Earthquake Information Worth Knowing

(Geohazards in the Top of the South Island, New Zealand)

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PART I
LIFE ON A PLATE BOUNDARY

1. Introduction

The northern part of the South Island, consisting of Nelson City with Tasman and Marlborough districts to the west and east respectively and here for convenience called the "Top of the South" region, lies within the most seismically active part of New Zealand. This zone of high seismicity extends from Fiordland northeast through the West Coast, North Canterbury, Nelson and Marlborough into the south and east of the North Island. Over the past 150 years a number of major earthquakes that have caused widespread damage, and have been felt throughout the country, have originated within the zone. Notable earthquakes are those of 1848 (Awatere or Marlborough), 1855 (Southern Wairarapa), 1888 (North Canterbury), 1929 (Murchison) **Figure 1**, 1931 (Napier) and 1968 (Inangahua). As well as these major events smaller earthquakes, which may occur at depths of up to 650 m below the earth's surface, are very numerous, something in the order of 10,000 events being recorded in New Zealand annually **(Figure 2)**.

While it is generally acknowledged that central New Zealand is in the high risk zone, no part of the country is immune from earthquakes. In recent years active faults have been recognised in areas, such as around Dunedin, which had previously been considered to be tectonically inactive.

2. Geological Setting

The earth is composed of three distinct layers comprising the inner core which is surrounded by the mantle and on which floats a relatively thin crustal skin. The crust varies both in thickness and composition. Beneath the seas the oceanic crust is in the order of 5-8 km thick and is composed of materials, such as basalt and gabbro that are rich in iron, and which are consequently heavy. In contrast the continental crust is composed of light materials, rich in silica such as sedimentary rocks and granite, and is considerably thicker than the oceanic crust. Where the continental crust has been compressed and buckled in mountain ranges it can be up to 25 km or more thick.

Continental crust is not, despite its name, always above water. New Zealand is part of a largely submerged fragment of the continental crust that broke away from the great southern continent of Gondwana in a series of events that ended about 60 million years ago. This fragment is now situated across the junction between two of the large segments of the earth's crust, the Australia and Pacific plates. These plates are not stationary but are in continuous motion. The direction and rates of movement of the two plates are dissimilar with the Pacific plate, relative to the Australian plate, rotating in a counterclockwise direction. In northern New Zealand the Pacific plate is plunging beneath the Australian plate along a west dipping plane. To the south of New Zealand the plane between the two plates is in the opposite direction. As continental crust is too light and buoyant to be dragged (or subducted) below the surface of the earth where the plates meet, the net result is that between northern and southern New Zealand plate movement manifests itself as a gigantic tear **(Figure 3)**. This tear is the Alpine Fault and its associated faults **(Figure 4)**. Recent research, using GPS data, shows that across the Alpine Fault in Westland the crust is compressing or shortening at a rate of 20 mm/year. The direction of the shortening is towards the WSW making a angle of about 19° to the trend of the Alpine Fault. A figure of 20 mm per year may not seem a great amount but over 100 years this cumulatively becomes 2 m and its significant becomes more readily apparent. This distortion of the crust can be accommodated in two ways, as slow deformation or more rapid movements on faults. Collectively this is responsible for New Zealand as we see it today. Vertical uplift has formed most of the mountain ranges and the horizontal movement along the Alpine Fault has separated the formerly contiguous areas of Nelson-Marlborough and Otago-Southland by 480 km **(Figure 5)**. The formation of the New Zealand landscape, dominated by its mountain ranges and volcanoes has come with a cost, for periodic rapid movements on the faults generate large shallow earthquakes. On the other hand if it was not for this disturbance along the plate boundary then probably all of the mass of continental crust that New Zealand is part of would be below sea level.

3. Major Faults in the "Top of the South"

The dominant fault in the South Island, and one of the major faults of the world, is the Alpine Fault **(Figure 6)**. This great fault extends NNE along the West Coast at the toe of the Southern Alps and enters the Buller catchment at Springs Junction. North of Springs Junction it changes direction to ENE so that it trends diagonally through the Tasman and Marlborough districts to reach Cook Strait at Cloudy Bay. In contrast to further south the sense of movement on the fault is dominantly horizontal so that the contrast in topography across it is not as marked as in Westland. The reason for this is the direction of crustal shortening in relation to the trend of the fault. In North Westland the angle is approximately 20° thereby resulting in one side of the fault partly overriding the other. The consequence of this is the rapidly rising Southern Alps, with the rocks forming the alps having been uplifted 20,000m over the past 5 million years, and further north the Spencer Mountains. However because the shortening direction is not at right angles to the fault, the two blocks are also sliding past each other in a horizontal sense. Further North, in the Wairau Valley, the shortening direction is approximately parallel to the fault so that the two blocks tend to slide past each other with vertical movement being a minor component. As well as the vertical and horizontal displacement of the crust on either side of the Alpine Fault erosion also contributes to delineating its position. Movement on the fault has crushed the rocks enclosing it causing them to be easily removed by erosion. This erosion has formed the relatively low saddle in the main divide at Tophouse near St Arnaud and the linear Wairau Valley.

The Alpine Fault is not the only fault in New Zealand. There are in fact many thousands of faults, a reflection of New Zealand's complex geological history as being part of the continental crust that formed the margin of the Gondwana continent. However, most of these faults are tectonically dead and can be, as far as earthquakes are concerned, ignored. Nevertheless there are still many hundreds of faults that are active or potentially active. These active faults are all associated with the plate boundary and the most important are those that branch off the Alpine Fault. These major faults include the NNW to NNE trending faults of West Nelson, the northeast trending Waimea-Flaxmore Fault System in east Nelson and the ENE trending Marlborough Fault System **(Figure 7)**.

3.1. Marlborough Fault System

The Marlborough Fault System, extending into Marlborough from the Alpine Fault, consists of a number of ENE trending faults which are parallel to the Alpine Fault in the Wairau Valley. The Northeast part of the Alpine Fault from Tophouse to near Blenheim is also known as the Wairau Fault or Wairau section **(Figure 8)**. The most northern of the Marlborough faults, and the only one north of the Alpine Fault, is the Queen Charlotte Fault Zone. Although not know to be active, erosion along the fault zone is responsible for the linear valleys that are now flooded by the sea and form Kenepuru and Queen Charlotte sounds.

South of the Wairau section of the Alpine Fault are the Waihopai, Awatere, Clarence, Hope and other lesser faults. The Waihopai Fault is similar to the Queen Charlotte Fault Zone in that it is either now inactive or has a very low degree of activity. In contrast the Awatere, Clarence and Hope faults are very active with both horizontal and vertical components of movement. Vertical movement has formed the fault angle depressions of the Awatere and Clarence valleys which are separated by the Kaikoura Ranges. The ranges have given their name to the latest period of mountain building, the Kaikoura Orogeny to affect New Zealand. This mountain building is still continuing and its associated seismicity is the reason for this presentation. While vertical movement is a conspicuous feature of the Marlborough faults, the horizontal displacement is equally, if not more so important. Such faults, where one block slides horizontally past another, are known as strike-slip or transcurrent faults. Because northwest side moves northeast, relative to the other, such faults are referred to as dextral strike-slip.

As already mentioned many of the Marlborough faults are very active. For example it has been demonstrated that over the past six million years the amount of horizontal displacement across the Awatere Fault **(Figure 9)** has been at least 30 km, giving an annual slip rate of over 5 mm/year. However, the actual movement does not occur at a regular rate but in short bursts separated by periods of inactivity. In 1848 the Awatere Fault ruptured for 100 km producing a major earthquake (M = 7.5) that was felt throughout the whole country. As well as the major ENE trending faults there are other more northerly trending faults including major faults just off the coast that truncate the Kaikoura Ranges. Further NNE is the Picton Fault Zone that extends from Tuamarina to Picton. While a major fault, it appears to be truncated by the ENE trending Marlborough Fault System and its potential for movement would appear to be relatively low.

3.2. West Nelson Faults

The West Nelson Faults branch off the Alpine Fault in the upper Grey and Buller catchments. These faults in the south generally trend between NNW and NNE but this changes to more northeasterly in the northwest of the Tasman District. These faults are commonly bounded on one side by a mountain range and on the other by a fault or fault angle depression. Such topography is commonly referred to as "basin and range". However, not all faults are range bounding. The West Nelson Faults include, from west to east, the Lyell, White Creek, Tanui and Tutaki faults in the southwest and the Wakamarama, Pikikiruna, Karamea and Motueka faults in the northwest. Because these faults are approximately at right angles to the shortening direction the dominant sense of movement is vertical with a minor horizontal component. Such faults are classified as reverse with a sinistral component. The White Creek Fault, and just to the west of the Tasman District, The Glasgow Fault, are well known, having produced the 1929 Murchison **(Figure 10)** and 1968 Inangahua earthquakes respectively. Other faults such as the Lyell Fault show off setting of the ground surface, clear evidence of prehistoric movement. The faults in the northwest of the region, show no such offsetting and could therefore be classified as inactive. An inactive fault is one that has demonstrably not moved during the past 125,000 years (ie since the beginning of the last glaciation). However, it can not be conclusively stated that these faults will not move in the future and therefore they should be regarded as potentially active but with a very low risk of movement. Movement on the faults has largely been in a vertical sense so that they separate mountain ranges from fault angle depressions. A good example of this is the Wakamarama Fault in Golden Bay. Uplift on the west side of the fault has produced the Wakamarama Range and the fault-line scarp (or range scarp) that looks so dramatic when viewed from Collingwood township.

3.3. Waimea-Flaxmore Fault System

This fault system, comprising the Flaxmore **(Figure 11)**, Waimea, Eighty Eight, Whangamoa and other faults, extends northeast through the east of the Tasman District and into Nelson City. North of the city the fault system is largely offshore although a part of it is exposed on D'Urville Island. Beyond D'Urville Island it has been recognised in the offshore Taranaki Basin. The fault system marks the eastern edge of the Moutere Depression, a major and complex fault angle depression that forms the lowlands between the Western and Eastern mountains of Nelson. Flooding by the sea of the northern end of the depression has formed Tasman Bay.

As with the West Nelson Faults the Waimea-Flaxmore Fault System is approximately at right angles to the shortening direction so that the dominant component of movement is in a vertical sense, in this case producing the ranges of east Nelson **(Figure 12)**. The faults have a horizontal component of movement so that the northwest sides of the faults are moving northeast relative to the other side. Therefore the faults, which dip southeast under the ranges, are classified as reverse/strike slip (dextral).

4. Landscape of Geologic Diversity

From the above it is apparent that the topography of the Top of the South is primarily the result of distortion of the earth's crust, particularly by movements on the various faults in the area. Before discussing the continuing activity on the faults it is worth briefly summarising the movements which constitute the Kaikoura Orogeny. Approximately 10 million years ago in, the Miocene period, the region was reduced by erosion to a low lying landscape. While tectonic activity had diminished it was not dead and localised fault movements produced areas of relief which were subject to erosion. This erosion produced gravel deposits of which the Port Hills Gravel in Nelson City is a good example.

These localised gravel deposits were soon obscured by widespread outpourings of fan gravels composed of greywacke sandstone. The greywacke was eroded from the rising Southern Alps and Spencer Mountains as a consequence of activity along the boundary between the Australian-Pacific plates. The fan deposits, akin to the present day Canterbury Plains, contain virtually no rocks derived from the north of the Alpine Fault indicating that the ranges of east and west Nelson were non-existent. As the fans continued to accumulate uplift of the eastern and western ranges commenced, approximately 500,000 million years ago, and the gravel was eroded off being only preserved in the intervening Moutere Depression, where it is now known as the Moutere Gravel, and locally elsewhere in smaller fault angle depressions **(Figure 13)**. Despite the uplift of the ranges the major rivers were able to maintain their courses with the Buller and Motueka rivers flowing through gorges cut in the western mountains. Other valleys, such as the Aorere, Takaka, Wairau and Awatere, developed along the edges of the fault angle depressions.

Imposed on these tectonic events were climatic episodes. The climate at the start of the Moutere Gravel deposition was warm but with the onset of the Pleistocene, about 1 million years ago, there were alternating periods of cold and warm, each lasting in the order of a hundred thousand years or more. During the glaciations erosion was widespread and the valleys were filled with moraine or outwash gravels.

Also as a consequence of these climatic fluctuations sea level rose and fell. Following the last glaciation the sea rose to its present level 6,000 years ago and flooded the seaward end of the fault angle depressions. Coastal processes eroded the headlands between the valleys producing sand and gravel that accumulated in the bays as beach ridges, barrier spits and other such deposits.

5. Seismicity

New Zealand's position astride a plate boundary is manifested each day by the generation of earthquakes. Only a few of these earthquakes are felt, because they either have a very low magnitude and/or are distant, such as being deep below the earth's surface. New Zealand has been recording earthquakes since about 1855 although because of limitations in the instrumentation (both equipment and distribution) these are up until relatively recently rather imprecise and most minor earthquakes were not recorded. There is now a very sophisticated network in place which measures virtually all earthquakes including those that are both deep in the crust and of very small magnitude.

Before expanding on this it is important to note that there are two earthquake scales in use. Firstly, there is the Richter Scale which measures the magnitude, or the amount of energy released. This is both an open ended scale and a logarithmic one. There is, in theory, no upper limit to the scale; it is the ability of the earth's crust not to completely fail that is the limiting factor. Being a logarithmic scale, the transition from one step to the next involves the release of an increasing amount of energy, an increase of 31 times the energy output for each step in magnitude.

As far as the effects of an earthquake, perhaps of more importance to most is the Modified Mercalli Scale. This measures what one feels, in addition to panic, during an earthquake, and as such it is a subjective measurement of an earthquake as opposed to a scientific measurement. A small earthquake just below the surface may be felt as strongly as a large earthquake that is some distance away in either a vertical or horizontal sense. In the latter case the earthquake will be felt more widely and if it is shallow in the crust, then as the epicentre is approached, that is the point on the earth's surface immediately above the focus or point where the earthquake originated, its effects will become more pronounced. For example the 1929 Murchison earthquake centred 100 km southwest of Nelson City, had a magnitude of 7.8 on the Richter Scale. This produced ground shaking of MMIX at Murchison and MMVIII at Nelson. Another distant earthquake, the 1855 Wairarapa earthquake (M = 8.0-8.2) which was the largest in New Zealand since European settlement, gave ground shaking of MMX in the Wairarapa-Wellington area and again MMVIII in Nelson. The 1893 Nelson earthquake, centred in the western approaches to Cook Strait and perhaps on the Waimea-Flaxmore Fault System, also but only just, produced ground shaking of MMVIII in Nelson. On the other hand the Inangahua earthquake of 1968 gave MMVI in Nelson.

Since European settlement there have been only two earthquakes that have resulted in surface rupture along a fault within our region. These were the 1848 Marlborough earthquake which produced a fissure about 100 km long in the Awatere Valley and the 1929 Murchison earthquake. More recently the 1968 Inangahua earthquake caused ground surface rupture at Inangahua Junction.

Surface rupture adds another hazard for not only is there ground shaking, which may affect a wide area, but obviously any structures built across a fault will be displaced by the amount of movement. In a large earthquake this movement can be considerable. In 1929 the Buller Road, now SH6, was displaced 4 m vertically and 2 m horizontally. In the Wairau Valley the Alpine Fault has progressively offset river terraces. The latest offset, approximately several thousand years ago, had a displacement of 0.9 m in both a horizontal and vertical sense. In comparison the oldest terrace may be offset by as much as 1.25 km horizontally and 120 m vertically. Another aspect of earthquake shaking that needs to be taken into account is the type of ground conditions present. The felt effects can vary significantly depending on

- the nature of the materials, and
- the thickness of those materials.

Dealing with the first of these, waterlogged sand or mud will shake more intensely than solid rock. In addition, in saturated sediments the water may be expelled turning dry land into liquid, a process known as liquefaction. Also influencing ground shaking is where earthquake waves passing through the material are reinforced or amplified by bouncing off harder rocks, such as a buried hill, below the surface. Both of these effects, sediment type and reinforcement of shaking, can result in widespread differences in earthquake damages over a relatively small area. This was well shown in an earthquake in Wellington in 1968 where damage to the central city buildings varied in an apparently inexplicable way until both the subsurface materials and subsurface topography were taken into account.

5.1. Distribution of Earthquakes

The seismic record for the Top of the South region shows that earthquake centres are not evenly distributed. When seen in a cross section there is a concentration of earthquakes within a zone that dips westward to a depth of 350 km. This zone encloses the boundary between the Australian plate and the under-riding Pacific plate **(Figure 6)**. For shallow earthquakes (<40 km) there is also, as seen in plan, a non uniform earthquake distribution. This is well shown for the 1993-94 year and also the record of all earthquakes >RM4 that occurred in the region over the past 150 years **(Figure 14)**. These figures indicate that seismic activity is high in the western Nelson mountains and from southern Marlborough northeast into Cook Strait. There is a relative lack of activity in a zone that approximately correlates with the Moutere Depression and this has been described as an aseismic corridor.

A comparison with the geological map shows that much of the shallow seismic activity corresponds with the known major faults **(Figure 14)**. The reason for the lack of activity in the Moutere Depression is not readily apparent. One possibility is that the Waimea-Flaxmore Fault System is now largely dead. A less palatable scenario is that the fault system is locked. Such a state would not be unusual in that the fault system is almost at right angles to the crustal shortening direction and therefore any movement has to overcome considerable resistance between the blocks on either side of the faults forming the zone. In contrast the Marlborough faults are more aligned parallel to the shortening direction and the crustal blocks can slide past each other more readily. Thus stress may not build up to the same extent or, putting it another way, the stress can accumulate to high levels on the Waimea-Flaxmore Fault System. As a consequence such faults may not move as frequently as the strike slip ones but when they do the amount of energy released could be substantially greater.

5.2. Activity on the Faults

- Active faults are defined as faults that have clearly moved since the end of the last interglacial, about 125,000 years ago. Movements on faults commonly produce surface rupture along all or part of. its length. However, this definition may not include all active faults for several reasons:

- The fault movement, either because of the depth of the earthquake or its relatively low magnitude did not produce rupture of the ground surface.

- The fault produced a minor rupture which has either not been recognised or has been destroyed by erosion.

- The return period of earthquakes is greater than 125,000 years.

- Previously inactive, dead faults are reactivated, as can occur due to a change in the motion of the Pacific and Australian plates.

- A completely new fault is initiated.

The latter is an extremely rare event as in New Zealand, with its long geological history of tectonism, active faults have tended to develop along pre-existing structural breaks. However, within a block between two very active faults, strain may be released by the initiation of a new fault either parallel to the faults or oblique to them.

As for the other possibilities, all of these are valid. Therefore faults which are similar to adjacent faults that are known to be active should, in the absence of any criteria to the contrary, be regarded as potentially active. Thus all of the approximately north trending faults in west Nelson, the Waimea-Flaxmore Fault System and the ENE striking Marlborough faults south of the Alpine Fault (Wairau section) are regarded as active or potentially active.

5.3. Recurrence Intervals and Slip Rates on Faults

The recurrence interval (RI) is the calculated return period for earthquakes on a particular fault or fault system. The RI converted to a yearly average is the slip rate (SR). It should be noted that the RI on faults in a particular group of faults or a fault system are not synchronised. Therefore the recurrence interval of an earthquake originating in an area containing a group of faults or a fault system is lowered, that is, an earthquake can be expected much more frequently than if the RI for individual faults only is considered. From the geological record, such as the dating of surfaces offset by faults, the recurrence intervals are lowest on the Alpine Fault, 500 years for the segment extending southwest from Nelson Lakes, to over 20,000 years on the individual faults in west Nelson and the Waimea-Flaxmore Fault System.

By measuring the displacements that have occurred during earthquakes, and seismological evaluation of historic earthquakes, it is possible to calculate the likely maximum magnitude of earthquakes that could originate on the various faults in the Top of the South region. Maximum magnitude earthquake that can arise on any of the faults in the Top of the South region is likely to be of at least similar magnitude to the 1929 Murchison earthquake (M = 7.8).

From the recurrence interval of earthquakes, the likely magnitude of future earthquakes and the effect of ground materials on the propagation of earthquake waves the following frequency of ground shaking is arrived at for Nelson City, which is in the approximate centre of the region and for Murchison which is closer to the Alpine Fault.

Table 1
Recurrence Intervals (RI) for selected faults

Fault	*RI (years)*	*Time since last event (years)*
Alpine (SW)	500	1100-1300
Alpine (Wairau)	1000-2300	800-1500
West Nelson faults	>20000	28 (Glasgow Fault - Inangahua earthquake)
Waimea-Flaxmore FS	>20000	>1000

Likely Earthquake Magnitude (Richter Scale) M = 7.0-8.0

Return Periods for Earthquake Ground Shaking

Modified Mercalli Scale	*Damage*	*Nelson City (years)*
MMVI	Minor	6
MMVII	Moderate	25
MMVIII	Moderate to Major	88
MMIX	Major	340

6. Conclusions

From both the seismological and geological records the following points are arrived at:

- Earthquakes can be generated on a large number of faults that are widely dispersed throughout the Top of the South region.

- The faults with the greatest potential for movement are the Alpine Fault followed by the faults adjacent to the Alpine Fault.

- Movement along any faults in the Top of the South region has the potential to reach at least M = 7.8.

- An earthquake of approximately M = 7.8 will cause severe ground shaking over the Top of the South region.

- A shallow earthquake of M = 7.8 will result in ground shaking levels of up to MMIX, possibly locally MMX, in the epicentral area (say an area of approximate radius of 50 km). Such an earthquake would produce ground shaking of MMVII at approximately 100 km from the epicentre. Considering that the maximum distance between any two points on the coast of the Northern South Island is only 150 km, any major shallow earthquake in central New Zealand will significantly affect the Top of the South region.

- Amplification of ground shaking can be anticipated in weak, particularly water saturated, rocks. Amplification may be up to two steps on the Modified Mercalli Scale. Such rocks are commonly found under the flat, low lying areas which are favoured for human habitation.

PART II
LIVING IN *EARTHQUAKE COUNTRY*

1. Introduction

Thanks Mike for presenting that picture of how and why the geological diversity of our region is reflected in earthquakes and faulting. Thanks also to Susan for the earlier introduction. As she mentioned I am an engineering geologist with much of my expertise and training completed in California. So what is a Californian doing talking to New Zealanders about earthquake hazards?? Well, while I have only been living and working here in Nelson for the last five and a half years, there are a surprisingly large number of similarities between the geologic settings of California and New Zealand. This includes both the size and extent of the San Andreas fault in California which is quite similar to the Alpine fault here in New Zealand.

In a super-simplified model if one held a double-sided mirror down the middle of the Pacific Ocean in the reflection of California in the North Pacific and that of New Zealand in the South Pacific there are a surprising number of similarities in spite of a separation of almost 10,000 km. In fact the level of seismicity in New Zealand is very similar to, and by some accounts slightly higher than that in California.

I'll spend the next 20 minutes talking about the implications of living in what I refer to as "*Earthquake Country*". I'll do this by using overheads to present the following main points:

- Historic earthquake damage in our region
- more Recent damage
- General risk, hazards and vulnerability
- Specific risks and issues
- Concluding with a Look to the future.

For some of these points I'll be referring to the handout (**Figure 1**) which you may have picked up on the way in or are welcome to pick up at the end of our presentation.

2. Earthquake Damage

At the risk of repeating some of what Mike has already presented we'll take a quick tour of some of the more memorable earthquake events in New Zealand that have taken place in or have been felt by our region **(Figure 2)**.

Now depending on your point of view the geohazards we live with here in the top of the South Island can be viewed as either a curse or as a somewhat qualified blessing. What qualifies our region as "*Earthquake Country*"? These include:

- Our unique, complex and generally unconsolidated geology
- The history of severe earthquake ground shaking events
- Young, often steep topographic relief with a general limit of available flat lying properties near the built up areas.
- Periodic intense rainfall events ie 200 mm in five hours.
- Steady growth pressures forever pushing the limits of feasible property development

All of these add up to an impressive list of specific geotechnical oddities (or challenges) which will be discussed in the following sections on earthquake risk. In short, these items make our region a veritable engineering geologist's paradise.

2.1. Historic Damage

You may recognise this overhead from one of the Civil Defence handouts available here tonight with a few embellishments of our own to bring home the point that our region truly is an "earthquake hot spot" for the country and in fact world class as such designations go.

As Mike has already pointed our, the majority of the earthquakes which have caused major damage in New Zealand fall with in the RED CIRCLE. Because the effects of a major earthquake in Wellington can be as devastating to our region as say another Murchison earthquake, our talk tonight deals with major ground shaking generated within this RED CIRCLE.

New Zealand's earthquake history began in about 1460 with Maori telling of a large shock near Wellington known as *Hao-whenua* - 'the land swallower'. Then Captain Cook's expedition felt earthquakes in the Marlborough Sounds in 1773. In the early 1840's organised European settlement in our region, consisting of newly arrived colonists, felt and recorded their first earthquake. In 1848 the Marlborough earthquake damaged and destroyed most of what existed of Wellington at that time. The 1855 South Wairarapa earthquake, only seven years later, was the only New Zealand shock in historic times to have reached magnitude 8.

2.2. Recent Damage

In the 20th century the picture has remained more or less the same with first, in 1929, the Murchison earthquake then in 1962 a series of earthquakes near Westport was followed by the 1968 Inangahua earthquake. This overhead **(Figure 3)** is a reminder of the severity of the 1968 event, for those of you, like myself, not fortunate enough to have experienced it directly. It shows the massive landslide which temporarily blocked the Buller River (above) and twisting of the railway lines through the area (below).

These and a host of other listings for earthquakes in New Zealand are contained on the flipside of the earthquake trivia handout we've put together. Note that the bolded entries have occurred within or immediately adjacent to our Top of the South region. The chart shows the date, name and size of the earthquake.

Which brings me to my next point....While Mike and I have tried to keep the geotechnical jargon to a minimum for this talk there may be those of you interested in the way earthquakes are measured. Mike touched briefly on this earlier.

Basically there are two ways that earthquakes are measured **(Figure 4)**. The Richter Magnitude Scale or simply "Magnitude" measurement of an earthquake is an instrumental measure of energy released by an earthquake at its source. It is a logarithmic scale and for each whole number increase on the scale there is an increase of 10 times in the measured wave amplitude of an earthquake on the recorder. And for every whole unit increase in Magnitude there is a 31 fold increase in energy.

Spheres representing energy released for Magnitudes 1, 2 and 3 earthquakes are shown on this overhead. At the same scale the energy released by the Murchison 1929 (Richter Magnitude 7.8) would be represented by a sphere with a diameter of roughly 55 m or about twice the length of this room.

Whereas the modified Mercalli Intensity Scale, or simply "Mercalli" is usually expressed as Roman numerals, is a subjective, non-instrumental way of rating the effects an earthquake has on people and their world around them. It was developed in the 1880's by an Italian and a Swiss scientist and subsequently modified in the 1920's by an American seismologist to reflect modern structures. As such while Mercalli intensities will vary throughout a given area, the Richter Magnitude is a fixed figure.

3. Earthquake Risk

What is risk? **(Figure 5)**. As this overhead shows, risk is a combination of natural hazard events and our vulnerability to them.

3.1. The Hazards

As Mike has already pointed out the primary geohazard in our area consists of ground shaking occurring as a result of either

1. a severe earthquake occurring on any one of the many faults in the district, or
2. a severe earthquake occurring on one of the many faults outside and adjacent to the district.

Recall the RED CIRCLE on the earlier overhead. In real terms the effect and hence the hazard is largely the same. Other secondary geohazards related to this include: surface rupture, landsliding, liquefaction, tsunamis and a whole host of related hazards. There is in fact a well-defined "suite" of geohazards typically associated with every large earthquake typically of Magnitude 7 or greater. This "major earthquake damage *suite*" **(Figure 6)** typically consists of:

- Surface faulting. *Up to 7 m of horizontal displacement occurred 15 km south of Blenheim in the 1848 Marlborough Earthquake. Ground cracking associated with the rupture was identified for a length of more than 100 km*
- Ground uplift in some regions. *This has radically changed the waterfronts in both Wellington and Napier*
- Subsidence and inundation (flooding) and others
- Seiches (Slosh waves) in lakes and rivers
- Landslides, often damming rivers. *A huge landslide temporarily blocked the Buller river as shown previously with an associated risk of major flooding resulting from uncontrolled release of the dammed lake. The scars are still clearly visible 6 km north of Lyell*
- Mysterious lights in the sky
- Liquefaction of weak saturated clays/sandy soils. *That is normally dry sandy soils turning to liquid during ground shaking.*
- Tsunami (Earthquake generated 'tidal waves') and
- Reactivation of dormant volcanoes

Most of these were documented in the Inangahua earthquake of 1968 and indeed every one of these occurred as a result of the 1960 Magnitude 8.5 Chilean earthquake including Tsunamis around the entire Pacific Ocean killing 10's of people in Hawaii and 100's in Japan and elsewhere.

We have not made any effort to, nor is it our intention to focus on the Civil Defence issues related to this risk as we'll leave that to Susan and her team.

3.2. Our Vulnerability

Unlike the hazard component of this risk equation our vulnerability, or exposure to the earthquake hazard and the social and financial consequences of its occurrence are largely a cultural and engineering issue **(Figure 7)**. In this next section I'll briefly discuss the various vehicles which exist to define, and in some cases reduce, our vulnerability.

Our vulnerability to the Earthquake Hazard is largely defined by the following:

The Resource Management Act (1991) requires our unitary authorities to

- Collect and distribute information on natural hazards including earthquakes

- Develop policies and objectives related to hazard avoidance and mitigation. For the case of the earthquake hazards this relates specifically to damage and effects of strong ground shaking and shaking induced slope instability. Each of the unitary authorities in our region has undertaken to fulfil its statutory obligations in a variety of ways.

The Nelson City Council commissioned a study of "Earthquake, landslide and coastal hazards in Nelson City" which was issued December 1993. The Tasman District Council commissioned its "Preliminary Assessment of Earthquake and Slope Instability Hazards in Tasman District" which was issued in June of last year. Some portions of Marlborough District Council have been assessed and others remain to be done so. These reports are available through your District Councils.

Mike and I have drawn upon some of the information presented in these studies in this talk, Mike being the principal author of the Nelson City Council study.

The Building Act (1991) defines controls to ensure that buildings are safe and to protect people from possible injury, illness or loss of mobility in the course of the use of a building. Provisions in the act deal with foundations, ground slope factors of safety and building on marginal land among others. Section 36(2) of this act is a unique exception to this general principle of hazard reduction and is discussed in more detail in a moment.

Earthquake Risk Building Assessments have been carried out on unreinforced concrete and/or masonry buildings and are now being applied to all pre-1975 buildings

IPENZ - the Institute of Professional Engineers in New Zealand and more in particular the *NZ National Society for Earthquake Engineering* and the *Geotechnical Society* are professional groups, some of who's goals are to define and reduce earthquake vulnerability in New Zealand.

Other *local controls* have been developed and perhaps one of the most useful ones for us here in Nelson is the Nelson City Council's Engineering Condition Registry for properties.

Then of course there is the *Ministry of Civil Defence* who organised tonight's talk and who encourages the community to consider and prepare for Earthquake and Civil Defence emergencies.

Lifeline Studies represent perhaps one of the most valuable tool for reducing our vulnerability. Wellington completed its Lifeline in Earthquake project in August 1991. This was a world first for what may be one of the most earthquake vulnerable capitals in the world. It comprehensively examined all of the lifelines of that major city including water, electrical, gas, sewage, stormwater, telecom, radios, building services, roading, railways, airports, ports, identifying the vulnerability's and measures to mitigate the effects of earthquakes. Christchurch is expecting to complete a similar study with a focus on the earthquake and flooding hazards in Canterbury in December of this year.

Portions of some of our region's lifelines are known to be at risk, ie. sections of the Maitai water supply line for Nelson built in the 1960's. Surface rupture from fault movement is a major issue in protecting lifeline services like water and power. A strong case can be made for completion of a lifeline study for our Top of the South region.

Which brings me to our section on.....

3.3. Specific Earthquake Risks (Vulnerability

As I mentioned earlier some of the secondary effects of major earthquake ground shaking include landsliding, liquefaction etc. In the case of landsliding there exist some recognised zones of major instability. Such areas include much of the Marlborough Sounds, eastern Richmond Foothills and portions of Nelson City. Many of these landslides are the result of weak rocks but some have been initiated by earthquake ground shaking for example the Richmond foothills and portions of the Tahunanui hillside.

3.3.1. Nelson Geotechnical Hazards Zones

You may recognise this overhead **(Figure 8a)** as the Tahunanui hillside. Note the beach, Rocks Road, shops at Tahunanui, Princes Drive. This overlay **(Figure 8b)** shows the limits of the active *Tahunanui Slump* which is a large, active rotational slump containing about 120 houses. Soils & Foundations has investigated more than 20 individual properties within it.

There have been extensive movements and related damage is well documented within the body of the active *Tahunanui Slump* with the most significant damage events developing, following prolonged, heavy rainfall and in association with major earthquake ground shaking in the area. Ongoing resurveys confirm that less damaging movements are continuing albeit at different rates in different areas. The *Tahunanui Slump* poses a hazard to development including the possibility that developments on parts of it could be a danger to life.

The probable cause of the development of this landslide is severe ground shaking from an earthquake centred in the Nelson area many thousands of years ago. The earthquake may have originated on one of the active faults of the adjacent Waimea-Flaxmore Fault System in Nelson City. Clearly seismicity has been a contributing factor in recent historic failures as both the 1929 and 1962 movements were associated with moderate ground shaking at the site.

Figure 9 shows the severity of slump damage which occurred on the Tahunanui hillside 1 month following the 1929 Murchison Earthquake. Its a view looking North from the intersection of Bisley Avenue with Grenville Terrace. There is a pinboard here tonight (in the back somewhere) with some of the information we've assembled to date on the *Tahunanui Slump*. We invite you to have a look at it.

We have been involved with delineation of other geohazards zones in the Nelson area including the Grampians Foothills area. While these geohazard zones are primarily concerned with landsliding and other slope instability risks - they are clearly at an elevated risk from damage resulting from earthquake induced ground shaking.

3.3.2. Richmond Geohazard Zones

In the Tasman District there are areas like the Eastern Richmond Foothills which warrant consideration for designation as a Geotechnical Hazard Zone similar to some of the other areas discussed above. **Figure 10** shows general stability risk categories in the foothills behind Richmond and other portions of the Barnicoat Range. The yellow zones indicate low to moderate risk and the blue zones are mapped as high risk. This report is also available to the public from the Tasman District Council.

3.3.3. Marlborough Sounds

Much of the Marlborough Sounds have been included on hazards maps showing landsliding and flooding risk. A regional assessment of geohazards in Marlborough has not yet been undertaken as has been done in the Nelson and Tasman Districts.

3.3.4. Other Geohazards

In 1990 heavy rains initiated this and other landslides, temporarily closing SH6 near Magazine Point. The landsliding visible in **Figure 11** developed as the result of heavy rainfall, similar falls and widespread landsliding would be the likely consequence of major ground shaking from an earthquake. There is an excellent student exhibit on this feature here tonight.

Figure 12 shows remediation we were involved with of the cliff face which generated the landslide shown previously. It is now stabilised with rockfall netting to allow controlled failures in future. Other rockfalls along the sea cliff to the north have resulted in less spectacular road closures and vehicle damage and pose a continuing risk to traffic.

Figure 13 shows a car that went over the chain fence along rocks road landing on the rocks near Magazine Point to avoid collision with the landslide shown in the previous overhead. Other sections of SH6 are at risk through the Whangamoas to the Northeast of Nelson as are portions of the highway through the Spooner and Hope Ranges to the Southwest. These roads will almost certainly experience similar damage to that the railway extensions suffered near Glenhope and Kawatiri in the 1929 Murchison Earthquake. The region’s ability to recover from a damaging earthquake would be further hampered as it is likely that roads may well be cut in all directions further isolating parts of our region.

Other specific geohazards in our region include the following:

3.3.4.1 Liquefaction (Soil becoming liquefied)

Much of Port Nelson and portions of Tahunanui are susceptible to liquefaction which could affect Nelson’s efforts to recover from the effects of a major earthquake by hampering use of both the wharves and the airport. Liquefaction induced ground damage is likely to include ground collapse, settlement, fissuring and sand boils and possibly widespread damage due to lateral spreading of large reclaimed areas at Port Nelson. A liquefaction study has been completed for Port Nelson.

Coastal area and river valleys throughout the Tasman and Marlborough Districts are the most likely to be affected by liquefaction.

Incidentally it may have become fairly clear to you tonight that you are advised to NOT use Rocks Road to leave Nelson City in the event of a major earthquake what with the Rockfall hazard, the *Tahunanui Slump*, and liquefaction at the Port and Tahunanui...

3.3.4.2 Tsunami (Earthquake 'Tidal Wave')

There have been 32 cases of Tsunamis affecting New Zealand's coasts, four of which have been recorded in our region. The largest of these was in 1868 when waves of up to 1.5 m were observed. Most of the Boulder Bank was reportedly overtopped at that time.

3.3.4.3 Avalanche

Avalanche risk in the ski fields at Rainbow and Mt Robert's may be an issue, depending on the time of year. Further St Arnaud is at risk of surface rupture from movements on the Alpine fault which traverses the township.

3.4. Other Specific Issues

3.4.1. Heritage Buildings Risk

I apologise for not having an overhead of earthquake damage to historic buildings in our region but offer this photo **(Figure 14)** of the Historic Pacific Garden Mall in Santa Cruz, California damaged by the 1989 Loma Prieta Earthquake. This area was a favourite hangout of mine for many years when I lived there and the overhead shows the type of damage which might occur to some of the masonry Heritage Buildings in our region. This earthquake incidentally, while not "The Big One" California is waiting for, was the largest to hit the San Francisco Bay Area since "The Big One" in 1906.

Seismic upgrading is feasible to protect occupants and preserve these buildings as has been done to the Nelson Mail, Stroud House and others in Blenheim. Fortunately many of the Heritage buildings which remain here are primarily wooden structures. In fact downtown Nelson may have the largest collection of wooden commercial buildings remaining in all of New Zealand and others exist in Blenheim and throughout Tasman District. The built environment of the inner cities is a prime factor in attracting residents and visitors alike. We believe the vulnerability of Heritage Buildings can be managed. Earthquake upgrading of Heritage buildings is largely an issue of dollars as the engineering techniques exist.

3.4.2. Section 36(2)

Unlike the primary emphasis of the *Building Act* which is aimed at generally reducing our vulnerability to such things as damage from earthquakes, Section 36(2) is concerned with allowing building work to proceed on lands of marginal stability *provided such work will not accelerate, worsen etc* the identified conditions of marginal stability. *Caveat Emptor* (let the buyer beware) is a principle part of this clause in the *Building Act*.

3.4.3. Prediction

While most people agree that it is desirable to be able to predict earthquakes. Consider if you will what such a prediction, once published, might do to:

- property values
- population shifts
- new construction etc

Of course on the other hand sales of camping gear, candles, bottled water and other emergency rations might see a surge with shortages and high prices.

4. Looking to the Future

4.1. General Issues

Earthquakes are pretty amazing things and major earthquakes are truly amazing things. They have a way of marking time. Some of you may well remember exactly where you were and what you were doing at the time of the Inangahua in 1968. Others of you may be fortunate enough to recall the Murchison in 1929. I remember exactly what I was doing in the California Loma Prieta earthquake of seven years ago. I was on my back, under my house in a cramped crawl space working on the plumbing at the time!

I can virtually guarantee that should you, or your children live in this region of New Zealand for much more of your life you will experience at least one severe earthquake. The chances are probably a little higher for me and my family what with trips back and forth between California and here.

Consider if you will our ***"Regional Earthquake Odometer"*** - forever rolling forward...

- every 25 years or so we experience a severe earthquake. Its been 28 years since the Inangahua
- every 100 or so years the country experiences a great earthquake and several of those recorded have been centred in and/or directly affecting our region. Remember the RED CIRCLE. The last such event, the South Wairarapa, was 141 years ago
- Every 500 years or so a major earthquake occurs on the Alpine Fault. The last such event was well over 1000 years ago
- every 35 or so years there have been damaging movements on the *Tahunanui Slump*. The last such event was 34 years ago

4.2. What Does it all Mean to 'The Man in the Streets'??

In summary what we are trying to point out tonight is that every part of our Top of the South region is at significant risk from severe earthquake ground shaking. What we are not trying to say is that 'the end is near...'. 17 people died in the Murchison earthquake, Many 10's of thousands of people felt it and were affected by it - possibly being injured by it either physically of financially.

Perhaps now is a good time to consider things like:

- is the hot water cylinder and the ceiling header tank braced against earthquake??
- is the house you live in, if its an older house, bolted to its foundation ??

- what is the rock or soil type your house is sitting on ??
- what is the hillside like up behind your house ??
- are there heavy pictures or shelves with nic-nacs - perhaps favourite rock samples - on the wall above your bed ??
- would you know what to do / where to go in an earthquake ??

My son Simon has got a nifty little hands-on exhibit here tonight and there are lots of other thought provoking displays, posters and essays around the room.

5. Conclusion

In the 20 minutes that Mike and I have each had tonight it has not been possible to cover all of the geohazards which exist in our region nor were we able to be any more specific about those we did discuss.

In conclusion...It has not been our intention to scare you about the earthquake hazard. But rather to inform you and enable you to prepare yourselves physically and mentally for the reality of living in "*Earthquake Country*". If Mike and I have accomplished that tonight we feel we have been successful in providing you with EARTHQUAKE INFORMATION WORTH KNOWING.

FIGURE LIST

PART I
LIFE ON A PLATE BOUNDARY

FIGURE LIST

PART II
LIVING IN *EARTHQUAKE COUNTRY*

Earthquake Information Worth Knowing

DID YOU KNOW . . . . . .

- **The only part of the earth that can claim to be earthquake free is Antarctica**
- **Our (Top-of-the-South) region has been shaken by *severe* earthquakes 5 times over the past 150 years (MM VII or greater)**
- ***Severe* earthquake induced ground shaking can be expected in our region on average every 25 years. The last such event, the Inangahua Earthquake, occurred 28 years ago**
- **Any major earthquake event will likely damage or sever lifeline services (ie water, sewage, power...) and disrupt air, road, and port transportation. A major earthquake will stretch emergency resources and people are advised to be prepared to look after themselves and their neighbours for up to 72 hours**
- **Aftershocks almost always follow the main event. The biggest aftershock is often a little more than a magnitude smaller than the main shock. In the month following the Magnitude 7 Inangahua earthquake in 1968, 15 aftershocks of Magnitude 5 or greater were recorded**
- **All earthquakes generate TWO shocks. You can guesstimate both the size and direction (location) of earthquakes by noting 1) the time lag between the P (Primary) and S (Secondary) waves and 2) the direction of ground motion. The P-wave always arrives first and the S-wave lags behind hence the bigger the time lag the further away the earthquake was**
- **The term *"earthquake weather"* commonly refers to unusual weather which is hot and muggy. While the term has its basis primarily in folklore it is based, in part, on fact - at least in California where minor earthquakes have been observed to coincide with sharp changes in barometric pressure**
- **It is widely believed that a sharp increase in the number of small earthquakes heralds the approach of a large one but this is the exception rather than the rule**
- **An earthquake of Magnitude 5.7 or greater occurs somewhere on the earth every 3 or 4 days with about 20 earthquakes of greater than Magnitude 7 occurring somewhere on the earth each year. A typical decade sees an average of 14 earthquakes of greater than Magnitude 8**
- **Never-the-less some years are worse for earthquakes than others and 1960 is among the most tragic in recent earthquake history (Chilean Magnitude 8.5, Pacific Basin Tsunami, others...). From the human perspective the Chinese *Tang Shan* earthquake of 1976 was the greatest natural disaster in modern times killing more than $^{1}/_{2}$ *million* people**
- **No part of New Zealand is without its earthquakes. In New Zealand a *"major"* earthquake of Magnitude 7 or greater can be expected about once a decade. Both the historical and geologic record suggest that *"great"* earthquakes of Magnitude 8 or more do not happen more than once a century**
- **The history of earthquake records in New Zealand began about 1460 with Maori tradition telling of a large shock near Wellington known as *Hao-whenua*, the land swallower**
- **The moon also experiences quakes referred to, logically enough, as *moonquakes***
- **The largest recorded event since instrument records have been available (1903) had a measure of 8.9 on the Richter Scale (Columbia, 1906)**
- **The level of seismicity in New Zealand is very similar to that of California. While Californians feel fewer shocks than New Zealanders the ones they do feel are more alarming because they are shallower (at around 30 km vs 100 km or more in New Zealand)**

SEE OVER

- **The fresh fault breakage that occurred as a result of the 1906 San Francisco earthquake on the San Andreas fault is the longest on record for a single shock estimated at *300 km*. The amount of displacement varied greatly with up to *7 metres* of horizontal displacement 50 km northwest of San Francisco. Almost no vertical displacement occurred**

  The fresh fault breakage that occurred as a result of the 1848 Marlborough earthquake on the Awatere Fault measured more than *100* km. The amount of displacement varied with up to *7 metres* of horizontal displacement as well as a lesser vertical component 15 km south of Blenheim

- **The 1855 Wairarapa (Wellington) earthquake is the only New Zealand shock in historic times believed to have reached Magnitude 8**

Failure of embankment fill, highway east of Inangahua
Photo Credit: N.Z.G.S, L.D Homer

Selected *MAJOR* Earthquakes in New Zealand

(**Bolded** entries have occurred within or had major impact on the Top-of-the-South)

Date	*Name/Location*	*Size RM*[1]	*Description*[2]
1843, July 8	Wanganui	7.5	(2)
1848, October 16	**Marlborough**	**7.1**	**(3)**
1855, January 23	**South Wairarapa**	**8.1**	**(5)**
1888, September 1	North Canterbury	7.0	
1897, December 7	Whanganui	7.0	
1901, November 17	Cheviot	7.0	(1)
1921, June 19	Hawkes Bay	7.0	
1929, June 16	**Murchison**	**7.8**	**(17)**
1931, February 3	Hawkes Bay	7.9	(258)
1934, March 5	Pahiatua	7.6	(1)
1942, June 29	**South Wairarapa**	**7.0**	
1950, February 5	South of South Island	7.0	
1950, August 5	South of South Island	7.3	
1953, September 25	Bay of Plenty	7.1	
1960, May 29	Fiordland	7.0	
1968, May 24	**Inangahua**	**7.0**	**(3)**
1987, January 27	Kermadec Islands	7.3	

[1] Richter Magnitude [2] Number of known dead

Note: The classification of a 'MAJOR' earthquake is reserved for earthquakes of RM 7.0 or greater. Other earthquakes of less than RM 7.0, notably the Edgecumbe (Bay of Plenty) Magnitude 6.3 earthquake, have caused significant damage in NZ but are excluded from this list. See "Earthquakes" by G A Eiby, 1989 for more reading and a more extensive listing.