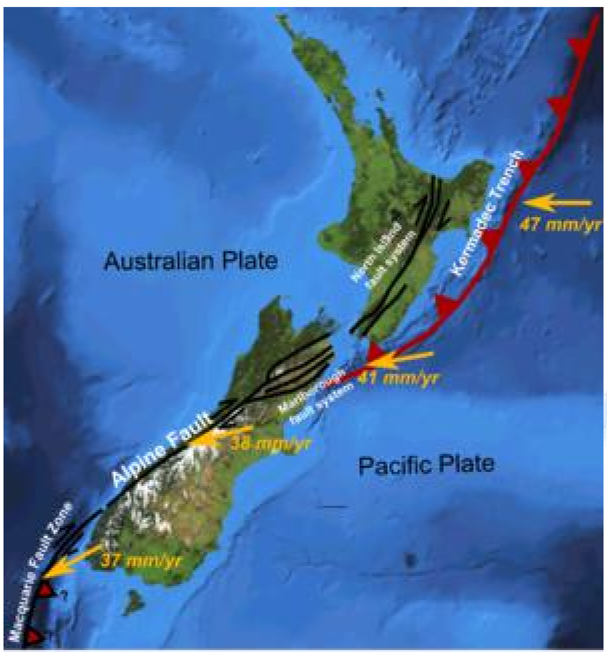
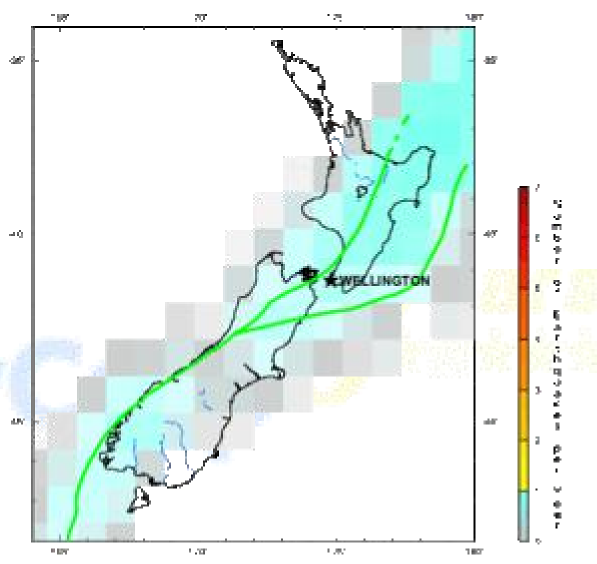
Active Seismicity of New Zealand: Distribution and Cause

Introduction:

Earthquakes in New Zealand are predominant because it belongs to the pacific ring of fire. This ring is geologically active. Approximately twenty thousand earthquakes have been recorded each year. Among these strong earthquakes are 200. There are major fault lines. They follow the length of the region. Most of the major faults consist of strike slip faults that are oblique. These faults consist of movements that are vertical as well as sideways.





Number of Earthquakes per Year, Magnitude 5 and Greater, All Depths

Major Tectonic Boundaries: Subduction Zones -purple, Ridges -red and Transform Faults -green

source:

Zones of major active fault line displaying variation in the displacement vector of Pacific Plate. Along the boundary, It is relative to Australian Plate . These fault lines are shown above.

Distribution:

Along the main ranges, most of the earthquakes in this region occur. They run from East Cape in northeast to Fordland in SW (southwest). Then they follow the plate boundary between the Pacific plates and Indo-Australian plate. Along central Alpine Fault, frequency of large earthquakes is less. There is no subduction of the plates. Tectonic forces are accommodated in various manners. The nation's capital, Wellington is the largest city. It is located within this zone that is high risk. Then comes Hastings. After that, Napier comes. Since European settlement, these cities have gone through major earthquakes.

Causes:

The most common cause for the active seismicity in New Zealand is reinjection (Bromley and Majer, 2012). Eventhough the New Zealand geothermal projects have been started on a large scale in the late 1950's , the reinjection did not commence til 1980's (Sherburn, 1984, Allis et al., 1985). Reinjection is now mandatory at all fields, mainly for environmental reasons It acts as a means of disposing of condensate and brine. Reinjection also provides potential improvement in long-term sustainable utilization of resources by sustaining the pressures through the fluid recharge, particularly where the natural recharge is low. Most fields have at least some potential for induced seismicity related to injection management. The reinjection strategy that are being used at most of the New Zealand fields has changed during their production history especially in terms of depths, locations, injection temperature, flow rates pressures and in-situ. The Injection at a relatively shallow depth (~500m) was very common as the starting strategy to minimize rapid reinjection fluid returns to the deeper production aquifers (~1-3km depth). These were possibly successful only when suitable aquifers could be found for injection and they must be of intermediate depth and temperature, and isolated by a very low permeability aquitard from production depth aquifers. Most fields now adopts an adaptive injection strategy that depends mostly on deep reinjection, i.e., at or below the depth from which production fluids are been extracted. The Fields where the reinjection depth has changed from shallow to deep include: Kawerau (1992 shallow to 2008 deep), Rotokawa (1997 shallow to 2006 deep), and Mokai (2000 shallow to 2008 deep). At Ohaaki reinjection changed from deep (1988) to shallow (1993). At Ngawha (from 1998) and Ngatamariki (from 2013), injection has thus far been deep.

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Fault lines:

Considering North Island, there is a feature concerning large plate boundary. That is known as the North Island Fault System. This system is under stress (constant) because of the plate movement. Australian plates and the Pacific plates are responsible for this movment. Following a continuous line from Wellington coast to the Bay of Plenty southwards, whole system has developed a line of mountain ranges i.e. Rimutakas, Tararuas, Ruahines and Kaweka. There are several major parallel faults In the Wellington area, i.e. Wellington Fault. There are many active faults in the Taupo Volcanic Zone, related with extension as well as rifting in the area. Another series of major parallel faults is there in the South Island. That is known as the Marlborough Fault System They converge further in south. There they produce the Alpine Fault. Significant part of the total plate boundary strain is carried by this fault. Along most of its length this feature is distinct. This is due to Southern Alps. Along its eastern side, they are uplifted. Hence, it is clearly visible from space. In the next 50 years, there is a high risk of a occurrence of a major earthquake. Across the South Island, there are still various relatively minor faults. Here, rupture is less frequent, i.e. those which triggered the Christchurch and Canterbury earthquakes. Geodetic and Structural data related to the Alpine Fault indicates that a major part pertaining the total plate displacement belongs to rapid oblique slip. This slip is on the fault. To the east, over a 200 km wide zone, there is a distribution of the remaining displacement (Norris et al. 1990).

New Zealand

MMI	City	Population
VIII	Darfield	2k
VII	Burnham	1k
VI	Rolleston	3k
VI	Rakaia	1k
VI	Leeston	1k
VI	Lincoln	2k
V	Oxford	2k
V	Christchurch	364k
V	Methven	1k
V	Woodend	3k
V	Amberley	1k
IV	Oamaru	13k
IV	Pleasant Point	1k
IV	Timaru	28k
IV	Greymouth	9k
IV	Westport	4k
IV	Hokitika	3k
III	Brightwater	2k
III	Blenheim	27k
III	Wakefield	2k
II	Wanaka	4k

Haiti

MMI	City	Population
IX	Gressier	26k
IX	Carrefour	442k
IX	Leogane	134k
VIII	Port-au-Prince	1,235k
VIII	Petionville	283k
VIII	Delmas 73	383k
VIII	Grand Goave	49k
VIII	Petit Goave	118k
VIII	Croix des Bouquets	229k
VIII	Miragoane	89k
VIII	Kenscoff	42k
VIII	Cabaret	4k
VII	Fond Parisien	18k
VII	Jacmel	138k
VI	Cotes-de-Fer	2k
VI	Cayes Jacmel	2k
VI	Fond des Blancs	3k

Comparison of intensities and population of Canterbury and Haiti earthquake

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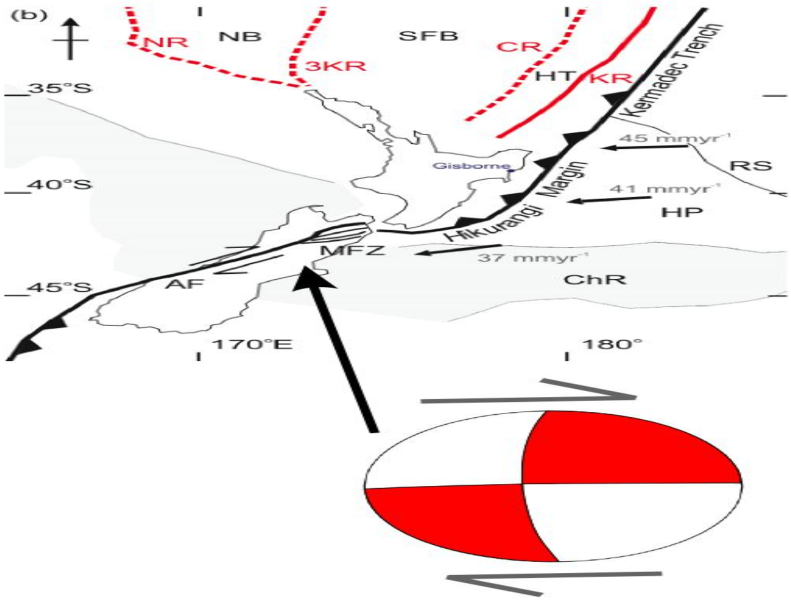
Focal mechanism:

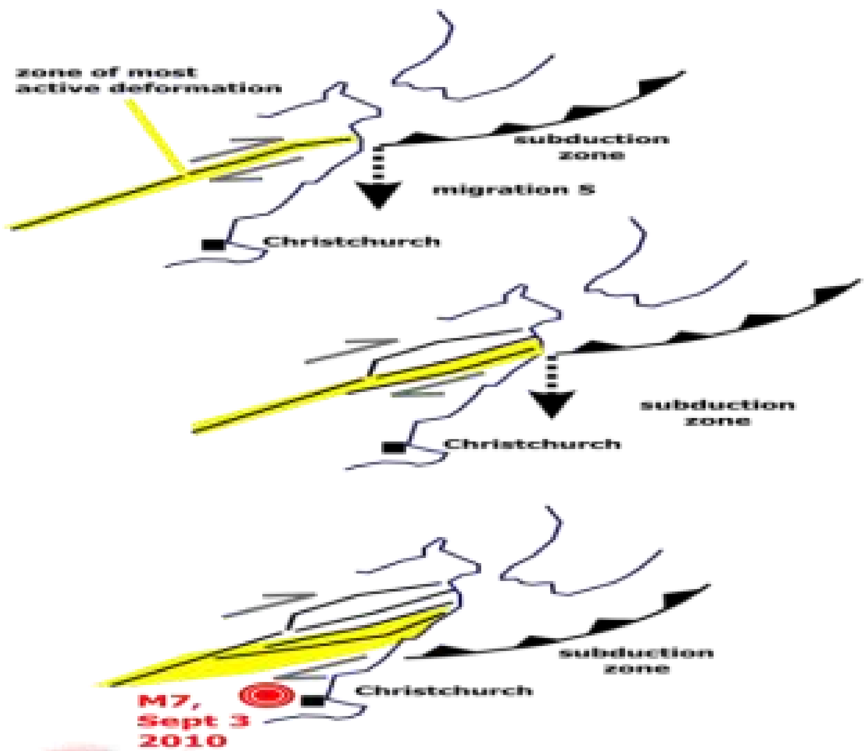
There is a large earthquake in the South Island of region. This was having a magnitude 7.0 (According to the USGS). On the Canterbury Plains, it was a shallow rupture, (near Christchurch). Largely strike-slip motion was indicated by the focal mechanism.



Source: NEWS & COMMENTARY FROM THE WORLD OF GEOLOGY & EARTH SCIENCE
Focal mechanism of September 3rd earthquake. Location of Earthquake with respect to the plate boundary in region

Refer above figure. It indicates that region is not just placed on top of the plate boundary. It is related to Australian plates and the Pacific plates. There is the change in the nature of that plate boundary on that point. This change happens in some basic manner. The subduction zone ends near the Northeast coast. This coast belongs to the South Island. Hundred kilometres away from north of Christchurch, it goes through the East Coast. This coast belongs to the North Island. This subduction zone allows passage of a transform boundary. Of the South Island, this boundary cut through the continental crust. Here, the plate motions belongs to largely dextral strike-slip faults. These faults belong to the Alpine Fault (AP) and MFZ (Marlborough Fault Zone) (in the figure above). In south of both of these fault systems, this latest rupture clearly occurred some how. The focal mechanism may be seen as strike-slip that is dextral. Orientation of this fault is east-west. It indicates that it is related to deformation. This deformation occurs at the boundary of plate.

Region of deformation (New Zealand) is distributed: the relative motions (related to the Pacific and Australian plates) are not adjusted on few faults in a small zone. There is a much wider zone, consisting of many faults. Relative motion is accommodated in this zone. Hence, it is obvious to observe large earthquakes accommodating plate motions. This happens at a distance from meeting place of two plates. However, earthquake occurrence in South Island region is probably related to continuous variation in the plate boundary nature (at the junction related to the continental transform and zone of subduction. In the Marlborough Fault zone, considering past records of displacement of the individual faults, in the geological past , it can be seen that the northern faults were relatively more active, older, and have quite small recent (i.e. last 100,000 years') displacements. Much larger recent displacements can be seen in case of the southern faults. They are younger. Reason is that the part of Marlborough faults that is the most northern was earlier related to the end part of the zone of subduction.. Both structures came out of alignment because zone of subduction moved towards south, creating new strands concerning Fault system of Marlborough. With the help of this plate motions were accommodated efficiently.

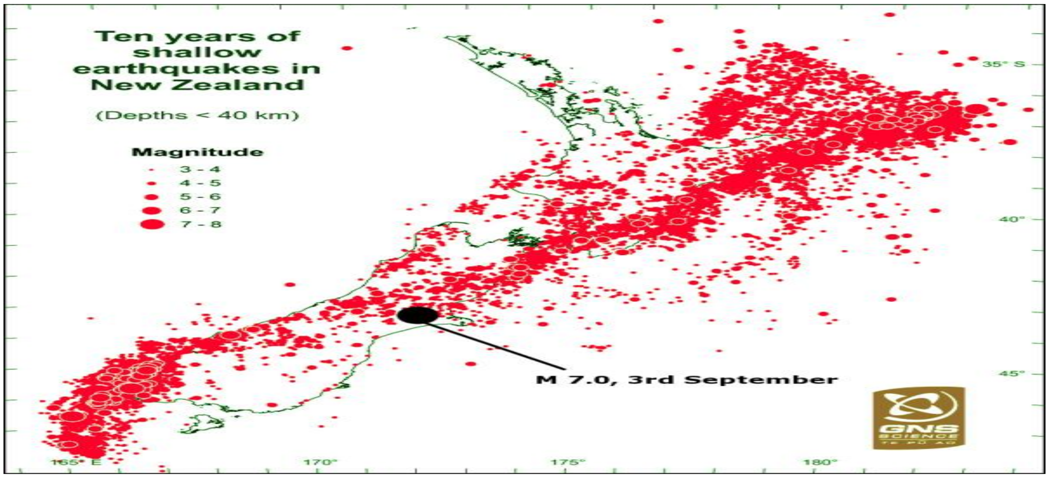


Development of new plate boundary faults (South Island) in response to southward propagation of the subduction zone

This is continuous tectonic evolution. From the end part of the zone of subduction it is now youngest part of Marlborough faults and to the south of the southernmos. Probably part of the deformation concerning plate boundary is getting shunted into the area around Christchurch. There it is adjusted by faulting that is dextral strike-slip. With the passage of time (geological), there will be development of a strand, concerning Fault system of Marlborough. This will be a new strand. That is more southerly. It indicates that in this region such earthquakes may not be a one-off event. It is not surprising, then, on the Canterbury plains, geophysical surveys have found a many faults below the recent sedimentary cover (in related study they were reported as reverse faults accommodating compression, if only 2 dimensional cross sections are available then it is not easy to identify strike-slip deformation). These faults were active.

Above map of major earthquakes (historic) in region. It indicates that such seismic events may occur at any place in the region. In this area, seismicity is referred as hazard. It is near to a densely populated area (Christchurch). This area is built mainly on Quaternary sediments that are unconsolidated. This may cause intensification of the potential shaking. It will distruct buildings that are unreinforced. Whilst this seismic event seems to have resulted into a significant amount of destruction, as per the previous literature casualties appears to be low.

A plot, Via GeoNet, is shown here. This plot consists of all the seismic events in region. Time span is ten year. This plot includes tremors of magnitude 4 and 3 that only disturb seismometers. This provides better picture. It shows how New Zealand's crust is deforming. It also indicates that previous earthquake occurs towards the edge of deformation zone (on the northeast South Island) that is distributed plate boundary. It was still within, deformation zone.



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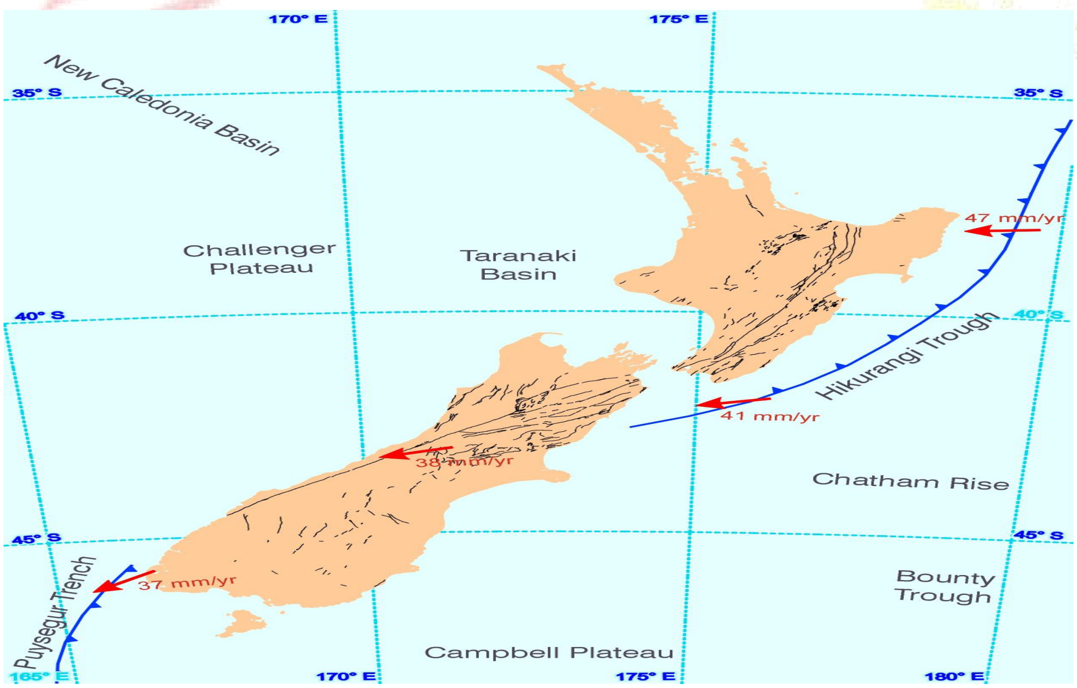
The historical seismicity map (Source: USGS) indicates that during over the few decades there were a many seismic events having similar focal mechanisms i.e. strike-slip. They were little further to the north-west. With magnitudes of around 6-6.5, they were near to the actual plate boundary.



The plate tectonic setting of the region, depicting plate motions that are relative (arrows with rates indicate mm/yr), traces of major active fault , approximate boundary of the Canterbury region is also shown (dotted line

source: **THE NEW ZEALAND SOCIETY FOR EARTHQUAKE ENGINEERING, Vol. 41, No. 2, June 2008**

Conclusion:

In New Zealand there are various examples of producing geothermal fields both with and without induced seismicity. Where induced seismicity has occurred, the favored mechanism is associated with the indirect effects. the indirect effects are increased fluid-flow on pre-stressed, pre-existing, fracture networks. The Fluid flow is driven by pressure gradients through the fractured network area and then induces stresses from cooling contraction. This fluid flow triggers seismic failure only on favorable fractures, through thermal, chemical, or pressure transients, or also by associated micro-stress perturbations. In several geothermal fields where levels of natural seismicity have been relatively low, and induced seismicity have not been observed, despite prolonged periods of pressure and temperature change, the most plausible explanation is that in-situ reservoir stress conditions at these locations are not close enough to critical. Reservoir fractures are not, therefore, actively poised for failure in the event of stress perturbations. Sewell *et al.*, (2013) and Sepulveda *et al.*, (2013) comment on the practical applications of the detailed microseismic information, from the point of view of a field operator, for Rotokawa and Wairakei, respectively. The hypocenter locations have
assisted in constraining the reservoir simulation models, in terms of : a) the probable locations of permeable upflows beneath the production aquifers, b) the probable depth of the brittle-ductile transition zone where permeability reduces due to high-temperature Sherburn et al plastic deformation, and c) the probable locations of major faults that act to compartmentalize reservoirs, restricting cross-flow but assisting parallel flow. Bannister *et al.*, (2013) stress the usefulness of double-difference tomography for this purpose, particularly if sufficient data from a large network of closely spaced instruments is available. Conditions likely to increase the probability of induced seismicity include:

1. Deep reinjection, below ~1.5 km.
2. Reinjection of fluids substantially cooler than the natural reservoir temperature (>100 oC temperature difference).
3. Reinjection at sufficient pressures or flow rates to increase pore fluid pressures over a large reservoir volume (>1 km3)
4. Reinjection into a critically stressed area that has high levels of natural seismicity.
5. The presence of active faults and associated fractures that might readily slip with perturbations in the stress field or with changes in rock cohesive strength.

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