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The Canterbury Earthquake sequence and implications for Seismic Design Levels

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NOTE

This report has been commissioned by the Canterbury Earthquakes Royal Commission to provide information on seismicity. The report includes commentary on seismic hazard models. These models are mathematically based statistical models that produce probabilities as to ground shaking from future earthquakes. Although all reasonable effort is made to construct robust models there is uncertainty inherent within the nature of natural events. For this reason, neither GNS Science nor the University of Canterbury can accept responsibility for any actions taken based on the modelling and excludes liability for any loss, damage or expense in any way resulting from those actions.

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EXECUTIVE SUMMARY

New Zealand straddles the boundary zone between the Australian and Pacific tectonic plates, which are moving relative to each other at 35–45 mm/yr. In the North Island, the plates are converging, and the relatively thin ocean crust of the Pacific Plate dives down westward beneath the eastern North Island just offshore of the east coast. Similarly offshore of Fiordland the thin ocean crust of the Australian Plate is diving eastward beneath Fiordland.

In the central and northern South Island, however, the crust of both the Pacific and Australian plates is very thick, so one cannot be driven beneath the other. Here the plates collide, with 75% of the motion between the plates being built up and then released during major earthquakes along the Alpine Fault. To the east of the Alpine Fault, the remaining 25% of the plate motion occurs through occasional earthquakes on a complex web of active faults This motion extends all the way to the east coast, where faults such as those beneath the Canterbury Plains accommodate 1–2 mm/yr of the overall plate motion. It is inevitable that this steady build-up of deformation across the Canterbury Plains will occasionally be released as earthquakes.

Because it straddles a major plate boundary, New Zealand has a long history of earthquakes ranging from tiny tremors detectable only by sensitive instruments to violent earthquakes causing major damage and many fatalities. The more powerful earthquakes have occurred at irregular intervals, separated by relatively quiescent periods. Since European settlement of the Canterbury Plains began in 1853, Christchurch has experienced intermittent damage from earthquake shaking on about 10 occasions. However, before the earthquakes in 2010 and 2011, few of these damaging earthquakes were local—more frequently, damage was caused by shaking from large earthquakes on more distant faults.

In the early hours of Saturday morning on 4 September 2010, people in Christchurch and the surrounding Canterbury region were jolted awake by a powerful magnitude 7.1 earthquake (the Darfield earthquake). By world standards it was a major earthquake, yet there were no fatalities and just a few injuries. The shaking caused damage in Christchurch to older brick and masonry buildings, and to historical stone buildings and Canterbury homesteads. The earthquake also seriously affected Christchurch's eastern suburbs and Kaiapoi—here layers of the ground liquefied, with silt oozing to the surface. The ground above the liquidised layers spread laterally, cracking the ground, footpaths, roads, and houses. Water and sewer pipes broke and water from broken mains flooded many streets.

The earthquake occurred on a previously unknown fault within the Canterbury Plains and left a well-defined surface rupture that has been named the Greendale Fault. This was a rare event, occurring in an area where previous seismic activity was relatively low for New Zealand. Since the Darfield earthquake, more than 7,000 aftershocks with magnitudes up to 6.2 have been recorded. These earthquakes are termed the Canterbury earthquake sequence.

A magnitude 4.7 event occurred on 26 December 2010, less than 2 km from the central business district (CBD) of Christchurch. Because it was so close to the city centre, this earthquake (termed the Boxing Day earthquake) caused further damage to buildings.

The most destructive earthquake of the Canterbury sequence occurred at 12.51 NZST on 22 February 2011, five and a half months after the Darfield main shock. This magnitude 6.2

aftershock (termed the Christchurch earthquake) occurred toward the eastern end of the aftershock zone and with an epicentre just 6 km southeast of the Christchurch city centre.

The Christchurch earthquake was the most deadly since the 1931 Hawke's Bay (Napier) earthquake, with 181 people killed and several thousand injured. About two-thirds of the fatalities were from the collapse of two multi-storey office buildings. Many were killed in the streets by falling bricks and masonry, and in two buses crushed by toppling walls. Five people died in the Port Hills area, killed by collapsing rock cliffs and falling boulders. Liquefaction was even more widespread than in the Darfield earthquake, occurring in a number of suburbs that had not been affected in September.

Particularly high ground accelerations were recorded in the Christchurch earthquake, a factor which led to the severe building damage, widespread liquefaction and landslides. Notable were the strong vertical accelerations that exceeded the horizontal motions at some locations. The February 22 earthquake led to an increase in aftershocks, with four of magnitude 5 or more occurring that day.

On 13 June 2011 a magnitude 6.0 earthquake occurred near the suburb of Sumner. This earthquake resulted in one fatality and caused yet more damage in Christchurch and Lyttelton, causing irreparable damage to many CBD buildings scheduled for repair. The earthquake once again produced high accelerations in the southern and eastern suburbs, causing more widespread liquefaction, and rockfalls from cliffs in Port Hills suburbs.

The Canterbury earthquake sequence has included a mixture of sideways (strike-slip) and vertical (reverse) faulting at shallow depths on previously unidentified faults in the Canterbury area at varying distances from the Christchurch CBD. Distance from the fault rupture has been a principal factor in determining how much shaking has been experienced. All of the three largest events have released high levels of energy for their size. It is thought that this is because the faults involved slip very occasionally and so are very strong.

Focussing of the seismic shaking, arising from the direction of rupture along the fault (known as directivity), is thought to have increased the severity of ground motions experienced in central Christchurch during the September and February earthquakes, but did not play a strong role in the Boxing Day or June earthquakes for the CBD area.

Overall there is a close match between the amounts of damage caused by the earthquakes and the horizontal ground shaking. Recordings of particular note were those from sites close to the CBD where the peak horizontal accelerations during the 22 February event were approximately twice as strong as during the other three earthquakes. Although the 4 September 2010 earthquake was significantly larger than the other events, its epicentre was over 35 km from the CBD. Consequently, ground accelerations at this distance were reduced. However, displacements (as opposed to accelerations) were by far the greatest during the 4 September 2010 earthquake (displacements are another important ground motion measure, especially in the case of tall buildings).

At certain recording sites in the Christchurch CBD, shaking from the three largest earthquakes exceeded both the 500-year and more stringent 2,500-year design levels in the New Zealand Loadings Standard for certain frequencies of shaking.

The level of seismic hazard in Canterbury is currently higher than normal because of the numerous aftershocks that are occurring. In addition, there is a slight possibility that an earthquake of a size comparable to the main shock might be triggered. This elevated level of hazard needs to be considered when reassessing the safety of existing structures and when designing new buildings and infrastructure. In order to provide appropriate seismic design coefficients, a new seismic hazard model has been developed for Canterbury that reflects this increased level of hazard, taking into account likely rates of aftershocks, the small likelihood of larger earthquakes and the normal background seismicity and fault sources. The enhanced ground shaking observed from the February and June 2011 earthquakes has also been incorporated. The new model (which is still being developed) raises the Z factor (or regional design level) from 0.22 to 0.3 for Christchurch (Wellington's value is 0.4).

The Alpine Fault is a major geological feature in New Zealand, being 650 km long and crossing the South Island from northeast to southwest. The average return period of the fault is in the range 260–400 years, with no major event occurring in the last 294 years. It is a potential source of earthquakes up to magnitude 8.2. An Alpine Fault earthquake, however, would be at its closest 160 km from Christchurch. Some preliminary work to estimate the ground motions in Christchurch from such an event is presented here. These motions were calculated for very soft ground conditions, as are found in the Christchurch CBD and indicate that the maximum horizontal acceleration would be less than 0.04 g (compared to 0.4–0.8 g in February), but the duration of shaking could be at least 3 minutes.

The National Seismic Hazard Model for New Zealand is used to predict likely long-term rates of ground shaking to inform the Loadings Standard used in engineering design. Key components of this model are the earthquake sources (where earthquakes are likely to happen) and the ground motions that those earthquakes are likely to produce. In light of the lessons from Christchurch, the next update to this model will need to assess the importance of such factors as unknown faults close to major cities, enhanced ground shaking from a given earthquake and directivity in the ground shaking produced.

For evaluating the risk of earthquakes occurring close to cities, it is impossible to identify all active faults in a region because the relatively small faults associated with magnitude 6 earthquakes often have no surface expression so are particularly difficult to find. For this reason, the national model uses additional background earthquake sources of up to magnitude 7.2 to supplement existing active fault information. This assumes that an earthquake of up to magnitude 7.2 could occur on an unrecognized fault nearly anywhere in New Zealand, although the likelihood of this happening in low seismicity areas of the country is very small. Given this uncertainty, we need to be sure that the shaking from such earthquakes is correctly accounted for.

The unusually strong shaking observed from some of the larger Canterbury earthquakes can be allowed for in hazard models, providing we can anticipate where such events will occur. Current thinking is that they are likely to occur in areas with a low deformation rate, where faults seldom rupture and, as a result, are strong.

Fault directivity effects are already incorporated in the national hazard model (and building designs) for some of our major active faults. However, if directivity is shown to have been a major factor in enhancing the shaking produced by the 22 February 2011 earthquake, consideration will need to be given to including directivity for smaller earthquakes. Directivity effects can also be included in building design if sufficient variability in shaking is allowed for. In the light of the extreme vertical accelerations that were generated by the 22 February 2011 earthquake, the approach to designing for vertical motions in the Loadings Standard also needs to be re-evaluated.

1.0 INTRODUCTION

The Canterbury Earthquakes Royal Commission is inquiring into the performance of buildings within the Christchurch CBD, and the adequacy of the current legal and best practice requirements for the design, construction, and maintenance of buildings in CBD's in New Zealand to address the known risk of earthquakes. The Commission has requested GNS Science to provide a report on the seismicity of the Canterbury region, as background information for their inquiry. This report has been prepared jointly by GNS Science and the University of Canterbury and includes input from GNS Science earthquake specialists, Jarg Pettinga from the University of Canterbury and Paul Somerville from the URS Pasadena office. The report also draws on the work of many other scientists and this is cited in the appropriate places in the text.

The scope of this report is firstly to provide background information on New Zealand and, more specifically, Canterbury earthquakes by describing plate tectonic process, rates of deformation of the earth, types of earthquake faulting that occurs and, as a consequence, significant historical earthquakes that have affected New Zealand and Christchurch.

We then look in detail at the four principal earthquakes from the Canterbury earthquake sequence, starting with the magnitude 7.1, 4 September 2010 event, then the M4.7 Boxing Day event, the devastating M 6.3, 22 February 2011 event and finally the M 6.0, 13 June 2011 event. For each event we examine the nature of the fault rupture, likely recurrence intervals, extent and severity of ground shaking, and how the ground shaking measurements fit with current models used to inform engineering design.

Next we look at two specific implications for Christchurch, namely the current level of seismic hazard due to aftershocks and the likely ground motions from a future Alpine Fault earthquake.

Finally, we look at the national implications of the Canterbury earthquake sequence in terms of where else such unexpectedly damaging earthquakes could occur and how large they could be. We then consider the implications for the National Seismic Hazard Model that underpins New Zealand building codes, and hence the engineering design of all major structures.

In general we have tried to make this report intelligible to the lay reader, but as this is a specialised and, at times, complex subject, we have used Appendices for more detailed or more complex topics. In the main body of the text we use numerous references to published scientific papers, which are more relevant to technical readers. Three of these papers deserve specific mention, and should be regarded as companion papers to this report. Firstly, Stirling *et al.* (2011) describe in detail the most recent update to the National Seismic Hazard Model, an earlier version of which underpins the current New Zealand Loadings Standard NZS 1170. Secondly, a GNS Science Report by Gerstenberger *et al.* (2011) describes the basis for an initial change to construction standards for Christchurch in light of the increased seismic hazard due to aftershocks. Finally, a GNS Science Report by Holden and Zhao (2011) describes recent modelling of an Alpine Fault rupture and the likely shaking it will produce in Christchurch.

Much of what is presented here should be regarded as 'work in progress'. It will take a number of years for earthquake scientists to analyse and fully understand the implications of all the data collected in the aftermath of the Canterbury earthquake sequence, whereas the Royal Commission has to report on a much tighter timeframe. What we present here must thus be regarded as preliminary findings that will be subject to change as the results from more analysis and detailed peer review prior to publication become available.

2.0 BACKGROUND

2.1 New Zealand—where two tectonic plates meet

The outermost layer of the Earth is called the 'crust' and it varies in thickness from ~10–50 km. Like a cracked eggshell, the crust is broken into several large segments, or tectonic plates, which are continually moving relative to each other. At the edges of these tectonic plates, they either pull apart (in 'rift' areas), slide past each other laterally (known as a 'strike-slip' plate boundary), or the plates can converge (in 'subduction' or 'collision' areas). Most of the world's earthquakes and volcanoes occur along the boundaries of these tectonic plates. The largest and fastest-moving major tectonic plate on Earth is the Pacific Plate, and its boundary, the Pacific Rim (also known as the 'Ring of Fire'), is well-known for its earthquake and volcanic activity. The earthquake and volcanic activity we experience in New Zealand results from the Pacific Plate grinding into the adjacent Australian Plate as the two plates continue their steady and inexorable march across the Earth.

New Zealand straddles the boundary zone between the Australian and Pacific Plates, which are moving relative to each other at 35–45 mm/yr (Fig. 2.1). In the North Island, the plates are converging, and the relatively thin ocean crust of the Pacific Plate dives down or 'subducts' westward beneath the eastern North Island along the Hikurangi Trough just offshore of the east coast. Subduction also occurs offshore of Fiordland, except here the thin ocean crust of the Australian Plate is diving eastward beneath Fiordland along the offshore Puysegur Trench.

In the central and northern South Island, however, the crust of both the Pacific and Australian plates is very thick, so one cannot be driven beneath the other. Here the Australian and Pacific plates meet in a glancing collision, so the continuous movement of the plates must be 'accommodated'—the rock moving toward the plate boundary must have somewhere to go. This occurs in two ways. One way is by sideways slip along the boundary, with the west coast moving north-eastward relative to the rest of the South Island at a rate of ~30 mm/yr. In addition to this sideways movement, the Pacific and Australian plates collide head-on at ~5–10 mm/yr (Beavan *et al.*, 2002). Unable to move directly forward, the edge of the Pacific Plate is being forced upward, leading to the growth of the Southern Alps over the last few million years. Repeated GPS measurements of plate tectonic movement throughout New Zealand (from the 1990's to present) show that most of the South Island is being continually contorted as it is forced southwestward into the Australian Plate (Fig. 2.2).

In the central South Island most (~75%) of the 35–45 mm/yr of motion between the Australian and Pacific plates occurs during major earthquakes along the Alpine Fault (Berryman *et al.*, 1992; Norris and Cooper, 2001). However, the land to the east of the Alpine Fault is also broken up into a complex web of active geological faults—here the remaining 25% of the plate motion occurs through occasional earthquakes on these faults. For example, along the eastern foothills of the Southern Alps and within the Southern Alps themselves there are a number of faults that may accommodate up to ~20% of the plate boundary deformation (Cox and Sutherland, 2007; Pettinga *et al.*, 2001, Wallace *et al.*, 2007).

The collision between the Australian and Pacific Plates is so intense in the central South Island that the slow tectonic deformation it causes penetrates all the way to the east coast of the South Island. GPS measurements suggest that faultlines beneath the Canterbury Plains region are accommodating ~5% of the overall Pacific/Australia plate motion, ~1-2 mm/yr on average (Wallace *et al*., 2007). It is inevitable that this steady build-up of ground deformation across the Canterbury Plains will occasionally be released as earthquakes.

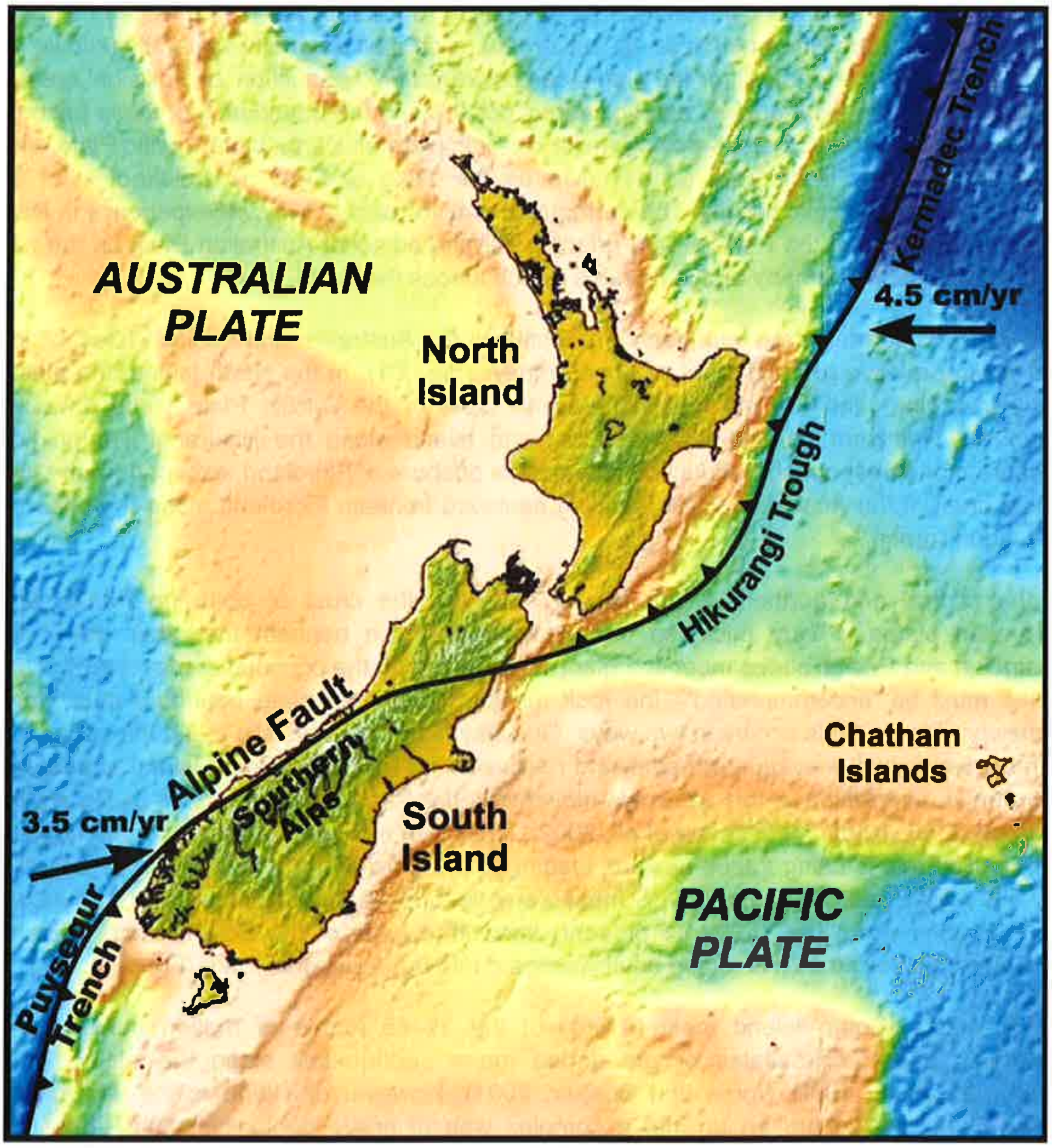

Figure 2.1 Plate tectonic setting of New Zealand. The westward pointing arrow in the upper, right corner shows movement of the Pacific Plate towards the Australian Plate in northern New Zealand, while the north-eastward pointing arrow in the lower left shows the movement of the Australian Plate relative to the Pacific Plate in southern New Zealand.

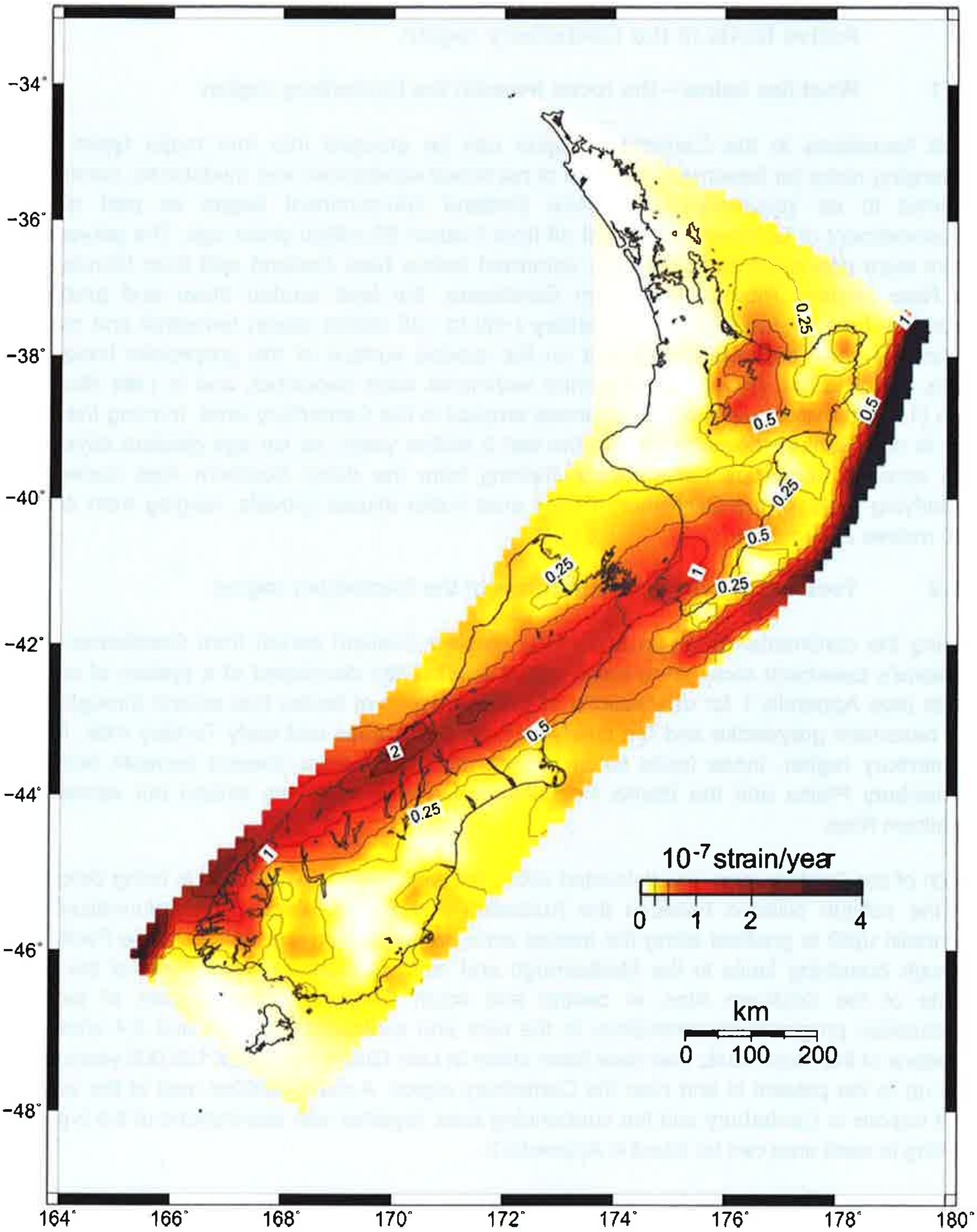

Figure 2.2 Over the last 15 years it has become possible to measure the deformation (strain) occurring in New Zealand directly by satellite surveying using GPS. The dark to red areas have the highest rates of deformation, while the land in the yellow to orange areas are deforming at relatively lower rates. Accumulation of strain in the New Zealand crust will eventually result in earthquakes, so areas with a high strain rate tend to have more earthquakes. Major faults such as the Alpine Fault have extremely high strain rates.

2.2 Active faults in the Canterbury region

2.2.1 What lies below – the rocks beneath the Canterbury region

Rock formations in the Canterbury region can be grouped into four major types. The underlying rocks (or basement) is made of hardened sandstones and mudstones, commonly referred to as 'greywacke'. The New Zealand sub-continent began as part of the supercontinent of Gondwana and split off from it about 85 million years ago. The greywacke rocks were deposited and complexly deformed before New Zealand split from Gondwana. As New Zealand moved away from Gondwana, the land eroded down and gradually subsided. Late Cretaceous to mid-Tertiary (~80 to ~25 million years) terrestrial and marine sediments were deposited; they rest on the eroded surface of the greywacke basement rocks. Later in the Tertiary more marine sediments were deposited, and in Late Miocene time (11 to 6 million years ago) volcanoes erupted in the Canterbury area, forming the area that is now Banks Peninsula. During the last 2 million years, as ice age glaciers advanced and receded numerous times, rivers draining from the rising Southern Alps buried the underlying rocks of the Canterbury Plains area under alluvial gravels, ranging from 200 to 600 metres in thickness.

2.2.2 Tectonic activity and fault zones of the Canterbury region

During the continental break-up and rifting as New Zealand parted from Gondwana, New Zealand's basement rocks were being pulled apart. They developed of a system of normal faults (see Appendix 1 for descriptions of different types of faults) that extend through both the basement greywacke and the overlying Late Cretaceous and early Tertiary rock. In the Canterbury region, these faults today are an inherited feature present beneath both the Canterbury Plains and the Banks Peninsula volcanoes, and they extend out across the Chatham Rise.

Much of the Canterbury region is located within the wide zone in which land is being deformed by the oblique collision between the Australian and Pacific plates. The deformation and mountain uplift is greatest along the narrow zone on and just to east of the Alpine Fault, and through branching faults in the Marlborough and north Canterbury areas. East of the main divide of the Southern Alps, in central and south Canterbury, the amount of tectonic deformation progressively diminishes to the east and southeast. Figs 2.3 and 2.4 show the locations of the major faults that have been active in Late Quaternary (past 125,000 years) time and up to the present in and near the Canterbury region. A more detailed map of the various fault regions in Canterbury and the surrounding area, together with descriptions of the types of faulting in each area can be found in Appendix 2.

An *active fault* is one that is likely to move within a period of concern to society. For the Canterbury region, a fault is considered active if there is evidence it has moved within the last 125,000 years. More than one hundred such active fault structures are recognised in the Canterbury region. Details of all known faults considered as possible earthquake sources are included in the GNS Science active fault database.

2.2.3 The spread of faulting into the Canterbury Plains

In the eastern foothills of the Southern Alps and North Canterbury hill country, NE-SW oriented faults and folds have been active over the last ~5 million years (e.g., Springbank and Hororata faults, Fig. 2.4). However, the zone of deformation at the Australia-Pacific plate boundary has been progressively widening during the last 1–2 million years and current activity indicates that this spread is continuing today. Across the Canterbury Plains and offshore regions, faults running broadly E-W indicate that current plate movement is re-activating the inherited subsurface faults. New surface faults have developed, such as the Ashley and Greendale faults. Since September 2010, patterns of aftershocks, including the February and June 2011 earthquakes, have revealed the existence of further previously unrecognized subsurface faults, including faults extending under Banks Peninsula and into Pegasus Bay.

However, because the alluvial gravels of the Canterbury Plains have remained largely undisturbed until the September 2010 Darfield earthquake, it can be inferred that movements along the inherited faults under the Canterbury Plains causing large earthquakes are generally rare and separated in time by long periods of quiescence extending over thousands of years.

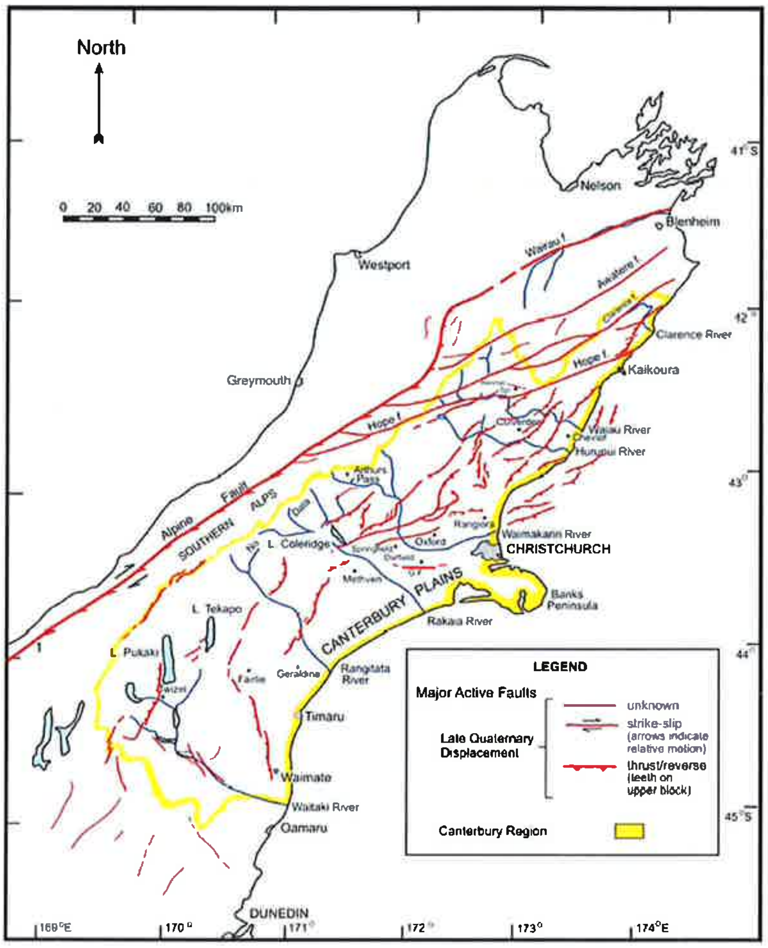

Figure 2.3 Map of the known active faults in the Canterbury region, including the recently formed Greendale fault (G.F.). Figure modified from Pettinga *et al.* (1998).

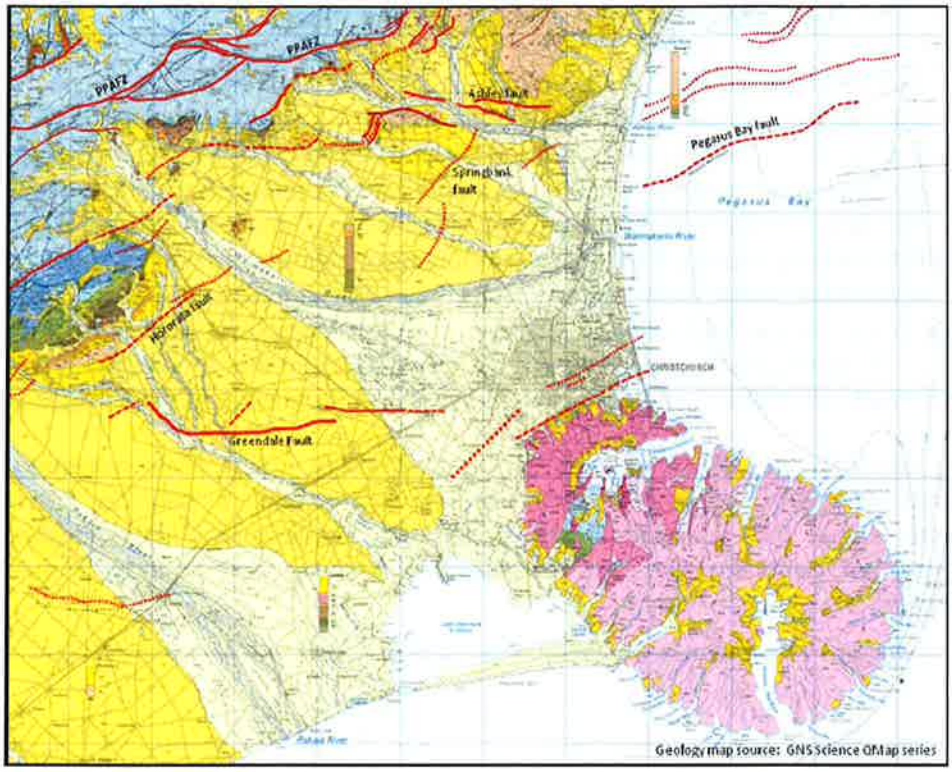

Figure 2.4 General geological setting of the northern Canterbury Plains. Active faults are shown in red (PPAFZ - Porters Pass-Amberley fault zone). The faults shown by dashed/dotted lines are uncertain in location or extent because they do not reach the surface. Base geological map from Forsyth *et al.* (2008).

2.3 Previous major earthquakes in New Zealand history

Because it straddles a major plate boundary, New Zealand has a long history of earthquakes ranging from tiny tremors detectable only by sensitive instruments to violent earthquakes causing major damage and many fatalities. Fig. 2.5 shows the distribution of earthquakes of magnitude 6.5 or greater, from the beginning of European settlement to the present time. These more powerful earthquakes have occurred at irregular intervals, separated by relatively quiescent periods. Brief summaries of many of the major earthquakes during this period can be found in Appendix 3.

Māori oral history includes accounts of large earthquakes, and arriving European colonists soon found that New Zealand was disturbingly shaky. Between 1840 and 1904 there were at least seven earthquakes of magnitude 7 or greater. One of them, the magnitude 8.2 Wairarapa earthquake in 1855, still ranks as New Zealand's most powerful earthquake in recorded history.

Few damaging earthquakes of magnitude 7 or greater occurred between 1905 and 1928. The years from 1929 to 1947, however, were marked by a substantial increase in earthquake activity, including a cluster of five magnitude 7 earthquakes in the three-year period from 1929 to 1931. Two of these earthquakes were responsible for a number of fatalities—17 people died in the 1929 Buller (Murchison) earthquake and 256 people in the 1931 Hawkes Bay (Napier) earthquake.

The latter half of the twentieth century in New Zealand was once again a relatively quiet period for earthquake activity, with just a few large magnitude earthquakes, most too far offshore to cause much damage. The beginning of the 21st century, however, has seen an increase in the number of magnitude 7 earthquakes, including several in the remote Fiordland area. The September 2010 Canterbury earthquake was magnitude 7.1, but the February 2011 magnitude 6.3 Christchurch earthquake caused considerably more damage.

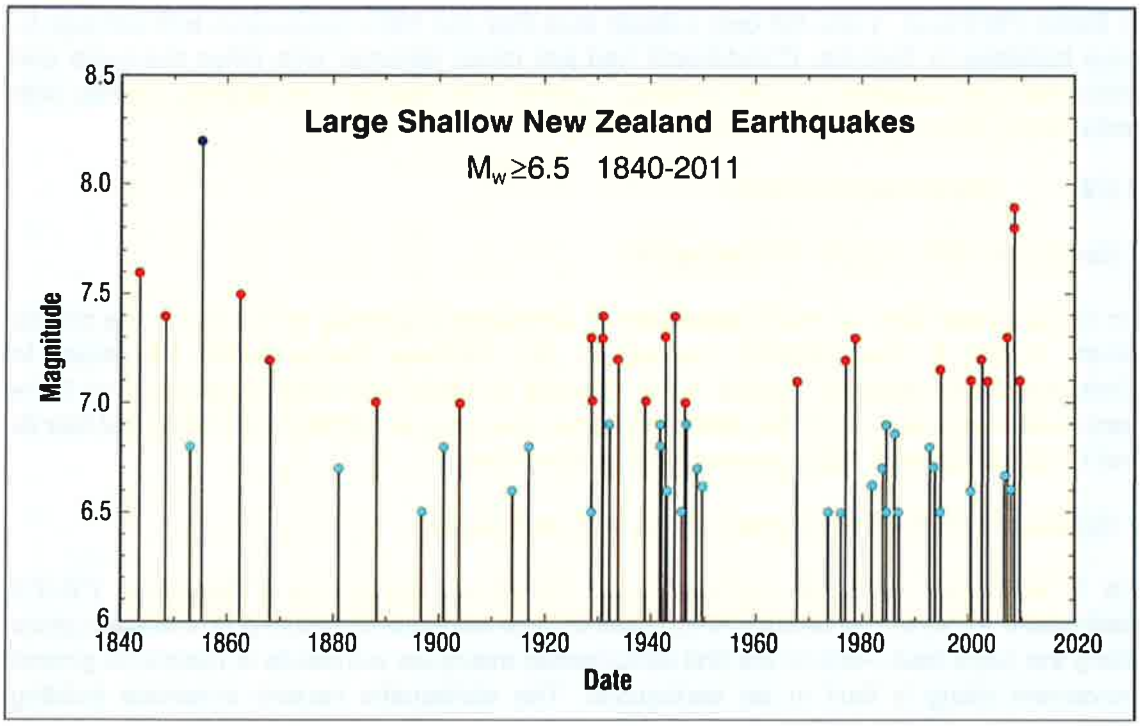

Figure 2.5 Diagram showing the distribution of earthquakes of magnitude 6.5 or greater from 1840 to the present. Some of the large earthquakes occurred too far offshore to cause any damage on land.

2.4 Previous earthquakes affecting Christchurch

Since organised European settlement of the Canterbury Plains began in 1853, Christchurch has experienced intermittent damage from earthquake shaking. However, before the earthquakes in 2010 and 2011, few of these damaging earthquakes were local—more frequently, damage was caused by shaking from large earthquakes on more distant faults.

2.4.1 Local earthquakes

The two earliest damaging earthquakes experienced in Christchurch, in 1869 and 1870, had epicentres in the local region.

5 June 1869 – Christchurch earthquake

On 5 June 1869, Christchurch settlers were shaken by an earthquake centred beneath the city, probably around the Addington-Spreydon area, with a magnitude of about 4.7–4.9. The earthquake was shallow, with most damage in the CBD, and nearby Avonside, Linwood, Fendalton and Papanui. There was minor damage to stone buildings and the tower of St John's Church on Latimer Square, and many fallen chimneys. The quake may have caused some ground settlement in the Heathcote Estuary, as the tide was described as running higher up the Heathcote River afterward.

31 August 1870 –Lake Ellesmere earthquake

On 31 August 1870 the Canterbury region was shaken by an earthquake with an estimated magnitude of 5.6–5.8, at shallow depth (< 15 km), centred near Lake Ellesmere, southwest of Banks Peninsula. It was felt over a larger area than the 1869 earthquake, with damage to brick buildings in Temuka. Christchurch had just minor damage, with fallen chimneys and minor structural damage to a few buildings. Lyttelton and Akaroa were strongly shaken, with rocks falling from cliffs around Lyttelton Harbour.

2.4.2 Distant earthquakes

5 December 1881 – Castle Hill earthquake

On 5 December 1881 an earthquake with an estimated magnitude of 6.0 shook the central South Island; it was probably centred in the Torlesse Range-Castle Hill area. In Christchurch, the shaking caused minor damage to stone and brick buildings, and there were broken windows and a few fallen chimneys. The spire of Christchurch Cathedral had its first recorded damage, losing some pieces of stonework.

1 September 1888 – North Canterbury (Amuri) earthquake

On 1 September 1888, the northern South Island was shaken by a magnitude 7.0–7.3 earthquake in North Canterbury Amuri District. The earthquake resulted in surface rupture along the Hope fault—one of the first documented examples worldwide of horizontal ground movement along a fault in an earthquake. The earthquake caused extensive building damage, landslides and liquefaction of river terrace sediments in the Amuri District. In Christchurch, the top 8 metres of the stone spire of Christchurch Cathedral collapsed during the quake. There was some damage to stone buildings and chimneys, and minor rock-falls occurred around Lyttelton Harbour.

16 November 1901 – Cheviot earthquake

On 16 November 1901 an earthquake centred near Cheviot, with an estimated magnitude of 6.8, struck the Canterbury area. Most brick and sod buildings in Cheviot collapsed. Christchurch had many broken windows, cracked stonework and toppled chimneys, and Christchurch Cathedral lost the top 1.5 metres of its spire. The quake also caused some liquefaction in Kaiapoi, affecting 2-3 town blocks.

25 December 1922 – Motunau earthquake

Remembered for many years as the Christmas Day Earthquake, a magnitude 6.4 earthquake occurred on 25 December 1922 near Motunau. The earthquake damaged many chimneys from Cheviot to Christchurch and caused minor structural damage. The large stone cross on Christchurch Cathedral spire fell to the ground, breaking some slate roof tiles. Liquefaction was described at Waikuku and Leithfield beaches.

9 March 1929 – Arthur's Pass earthquake

On 9 March 1929, the Arthur's Pass National Park area was shaken by a magnitude 7.0 earthquake along the Poulter fault. The earthquake caused many landslides and closed the main highway to the West Coast for several months. In Christchurch damage was very minor, with some damage to the north wall and oriel window of the Provincial Council Chambers.

16 June 1929 – Buller (Murchison) earthquake

The Buller earthquake, centred near Murchison, had a magnitude of 7.3 and was one of the stronger earthquakes in New Zealand history. It was far enough away to cause only minor damage to a few chimneys and windows in Christchurch.

9 March 1987- Pegasus Bay earthquake

On 9 March 1987, a magnitude 5.2 earthquake centred out in Pegasus Bay about 50 kilometres northeast of New Brighton damaged some chimneys in North Canterbury and cracked paving in the New Brighton area.