การดำเนินการที่และการศึกษาผ่านดินไหวMOV  opratival spirit หมู่บ้านจากประเทศนิวซีแลนด์และการปรับใช้ในประเทศไทย

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Characterising source-based seismic hazard: NZ Active Faults Database and integration into Google Earth and GEM

GNS Science maintains the New Zealand Active Faults Database. This database has been designed to hold all data collected from investigations of active faults. Along with the locations of active faults, the Active Faults Database contains the results from field measurements of offset features, trenching, and dating. It also stores interpretation of these results in the form of the average fault recurrence interval, slip rate, and date of last movement. This detailed information, which is collected at many points along a fault, has been summarised and presented here for each fault.

Whilst the maps of fault locations presented on these pages are derived from detailed location data, the fault features have been generalised to assist presentation. The maps should be treated as overview maps only. They should not be used for as a substitute for detailed mapping.

The Active Faults Database is a growing database and will be subject to change as new information becomes available and new interpretations are developed. Consequently information presented on these pages will also change.

GNS has made every reasonable effort to ensure the information given on these pages is accurate, complete, and up-to-date. However GNS make no warranties or representations as to its accuracy or completeness and shall not be liable for any injury or death, or for damages of any kind arising out of access to, or use of the information, or any errors, omissions, misprints, or out-of-date information.
Interactive Map, Query and Sorting Functions, Supporting References Page with working links: Excellent Research Planning and Teaching Tool
The 2010-2012 Canterbury earthquake sequence

Complex faulting ($SS_D$, $SS_S$, $R$, $N$)
1 surface rupture, at least 12 ‘blind’ faults
Rupture-induced river avulsion

Fault rupture damage: Important questions
- Relationship between earthquake magnitude, surface displacement, and SRL
- Thresholds between surface cracking and folding
- Width of deformation zone
- Return times (surface rupture and slip on related faults)

→ Forecasting earthquake hazards, designing resilient structures and lifelines, land-use planning (fault set-backs), interpreting paleo-earthquakes from the geologic record

Damage to lifelines

Damage to structures
Surface rupture trace: from the subtle to sublime
High resolution datasets

Airborne lidar
Terrestrial lidar

Lidar differencing

Courtesy Garth Archibald, GNS Science

Van Dissen et al. 2011
Duffy et al. 2013
MAPPED SURFACE RUPTURE LENGTH (HISTORIC) = 29.5 ± 0.5 km
Mw 6.8-6.9

IDENTIFIABLE WITHOUT AGRICULTURAL FEATURES (GEOLOGIC) ≤ 20 km
Mw 6.6-6.7

GF SUBSURFACE RUP LENGTH (GEODETECTIC / SEISMOLOGIC) ~48 km
Mw 6.9-7.0

COMBINED SUBSURF RUP LENGTH (GEODETECTIC / SEISMOLOGIC) ~86 km
Mw 7.1

Importance of understanding how geologic record of active faulting rel to subsurface rupture potential:

\[ E \text{ Mw 7.1} = 6 \times E \text{ Mw 6.6} \]
Subsurface mapping and GPR surveying of faulted sediments

- Many surface fractures terminate in uppermost 30-50cm (pedogenesis and loess filled channels increases cohesivity and promote fracturing)
- Thoroughgoing R fractures penetrate deeply and appeared to show increase in subsurface displacement

Hornblow et al.
Digging laterally along fault to expose paleochannel cross-sections and measure piercing points (channel facies and margins)
The penultimate earthquake:
Between ~22 and ~28 ka
Consistent slip-at-a-point

2010 offset measured along structure on surface H= 60±-10 cm

Offset on upper channel:
H=65 cm, V=10 cm

OSL age 21.6 ± 1.5 ka

Offset on lower channel:
H=120 cm, V=20 cm

OSL age 28.4± 2.4 ka

Hornblow et al
• BY MEASURING TOTAL SLIP OVER WIDER AREAS, WE INCLUDED BOTH DISCRETE FRACTURING AND BROAD FOLDING IN OUR ANALYSIS
• Deformation zone ~30 to 300 m wide
• Average width ~80 m
• 50% of horizontal displacement occurs over 40% of total width
• Offset measurements restricted to narrow surface cracking zone will underestimate surface displacements

Van Dissen et al., 2011
Better documentation of relationships between discrete and distributed deformation – Mw 7.0 estimated from discrete displacements only - confidence in eq scaling from geol offsets

Van Dissen et al 2012

Quigley 2013

Displacement on discrete fractures ~120 cm
Displacement across ~280 cm
Surface folding zone (fence not used)
Displacement from broad folding ~340 cm (using fences and agricultural features)

Profile 38
D = 4.4 m

Profile 39
D = 3.9 m
Source: specific analogue modelling of surface rupture:

What controls rupture morphology and displacement variations? Where is the best place to site a trench, and what fractures will most faithfully record prior earthquakes?

Single layer, cohesive material (talc) best replicates km-scale surface rupture morphology. Surface complexities created with simple, planar uniformly dipping basement fault.
Multi layer model best replicates m-scale surface rupture morphology
Surface complexities created with simple, planar uniformly dipping basement fault beneath layered ‘strata’
Defining fault avoidance zones
From point measurements to complex rupture scenarios: integrating Coulomb stress modelling into paleoseismic investigations

What happens if the dominoes topple the other way?
Coulomb ‘static’ stress evolution for rupture initiating on CCF

Courtesy: Abigail Jimenez, Sandy Steacy (Ulster)
Coulomb ‘static’ stress evolution for rupture initiating on GF
Coulomb ‘static’ stress evolution for rupture initiating on Darf NW
The Future: Probabilistic Determination the Maximum Mw of Fault Systems

Timothy Stahl, Graduated PhD student, now NSF Postdoctoral Fellow at the University of Michigan
• Determine the need for this type of analysis:
  – Intersecting faults at depth or at surface?
  – Paleoseismic evidence of interaction?
  – Coulomb stress analysis?
  – Within historical limits of “jumping” distances?
• Assemble all necessary data:

• Geologic: fault length, segmentation, surface dip, rock properties

• Geophysical: fault geometry, structure, rock properties, historical hypocentral depths and subsurface earthquake slip

• Paleoseismic: SEDs, event ages, slip rates, etc.

• Decide on a final fault model (e.g. C to the left, assembled from mapping and A & B)
• We used a distance-based jump probability, so it is imperative that we know (a) the fault geometry in the subsurface and (b) likely earthquake depths
• Decide on reasonable input probability distributions for the parameters determining $M_w$

• Run several simulations for different fault geometries

• Output are distributions of $M_w$ for different simulation runs
## Additional Info on our Model

<table>
<thead>
<tr>
<th>Input parameter</th>
<th>Shear modulus(^a)</th>
<th>Average Surface Displacement(^c)</th>
<th>Subsurface:Surface Displacement Ratio(^b)</th>
<th>FPF Area (listric)(^d)</th>
<th>FCF Area (listric)(^d)</th>
<th>Jump Distance(^d)</th>
<th>R_p(^d)</th>
<th>FPF Surface Length</th>
<th>FCF Surface Length</th>
<th>Subsurface:Surface Length Ratio</th>
<th>Fault dip</th>
<th>Seismogenic thickness (ST)(^d)</th>
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<tbody>
<tr>
<td>Model PDF</td>
<td>Fixed</td>
<td>Fixed, Calculated from field mapping</td>
<td>Trapezoidal</td>
<td>Fixed from model</td>
<td>Fixed from model</td>
<td>Normal</td>
<td>Fixed</td>
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<td>Trapezoidal</td>
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<td>Fixed from field mapping, geophysics</td>
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<tr>
<td>PDF constraints(^*)</td>
<td>2.7E11</td>
<td>2 m</td>
<td>1-1/4/3-5/3</td>
<td>2046 km²</td>
<td>585 km²</td>
<td>2.5 (± 2.5) km</td>
<td>3</td>
<td>35.7</td>
<td>0, 15, 40</td>
<td>1-1/4/3-5/3 FPF: 55° @ 0-5 km; 30° @ 5-ST km; FCF: 55° @ 0-ST km</td>
<td>12 (± 2) km</td>
<td></td>
</tr>
</tbody>
</table>
The Future:

LiDAR-informed detailed rupture trace mapping coupled with probabilistic paleoseismology

Narges Khajavi, current PhD student, looking for Postdoctoral Research!
Careful site selection, densely spaced trenching
Trench site correlations with full uncertainty limits

Acknowledgement of ‘missing events’
Comparing apparent trench displacements with large scale fault geomorphology to determine slip kinematics and slip rate
Paleoseismic challenges for Thailand*
(*humbly based on a 4 day whirlwind trip and my limited knowledge)

• Paleoseismic trenches well located, well mapped, stratigraphy well dated
  – Error reporting and uncertainty bounds with respect to timing of past seismic events? (e.g. ‘2000 yr BP’ vs ‘1500±500 yr BP’?)
  – Consideration of trench 3-dimensional displacements? Consideration of ‘apparent vertical’? Consideration of trench kinematics with respect to fault geomorphology and regional contemporary strain field?
  – Detailed comparisons of trench chronologies within error limits; are ‘different event’ actually the same?
  – Detailed mapping of surface traces and displacements: confined and discrete vs distributed traces?
Paleoseismic challenges for Thailand*

(*humbly based on a 4 day whirlwind trip and my limited knowledge)

• Detailed mapping of surface rupture traces: vegetation issues addressed with drone-based lidar? Resourcing for airborne lidar acquisition? Overseas collaboration?

• Appropriate Mw scaling relationships? We find W+C to underestimate Mw for NZ, plenty of information on GEM website about appropriate scaling relationships

• Better integration of errors, probabilistic approaches to eq event timing, segmentation models, coseismic displacements, Mw potentials

• Other proxies for strong earthquakes
Blind faults densely populate continental crust and are under-represented in source-based seismic hazard catalogues.

Fractal geometries and G-R scaling
Surface rupture thresholds
Buried and eroded fault scarps

Pettinga et al 2001; Nicol et al 2011
>15-30 other faults we know that can generate eqs strong enough to cause liquefaction

paleoliquefaction at the same sites of contemporary liquefaction
Mackey, B., and Quigley, M., (2014) Strong proximal earthquakes revealed by cosmogenic $^3$He dating of prehistoric rockfalls, Christchurch, New Zealand, Geology

~6 ka hiatus since penultimate rockfall encompasses many earthquakes on largest known sources

Penultimate Greendale Fault event ca. 25 kyr ago, proximal strong shaking RI << nearest source RI identifiable from surface evidence
Khajavi, N., Langridge, R., Quigley, M., Smart, C., Rezanejad, A., Martín-González, F., Late Holocene rupture overlap and earthquake clustering on the Hope Fault, New Zealand, GSA Bulletin in press


Mackey, B., and Quigley, M., (2015) Strong proximal earthquakes revealed by cosmogenic 3He dating of prehistoric rockfalls, Christchurch, New Zealand, Geology


Khajavi, N., Quigley, M., Langridge, R., (2014) Influence of topography and basement depth on surface rupture morphology revealed from LiDAR and field mapping, Hope Fault, New Zealand, Tectonophysics