4. EARTHQUAKE HAZARDS

Reference:

West Coast Regional Council: Natural Hazards Review 2002, DTec Consulting Ltd., Christchurch (the DTec Report)

Special Note:

The section of the DTec Report on Earthquakes is based on historical evidence of earthquake on the West Coast since European settlement of New Zealand. Since there have been no movements on the Alpine Fault during this period, material about this is not included in this section. However as a major movement on or about the Alpine Fault is currently predicted, a full discussion regarding this can be found in Appendix 1

Earthquakes are reflected topographically as

Surface rupture

Liquefaction

Seiches

<u>NB also refer Landslide effects in Landslide Hazards Section</u>

Examples of these, both past and projected, can be found:

For Surface Rupture - at White Fault, Buller River

For Liquefaction – at North Beach, Westport and Blaketown, Greymouth

For a Seiche - at Lake Rotoroa

Geologists inspect a fault line running through the "Tilted Terraces" by the Atarau Rd. north of Blackball.

Photograph by M Trayes WCRC

Excerpts from DTec Report pp 88 - 97

EARTHQUAKE HAZARDS

Introduction

Of all the natural hazards in the West Coast Region, earthquake hazards present the single largest risk. This is due to the region's position across a major active plate boundary, the number of active faults in the region itself and surrounding regions, the inevitability of large scale earthquakes occurring, and the multiple effects of earthquakes, including ground shaking, liquefaction, land-sliding, river avulsion, tsunamis and fire outbreaks.

Numerous earthquakes have affected the region historically: the two largest and most famous cases being the 1929 Murchison Earthquake (M7.8, Dowrick and Smith 1990), and 1968 Inangahua Earthquake (M7.1, Adams *et al.* 1968). Both caused widespread destruction to property and were responsible for the loss of a number of lives; seventeen people died in the 1929 earthquake (including the Tasman District and northwest Nelson area), and 3 died in the 1968 earthquake. The scars on the landscape from both events are still obvious. These two earthquakes, and *all* others recorded historically, were associated with local faults, which are relatively small when compared to the Alpine Fault.

Earthquake hazards have been intensively investigated and much of the relevant research was reviewed in Benn (1992). The most significant studies since then have concentrated on prediction of the movement of the Alpine Fault, and faults in the Canterbury Region, (Pettinga *et al.* 1998, Yetton *et al.* 1998, Stirling *et l* 1999). Yetton *et al.* (1998) suggested that the Alpine Fault ruptured about once every 250 - 260 years on average, with associated earthquakes of~M8, and ground shaking intensities in the epicentral region of MM9-MM10.

Causes Of Earthquakes

The north-west corner of the South Island, and the South Westland/Fiordland area are two of the most seismically active areas in the country. The West Coast Region is particularly prone to earthquakes due to its location across the actively deforming boundary of the Indian and Pacific plates (e.g. see Benn 1992, Pettinga *et al.* 1998, Yetton *et al,* 1998 , Stirling *et al.* 1999). Relative movement across the plate boundary occurs within a deformation zone between 70-350 km wide. On the West Coast, the Alpine Fault represents the surface expression of the plate boundary. At 650km long (Yetton *et al.,* 1998), the Alpine Fault is a major fault in world scale terms, and extends the entire length of the region and beyond (from Milford Sound in the south-west to Blenheim in the north-east).

As well as the Alpine Fault, there are numerous other active faults in the region (Figure 2). These are concentrated in the northern section of the region in the Paparoa Tectonic Zone (PTZ) (Laird 1968, Suggate 1978), and in south Westland and Fiordland, in the South Westland Shear Zone (Suggate 1978). Faults from the Marlborough Fault Zone (MFZ) also extend into the region and connect with the Alpine Fault (Yang 1991, 1992, Pettinga *et al.* 1998, Stirling *et al.* 1999). All appear to have been active at some time in the Quaternary period (i.e. geologically very recently).

The main faults in the PTZ are the White Creek Fault, Inangahua-Glasgow Fault, Lower Buller Fault, Lyell Fault, Mt William Fault, and the Montgomerie Fault. The White Creek Fault was considered dormant until 1929 (Ferrar and Grange 1929), when displacement on the fault caused the M7.8 Murchison Earthquake (Dowrick and Smith 1990). Movement of the White Creek Fault during this earthquake was in the order of 5m vertically (Fyfe 1929) and 5m obliquely (Berryman 1980, see Section 5.3). Movement of several faults occurred during the Inangahua Earthquake (see effects section), although almost all of the identified surface rupture occurred on the Inangahua-Glasgow Fault. Lensen and Suggate (1968) stated that:

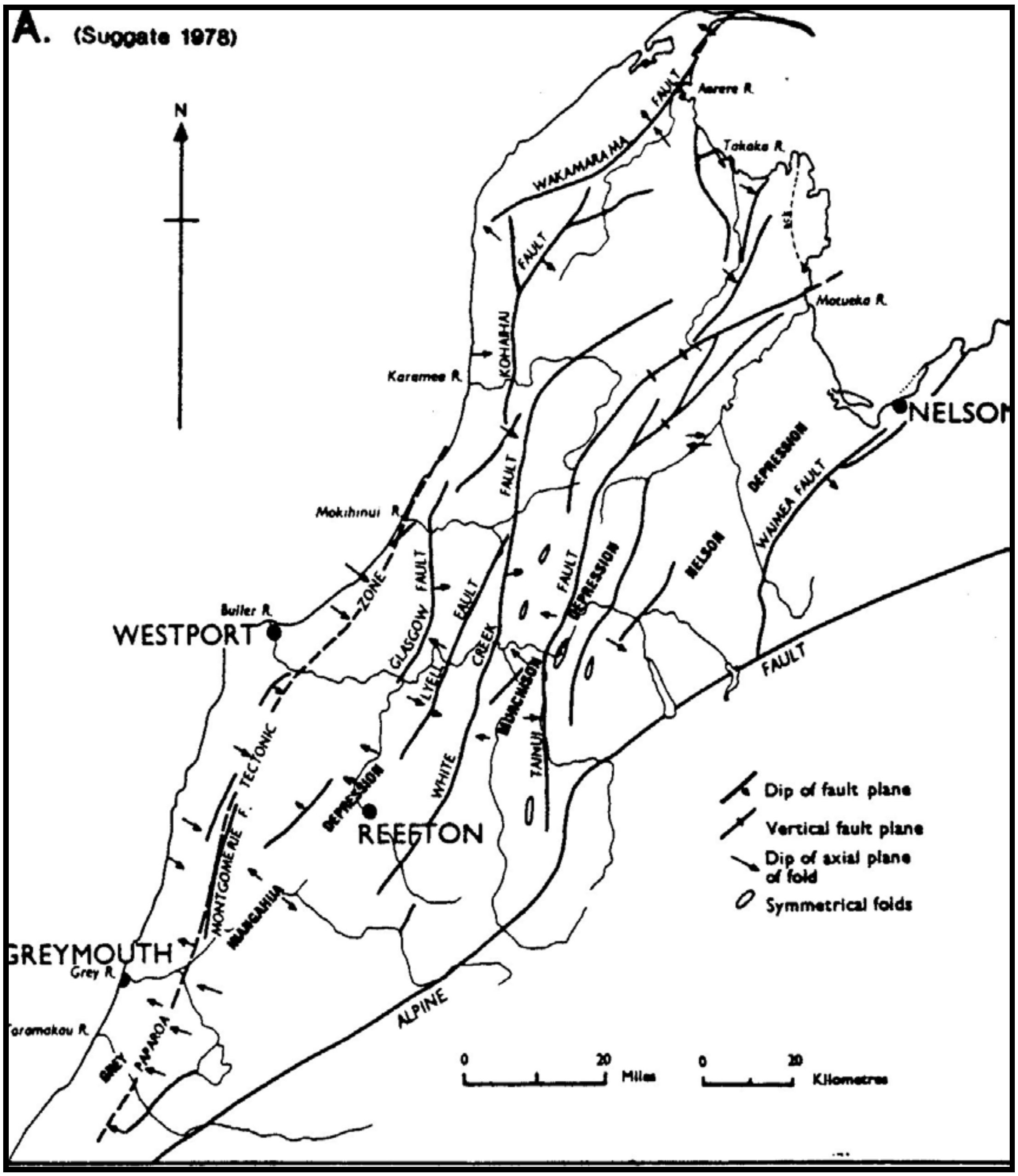
> *In detail it appears the most, although not all, of the relative movement occurred across four of the five main faults in the area (White Creek, Glasgow, Lower Buller, and Lyell), the Mt William fault being the exception. Surface faulting however, was found at only one fault — the Glasgow Fault, although along a short section of the Lyell Fault a short surface break was observed.*

Young (1963) and Laird (1968) recorded faulting of Quaternary gravels at the Montgomerie Fault, which indicated recent movement of the fault. In South Westland, Suggate (1978) suggested a distinct zone of shear faulting in Tertiary rocks was probable, characterised by closely spaced faults, separating steeply dipping slices of Tertiary rocks — some late Tertiary in age. These features are not characteristic in North Westland and thus, the South Westland Shear Zone was proposed. Suggate noted that Late Quaternary deposits buried large areas of Tertiary rocks, and more research was required in the area to establish the exact nature and history of faulting.

For the South Island's West Coast (from Fiordland to North West Nelson), Smith and Berryman (1986) described Fiordland as the most seismically active area in the country even though large earthquakes generated in this area tended to produce low MM intensities. The Alpine Fault was noted for its low present and historical seismicity (see Section 5.5), and the Paparoa/Buller area was distinguished by its compressive reverse faulting, folding, and large earthquakes in the twentieth century.

Major faults, folds and tectonic zones of the West Coast

(northern area)



This map, originally drawn up by Pat Suggate, former DSIR Geologist, can be found on p.10, "A Review of Earthquake Hazards on the West Coast" by JL Benn, 1992, published WCRC.

Effects Of Earthquakes

The regional effects of earthquakes are numerous and have been described in detail in Benn (1992) and more recently in Yetton *et al.* (1998). Earthquake effects and their general time scales in relation to the earthquake shock include:

- **Ground shaking**: Immediate
- **Surface rupture**: Immediate
- **Liquefaction**: Immediate.
- **Landslides**: Immediate - Moderate/Long Term
  Note: An earthquake can initially weaken slopes, and then subsequent trigger mechanisms may actually cause the slope to fail and slide. (See Chapter 3 & Appendix 3)
- **Landslide dammed lakes**: Immediate - Long Term.
  Note: Dams and lakes can form almost instantly, and fail in a few hours, or last thousands of years. (See Chapter 3 & Appendix 3)
- **Tsunamis**: Immediate - Short Term.
  Note: Near field tsunamis generated by local earthquakes will be felt within a matter of minutes (See Chapter 4)
- **Seiches**: Immediate
- **River avulsion and sedimentation by landslides**: Immediate - Long Term (See Chapter 1 and Appendices 1 & 3)
- **Severing of engineering lifelines** (roads, rail, water supplies, sewage pipes, telecommunication lines, powerlines): Immediate - Moderate Term.

The time scales mentioned above give an indication of the duration of the effects actually occurring, but the physical clean-up, repair work, and economic effects may last for many months, or years. The effects mentioned between numbers 4-8 above were discussed in detail in previous chapters, and hence only passing references are made to them in this chapter.

Surface Rupture
Berryman (1984a) noted that a good correlation existed in New Zealand between surface rupture (faulting) and shallow earthquakes equalling M7 or greater. It was also observed by Berryman that a good correlation existed between surface rupture and felt intensities of greater than MM9. However, examples of surface rupture have occurred with earthquakes of less than M7. These include the 1929 Arthur's Pass earthquake (M6.9, Rynn 1975, M7.1, Dowrick 1991, Yang 1992), the 1983 localised earthquake swarm ofM3-M4 on the Kaiapo Fault (north Taupo Fault Zone, Berryman 1983), and the Edgecumbe earthquake in 1987 (M6.3 DSIR1987).

Notable West Coast examples of surface rupture include the 1929 Murchison Earthquake (M7.8) and the 1968 Inangahua Earthquake (M7.1). Respective felt intensities of these earthquakes in the epicentre regions were MM9 and MM 10. Surface rupture on the White Creek Fault during the Murchison Earthquake was 4.5m vertical where the fault crosses the Buller Gorge Road (now SH6) (Ferrar & Grange 1929, Fyfe 1929, Hendersen 1932, Bastings 1933). Maximum uplift of 4.9m occurred about 503m east of the fault, and was recorded by Fyfe (1929). The uplifted block tilted gradually to the east, with the tilt becoming non—existent at about 19.5km from the fault. Hendersen (1937) detected the fault trace displacement for 8km, and Berryman (1980) recorded 2.1m of sinistral horizontal movement and 3.1m vertical movement at a fence crossing the fault scarp.

Limestone rocks in the Buller River just downstream of the "Longest Swingbridge." The White Fault runs across the river in this vicinity. Across the swingbridge on the south side, there is an interpretation trail explaining about the degree of uplift and change in the area due to the 1929 Murchison Earthquake. *Photograph by M Trayes, WCRC.*

During the Inangahua Earthquake, surface rupture was recorded on the Glasgow-Inangahua Fault, and the Rotokohu Fault traces. Maximum displacement on the Glasgow-Inangahua Fault was near the railway lines at Inangahua. Lensen & Otway (1971) recorded 190mm of sinistral displacement, 400mm of vertical displacement, and a shortening component of 270mm (i.e. high angle reverse faulting as in the Murchison Earthquake). Maximum uplift occurred 4km east of Inangahua, and an area of at least 1 000km^2 was uplifted by an average of 1m. The Rotokohu Fault traces were formed during the Inangahua Earthquake, and were formed by slippage of bedding planes (bedding plane faults) in underlying Tertiary sediments. All were up-thrown to the south- east, with maximum vertical and dextral displacements reaching 1m on some traces: 400mm of thrusting was indicated by compressional rolls on the ground surface (Lensen & Otway 1971).

Although no movement of the Alpine Fault has been recorded historically, geological evidence suggests that individual dextral movements associated with large-scale earthquakes are in the order of about 8m horizontal (Hull & Berryman 1986, Yetton *et al.* 1998). The most recent earthquake on the Alpine fault occurred in 1717AD, with an associated minimum rupture length of 375km, from Milford Sound to the Haupiri River (Yetton *et al.* 1998). This rupture may actually be up to 450km in length (see Section 5.5).

Liquefaction

Liquefaction occurs as a result of ground shaking, when pore fluids in fine grained sediments are prohibited from escaping, hence the sediments become saturated, lose their strength and behave like a fluid — that is, the sediments flow. Liquefaction is commonly associated with geologically young sediments, especially those less than 10 000 years old, deposited in low energy environments such as lagoons, estuaries and artificially reclaimed ground. Bell (1994) also noted a high ground water table was necessary for liquefaction to occur. Fairless and Berrill (1984) noted that with the exception of the 1895 Taupo Earthquake (greater than M6, in pumice soils which have unique properties), all cases of liquefaction in New Zealand have occurred in earthquakes of at least greater than M6.9. However, liquefaction occurred in the 1913 Westport (Fairless & Berrill 1984), which was assigned a magnitude of greater than M5 by Eiby (1968), although the exact magnitude is not known. Liquefaction was also recorded in the January 1991, M6 Westport earthquake (Benn 1992). Keefer (1984) suggested that M5 might be the minimum magnitude required for liquefaction to occur. For New Zealand, Hancox *et al.* (1998) claimed that MM7 was the minimum shaking intensity threshold for sand boils, and MM8 was for lateral spreads. They also noted that both might occur at one intensity level less, in highly susceptible materials.

With the region's main settlements being established on river mouth/estuarine deposits, and reclaimed lagoons, there is a considerable risk of damage by liquefaction during earthquakes. Fairless & Berrill (1984) commented that *......it is now recognised that liquefaction is a fairly common seismic effect and one with great potential for destruction*.

Liquefaction causes damage by water ejection (like a high pressure fountain), sand boils, settlement of sediments, landslides on moderate slopes, foundation failures, and floatation of light structures. Numerous examples of liquefaction Have been reported on the West Coast (Fairless & Berrill 1984, Berrill *et al.* 1987a, 1987b, Adiam 1988, Berrill *et al.* 1988, Bonn 1992). The most damaging case, described by Berrill *et al.* (1988), occurred during the Inangahua Earthquake: At 10A Romilly St, Westport, a sand boil under the house had sufficient force to lift the house, rotate it, and leave it skewered on it's foundations. The house had to be demolished. Appendix 4 summarises liquefaction cases recorded in Benn (1992).

As can be seen from Appendix 4, most cases of liquefaction have been recorded in the Buller District, being coincidental with earthquake epicentres in the district. However, if earthquakes are generated elsewhere in the region, it can be expected that reported liquefaction cases would also increase from those areas. Berrill *et al.* (1988) noted that liquefaction becomes more sporadic with increased epicentral distances, and all West Coast examples have been recorded from level or near level ground.

Benn (1992) noted that:

Widespread liquefaction is possible on the West Coast, given the geologically young, near level flood plains of many river valleys. The most extensive flood plains (potentially the highest liquefaction risk) occur in the Grey and Inangahua river valleys, the Buller and Karamea river flood plains, and in the valleys of the Arahura, Hokitika, Wanganui and Poerua Rivers.

All of these floodplains have been intensively settled and developed. Hence, because all the major West Coast settlements are located on river flats (e.g. Inangahua, Murchison, Reefton) or at river mouths in a lagoonal environment (e.g. Greymouth, Westport, Karamea, Hokitika, Okarito), the potential for liquefaction damage is high.

Potential liquefaction sites can be determined to a certain degree by basic soil identification, and scientific soil and pore pressure tests, although Fairless & Berrill (1984) noted that predictions of liquefaction potential are far from reliable due to the mechanics of liquefaction not being fully understood. However they did state that *If we ask whether liquefaction would have been predicted at Three Channel Flat* (Inangahua area, Buller Gorge) *given the soil properties found, the answer is definitely yes*.

Benn (1992) suggested that locating potential liquefiable sites should be considered important, especially in areas of intense development or proposed development. Fairless & Berrill (1984) concluded that Three Channel Flat and Kilkenny park in Westport would be interesting to investigate further because of their recorded liquefaction, as would the Grey River site if it could be located more precisely. This was suggested: *to establish soil properties there and to check the results of various predictive liquefaction models against the known occurrence of liquefaction .*

Identifying potential liquefaction sites and creating hazard maps was one of the main hazard priorities expressed by the three District Councils, when interviewed for this project (Chapter 7).

Seiches in Lakes

Landslides falling into lakes, or disturbances of the lake floor by submarine slides or fault ruptures, can cause waves in the order of tens of metres high (Hawley 1984). Two such reported cases occurred during the 1929 Murchison earthquake, when it was reported from Lake Rotoroa (now in the Tasman District):

Lake Rotoroa rocked from side to sided like a huge basin of water being tipped out. Half an hour after the main shake, the water receded from the hotel shore and exposed the lake bed for 50 yards. It then came back in a series of large waves. The bridge over the Gowan River at the lake was torn from its piles and banks of the river and was hurled upstream by the Gowan waters, which were temporarily/lowing back into the lake. The water then returned back to its normal course (Greymouth Evening Star 20/06/29, *in* Benn 1992).

The same edition of the paper also reported: *Lake Moana (Brunner) sank down in the middle then came up like a typhoon.* Lake margins were flooded. It is assumed that these two seiches were generated from submarine disturbances, as no contemporary reports or observations of landslides falling directly into either lake have been found.

Benn (1992) noted that since there are numerous deep lakes in the region, located in steep sided glacial trench valleys, landslides into lakes and seiches are a potential threat throughout the region. At Lake Brunner and Lake Kaniere there is a threat to the substantial settlement and development around their shores, However, development is not intense around many of the other smaller lakes in the region. Yetton *et al.* (1998) stated that: *In general lake seiches are more likely to cause damage during an Alpine Fault earthquake than are tsunami.* This was based on the proximity of the lakes to the Alpine Fault trace, and it was noted that Lake Brunner and Lake Kaniere were 7km and 500m from the fault respectively, and both have steep peaks on their shorelines, elevated at more than 1000m above the lake levels. Yetton *et al.* also noted the potential effects of seiches on individual lakes throughout the region.

Earthquake Magnitude, Intensity and Frequency

Earthquake Magnitude

An earthquake's magnitude (M) is instrumentally recorded and measures the amount of energy (Ergs) released in an earthquake at its source. The magnitude is measured on a logarithmic scale, with the amount of released energy increasing about 32 times for each unit of increase in magnitude. Table 5 shows the comparison.

Table 5. Comparison of Difference in Magnitude and Radiated Energy for any Two Earthquakes. (after Ziony 1995).

Difference in Magnitude	Number of Ergs (Energy Released)	Difference in Radiated Energy
5	20xl0^{13}	32 000 000
4	6x10"	1 000 000
3	2xl0^{10}	32000
2	6xl0^{8}	1000
1	2xl0^{7}	32(31.6)
0.1	6x 10^{5}	1.4

To date the largest magnitude earthquake centred, and recorded, on the West Coast, is the 1929 Murchison Earthquake at M7.8 (Dowrick & Smith 1990). The second largest was the 1968 Inangahua Earthquake at M7.1 (Adams *et* a/. 1968). Based on geological evidence of pre-historical events, Yetton *et al* (1998) and Pettinga *et al.* (1998) predict that the next Alpine Fault rupture is likely to produce an earthquake of M8 — 0.25, and will be larger than any other earthquake that has occurred in the last 100 years. The range of magnitudes presented in Table 6 below, for the Toaroha River Event (171 PAD) (see Section 5.5) is due to the possibility of two rupture lengths, of 375km based on trenching evidence, and 450km based on tree ring evidence: For 375km of rupture length, Wells & Coppersmith (1994) suggested an associated earthquake ofM8 - 0.15, whilst Anderson *et al.* (1996) suggested M8 — 0.26 for the same distance. For 450km of rupture. Wells & Coppersmith (1994) predicted an earthquake ofM8.15 - 0.2, and for the same rupture, Anderson *et al* (1996) predicted M8.05 - 0.26.

Earthquake Intensity

In relation to hazards, earthquake intensity (MM) is more relevant than magnitude. The intensity of an earthquake is the measure of the *felt effects* at the earth s surface, and these vary according to proximity to the epicentre, local geology and engineered structures (Cowan & Pettinga 1990). Eiby (1966) devised a Modified Mercalli Scale (New Zealand version) for measuring such intensities. The scale ranges from MM1, where the shock is usually unfelt by humans, to MM 12, where damage to structures is virtually total and large rock masses are displaced. The full scale is shown in Eiby (1966), Benn (1992), Pettinga *et al.* (1998).

The highest MM intensity recorded on the West Coast is MM 10, in both the Murchison Earthquake (Adams 1981, Berrill *et al.* 1988), and the Inangahua Earthquake (Adams *et al.* 1968, Adams 1981). Table 6 shows estimated MM intensities (and magnitudes) from Yetton *et al.* (1998), for the two most recent Alpine Fault earthquakes (see Section 5.5), and the most likely intensities to be expected at various locations in the next Alpine Fault event.

Table 6.
Predicted Intensities for the Two Most Recent Alpine Fault Earthquakes and the Most Likely Modal Intensity as a Guide to the Next Event (After Yetton *et al.* 1998)

Location	**Predicted Intensities (MM Units)**		
	Crane Creek Event *Date M*	Toaroha River Event *Date M*	Modal Intensity
	1625 AD >7.8	1717 AD ~8(.05)-0.26	<2100AD? 8-
Otira	=9	=9	=9
Franz Josef	=9	=9	=9
Hokitika	9	8	8-9
Greymouth	8	8	8
Westport	7	7	7
Reefton	8	7	7-8

Yetton *et al.* (1998) produced isoseismal models, from which the data in Table 6 were extracted, and stated that an area of MM 10 closest to the fault trace was likely in previous events (and predicted events), but was not shown on their isoseismal models due to the possible influence of local fault effects.

Earthquake Frequency

Benn (1992) summarised the work of a number of researchers, who investigated the return periods (frequencies) for fault movements in the region, including that of the Alpine Fault. At that time, based on the work of Adams (1980) and Hull & Berryman (1986) it was thought that the Alpine Fault ruptured about once every 500 years on average. However, recent research has radically changed this thinking. A variety of independent research lines now indicate that the Alpine Fault ruptures on average, about once every 250-260 years. Bull (1996) used lichenometric dating of large rockfalls and determined that Alpine Fault earthquakes had occurred in 1748AD, 1489AD, 1226AD and possibly 967AD (all - 10 years). The implied recurrence interval was 261-14 years. Cooper & Norris (1990) used ^{14}C dating of sag pond material from near the fault scarp in South Westland, and tree dating methods. They suggested large Alpine Fault earthquakes had occurred somewhere between 1650AD and 1725AD, and possibly around 1980 - 60 BP.

Yetton *et al.* (1998) produced four lines of independent evidence for which the results were very constant with each other (see research section). Based on this evidence, Yetton *et al.* inferred earthquake dates of 171 PAD, 1620AD - 10 years, 1425AD - 15 years. Other earthquakes inferred with decreasing reliability, were estimated to have occurred around 1200AD, 940AD, 600AD, 25BC (based on the evidence of a number of researchers (see Yetton *et al.* 1998, pp 85-86). As the four independent lines of evidence are consistent with each other, the fault rupture dates of Yetton *et al.* are the most reliable produced to date. It was also noted that some intermediate timed events have probably occurred but have not yet been recognised. Yetton *et al.* stated:

The implied pattern of earthquake occurrences is not regular but averages around 200 years and varies from 100 years to at least 280 years, which is the lapsed time since the last earthquake. Probability estimates can be made using the record of earthquake recurrence derived from a combined analysis of earthquake timing on other plate boundary faults around the world.

These calculated earthquake probabilities are presented in Table 7, which shows there is a very high probability of an Alpine Fault earthquake occurring in the next 50 to 100 years.

Table 7. Probability Estimates for the Next Alpine Fault Earthquake on the Central Section of the Alpine Fault (Yetton *etal.1998).*		
Years Hence	**Probability of an Earthquake Event (%)**	
	Average	**Range**
5	10	6-14
15	27	12-26
20	35	20-45
30	45	30-60
40	55	40-70
50	65	50-75
70	75	60-90
100	85	75-95

For other faults in the region, the return periods presented in Benn (1992) are still valid until further research is undertaken to determine otherwise. Table 8 presents the mean return periods for various earthquake intensities, from all these other potential sources of earthquakes

Table 8. Mean Return Periods for Various Intensities at Selected Locations				
Location	**Earthquake Intensity**			
	MMVI	**MMVII**	**MMVIII**	**MMIX**
	Mean Return Period (Years)			
Nelson	5	16	56	200
Westport	8	26	91	330
Greymouth	10	34	110	410
Otira	9	31	100	370
Arthur' s Pass	9	31	100	370
Mt Cook	14	48	170	600
Queenstown	12	54	250	1100
Milford Sound	12	62	330	1800

Note: Arthur' s Pass/Otira data from Paterson (1996). All other sites from Smith (1990)

Resource Example 1.

a) RE Liquefaction From Appendix 4, DTec Report:

LIQUEFACTION EVENTS

1913 Westport Earthquake*.*

Liquefaction at:

- Cape Foulwind *27km from epicentre. Fairless & Berrill (1984)*

1929 Murchison Earthquake**.**

Liquefaction at:

- Three Channel Flat, Inangahua *23km from epicentre (Berrill et al. 1988)*
- Keoghan's Farm, Sergeants Hill, Westport *45km from epicentre (Berrill et al.* 1988.)
- Little Wanganui *41km from epicentre (Berrill et al. 1988.*
- Karamea School 54km from epicentre (Berrill et al. 1988).
- Kongahu Estuary Karamea *54km from epicentre (Berrill et al. 1988*).
- Arapito, Karamea *52km from epicentre (Berrill et al. 1988.)*
- Four Rivers Plain Murchison *4km from epicentre (Berrill et al. 1988.)*
- Greymouth Lagoon *114km from epicentre (Berrill et al. 1988).*
- Blaketown residence *Cracks 1.2m wide in backyard, water and mud poured in up to 30mm deep in backyard. Precise location unknown (GES 17/6/1929, Benn 1992).*
- Paroa residence *Crack in backyard-fountain 6m high. Precise location not known (GES 18/6/1929, Benn 1992).*
- Greenstone River *122km from epicentre. Curious circular rings in mud reported [sand boils]. Greenstone river shot 1-1.2m high (GES 20.6.1929, Benn 1992). Significant case as it was the most distant recorded from the Murchison earthquake epicentre - ~19km further south than the Grey Lagoon example (Benn 1992).*
- Orowaiti River, near Westport *At Palmer's Farm, cracks in the ground, and in some places ground dropped 300mm or more, with water was being forced up through the cracks (Palmer 1970).*

1968 Inangahua Earthquake.

Liquefaction at:

- Three Channel Flat *10km from epicentre (Berrill et al. 1988).*
- Nixon's Farm *12km from epicentre (Berrill et al.1988).*
- Inwood's Farm, Inangahua *11km from epicentre (Berrill et al. 1988).*
- Walker's Flat, Buller Gorge *12-15km from epicentre (Berrill et al.1988)*
- O'Conner's Farm, Westport *30km from epicentre (Berrill et al.1988*).
- Durkin's Farm, Westport *32km from epicentre (Berrill et al 1988).*
- Reedy's Farm, Westport *33km from epicentre (Berrill et al. 1988).*
- Kilkenny Park, Westport *34km from epicentre (Berrill et al. 1988).*
- Keoghan's Farm, Westport *29km from epicentre (Berrill et al. 1988).*
- Ross's Farm, Browns Rd, Inangahua *Near the milking shed, jets of water coming up through ground, nearly 2m high (Benn 1992).*

1991 (January) Westport Earthquake

Liquefaction at:

- Nine Mile Beach, Charleston *Sand boils and cracks along beach. Subsidence of beach, especially around large driftwood logs, leaving the logs perched on pedestals of sand (Benn 1992).Re Liquefaction, Newspaper item, Greymouth Evening Star, 11/1/2003*

b) RE Liquefaction: article from Greymouth Evening Star 11/1/2003

Student hoping to rattle Some local memories

In 1929, the Murchison Earthquake caused considerable damage in Greymouth. Lives were lost arid property damage was widespread throughout the whole Grey-Butler area. After the earthquake there were numerous reports of sand and water geysers being ejected from the ground. This interesting phenomena is the subject of research currently undertaken at: the Department of Civil Engineering of the University of Canterbury by Miss Kirsti Carr, who is undertaking research for her Master of Engineering Degree.

To obtain a better understanding of the events of June 17,1929, Kirsti Carr has been pursuing historical accounts of the earthquake. Her efforts to date have focused on ascertaining where in the district these extrusions of water and sand occurred.

The process responsible, known as liquefaction, has been seen all over the world in earthquakes such as Kobe, Alaska and in California.

It has been responsible for massive loss of buildings, roads, bridges and essential services such as electricity and watt supplies. The damage from the Murchison earthquake was worse on the western side (Greymouth), in the vicinity of Blaketown than other areas.

A Mr G How of the Harbour staff observed at the time the river was affected. "Water and debris spouted up for considerble distance, and later the river fell some inches near the goods shed. The disturbance of the water lasted for some time after the major shake."

Fissures were also reported near Victoria Park, in the road at Omoto near the Racecourse and at Nelson Creek. A waterspout from a fissure was noted at Paroa.

The Grey River Argus reported at one residence in Blaketown,, on the comer of Blake and Collins streets belonging to Tony Negri, cracks four feet wide opened in the backyard, and spectators were considerably alarmed to see, water, mud and sand pouring into the section.

The inundation ceased and left a coating almost a foot deep on the back of the yard. A wash-house was also flooded.

"Several cracked portions of the roads and footpaths bear ample evidence of the quake's severity. visitor to the town this afternoon from Paroa stated in one residence's yard aiin fountain had sprung up from an earth crack, and was spouting 20 feet high"

In the earthquake, sands below the water table behave like quicksand , affecting the stability and strength of soils, which can lead to the collapse of slopes and foundations.

"Typically its effects have been seen in areas by the sea, near a river or close to an estuary. In the aftermath of an earthquake, liquefaction is often evidenced by the presence of sand boils, or cracks in the road as were seen in what is now Steer Avenue in 1929," Miss Carr said.

In order to better understand how the ground around Greymouth will be affected by an earthquake, in the coming months Miss Carr and her research team will be a taking drill samples and testing the soil -strength at many locations around Greymouth. Some locations have already been identified from newspaper records and old photos, but these do not offer much in the way of detail.

Miss Carr is seeking people with any information regarding the effects of the Murchison Earthquake or other more recent earthquakes on the West Coast, especially if any recollection of seeing sand boils, cracks in the ground or pooliing of water on the surface.

She can be contacted via Anthea Reynolds at the Grey District Council or email k.carr @civil.canterbury.ac.nz or write to Kirsti Carr, Department of Civil Engineering, University of Canterbury, Private Bag 4800, Christchurch.

Resource Example 2

Transcript of an oral interview with Ken Kees regarding the time of the 1929 Murchison Earthquake and it's impact locally, particularly in and around the Kongahu Swamp south of Karamea. The interview was done at Ken's present home at Little Wanganui on Saturday, November 1st, 2003 by Mary Trayes. Ken was 82 years old when the interview was made and only 8 at the time of 'quake. He was chosen for the interview because he is the only person still living who attended the Wangapeka Valley School at the time of the 1929 earthquake.

Some Effects of the 1929 Murchison Earthquake

"I'm Ken Kees. I was born in Runanga on 29th March 1921. And around the 1929 earthquake I was living approximately a mile and a half from where I am living today, at the cross roads into the Wangapeka Valley.

At the time of the big earthquake - that '29 earthquake I was at school up the Wangapeka Valley, that's roughly a mile from the cross road. Wasn't a very nice feeling I can tell you. These are the things I noticed most. All the slips that were left on the mountains and my house that I lived in at that time, was shaken so badly off its piles. Back about 18inches. Had to be propped to hold it before it could be repiled. Also the day of the earthquake at the school I can remember a crack opening up along the road for about half a chain, about 3" (wide).

My mother, she was at home at the cross roads and at times she said that you could see the land over the swamp on the beach side and other times you couldn't. The swamp was up and down like an ocean wave.

To my knowledge, have never heard anyone else talk about waterspouts in the actual swamp - more that the waterspouts and the sand coming from them through the ground, coming up to the surface - were more on the river flats and bush edge around my home. That's where the waterspouts were. More round this area where the house is now. Just straight down the paddock.

I never actually saw the waterspouts. But 6 or 8 inch, you'd see mounds built up. One I remember straight down from house. I suppose I got a couple of barrow loads of sand off it. The other little ones were either after the Inangahua (1968) one or the Westport (1962) one. Not sure which one it was now. And those were round bush edge but today you wouldn't find any sign of these because the paddock down where I got the couple of barrow loads of sand, they've gone.

I mentioned all the sand spots I spotted when I was ploughing the ground to my neighbour and he told me all about the waterspouts and around the flat just round the '29 earthquake, when it was on and few days afterwards. He said they went up quite high but how high he didn't remember. Nowhere round the river flats now would I be able to expect to pick up these signs today because they've been either worked over or the sand's been flattened out and that with the cattle.

To my knowledge none of the aftershocks brought up this sand or water-spouts but I was too young to be roaming looking around to see it. Most of it was all told to me by my neighbour, Bert Baker. He's long since gone now.

As for any liquefaction on the swampy part of the Kongahu swamp, I never heard of any. It was only round the bush edge and nearer the harder ground round the house where I live today. Those were the only places I heard of them. Out on the swamp or near cross roads I never saw any up there.

The water and sand spouts I didn't actually see them . It was told to me by my neighbour Bert Baker. The only part that I saw was build up of sand that had been where I was ploughing or wandering round the bush edge just after the Inanaghua or Westport earthquake . But the '29 earthquake I was just too young to see anything. It was all told to me by my neighbours, or father, or mother.

Some of the sand come up out the ground were about 18" high and that. They have been flattened down. Those were the real big ones. They have been flattened down over a period of time. That'd be over 30 or 40 odd years after the main quake. So it was quite a time.

Wangapeka school was roughly a mile on the straight when you went over the hill from where I lived at the cross road. It would be a mile, a good mile I say, at end of straight. Today there's a big rhododendron growing on the side of the road at our school site. Present day owned by - I couldn't say his name - he's a new chap, used to be Ross Simonsen's place. But just can't remember that name. ……. Jackson, Bill Jackson. He owned the farm now on the other side of the road from the school.

Underneath us here you go down there's gravel for a start off. Way down. Then you keep on going you come along to sand. When I humped and hollowed over the bush there 'bout ten to twelve feet down we were bringing up pure beach sand. That's just about 50 yards of that from the house, yet the ground was quite damp on top.

Logs in the swamp? The swamp down here she's got some monstrous logs. The Kongahu swamp here. Got rata logs, and red pine, white pine. Been a white pine forest over it at some time or another. You get the stump roots. That's about all you find that tells you a forest ever grew in there. But no they'd pick up rata trees. We been burning rata wood coming off the swamp there for the last 12 months. Oh, yes there's some big rata logs come out and trees come off the swamp.

Silver pine is another tree that grew on the swamp there in the early days. Not so prominent round the bush edges now. Might strike a little but not much. But in the earlier days out in the swamp itself there was acres of it. Must have been growing because they were cut for fence posts. Some of them gone dead with the fires over a period of time. But died off so had to have grown there at some time."

Footnote:
In October 2003 local contractor Selwyn Lowe, using a digger to hump and hollow some of Leigh Kees land (Ken's son) between Ken's present house and the old homesite at the crossroads into the Wangapeka Valley, pointed out a number of places to the interviewer where sand had come right up through the swamp and was visible on the top. The white sand was quite noticeable against the dark peat - bog soils he was turning over and was due, he thought, to waterspouts or sandboils which had happened at times of past major earthquakes like the 1929 one. He had also turned up numerous huge tree stumps and part logs of rata and kahikatea which he surmised to be the remains of at least two former lots of forest cover in the swamp. Currently there is only anecdotal evidence as in Resource Example 1 and above regarding these liquefaction effects in the Kongahu Swamp and its environs. Until a more formal paleoenvironmental study is done with trenching, carbon dating of logs and analysis of the sediment layers, (as per that completed for Okarito Lagoon in 2001), we can only assume past levels of disturbance.

Resource Example 3.

a) Map showing Modified Mercalli Intensities

The lines show all the points where similar levels of intensity – "shaking" - were felt as a result of the 1968 Inangahua Earthquake which measured 7.1 on the Richter Scale. Westport is shown as having had shaking at levels VIII, sufficient to topple chimneys, liquefy sandy areas with corresponding building damage and surface rupture of roads.

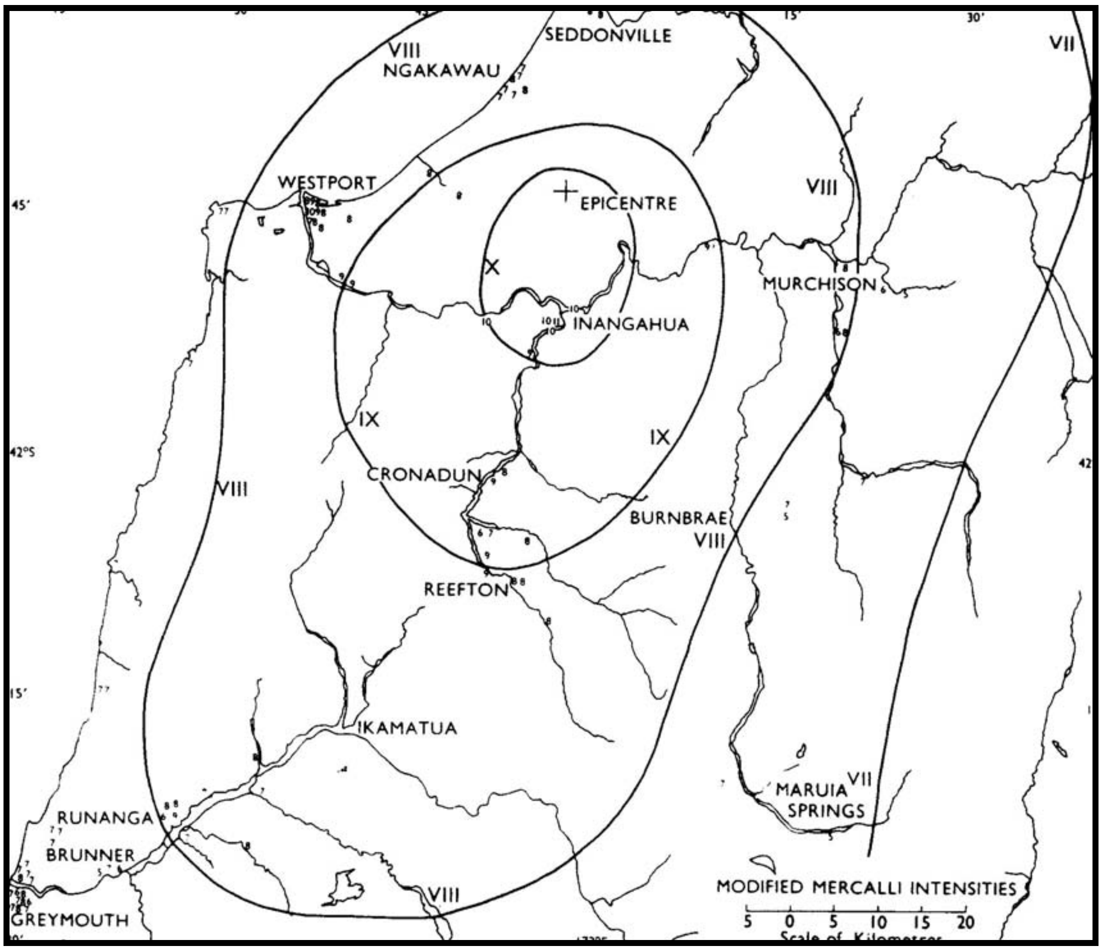
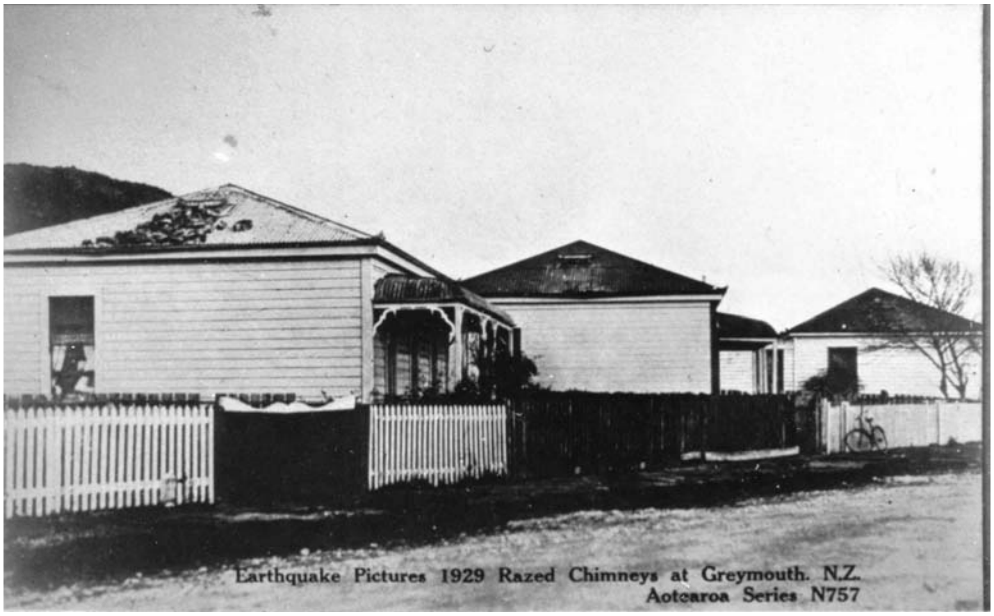


Fig. 11 Modified Mercalli Intensities for the Inangahua earthquake epicentral region. (Adams et al. 1968). This map is from page 22, "*A Review of Earthquake Hazards of the West Coast*" by JL Benn, 1992, published WCRC.

Resource 4. Photo File

a) Black & white scenes of the effects of the 1929 Murchison Earthquake. These copies of the original postcards are kept at *History House in Greymouth*, original authorship unknown. Original photographs of the earthquake's effects in Greymouth are rare: most scenes known are from newspapers at the time.

Collapses of shop frontages onto the footpaths were common in both Greymouth and Westport as a result of the 1929 Murchison Earthquake.



Loss of chimneys was a feature right round the region after the 1929 Murchison Earthquake indicating the shake had reached at least Mercalli Level VII. Most domestic chimneys were made of non-reinforced brick or concrete at that time.

This picture was taken in Preston Road. The road fissures have been caused by liquefaction of the sandy soils in the Blaketown area.

b) Black and white scenes after the 1968 Inangahua Earthquake from former Ministry of Works collection, courtesy of *Kevin Caldwell*, Greymouth resident.

One of the biggest effects of the earthquake was slumping of roads which made communi-cations after the earthquake very difficult. However the use of (for the first time after a major natural hazards event) did help to make it much easier to implement an emergency response

One casualty of the many slumps in the roads was this car, going nowhere.

Rail communications were also badly affected as witnessed by this photograph of derailed rolling stock. In many places formerly straight steel rails were bent and twisted, testimony to the violence of the earth's movement

Resource Example 5.

a) Sample material available from GNS website on Earthquake Reporting

NEWS RELEASE: 22 AUGUST 2003
FIORDLAND QUAKE BIGGEST FOR MANY YEARS

"Today's magnitude 7.1 earthquake in Fiordland ranks as one of the largest "on-land" earthquakes in New Zealand for many years, the Institute of Geological and Nuclear Sciences Ltd (GNS) said.

It occurred at 12.12am and has a provisional location of about 70km northwest of Te Anau and about 12km deep. This is close to Secretary Island, at the entrance to Doubtful Sound.

It was felt strongly in Te Anau, where there were reports of goods shaken off shelves. Many people in the southern half of the South Island were woken abruptly when the quake struck. Heavy damage is not expected outside the Fiordland region because the epicentre was a long way from populated areas.

'Coastal Fiordland is one of the most seismically active parts of New Zealand, said GNS seismologist Warwick Smith. 'The Australian and Pacific tectonic plates are being forced together in the Fiordland area resulting in stress and strain building up in the earth's crust. Earthquakes are a stress relief mechanism,' Dr Smith said.

'A magnitude 6.2 aftershock was recorded at 2.12am at the same location. Aftershocks are likely to be frequent for several days, and smaller aftershocks will continue for months. Anyone in the vicinity of the epicentre would have felt dozens of aftershocks within a few hours of the main shock.'

The Secretary Island area experienced an earthquake of magnitude 6.7 in 1993, and two others of magnitude 6.1 in 1988 and 1989.

The last on-land earthquake of comparable size to last night's main shock was at Inangahua on the West Coast on 24 May 1968. In February 1995 there was a magnitude 7.0 quake off East Cape, but little damage resulted because of its great distance offshore.

'On average, New Zealand can expect an earthquake of magnitude 7 or greater about once a decade and a magnitude 8 once every century.'

GNS recorded the earthquake on the GeoNet national monitoring network. Its development has been funded by the Earthquake Commission and the Foundation for Research Science & Technology.

Duty seismologist Brian Ferris made the information available via the GeoNet website within 30 minutes of the earthquake.

A group of GNS seismologists will travel to Fiordland later today to deploy up to eight portable seismographs near the epicentre to record aftershocks.

Aftershocks are a rich source of information for seismologists. They provide information on the extent of the "fault break" in the crust and provide insights into what is likely to have caused the earthquake and its impact on any nearby faults.

Two years ago after a slightly smaller earthquake near Jackson Bay on the West Coast, GNS seismologists recorded 2000 aftershocks on their portable instruments over a three week period. Most were small – between magnitude 1 and 3. About 400 were useable for further analysis.

b) GNS Earthquake Reports from their website at www.gns.cri.nz

The Four Week Interval from Sept 11th to Aug 15th 2003

Including the Fiordland Earthquake

Posted 12.9.03 for week from September 5 to 11th 2003

- Time: 8 September 2003 at 5:04 pm

Magnitudes: 3.5
Depth: 32 km
Location: 20 km southwest of Wanganui
Felt in Wanganui

- Time: 9 September 2003 at 10:47 am

Magnitude: 4.9
Depth: 25 km
Location: 70 km west of Te Anau
Felt in Te Anau, Manapouri, Dunedin and Scott's Gap - aftershock of the magnitude 7.1 event on 22 August. Another magnitude 4.7 aftershock on September 7 at 7:21 pm was felt in Te Anau, Manapouri and Invercargill.

- Time: 6 September 2003 at 10:30 pm

Magnitude: 4.0
Depth: 60 km
Location: 10 km north of Opotiki
Felt at Te Kaha and Nukuhou North

- Time: 5 September 2003 at 6:58 pm

Magnitude: 4.2
Depth: 12 km
Location: 70 km north of Te Araroa posted by jeff
2003_09_01_quakearch.html#106332689764604728">12:34 PM

Posted 5.9.03 for week from August 29 to September 4th 2003

- Time: 4 September 2003 at 8:40 pm

Magnitudes: 6.1
Depth: 25 km
Location: 60 km west of Te Anau
Felt in Fiordland, Southland, Westland and Otago. No damage reported.
This is the second biggest aftershock of the Mag 7.1 earthquake on 22 Aug. Six smaller aftershocks, all of magnitude less than 5.0, have been reported felt over the past week.

- Time: 1 September 2003 at 10:19 pm

Magnitude: 3.8
Depth: 12 km
Location: 30 km north of New Plymouth
Felt at Egmont Village, New Plymouth and Waitara

- Time: 1 September 2003 at 1:28 pm
Magnitude: 3.8
Depth: 60 km
Location: 20 km west of Te Kaha
Felt at Pakihi Valley and Waiune

- Time: 30 August 2003 at 11:58 pm
Magnitude: 3.3
Depth: 18 km
Location: 10 km south of Westport
Felt in Westport

- Time:
Time: 2003 August 27. 3:39 p.m.
Magnitudes: 4.1
Depth: 37 km.
Location: 40 km. east of Cheviot.

Posted 29.8.03 for week from August 22 to 28th 2003

- Time: 2003 August 26. 9:29 a.m.
Magnitude: 3.6
Depth: 12 km.
Location: 10 km. east of Tokomaru Bay

- Time: 2003 August 23. 10:42 p.m.
Magnitude: 3.8
Depth: 30 km.
Location: 20 km. south-east of Wellington.
Felt widely in the Wellington region.

- Time: 2003 August 22. 12:12 a.m.
Magnitude: 7.1
Depth: 12 km.
Location: 70 km. west of Te Anau.
Felt throughout both the North and South Islands, and also in Sydney, Australia.
Most severe building damage reported was in Te Anau, where a chimney collapsed and a water main burst.

Minor structural damage, such as cracking to walls and ceilings, reported as far north as Dunedin. Goods off shelves reported as far north as Christchurch.

There was a widely felt magnitude 6.2 aftershock at 2:12 a.m. on Friday morning, and there have been 18 others with magnitude of between 5.0 and 5.9, as well as many smaller events, that have been felt since the main shock.
The last aftershock with a magnitude of over 5.0 was a magnitude 5.7 event that occurred on August 27 at 1:42 p.m.
posted by jeff 2003_08_01_quakearch.html#106212497809729806">2:42 PM

Preliminary Report Posted on 23.8.03

- The lower South Island was shaken by powerful magnitude 7.1 earthquake at 12:12 am on 22 August. The earthquake, centred at a depth of about 12 km, occurred offshore near Secretary Island, Fiordland. In Te Anau and Queenstown the tremor frightened tourists and threw goods off shelves in shops. The quake was also felt in Invercargill, Gore, Dunedin, Timaru and Christchurch. The main tremor has been followed by hundreds of aftershocks, including a Mag 6.2 quake at 2:12 am.

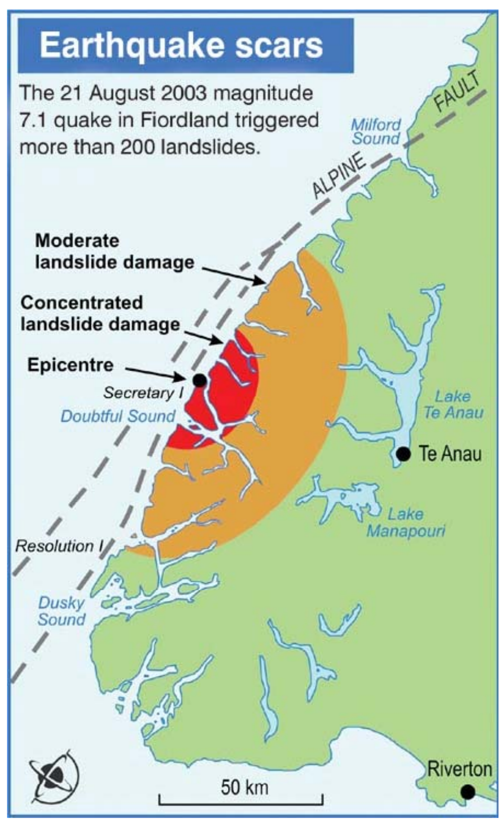
Posted 22.8.03 for week from August 15 to 21st 2003

- Time: 20 August 2003 at 2:48 pm
Magnitudes: 4.7
Depth: 91 km
Location: 40 km north-west of Te Anau
Felt in Fiordland and Southland

- Time: 19 August 2003 at 2:56 pm
Magnitude: 4.2
Depth: 5 km
Location: 20 km west of Arthur's Pass. Felt at Hokitika

- Time: 19 August 2003 at 2:31 pm
Magnitude: 3.9
Depth: 37 km
Location: 20 km north of Waverley. Felt at Rapanui and Wanganui

- Time: 16 August 2003 at 8:28 am
Magnitude: 3.5
Depth: 52 km
Location: 20 km west of Pongaroa.
Felt in Eketahuna



Map taken from the Natural Hazards Centre Website run by NIWA. Also published in "Natural Hazards Update, No. 5, 2003"

Earthquakes References

General Information Sites

Tephra Magazine:* *Vol.17, June 1998:* All articles are about NZ earthquakes

Aniwaniwa:* *No 13, 2000:* "NZ's Offshore Fault Zones", Scott Nodder, NIWA

Earthquakes: *#* S van Rose, Institute of Geological Sciences, UK. Published HMSO 1983

Natural Hazards: *#* JM Hensman, L Brockelsby, JR Hensman. Published by New House Publishers Ltd., Takapuna, NZ, 1993.

Natural Hazards - Earthquake Edition: # J Pringle & J Campbell. Published by Heinemann, 1986

Natural Hazards Update, Quarterly Newsletter of NIWA and GNS on all types of NZ Natural Hazards. Sometimes information specific to West Coast. Available online.

Regional Information Sites

Probability and Consequences of the next Alpine Fault Earthquake: Mark D. Yetton, Geotech Consulting Ltd. with Andrew Wells and Nick J. Traylen. March 1998. Funded and published by EQC. Copy available through WCRC EE Officer.

A Review of Earthquake Hazards of the West Coast: Report for WCRC by John Benn, 1992. Key resource, major bibliography. Copy available through WCRC EE Officer.

Liquefaction in the Buller Region in the 1929 & 1968 Earthquakes*:* Report by J B Berrill & PY Foray, 1988. Published in Bulletin of NZ National Society for Earthquake Engineering, vol 21, No 3, p 174 – 189,

Tephra Magazine* *Vol.19, June 2002:* "The Next Great West Coast Earthquake", M. McSaveney, GNS.

Tephra Magazine* *Vol.17, June 1998:* "The Alpine Fault", Mark Yetton, Geotech Consulting Ltd.

Grey River Argus: back copies for research on microfilm at Greymouth District Library

Greymouth Evening Star*:* back copies for research held at the Star Office, Greymouth

West Coast Times, (Hokitika)*:* back copies for research held at Star Office, Greymouth

Westport News*:* back copies for research held at the News Office, Westport

Earthquakes Websites

General Information Sites

www.gns.cri.nz	Best site for data on earthquakes. On line, up to date monitoring. Much useful information.
www.gns.cri.nz/quaketrackers	This is a schools based project website with excellent material for Years 7 – 13.
www.geonet.org.nz/drums.html	On line seismograph: changes every few minutes and linked to various seismographs round the country. Also lists link sites
www.naturalhazards.co.nz	Expert consultants, engineers re disaster prevention, mitigation, recovery
www.earthquakeengineering.com	Experts in building, engineering for earthquake areas, NZ and worldwide
www.nzsee.org.nz	Society for Earthquake Engineering, professional body group
http://earthquake.usgs.gov/4kids/eqterms.html	A very comprehensive glossary of terms for student use
www.naturalhazards.net.nz	Natural Hazards Centre site run by NIWA / GNS. See online copies "Hazards Update" publications.
www.eqc.govt.nz	The NZ Earthquake Commission provides natural disaster insurance for property owners. Good site for information about property protection.
www.earthquake.usgs.gov/4kids/eqterms.html	Very useful glossary of terms relating to earthquakes designed for student use
www.scecdc.scec.org/eqabc.html	US site with definitions basic terminology needed for understanding work about earthquakes and faults
www.naturalhazards.net.nz	For online versions of *Natural Hazards Update*, joint NIWA and GNS quarterly newsletters

Regional Information Sites

www.gns.cri.nz/news/release/alpf.html

This is an up to date media release the Alpine Fault: it summarises and draws together previous research on the Fault and gives information about likelihood of future earthquakes.

www.wcrc.govt.nz	Regarding regional Civil Defence for Natural Hazard events. Also District Council websites.