Earthquakes in the South Island of New Zealand

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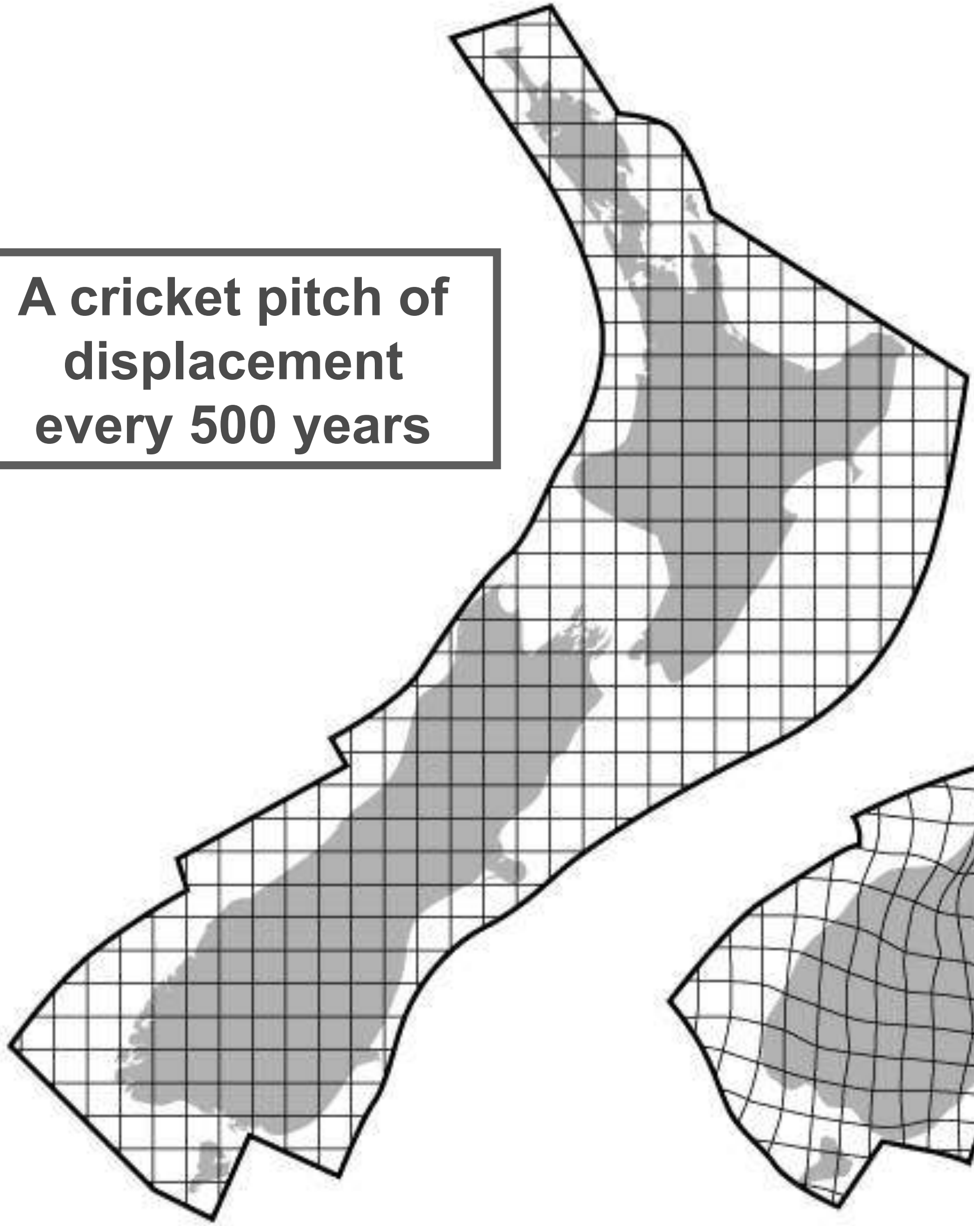
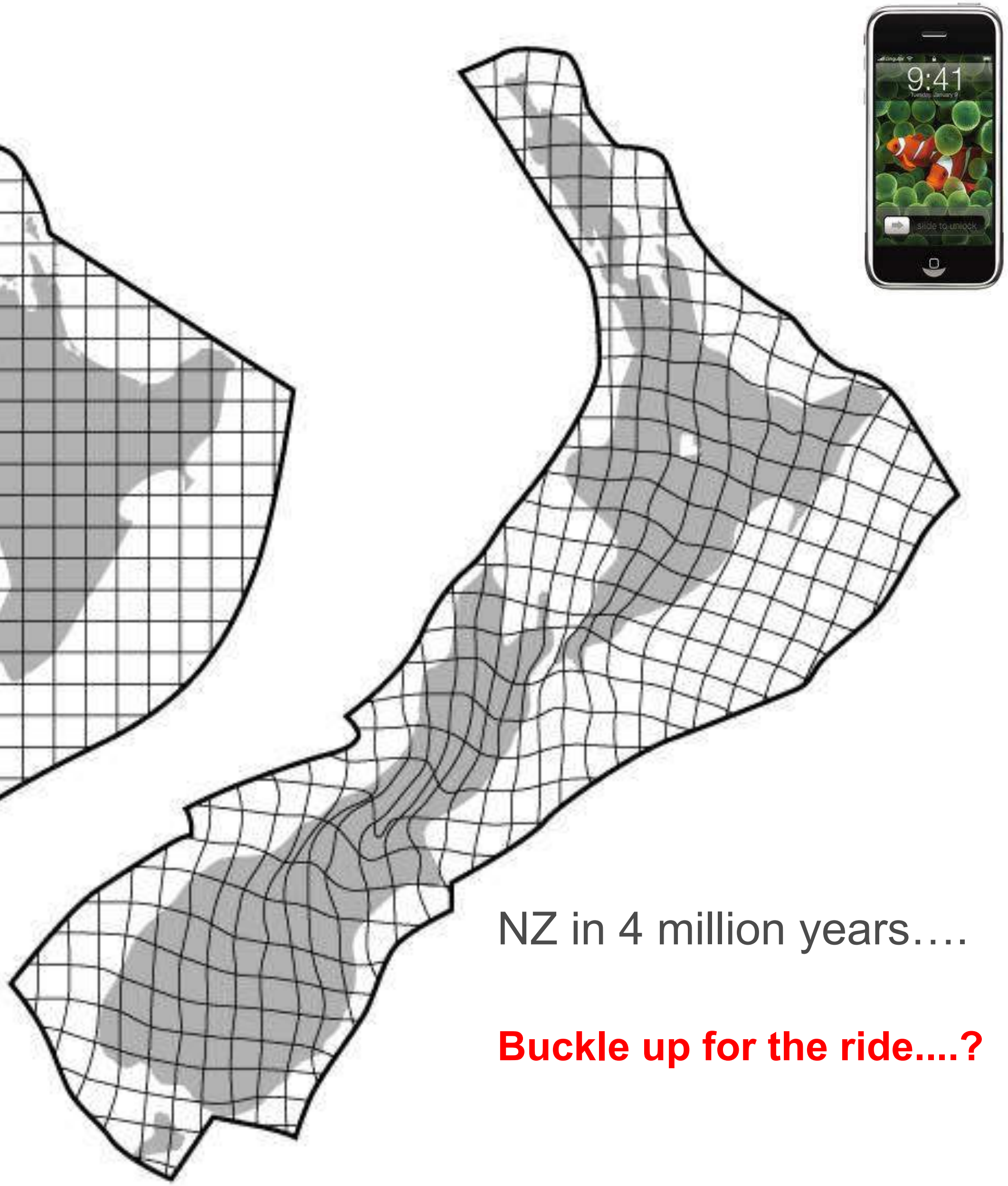
with material from Richard Norris, Russ van Dissen & Mark Stirling

A cricket pitch of displacement every 500 years





NZ in 4 million years….

Buckle up for the ride....?

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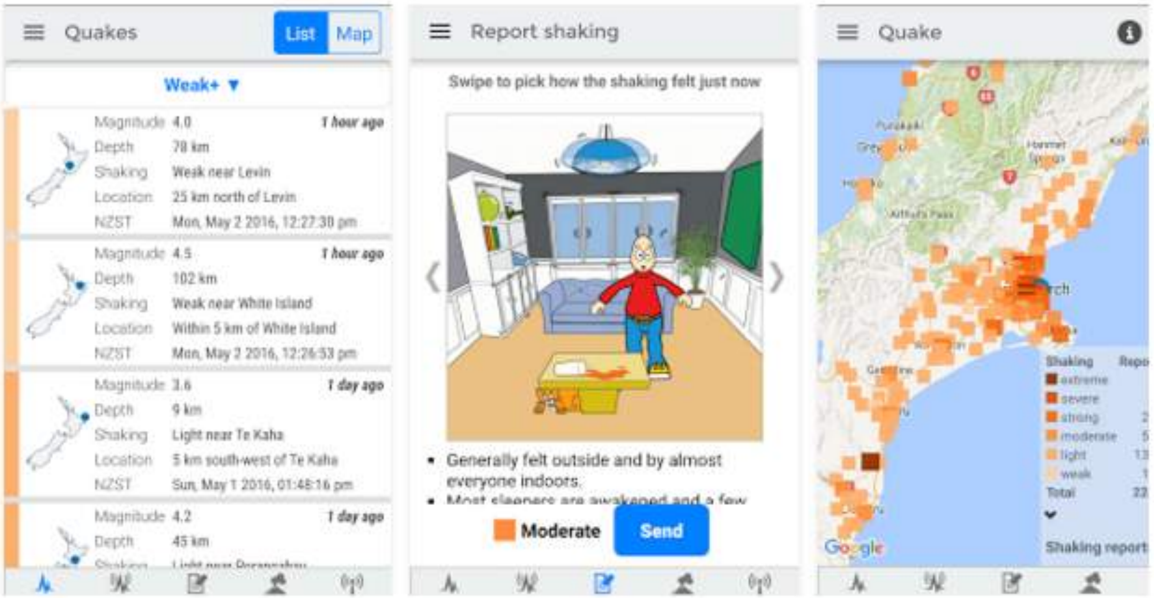

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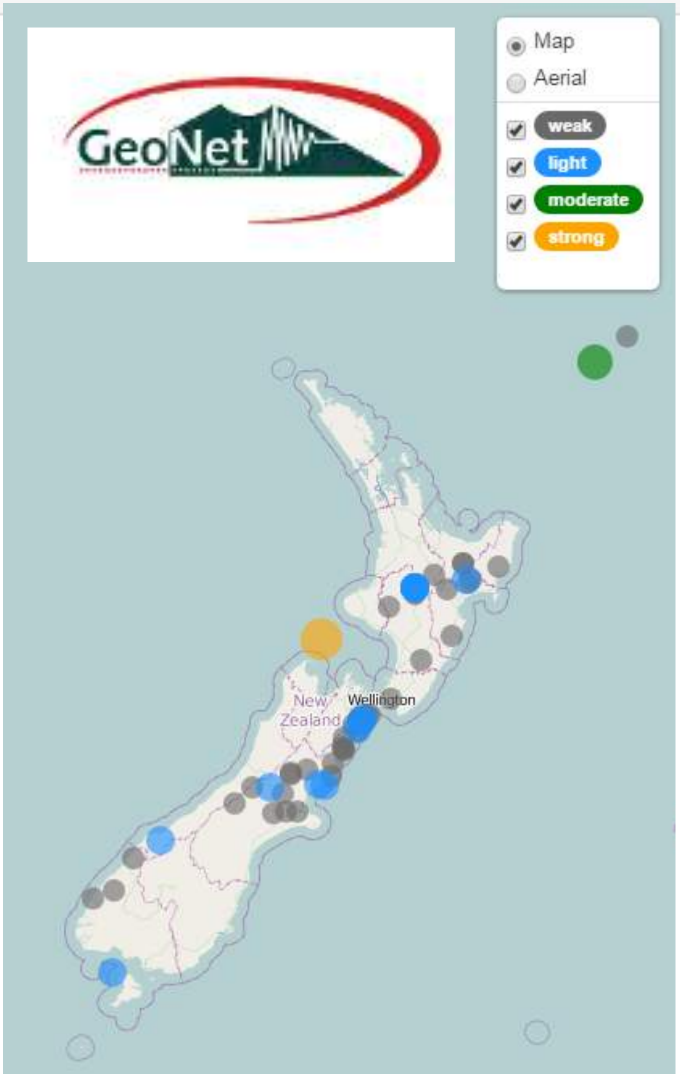
Quake Statistics

Sparkline showing daily earthquake numbers over the past year in the New Zealand region.

Quakes per day (last year)

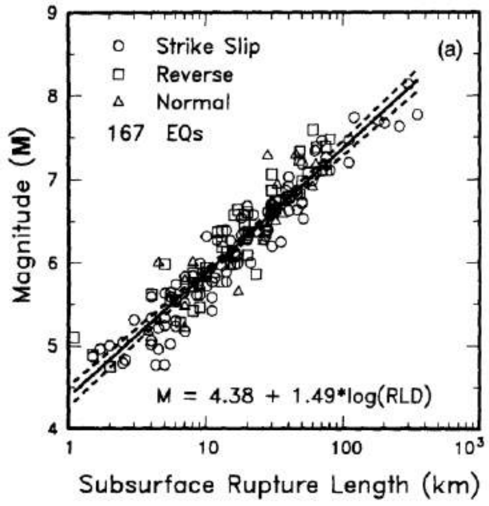
Table summarising earthquake numbers over the past week, month and year.

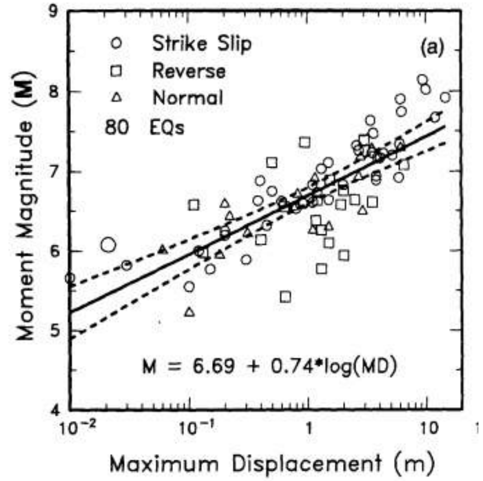
Magnitude	Last week	Last month	Last year
< 2	758	1442	13995
2 - 3	335	1068	19385
3 - 4	34	104	4578
4 - 5	10	37	1069
5 - 6	1	2	133
>= 6	0	0	8
Total	1138	2653	39168



Fault Length & Displacement

EQ (approx.)	Length	Disp.
M4	1 km	10 mm
M5	3 km	1-3 cm
M6	10 km	10 cm
M7	50 km	1-3 m
M8	300 km	10 m





Empirical fault scaling
Wells & Coppersmith (1994)
BSSA 84(4): 874-1002

Earthquake Size

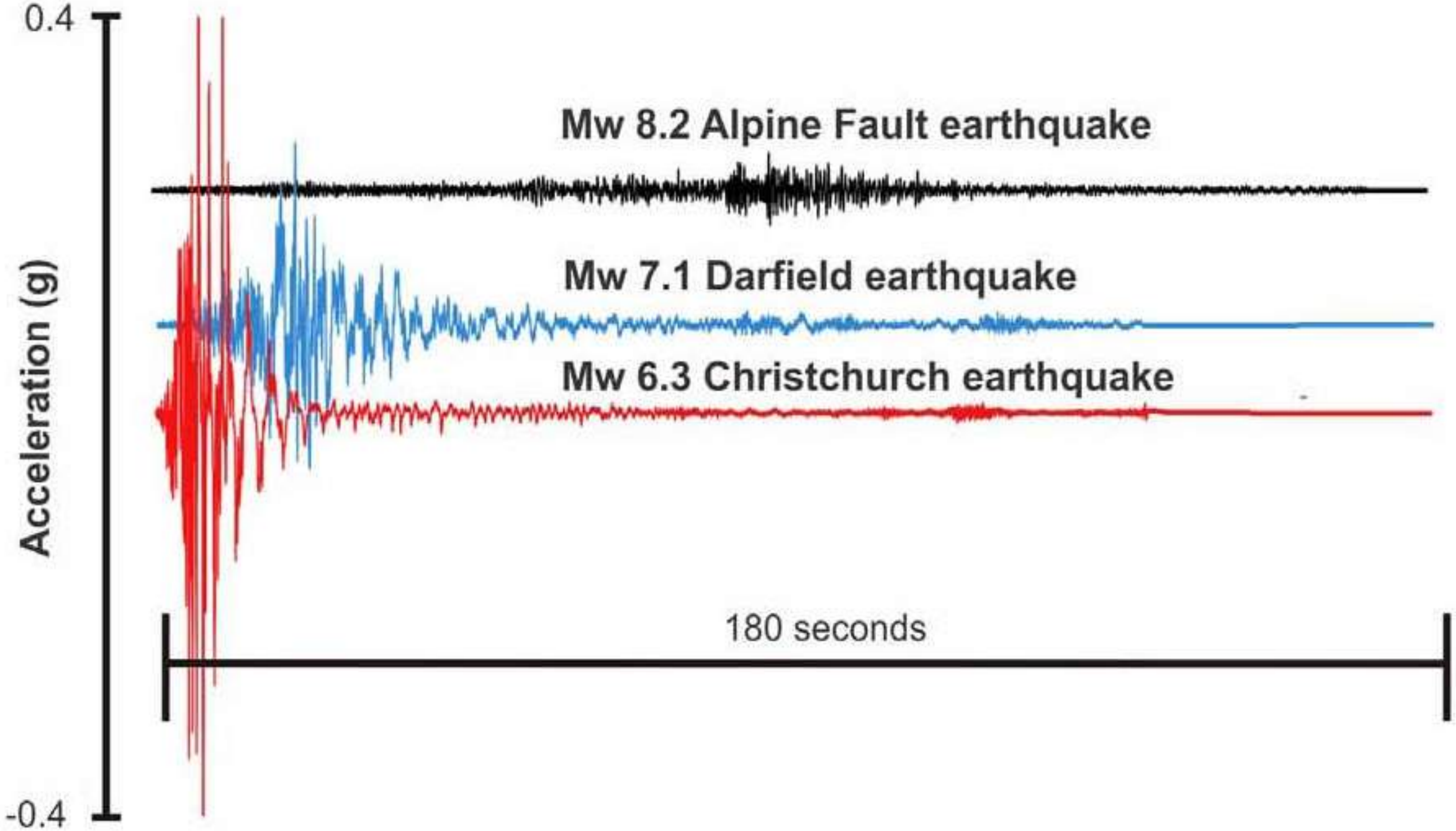
- **MAGNITUDE:** M a measure of energy released
- **Richter Scale:** 0 → ?9+
- Logarithmic: Each step c. 30x more energy

- M7 event (Fiordland, 2003) released c. 1000 more energy than M4.9 event (Dunedin, 1974);
- Japan earthquake of 2011(M9) released about 20,000 times more energy than the Feb 2011 Christchurch earthquake (M6.3).

Christchurch shaking influenced by:

EQ Size/Moment
Proximity
Energy release
Directivity

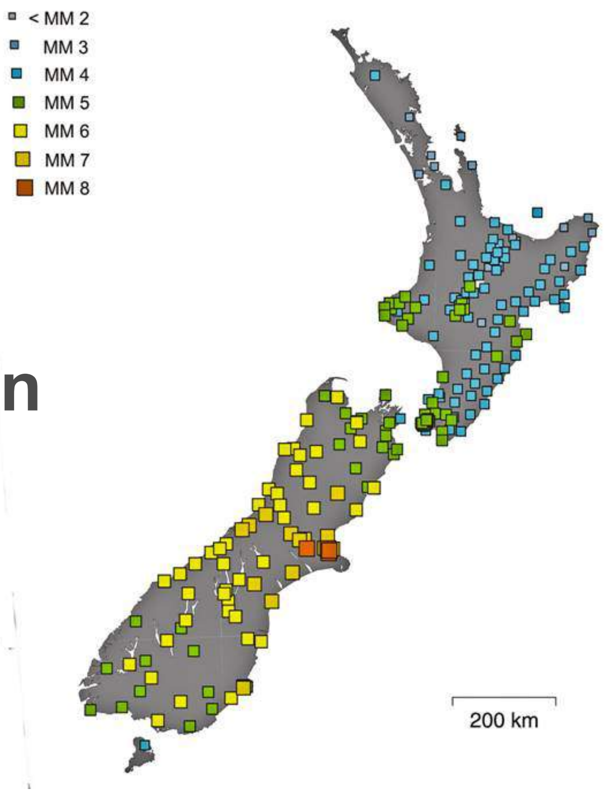
?Blind fault
?Soil strength
?Basin shape



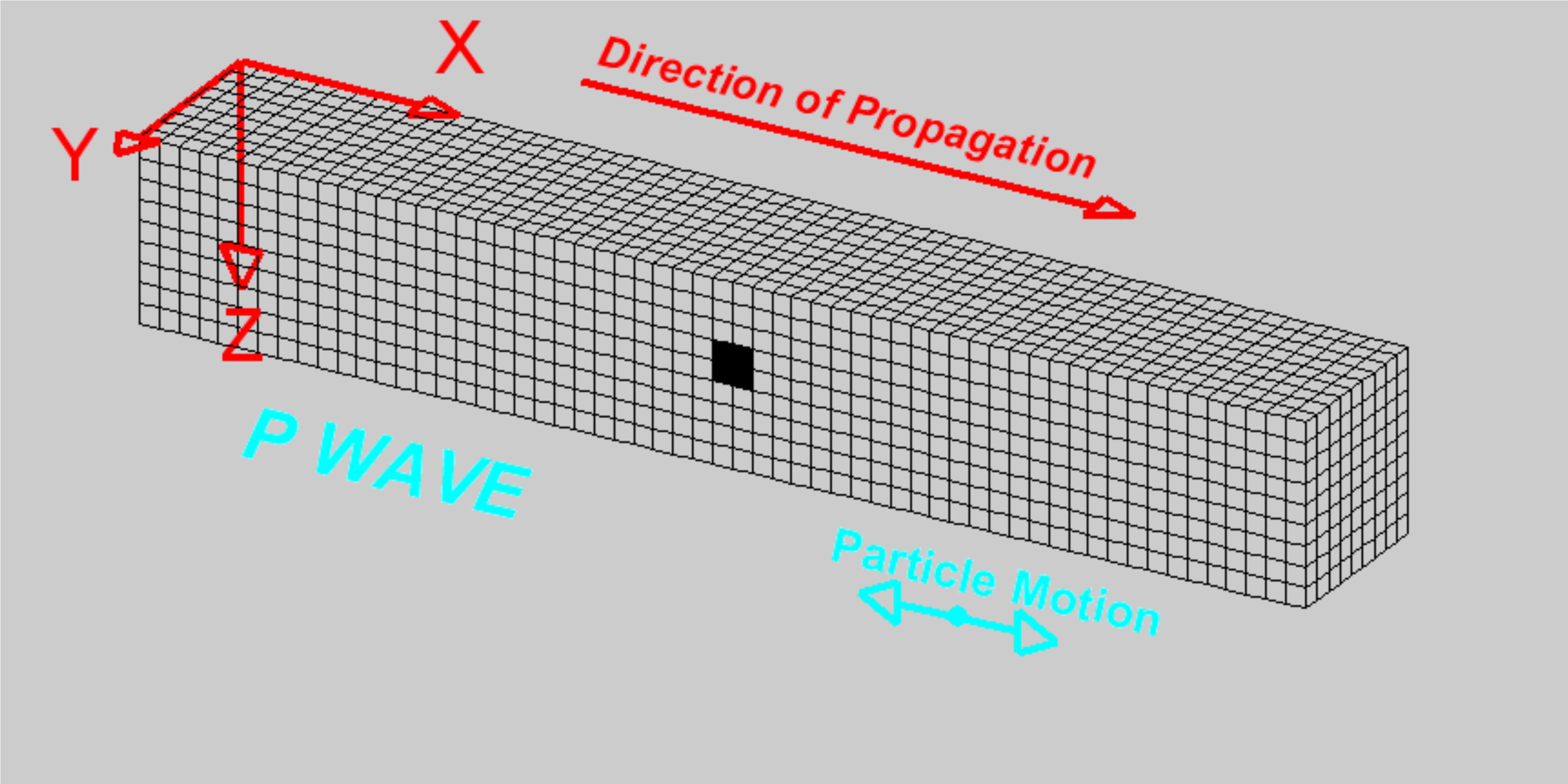
Three minutes of synthetic acceleration time histories for the larger of the two horizontal components, in terms of PGA, for a potential Alpine Fault event (black) compared with the accelerations from the Mw 7.1 Darfield earthquake (blue) and the 22 February Mw 6.3 Christchurch earthquake (red) as recorded at the Christchurch Botanical Gardens GeoNet station (CBGS). (Source: Canterbury Earthquakes Royal Commission/GNS Science).

Earthquake Shaking

- **INTENSITY:** degree of shaking based on human observation, damage etc.
- Intensity varies as $1/d^2$ where d = distance from epicentre
- **Modified Mercalli (MM) scale** - I→X, from not felt at all to total destruction
- Intensity also depends on
  (i) type of faulting
  (ii) ground conditions

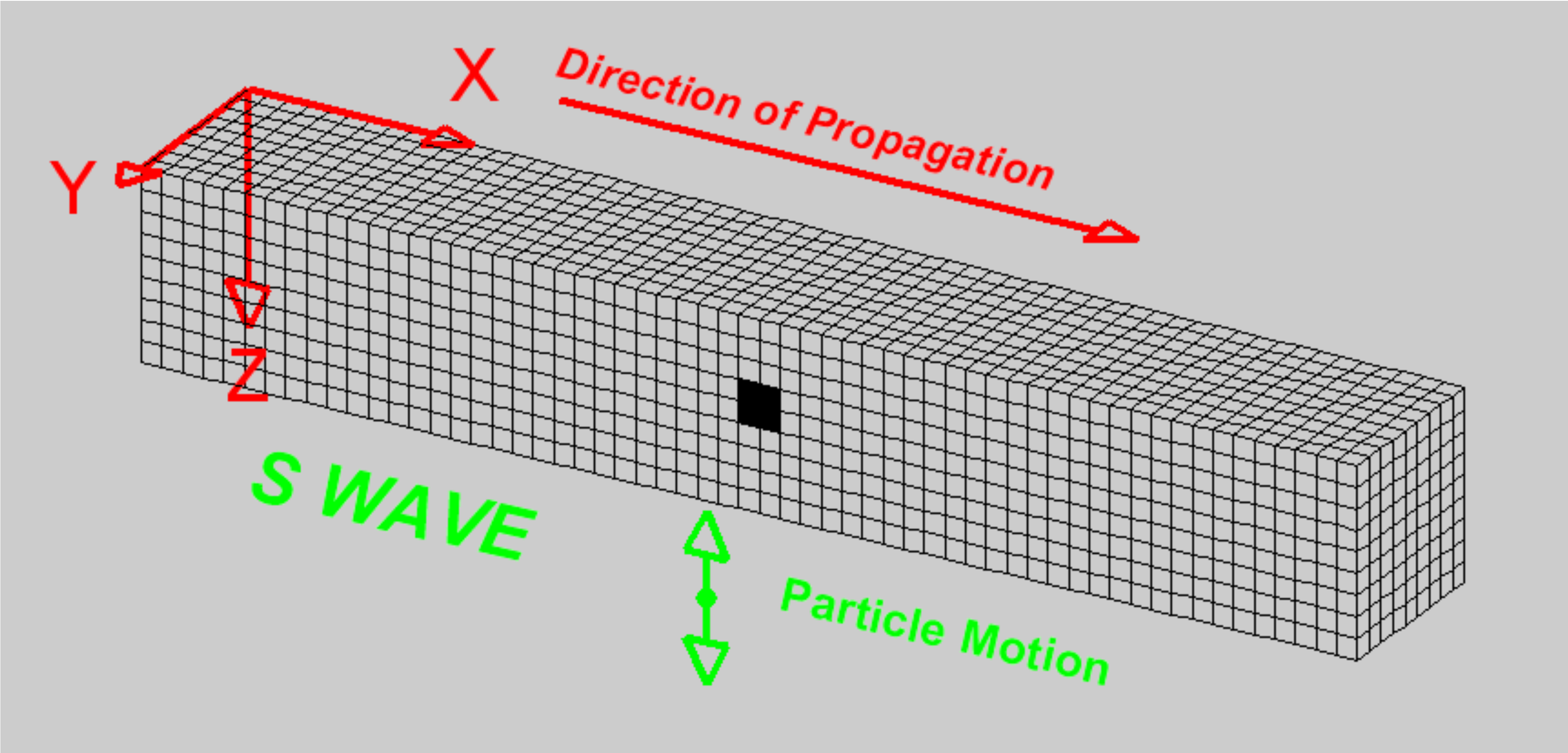


Compressional Wave (P-Wave) Animation



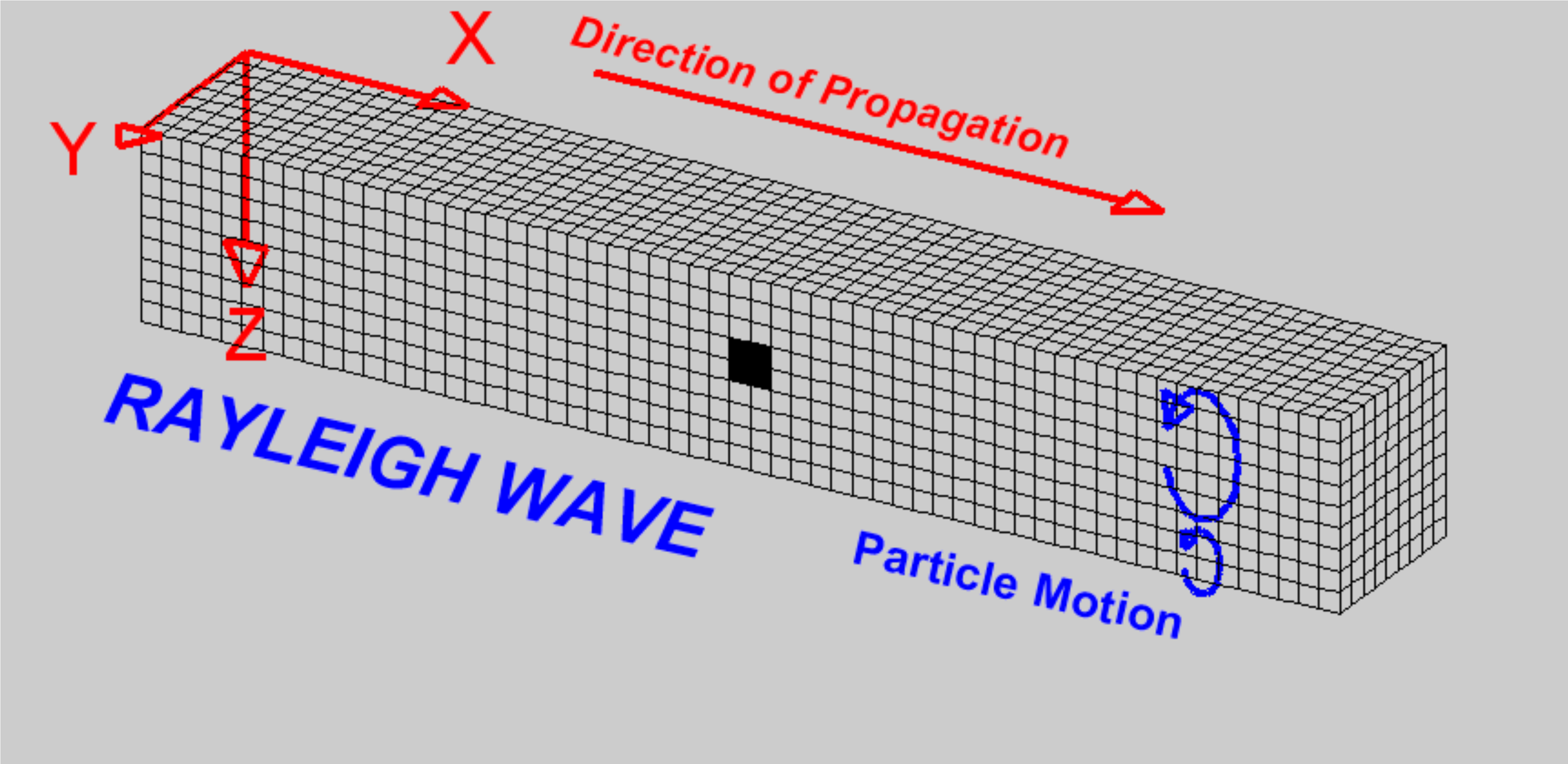
Deformation propagates. Particle motion consists of alternating compression and dilation. Particle motion is parallel to the direction of propagation (longitudinal). Material returns to its original shape after wave passes.

Shear Wave (S-Wave) Animation



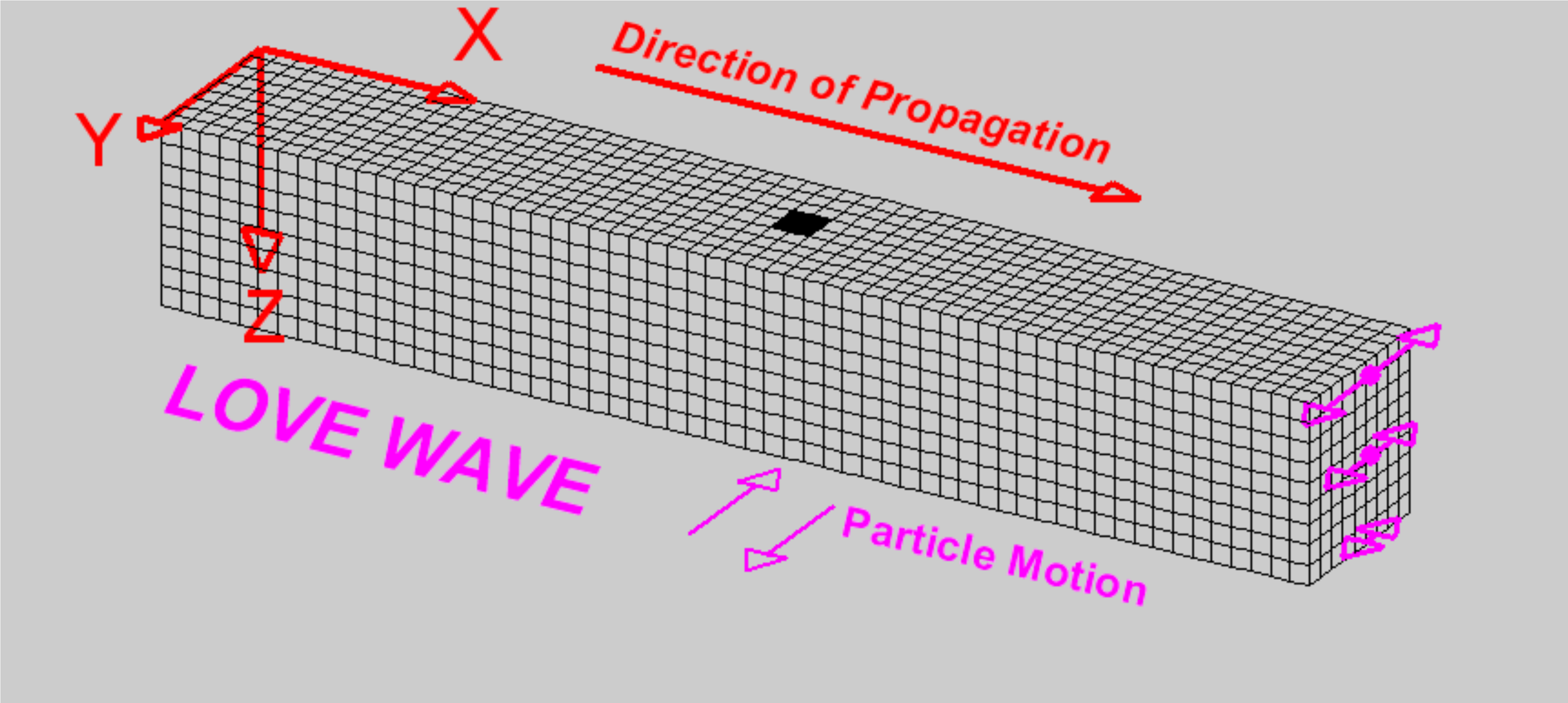
Deformation propagates. Particle motion consists of alternating transverse motion. Particle motion is perpendicular to the direction of propagation (transverse). Transverse particle motion shown here is vertical but can be in any direction. However, Earth's layers tend to cause mostly vertical (SV; in the vertical plane) or horizontal (SH) shear motions. Material returns to its original shape after wave passes.

Rayleigh Wave (R-Wave) Animation



Deformation propagates. Particle motion consists of elliptical motions (generally retrograde elliptical) in the vertical plane and parallel to the direction of propagation. Amplitude decreases with depth. Material returns to its original shape after wave passes.

Love Wave (L-Wave) Animation



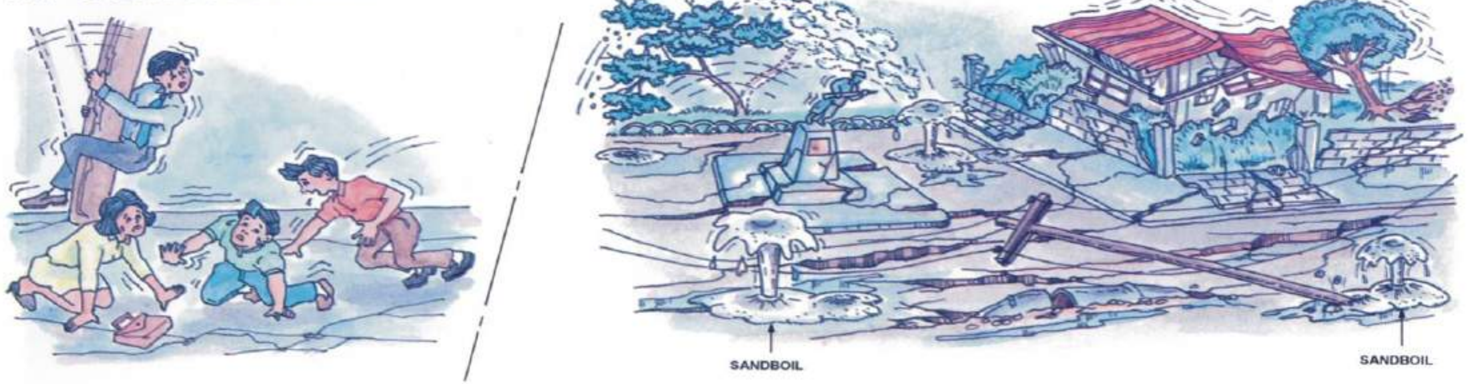
Deformation propagates. Particle motion consists of alternating transverse motions. Particle motion is horizontal and perpendicular to the direction of propagation (transverse). To aid in seeing that the particle motion is purely horizontal, focus on the Y axis (red line) as the wave propagates through it. Amplitude decreases with depth. Material returns to its original shape after wave passes.

MM Intensity Scale

V	Most sleepers wake
VI	Minimal property damage, Furniture moved
VII	Some property damage, Loss of life unlikely
VIII	Damage to weak buildings, Loss of life possible
IX	Extensive damage, Some loss of life

VI. VERY STRONG

IX. DEVASTATING



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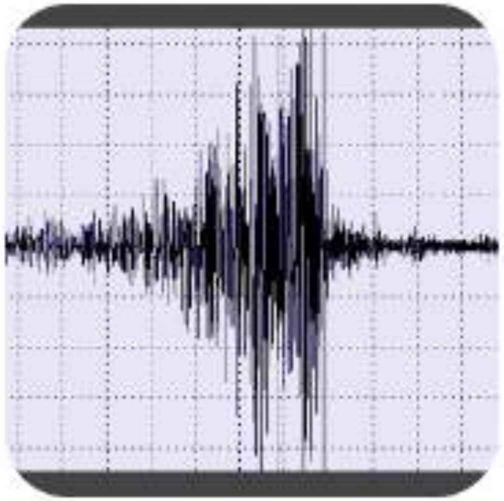

Seismometer

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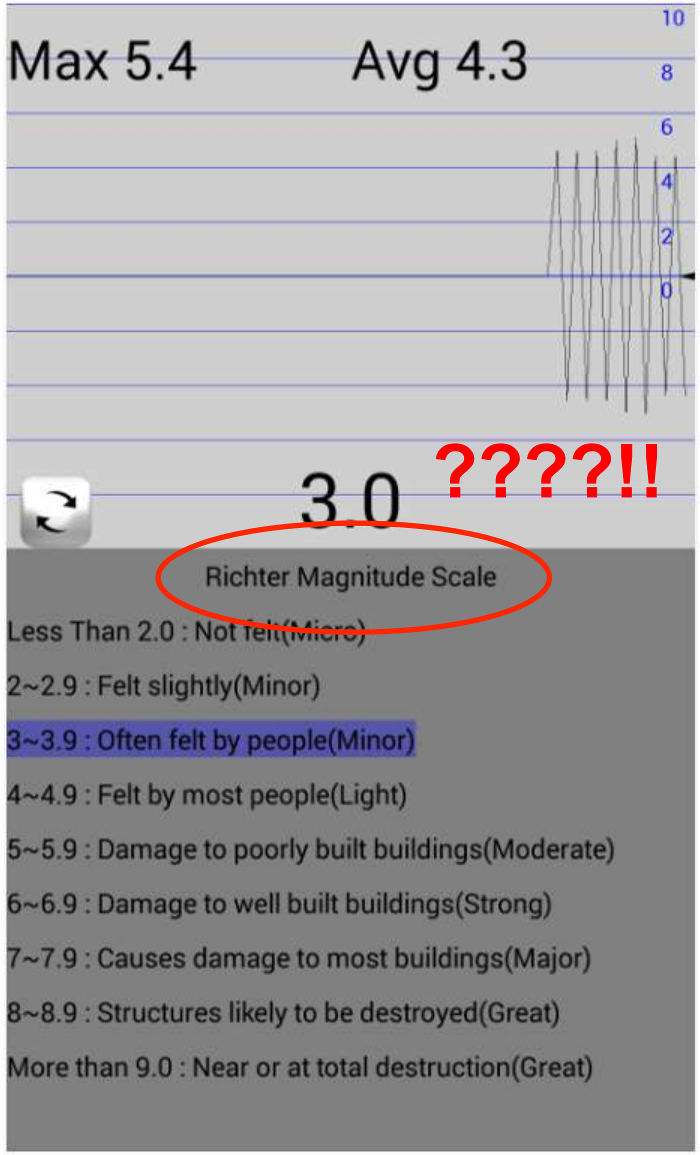
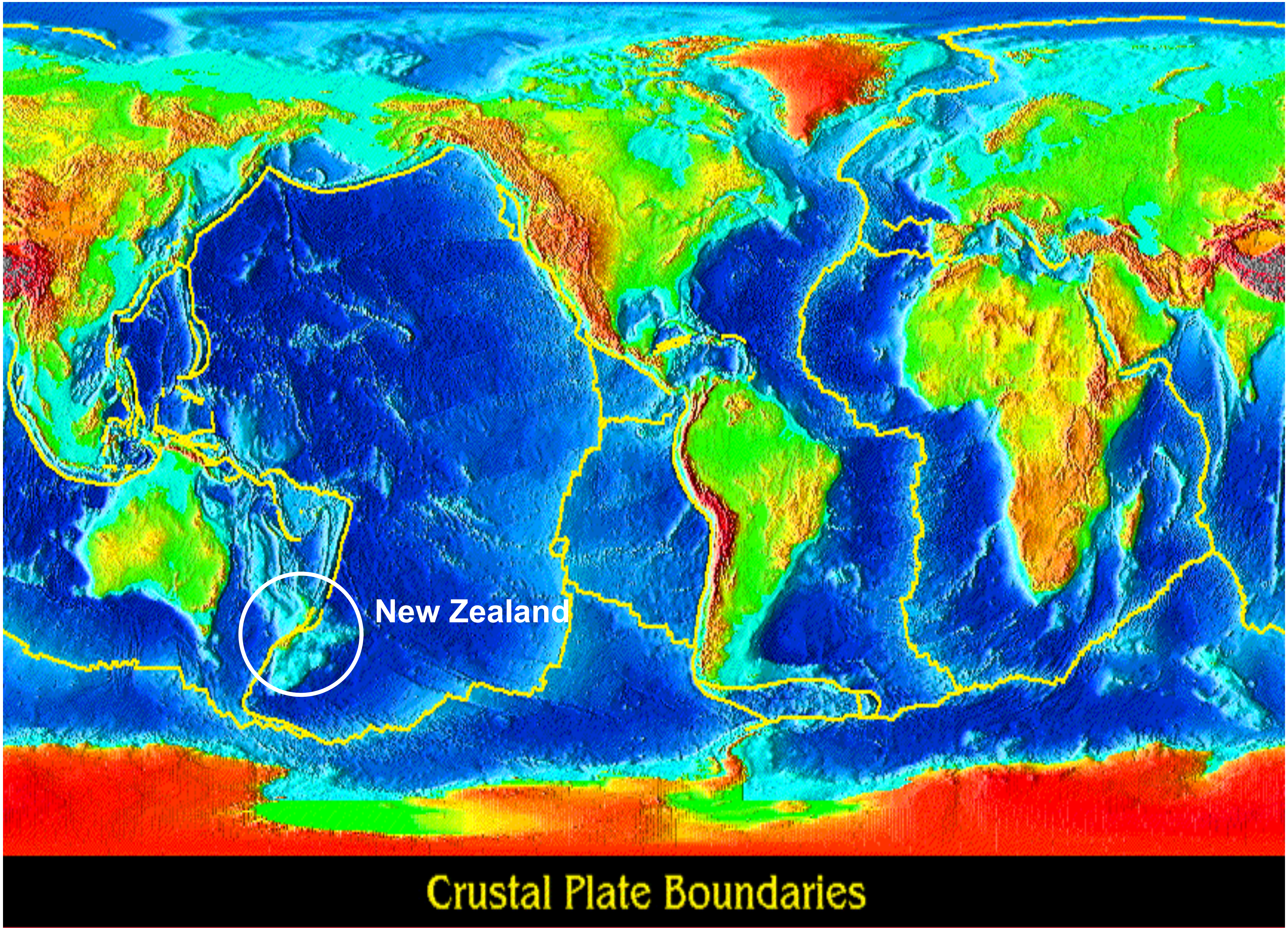
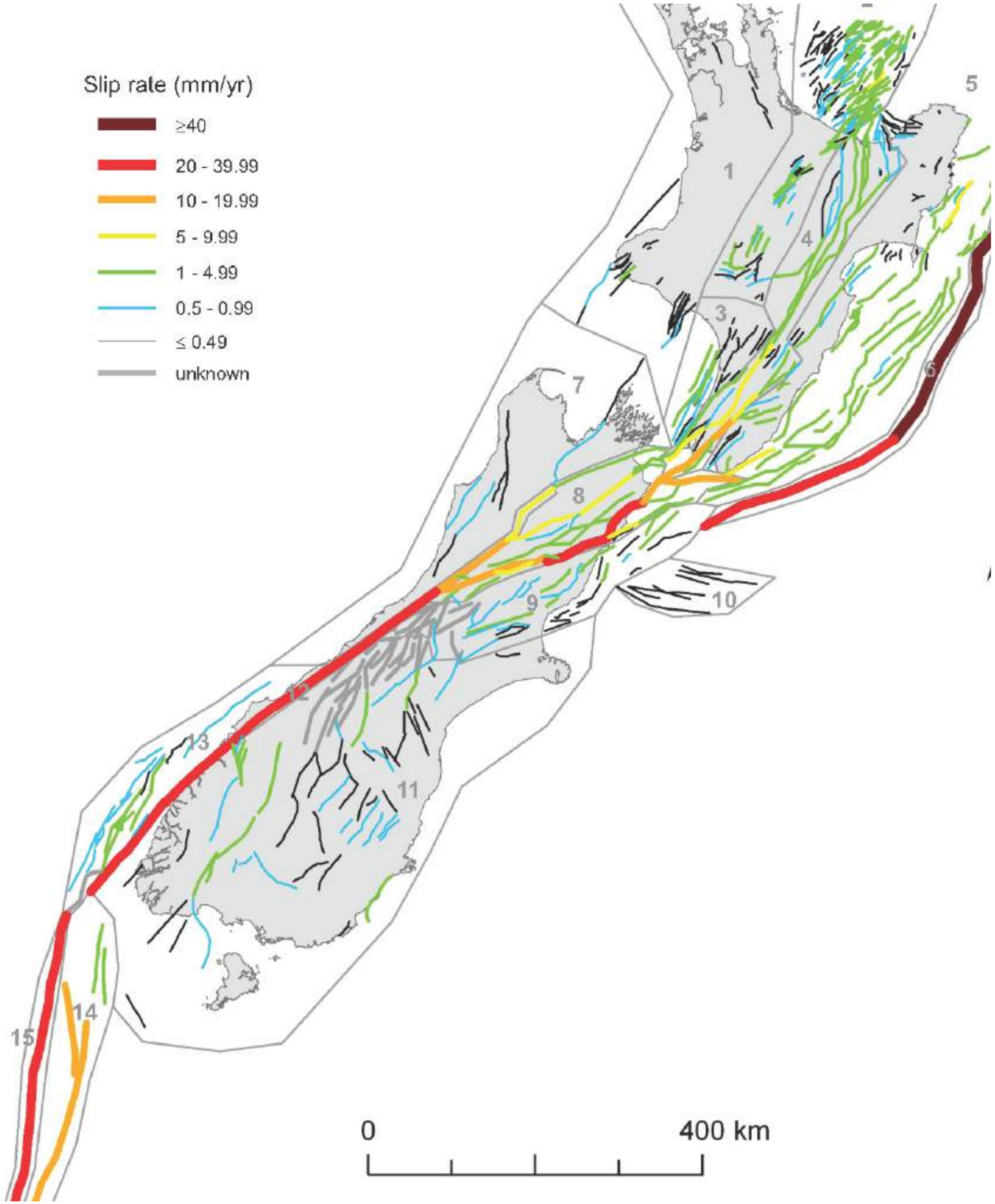




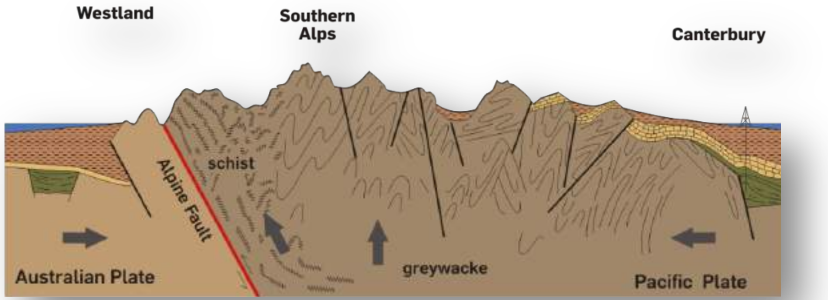
GNS Science

Active Faults



Alpine Fault
- 27 mm/yr
- 260-400 year RI

Nevis-Cardrona
- 0.4 mm/yr
- 5000–10,000 year RI



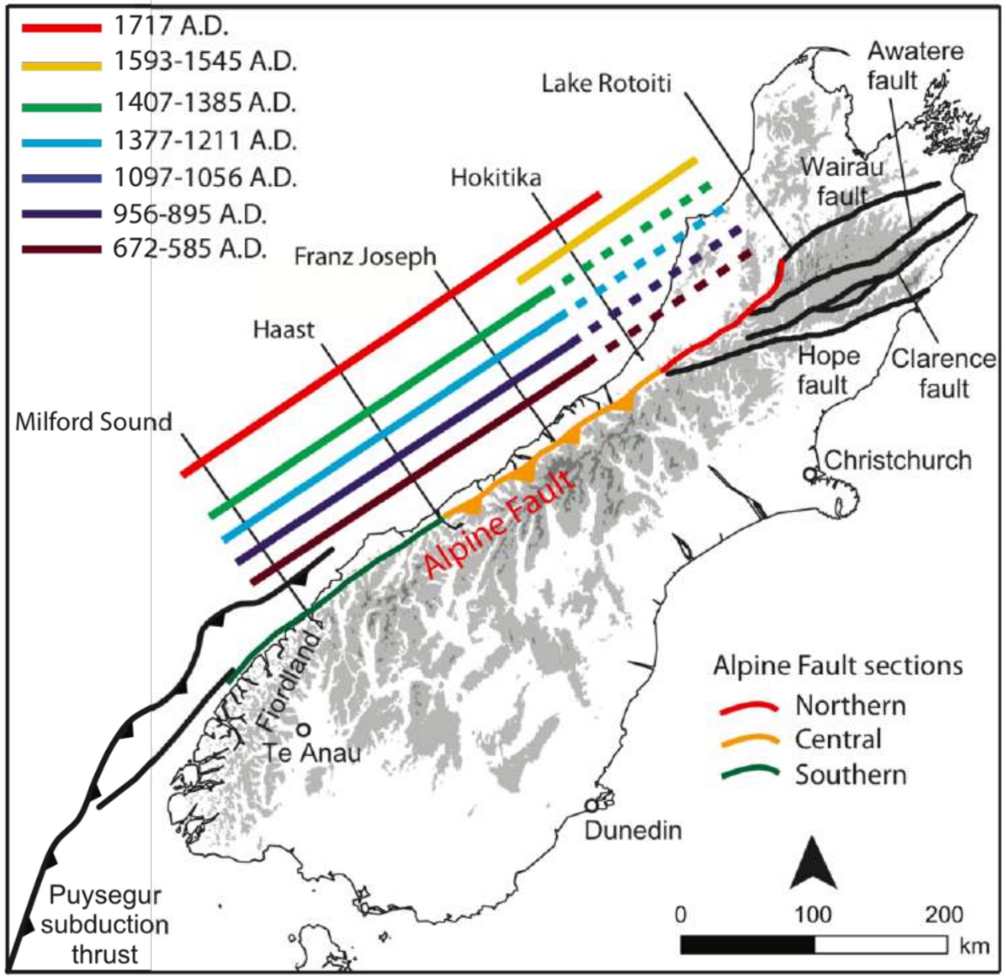
One of the longest, straightest, fastest moving plate boundary transform faults in the world.

- Accommodates 75% of plate motion
- Rapid slip rate of 20-30 mm/year

The Alpine Fault

Earthquakes on the Alpine Fault

- **Last ruptured in 1717 A.D.**
- **27 events since ~6000 BC**
- **Return Interval ~260-400 years (average 291 ± 23 years)**
- **No major event in past 300 years**
- **Likelihood ~29% in next 50 years**
- **~380 km rupture = $M_w 8$**



2016 Kaikoura Earthquake: some vital statistics

14 Nov. 12:03 AM (local)

M_w 7.8

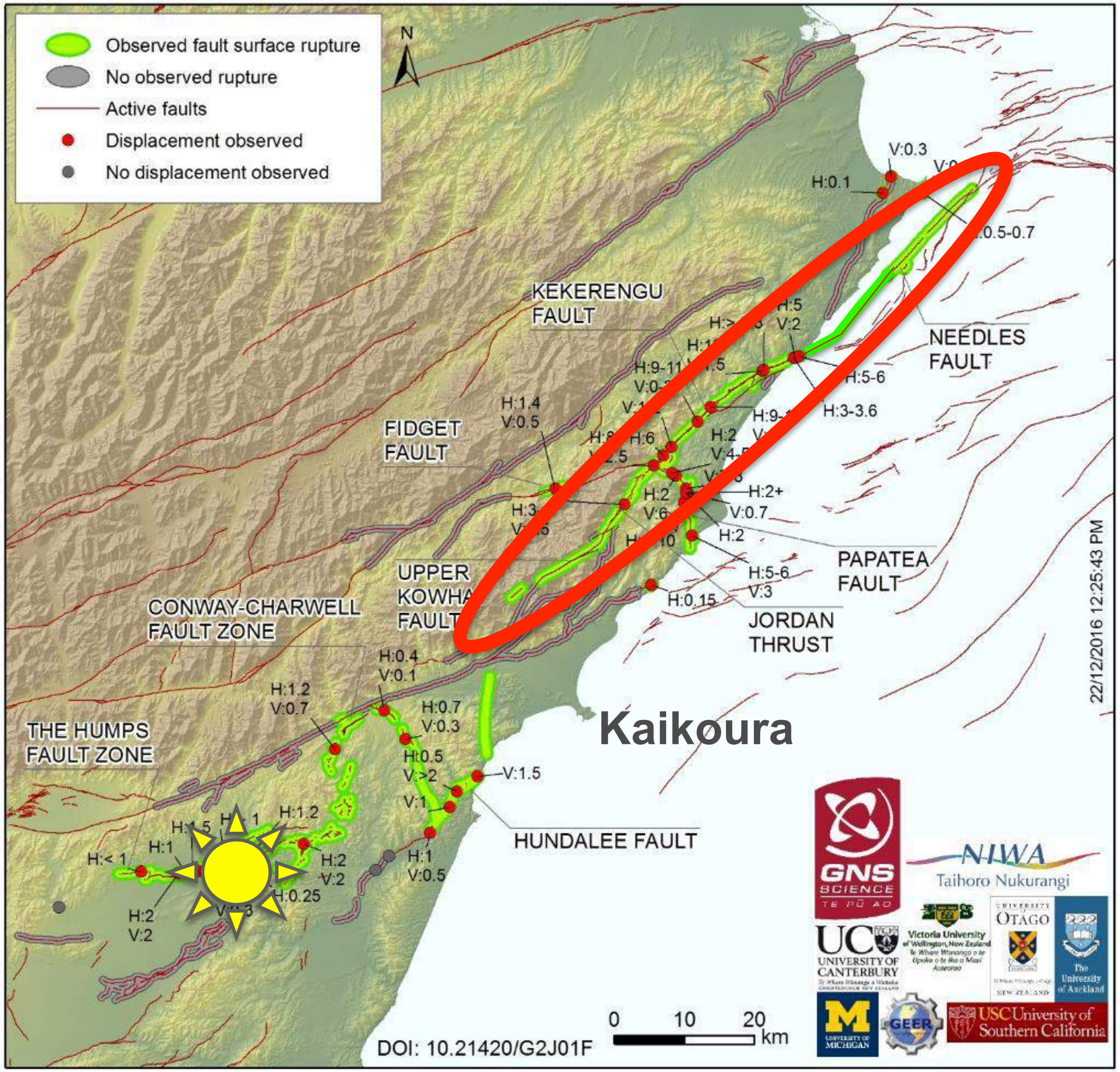
Lasted ~2 minutes

Mainshock:
- ~20 km south of the Hope Fault
- ~15 km deep

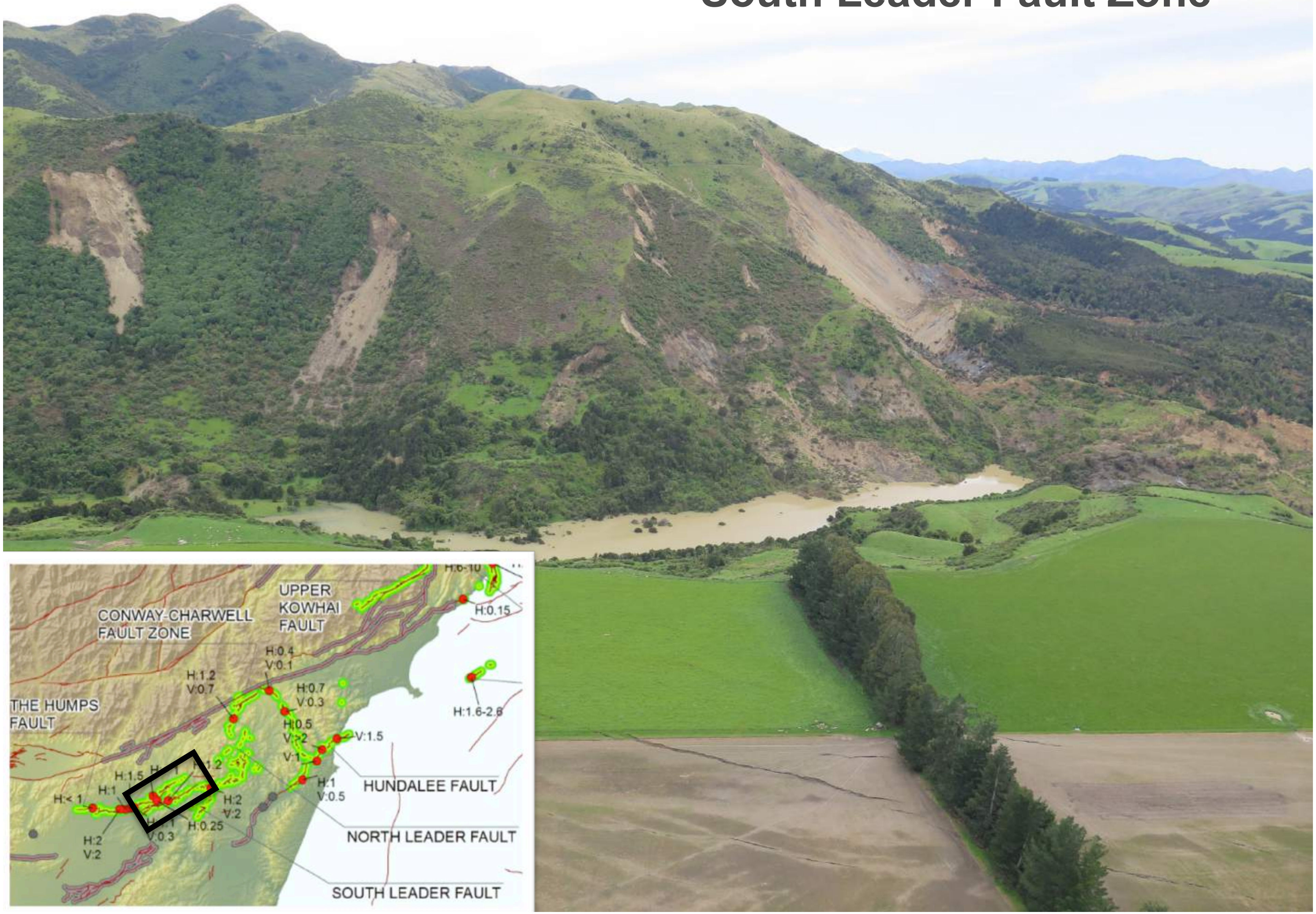
Rupture propagated NE as complex sequence with several distinct pulses of energy release

Arrested near Cape Campbell

Approx. 180 km-long zone of rupturing



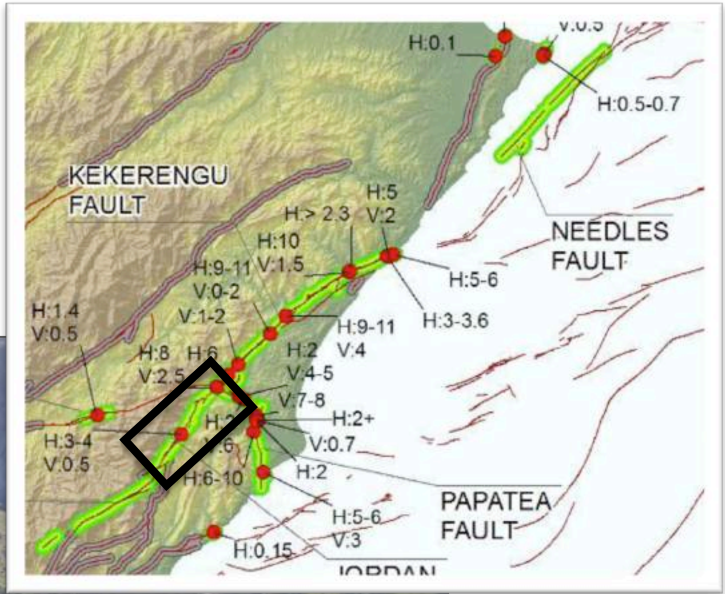
South Leader Fault Zone




South Leader
Fault Zone

Conway-Charwell Fault Zone

Jordan Thrust



Kekerengu Fault
Shag Bend

- Dextral displacements of up to 10 to 11 m,
- but progressive decrease to south

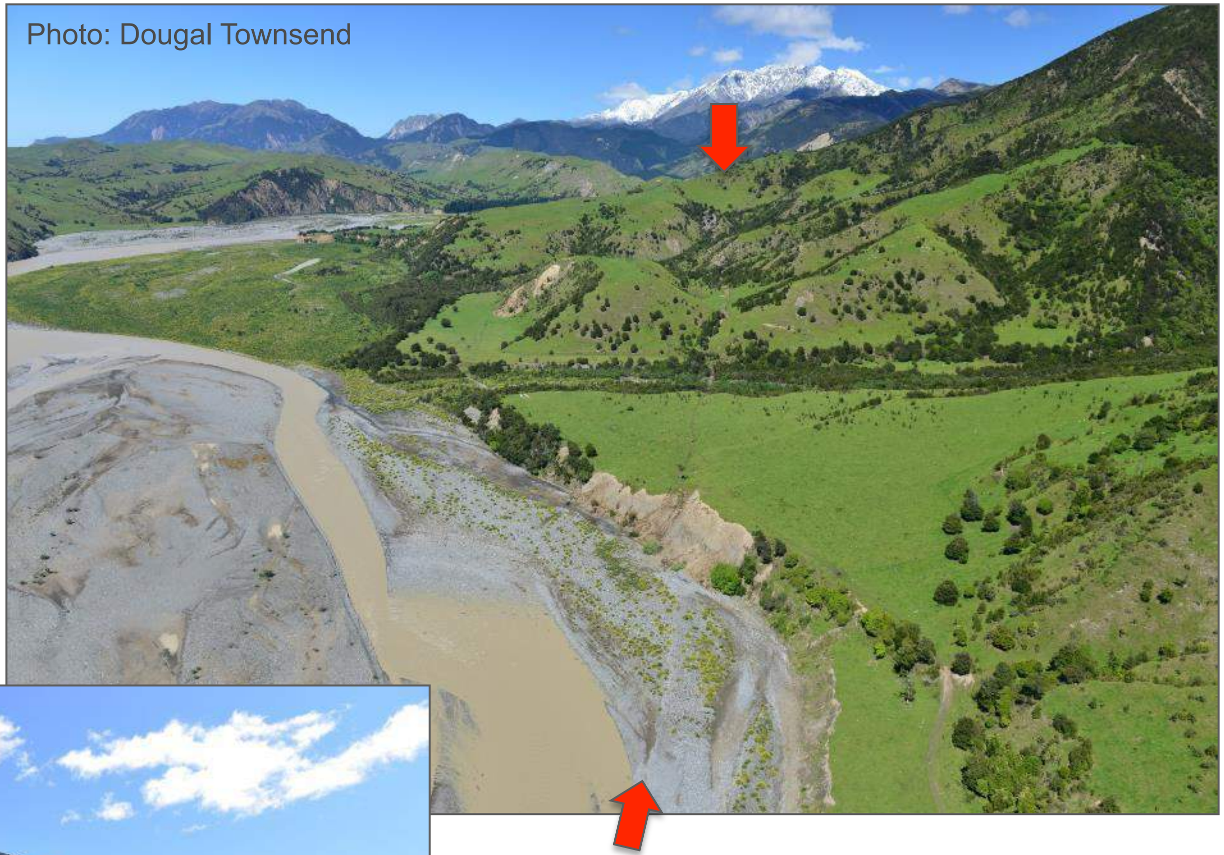


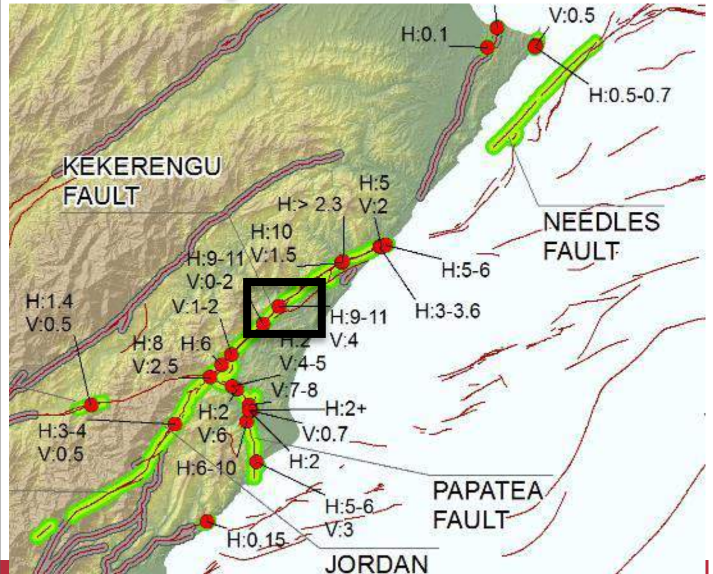
Photo: Dougal Townsend

Photo: Dougal Townsend


Photo: Will Ries

Kekerengu Fault
Clarence River

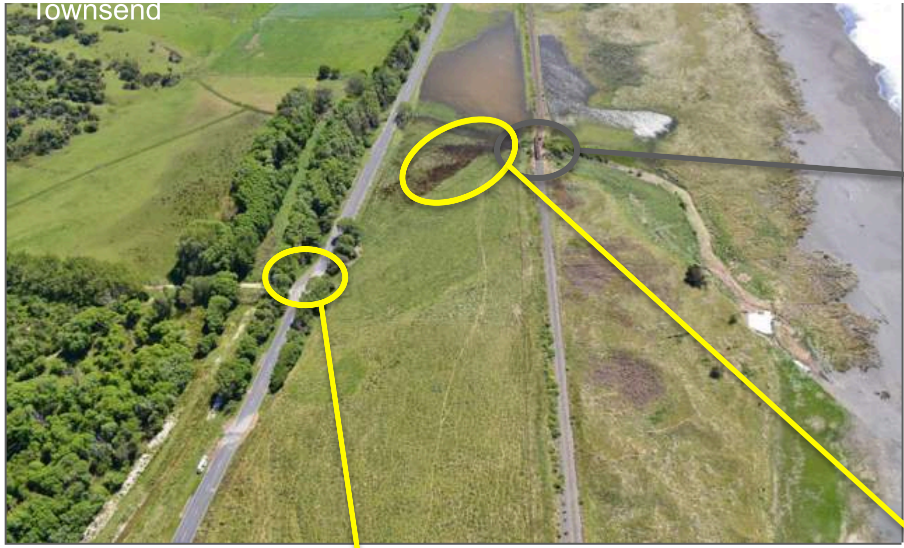
Photos: Will Ries



Bluff Station Cottage

Bluff Station Cottage

Kekerengu Fault

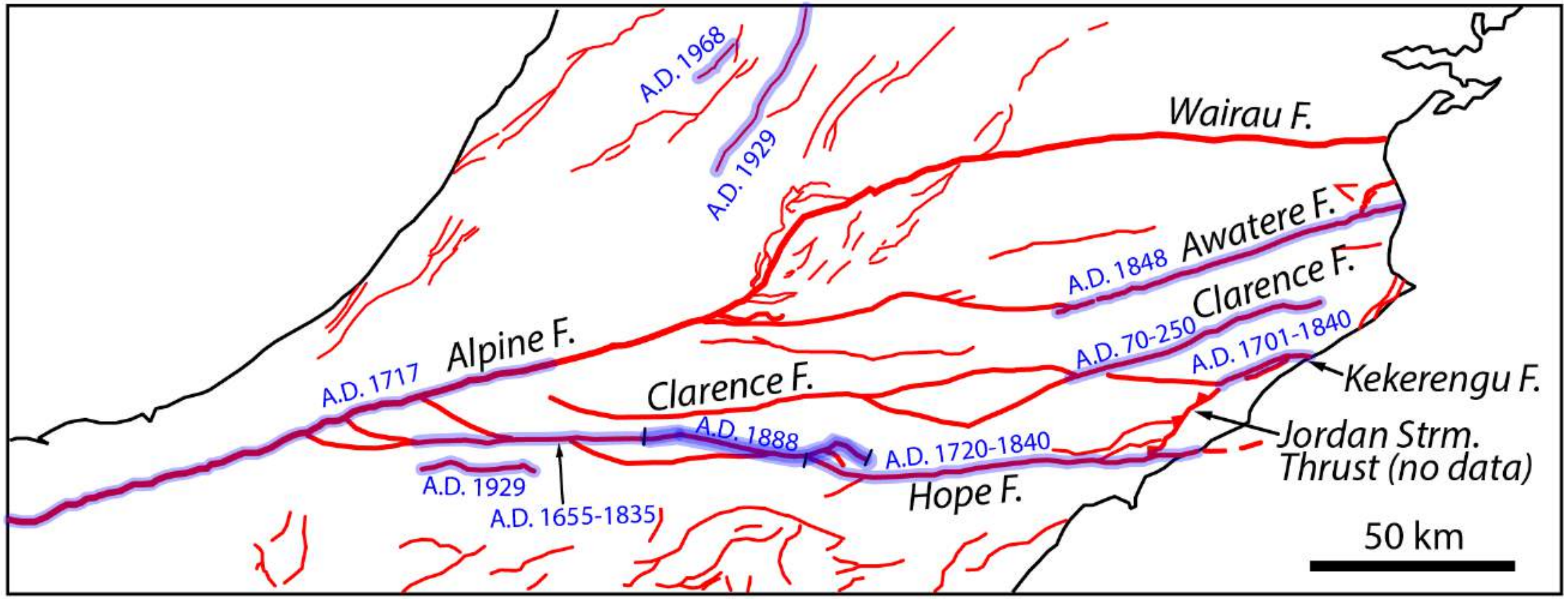

Townsend


Little

Photo: Tim Little


Photo: Tim Little

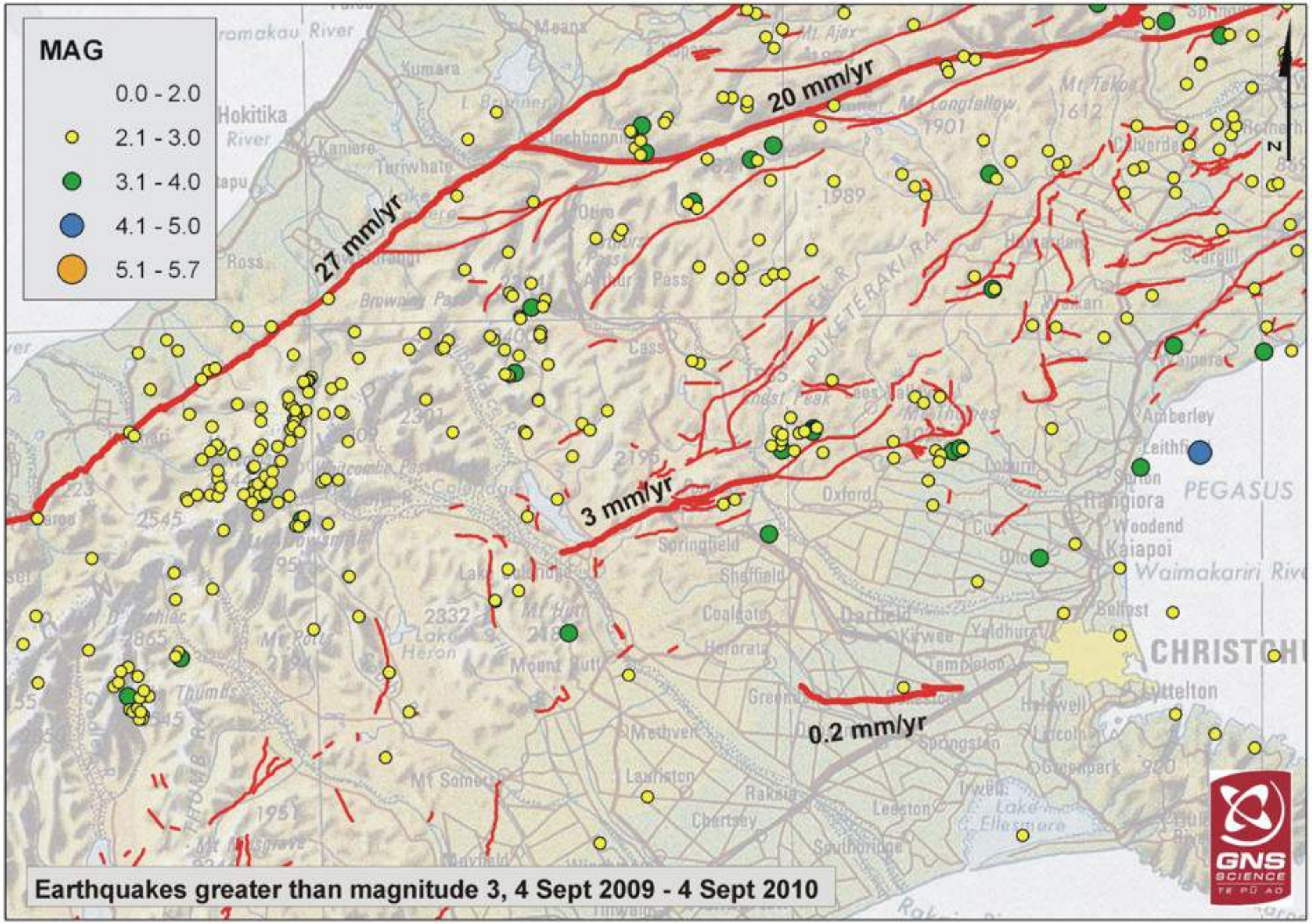
Youngest Known Surface Rupturing Events (prior to AD 2016)



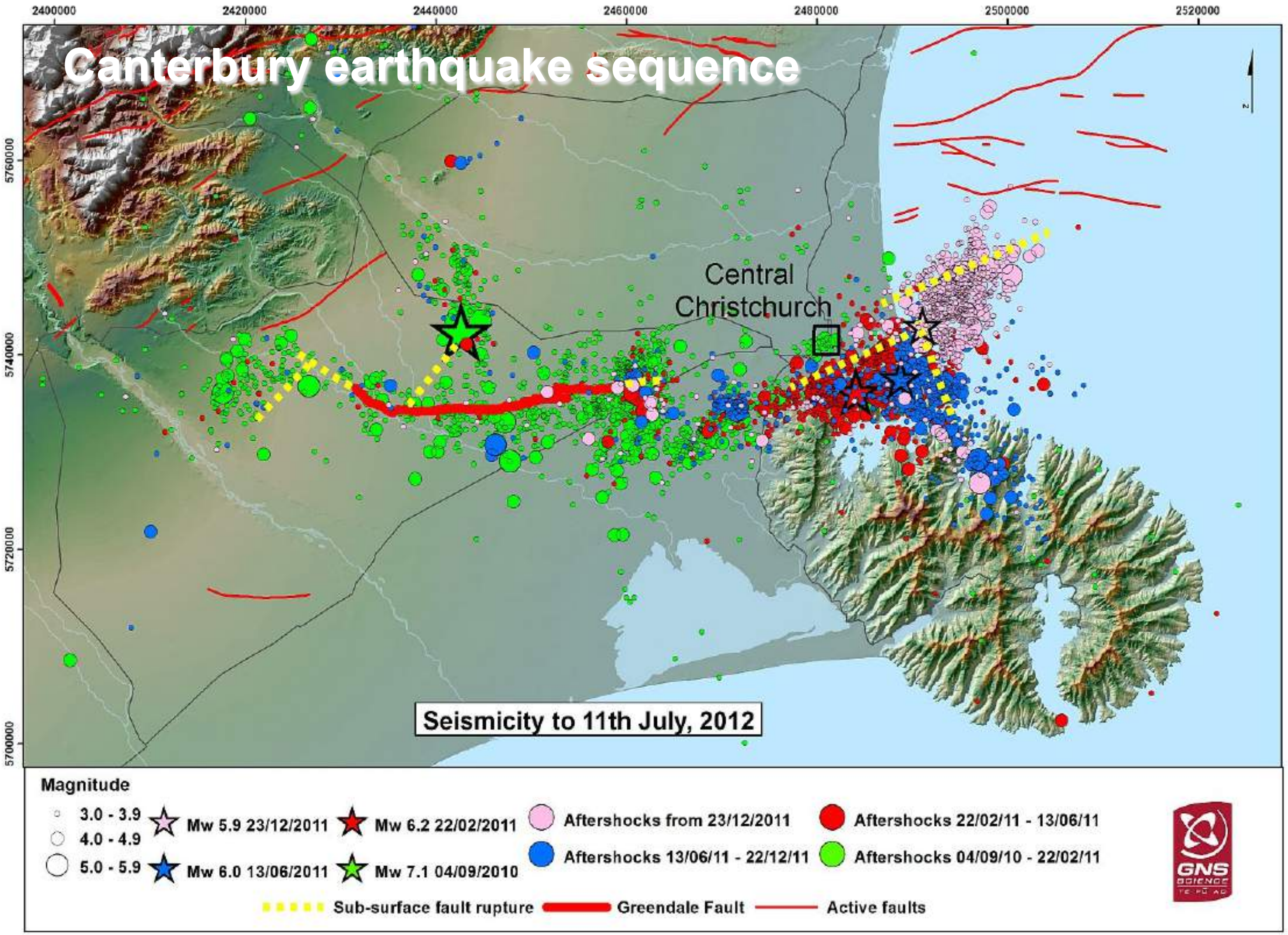
Modified from Langridge et al., 2013

- Alpine Fault to Hope Fault to coastal Kekerengu Fault all have low (~200-400 yr) recurrence intervals, and all 3 have all “cleared the deck” through central New Zealand once since AD 1717.
- In 2016, the Jordan-Kekerengu-Needles faults cleared it again, this time with the contribution of many other shorter faults that have longer mean recurrence intervals—AND without complicity of the Hope Fault.
- The 2016 style of composite MFS rupture is probably not “typical”

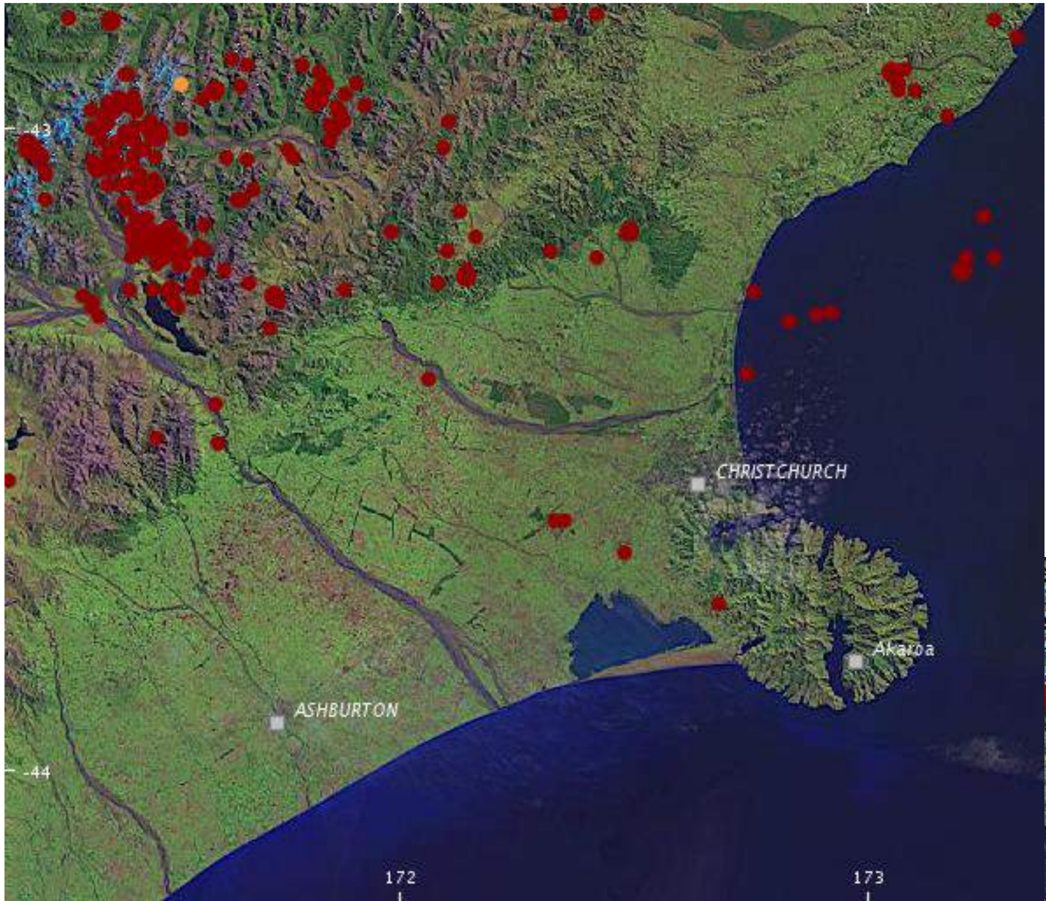
Regional Context – Actively Deforming Zone



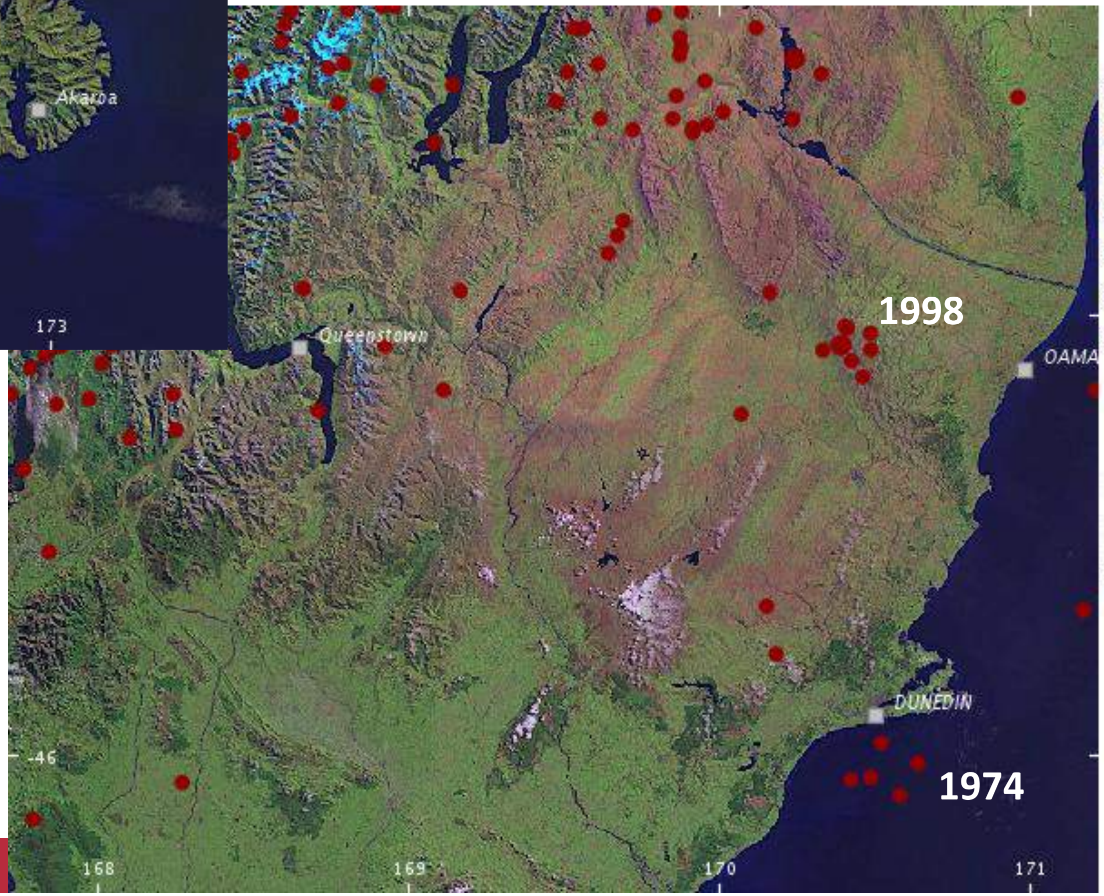
Could “a Christchurch” happen in Dunedin?



Earthquakes in N. Canterbury, 1959-2009



Earthquakes in Otago 1959-2009



(Geonet)

Nearby Active Faults

Recurrence intervals:
- Poorly constrained
- Irregular
- Long

Surface fault rupture
- Active - Accurate
- Active - Approximate
- Active - Concealed
- Active - Inferred
- Boundary

Akatore fault - active earthquake fault: skyline view south of Dunedin

Akatore Fault earthquakes

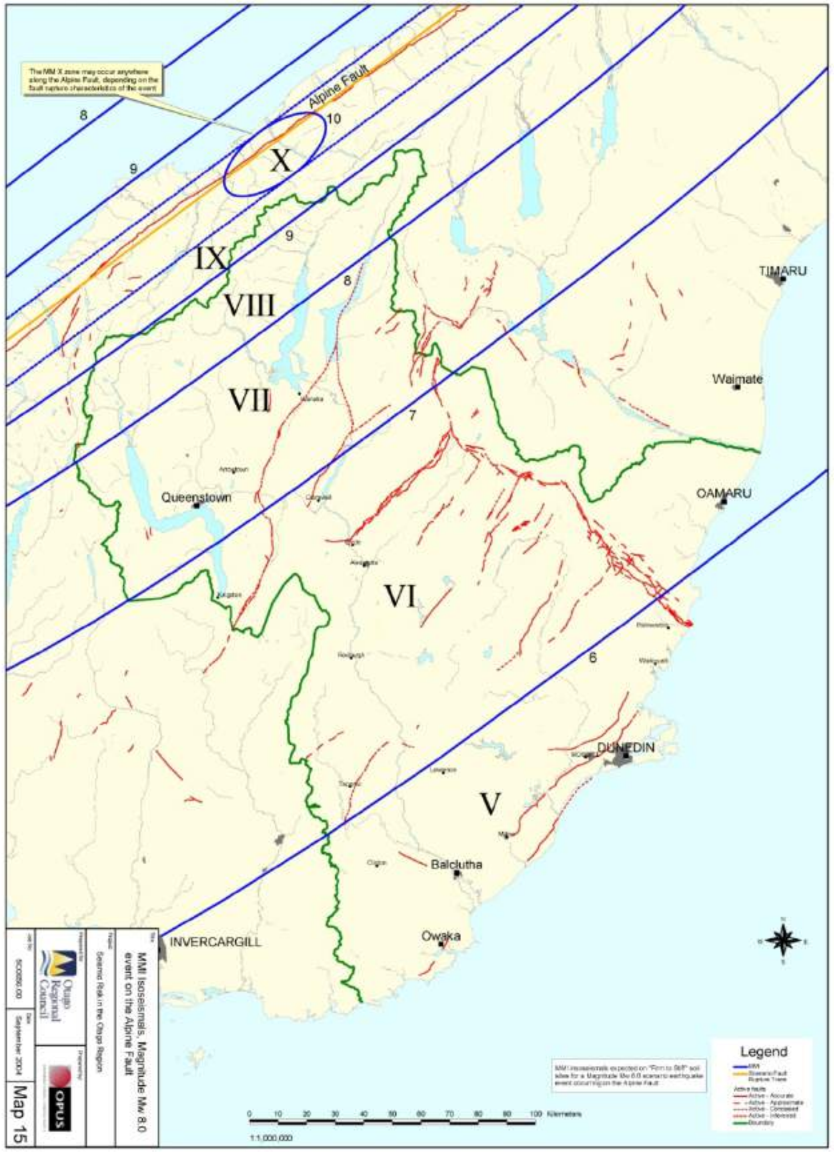
- 2 m offset along 40 km of fault producing ~M6.5 - 7.5 earthquake
- Three in last 10,000 years
- Two events within 1000 years
- (In)frequency of major events perhaps 1 in 2500 years

W.I.P. Prof Mark Stirling
University of Otago

- Maximum credible event for Dunedin ~MMIX

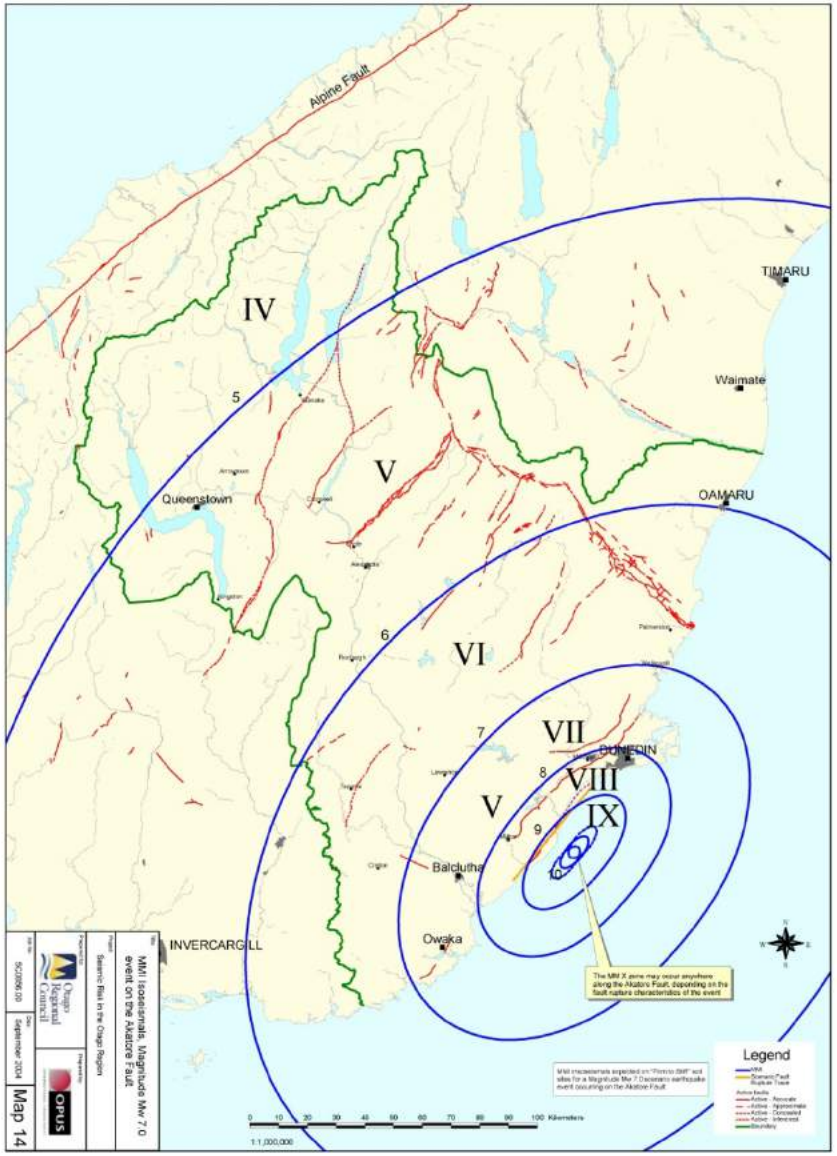
Alpine Fault Mw8

(Scenario: Opus 2005)



Akatore Fault Mw7

(Scenario: Opus 2005)



National Seismic Hazard Model (NSHM)

Predicts long-term rates of ground shaking.

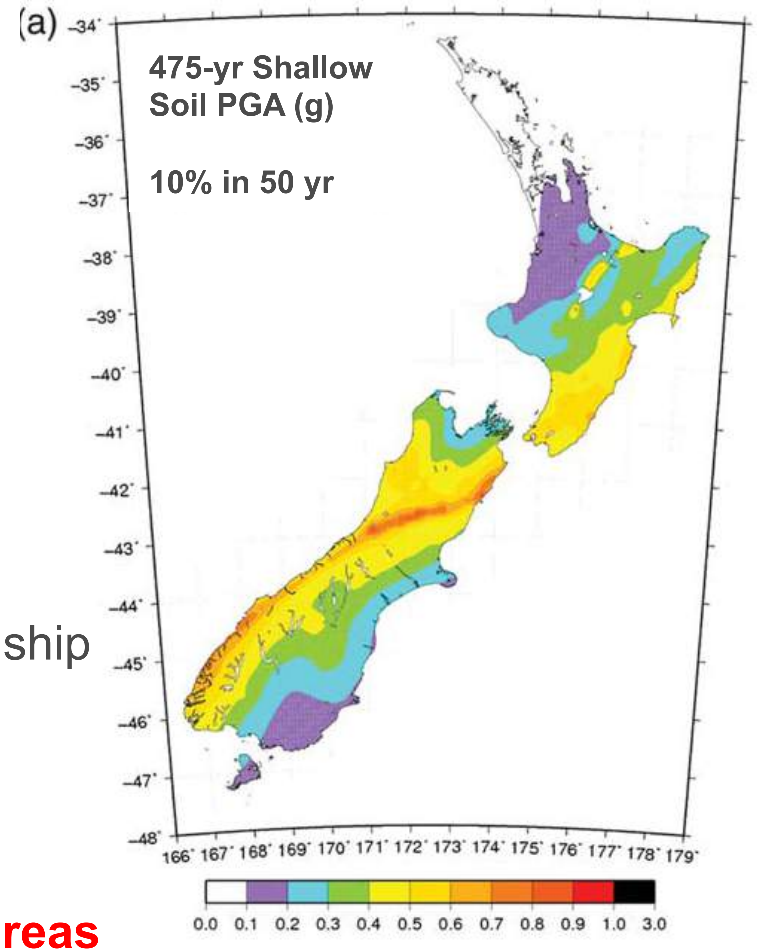
Identifies active fault sources (moved 125 ka), models earthquakes and return periods.

Adopts background seismicity model up to M7.2 supplement existing active fault information

Small faults (M~6 earthquakes) often have no surface expression and are difficult to find.

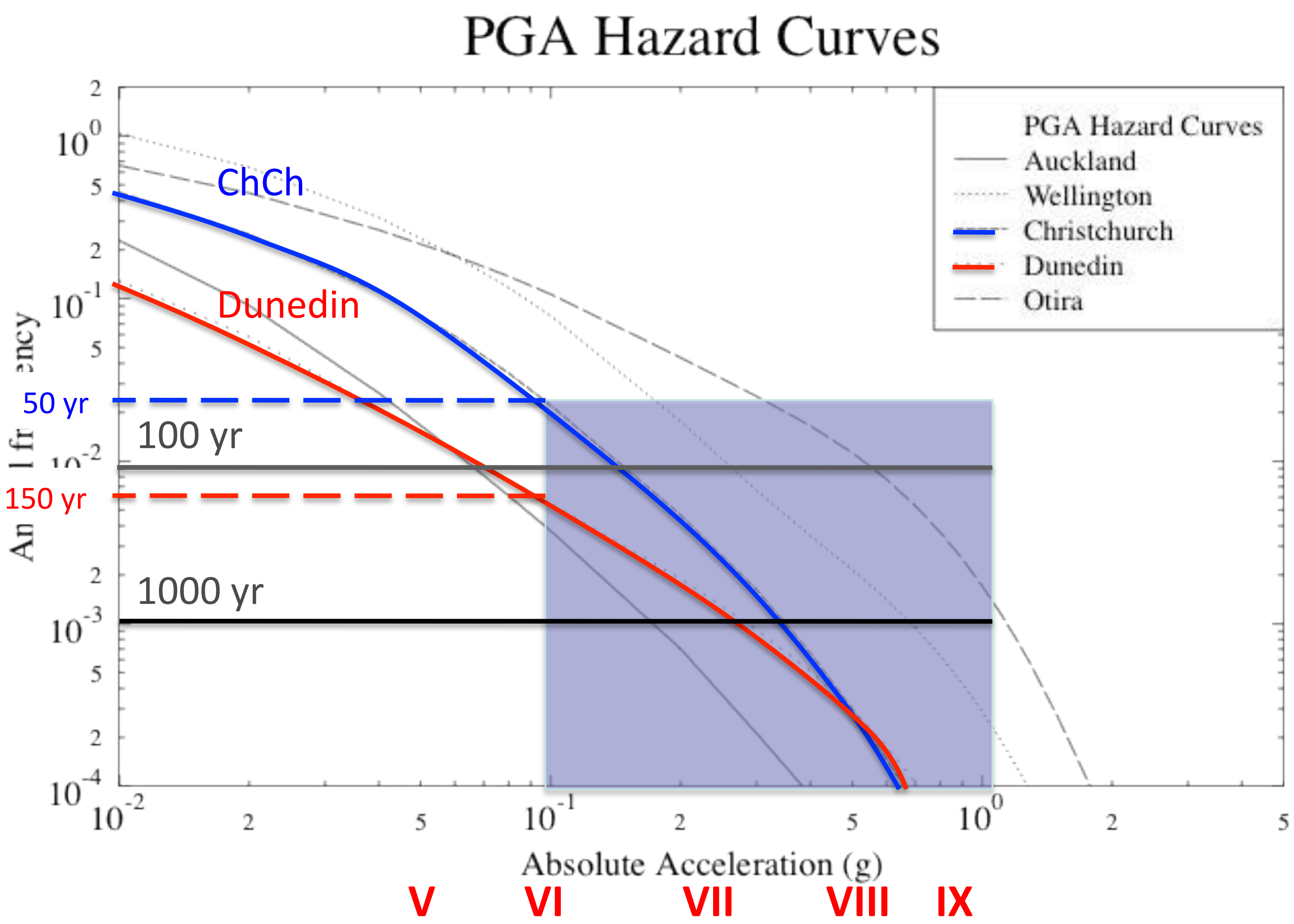
Combines earthquakes with an attenuation relationship to obtain probabilistic estimates of ground motions.

Basis for the design spectra of NZS1170.5:2004.



Dunedin is one of the least seismically active areas

Relative Intensity curves - NSHM



Expected Ground Shaking in Dunedin
MM Intensity – for firm ground

MMI Intensity	Expected Effect	Average Recurrence interval (years)
V or greater	Felt by nearly everyone	~30
VI or greater	Minimal property damage. Objects fall	~100
VII or greater	Some property damage. Loss of life unlikely	~500*
VIII or greater	Significant damage Loss of life possible	~2500

- Intensity could be up to 1 value higher on soft ground
- *This means 1 chance in 500 of it happening any year

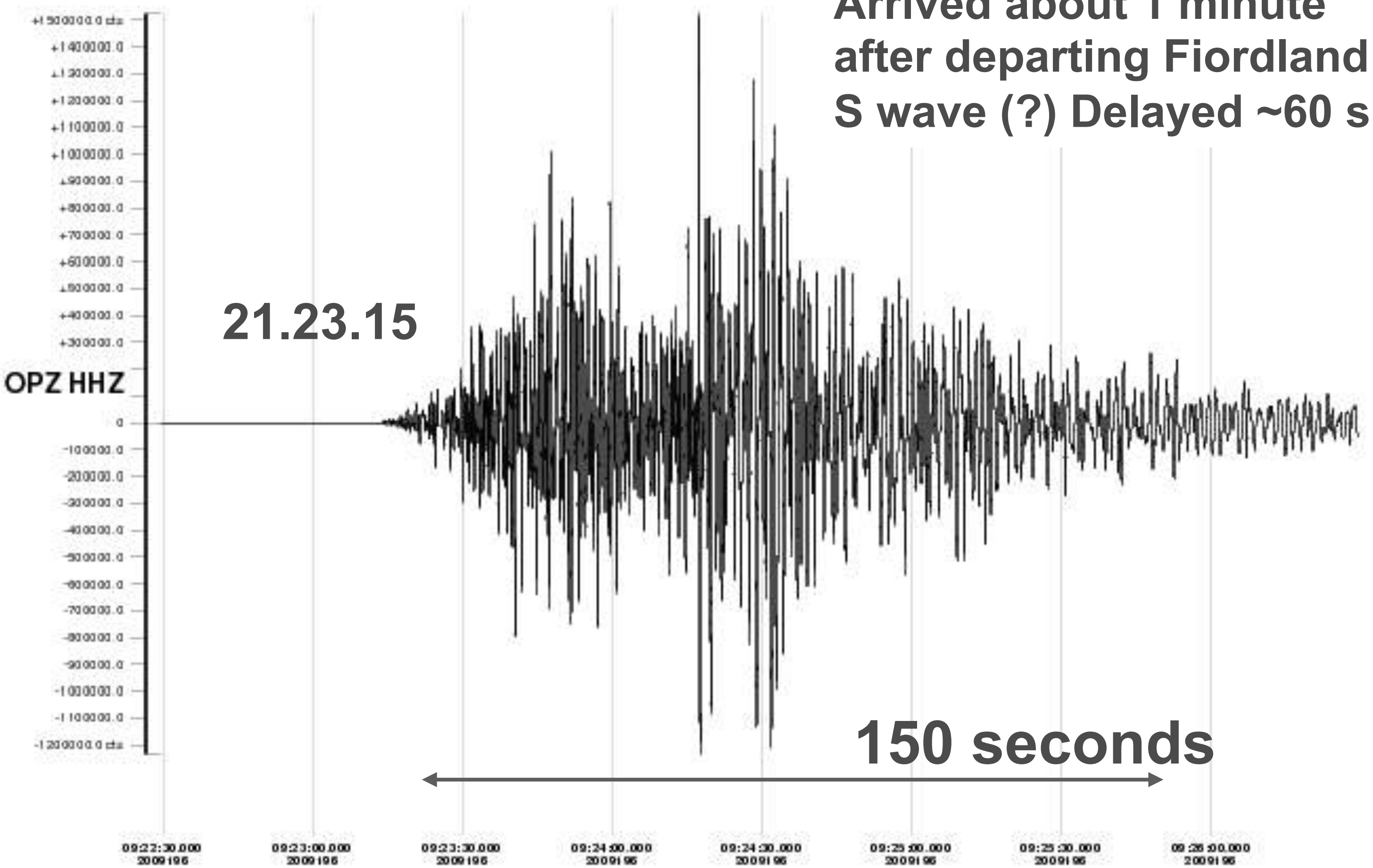
Summary (Take Home Message)

- We have chosen to occupy the 'Shaky Isles'
- Distinguish between Magnitude (Mw) and **Shaking Intensity (MM)**
- Alpine Fault – Mw~8 **MM V-?VI** in Dunedin, ~260-400 yrs
- Nearby faults – Mw~6.5-7 **MM VIII-?IX** in Dunedin, low R.I. ~2500 yrs
- Events like those in Christchurch could very well happen here

To Conclude

Fiordland M7.8 2009 @ Otago Peninsula

Arrived about 1 minute after departing Fiordland
S wave (?) Delayed ~60 s



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