversed the beach track between Waitotara and Wanganui the morning after the earthquake but he records nothing which indicates a higher than normal tide.

In the South Island, the *Nelson Examiner* (Feb 21) reports that "at the mouth of the Wairau river a gigantic wave swept the beach ... without inflicting any damage" and "that the ebb and flow of the tide, at short intervals, occurred" but no changes in the water levels are noted at Nelson itself. There are no other accounts of the tsunami effects in the Wairau Valley although it might be expected that a bore could have been generated in the Wairau River and that the beach could have been significantly altered by currents associated with the tsunami waves.

Trolove (1855), at Woodbank, notes in his 26th January entry (3 days after the mainshock) that "the sea has been inland many feet above high water mark. Indeed in some places the sea occupies what used to be green bushes and grass" and on 30th January, when he goes to The Flags, he finds his boat deposited about 18 metres inland. Lyell (1868), on information given to him by Frederick Weld of Flaxbourne, states that "waves rolled in along the Marlborough coast for 50 miles (80 km)" although the association with the shock on the 23rd or with another earthquake, of equal strength, which occurred the next morning is not clear. The association of the tsunami waves with the mainshock is no more certain in his 1856 article (Lyell 1856b).

Crawford (1875) cites Mantell as the source of the information that a "great sea wave" occurred in Otago. Davie (1870), however, recalls none being reported on the Canterbury coast. It has been suggested in the previous section that the wave at Otago may have been a seismic seiche in Otago Harbour.

Trolove (1855) and Lyell (1856b; 1868) both comment on the occurrence of further tidal disturbances along the Marlborough coast with aftershocks. One earthquake in particular attracted attention. On the afternoon of February 3rd Trolove was loading wool at the Flags when he "saw a heavy shock out to sea. It made the sea appear on the horizon like a hilly and undulating country; it also caused a swell on the beach for about an hour after". Lyell's 1856 account of tidal disturbances following an aftershock "on the second day after the first earthquake" is similar to Trolove's, so much so that the question arises as to whether Lyell has the date correct. Perhaps significantly he omits it in his 1868 version, writing only that "at a place called the Flags between Cape Campbell and Waipapa, some men were loading a vessel with wood [Trolove was loading *wool*!], when they distinctly saw an earthquake approaching them from a point called the 'White Rocks' 3 miles (4.8km) to the northward. Its approach was rendered visible by the rolling of stones from the top of the cliffs, also by landslips and clouds of dust, and by the accompanying sea wave". A rather more severe than normal aftershock at 1530 is recorded in Wellington extracts.

Other earthquakes apparently caused irregularity of the tides for several weeks (Lyell 1856b;1868 and Bennett 1855), particularly noticeable to Roberts and others who were attempting to ascertain the exact amount of uplift and possible subsequent subsidence in Wellington (Lyell 1868).

(c). Seiche and tsunami effects in Wellington Harbour

Barnett *et al* (1991) have used the 1855 earthquake as a scenario model for the generation of tsunami and seiche in Wellington Harbour. Three distinct types of possible wave generation were identified:

Type I. Wave resulting from the displacement of water by sudden lateral displacement of the harbour perimeter, causing what is referred to as an "immediate wave". The extent and duration of the horizontal ground displacement, the height, profile and orientation of the shore determine the properties of the wave, a vertical wall normal to the direction of horizontal displacement of short duration producing the greatest effect. This wave occurs within 1-2 minutes of the earthquake initiating the horizontal movement.

Type II. Waves resulting from seismic forcing internal to the harbour. The Type II wave is called a "seismic seiche" because it initiates seiching of the harbour that is dependent on its resonance properties. Causes include the passage of seismic waves from a distant earthquake but in an 1855-type event, the greatest contribution to this type of wave is differential vertical displacement across the harbour. The collapse of the "immediate wave" is minor in comparison. The Type II wave reaches its maximum along Lambton Quay about 12 minutes after the initiating earthquake and is the dominant wave in the harbour from the subsidence of the Type I wave to the arrival of the Type III wave.

Type III. Waves resulting from seismic forcing external to the harbour, i.e. the classical tsunami. The properties of this wave are determined by the generating source, the propagation path and the resonance properties of the harbour. In an 1855-type event it is estimated that the first wave would not arrive in Lambton Harbour until about 30 minutes after the initiating earthquake (A. Barnett, pers. comm. 1996).

The effect of the earthquake on the waters of Lambton Harbour clearly created a spectacle and numerous people observed and recorded the effect of the uplift on the shore and the abnormal ebbing and flowing of the tides. It is fortunate that the *Pandora* was anchored in Lambton Harbour during the earthquake and the oscillation in the water levels was well observed by its officers, especially Commander Drury. The numerous accounts have been examined to try to establish whether each of these types of waves can be identified individually, particularly the Type I wave. Barnett *et al* (1991) had available to them only a limited number of descriptive accounts.

The Type I wave is difficult to identify conclusively and yet it may provide a means by which horizontal movement can be inferred, as there are no known contemporary observations of horizontal displacement of the Wairarapa Fault itself. Although it is without doubt that a wave or waves of uncertain height flooded some houses and shops along a portion of Lambton Quay known as the "low beach", stories conflict and details are lacking on whether the flooding occurred during or "immediately after" the first shock and on how deep and extensive it was. The reliability of accounts becomes important. Few are contemporary and first-hand, others are first hand but have been written up to 70 years later.

Among contemporary descriptions from diaries and journals none are personal observations. Jolliffe (1855) records that "during the first or grand shock the tide rose several feet and flooded the floors of the shops facing the sea" but he was at Te Aro during the earthquake. Another extract from the *Pandora*, the Meteorological Register, states that "the tide at the time of the first shock was high and immediately rose several feet". William Bennett's (1855) diary records that he "heard that immediately after the shock the sea had rolled in and flooded all the road along the beach". Having experienced the shock in Lyttelton, William Smith (1855) arrived in Wellington about 36 hours after the first shock. He records in his journal that "the sea had arisen three times in a huge wave and dashed over the sea wall and up to the houses along the Strand [Lambton Quay]". This account differs from the others which record that the sea only encroached once into the houses. As Smith's account is obviously based on information given to him after the event some confusion may have resulted. According to a letter from an "eyewitness" printed in the *Australian and New Zealand Gazette* (Jun 02 1855) "during the earthquake the tide rose so high that it came over the quay, and since then it has receded". The only other contemporary account comes from Morton Jones (1855), another officer of the *Pandora*, on board his ship during the shock. He writes that, "the tidal level appears to have risen some seven or eight feet (2.1 or 2.4m) and consequently overflowed Lambton Quay. A portion of the brick sea wall now in course of erection was destroyed" giving no information on the timing of the flooding.

Despite being written some years after the earthquake, several reminiscences are particularly useful. For instance, Blake (1909), recalling his experiences as a youth, records that "shortly after nine o'clock I had retired to rest, and found my companions all in the land of dreams. When the sickening rumble commenced ... I called loudly, An earthquake! The occupants were soon up and staggering about in the endeavour to don their apparel. There was one exception ... [we] found him in the dark". They exited the house by going along the roof ridge as the outside staircase had fallen, and finally to the shore to find the "sea slowly but surely bubbling over the breastwork and into some of the establishments. Women and children were rushing to and fro ... terrified at the sight of the encroaching tidal wave". This extract implies at least a few minutes had elapsed after the start of the earthquake. Charles Matthews (1925), a child at the time of the earthquake, records in his dictated memoirs nearly 70 years after the earthquake that the family scrambled up the back of their house to Mulgrave Street as the sea's "intrusion along the foreshore threatened our shattered house" but, prior to climbing up the hill, they had first to reach their home from a neighbour's place. The location was probably Thorndon Quay (the 1855-56 electoral roll indicates the Matthews family resided at Pipitea) rather than Lambton Quay. In contrast to these extracts, another account places the time of flooding much earlier: "about 9.30 pm Mr Brady [a Mr Bradey is listed on the 1855-56 electoral roll as having his residence on Lambton Quay, possibly on sections 488-489], (Fig.42) was walking along Lambton Quay when the first of the three shocks took place. He was thrown to the ground, and while trying to rise the sea, carrying logs of wood and debris, rushed in ..." (Fildes Collection, Extract 5, date unknown). Edwin Meredith's (1898) recollections are second hand as he lived on the east coast and are no more helpful: "the immediate effect of the upheaval [was] to set the water of the harbour rolling or flowing from each side alternatively to the other, with the result that first the sea came over Lambton Quay, and into the shops 3 or 4 feet (0.9 or 1.2m) deep ". The recollections of Charles Carter (1866) can probably be regarded as fairly reliable, as they were written only 11 years after the earthquake and as Carter was apparently thought highly of by the Government as evidenced in his appointment as a Commissioner of the Earthquake Committee. As he ran from the Royal Hotel about 100 metres from the junction of Hill Street and Mulgrave Street, towards the Council Chambers (which collapsed), he heard the waves dashing on the beach. Later in the night he returned to the beachfront to find "that the waters of the harbour had risen from two to three feet (0.6 or 0.9m) higher than they had ever been known to do and had flooded some of the houses on the low beach". He did not observe this as he ran from along the part of Lambton Quay north of the present junction with Bowen Street during and just after the earthquake and it is clear the water did not encroach there, at least during the earthquake. Finally as well as along Lambton Quay, the road to the Hutt was also inundated during or shortly after the earthquake (Kilmister 1932).

Other estimates of the depth to which the buildings on Lambton Quay were flooded by the wave and the amount the water rose are given: Fox (1855): "the water rose 8-10 feet (2.4 - 3.0m) within the harbour, flowing across the road into houses 20-30 yards (18 - 27m) above high water mark"; *Taranaki Herald* (1855): 3 feet (0.9m) high in houses, the *Independent* (Feb 28 1855) disputing this height as too much; Jones (1855): water rose 7-8 feet (2.1 - 2.4m); Pilcher (1855): water about 4 feet (1.2m) above high water mark and 1 foot (0.3m) deep in shops on the low beach. Although not an eyewitness of the flooding (nor are Fox or Pilcher or presumably the newspaper writer), Jones, as an officer from a survey ship, might be suggested as best judge of the height the wave would have to attain to reach the houses having at the same time a knowledge of the state of the tides. Withers (1901) and Coote (1855) both comment on goods having been washed out of the shops. Mrs Coote writes that, the next morning "the contents of many of the shops were floating about on the water or thrown up on the shore" and Withers refers to "a box of toilet soap washed out of the only chemist (Mr Barraud)". In Fig.43a, showing a portion of Lambton Quay to the north of the present Cable Car, the third shop from the right appears to have "Barraud" on its sign (see Fig.42). This may helpful in determining the extent of flooding, and might possibly be used to gauge height from the tide marks clearly shown in the photograph.

A knowledge of the state of the tide, the probable location of the areas flooded, their orientation to the direction of horizontal

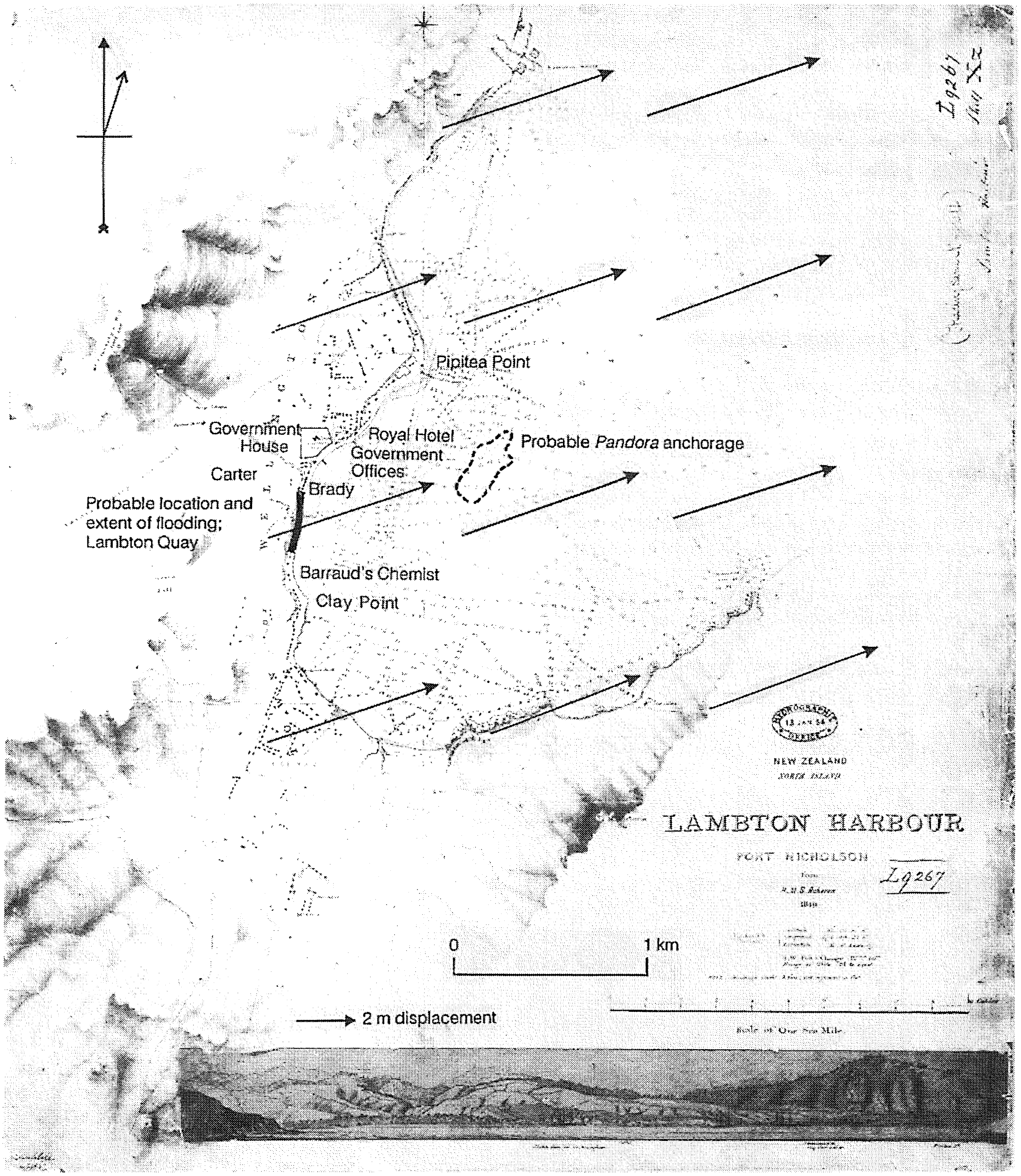


Fig.42. Map showing probable location of the* Pandora*, area of flooding by the first wave, eyewitness and building locations, and direction of inferred horizontal land shift caused by dextral movement along the Wairarapa Fault (after Barnett* et al *1991). Base map is from the British Admiralty Hydrographic Survey of Lambton Harbour by J. L. Stokes in 1849 (Survey Map No. L9267/XZ).

movement and the profile of the shore in front of them is required to determine the size and occurrence of a Type I wave. Tidal information is not given in either of the two Wellington newspapers in January 1855, but Jolliffe (1855) and the *Pandora's* meteorological record (1855) both state that the tide was high at the time of the earthquake and that for the best part of the day the wind had been persistently from the northwest. Consequently the wind would have contributed little wave action on the western shores of Lambton Harbour. Carter (1866), however, refers to waves breaking on the shore near the Council Chambers during the earthquake. According to Wakefield (1845), the anchorage of Lambton Harbour was virtually landlocked with a beach on which "no surf would ever break", but Wakefield was comparing Lambton Harbour with Petone Beach which is exposed to strong surf in southerly winds. More realistically, John Plimmer (Ward 1928) suggests that at least some wind conditions could produce a "heavy wash" which made passage along the beach difficult unless one wished to get wet! This is confirmed by Baillie (1924) who notes that, in the early days of the settlement, "along the quays [Thorndon and Lambton Quays and part of Willis Street, also known as 'The Beach'] the water at high tides in many places covered part of the roadway". However, in 1847 tenders were called to construct a timber breastwork along parts of Lambton Quay, which Anderson (1984) tentatively locates near Bowen Street. This seems in accord with an early sketch by John Pearse (Fig. 43b), the hotel being located just to the south of present Bowen Street. In 1850 the road was still not wide so that two carts could apparently not pass in places, and in 1854 a 180m long brick wall was begun in order to widen the road to about 18m. Evidently, at the time of the earthquake, at least some parts of Lambton Quay were fronted by a timber wall and offshore by the brick wall under construction. Part of this brick wall was apparently destroyed by wave action following the earthquake (Jones 1855).

An 1860 photograph of part of Lambton Quay just north of the present Lambton Quay/Willis Street intersection (Fig.43a) suggests that the brick wall had not been extended to the northern end of the Quay. Presumably the immediate need for it had passed because of the uplift. The photograph also shows clearly the high tide level and evidence of fill behind the wall and further along the beach. John Pearce's sketch (Fig.44), executed within a year of the earthquake, does not show a brick wall further along the beach and little suggestion of a timber breastwork close inshore. However, his sketch clearly shows houses and shops barely above the top of the beach with a narrow roadway in front. Other sketches and photographs held at the Alexander Turnbull Library, Wellington, confirm this. The extract from the journal of Henry Smith (1855) quoted above certainly indicates the presence of a sea wall.

The lowest point of present day Lambton Quay has been identified as near Stout Street where it is no more than 2.1m above New City Datum (Wellington City Council Drainage Department, pers.comm. 1996) or 3.0m above Navy Chart Datum. Taking into account 1.2m of uplift, about 15cm sea level rise since 1855 (A. Barnett, pers. comm. 1996), and assuming the present tidal range was similar in 1855, the location of the lowest point of Lambton Quay would have been less than 0.5m above "mean High Water Springs" tide level under good conditions, barely above the highest tides and possibly awash in adverse wind conditions. It is uncertain how well this height reflects the conditions on the other, or western, side of Lambton Quay in 1855 and further investigation to determine how far beneath the present Lambton Quay the old beach is located is warranted. Undoubtedly Lambton Quay has been altered and filled since 1855. However, it seems reasonable to assume that this part of Lambton Quay represents the 1855 "low beach" and it is consistent with the comment of Brady quoted above as his property was closeby (Fig.42). This location would also have been closest for Carter, who lived at the corner of Bowen Street and The Terrace (Fig.42), to visit on the night of the earthquake. Hence, the flooding of the shops and houses probably extended from about Stout Street south for several hundred metres (Fig.42). Thorndon Quay appears to have been threatened with the rise in water but actual flooding is not referred to.

Fig 43** a. **Post-earthquake (1860) photograph of Lambton Quay. Typical wooden houses are shown together with the fill (earthquake debris?) behind the uncompleted sea wall that was presumably abandoned after uplift made it unnecessary. The cutting shown in the central part of the photo is the location of the present cable car (Ref. No. B3926-½, Alexander Turnbull Library, NLNZ).

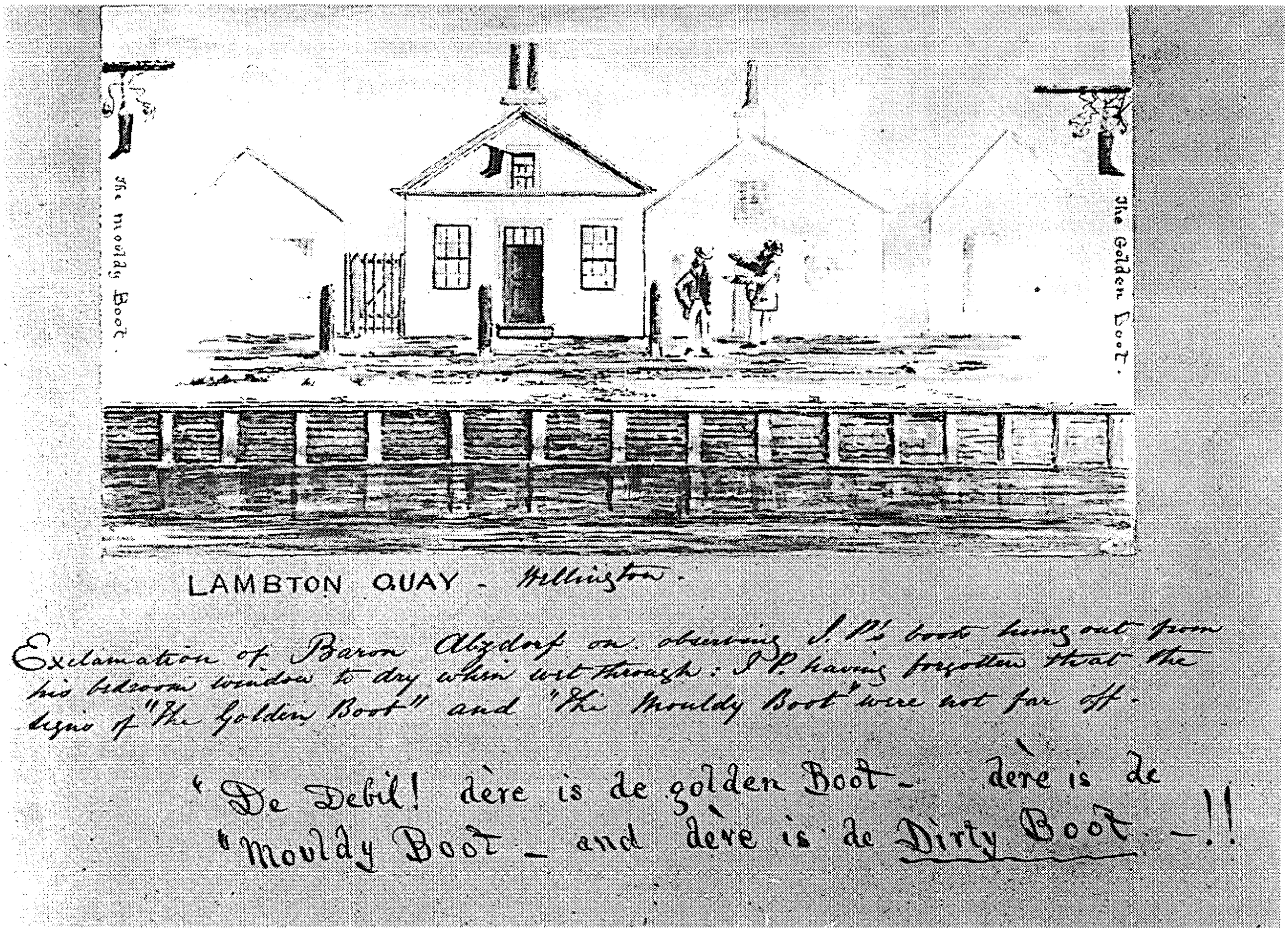


Fig.43. b. Pre-1855 ink and wash sketch of Lambton Quay to the south of the present Bowen Street, showing timber breastwork. (J. Pearse Album 1851-1856. Ref. No. F6215-½-B, Alexander Turnbull Library, NLNZ).

These extracts make it fairly certain that during or immediately after the earthquake a wave or waves were generated, that were heard to break on the beach near the Council Chambers, and that flooded the shops and houses in parts of Lambton Quay to a depth of no more than 0.9m. The location was probably close to the south end of Stout Street, that is, the lowest part of Lambton Quay where the houses were possibly no more than 1m above mean high water mark. At the time of the earthquake the tide was high: the road was less than 18m wide, possibly fronted by a timber breastwork. The orientation of Lambton Quay around and to the south of Stout Street is nearly normal to the direction of horizontal displacement of the harbour water as inferred by Barnett *et al* (1991) (Fig.42). Hence a number of conditions for the generation of a Type I wave are present but because of the uncertainties in the timing and wave heights, inferring regional horizontal displacement requires evidence from another source and that other sources for the flooding, such as a Type II wave, must be eliminated, perhaps requiring further modelling.

Further evidence may come from Drury's account in his Remarks Book for January 25 (*Spectator* Feb 7 1855). During the earthquake the Pandora was anchored in Lambton Harbour at a location offshore from the Government Offices (Fig.42), (many sketches of early Wellington show ships at anchor in this area). According to Drury, "It [the earthquake] continued with severity for more than a minute, the ship slewed broadside to the wind (recorded elsewhere as coming from the NW or NNW); the ship was then in 6 fathoms". The result of an impulsive movement of the anchor (attached to the sea floor) of up to 5.5m to the northeast (i.e. half the total 1855 horizontal displacement along the Wairarapa Fault referred to in the section on Faulting; see also Barnett *et al.* 1991) would have the effect of turning the ship from facing into the wind to facing broadside to it, during the earthquake, as described by Drury. This evidence for horizontal displacement of the fault also requires that other means of producing the effect be eliminated, i.e. that slumping of sea floor sediment into the deeper water of Lambton Harbour during the shaking (see section on Uplift and Subsidence) could not account for it.

The greatest contribution to the Type II wave is from differential uplift across Port Nicholson. Westward tilting resulting from 2.0m uplift along the eastern side of the Harbour and 1.2 m on the western side (see section on Uplift and Subsidence) would have caused the water in the harbour to move from one side to the other, so that there was firstly a slow build up on the western shore, including Lambton Harbour, and lowering along the eastern shore of the harbour and then an oscillation with a period of about 20 minutes. It has been suggested by Barnett *et al* (1991) that the wave generated by the differential uplift (which they name "seismic seiche") would not reach its maximum on the western side of the harbour until about 12 minutes after the earthquake, whereas the wave resulting from the horizontal movement would be almost immediate. The differential uplift across the harbour is slightly greater than that used by Barnett *et al.* (1991) who assumed the uplift of the eastern and western sides of the harbour to be 2.7 and 2.1 m respectively. They find that seismic seiching is unlikely to raise water levels more than 1m above high tide level, the modelling also suggesting that the first wave is not the highest. An increase of 0.2m in the differential uplift may produce a wave of sufficient height to flood the houses and shops and hence remodelling of this effect is required.

Following the first wave, the water "receded to many yards lower tide than had ever been known before even during extraordinary Spring Tides - indeed during the whole night the tides kept ebbing and flowing every 25 or 30 minutes" (Jolliffe 1855). Jones (1855a) also records that the water "continued to ebb and flow at short intervals (from 20 min to half ?? hour) during the remainder of the night ebbing far below Low Water Springs but I believe not again flowing after the first severe shock beyond the High Water Mark". In his private journal, Jones (1855b) adds the word "suddenly" to the ebbing and flowing of the tide and the fact that a barquentine grounded four times during the night. The grounding of ships is mentioned by several others, the *Spectator* (Feb 7) probably being the source. The ebb and flow of the tides is also noted by many, the fluctuation mostly reported as occurring about every 20-30 minutes, and continuing for 8-12 hours. Pilcher (1855), in contrast, notes that the tide "rose every 10-15 minutes", probably from personal observation. Coote (1855) visiting the shore the next morning, observed the extreme lowness of the tide and the extent of the sand and that "all at once it was covered again by sea, this advancing and receding of the tide took place three times in 20 minutes". Probably the most well known account is that of Commander Drury in the *Spectator* (Feb 7), "for eight hours subsequent to the first and great shock , the tide approached and receded from the shore every 20 minutes, rising from eight to ten feet (2.4 to 3m), and receding four feet (1.2m) lower than at spring tides. One ship, I heard, was aground at anchorage four times. The ordinary tide seemed quite at a discount, for the following day (24th) it scarcely rose at all". It is difficult to know when and where Drury made his observations as immediately after the first shock he and Lieutenant Jones disembarked to lend assistance on shore and did not return to the ship until 2am, "the tide having at that time receded about 4 feet (1.2m) lower than ordinary spring tide". On several occasions during their tour they were close enough to the shore to observe the tidal fluctuations, but it is more than likely that Drury recorded them after he returned to the ship in which case the extract probably records vertical measurements made by sounding from the ship. By 2am it is likely that the tide had ebbed and the effect of uplift asserted itself as probably implied by Drury's comment that the tide was "4 feet (1.2m) lower than ordinary spring tides". It is possible that Drury did not observe the lowest levels. It is uncertain whether a peak to trough amplitude of 2.4-3.0m is implied, the minimum occurring at about 1.2m below the low Spring tide mark (pre-uplift), or a rise of 2.4 - 3.0m above it is implied. A 2.4 - 3.0m wave above pre-uplift low tide level would reach above pre-uplift high tide level, in agreement with Smith's (1855) comments, but not those of Jones (1855)! It is quite clear, however, that the shops were not flooded a second time.

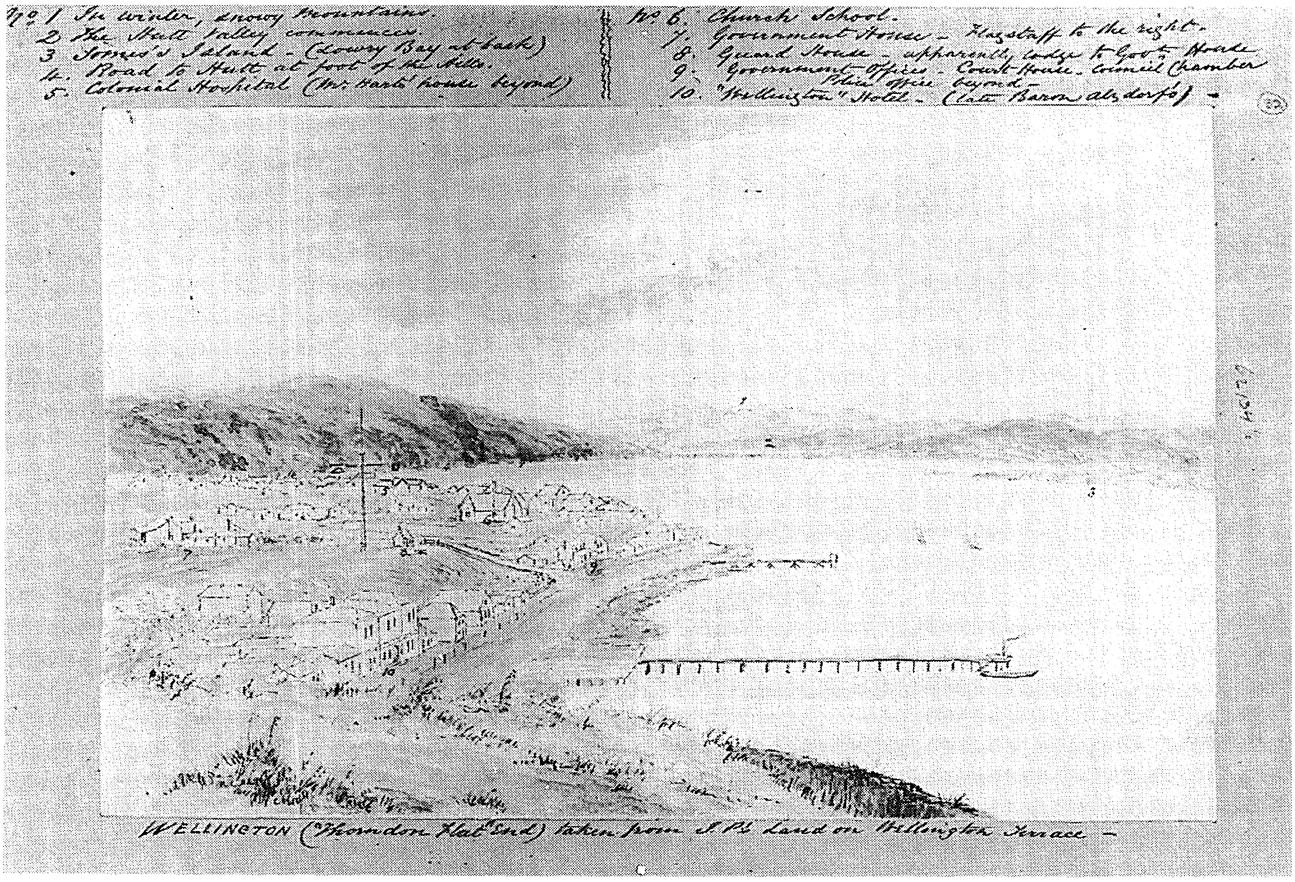


Fig.44. Sketch by John Pearse (post-1855 earthquake and probably 1856) showing a view of Thorndon and Pipitea Point from Wellington Terrace and the uplifted (i.e. widened) beach with tidal range (darker grey area). The length of beach front along Lambton Quay up to the road going inland was probably the area inundated by the immediate wave following the first great shock of the earthquake. (Ref. N. 62134-1/2, Alexander Turnbull Library, NLNZ).

According to Mallet (1858), "a great sea wave came in immediately after the first shock, about five feet (1.5m) above the highest tide inside the harbour, and 12 feet (3.7m) higher outside". The *Spectator* (Feb 7) columns relate a similar story; that "about ten minutes after the first great shock a great wave entered the harbour, which was estimated to be about twelve feet (3.7m) in vertical height". Where this was observed and by whom is not given. There were permanent residents at the entrance to the harbour who could have made the observations - Daniel Dougherty, the pilot, and the Maoris who maintained a ferry service across the harbour entrance to Pencarrow Head. Celia Manson's (1981) story of the Dougherty's experiences records large waves crashing on the shore during the earthquake but enquiries with close family members reveal no knowledge of diaries which might have formed the basis of the story. A one metre amplitude sinusoidal wave entering the harbour has been shown by Barnett *et al* (1991) to be capable of producing a wave of 3-4 m on either side of the harbour entrance, their model also matching quite well the observed seiching in the harbour and the 2-3 m amplitude waves in Lambton Harbour referred to by Drury.

In addition to the three types of waves, Barnett *et al.* (1991) recognised the need to take into account the normal tidal oscillation and the fact that water levels in the harbour had to adjust to a new sea level within the harbour due to the uplift. Presumably harbour levels would begin to fall away soon after the earthquake, both because of the high tide and the uplift but the "immediate wave" would be unaffected. In addition to complexities introduced to the analysis by tidal oscillation and excess of water in the harbour there is also a suggestion in the data (see section Ground Deformation) that slumping of soft sediments may have occurred in Lambton Harbour, itself possibly producing a minor wave.

Additionally, modelling has been based on 2.7 metres of uplift in Cook Strait initiating the tsunami and McSaveney & Hull. (1995) have now shown that it is up to 6m onshore near Turakirae Head (Figs. 38, 39). The present study provides much more detail on the effects of the earthquake on Wellington Harbour and in Cook Strait. It is to be hoped that further modelling of the tsunami data for Cook Strait and the tsunami and seiche data for Wellington Harbour is carried out in conjunction with dislocation modelling of the earthquake deformation in order to provide better constraints on the co-seismic onland and offshore deformation in Cook Strait and determine whether a Type I wave occurred. Further investigation to determine the level of the 1855 Lambton Quay beach would be helpful for estimating Type I - III wave heights.

At present we know of no tsunami observations other than from the New Zealand. Tide gauges installed at San Diego and San Francisco, California, and at Astoria, Oregon, may have recorded a tsunami but the 1855 earthquake was not among the events (J. Lander, pers. comm. 1996) for which records were examined for the Catalogue of United States tsunamis (Lander & Lockridge 1989). The records are available at the National Ocean Survey, NOAA, in Maryland (J. Lander, pers. comm.1996).

ATMOSPHERIC EFFECTS

According to several people a strong NW wind that was blowing before the earthquake ceased immediately after. Jolliffe (1855) records in his journal that, "The wind at the commencement of the great shock was blowing hard from the NW. with frequent squalls and showers of rain. After the shock it died away and ultimately was almost calm with no rain and the stars shining brightly", and that during the frequent aftershocks: "After each shock had passed, it went quite calm and after an interval of a few seconds followed a rush of wind that lasted only a few seconds and then passed off." According to Commander Drury's Remark Book (*Spectator* Feb 7 1855), however, the weather pattern appears to have been quite variable, and he had "no reason to believe ... that the calm preceding, or the gale attending, the earthquake, had any connection with the subterraneous convulsions. We witnessed, during the 48 hours following, every variety of wind and weather, yet with repeated shocks; but although I would disconnect the atmospheric influence with the earthquakes, we had every reason to believe that latter had immediate local influence on the atmosphere, producing violent gusts after the shocks".

The observation by Jolliffe of the calm that followed the first great shock suggests the production of an atmospheric pressure wave counterpart of the tsunami and seiche effects that could have conceivably resulted from the sudden uplift of an extensive area of land and sea surfaces. Drury accounts for the phenomenon by drawing attention to the fact "that an action, or firing will produce a local calm by the disturbance of the atmosphere".

BIOLOGICAL ASPECTS

Superficial ground deformation (e.g. landsliding; fissuring), tsunami, seismic seiche and tectonic uplift caused by the earthquake resulted in widespread destruction of vegetation and decimation of marine life.

(a). Shellfish

(i).The rocky coast

The effect of sudden uplift of a large part of the Wellington peninsula during the 1855 earthquake stranded and killed most of the rocky coast littoral fauna (and flora). There are several reports of the effects in Wellington Harbour. The *Spectator (F*ebruary 7 1855) records that "all the shell fish attached to the rocks, that live below low water mark, in consequence of the elevation of the land are dead, and the number is considerable enough to cause a strong smell to be perceived by those walking round the east side of the harbour towards Evans Bay". Jolliffe (1855) states that "All around the harbour is a belt of mussel shells in some places a foot (0.3m) or more deep that were thrown up after the first grand shock - fish - crayfish and other creatures of the sea were thrown up along the coast in numbers and close to Wellington beds of oysters were exposed by being left by the low tide when previously they were covered with water". Commander Drury (letter to *Spectator* February 20 1855) also refers to the "present generation of oysters and other shells now left above the high water level" adding "another strata to the growing formation of this country". The stranding of beds of rock oysters mentioned by Jolliffe and Drury is interesting as these are now rarely found in Wellington Harbour, suggesting that the uplift in 1855 could have been responsible for wiping out virtually an entire oyster generation. In this respect, Stevens

(1956) records the presence of the rock boring mollusc, *Anchomasa similis* (Gray) still remaining in the holes that they had drilled in stacks above the raised shore platform at Point Howard. He mentions that this species is now extremely rare in Wellington Harbour and considers this rarity to be largely the result of widespread extinction because of the 1855 uplift. Three years after the earthquake, Crawford (1858) mentions that "dead marine shells including many barnacles now repose above high water mark" and that "vegetation has already commenced on the old [uplifted] sea bottom". At Turakirae Head where the greatest amount of uplift occurred, abundant remains of former sub-littoral, intertidal and supratidal flora and fauna still remain among the stranded 1855 surge pools. According to McSaveney (1995), 97 species of molluscs, 4 species of barnacles, and representatives of 5 other phyla, some still in life position (barnacles, worm tubes and calcareous algae) and others existing where they have dropped from life positions beneath large boulders (paua, limpets, snails) are present. Most of the remains still preserve life colour and exhibit little degradation. Nevertheless, the uplift also had its benefits for humans. At Lowry Bay, and probably elsewhere, the Jackson family were amazed to see ".... a wildly excited lot of Maoris ... busy gathering the harvest of shell fish - left bare" by the uplift (Bagnall 1972).

(ii).Tidal estuaries, sandy beaches

The effect of uplift would have been even more apparent in tidal estuaries. In Pauatahanui Inlet, Adkin (1921) records information from an old resident who recalls the tidal flats were "for a time noisome on account of putrefying shell-fish and other marine matter". Cockles (*Chione stutchburyi*) account for over 80% of the tidal marine fauna in Pauatahanui and any changes due to earthquake uplift would certainly be reflected by the cockle population. These shellfish now occupy almost the whole area of the substrate (coarse sand and soft mud) of the intertidal area from just below high-tide level down to low-tide mark. Spring-tidal range in the inlet is approximately 1.4m. Instant death of populations could have therefore been caused by a small amount of uplift during the 1855 earthquake which would have stranded that part of the population within 0.6m below high tide level. It is also clear that a rapid influx of sediment following the earthquake could have had a major impact on intertidal organisms. For example, an increase in sediment suspension in the vicinity of Browns Bay due to cut-and-fill operations in the 1960's smothered and killed intertidal communities. Adult cockles are unable to get to the surface if the depth of sediment exceeds 7cm and young cockles are killed by the sudden deposition of much thinner layers. The loss by uplift of eel grass beds, which contribute a considerable amount of nutritive particulate matter contained in the water at Pauatahanui Inlet, would have also been disastrous to the cockle population as their survival depends on periods of more than 3.5 hours of submergence during which time they are actively feeding.

A sediment core from the end of Petone Wharf (Harper 1995) shows that part deposited before the earthquake contains fewer freshwater diatoms than the post-1855 part of the core. The transition is gradual indicating that the increase in freshwater diatoms was not directly due to sudden uplift of the beach in 1855 but rather also suggests the effects of bush clearance. This resulted in the Hutt River becoming more wider, shallower and sunlit, allowing growth of the diatom population. Also, by draining marshy areas near the river mouth the uplift would have largely removed their capability as traps of river silt and diatoms.

(b). Fish

The *Spectator* (February 7 1855) records that "two coasters, one from the Kaikouras and one from Port Underwood, on their approaching the harbour the next morning [after the earthquake] at daylight, passed through an immense quantity of dead fish, principally ling, and quantities of dead fish were found on the beach, and at Burnham Water". The prevalence of one sort of fish amongst the dead," a species of ling whose habit it is to lie on the bottom" is also verified by William Bennett (in Mallet 1858) from information received via the captain of the vessel on which he was travelling to Hawke's Bay. Walter Mantell (in Lyell 1856b) relates that some of the dead fish found floating in Cook Strait were a "species never before seen". According to Hochstetter (1864), a Captain Kennedy two days after the earthquake, saw the surface of the sea still covered with dead fish.

Ling are deep water bottom dwelling fish of the outer shelf area and as such are highly sensitive to rapid pressure changes. It is inferred that they were probably killed when they were forced up from the bottom by turbulence related to submarine slides initiated by the earthquake or possible high frequency pressure waves. Within a few hours of the Alaskan Earthquake of 1964 large numbers of red snapper, some of exceptional size, appeared at the surface in Knights Passage and Valdez Narrows (Plafker *et al.* 1969). Like Ling, this species normally inhabit deep water and are also sensitive to rapid pressure changes. In this case the fish were assumed to have been killed by rapid vertical movements related to landslide-generated turbidity currents.

Recollections of the Sutherland Family (Sutherland 1947) record that the day after the earthquake "it was seen that the shake had been accompanied by an exceptionally high tide which left thousands of fish on the sandhills between Evans Bay and Lyall's Bay", and "riding around to Houghton Bay, William and Elizabeth found an enormous quantity of fish caught high and dry in a very simple manner. The phenomenal tide rose over a field of rushes which acted as a strainer to hold the fish as the waters receded". According to Edward Withers (1901) thousands of dead fish were also "piled up from Oriental Bay right round to Petone, but a lesser tidal wave swept them away and relieved the townspeople's fear of pestilence". An article in the *Rotorua Chronicle* (March 1, 1919; unknown source) mentions that "One most curious effect [of the tidal wave] was the masses of fish thrown up on the beach between town [Wellington] and Terawhiti. They were carried up by the great wave, and left stranded there above the high water mark, and the late Mr. John McMenamin of Terawhiti Station used to tell us of his ride along this bank of fish, his horse floundering and slipping among them as he galloped homeward after the 'quake' ". At Otaki, Thomas Bevan (1905) recalls that "the sea-waves had come up to the front of the house, leaving hundreds of fish stranded on the sand".

The fish stranded by the tidal wave are assumed to have been near-shore feeding shoals that were caught by the wave and carried inland. They would not have been affected by the wave if they had been further out from the shore. It is interesting to note that no such fish strandings were reported to have occurred during the Alaskan Earthquake despite the generation of tsunamis. The time of the earthquake was 5.36p.m. (Alaska Standard Time), the tide was almost zero (mean lower low water) (Plafker *et al.* 1969) and fish may not have been feeding close to the shore.

The cracking of iron pans beneath lakes amongst the sand dunes of Horowhenua and Manawatu caused the drainage of small lakes and ponds. At Manga-pirau lagoon near the mouth of the Waikawa River, Thomas Bevan (1905) recalls "hundreds of eels left high and dry". Similar strandings presumably occurred in other drained water bodies but no reports are available.

(c). Domestic Animals

There are a few reports of the effects of the earthquake on domestic animals. "Horses staggered as if shot" (Cameron, date unknown). According to Edwin Meredith (1898) at Orui on the east Wairarapa coast, cows that were browsing on "the terrace, came rushing down in a tumultuous mob, and the fowls, which were roosting in trees also on the terrace, were shaken off their perches and came flying down, giving loud expression to their alarm". J. Burnett (1904) of Wanganui recalled that on the day of the earthquake, and prior to the event, "poultry crept about with their wings and tails drooping, and a number of wild goats which fed near where I lived, and which generally ran like deer if anyone went within a hundred yards of them, could on that day hardly be kept out of the house or mill".

(d). Vegetation

Although there must have been a large number of trees and other forms of vegetation destroyed by landsliding there are few specific descriptions available. As viewed from Wellington for example, nearly a third of the vegetation was estimated to have been stripped from the western flank of the Rimutaka Range (e.g. *Spectator* Feb 7 1855). Forty-six years after the earthquake, McKay (1901) describes the landslides descending into the Orongorongo River that had "carried away hundreds of acres of bush in each case, burying and piling it up in utter confusion". A study of the revegetation of an 1855 landslide into the Ruamahanga River at Kopuaranga, Wairarapa, indicated the survival of only one tree, a totara of sufficient girth, that could represent the pre-1855 forest cover of the slide area (Grapes 1988).

Vegetation in lakes and swamps was also especially vulnerable to the effects of seismic seiching. According to the *New Zealand Magazine* (October 1862; unknown source), " a small, but deep lake near Wanganui, ... surged backwards and forwards many times in a remarkable manner, and was covered the next morning with masses of raupo, torn up from a depth of several feet in the swampy heads of the bights into which the lake runs". Similarly, in Wellington, the Te Aro swamp disintegrated causing the release of "small islands of flax and toi-toi" that were found to be floating about in the harbour and "interfering with the passage of small coasters in the vicinity" (Ward 1928; p.304). Inundation from the tsunami, such as described by Trolove (1855) with the sea occupying "what used to be green bushes and grass" on the Kaikoura coast, would also have resulted in the destruction of near coast vegetation through saline poisoning.

AFTERSHOCKS

The aftershocks of the principal earthquake on January 23 were numerous and protracted. Wellington extracts, in particular, record many shocks for several months. In the first 24 hours individual shocks, some violent, occurred at least every half hour and were accompanied by almost continuous vibration that was most detectable when at rest or leaning against a wall. (Jolliffe 1855 & many others). The frequency of stronger shocks, according to some, decreased temporarily about 8 hours after the mainshock but the near constant tremor continued. According to Moir (1855) there were many hundreds of shocks in the first two days, while at Otaki, Stock (1855) gives a figure of at least 250 shocks in the first 11 hours, noting that "at one time of the night, as soon as one had ceased, we could hear the warning rumble of another". He counts another 100 shocks in the next 24 hours. Writers from Waitotara to Whareama in the North Island to Motueka and the Marlborough district in the South Island comment similarly on the frequent, and sometimes almost incessant, shocks for several days. Even at distances of several hundred kilometres from Wellington, - in New Plymouth (250 km), Wairoa (300 km), Christchurch and Lyttelton (300 km), some diarists considered that the earth seemed to be never quite still for the first 24 hours, although this may be somewhat exaggerated as others comment on isolated shocks only.

At least 15 individual earthquakes ("several" appearing in many accounts being equated to at least 2) were felt in New Plymouth, in the first 3 days, eight in Christchurch, Lyttelton and Wairoa while in Gisborne, Jane Williams (1855) records feeling five shocks up to early February. Diarists at New Plymouth, Napier and Christchurch report small earthquakes at several per day for at least two weeks. Typically six weeks is recalled in reminiscences as the length of time that earthquakes occurred with some regularity but William Trotter (1855), a gardener in the Hutt Valley, and another diarist, Frederick Trolove (1855), of Kekerengu, continue to note shocks at a rate of one or two per week until December at least. In March 1856, Trolove tiredly writes "earthquakes as usual".

Table 3 summarises the aftershock information, which is graded for reliability of source (i.e. contemporary first hand accounts, reminiscence or second hand), to the beginning of March. Identification of the larger aftershocks and estimation of their magnitudes is hampered by disappointingly few good records of the times and dates of these events and even fewer details of their effects. Few times can be correlated with certainty even allowing for discrepancies resulting from misreadings of times, particularly with minutes before and after the hour, and differences in local solar time. Away from centres of population, remarks such as *morning*, *afternoon* or *evening* are common, accurate time possibly being of little concern. There is little intensity information specific to particular aftershocks.

The newspapers in Wellington in particular, report that no significant damage occurred as a result of any aftershocks. Yet, contemporary evidence indicates intensities of at least MM6 were common. Rocks fell from the cliffs near Miramar with each shock during the first night (Cameron: date unknown), puketea trees on the Tinakori Hills dropped dead branches for several days (Smedley 1980), and for up to a week, each time the gang building the road from Upper Hutt to Featherston over the Rimutaka Hill tried to pile up the chimney stones they fell (Hall 1894). In the Wairarapa, furniture was overturned with at least one aftershock (Bidwill & Woodhouse 1927). In the Hutt Valley, Alfred Ludlam (March 1855 letter quoted in Ward 1928) notes that during the first night, "when a fresh shock came, the house appeared to almost bend to the ground". Jolliffe (1855), in Wellington, could not sleep because "frequent shocks shook the house so violently" that he "did not like to remain inside" and Jones (1855) comments that "the shocks [night Jan23/24] continued much less severe than the first, but still alarming and causing great vibration to the slight

Table 3 AFTERSHOCK DATA

Date	Local Time	"Felt" Location	Comment	Reliability Grade	Source
Tuesday January 23	2111		MAINSHOCK		
Tuesday January 23	about 2400	Wellington	the most severe shock [inconsistent with other observations in Wellington]	C	Cameron (date unknown)
	about 2400	Hutt Valley	severe shock	C	Colley 1907
	about 2400	Lyttelton	distinctly felt		*Lyttelton Times* 1855
January 23/24	middle of night,	*Kekerengu*	continuous shocks lighter than first, "most awful shock" imaginable in middle of night, apparently greater than mainshock	A	Trolove 1855
January 23/24	during night	Wellington	many shocks causing rock falls	C	Cameron (date unknown)
			scarcely half hour without shock, constant tremulous motion	A	*Spectator* 1855
			sharp quake every half hour, all night tremblings	A	Bennett 1855
			vibrations all night, occasional shocks of some violence, some a single jerk backwards & forwards	A	Mallet 1858
			many shocks, none as violent as first, fewer after 0300-0400	A	Coote 1855
			almost constant vibration, less frequent towards morning	A	Jones 1855
			vibration all night with occasional shocks of some violence, decreasing towards morning	B	Hector 1891
			succeeded by repeated shocks, not so long or violent as first	A	*Australian & New Zealand Gazette* 1855
			every 5 minutes a shock which made it difficult to keep one's balance	A	Pilcher 1855
			tremblings all night	A	Anon 1 1855
			succeeded incessantly by others, none as strong as first	A	Hort 1855
			frequent shocks, none as severe as first. Tremulous motion continuous but only felt when at rest	A	Jolliffe 1855
			several strong shocks, nothing to cause great alarm	B	Matthews 1913
	during night	Petone, Hutt Valley	violent shock not long after first	B	Bassett 1925
	during night	Hutt Valley	house rocked & creaked repeatedly	A	Deane 1855
			shocks at short intervals for 3 days and nights	A	Mason 1855
			47 shocks	B	Florance c. 1858
	during night	Rimutaka Hill	shocks all night	B	Hall 1894
	during night	*Orui*, near Whareama	earth seldom devoid of vibration for more than a few minutes. Some shocks quite severe	B	Meredith 1898

	during night	Otaki	violent shock not long after first. Many other shocks	B	Bevan 1905
			at least 250 shocks, some very sharp. From 0200 shocks seemed closer, different movement	A	Stock 1855
	during night	Nelson	more or less tremulous state till 27th, none very severe	A	*Nelson Examiner* 1855
	during night	*Altimarloch*	great number of shocks, none as severe as first	A	Mowat 1855
	during night	*Flaxbourne*	very strong tremors	B	Lyell 1856b
	during night	Wanganui	shocks for 24 hrs with little interval	A	*Spectator* 1855
			several other severe shocks, agitated greater part of night	A	Allen 1904
	during night	Waitotara	mainshock followed by two violent shocks, further shocks made it difficult to walk	B	Field 1891; Burnett 1904
	during night	New Plymouth	continued small shocks all through the night	A	Blackett 1855
			several other shocks felt	A	*Taranaki Herald* 1855
			constant perceptible movement	A	Atkinson 1855
			about 9-10 shocks	A	Messenger 1855
	during night	Christchurch	several severe shocks	A	Aldred 1855
			several other shocks felt by some	A	Caverhill 1855
			strong shocks repeated several times occasional tremors	A	Chapman 1855
	during night	Lyttelton	no more violent shocks, but earth not still till morning (crockery rattled)	A	Smith 1855
			several minor shocks felt by some	A	*Lyttelton Times* 1855
	during night	on board ship, Queen Charlotte Sound	slight shocks at intervals	A	Brooking 1855
	during night	Wairoa	one or two slight shocks. Scarcely lost tremulous motion all night	A	Hamlin 1855
	during night	Gisborne	3 slight shocks in next 30 hours i.e. Jan 23 2130 - Jan 25 0330	A	Williams 1855
	during night	Motueka	heavings continued at intervals, and for 3 days	B	Washbourn 1970
Wednesday January 24	0300	*Flaxbourne*,	a shock, which Weld supposed to be local, of same strength as mainshock (see Kekerengu, middle of night 23/24)	B	Lyell 1856b
	0445	Wellington	another minor but severe shock	A	Bennett 1855
	0515	Wellington	another severe shock	A	Anon 1 1855
	0700	Christchurch	distinct shock	A	*Spectator* 1855
			some felt shock in morning	A	Caverhill 1855
	0700	Wairoa	sharp, but not long, shock	A	Hamlin 1855
	0700	Lyttelton	earthquake	A	*Lyttelton Times* 1855
	2100	*Altimarloch*	another fearful shake	A	Mowat 1855
	2100-2200	Otaki	9 shocks	A	Stock 1855
	about 2200	Wairoa	another shock and 2 more in next two hours. 1 or 2 slight shocks during night (diary entries confusing, Jan 24 or Jan25)	A	Hamlin 1855
	2330	on *Pandora,* Wellington	sharp shock	A	Jolliffe 1855

	2330	Christchurch	another earthquake felt	A	Caverhill 1855
	during morning	*Flaxbourne*	another ... of equal violence as first. (see entry at Jan 24 0300)	B	Lyell, 1856 d
	during morning	Waitotara,	earth cracks opened and closed with shocks	B	Burnett 1904; Field 1891
	during day	Wellington	trees shook all day	B	Judd 1934
	during day	Wellington	vibrations & small shocks at short intervals	A	Bennett 1855
	during day	Wellington	mild shocks at intervals all day	A	Jolliffe 1855
	during day	Wellington	slight shocks continuing; almost constant vibration	A	Jones 1855
	during day	Wellington	shocks at greater intervals as day progressed; tremulous motion continuous	A	*Spectator* 1855
	during day	Wellington	all day at short intervals	A	Anon 1 1855
	during day	*Altimarlock*	earthquakes nearly every half hour	A	Mowat 1855
	during day	*Kekerengu*	shocks at least every 10 minutes, lighter towards afternoon	A	Trolove 1855
January 24/25	during night	New Plymouth	small shocks all day and evening	A	Blackett 1855
			several slight shocks	A	Messenger 1855
			several slight shocks	A	Atkinson 1855
	during night	Christchurch	at intervals	A	Aldred 1855
	during night	Wellington	24th pm and early 25th several severe shocks, no "injury"	A	*Spectator* 1855
	during night	*Kekerengu*	three heavier shocks than any before (2100?; 2330?; 25th 0045?). Perpetual motion all night, house continuing to crumble. Direction NW to SE, or little more S.	A	Trolove 1855
	during night	Christchurch	several earth tremors during evening & throughout night	A	Lean 1855
	during night	Lyttelton	minor shocks other than at 2400 on 23rd and at 0700 on 24th	A	*Lyttelton Times* 1855
	during night	New Plymouth,	two smart shocks	A	Messenger 1855
Thursday January 25	0045	On board *Pandora,* Wellington	very severe shock, but short in duration	A	Jolliffe 1855
	0055	Wellington	very sharp, but comparatively short shock. No further damage	A	*Spectator,* 1855
	a little before 0100	On board *Pandora*, Wellington	a very severe shock	A	Jones 1855
	no times given	Gisborne	3 slight shocks in next 30 hours i.e. Jan 23 2130 - Jan 25 0330	A	Williams 1855
	0900	Cook Strait, between Wln and Nelson	felt at sea	A	Jones 1855
	1100	Wellington	sharp	A	Anon 1 1855
	1130	Wellington	sharp	A	Bennett 1855
	1150	Cook Strait, between Wln and Nelson	felt at sea	A	Jones 1855
	1300	Wellington	sharp	A	Anon 1 1855
			smart, earth continues almost at all times in a tremor, & occasionally lifts, shakes and rolls for a few seconds	A	Bennett 1855

	1645	Wellington	smart	A	Anon 1; Bennett 1855
	1715	Wellington	2 more equal to one at 1645	A	Anon 1 1855
	1930	Wellington	sharp	A	Bennett 1855
			smart, followed by second	A	Anon 1 1855
	2100	*Altimarlock*	very sharp shock	A	Mowat 1855
	2105	Wellington	another constant vibration	A	Bennett 1855
				A	Anon 1 1855
	about 2200	Wairoa	another shock and 2 more in next two hours. 1 or 2 slight shocks during night (diary entries confusing; Jan 24 or Jan 25)	A	Hamlin 1855
	2300 or 2400	*Kekerengu*	heaviest shock of any	A	Trolove 1855
	2400 or 0100	*Kekerengu*	another very severe shake, in morning house totally destroyed. Woodbank house also destroyed by this time.	A	Trolove 1855
	day/night	*Altimarlock*	ground in one continual shake	A	Mowat 1855
	during day	Wellington	earth almost at all times in a tremor, occasionally lifts & shakes for few seconds	A	Bennett 1855 Anon 1 1855
			several smart shocks, none causing injury	A	*Spectator* 1855
			shocks continuing so violent & frequently that righting a heavy chest thought in advisable	A	*Spectator* 1855
	during day	Christchurch	several felt	A	Lyttelton Times 1855
		The Flags, Marlborough	earthquake from NW, made visible by stones rolling from cliffs & sea wave	A	Lyell 1856b, repeated in 1868 with no date
	no times given	Wellington	three shocks more severe than previous ones [inconsistent with other observations in Wellington]	C	Cameron (date unknown)
	no times given	Otaki	about 100 slight shocks per 24 hours		Stock 1855
Friday January 26	0550	Wellington	slight	A	Anon 1 1855
	0610	Wellington	slight	A	Bennett 1855
	0640	Wellington	two, close together	A	Bennett 1855
	0845	Wellington	another	A	Bennett 1855
	0900	Wellington	another	A	Bennett 1855
	2100	Wellington	slight	A	Anon 1 1855
	2200	Wellington	smart	A	Anon 1 1855
	2205	Wellington	smart, followed by another	A	Bennett 1855
	2255	Wellington	smart	A	Anon 1 1855
	2305	Wellington	sharp	A	Bennett 1855
	no times given	New Plymouth	several slight shocks	A	Messenger 1855
	no times given	*Altimarlock*	frequent shakes	A	Mowat 1855
	no times given	*Kekerengu*	two or three sharp shocks	A	Trolove 1855
	during night	Wellington	several slight shocks	A	Aldred 1855

	during night?	Wellington	as many as 30 shocks, big & little	A	Anon 1 1855
	during night	*Kekerengu*	shakes not so constant as during day, but sharper	A	Trolove 1855
Saturday January 27	during day	Wellington	Shocks continue but with less force & frequency	A	Anon 1 1855
	during day	*Altimarlock*	frequent earthquakes	A	Mowat 1855
	no times given	*Kekerengu*	shocks every 2 hours, but not severe in comparison to earlier shocks. Sharp shock in middle of night	A	Trolove 1855
	no times given	New Plymouth	several slight shocks	A	Messenger 1855
Sunday January 28	0830	Wellington	smart	A	Anon 1 1855
			smart	A	Bennett 1855
	0900	Wellington	slight	A	Anon 1 1855
			slight	A	Bennett 1855
	1545	Wellington	smart	A	Anon 1 1855
			smart, followed by second	A	Bennett 1855
	during day	New Plymouth	several slight shocks	A	Messenger 1855
	during afternoon	Nelson	2 slight shocks	A	Jones 1855
	no times given	*Altimarlock*	frequent shaking	A	Mowat 1855
	no times given	*Kekerengu*	light shocks every hour or so. Quick shock or two at night.	A	Trolove 1855
Monday January 29	1000	Wellington	smart	A	Anon 1 1855
	2050	Wellington	smart	A	Anon 1 1855
	2200	Wellington	smart	A	Bennett 1855
	2209	Wellington	slight	A	Bennett 1855
	during day	Wellington	tremblings throughout	A	Anon 1 1855
			tremblings all day	A	Bennett 1855
	during day and night	New Plymouth	a few shocks	A	Messenger 1855
	no times given	*Altimarlock*	the ground in one continual shake	A	Mowat 1855
	no times given	*Kekerengu*	shocks as usual	A	Trolove 1855
	no times given	Hutt Valley	still having sharp shocks	A	Trotter 1855
Tuesday January 30	0430	Wellington	severe shock, several lighter ones next 4 hours	A	Anon 1 1855; Bennett 1855
	1210	Wellington	smart	A	Anon 1 1855; Bennett 1855
	1615	Wellington	smart	A	Anon 1 1855
	1630	Wellington	sharp	A	Bennett 1855
	1900	*Kekerengu*	sharp, quick shock	A	Trolove 1855
	2300	Wellington	smart	A	Anon 1 1855; Bennett 1855
	no times given	New Plymouth	several light shocks	A	Messenger 1855
	no times given	*Altimarlock*	numerous earthquakes	A	Mowat 1855
Wednesday January 31	0800	Wellington	smart, several lighter ones during day	A	Anon 1 1855
			shock	A	Bennett 1855
	no times given	*Altimarlock*	frequent earthquakes, not as sharp as on 30th	A	Mowat 1855

Thursday February 01	1800	Wellington	sharp	A	Anon 1 1855; Bennett 1855
	no times given	*Altimarlock*	4 or 5 earthquakes	A	Mowat 1855
	no times given	Hutt Valley	still having shocks, not very heavy	A	Trotter 1855
	1200	*Altimarlock*	very sharp shock, several shocks during the day	A	Mowat 1855
Friday February 02	1530	Wellington	severe	A	Anon 1 1855; Bennett 1855
	1400	*Kekerengu*	shock brought down stones from cliffs? near White Rocks	A	Trolove 1855
	during day	Nelson	some shocks felt	A	Jolliffe 1855
February 02/03	during night	On board *Pandora* Nelson	slight shock but long duration	A	Jolliffe 1855
Saturday February 03	2200	Wellington	smart	A	Anon 1 1855; Bennett 1855
	no times given	*Altimarlock*	2 or 3 slight shocks	A	Mowat 1855
	after 1600?	*Kekerengu*	saw heavy shock at sea; caused swell on beach for an hour	A	Trolove 1855
	no times given	Hutt Valley	earthquakes still	A	Trotter 1855
Sunday February 04	no times given	Wellington	slight shocks	A	Anon 1 1855
			slight shocks at long intervals	A	Bennett 1855
	1300	*Altimarlock*	earthquake, two during night	A	Mowat 1855
	no times given	Hutt Valley	slight shocks	A	Trotter 1855
Monday February 05	0300	Wellington	several shocks	A	Anon 1 1855
	0400	Wellington	several shocks	A	Anon 1 1855
	evening	Wellington	several shocks	A	Anon 1 1855
	no times given	Christchurch	earthquakes still continue	A	Aldred 1855
Tuesday February 06	0530	Wellington	slight	A	Anon 1 1855
	1700, 1705	Wellington	smart	A	Anon 1 1855
	2300	Wellington	severe	A	Anon 1 1855
	during night	*Altimarlock*	several earthquakes	A	Mowat 1855
	during night	New Plymouth	a sharp shock	A	Messenger 1855
February 06/07	during night	Hutt Valley	heavy shock followed by slight ones	A	Trotter 1855
Wednesday February 07	during night	*Altimarlock*	some slight earthquakes	A	Mowat 1855
Thursday February 08	2200	Wellington	one of the most severe shocks yet felt	A	Anon 1 1855
	during day	Wellington	rolling shocks continue	A	Anon 1 1855
	no times given	*Altimarlock*	several slight shocks	A	Mowat 1855
Friday February 09	early morning	Wellington	many slight shocks and tremblings	A	Anon 1 1855
	1030	Wellington	very severe shock	A	Anon 1 1855
	after 1830	*Altimarlock*	3 or 4 earthquakes	A	Mowat 1855
	2100	*Kekerengu*	sharpish shock, stones dislodged from hill. 2 or 3 shocks during night	A	Trolove 1855
Saturday February 10	0900	Wellington	slight	A	Anon 1 1855
	2100	*Altimarlock*	smart shock. Several earthquakes during day	A	Mowat 1855

Sunday February 11	no times given	Wellington	2 or 3 per day, slight, 20-40 sec duration	A	Jolliffe 1855
	no times given	*Altimarlock*	several earthquakes at Mahia and severe at Wairoa	A	Mowat 1855
Monday February 12	0030	Wairoa	very severe earthquake, not felt as strongly at Table Cape	A	Hamlin 1855
	after midnight	Gisborne	sharp shock	A	Williams 1855
	0400	*Altimarlock*	earthquake	A	Mowat 1855
	0030-1000	Wairoa	7 slight shocks	A	Hamlin 1855
	no times given	Hutt Valley	still having slight shocks	A	Trotter 1855
Tuesday February 13	2300	Wellington	severe shock	A	Anon 1 1855
Saturday February 17 or Sunday February 18	during night	*Altimarlock*	earthquake made all shake again, one at daybreak	A	Trolove 855
	0400	Wairoa	sharp shock	A	Hamlin 1855
	0415	Wairoa	another shock	A	Hamlin 1855
	2000	Wairoa	smart shock	A	Hamlin 1855
Tuesday February 20	no times given	Woodbank	sharp	A	Trolove 1855
	no times given	Hutt Valley	slight shocks continue	A	Trotter 1855
Wednesday February 21	2000	Hutt Valley	earthquake	A	Trotter 1855
Thursday February 22	1500	Hutt Valley	earthquake	A	Trotter 1855
Friday February 23	no times given	Wanganui	slight shocks	A	Anon 1 1855
Sunday February 25	no times given	Hutt Valley	earthquakes still continue	A	Trotter 1855
about 5 weeks after January 23	morning	Wellington	heavy earthquake	A	Hort 1855
Wednesday February 27	1500	Wanganui	long continued roll & shakes	A	Anon 1 1855
March 01-03	no times given	Wanganui	slight shocks continue	A	Anon 1 1855
March 01	afternoon	*Kekerengu*	2 shocks	A	Trolove 1855
March 08	morning	*Kekerengu*	slight shock	A	Trolove 1855
March 15		*Altimarlock*	shocks still constantly felt	A	Trolove 1855
March 18	during night	*Kekerengu*	2 shocks	A	Trolove 1855
March 21	morning	*Kekerengu*	sharp	A	Trolove 1855
March 23	1600	*Kekerengu*	would have been considered heavy if not for previous shocks	A	Trolove 1855
March 25	1000	*Kekerengu*	earthquake	A	Trolove 1855
March 30	no times given	Wellington	short sharp shock	A	Jolliffe 1855
April 28	no times given	New Plymouth	slight	A	Blackett 1855
April 30	no times given	New Plymouth	slight earthquake during night, several small shocks	A	Blackett 1855
May 02	2000	New Plymouth	slight	A	Blackett 1855
MORE GENERAL COMMENT		Canterbury	slight tremors for 10 days (until Feb 06)	A	Hamilton 1855
		Wanganui	frequent sharp shocks for 3-4 weeks, gentle rocking at night	B	Burnet 1904; Field 1891
		Christchurch	slight shocks for two weeks, none so severe as first	A	Hall 1855

		Christchurch	continuance of tremor sufficient to annoy for 4-5 days	A	McIntyre 1980
		Wellington	many hundreds of shocks over two days. Many very severe ones.	A	Moir 1855
		Hutt Valley	for first week motion never wholly ceased	A	Mallet 1858
		Hutt Valley	scarcely 24 hours without a shock (up to 21 March)	A	Mason 1855
		Near Collingwood	"heavings" at intervals for three days	B	Washbourn 1970
		Wairarapa	none as severe as first	A	Anon 4 1855
		Napier	scarcely free twice or thrice weekly from Jan 23 to Feb 23	A	Colenso 1855
		Wellington	At end of Feb, only one or two per day	A	Fox 1855
		Gisborne	two slight shocks (Jan 25 - Feb 01?)	A	Williams 1855

wooden houses". Some of the stronger earthquakes with intensities greater than MM6 had the potential to cause further damage to household goods, loosened masonry and weakened buildings in Wellington. Strong earthquakes are reported to have occurred during the night after the mainshock when Joliffe, Drury and Jones of the survey ship, *Pandora*, were still touring the town but their journals (1855) and the newspapers make no reference to any further damage to structures or their contents, although elsewhere the dangerous state of some buildings, is mentioned, "several stores are unapproachable, until neighbouring dangers are removed" (Drury, in *Spectator* Feb 7 1855).

It is possible that no further significant damage to buildings occurred in Wellington, but there were political and social advantages of refusing to recognise the full consequences of the earthquake as referred to in another section. Other explanations might be sought, however. Further damage to household goods may not have been observed as many did not return to their houses after the earthquake but preferred to sleep in tents for days or weeks, apparently irrespective of whether or not their houses were seriously damaged. The experience of three damaging earthquakes at 36 hour intervals in 1848 was evidently still fresh in people's minds. Some even methodically packed away undamaged goods (Pilcher 1855). Debris and buildings in a dangerous condition were quickly cleared by the 65th Regiment no doubt aware of the deaths of three people in a large aftershock in 1848. In addition it is probable that any further damage was considered trifling in comparison to the effects of the first shock, agreed by most to be the severest. Elizabeth Hollard's (1930) reminiscences of the Hutt Valley indicate this may be a reasonable explanation as she writes "there was great destruction of household treasures, but the continuance of the shocks was so nerve wrecking in effect that many people believing that the end of all things was near, were quite indifferent to the ruin of their goods". Jolliffe (1855) comments in his journal in mid February on several earthquakes of "20-40 seconds duration" that he considered "slight in degree" indicates that these apparently minor events were not trifling.

Few locations other than Wellington and Marlborough provide information on the relative severity of the aftershocks. Because of the size of the fault rupture zone and consequently the likely aftershock area, events that can be identified by severity in Wellington or Marlborough will not provide a complete list of large aftershocks. For example, a magnitude 6.5 event at the southern end of the fault plane should be felt at intensity MMVII - VIII in Wellington and be felt in New Plymouth, Christchurch and Wairoa to MMIV, and Gisborne to MMIII, while the same event at the northern extremity might only be felt at intensity MMV - VI in Wellington, but similarly at each of the other locations with perhaps MMIV at Gisborne also. The radius or area of perceptibility becomes the most useful tool for identifying the largest events and estimating their magnitudes but even this is limited by lack of detail on times of events.

The largest of the aftershocks were felt at Gisborne, three in the first 30 hours and two slight shocks in the next week (Williams 1855). At Wairoa, one or two slight shocks were identifiable during the first night, although Hamlin (1855) comments that "the earth seemed scarcely to have lost its tremulous motion during the night". Another shock was felt distinctly at about 7 am on January 24, with five more being felt in the next two days. At New Plymouth, Messenger (1855) notes 9-10 individual earthquakes in the first 24 hours while Blackett (1855) and Atkinson (1855) imply many small earthquakes or just perceptible vibration. Others in Taranaki only note several earthquakes. The *Lyttelton Times* reports the Jan 24 0700 event and one earlier at about midnight, being felt at Lyttelton and in Christchurch, as well as several others, for which there are no times given. Intensities of at least MMIV must be assumed for the events to be detected by sleeping persons. Confirming this intensity at Lyttelton, Smith (1855) writes that "there were no more violent shocks.... but with the creaking and straining of our wooden tenement, the ringing of bells, and the jingling of crockery, sleep was out of the question".

Given the limitations, events at about 2400 January 23, about 0700 January 24, 0045 January 25, seem to be the largest of the aftershocks in the first 30 hours and the area of perceptibility suggests magnitudes of about 6.5 but none seem sufficiently strong to have reached magnitude 7.0. The first of these was not individually identified in contemporary reports from Wellington as the strongest event among a number of strong shocks during the night, noting that the reminiscences of Cameron (date unknown) and Colley (1907), which do identify an earthquake in the middle of the night as very severe (listed in the Table 4), are second hand and considerably less reliable. A number of reminiscences and parts of the Colley material, in particular, confuse effects with the earthquakes of 1848 or merge effects on other days and nights. The 0700 event is also unidentified in Wellington, although Bennett (1855) and Anon 1 (1855) mention a severe earthquake at about 0500, which is not mentioned specifically by anyone else. It seems improbable that they mistook the time until one reads later in Bennett's diary that his watch seems to have been at the watchmaker's at the time. It is almost certain that Anon 1 was staying at the same boarding house as Bennett during the earthquakes, and the similarity of their observations also suggests that they spent some time together. Either or both of these events (2400 Jan 23 and 0700 Jan 24) may have been centred remote from Wellington and caused lesser intensities there than other smaller and closer earthquakes.

Another event at 2330 Jan 24 seems to have been felt strongly in Wellington and as far afield as New Plymouth and Christchurch and possibly Wairoa, but not recorded in the extract from Gisborne. Its magnitude is probably at least 6. Anon 1 (1855) and Trotter (1855) record several other events that seem to be severe or very severe in Wellington and the Hutt Valley at 1530, Feb 2; 2200, Feb 6; 2300, Feb 8; 1030, Feb 9; 2300, Feb 13, but for the most part these are not specifically identified elsewhere. It is possible that two of the shocks were those mentioned by Williams (1855). At Gisborne, Williams also refers to a sharp shock on February 12 but it is clearly unrelated to the aftershocks of January 23 as Hamlin (1855) also records a severe shock at this time at Mahia. It was followed by several aftershocks over the next few days. Interestingly Hamlin (1855) writes, "the sea roared and the water [was] thrown up much beyond its usual height on the bank.", although this comment might refer to the January 23 event rather than the shock of February 12. The event on February 2 brought down stones from a cliff near Flaxbourne in eastern Marlborough. Mowat (1855) at Altimarlock in the Awatere, mentions a very sharp shock at 1200 on the same day but none during the afternoon, from which one might suspect he has his time incorrect.

Other than the second hand, and hence potentially unreliable, reminiscences of Cameron (previously referred to), all contemporary reports from Wellington and most of the whole of New Zealand record the principal earthquake as the most severe. Only one area reports earthquakes that are stronger than the principal earthquake. At Kekerengu, on the northeast coast of the South Island, Trolove (1855) watched as his homestead gradually disintegrated over a period of three days, from a series of shocks which he considered to be more severe than the first earthquake on January 23. Trolove's diary was apparently written on a regular basis, particularly when he was at Kekerengu, and when he travelled further afield it was updated every few days, so to a large extent his observations cannot be dismissed easily as unreliable. The relevant part of his diary reads:

> Tues 23rd Jan . ... About half past 9 o'clock or 10 pm a very severe shock of an earthquake took place. So sudden and severe was it that in running out of the house we had great difficulty in keeping our balance. We staggered like drunken men. The shocks continued lighter, and the earth constantly in motion either in little convulsive starts or oscillating like a pendulum until, I should say, the middle of the night when a most awful shock the imagination could conceive forced us once more out of the house in the greatest confusion and alarm. It is impossible to describe one's feelings in such a moment - the earth trembling beneath your feet - everything in the house tossed to and fro, bookshelves and books falling, rafters and roof creaking, chimneys falling, walls rent and split all in a few seconds. For the rest of the night I thought it safer to sleep in the Wool Shed ...
>
> Wed 24th Jan. ... All day the earth has not ceased shaking for 10 minutes.
>
> Thurs 25th Jan. We have had a fearful night indeed and we have had 3 heavier shocks than any before [presumably the night of 24/25]. During the whole night we have been in (I may almost say) perpetual motion. The shocks were always preceded by a hollow rumbling ... As I lay in the woolshed I could see the poor old house , which I put up with my own hands, tottering with every shock, and now and then part of a chimney or wall would drop to the ground....
>
> Fri 26th, Sat 27th, Sun 28th, Mon 29th. Thursday night 11 or 12 o'clock pm [At Madcap's Flat, not Kekerengu] we had the heaviest shock of any. About an hour after there was another very severe shake. Jurdon and Cate came just after the shock.... Friday morning at the earliest dawn I peeped out of the hut to see if the house was still standing there, or whether the hill had slipped any more during the night. What a change it presented. In the grey morn a few hours, nay a few days past, you might have seen one of the neatest NZ cottages ... Its destruction was now complete. Its ruin is not to be repaired ... I rode down to Jurdan's along the beach (my shepherd) thinking that the house he was living in would not be harmed by the shocks. It was the first house I built on the run and made of toi-toi and posts in the ground three feet with a clay chimney. I came upon the spot and Woodbank was no more! Jurdon, whom I had taught to write completed my surprise and consternation by these words written in pencil and put on the top of a pole which was supported in a rent made by the earthquake. [It is clear here that Jurdan had been to see Trolove during the night but must have returned to Woodbank. It is presumed that if the damage to the hut had occurred previous to Thursday night's shocks Trolove would have been aware of it]. (Trolove 1855)

In August, Trolove is again at Woodbank where "the old house altho' 10 feet out of the perpendicular and the floor cracked diagonally 3 feet wide and 3 deep served us for kitchen and dining room". In early February Trolove rode to the Awatere and Wairau Valleys and comments that he is "confident they [the shocks] have not been so severe in the Awatere and Wairau as at Flaxbourne and Woodbank".

Trolove's remarks suggest that the intensity of the mainshock was MMVII only and by inference the others were the same or greater, the last shock apparently causing the ruin of the Woodbank hut by fissuring. The events which Trolove identifies are:

1. Jan 23 middle of the night
2. Jan 24 2100?
3. Jan 24 2330?
4. Jan 25 0045?
5. Jan 25 2300 or 2400 - reportedly the heaviest shock.

The first earthquake Trolove records as stronger occurs during the night of January 23/24. Writing from information given to him by Frederick Weld of Flaxbourne, Lyell (1856b) records that Weld felt a shock at 0300 Jan 24 which he "supposed to be local" and "had the same strength as the first one". In his later account, Lyell (1868) does not record the time, but otherwise the facts remain unchanged. Unfortunately no Weld journals which cover this time period are known (Graham 1983). At Altimarlock 30km from both Flaxbourne and Kekerengu, Alexander Mowat (1855) records no other earthquake on the first night of an intensity to match that of the principal shock. An earthquake was felt at Lyttelton at 2400, and possibly at Wairoa and Gisborne but is not specifically mentioned at Wellington. Events 2 and 5 are also not mentioned in Wellington extracts and therefore assumed to be not particularly strong shocks there. Event 3 is severe in Wellington and specifically identified as felt in Christchurch. Event 4 is severe or even very severe in Wellington and probably one of the events mentioned as felt in Gisborne and Christchurch.

A magnitude 6.5 in Cook Strait near the offshore extension of the Wairarapa Fault within the presumed main rupture zone would be felt strongly in Wellington and at Flaxbourne, Kekerengu. and Woodbank. Although it is doubtful the duration would be comparable, the shocks could have had an intensity similar to and possibly more than the mainshock at Flaxbourne and Kekerengu but would also be felt strongly at Altimarloch. It is difficult to explain the felt effects of events 1 and 5 in this way. In particular, event 5, the strongest according to Trolove (1855), is not mentioned by Mowat (1855) at *Altimarloch*, although he notes a "very sharp" shock at 2100 which is also described as "another constant vibration" by Bennett (1855) in Wellington. Apparently Weld does not mention this shock to Lyell, nor is it mentioned in Wellington extracts. The obvious high intensity at Woodbank, causing the fissuring, is difficult to attain with a shock in Cook Strait. Hence, neither events 1, 2 or 5 can be explained by an earthquake in Cook Strait within the assumed rupture zone. It is a question of whether Trolove's judgement of the severity of the earthquakes is reliable as they completed the demolition of his house and the one at Woodbank, or whether a sequence of very shallow earthquakes could have been initiated close to Kekerengu, outside the main rupture zone. A shallow magnitude 6 earthquake close to the coast could cause MMVIII locally. The occurrence of "off-fault" earthquakes, beyond the main rupture is not unprecedented, a recent example being the Landers, California, sequence (Hauksson *et al* 1993). One can only speculate on the occurrence of the events and ponder on the reasons why event 1 was "supposed to be local" by Weld (Lyell 1856b). While the evidence strongly suggests that the aftershocks originated very close to Kekerengu, it could also be that Trolove's judgement was unreliable.

As there is virtually no information on individual aftershocks from Wanganui or the Wairarapa area any larger events elsewhere within the rupture zone cannot be identified, although "several severe shocks were subsequently felt [in Wanganui] they were only small in comparison [with the principal earthquake]" (Allen 1904). In the first 24 hours aftershocks were sufficiently strong at Waitotara to make walking unsteady, to cause small rock slides on coastal cliffs and fissures on alluvial river flats to move. At Napier Colenso (1855) in mid-February alludes to many earthquakes having been felt and still continuing to occur at one or two per week. Magnitude 5.5 earthquakes near the northern extent of the fault plane would generally be felt in Napier. Some of the earthquakes felt by Colenso could have been those on February 12 et seq. described by Hamlin (1855) and Williams (1855).

In summary, it is probable that at least five shocks had magnitudes greater than 6.5 but probably less than 7.0. Many, quite probably hundreds, with magnitudes 5.0-6.4 occurred, these accounting for the frequent small shocks and vibrations over several weeks in Christchurch, Motueka, Wanganui, New Plymouth and Napier. The number of magnitude 6.5 events is mainly based on the observations at Gisborne rather than New Plymouth or Christchurch where one or the other but not both locations might feel lesser magnitude events. It is more than probable that the Williams family in Gisborne missed feeling some events because of their activities, particularly during the daytime. Many hundreds, or more probably thousands, of shocks of magnitude 4 and above are indicated by the constant tremor and small shocks at Wellington, Wanganui and at Otaki.

The highest magnitude aftershocks are often about one unit lower than the mainshock (Kisslinger 1996). Hence a magnitude 8.1-8.2 earthquake might produce small number of aftershocks with magnitudes of about 7.0, several with magnitudes 6.0-6.9 and perhaps several hundred with magnitudes 5.0-5.9. For comparison, the 1964 Alaska earthquake (M_w9.2) produced no aftershocks with magnitudes exceeding 7.0, six had magnitudes 6.0-6.9 and 127 had magnitudes 5.0-5.9. The largest aftershock had a magnitude of M_s6.7 (Cloud & Scott 1972). Hence the numbers of aftershocks which occurred in 1855 are consistent with the assumed mainshock magnitude.

RESPONSE AND RECOVERY

Although incidental to this study of the seismological and geological effects of the 1855 earthquake, the historical extracts give some insight on aspects of social response and recovery. Naturally there is more information on Wellington than elsewhere and the extracts only cover a period of several weeks immediately following the mainshock. Nevertheless they probably provide a starting point for further study by historians or social scientists.

Several factors seem relevant to the response of Wellington's European population: their character, their isolation from their homeland resulting in their need to depend on one another and the settlement's experience of a large earthquake several years before. Settlers who had risked their future in coming to a far-away, undeveloped land might be expected to be resourceful and adaptable and undeterred by unexpected setbacks. A prosperous future lay in the success of the settlements. At a public meeting following a few days after the earthquake Jerningham Wakefield commented on the characteristics of the population, saying that he "felt sure that the people of Wellington did possess those qualities of prudence and endurance; that as they had struggled through far more grievous afflictions, so they would cheerfully meet this, and even be prepared to triumph over difficulties" (*Spectator* Feb 10 1855).

Other praiseworthy attitudes were also evident; "Amidst all these disasters there exists universally a generous sympathy here [which] I never anywhere else witnessed.... Such a degree of honesty exists here, without closing a door or window you can have your house wholly untenanted, without the slightest apprehension or even imagination of anyone interfering herewith, much less abstracting anything" (Hort 1855). Similarly, "Those who had suffered less than their neighbours were assiduous in rendering assistance.... With shops exposed, and every temptation to plunder, there seemed to be neither fear nor thought of robbery, but a generous and manly feeling to lessen each other's burdens pervaded all classes, from the Superintendent to the lowest mechanic, from the Colonel to every soldier of the 65th regiment" (extracts from Drury's Remarks book published in the *Spectator* Feb 7 1855).

Not all were persuaded to remain in the Wellington settlement. Despite the comment in the *Spectator* (Feb 7 1855) that "None have left, or are preparing to leave Wellington" departures occurred although perhaps not so dramatically as had occurred in 1848. After that earthquake, one attempt by about 60 settlers to depart by boat was thwarted by its foundering at Wellington Harbour entrance, the passengers having to return in a sorry state by walking over the hills (Eiby 1980). According to Colley (1907), daughter of the Hon. H. W. Petre of Lower Hutt, "The great earthquake in 1855 upset all Father's plans; he lost confidence in New Zealand and made up his mind to return to England". Similarly Anon 1 (1855) writes "Mr B., a civil engineer, has come to the conclusion that men of his profession will never be wanted in such a country and so has decided to return to England at the first opportunity". Redwood (1887) writes "numbers left Wellington in terror". Several months after the earthquake, people were still considering whether to stay in Wellington, "So it is that people are beginning to fly from it [the calamity in Wellington]. Paul and his family return forthwith to Canterbury. Bowler is come down to select a place for building here, instead of building in Wellington as he was on the point of doing" (McIntyre 1980).

Fortuitously, the earthquake resulted in only one death and very few injuries in Wellington, hastening the process of recovery and reconstruction. The experience of previous large earthquakes probably lessened alarm and panic. Demolition of buildings was begun almost immediately, soldiers "clearing away the ruin caused by its effects (*Spectator* Feb 3 1855) and "Fatigue parties of soldiers are busy pulling down a number of houses and stores in the principal street" (*Australian & New Zealand Gazette* June 2 1855). People were no doubt aware of the deaths of three people in a large aftershock in 1848. Within days business was resumed, - "Business was suspended the whole of that week but is going on as usual now [early March]" (Pilcher 1855). Large aftershocks hampered some operations, for example, reopening of the Union

Bank. It was delayed until the safe could be righted, the procedure being considered too hazardous for about four days (*Spectator* Feb 10 1855). Publication of the *Spectator* was delayed by one day only. According to Carter (1866),"the very day after this awful night - when the worst was past - confidence began to be restored. Repairs were effected, business was resumed, the newspapers were published as usual, and what was more noticeable and strange, the virulence of politics - mitigated for a night - resumed its sway".

Whether by design or accident the people of Wellington were distracted from their own affairs to become involved in political debate. Newspapers resumed discussion of matters that had been of concern before the earthquake ("the education question") but one event in particular attracted wide interest, "a very disagreeable quarrel arose between the Provincial Government and Military Authorities about some tents required for the people rendered homeless by the earthquake, which led to a most uncalled-for attack on Colonel McCleverty" (Coote 1855). The disagreement also related to the use of Government House. The collapse of the Council Chambers led to a request from the Colonial Secretary for the temporary use of Government House for holding Council meetings. Use was denied by the 65th Regiment Officer in charge until it was inspected and declared safe. This and the denial of the use of some tents, because of their being needed to protect Military property, led to a very heated political exchange (*Spectator* Feb 10 1855, Provincial Council papers March 1855). Clearly the situation provided the occasion for the Provincial Government to vent their discontent with the presence of a regiment under orders from the administration in Auckland. Among the general populace only praise and appreciation for the efforts of the 65th Regiment could be found.

Although reconstruction was begun quickly (Carter 1866), some repairs were not completed many months later, "Poor old Alzdorf's Hotel is still a ruin" and "[Clifford's] house ... is in all confusion of repair" (Sewell, diary entries July 29 and Sept 27 1855 resp.). Some were never attempted because of the perceived recurring danger (Redwood 1887). "It was a long time, however," according to the Cyclopaedia of New Zealand (1897, p247), "before the results of the earthquake of 1855 had so far faded from the thoughts of the people as to admit of any attempts at building in brick. Ten years later when the General Government removed to Wellington, Government House and the Houses of Parliament were erected in wood; and eleven years later still, when the abolition of the provinces and the consequent centralisation of all government functions took place, the new Government buildings were erected in wood, though a few brick buildings had been ventured by that time. It is impossible to estimate the deterrent effects caused by the dread of earthquakes. Scores of fine buildings have been run up in wood which otherwise would have been brick, and scores of brick structures are of three stories which would otherwise have been five or six." By 1897 the lessons of 1848 and 1855 were beginning to be forgotten, "Of late years very much better taste has been displayed in the architecture of houses, churches, schools and in fact all kinds of buildings. The use of bricks and other rigid materials is not only encouraged, but enforced in some parts of the city" (Cyclopaedia of New Zealand 1897, p214).

Notwithstanding the loss of life, damage and alarm that the earthquake caused, its benefits were not long in being recognised. The Hutt Road and much of the business area of the City of Wellington and industrial area of Seaview are sited upon land uplifted by the earthquake enabling reclamation from the sea. The buildings on Wellington's foreshore today rest upon the debris of 1855.

SUMMARY AND CONCLUSIONS

1. The first and main earthquake shock of January 23, 1855 occurred at 2111 WCT (Wellington Civil Time) or 0932 UT (Universal Time). On the basis of felt intensity, comparison with isoseismal maps for the 1931 Hawke's Bay (M_s 7.8) and 1929 Buller (M_s 7.8) earthquakes, and forward elastic dislocation modelling using a listric fault configuration, the magnitude of the principal 1855 event is estimated to have been within the range M8.1 - 8.2. The duration of the mainshock in Wellington was at least 50 seconds and probably consisted of two events. Accounts from Wellington, Wairarapa and Marlborough indicate a short S-P interval whereas in Wanganui there was a somewhat longer time interval to the arrival of S waves. An epicentre close to Wellington, and here chosen to be 41.4°S 174.5°E±0.5°, is in accord with this observation and the macroseismic epicentre suggested by isoseismals. This location reflects the southwestern limits of the probable earthquake source zone, i.e. it lies close to the probable offset in the subducting Pacific Plate below Cook Strait and close to the observed change in dip of the plate, and at a depth (25km) approximately corresponding to the intersection of the Wairarapa Fault.

2. The earthquake was felt over the whole of mainland New Zealand from at least Auckland to Dunedin. It was strongly felt with damage to buildings and chimneys as far north as New Plymouth (MMVI and greater) and extending south to approximately Cheviot in north Canterbury. Damage to household items (MMV and greater) was experienced from at least Napier to Christchurch. Within the highest intensity areas (MMXIII - MMIX) in the central part of New Zealand many masonry buildings and some wooden structures were seriously damaged with some collapsing. Fatalities of the earthquake are variously put at between 5 and 10.

3. The earthquake caused severe ground disturbance in those areas underlain by alluvial gravels and sediments (river valleys and coastal plains) and on adjacent hill sides in the form of fissuring, differential subsidence, lateral spreading, liquefaction, gas expulsion and landslides. The area over which ground damage was reported is about 135,000 square kilometres. The area of most extensive ground damage, about 52,000 square kilometres, included Wanganui - Waitotara; Manawatu - Horowhenua; Wairarapa; Rimutaka Range; the Hutt Valley and Wellington; Marlborough, in particular the lower Wairau and Awatere valleys and Kaikoura coast.

4. Uplift of some 5000 square kilometres of the Wellington peninsula west of the Wairarapa Fault and subsidence of the lower Wairau Valley occurred. Measurements of stranded coastal features (rocks and raised beaches) relative to mean low water spring tide levels indicate that the greatest amount of uplift (6m) was locally attained in the vicinity of Turakirae Head, Palliser Bay, and that the uplift gradually decreased in the northwest direction across the Wellington Peninsula to zero at Wainui, about 16km north of Paekakariki on the west coast of the North Island. Subsidence in the lower Wairau Valley of up to 1.5m can be partitioned between differential compaction of waterlogged sediments and tectonic subsidence north of the Vernon Fault.

5. The earthquake was accompanied by rupturing along the Wairarapa Fault from the coast at Palliser Bay to beyond Mauriceville and possibly Alfredton in northern Wairarapa. The minimum rupture length (including the offshore extension of the Wairarapa Fault) was about 140 km. Vertical displacement (upthrow on the NW side of the fault) progressively decreased northeast along the fault from an offshore maximum of 6m at Turakirae Head to about 0.3m at Mauriceville. There are no contemporary accounts of horizontal movement taking place, but the smallest dextral displacements along a 72km stretch of the fault are between 9 and 13m. These are indicated by dog-legged streams, abandoned river channels and protruding half-scarps that are inferred to represent the 1855 movement.

6. The earthquake caused seismic seiching in many rivers, lakes and harbours from the Waipa River (Waikato District) in the north to possibly Port Chalmers at Dunedin in the south. A tsunami with waves up to 10m high swept the coast on both sides of Cook Strait. During or immediately after the main shock a wave or waves were generated that flooded parts of Lambton Quay bordering Lambton Harbour, Wellington, to a depth of not more than 0.9m. Available data suggest that this "immediate wave" could have been caused by sudden lateral displacement of the harbour perimeter in a NE direction due to dextral movement on the Wairarapa Fault. Seiching occurred as a result of the collapse of the "immediate wave", differential uplift across the harbour caused by westward tilting (2.1m on the east side and 1.2m on the western side), and arrival of the tsunami, which was generated in Cook Strait. The water oscillated back and forth across the harbour with a period of about 20 minutes and continued for 8 - 12 hours. Further tsunami were caused by aftershocks.

7. Landsliding, tsunami, seiching and tectonic uplift caused by the earthquake resulted in widespread destruction of vegetation and decimation of marine life. Large numbers of bottom dwelling, pressure sensitive fish such as Ling were found floating in Cook Strait following the earthquake and may have been killed when they were forced up from the bottom by turbulence caused by submarine landsliding. In addition, large numbers of fish, presumably near shore feeding shoals, were stranded along the south Wellington coast and around the shores of the harbour by the tsunami. About one third of the vegetation was stripped from both flanks of the Rimutaka Range.

8. Aftershocks of the January 23 event were numerous and protracted over several months. At least five aftershocks had magnitudes greater than 6.5, but probably less than 7.0. Hundreds with magnitudes 5.0 - 6.4 occurred and accounted for the frequent smaller shocks and vibrations felt over several weeks in Christchurch, Motueka, Wanganui, New Plymouth and Napier. Many hundreds, and probably thousands of aftershocks of magnitude 4 and above are indicated by the constant tremor and small shocks experienced at Wellington, Wanganui and Otaki. A report from Kekerengu on the Kaikoura coast suggests that at least one aftershock was more severe than the principal shock felt in the same area. This could have been local and initiated close to Kekerengu, outside the main rupture zone of the seaward extension of the Wairarapa Fault. The number of aftershocks and their magnitude range are consistent with the assumed mainshock magnitude.

9. Local newspapers and public meetings in Wellington downplayed the worst effects of the earthquake and emphasised the positive benefits, e.g. uplift of land. The reasons were closely linked with important political issues, namely the concern about the effects of the earthquake on immigration, especially to Wellington, and Wellington's aspiration to become the future centre of government over Christchurch and Auckland. Fortuitously the earthquake resulted in only one death and very few injuries in Wellington which hastened the process of recovery and reconstruction.

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[1] NLNZ is the preferred citation style for National Library of New Zealand, Wellington, New Zealand.