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Predicting the Past: Using Liquefaction Maps and Archaeological Records to Determine How Previous Seismic Activity was Felt

Abstract

Lying directly on the convergence of two plates, New Zealand has long been affected by plate tectonics. While this convergence has formed great landscapes, it has also been the source of natural disasters, which have affected the people that inhabit the islands from their earliest settlements 700 years ago. Most recently, large earthquakes in the Canterbury plains caused liquefaction in the region creating not only structural damage, but also health risks as water sources were contaminated. In mapping where the potential for liquefaction damage lies in relation to the faults as well as the past locations of Maori settlements, it is possible to see a relationship between the two and determine how early people in this country might have been affected by the active plate tectonics; consequently, making preparations for such events in the future simpler.

Introduction

The Canterbury Plains are continuously affected by seismic activity. Just last year (22 February 2011) an earthquake near Christchurch took 185 lives. While that may seem a little unheard of in this day and age with the technology that we have, disasters of this magnitude are not out of the ordinary. As such, it is important that all of the possible risks are evaluated so that populations can be prepared in the future.

One of the major reasons for damage in the February 2011 Christchurch earthquake was liquefaction, which occurs when the ground settles during a quake, because it has a high potential to create structural damage or malfunctions (Sun 2012). In this particular event, the widespread liquefaction and lateral spreading induced extensive damage on lifelines and residential houses in areas nearby streams, rivers, and wetlands within Christchurch and Kaiapoi (Orense 2011).

First settled by Maori 600-700 years ago (Wilson 2009) the Canterbury Plains are New Zealand's largest areas of flat land (Orense 2011). Located within the plains, Christchurch has a population of about 350,000. This area covers approximately 450 km2 making it the second-largest city in New Zealand (Cubrinovski 2011). These plains were formed by the overlapping fans of glacier-fed rivers from the Southern Alps, the mountain range of the South Island; as such, their soils are variable, derived from greywacke from the mountains, loess, clay, and volcanic rock (Ornese 2011). As Christchurch is situated on an alluvial plain on these variable sediments, it is considerably vulnerable to liquefaction (Sun 2012).

Kaiapoi, a town north of Christchurch and previously the most important pa in the region as it was a centre of trade for greenstone from the West Coast (Wilson 2009), was also very affected by liquefaction as a result of the February 2011 earthquake. The town lies low on the banks of the Kaiapoi River, once a branch of the Waimakariri, a large braided river which transports gravelly sediment (Wotherspoon 2012). As such, its sediments are also very vulnerable to the risk of liquefaction, which had been seen before in historic earthquakes, such as the 1901 Cheviot earthquake. There is well-documented evidence of liquefaction in Kaiapoi from this event. The details can be found in newspaper reports which described lateral spreading, ejection of sand, and ground settlement in the region (Wotherspoon 2012). This evidence of liquefaction in Kaiapoi could help to determine potential risks in the future and show what effects existed in the past such that we might be able to deduce effects from events such as these from before written records. Looking at the historical evidence from Kaiapoi, it is clear that the most severe areas of damage are in areas where the river previously flowed. This indicates the importance of knowing the location of old river channels when defining liquefaction prone regions (Wotherspoon 2012). If knowing previous locations of flowing water is key in determining potential locations at risk of liquefaction, an effective model could be available to determine what areas are at risk in the future and what might have been at risk in the past.

Other methods do exist for predicting what areas are at risk of liquefaction in the future. Sun outlines four methods utilized to predict areas at risk prior to the

February 2011 earthquake and compares their predictions to what actually took place. The four methods are the Miyajima method, the Suzuki method, the Kostadinov and Yamazaki method (KY method), and the Yuan and Sun method (YS method) (Sun 2012). Each of these methods was somewhat successful in predicting what areas could be at risk of liquefaction, but no model was perfect.

In considering how earthquakes affected the early settlers in New Zealand, the question becomes can these models be used to predict events that might have already happened before written records? In gaining an understanding of how the disasters associated with earthquakes affected people of the past, valuable knowledge of how we can prepare for the future is also gained. It is known that prehistoric coastal sites were abandoned likely due to tsunamis associated with earthquakes, what is unknown is how earthquakes might have affected early settlers away from the coasts and whether liquefaction played a role in the livelihood of these people.

Methods

In order to analyze any correlation between early Maori settlements and seismic activity in the Canterbury region, the current research is using maps of the liquefaction in the area from before and after the recent large seismic events. Liquefaction presents clear evidence of a seismic event occurring unlike damage to infrastructure, which is often quickly replaced or repaired leaving very little trace that the disaster occurred. Because the damage from liquefaction occurs to the land itself, it is likely that early settlers were affected by it and easier to predict where it occurred.

In mapping where liquefaction occurred before and after the recent large earthquakes in the Canterbury region, it is possible to see patterns of where it is likely to occur. It is possible to use this information to gain understanding of how liquefaction might have happened in the past and affected early peoples. By looking at what the land looked like in the past, it is possible to predict how liquefaction affected the region at the times of historic large earthquakes. This can then be mapped alongside what is known about the locations of early Maori settlements to determine possible correlations.

Results

During large earthquake events, liquefaction occurs frequently in areas with high water tables. These levels change seasonally, making the potential for liquefaction variable (Beca Carter Hollings & Ferner Ltd 2005). Because the potential is greater in areas with higher water saturation, it stands to reason that the potential is also greater around major streams and rivers. This potential is not limited to areas surrounding places where the water is currently flowing, as there is evidence that there is a greater risk liquefaction and lateral spreading in areas where water used to flow in the past (Wotherspoon 2012). This presents a risk in the Canterbury region as the rivers are constantly changing. The variability of the Waimakariri River, in particular, means that the areas around Christchurch and Kaiapoi are vulnerable to this type of damage. Historically, the area of Kaiapoi was surrounded by branches of the Waimakariri (see Appendix 1). As the landscape has changed over time, these original water channels were forgotten or ignored and people built on top of them. This put the area at a high level of risk of liquefaction in the event of a major earthquake. The risk was evident prior to the September 2010 and February 2011 earthquakes; however, people did not know the extent to which the area could be affected.

The models of where liquefaction is likely to occur from before the two most recent events (Appendix 2), in general, fairly accurately predict locations for potential damage in the Christchurch region (Fig 1). It is also evident that these areas of potential damage line up with archaeological sites within the region (Fig 2 & 3) indicating that people of the past likely lived in areas with high-risk levels for liquefaction as well.

At the current state, it is unclear how the historic earthquakes affected the early settlers in the Canterbury Plains. The written records give evidence and locations of large earthquakes from 1848 through the present (Fig 4 & 5); however, they do not give evidence of large seismic events before European settlement in the area and the reasons behind the migrations of the earliest settlers in this region remain unclear.

Discussion

Liquefaction has played a major effect in the two recent large earthquakes in the Canterbury region (22 February 2011 and 4 September 2010) and it has the potential to affect many more people for years to come because this type of damage is a major cause of structural damage and water contamination from earthquakes. In predicting where liquefaction is likely to occur, it is necessary to not only look at types of soils, but also water table levels and previous river channels. Combining this knowledge presents a fairly accurate representation of where liquefaction and lateral spreading are likely to occur. This can be applied to landscapes that are known of the past to determine where damage might have occurred, and also to landscapes of today all over the world to determine areas that are at risk in the future.

In today's society people are generally firmly planted and settled in one location making this type of damage devastating when it occurs. In the past, however, this was not necessarily the case. Early settlers in the Canterbury Plains were not firmly tied to the ground they settled on. They felt strong connections to the land itself and were aware of the extent to which they relied on it for food and water; however, these Maori people made regular annual movements (Challis 1995). If these people were in the habit of making annual migrations anyway, liquefaction as a result of a large seismic event would not necessarily affect them to a great extent. With annual movement and migrations, their residencies were not permanent; therefore, damage to them would not present a huge challenge. The people likely carried on with their migrations in the same manner, rebuilding their settlements as necessary. There is no evidence yet that their movements and migrations were a reaction to seismic activity, although it is likely to have played a part to some extent in their lives just as natural disasters continue to affect people all over the world even if they do not cause a great extent of damage.

It is important to understand the effects that large seismic events had on people of the past so that their potential risks can be established for the future. Future studies into how Earth processes affected people historically will allow for better disaster preparedness and management globally in the future.

BIBLIOGRAPHY

Beca Carter Hollings & Ferner Ltd. 2005. "Christchurch Liquefaction Study – Stage IV (Addendum Report) ECan Report N° U04/25/2." Environment Canterbury.

Brailsford, Barry. 1997. *The Tattooed Land*. 2nd ed. Hamilton, N.Z.: Stoneprint Press. Print.

Challis, Aidan J. 1995. "Ka Pakihi Whakatekateka O Waitaha: The Archaeology of Canterbury in Maori Times." *Science and Research Series* No.89. Wellington.

Cubrinovski, Misko et al. 2011. "Soil Liquefaction Effects in the Central Business District during the February 2011 Christchurch Earthquake." *Seismological Research Letters* 82.6 : 893-904.

Goff, J.R., B.G. McFagden. 2000. "Catastrophic Seismic Events and their Impact on Prehistoric Human Occupation, Coastal New Zealand." *Antiquity* 75: 155-62

Goff, J.R., B.G. McFagden. 2003. "Large Earthquakes and the Abandonment of Prehistoric Coastal Settlements in the 15th Century New Zealand." *Geoarchaeology: An International Journal* Vol. 18, No. 6.

Green, Russell A et al. 2011. "Use of DCP and SASW Tests to Evaluate Liquefaction Potential: Prediction vs. Observations during the Recent New Zealand Earthquakes." *Seismological Research Letters* 82.6: 927-938.

Hutchinson, I., A.D. Mcmillan. 1996. "Archaeological Evidence for Village Abandonment Associated with Late Holocene Earthquakes at the Northern Cascadia Subduction Zone." *Quarternary Research* 48, 79-87. Article No. QR971890.

McFadgen, B.G., J.R. Goff. 2005. "An Earth Systems Approach to Understanding the Tectonic and Cultural Landscapes of Linked Marine Embayments: Avon-Heathcote Estuary (Ihutai) and Lake Ellesmere (Waihora), New Zealand." *Journal of Quaternary Science* 20(3) 227-237.

New Zealand Archaeological Association. 2009. <http://www.archsite.org.nz/default.aspx>

Orense, R. P. et al. 2011. "Comparison of liquefaction Features observed during the 2010 and 2011 Canterbury earthquakes." *Seismological Research Letters* 82.6: 905-918.

Sun, Rui, Fuhui Tang, and Longwei Chen. 2012. "Blind detection of liquefaction by existing methods for New Zealand M L6.3 earthquake on Feb. 22, 2011." *Earthquake Engineering and Engineering Vibration* 10.4: 465-474.

Taylor, Publisher et al. 2012. "New Zealand Journal of Geology and Geophysics The M w 6. 2 Christchurch earthquake of February 2011: preliminary report." *New Zealand Journal of Geology and Geophysics* April: 37-41. Print.

Wilson, John. "Canterbury region - Discovery and settlement." Te Ara - the Encyclopedia of New Zealand, updated 2 March 2009 <http://www.TeAra.govt. nz/ en/canterbury-region/6>

Wotherspoon, Liam M., Michael J. Pender, and Rolando P. Orense. 2012. "Relationship between observed liquefaction at Kaiapoi following the 2010 Darfield earthquake and former channels of the Waimakariri River." *Engineering Geology* 125: 45-55.

200 FIGURES

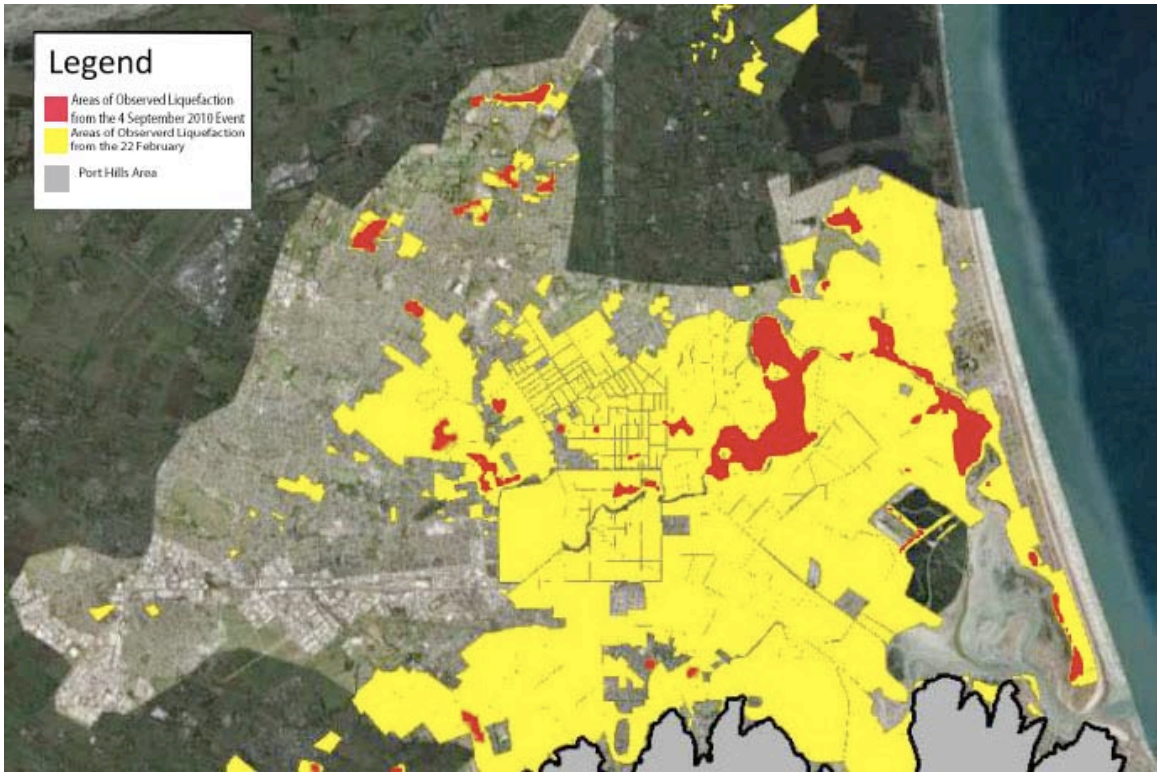
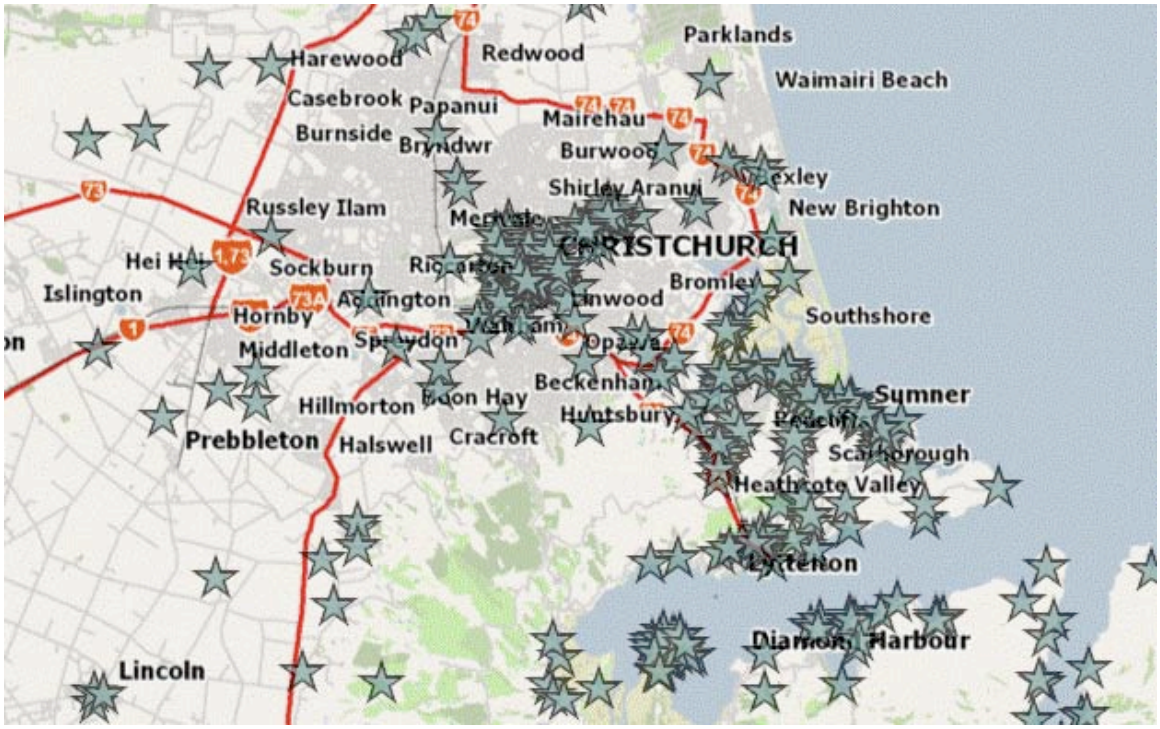


Figure 1 Areas of liquefaction damage in Christchurch from the September 2010 and February 2011 earthquakes. Adapted from the Canterbury Earthquake Recovery Authority



205 **Figure 2 Distribution of archaeological sites in the Christchurch region. Adapted from the New Zealand Archaeological Association**

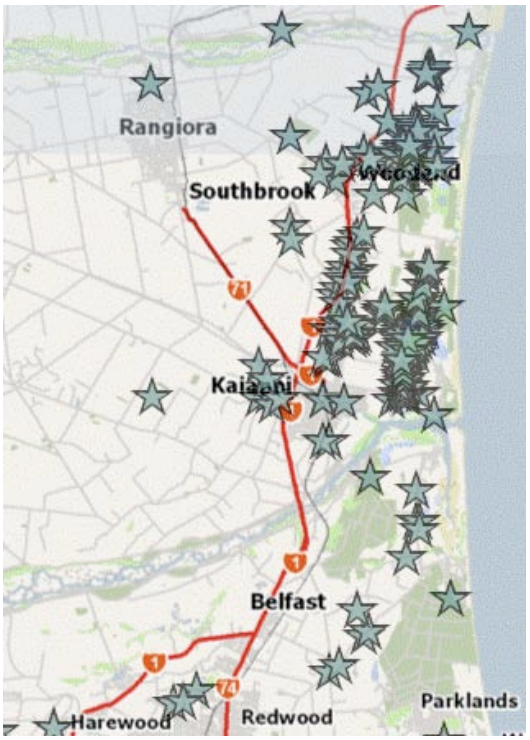


Figure 3 Distribution of archaeological sites in the Kaiapoi region. Adapted from the New Zealand Archaeological Association

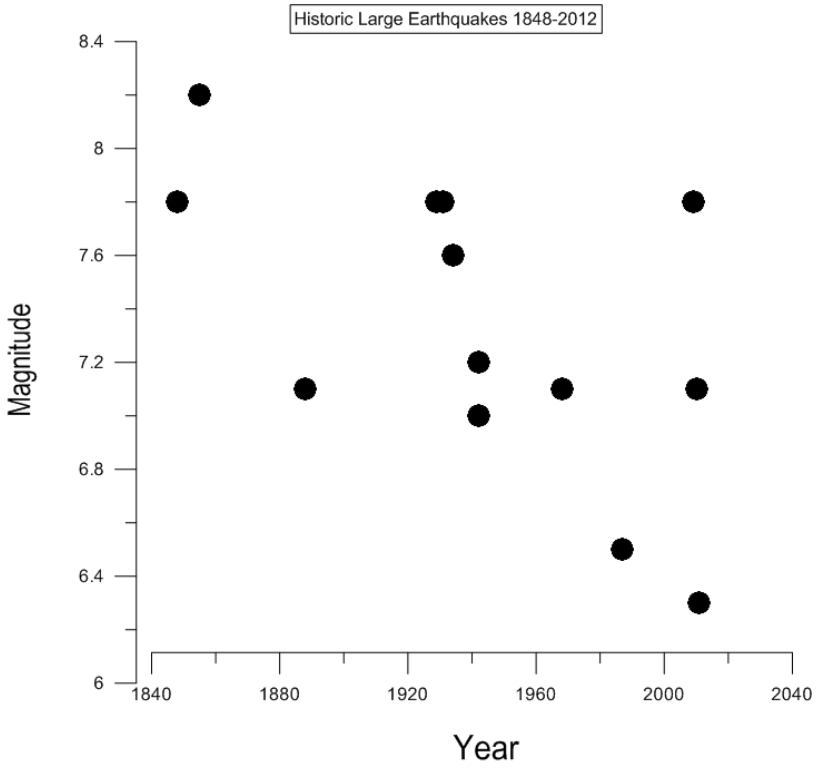
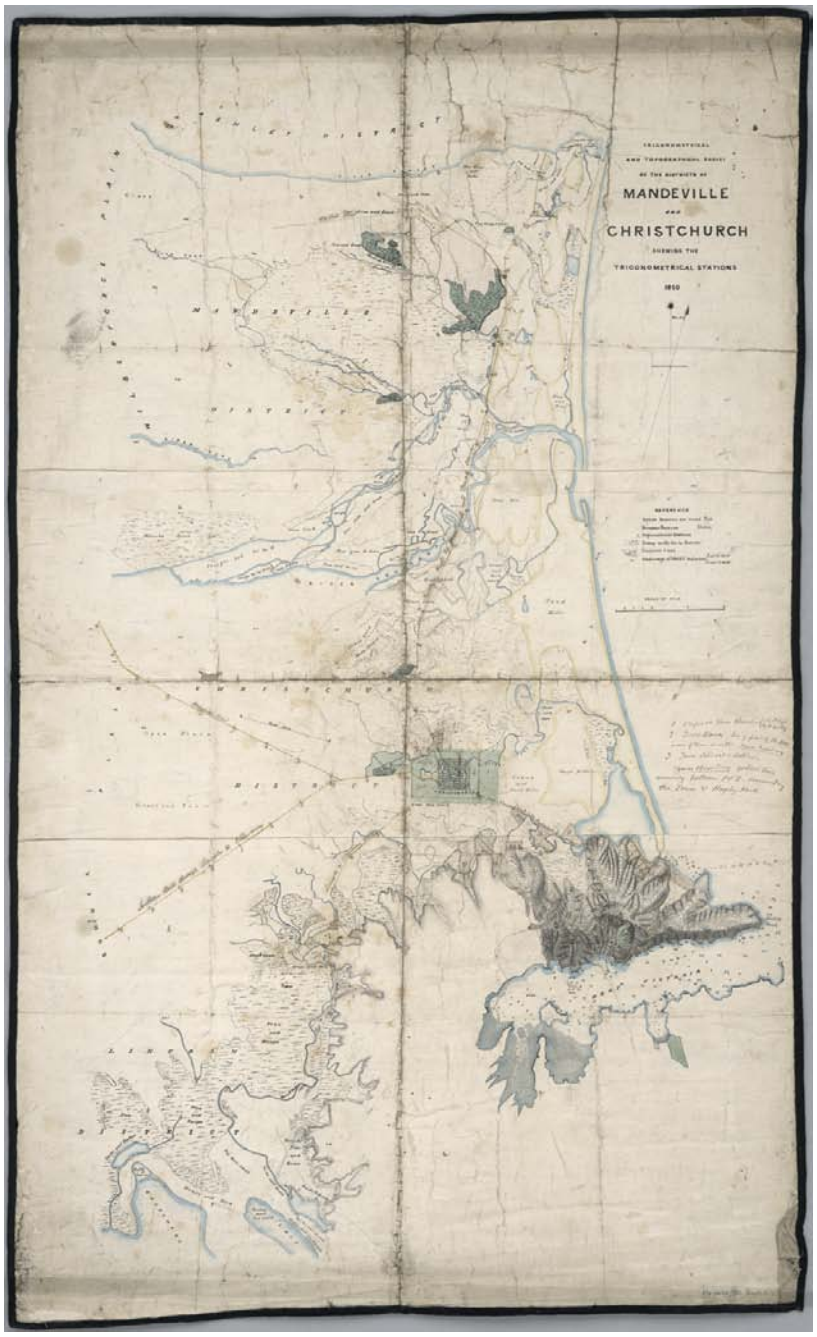


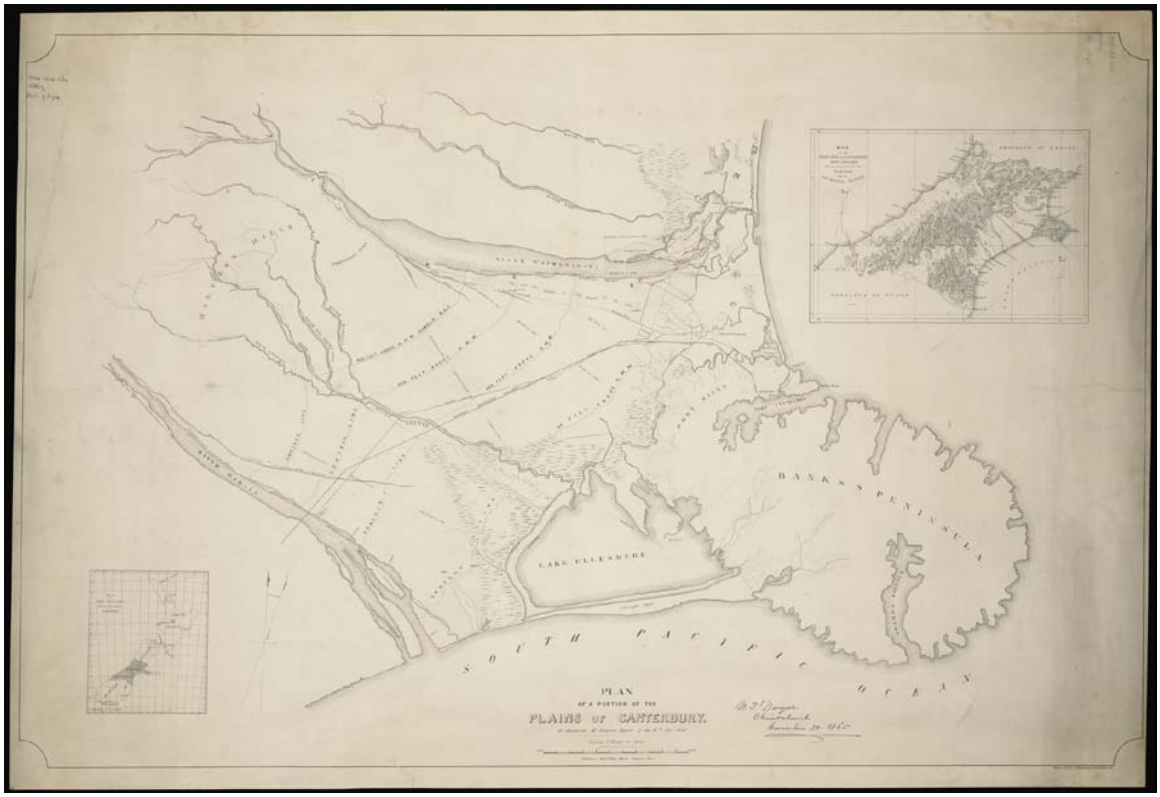
Figure 4 Magnitude vs Time of historic large earthquakes (M > 6.3) from 1848-present in New Zealand

Figure 5 Locations of historic large earthquakes (see Figure 4)

215 Appendix 1



Map 1 Map of Canterbury from 1850. Courtesy of Anthony Olsen



Map 2 Map of the Canterbury Plains from 1865. Courtesy of Anthony Olsen

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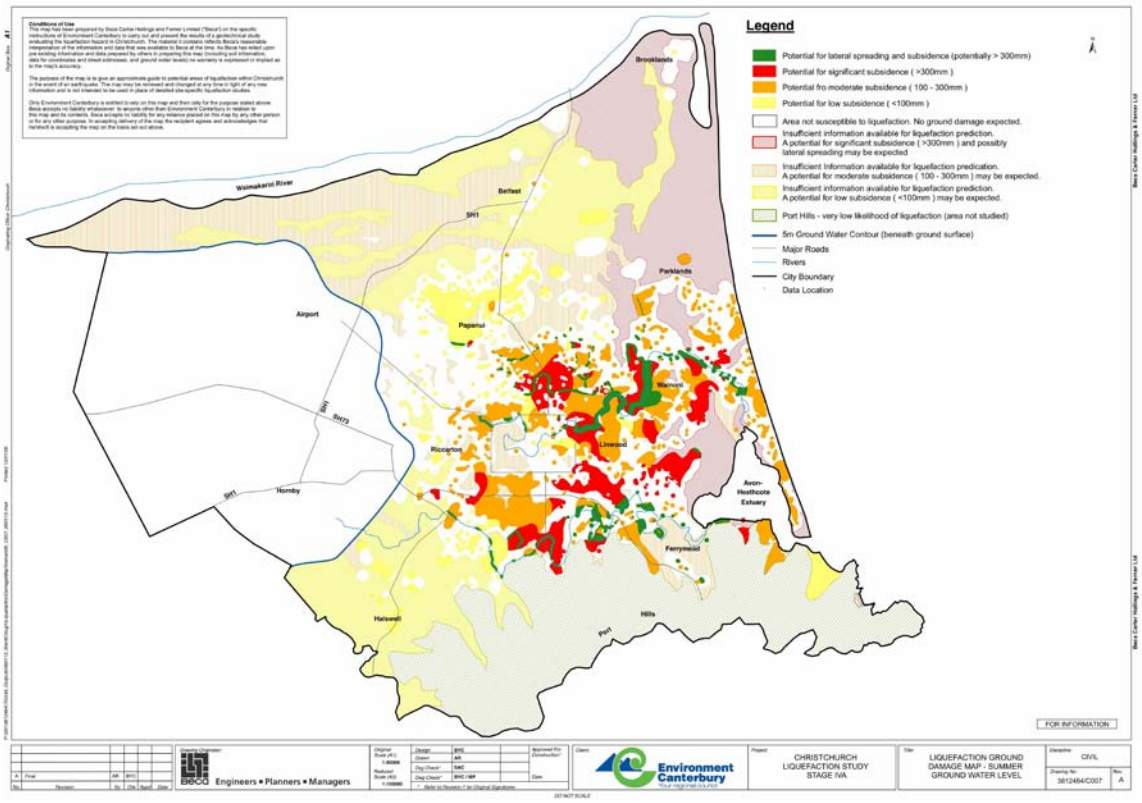
Appendix 2



Map 3 Predictions of levels of risk for liquefaction in Christchurch from the Christchurch Liquefaction Study - State IV (Addendum Report)