the ROYAL SOCIETY of NEW ZEALAND
TE APĀRANGI

OFFICE OF THE PRIME MINISTER'S
SCIENCE ADVISORY COMMITTEE

The Canterbury Earthquakes:
Scientific answers to critical questions

The Canterbury region has had six months of unexpected and extremely difficult challenges as a result of a sequence of damaging and deadly earthquakes and the associated aftershocks. The result is significant uncertainty within the public about why the February 22 aftershock was so damaging and deadly compared to the larger magnitude event on September 4, 2010. In order to provide information on these and other questions, the Royal Society of New Zealand, together with the Office of the Prime Minister's Science Advisory Committee, has convened a group of earthquake science experts including those from the Natural Hazards Research Platform, a collaborative research consortia hosted by GNS Science, to provide answers to critical questions based on current best scientific information and knowledge.

An enormous scientific effort is underway but it is difficult to define all of the critical attributes of an earthquake quickly after the event. As a result, our understanding of these earthquakes will improve and much more information will become available to be used in further scientific analyses and advice in the weeks and months ahead. The information below is provided for the purpose of improved understanding of the science relating to the Canterbury earthquakes.

Prediction

Why didn't scientists know about the faults that caused the two earthquakes?

Prior to September 4th, there were no surface signs of the Greendale Fault or the fault that generated the Lyttelton aftershock and there was no evidence for seismicity on these faults (i.e. 'foreshocks'). Seismic surveys have located some 'hidden' faults across parts of the Canterbury Plains, but these particular regions had not been surveyed for this purpose. An oil-gas seismic survey had been carried out but did not reveal any convincing evidence for the presence of the Greendale Fault. Following September 4th, there was significant aftershock activity in the area of the Lyttelton Fault and around many faults in the region but there was no clear indication that a larger earthquake was imminent there.

It was predicted that aftershocks from the September 2010 earthquake might reach magnitude 6, and some smaller aftershocks had already occurred under Christchurch city. Why wasn't some warning given about the possibility of a big and damaging aftershock under the city?

Warnings were given over the risks from large aftershocks[1]. The prediction of aftershocks of approximately magnitude 6 is based on statistical analysis of historical earthquakes (Bath's Law),

[1] http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10671602

which states “the average difference in magnitude between a mainshock and its largest aftershock is 1.2, regardless of the mainshock magnitude”. A quick survey of some of New Zealand’s largest historical earthquakes conforms to this average, although there is significant variability. The 6.3 aftershock is not outside the average range. The isolated and smaller aftershocks that occurred under the city CBD do not necessitate the presence of a larger fault capable of generating larger earthquakes, however this is possible. Seismic and aerial surveys are targeting this area in the near future to provide constraints on the geometry, extent, and magnitude potential of a fault under the city.

Why did the February aftershock occur so long after the September 2010 earthquake?

It is not unusual to have a 6 month gap between a magnitude 7.1 earthquake and a 6.3 aftershock.

How predictable was the 22 February quake - and what was the influence of the moon and the tides; do more earthquakes happen at night?

Despite substantial scientific effort, the specific **timing, location, or magnitude of earthquakes cannot be predicted**. Although it is not possible to reliably predict individual earthquakes, it is possible and routine to identify areas and times of higher or lower earthquake activity based on models of crustal stresses and faulting. In addition, on the basis of observations of past earthquakes, it is possible to expect a series of aftershocks after an earthquake which follows a general and decreasing pattern, but there is always some level of unpredictability as to their timing, location and severity. For this reason, it is not possible to give specific predictions about aftershocks in terms of severity, location and timing.

Recent popularized ‘predictions’ regarding the Canterbury earthquakes and their relationship to phases of the moon are not scientifically correct. Although there is some evidence that the moon can sometimes influence very small earth tremors, there is no credible evidence linking the moon to medium or large earthquakes.

There is no relationship between the time of day and the frequency of earthquakes. More earthquakes will be felt at night only because people are in bed or at rest and thus have more contact with the ground, making them more sensitive to feeling the ground movement during earthquakes.

Are the recent natural disasters in Queensland, Japan and New Zealand linked in any way?

No. The Canterbury earthquakes are in no way related to the flooding events in Queensland or the massive earthquake in Japan.

Facts

Why was the magnitude 6.3 earthquake able to cause so much more destruction in the CBD and Christchurch suburbs than the magnitude 7.1 quake last September?

The main reason was that the earthquake was so close to Christchurch. Although the total energy released by the 22 February 6.3 aftershock was only about 1/20 of the energy from last

September's magnitude 7.1 event, the 6.3 event **was much closer** to the Christchurch CBD (~6 km to the SE) than the 7.1 earthquake (~44 km W of Christchurch CBD) so a **greater percentage of the total energy** released from the 6.3 earthquake hit Christchurch itself (See Figures 1 -3). Seismic energy spreads out away from an earthquake and at the same time is absorbed by the Earth. Damage generally decreases with increasing distance from the earthquake. In September the region with very high ground accelerations (comparable to those felt in the CBD in February) was near Hororata and Greendale, away from major population centres. In the Christchurch CBD, the ground accelerations produced by the September magnitude 6.3 earthquake were 3-4 times greater than during the 7.1 earthquake; in the eastern suburbs they were about 6 times greater[2]. In summary, it was the closeness of the earthquake to the city and its shallowness that led to the increased destruction. Overall the levels of ground shaking in the CBD during the magnitude 6.3 earthquake were consistent with ground shaking observed for other similar-sized earthquakes elsewhere in the world.

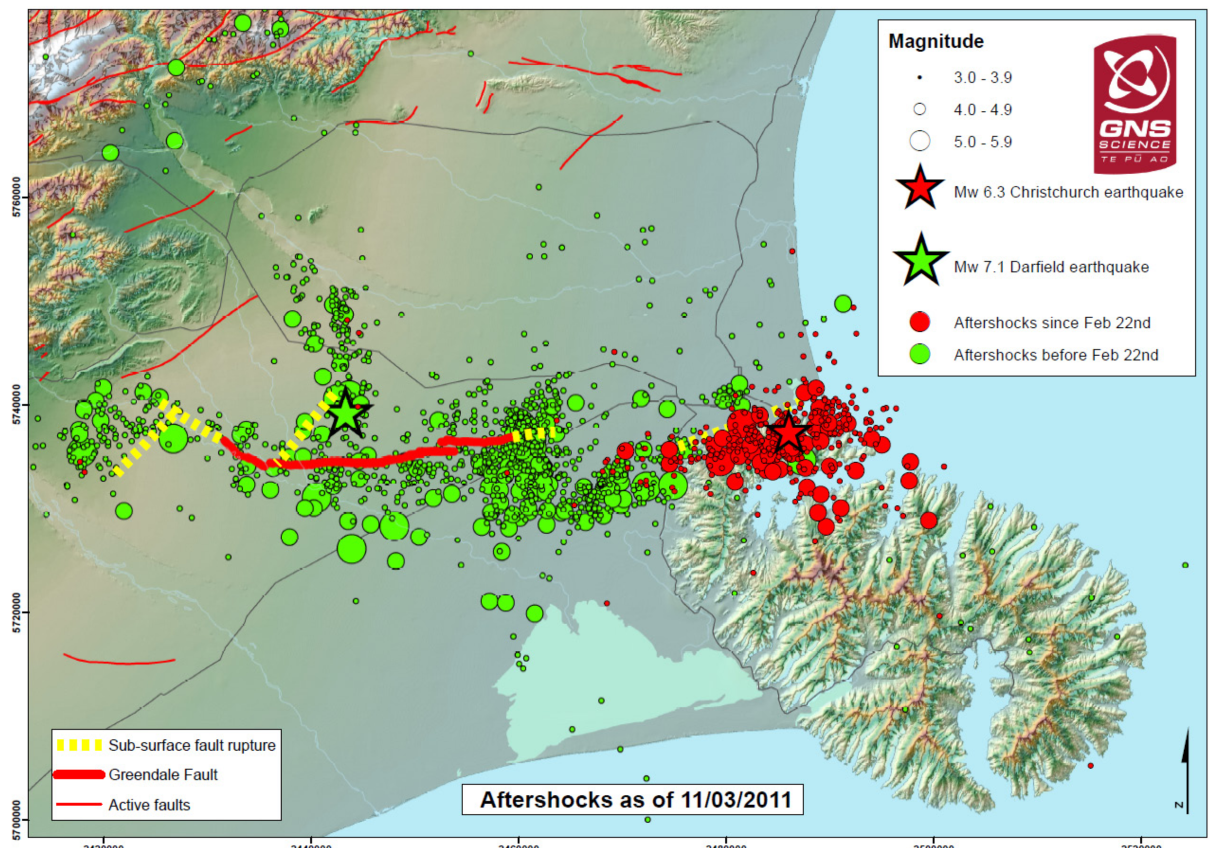
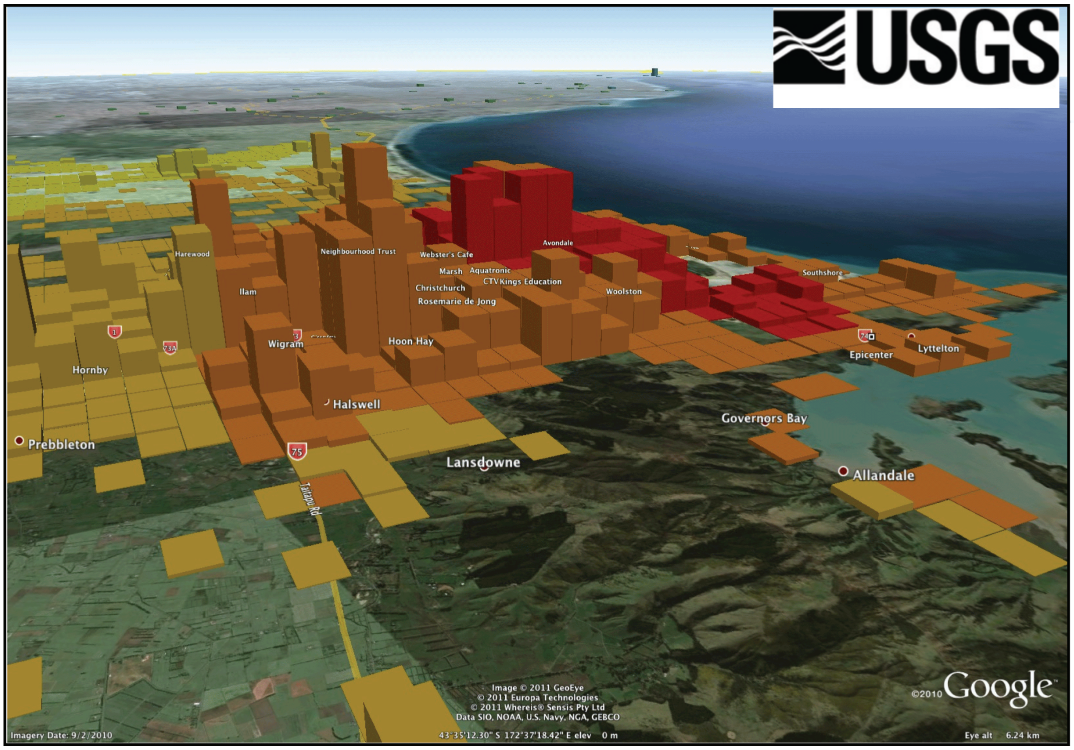


Figure 1: Graphic showing location of main shock, aftershocks above magnitude 3, and fault ruptures in Canterbury. Graphic by Rob Langridge and William Ries, GNS Science.

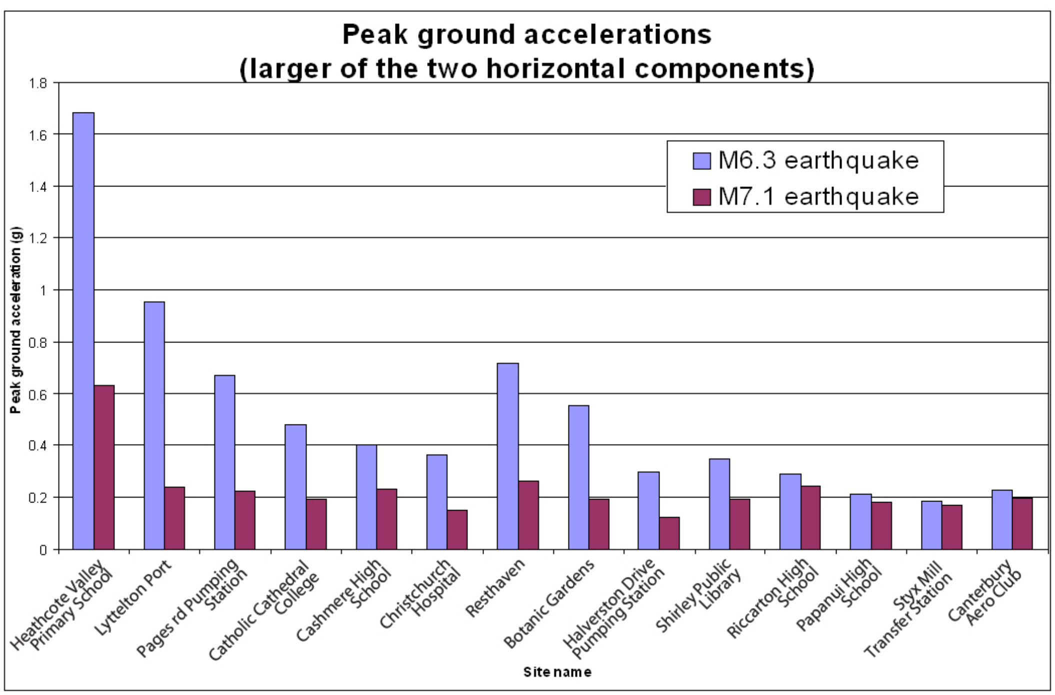
[2] USGS http://earthquake.usgs.gov/learn/topics/NewZealand2011_slides.ppt



Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	23*	46k*	91k	50k	63k	228k	92k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

Figure 2: Christchurch Earthquake Population Exposure showing the extent of earthquake ground shaking (represented in colour) overlain on population density (represented as height of vertical bars) at a grid size of 1 km2. The colour key is based on the Mercalli scale, which is a measure of shaking, and explains how sever the ground shaking is for each colour. (Source: USGS)



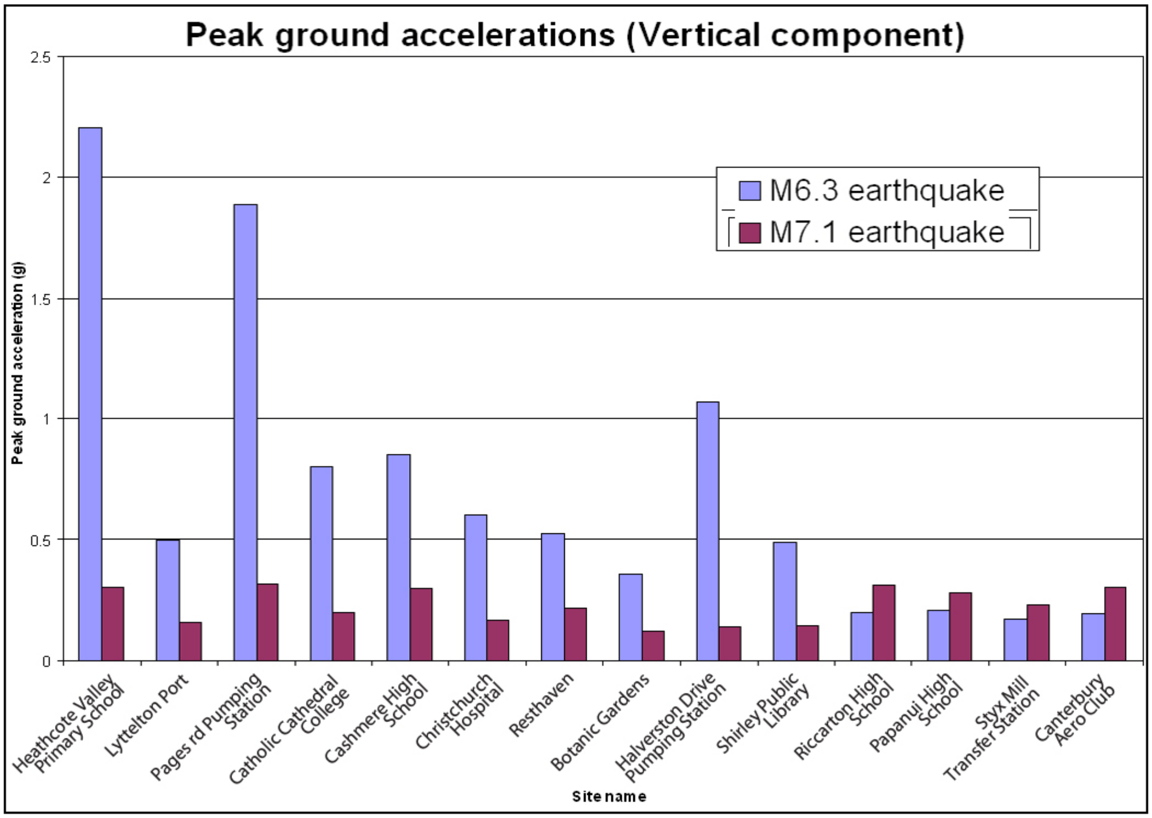


Figure 3a and 3b: Comparisons of the ground accelerations in the Christchurch CBD between the 2011 Christchurch and 2010 Darfield earthquake. Left to right, the recordings are arranged roughly in increasing distance from the epicenter of the earthquake on 22 February 2011

Was the Christchurch magnitude 6.3 earthquake an aftershock?

Yes. The term 'aftershock' refers to an earthquake that is **smaller in magnitude** than the preceding main shock, part of the sequence of earthquakes that **closely follows the main shock in time**, and **in the region influenced by changes in crustal stress levels** due to the main shock. The M 6.3 earthquake fits all of these criteria and is therefore considered an aftershock.

What is liquefaction and what causes it?

Liquefaction is the term used to describe when some soils behave more like a liquid than a solid during the shaking from an earthquake. During an earthquake the soil particles are rearranged and compacted, forcing out water onto the surface, creating sand volcanoes or sand boils, water fountains and surface cracking (See Figure 3). Along with liquefaction, lateral spread can also occur, which is when the liquefied soil flows in to lower areas such as river channels, under the force of gravity.

Figure 4: A representation of the liquefaction process (source: Environment Canterbury)

After liquefaction, does the ground ever stabilise again?

The risks from liquefaction will remain. Strength-depth profiles under some parts of Christchurch indicate up to 9m of 'liquefiable' material. Immediately following some of the largest aftershocks from the 7.1 earthquake, liquefaction reappeared in the same areas. During the 6.3 earthquake, liquefaction was widespread and vents continued to surge during the aftershocks immediately following this event. Although some ground settlement may occur, the large reservoir of liquefiable material and these examples suggest that similar characteristics of ground shaking are likely to result in similar amounts of liquefaction in the future.

Have new faults appeared under Christchurch after these earthquakes?

It is not yet known. All aftershocks are earthquakes and most earthquakes occur on faults. There has been some aftershock activity under Christchurch, however this activity has occurred on small faults that may not be connected. In order to better understand the extent of faults under the city, further seismic studies are required.

Are the faults around Christchurch a southern extension of the Marlborough Fault Zone?

No. The Marlborough Fault Zone is a system of four major and many minor faults that link the offshore plate boundary located east of the North Island, to the Alpine Fault along the West Coast, South Island.

Future Activity

Will there be another damaging earthquake in Christchurch in the future, linked to these quakes?

The pattern of aftershocks so far (which is fairly typical) suggests that **a magnitude 5 aftershock or greater is still likely** during the time that the aftershocks continue to decline in intensity and frequency. The exact timing and location cannot be predicted. What damage such an aftershock might cause depends critically on location and depth of the earthquake, just as it did for the February event. There are some indications that the aftershock locations are moving eastwards away from Christchurch.

How long will the current sequence of aftershocks go on for?

The frequency of aftershocks will generally decrease over time, and earthquakes that can be felt will become less common. A**fter 1 year from now the rate of earthquakes that people can feel may be on the order of one per month.**

Is the next one likely to happen at sea, and could there be a tsunami?

A major tsunami is very unlikely. Calculations of the possible tsunami that may occur if the magnitude 7.1 Sept 4th earthquake were to occur offshore in the future indicate the hazard is mostly restricted to beach areas and estuaries. The best way to be prepared for any tsunami that may follow such an earthquake is to move away from the beach or other low lying areas as soon as the earthquake shaking is over, which might last for 20-30 seconds.

A number of aftershocks associated with the September 2010 earthquake and the 22 February 2011 earthquake have occurred offshore to the east of Christchurch, and further aftershock activity of a generally declining nature in that region is expected. We know that to generate a significant tsunami generally requires earthquakes larger than magnitude 7.5, and a substantial vertical displacement of the sea floor.

Will these earthquakes trigger an eruption of the Banks Peninsula volcano, and are other volcanic areas like Timaru, Oamaru and Dunedin likely to get earthquakes like this?

No. The last time the Banks Peninsula volcanoes erupted was ~5.8 million years ago. There is no evidence of magma remaining beneath Banks Peninsula. Hot springs are common in non-volcanic regions throughout the South Island but this does not indicate renewed volcanic activity. There is no link between these geologically ancient events and the current patterns of earthquakes in Canterbury.

Are the recent earthquakes in Wellington caused by the Christchurch ones?

No. In 2009, New Zealand experienced over 500 earthquakes larger than magnitude 4.0. In a typical year, magnitude 4.0-4.5 earthquakes occur, on average, at least once per day[3]. The magnitude 4.5 and 4.7 earthquakes that occurred near the Kapiti coast and beneath Upper Hutt are typical of previous earthquakes in the area. Earthquakes in the Wellington area are part of a different segment of the plate boundary through New Zealand. Thus the current Canterbury earthquakes are in no way related to the faults of the Wellington region and in no way increase the likelihood of earthquakes there, or anywhere else other than Canterbury.

[3] http://geonet.org.nz/earthquake/earthquake-facts-and-statistics.html

Do these earthquakes mean that New Zealand is in a more active phase of seismic activity and there will be more earthquakes in other places in New Zealand?

There is no evidence that the rate of earthquake activity in New Zealand or anywhere else in the world is increasing. More than 100 earthquakes of equal or larger size to the Christchurch event occur each year around the globe. The rate of this activity has not changed over decades.

Is the big earthquake predicted for Wellington now more likely to happen in the near future?

No. The effects of the Canterbury earthquakes in changing the stresses in the New Zealand crust do not extend as far as Wellington – the changes are contained within the Canterbury region. Thus the likelihood of a major earthquake in the Wellington region has neither increased nor decreased as a result of these events.

Which city is safest to live in to avoid another earthquake – Christchurch, Wellington, Hamilton or Auckland? What about other risks in those cities – volcanoes, cyclones, tsunamis?

All regions of New Zealand are vulnerable to natural hazards. For some locations it is earthquakes, or volcanic activity; for other locations it may be flooding, or tsunami. Although some locations may have lesser hazard to local earthquakes, a large earthquake along the plate boundary faults in either the North or South Islands would cause strong ground shaking over large areas including all of the major cities in New Zealand.

Does every year that the Alpine Fault does not rupture make the risk in a subsequent year higher and does every year it does not happen increase the severity of the earthquake when it happens?

The Alpine Fault is significantly longer than any of the faults in the Canterbury region, and thus it can produce substantially larger earthquakes (see Figure 5). Current estimates are that an earthquake of magnitude 8.0 or larger would be possible, if the entire Alpine Fault were to rupture in a single earthquake. Given its distance from Christchurch, its impact is unlikely to be greater than the M7.1 earthquake. The recurrence rate for major Alpine Fault earthquakes is between 150-500 years, with the last major event inferred to be in 1717[4], and thus an event in the next 40 years is considered to have a high probability.[5] This probability does not systematically increase each year and the severity of the earthquake is related to the length of the fault rather than the duration between quakes.

[4] Berryman, K. R.; Cochran, U. A.; Clark, K.; Biasi, G. P.; Pantosti, D.; Marco, S.; Langridge, R. M.; Villamor, P.; Litchfield, N. J.; van Dissen, R., 2010, An 8000 year (20 event) record of surface rupturing earthquakes on the Alpine Fault, New Zealand, *American Geophysical Union, Fall Meeting 2010, abstract #T41C-07*

[5] http://www.gns.cri.nz/Home/Learning/Science-Topics/Earthquakes/New-Zealand-s-Fault-Lines/Major-Faults-in-New-Zealand/Alpine-Fault

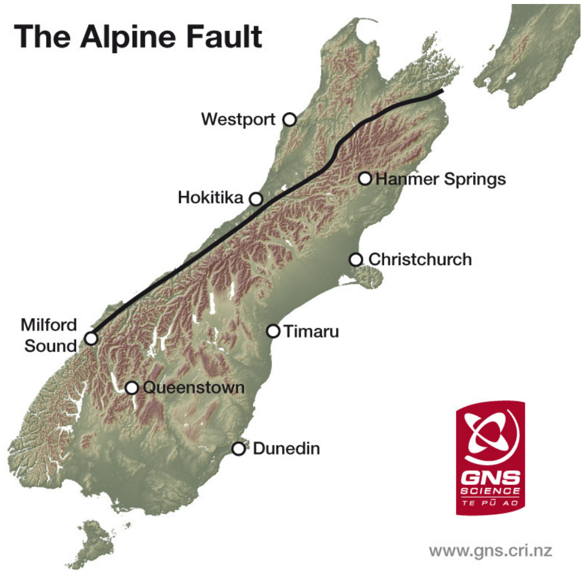


Figure 5: Map showing the extent of the Alpine Fault on the South Island. (Source: GNS)

What part of New Zealand has the least risk of earthquakes?

There is no place in New Zealand that is earthquake-free, however Figure 6 shows a map with 10 years worth of quakes, and Northland and Southland have relatively fewer quakes than other parts of the country. Nevertheless, where an earthquake is centred is only half the story, as a strong quake can still cause damaging shaking a considerable distance from its epicentre. Similarly, 10 years data is not a long time in geological terms. As we have seen in Canterbury, faults can be silent and unseen for many thousands of years before rupturing and causing damage.

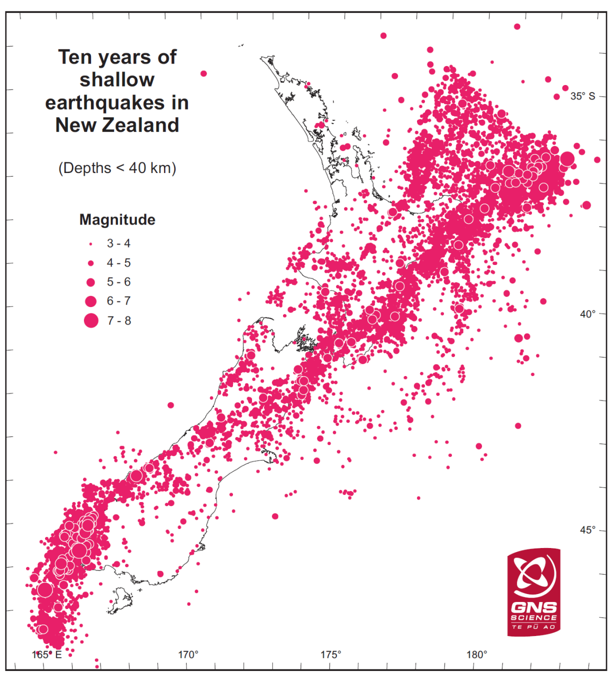


Figure 6: A Map showing the location of 10 years of shallow earthquakes in New Zealand (Source: GNS)

Rebuilding

What scientific studies have been done or could be done to help in our urban development planning for the future? e.g. geological mapping and monitoring, and event and impact forecasting.

In regions such as Canterbury, where the basement rocks are covered by gravels and other deposits, the location of faults and how they link to each other cannot be determined by surface observations alone. **A range of geophysical measurements can be made, and are now being made, to determine properties of the crust and identify the locations of buried faults**. In addition, after major earthquakes such as experienced in Canterbury and Christchurch, the entire region will have many very small earthquakes. With detailed observations, we can and are mapping the locations of these very small earthquakes and are finding other faults in the area, not otherwise visible at the surface. With an inventory of these faults, we are in a better position to address issues such as the maximum size of possible future earthquakes, how faults relate to each other, and whether there are some locations ill suited to high density development[6].

When large areas of a city and its infrastructure have been destroyed in an earthquake - what's next?

Other cities have recovered from similar damage. Christchurch is not alone in having experienced a devastating earthquake causing extensive damage and fatalities throughout the city: San Francisco, Tokyo, Kobe, Santiago, Mexico City and Napier have all suffered devastating earthquakes and had to grapple with the challenges of rebuilding. The effects of the recent large earthquake and, particularly the accompanying tsunami in northern Japan are well known. The decisions to be made go well beyond the realm of science alone, although science and engineering can and will inform policy makers. However, New Zealand has always been an earthquake prone part of the world. It will therefore be important to plan, design and engineer to deal with such risks, as was the case after the Napier earthquake. It may be that the detailed investigations now under way will lead to recommendations that some areas in Christchurch should not be rebuilt, or should be used for alternative purposes. At this stage, it is far too early to be definite.

Is Christchurch now a safe place to live in?

Yes: While all of New Zealand is at risk of earthquakes, what will keep people safe is thorough science, good engineering, strong and well-enforced regulation, and comprehensive preparation and disaster planning.

[6] The Darfield Earthquake: the value of long-term research. Royal Society of New Zealand, November 2010

Science effort

Who is responsible for earthquake research in New Zealand?

The Natural Hazards Platform was set up in 2009 to encourage better collaboration among research providers and improve the uptake of research by end-users. NIWA and GNS Science act jointly as 'anchor' organizations for the platform, partnered by Auckland, Massey, and Canterbury universities and Opus International Consultants. In addition there are a range of other universities and organizations involved in this area.

What institutions are working on the Christchurch earthquake?

The Canterbury earthquakes have global significance and are a focus of research for both New Zealand based and international groups. This research includes geological, seismological, and engineering analyses.

Institutions involved in earthquake research in New Zealand include: GNS, , the University of Canterbury, University of Auckland, Lincoln University, the Victoria University of Wellington, the University of Otago and a number of overseas institutions, including the United States Geological Survey.

What kind of research is going on?

There is a an extensive range of research currently taking place in New Zealand including: the study of present earthquake aftershocks and their location; the study of geological sub-surface structure of Canterbury area; geodetic signals before, during and after the quakes; and the mapping of the hill-slope instabilities. Research on psychosocial aspects of the disaster is also underway. New Zealand has a very deep record of earthquake engineering research.

How much money does the government spend on earthquake research?

Government Vote RS&T funding on earthquake research is:

Earthquake related work in the Natural Hazards Research Platform	$5.5 m pa
Other hazard specific work (hazardscape)	$0.5 m pa
Plate tectonics	$2.6 m pa
Marsden Fund	$2.0 m pa
Strategic Relocation Fund	$1.8 m pa
TOTAL:	$12.4 m pa

There will also be Vote Education research funding for the tertiary institutes which is also supporting earthquake research.

The EQC also supports earthquake research through Geonet ($8 mp) and additional support of academic earthquake research ($0.5m pa)

How does our earthquake expertise compare with that in other earthquake-prone areas, for example Japan and California? How do we share knowledge with those scientists?

Our expertise is internationally regarded as being of the highest order. We have a long history of collaboration with ither leading research groups overseas such as in California and Japan.

Is there broad scientific agreement about what has happened and is likely to happen now, or do different research groups hold different opinions?

The general details of the earthquakes are known and there is good agreement on the basic facts.