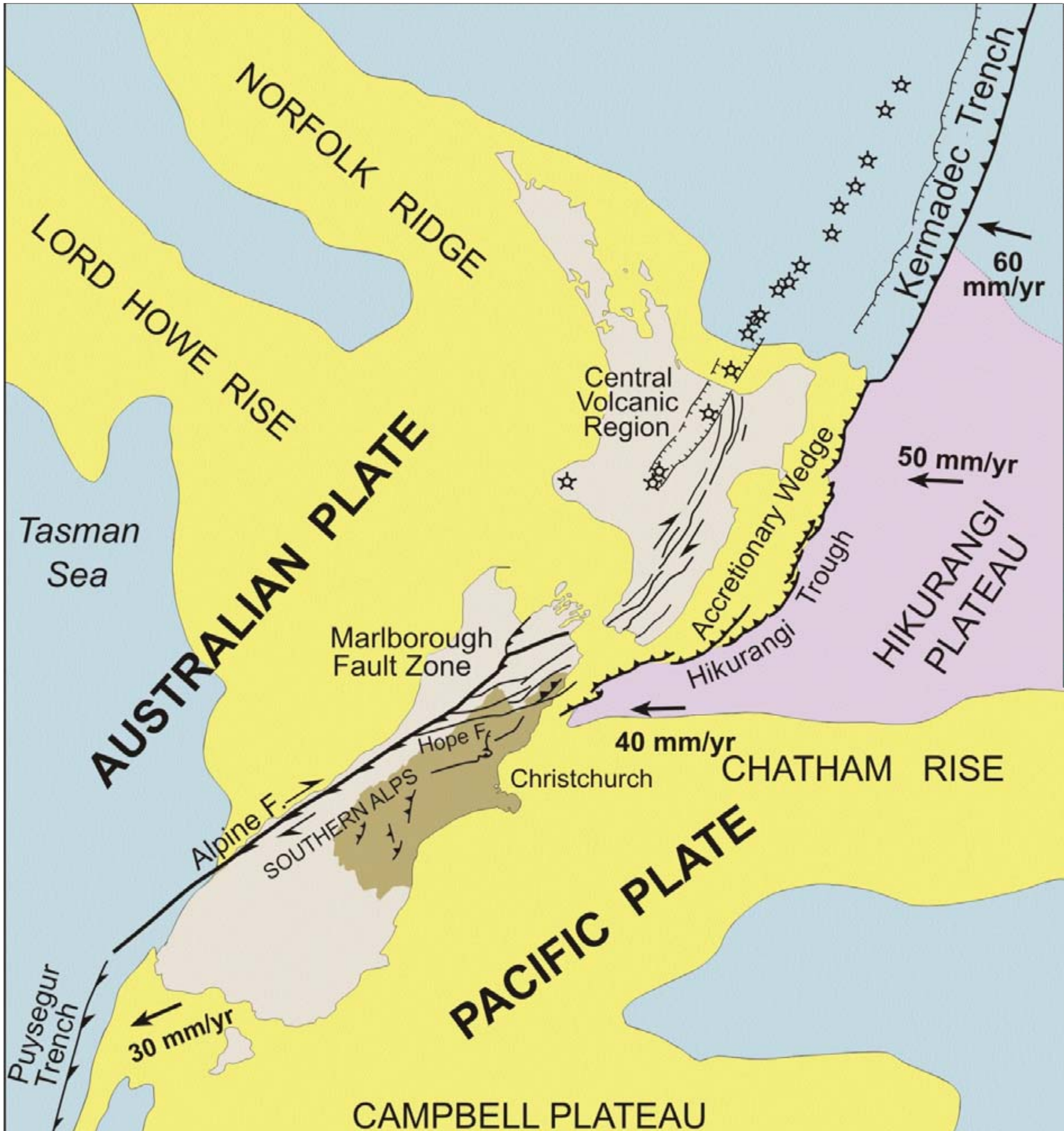
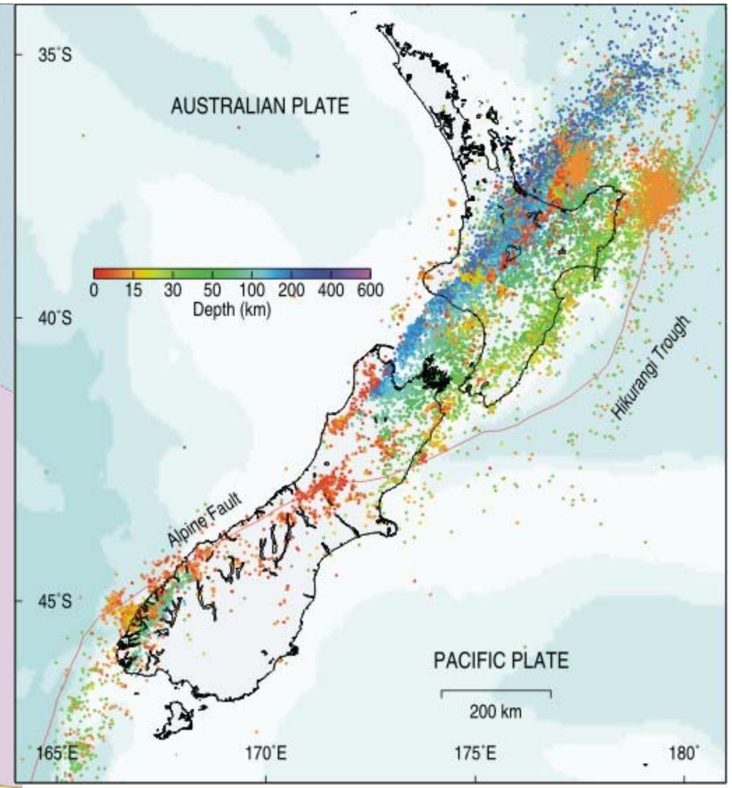
การทำแผนที่และการศึกษาแผ่นดินไหวบรรพกาลของรอยเลื่อนมีพลัง มุมมองจากประเทศนิวซีแลนด์และการปรับใช้ในประเทศไทย

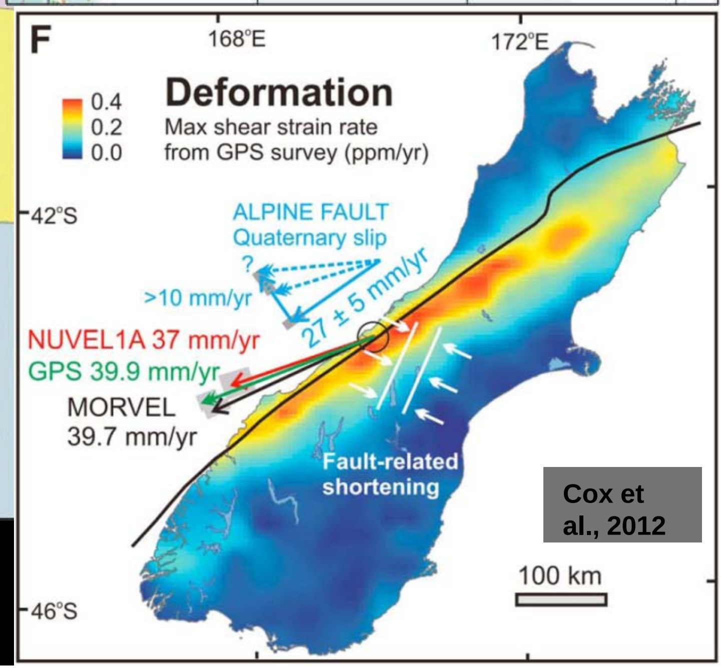
Dr. Mark Quigley
Associate Professor of Earthquake Science
University of Canterbury and University of Melbourne

EQC EARTHQUAKE COMMISSION KŌMIHANA RŪWHENUA
THE UNIVERSITY OF MELBOURNE
UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

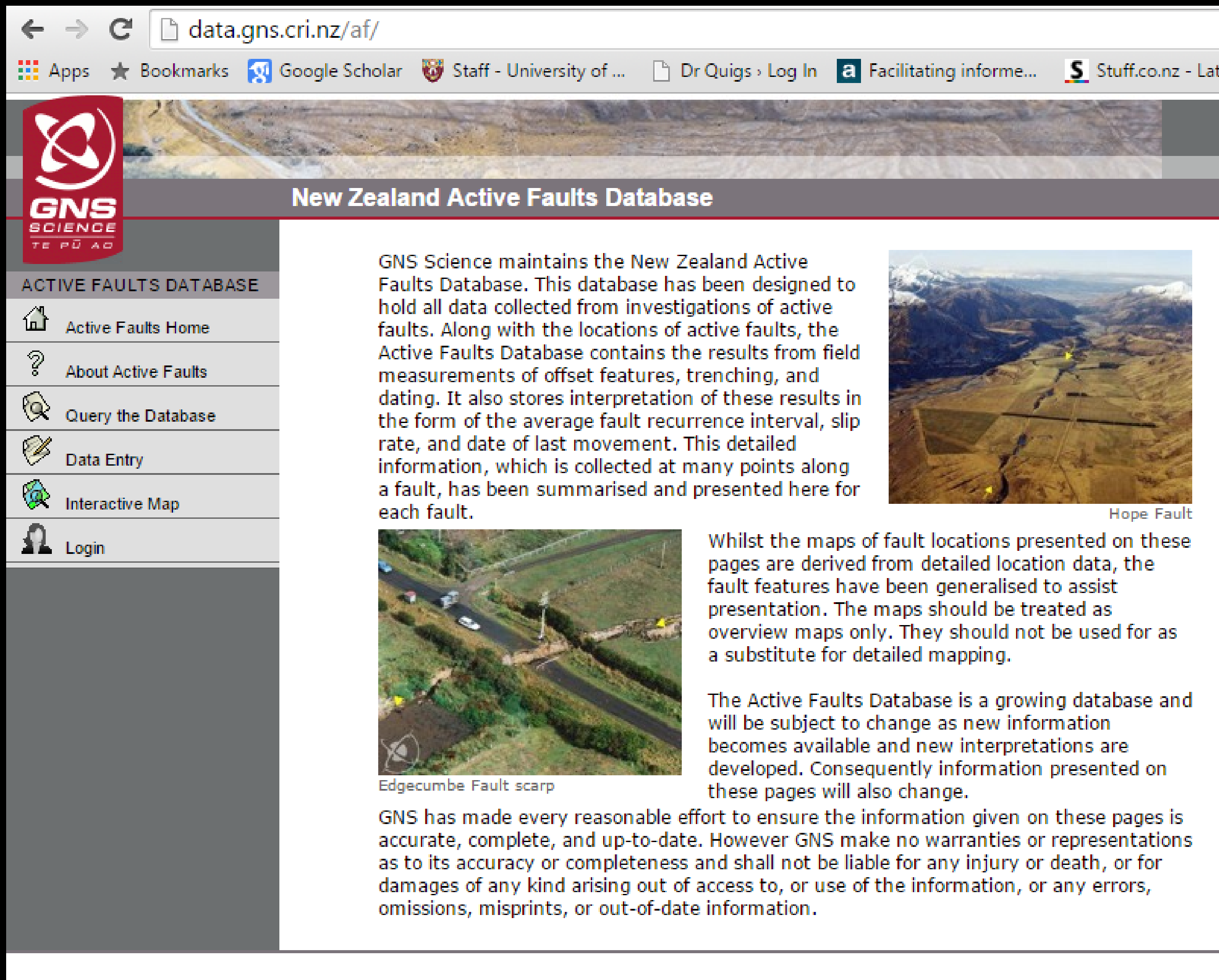


The NZ Seismic Story





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



data.gns.cri.nz/af/

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GNS SCIENCE TE PŪ AO

New Zealand Active Faults Database

ACTIVE FAULTS DATABASE

- Active Faults Home
- About Active Faults
- Query the Database
- Data Entry
- Interactive Map
- Login

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.

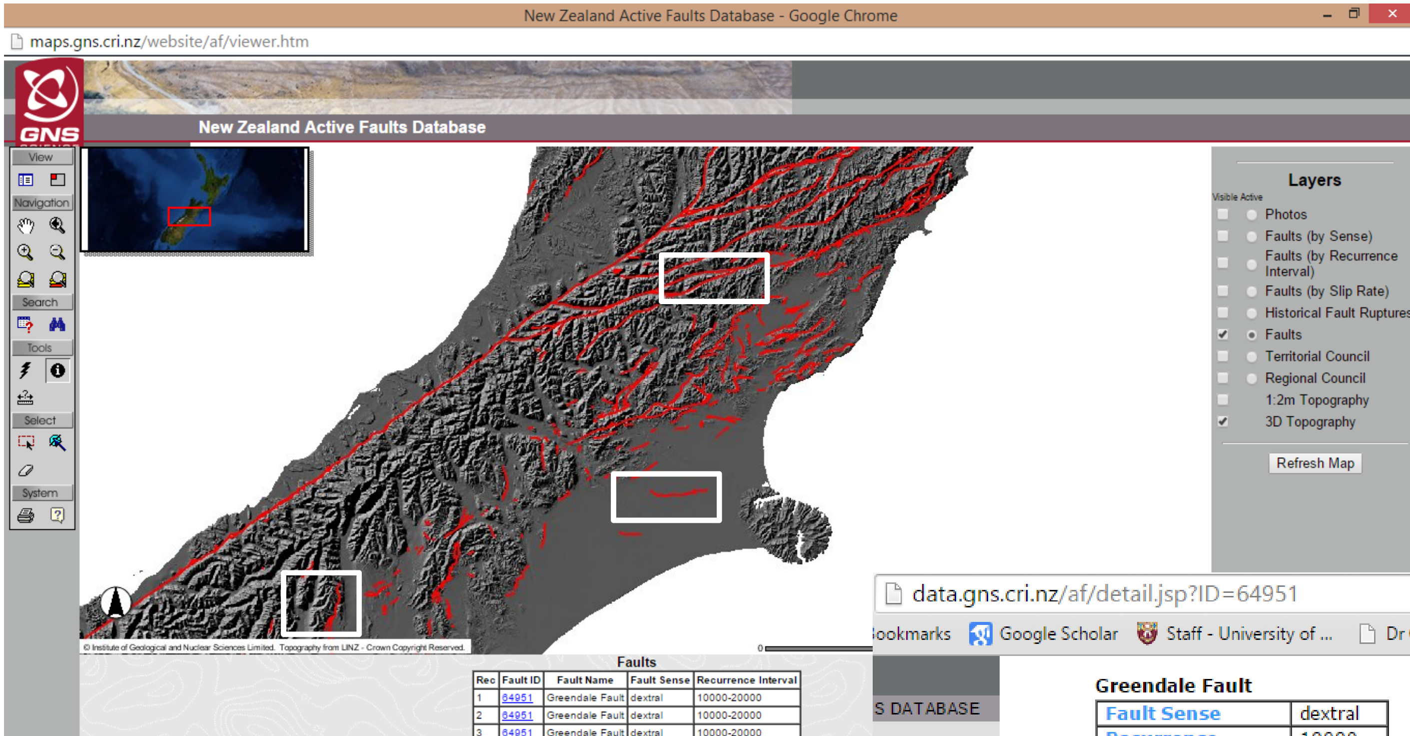
Hope Fault

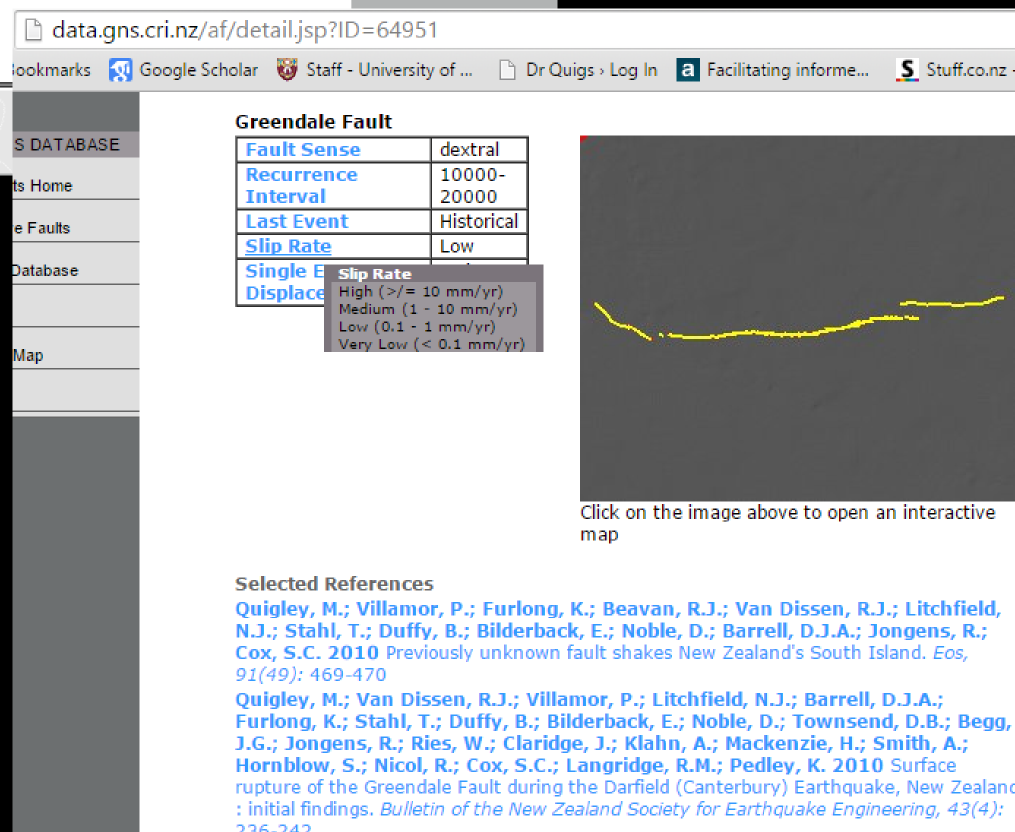
Edgecumbe Fault scarp

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.

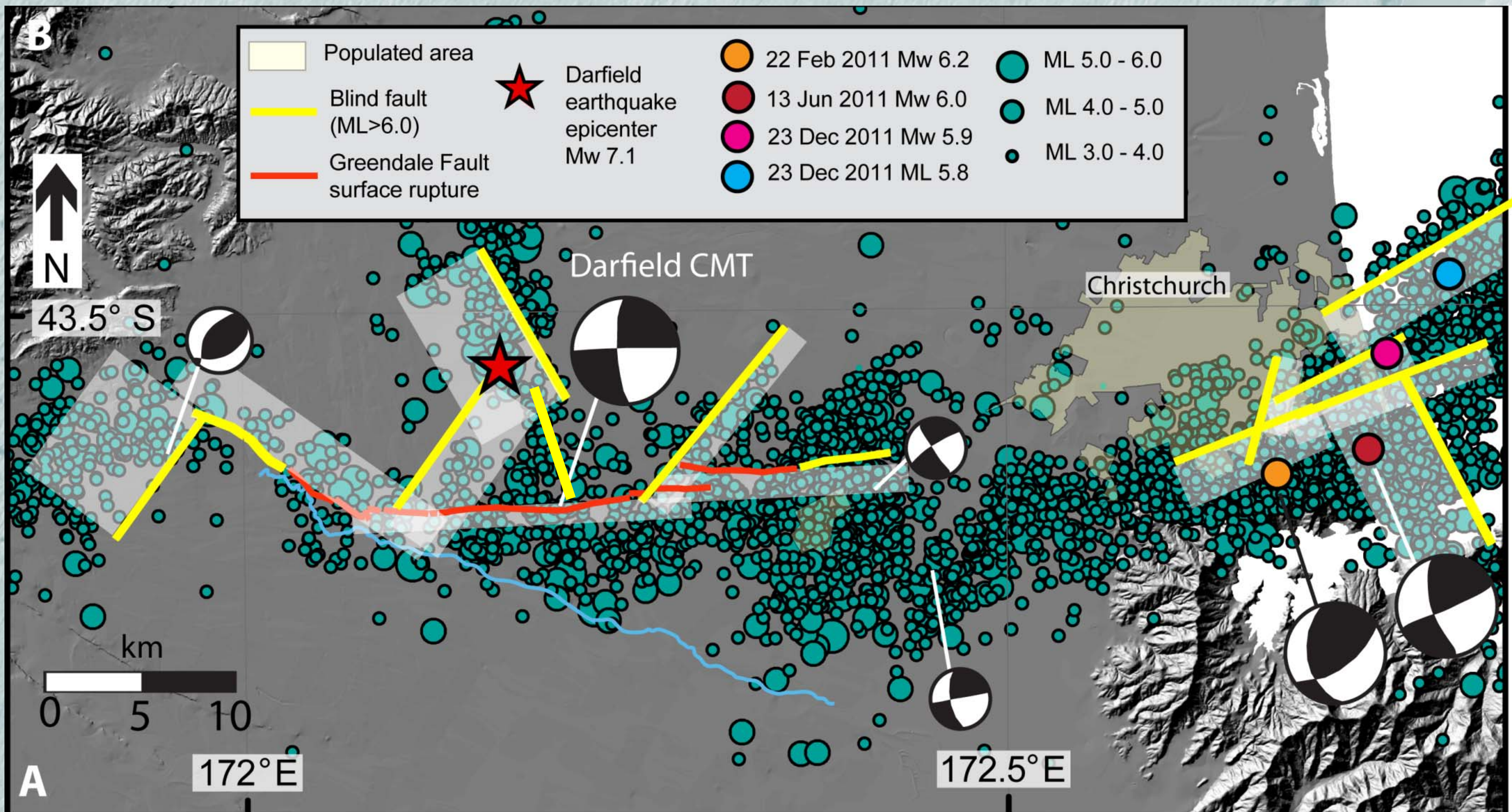
GNS has made every reasonable effort to ensure the information given on these pages is accurate, complete, and up-to-date. However GNS make no warranties or representations as to its accuracy or completeness and shall not be liable for any injury or death, or for damages of any kind arising out of access to, or use of the information, or any errors, omissions, misprints, or out-of-date information.



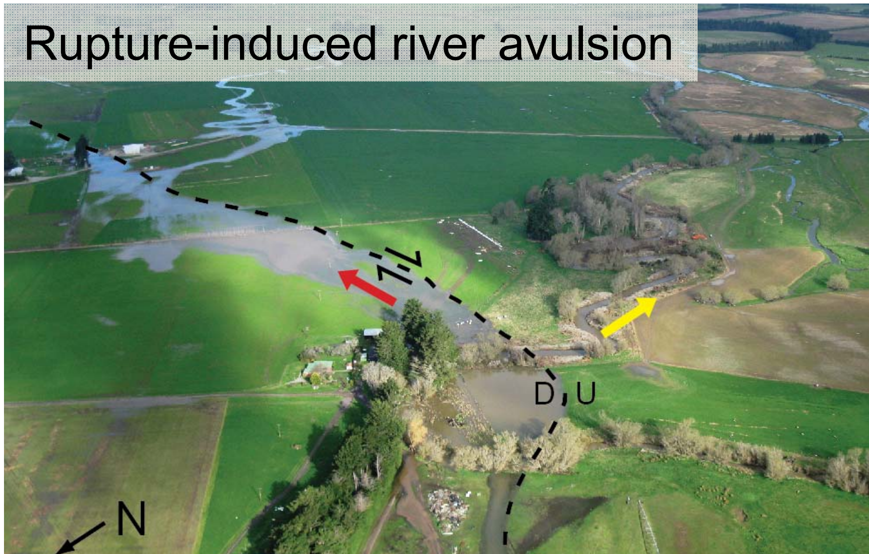


Interactive Map, Query and Sorting Functions, Supporting References Page with working links: Excellent Research Planning and Teaching Tool

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


Photo: Mark Quigley

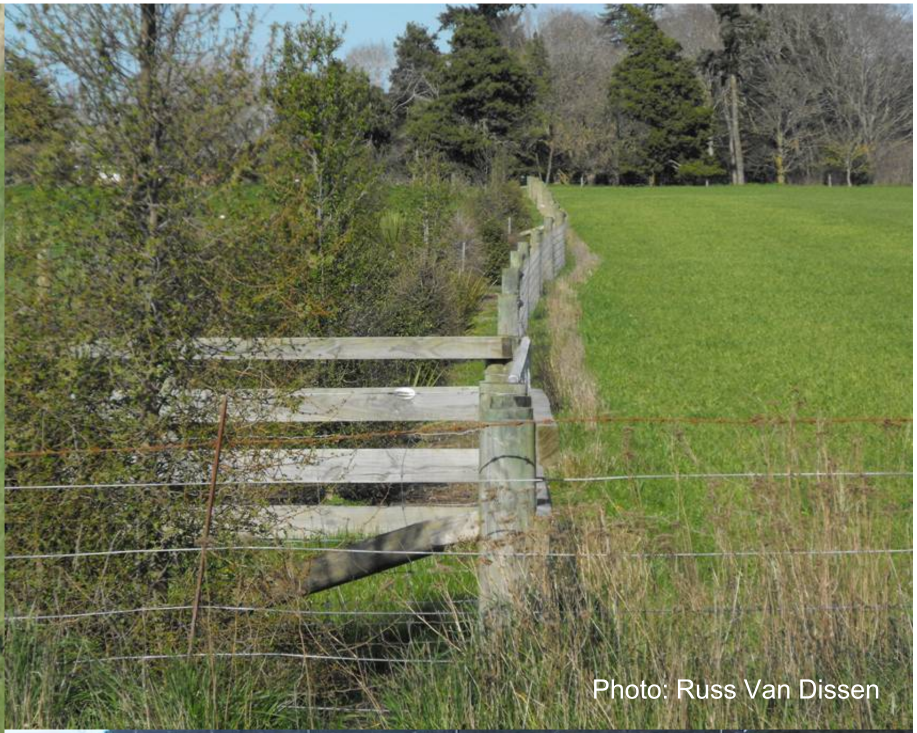


Photo: Russ Van Dissen

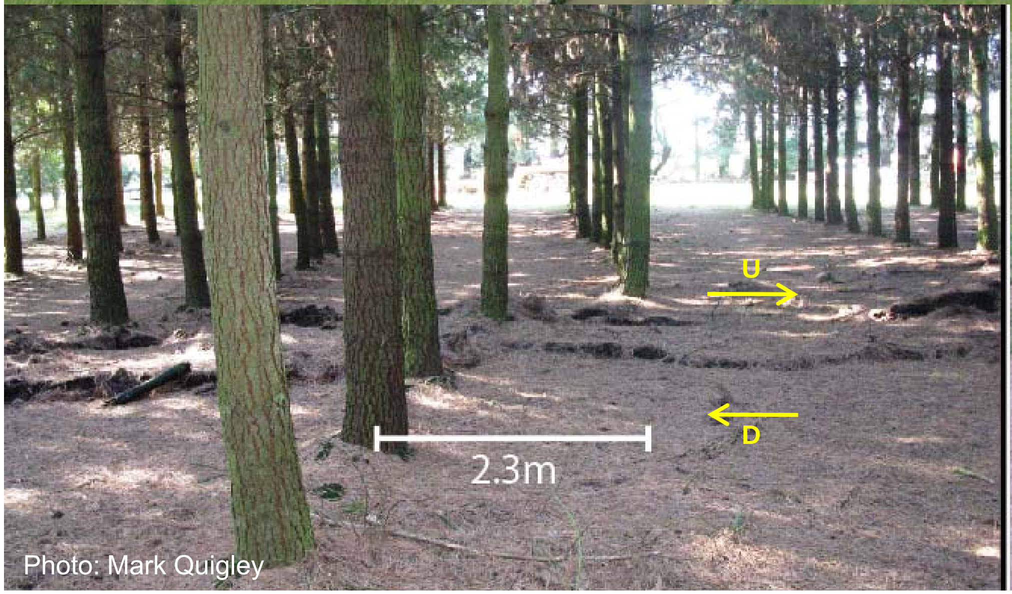
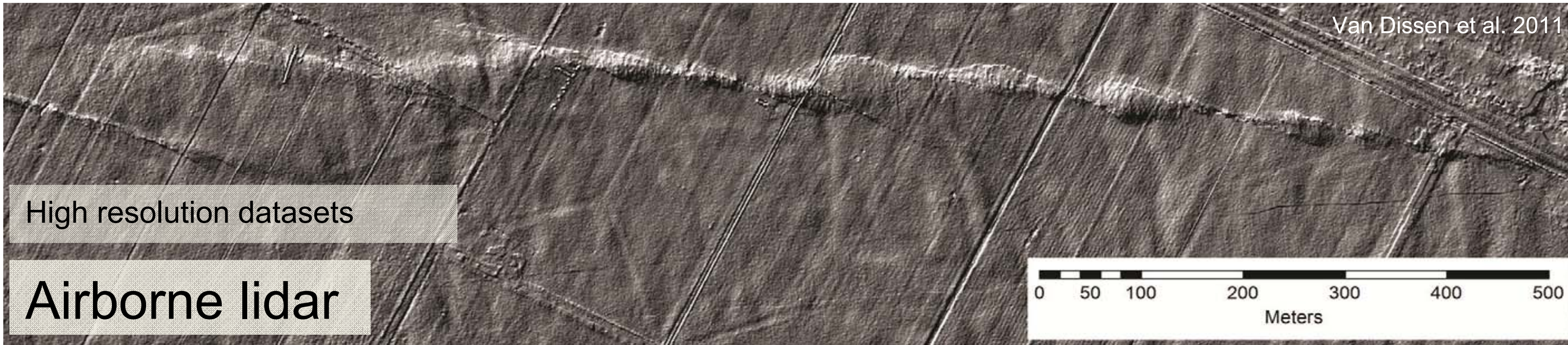
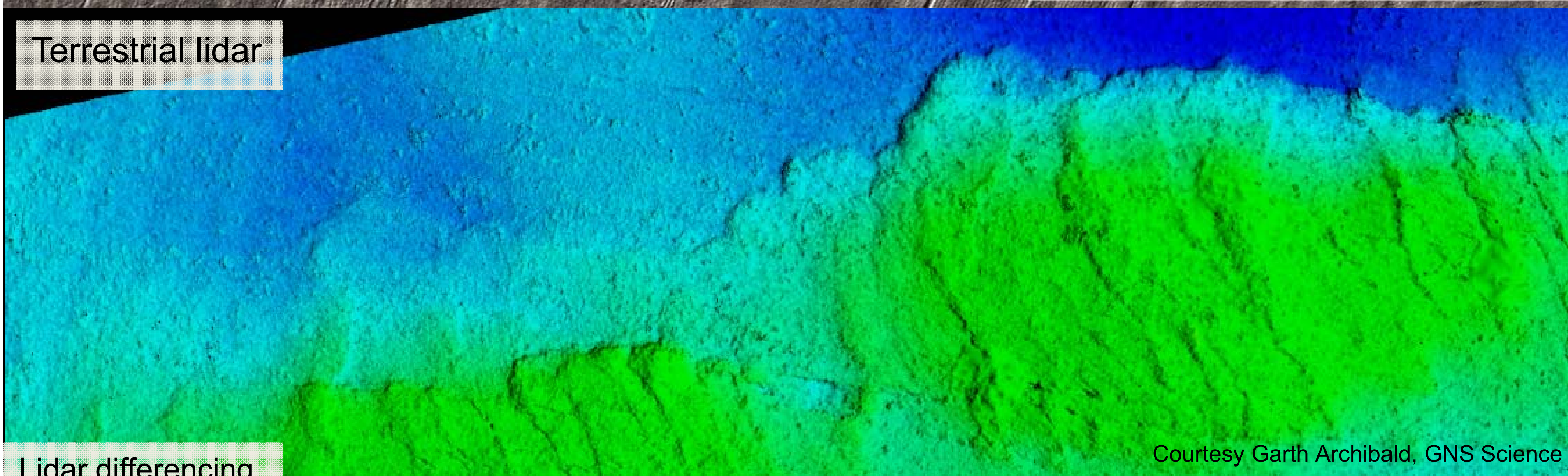
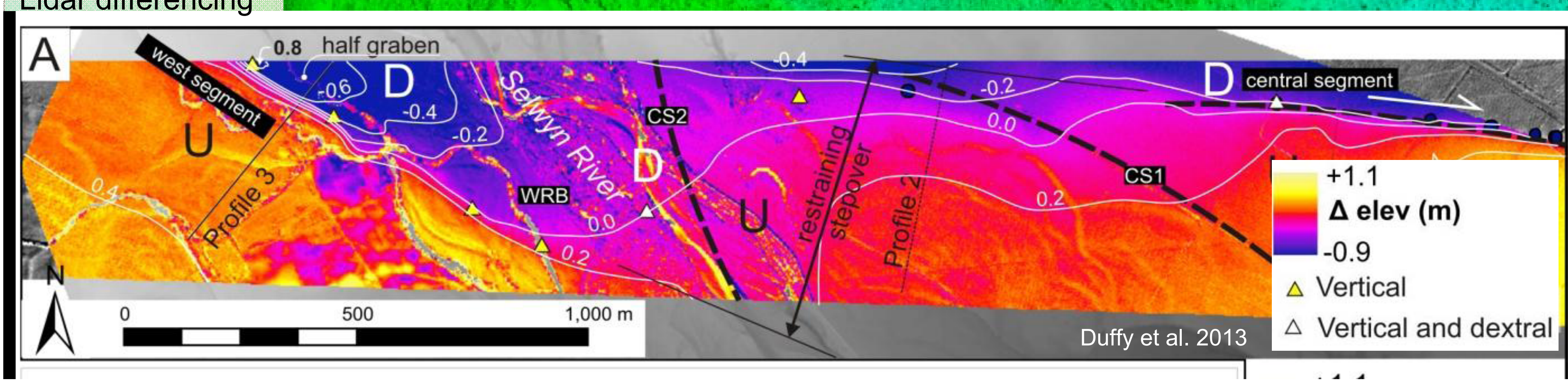


Photo: Mark Quigley


Photo: David Barrell


Van Dissen et al. 2011
High resolution datasets
Airborne lidar
0 50 100 200 300 400 500
Meters


Terrestrial lidar
Courtesy Garth Archibald, GNS Science

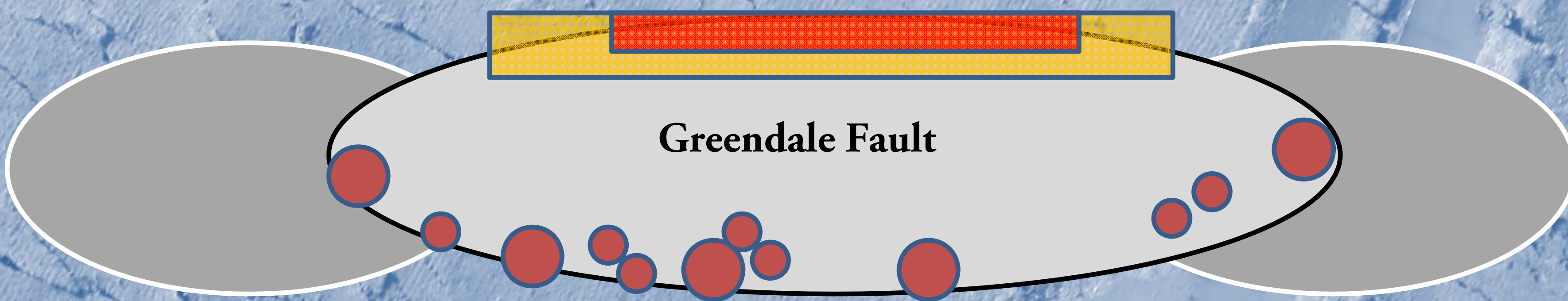

Lidar differencing
A
west segment
0.8
half graben
D
-0.6
-0.4
-0.2
Selwyn River
CS2
D
U
WRB
0.0
0.2
0.4
Profile 3
U
restraining stepover
Profile 2
-0.4
-0.2
0.0
0.2
D
central segment
CS1
+1.1
Δ elev (m)
-0.9
Vertical
Vertical and dextral
N
0 500 1,000 m
Duffy et al. 2013

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 (GEODETIC / SEISMOLOGIC) ~48 km

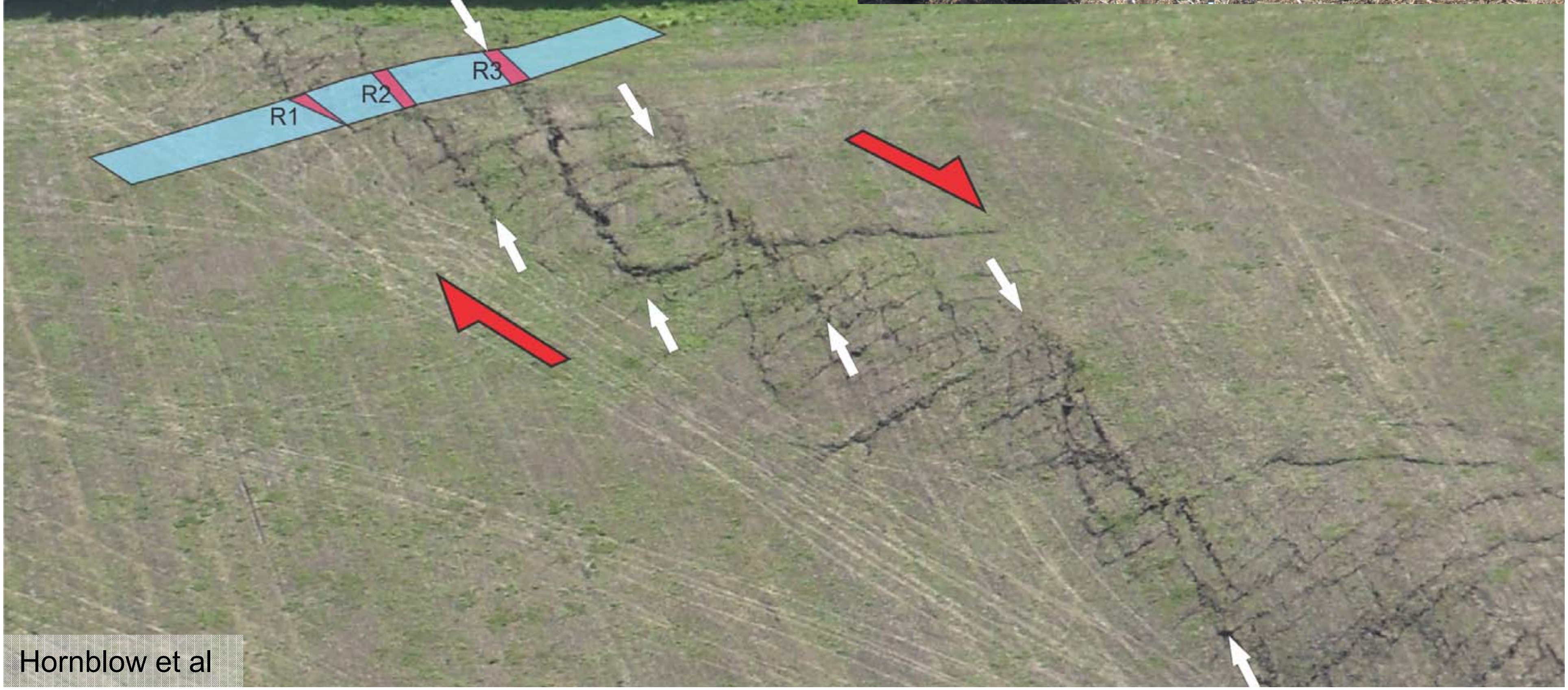
Mw 6.9-7.0

COMBINED SUBSURF RUP LENGTH (GEODETIC / SEISMOLOGIC) ~86 km

Mw 7.1

Importance of understanding how geologic record of active faulting rel to subsurface rupture potential: *E* Mw 7.1 = 6X *E* Mw 6.6

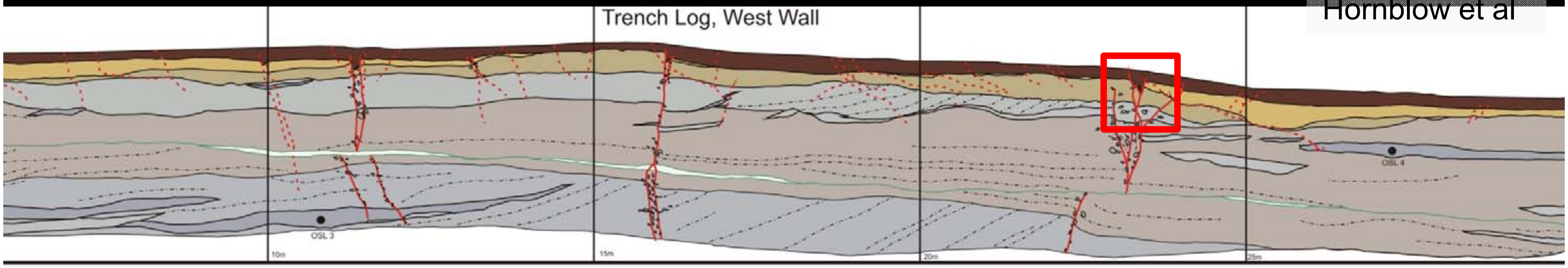
Greendale Fault paleoseismology project



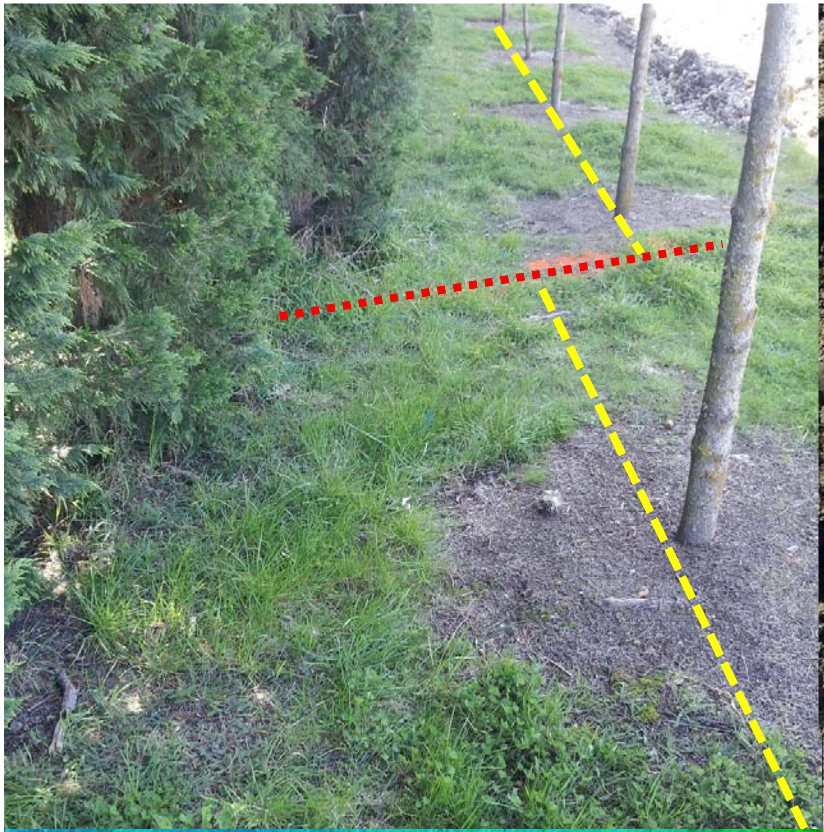
Hornblow et al

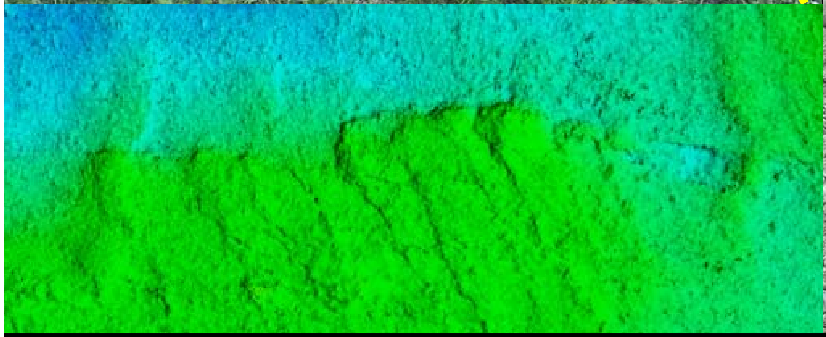
Subsurface mapping and GPR surveying of faulted sediments

Hornblow et al



- 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



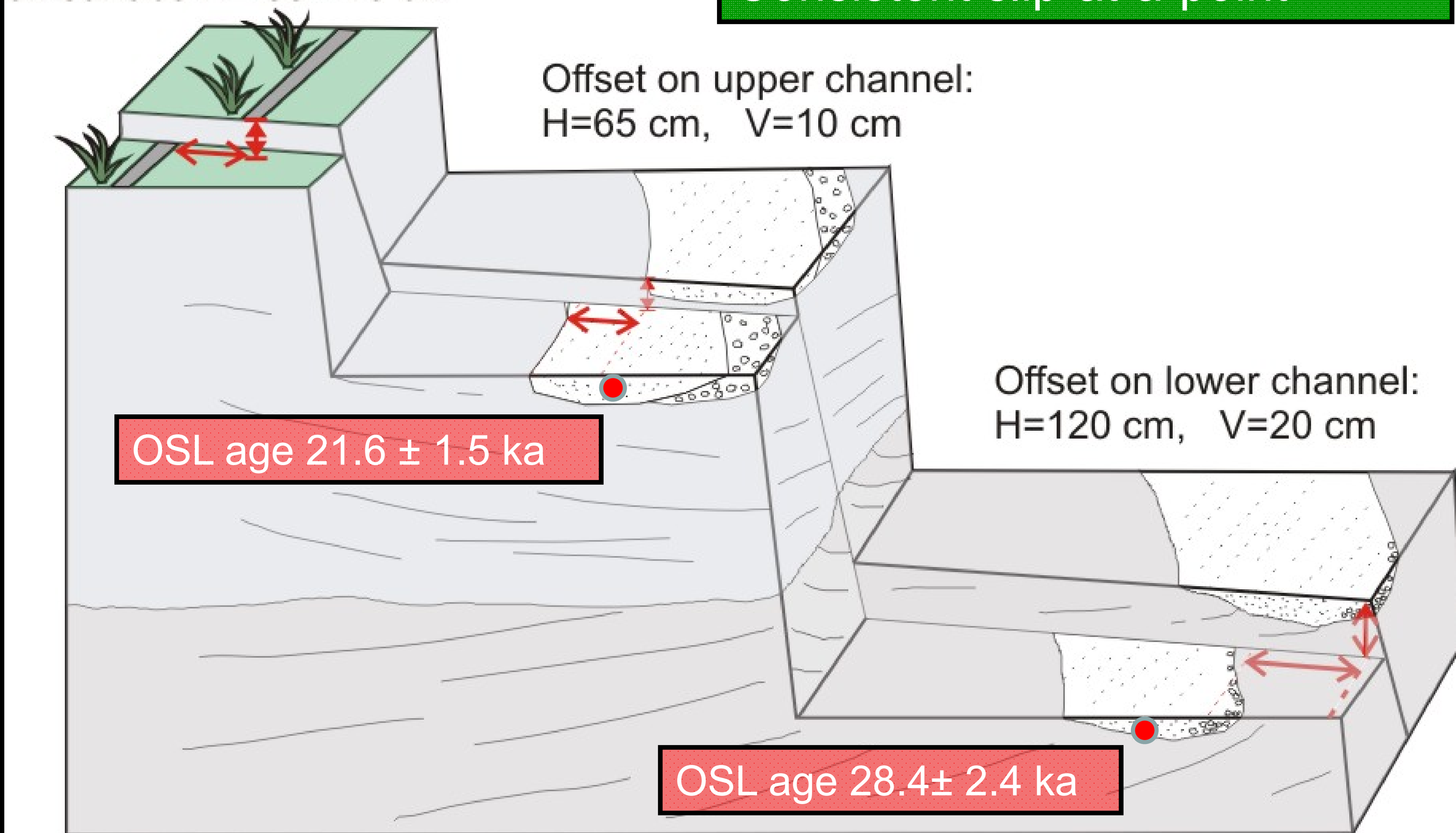


Digging laterally along fault to expose paleochannel cross-sections and measure piercing points (channel facies and margins)

The penultimate earthquake:

Between ~22 and ~28 ka

Consistent slip-at-a-point



Hornblow et al

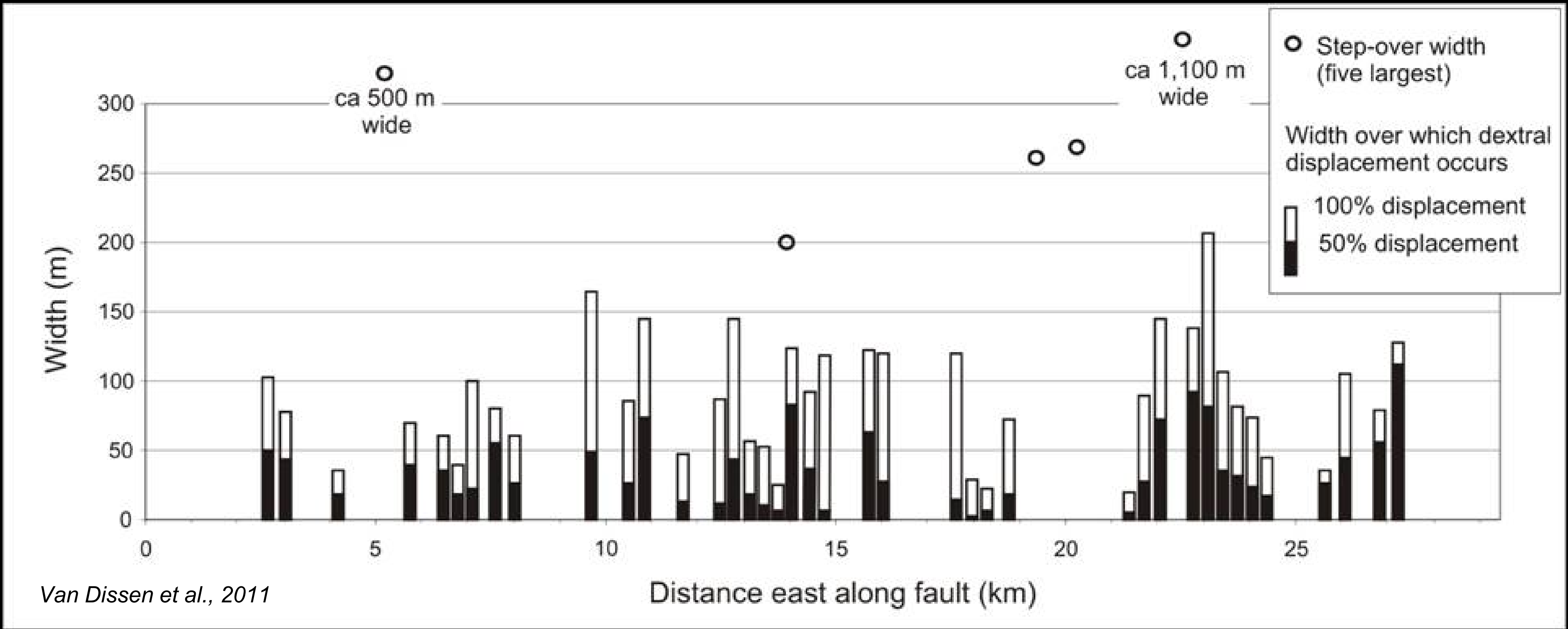
• BY MEASURING TOTAL SLIP OVER WIDER AREAS, WE INCLUDED BOTH DISCRETE FRACTURING AND BROAD λ FOLDING IN OUR ANALYSIS

•Deformation zone ~30 to 300 m wide

• Average width ~80 m

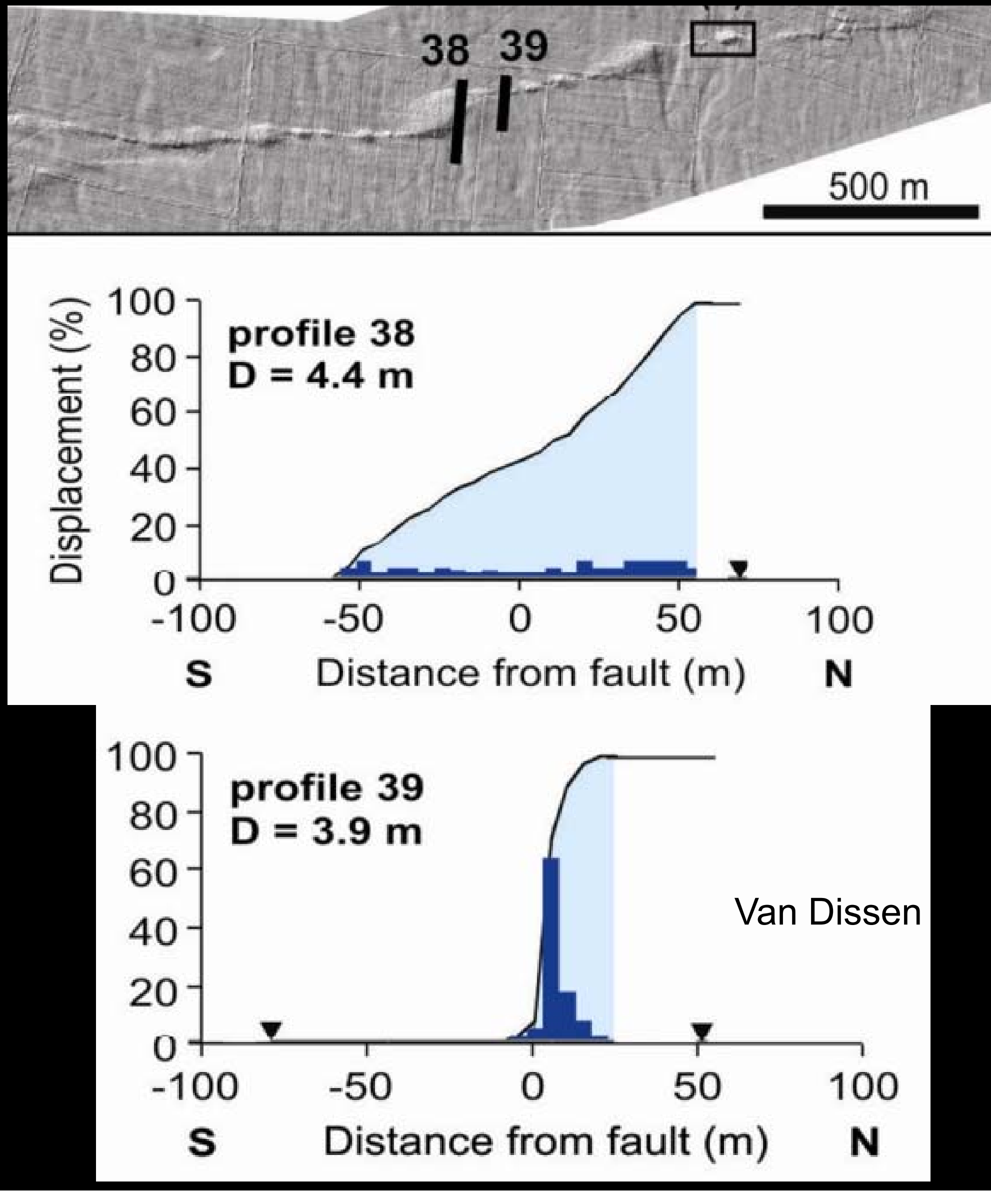
•50% of horizontal displacement occurs over 40% of total width

• **Offset measurements restricted to narrow surface cracking zone will underestimate surface displacements**



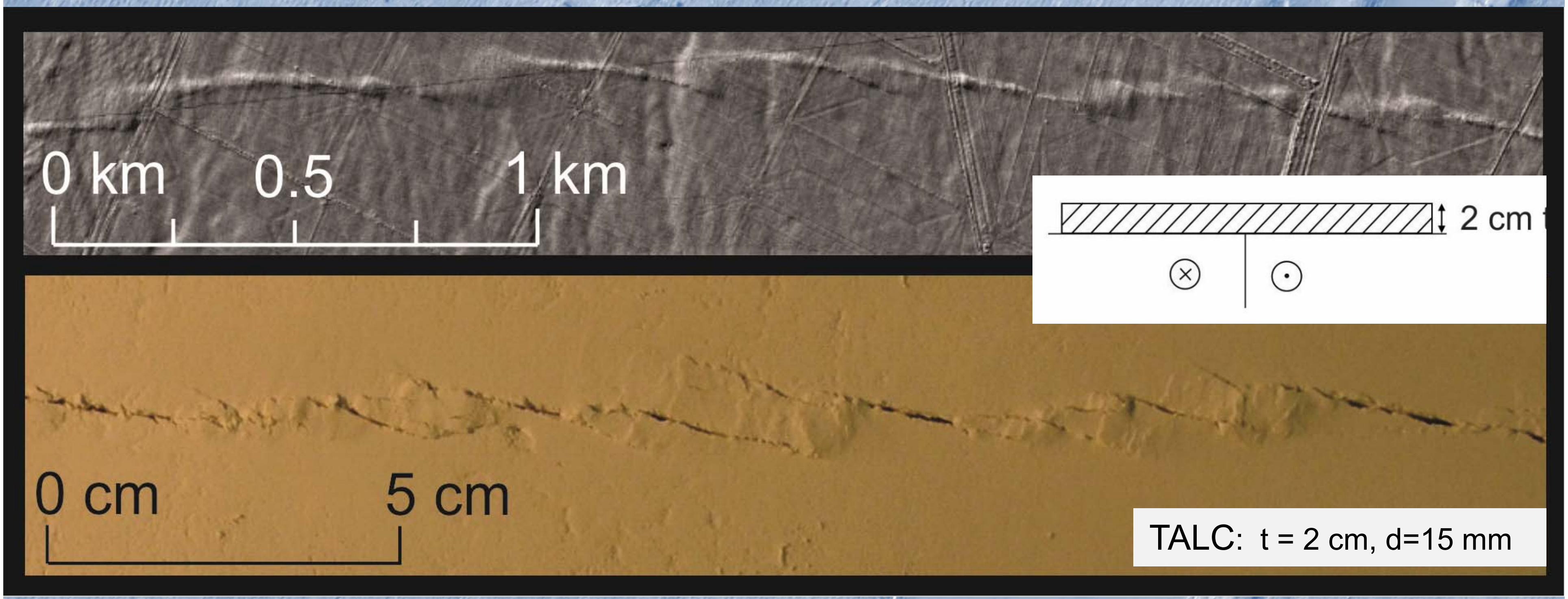
Van Dissen et al., 2011

Better documentation of relationships between discrete and distributed deformation – Mw 7.0 estimated from discrete displacements only - confidence in eq scaling from geol offsets



Source: specific analogue modelling of surface rupture:

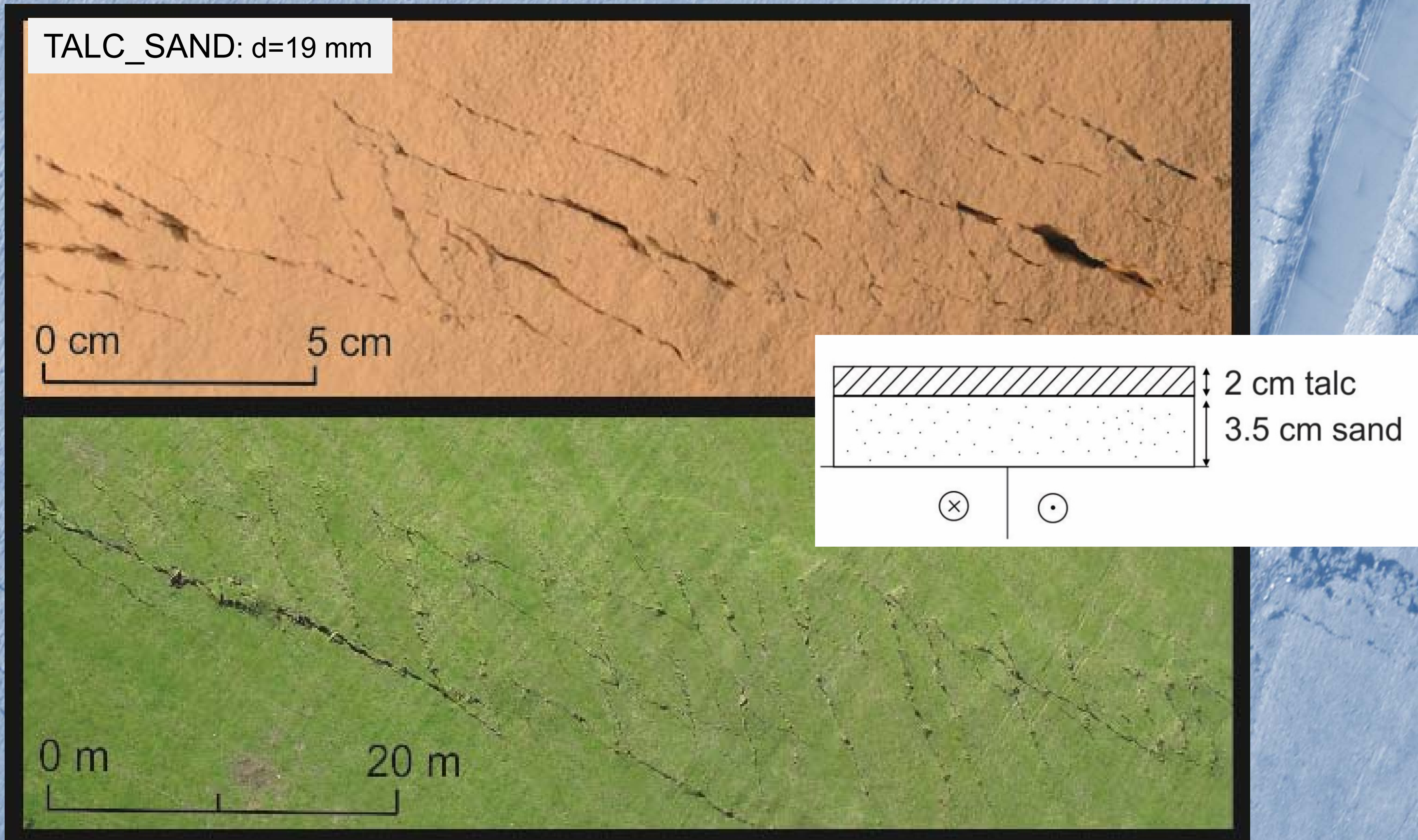
What controls rupture morphology and displacement variations? Where is the best place to site a trench, and what fractures will most faithfully record prior earthquakes?



Single layer, cohesive material (talc) best replicates km-scale surface rupture morphology

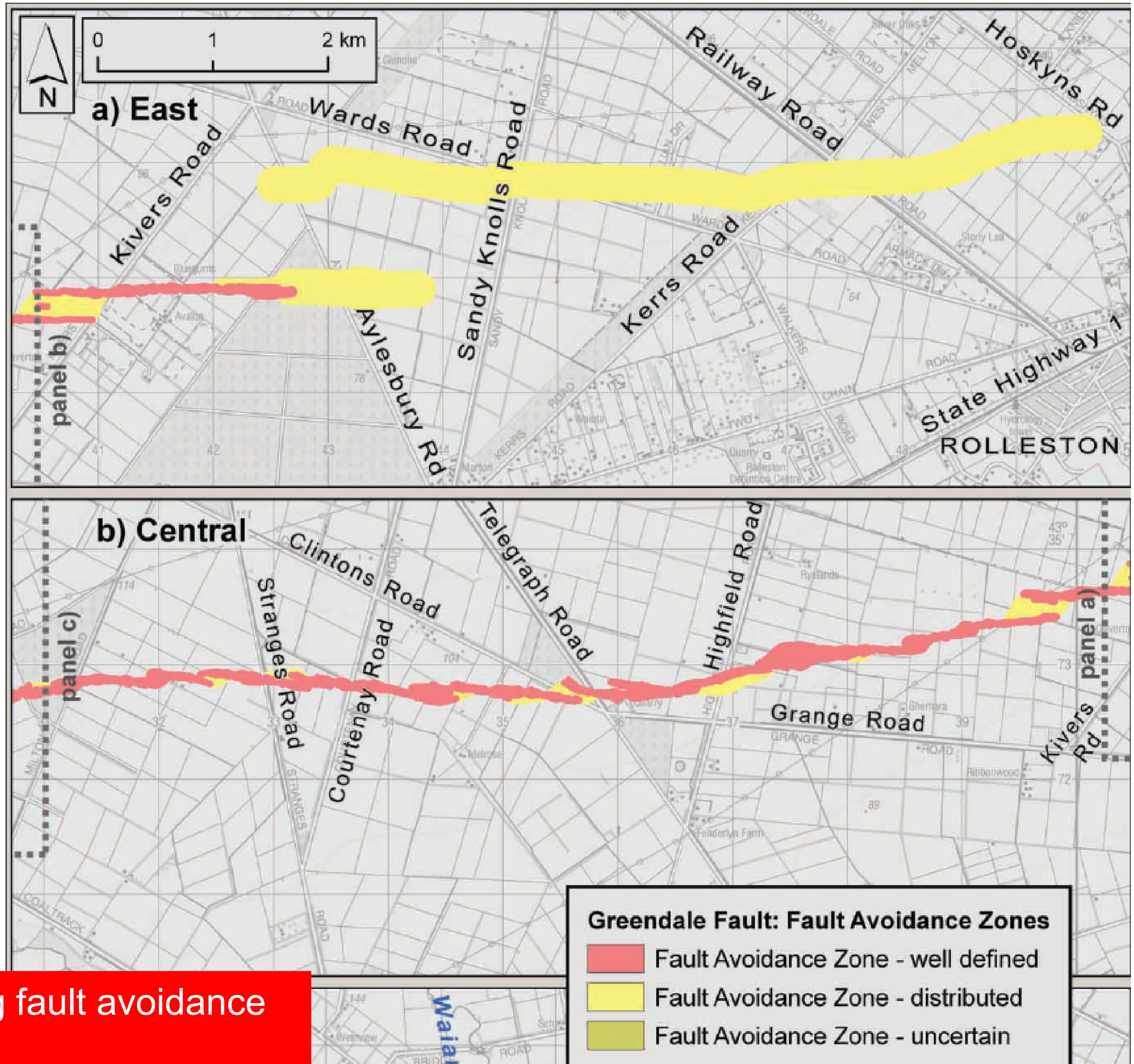
Surface complexities created with simple, planar uniformally dipping basement fault

Sasnett, 2013



Multi layer model best replicates m-scale surface rupture morphology
Surface complexities created with simple, planar uniformally dipping basement fault beneath layered ‘strata’

Sasnett, 2013

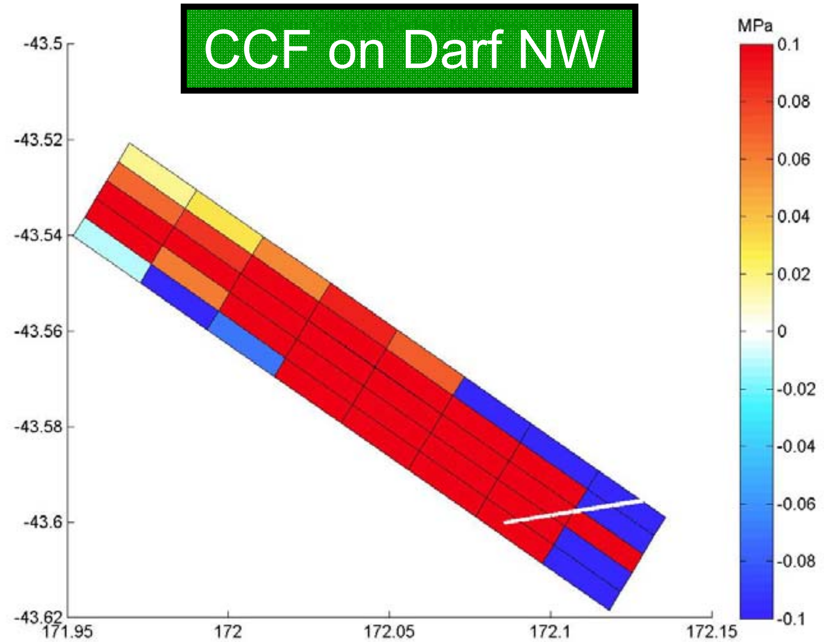


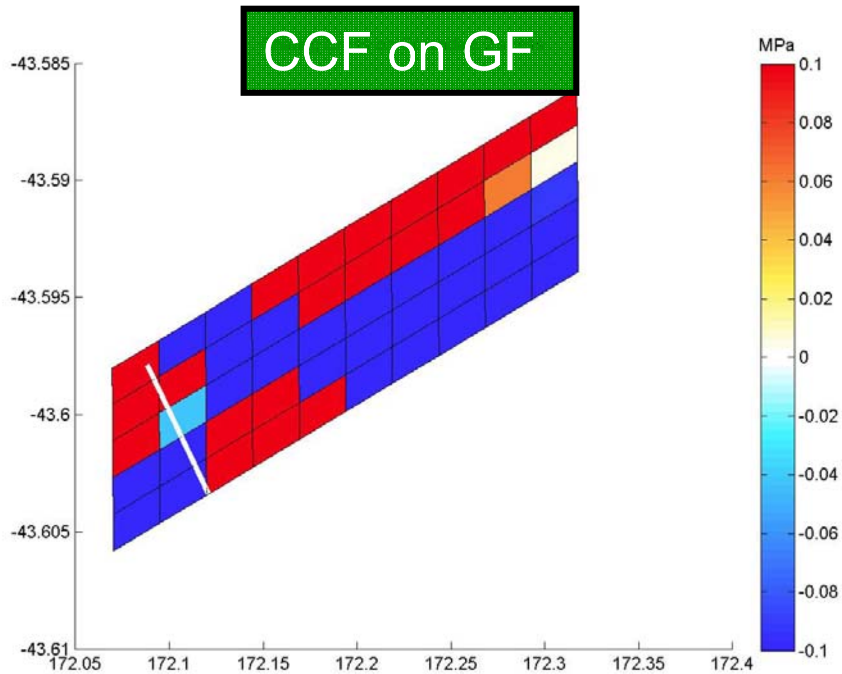
Defining fault avoidance zones

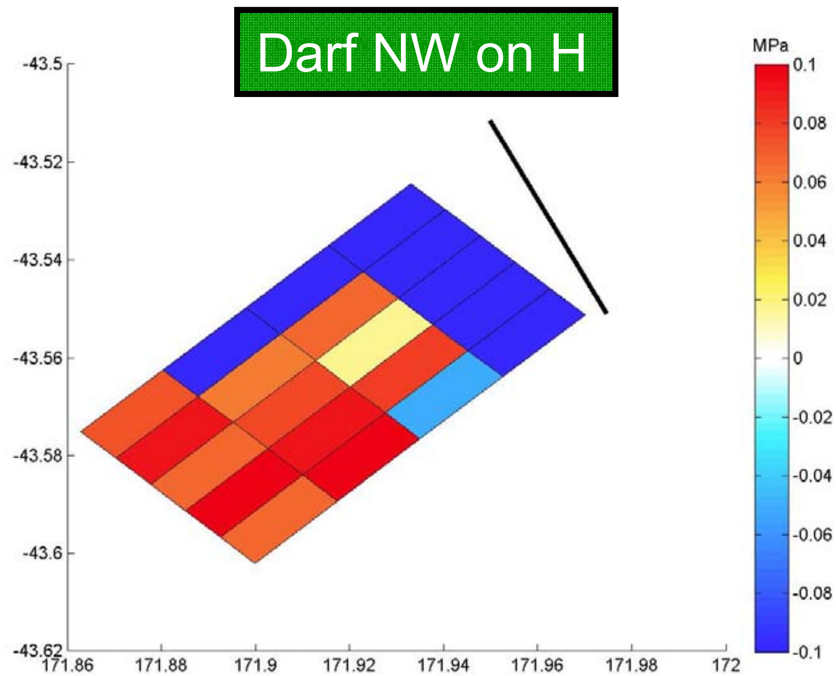
From point measurements to complex rupture scenarios: integrating Coulomb stress modelling into paleoseismic investigations

What happens if the dominoes topple the other way?

Coulomb 'static' stress evolution for rupture initiating on CCF

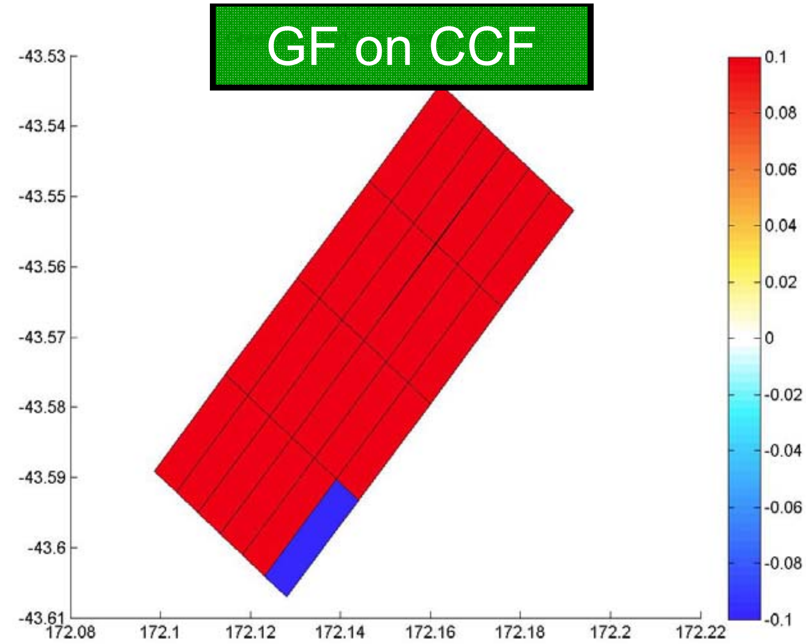


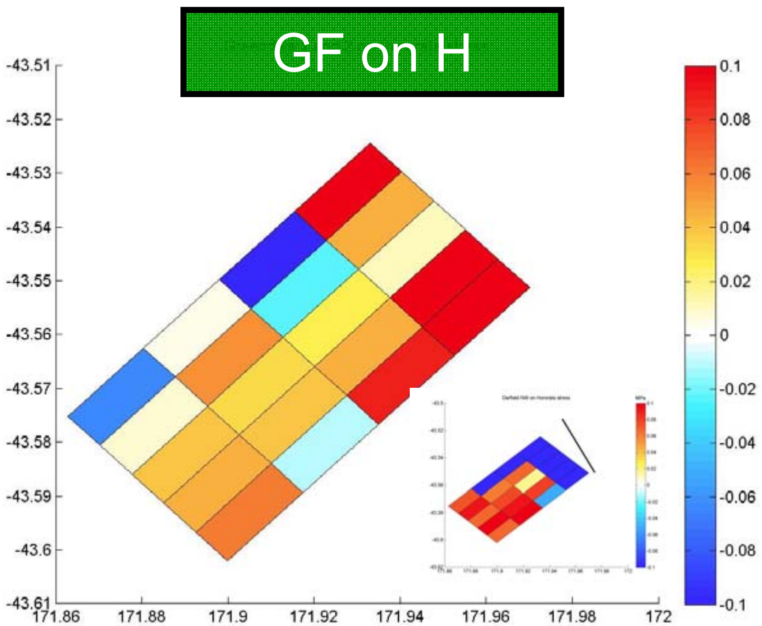


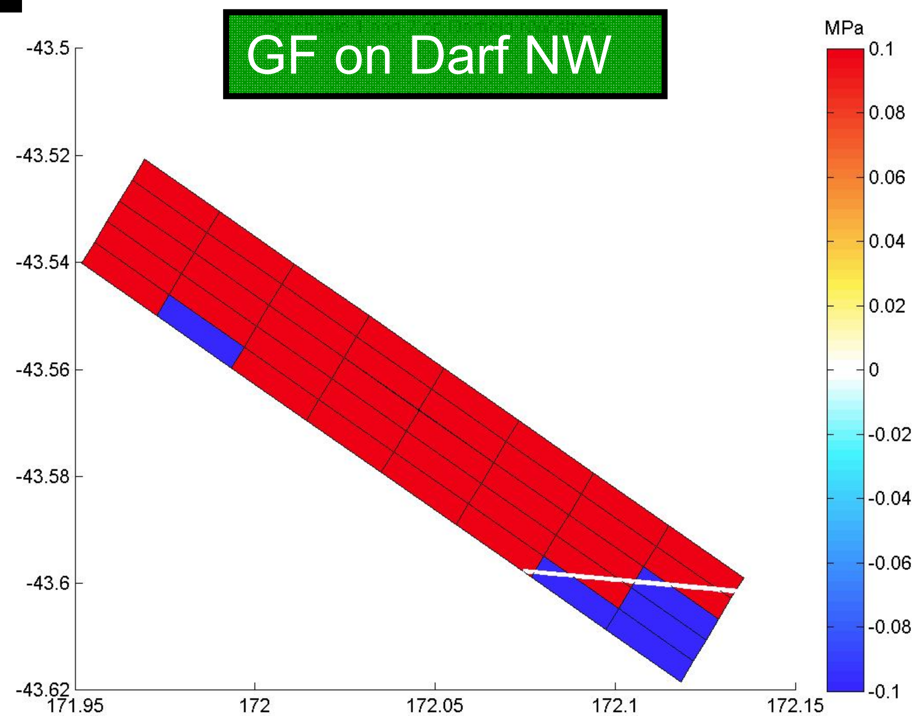


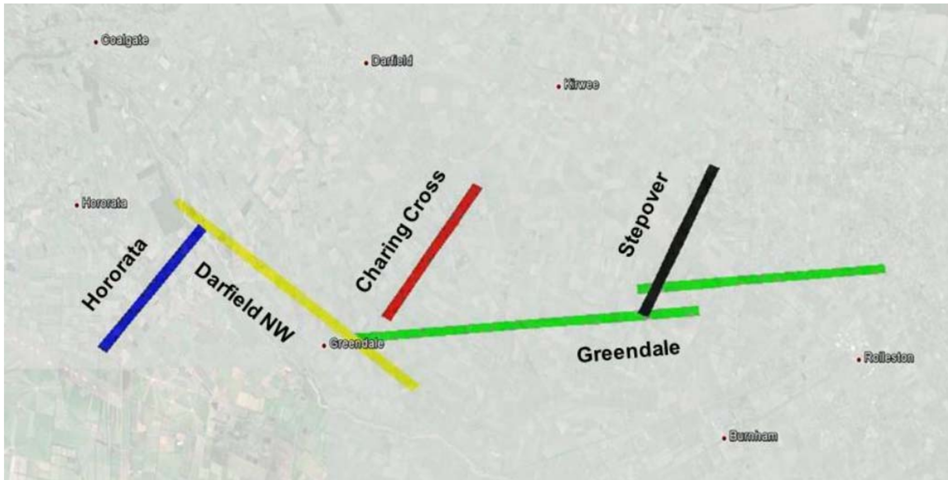
Courtesy: Abigail Jimenez, Sandy Steacy (Ulster)

Coulomb 'static' stress evolution for rupture initiating on GF

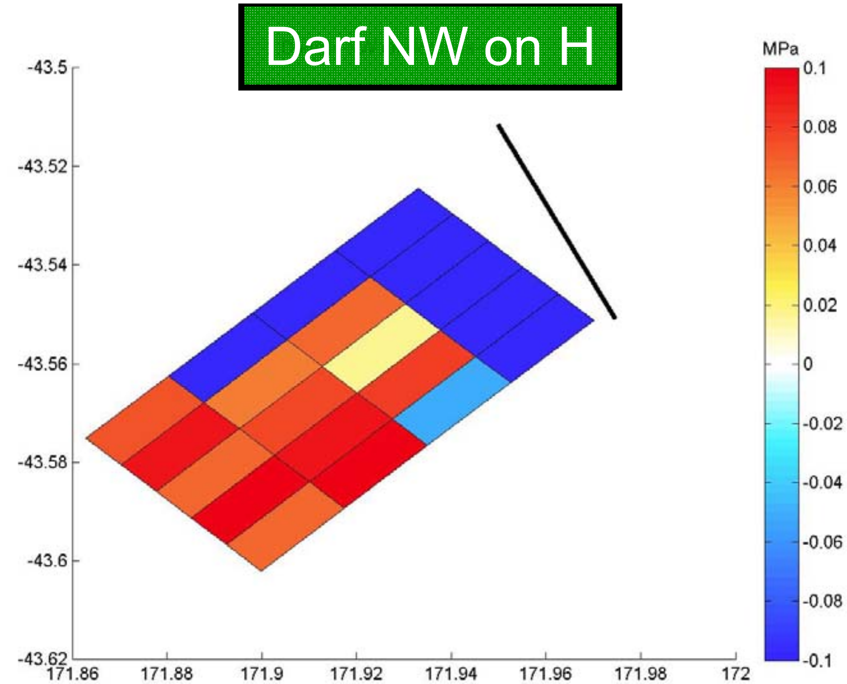


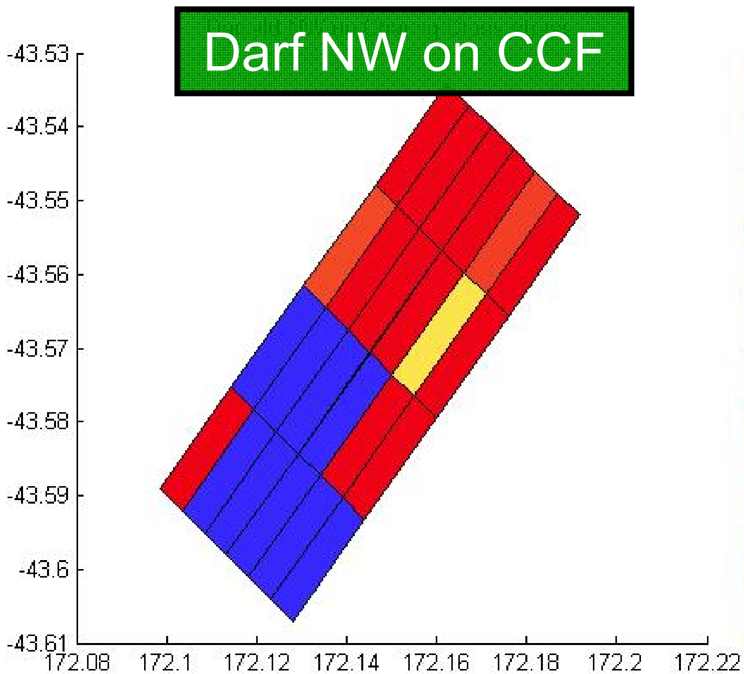


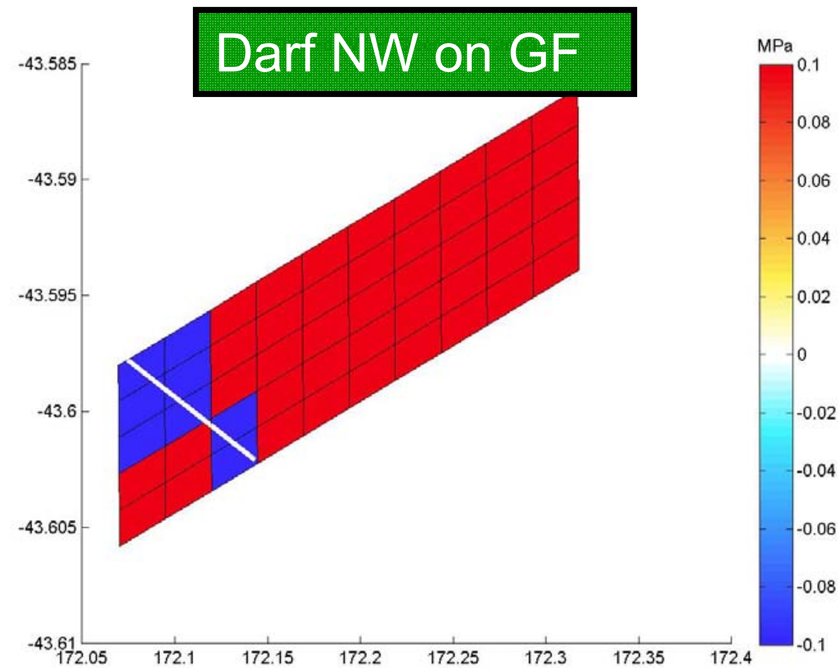




Coulomb 'static' stress evolution for rupture initiating on Darf NW



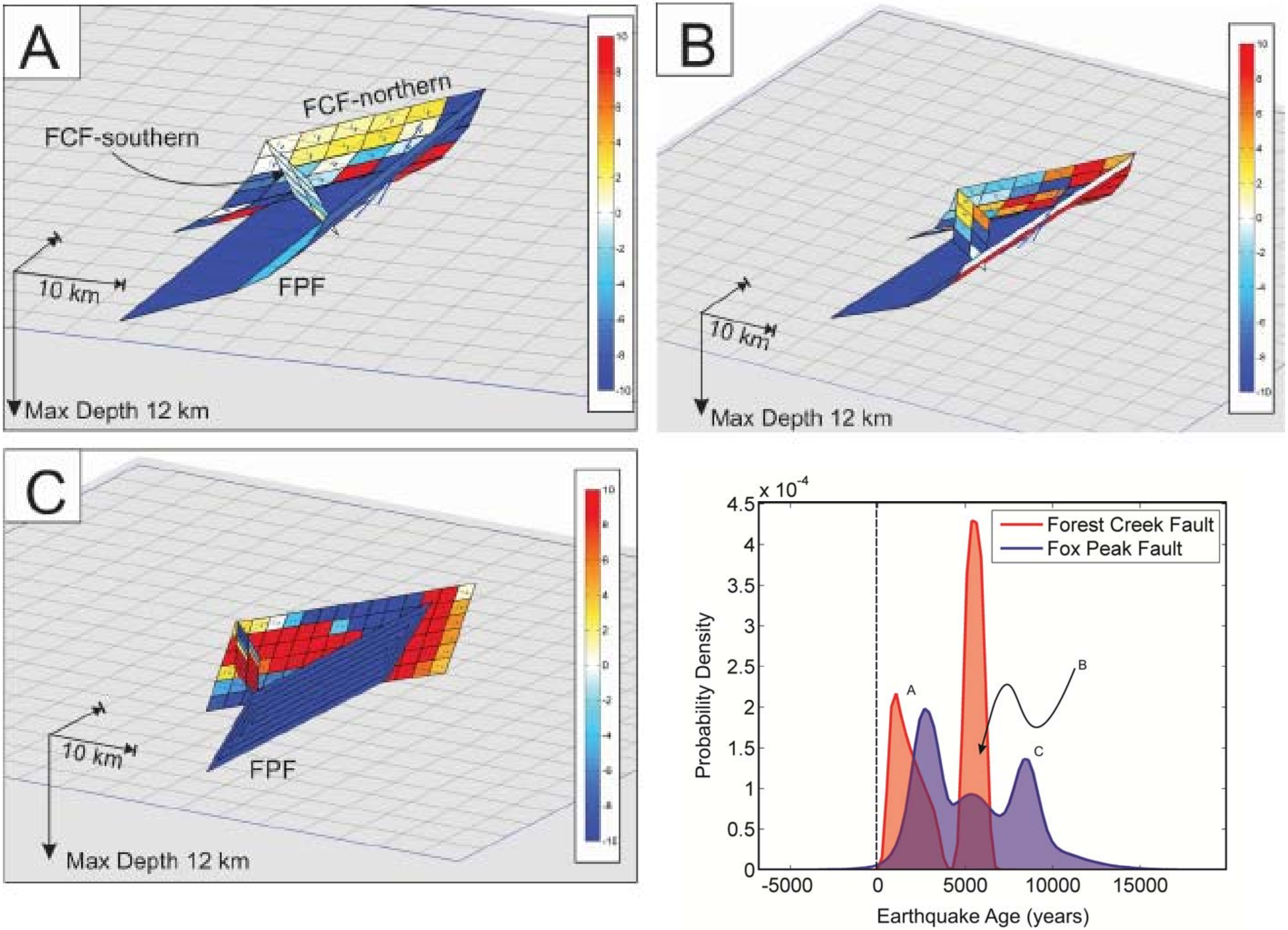


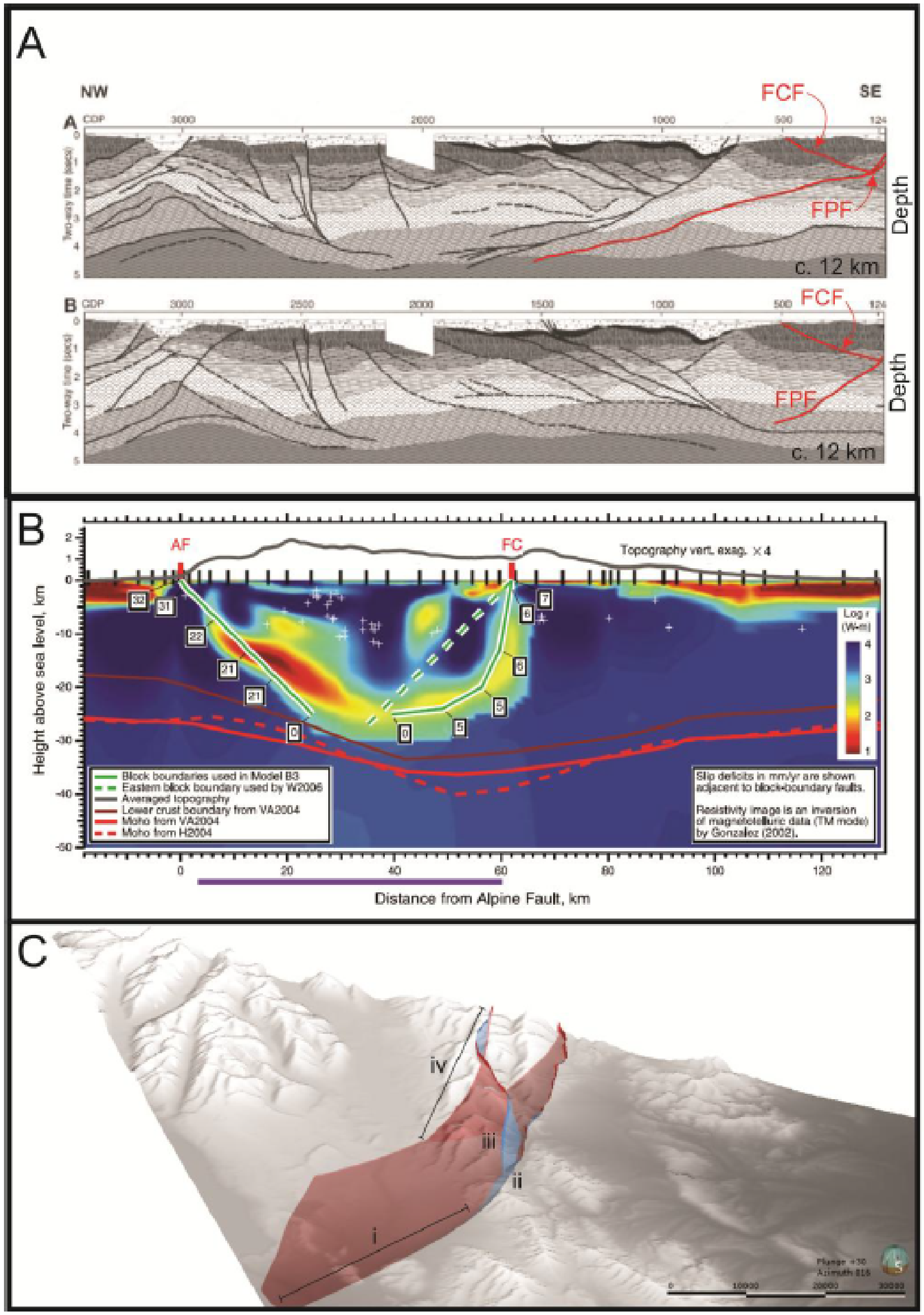


The Future: Probabilistic Determination the Maximum Mw of Fault Systems

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?


A
FCF-northern
FCF-southern
10 km
FPF
Max Depth 12 km
B
10 km
Max Depth 12 km
C
10 km
FPF
Max Depth 12 km
x 10^-4
Forest Creek Fault
Fox Peak Fault
Probability Density
Earthquake Age (years)
A
B
C
-5000
0
5000
10000
15000



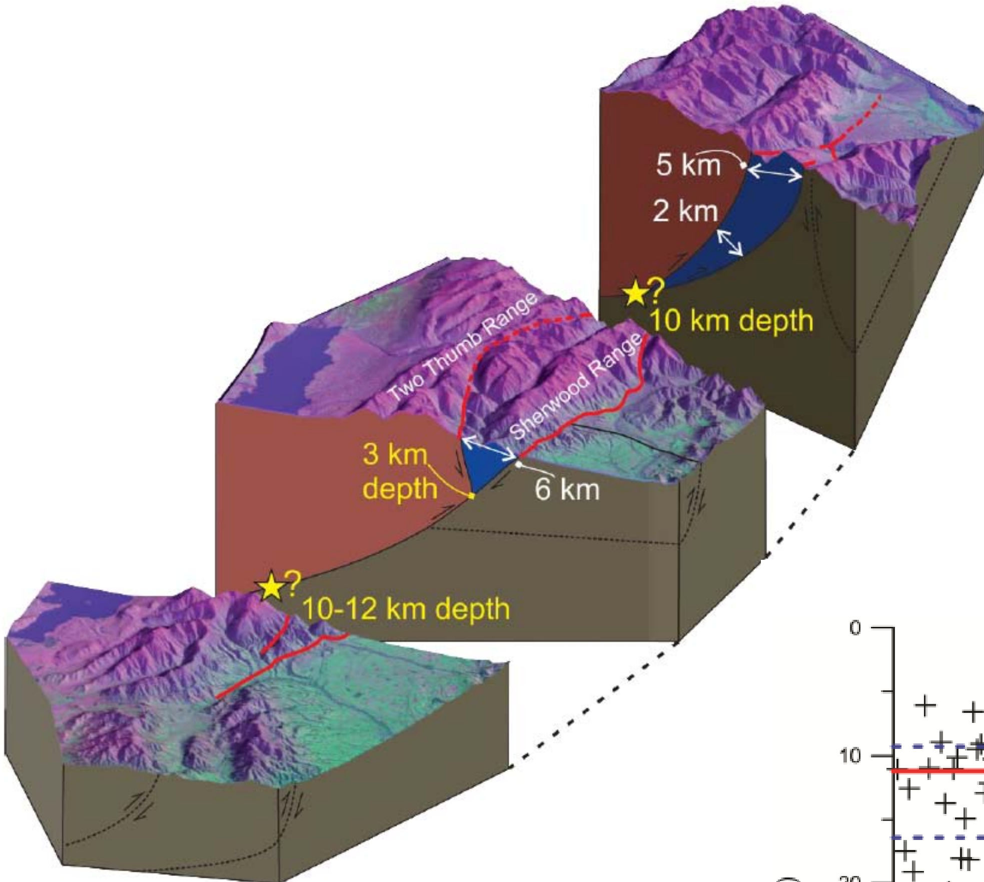
•Assemble all necessary data:

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

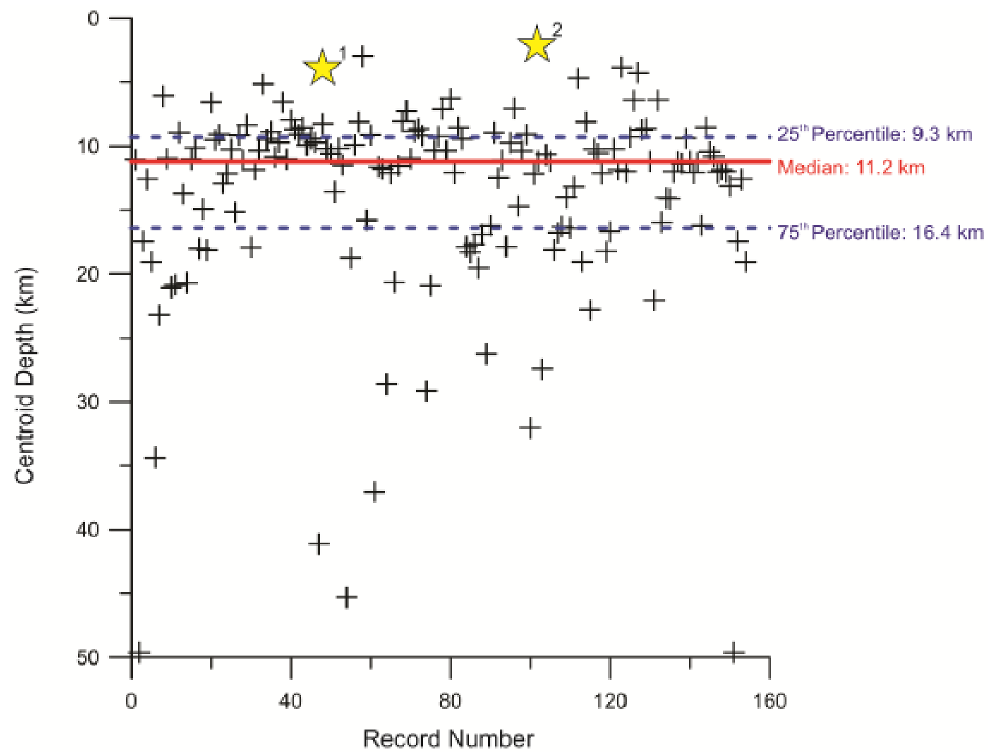
•Geophysical: fault geometry, structure, rock properties, historical hypocentral depths and subsurface earthquake slip

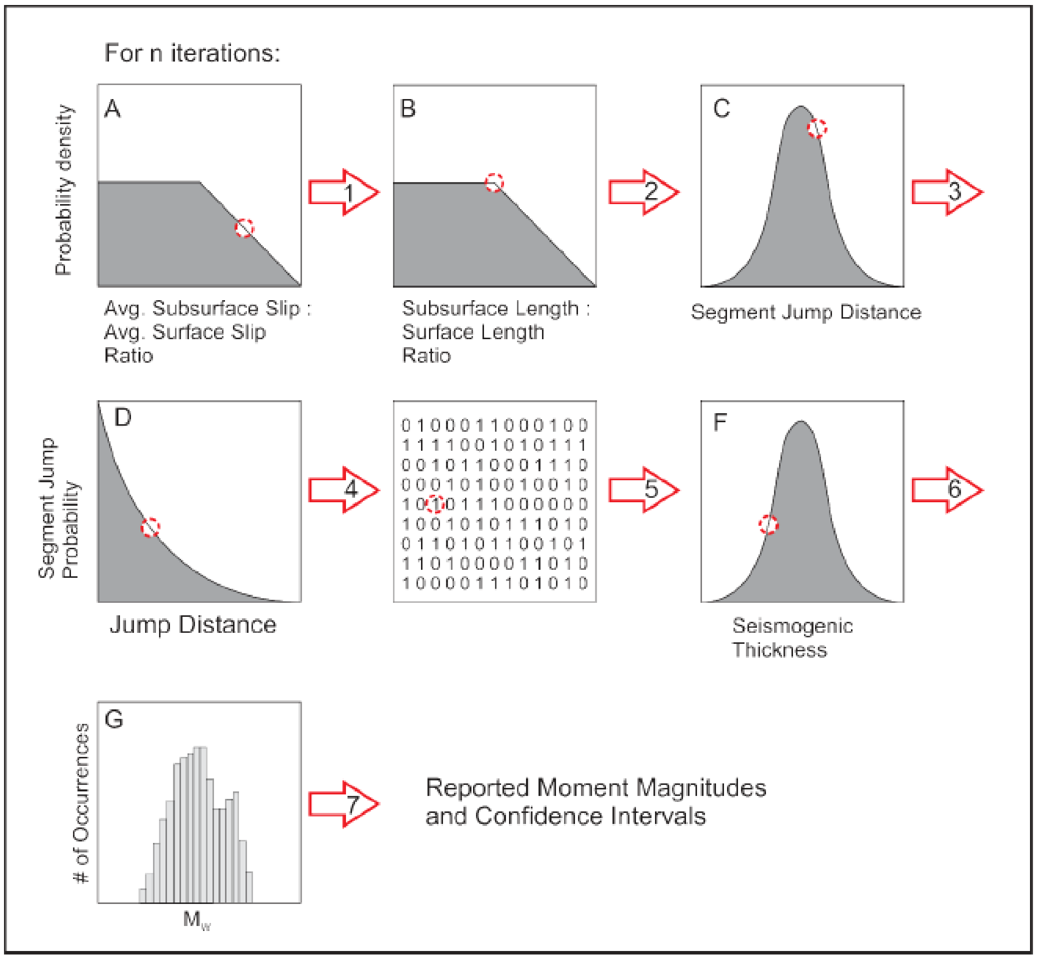
•Paleoseismic: SEDs, event ages, slip rates, etc.

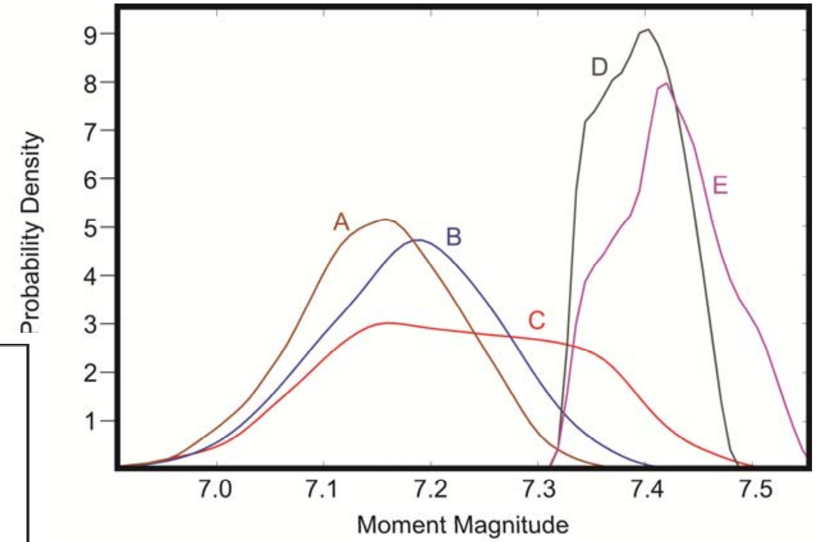
•Decide on a final fault model (e.g. C to the left, assembled from mapping and A & B)



•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 Mw

•Run several simulations for different fault geometries

•Output are distributions of Mw for different simulation runs

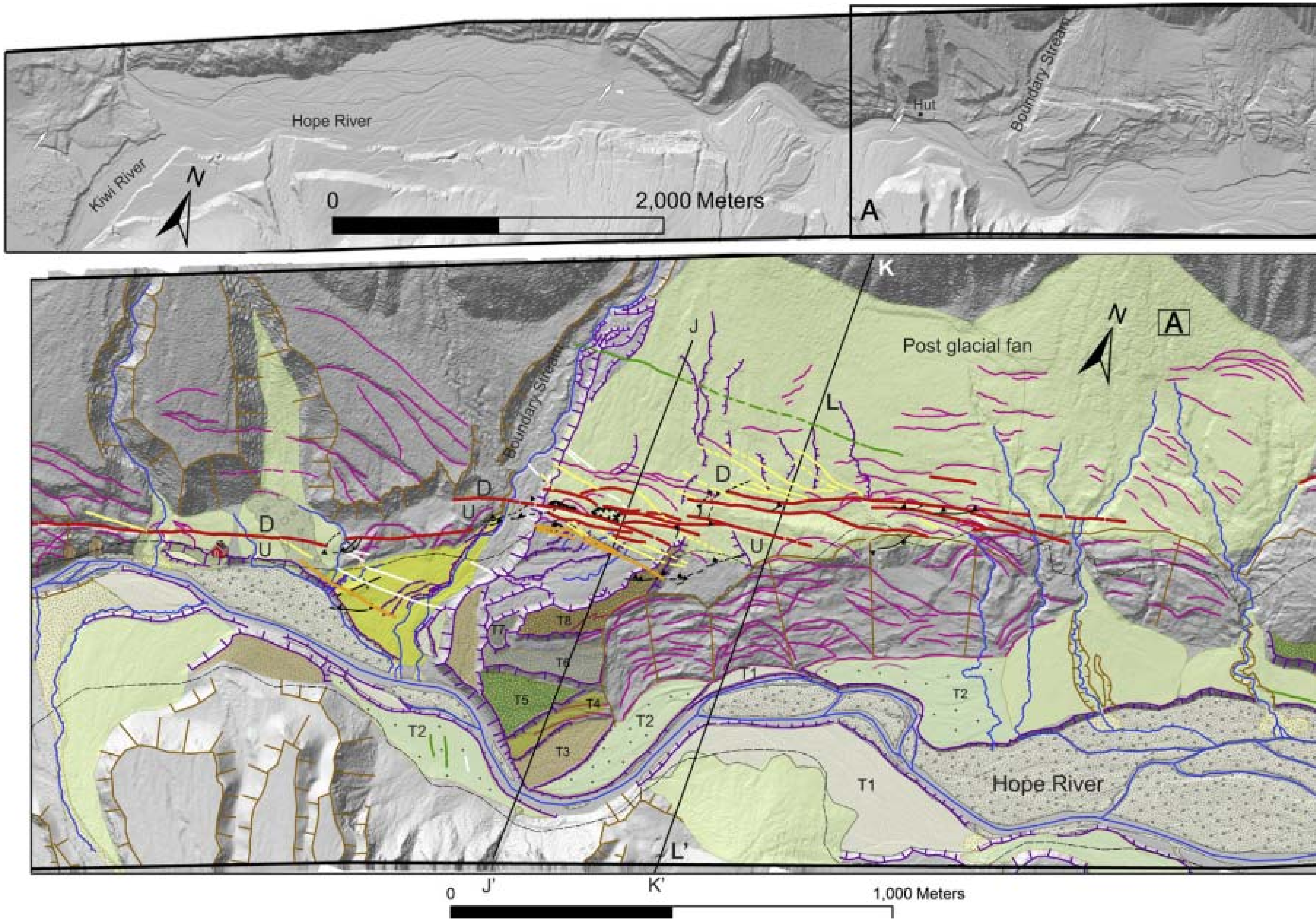
Additional Info on our Model

Input parameter	Shear modulus[a]	Average Surface Displacement[c d]	Subsurface:Surface Displacement Ratio[a,b,c,d]	FPF Area (listric)[d,h,i,k]	FCF Area (listric)[d,h]	Jump Distance[g,h,i,j]	R_0[gl]	FPF Surface Length	FCF Surface Length	Subsurface: Surface Length Ratio	Fault dip	Seismogenic thickness (ST)[a,d]
Model PDF	Fixed	Fixed, Calculated from field mapping	Trapezoidal	Fixed from model	Fixed from model	Normal	Fixed	Fixed	Fixed	Trapezoidal	Fixed from field mapping, geophysics	Normal
PDF constraints*	2.7E11	2 m	1-1-4/3-5/3	2046 km^2	585 km^2	2.5 (± 2.5) km	3	35.7	0, 15, 40	1-1-4/3-5/3	FPF: 55° @ 0-5 km; 30° @ 5-ST km; FCF: 55° @ 0-ST km	12 (± 2) km

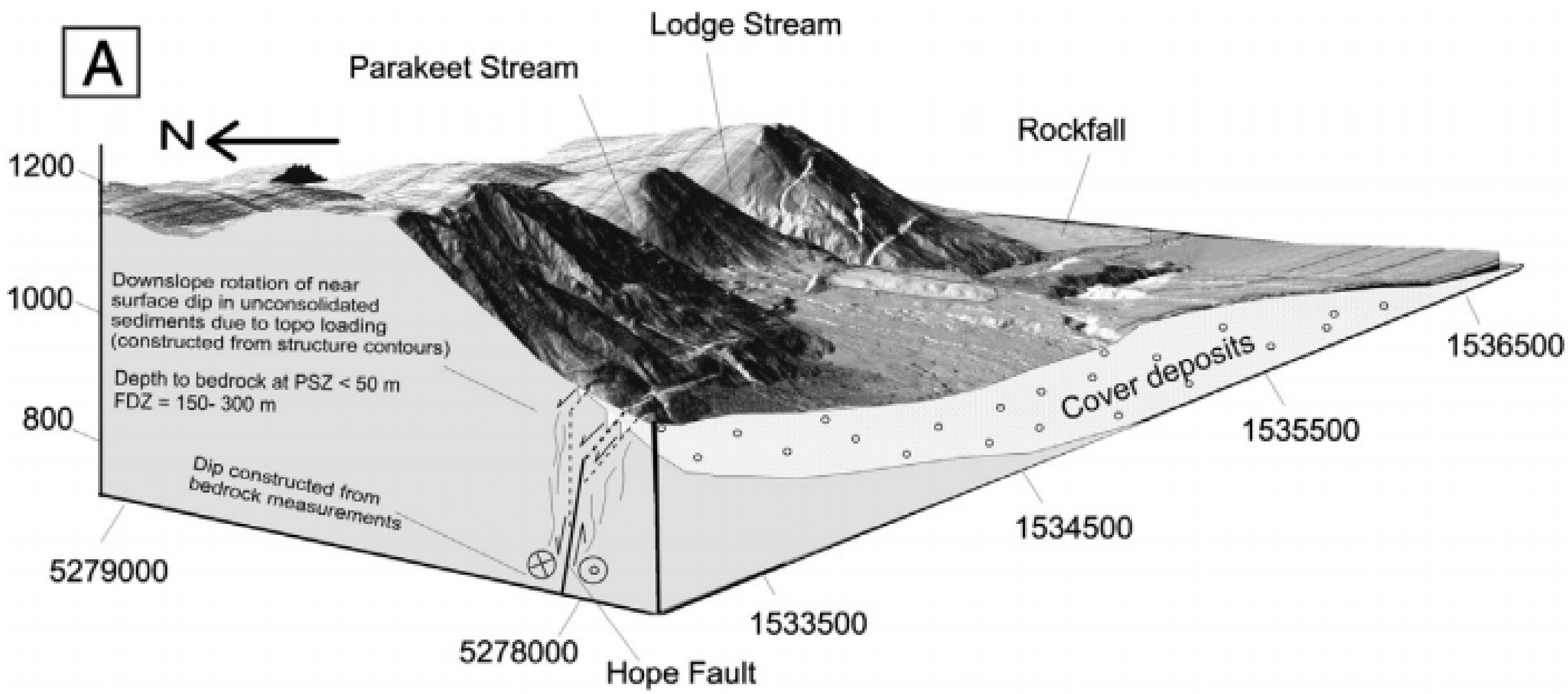
The Future:

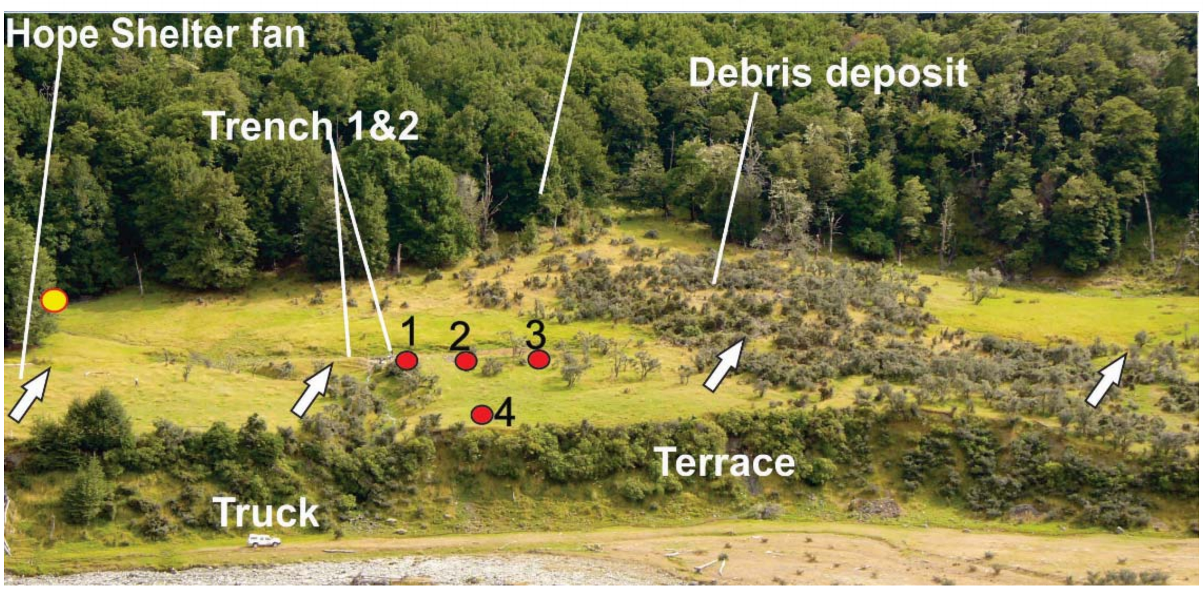
LiDAR-informed detailed rupture trace mapping coupled with probabilistic paleoseismology

Narges Khajavi, current PhD student, looking for Postdoctoral Research!

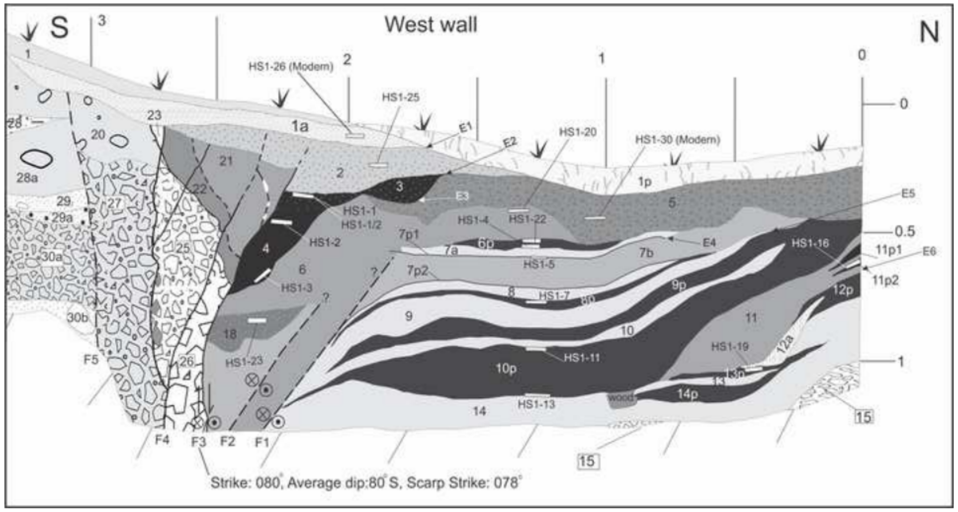


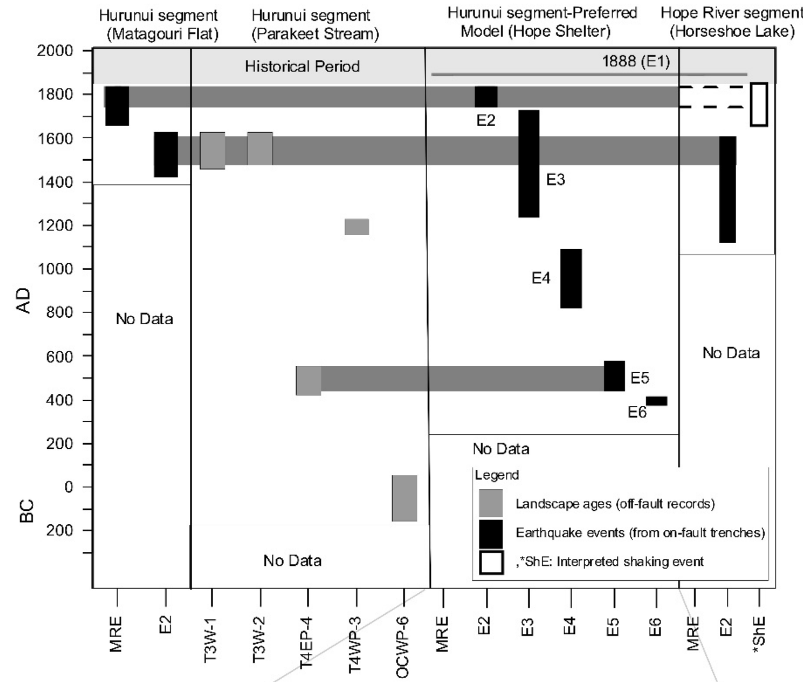
Hope River
Kiwi River
N
0
2,000 Meters
Hut
Boundary Stream
A
K
J
L
N
A
Post glacial fan
Boundary Stream
D
U
D
U
D
U
T8
T7
T6
T5
T4
T3
T2
T2
T1
T2
T1
Hope River
J'
K'
L'
0
1,000 Meters

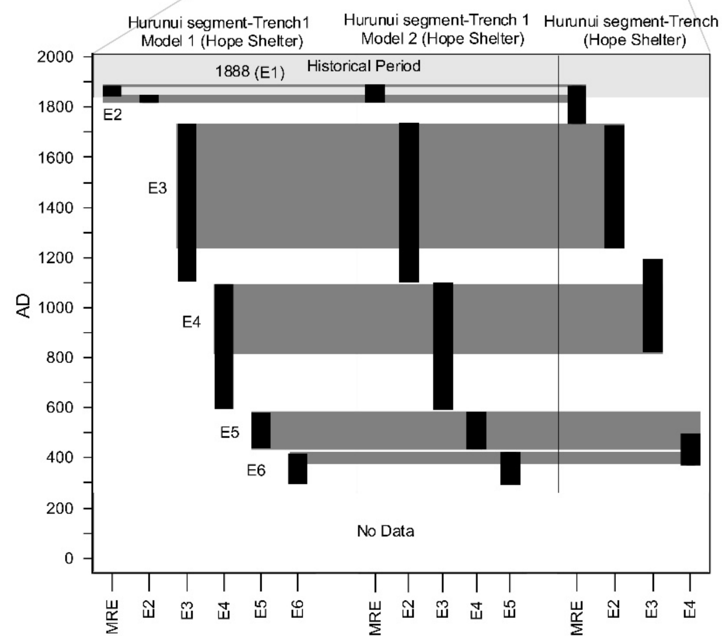




Careful site selection, densely spaced trenching

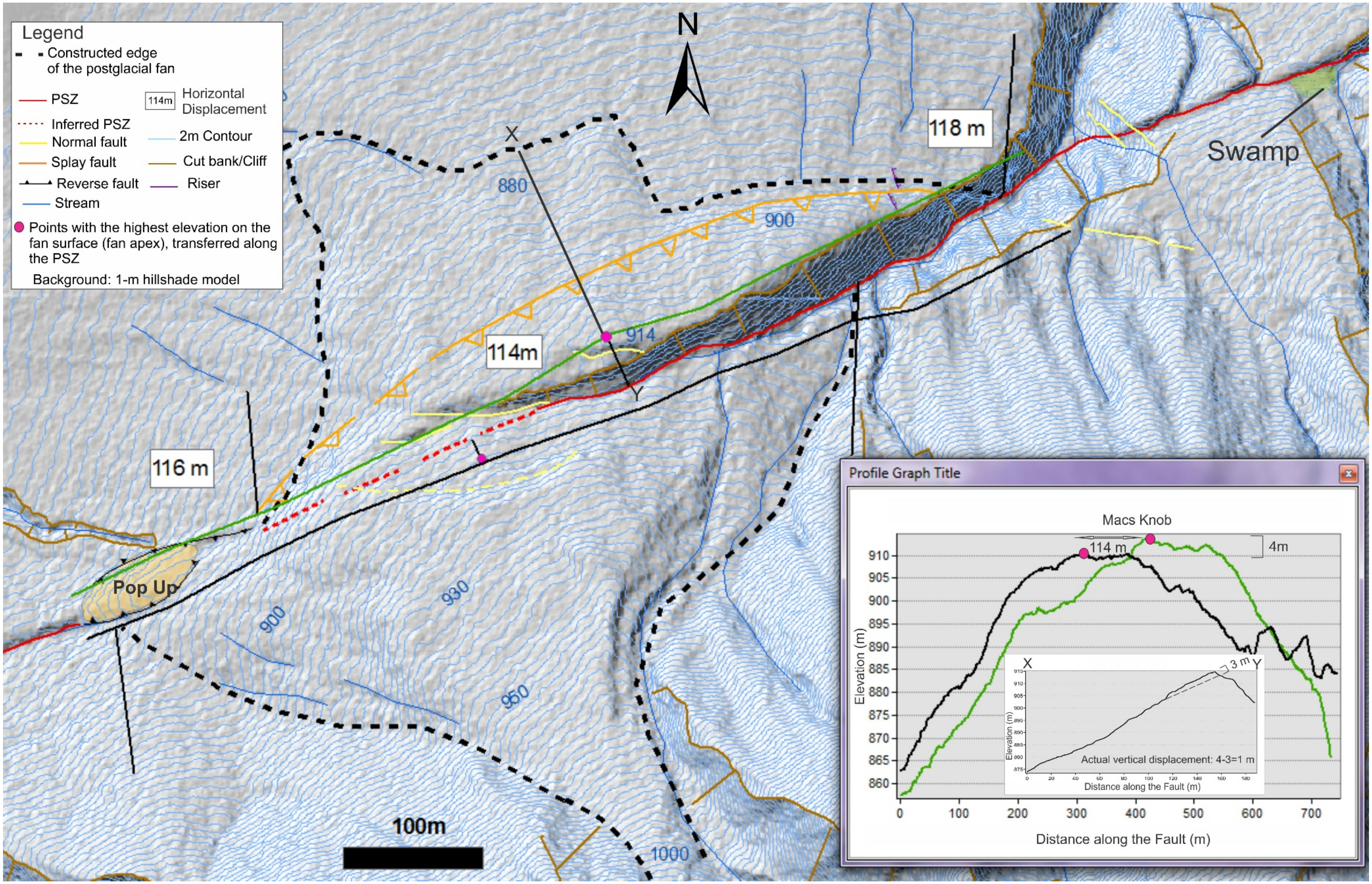






Trench site correlations with full uncertainty limits

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)

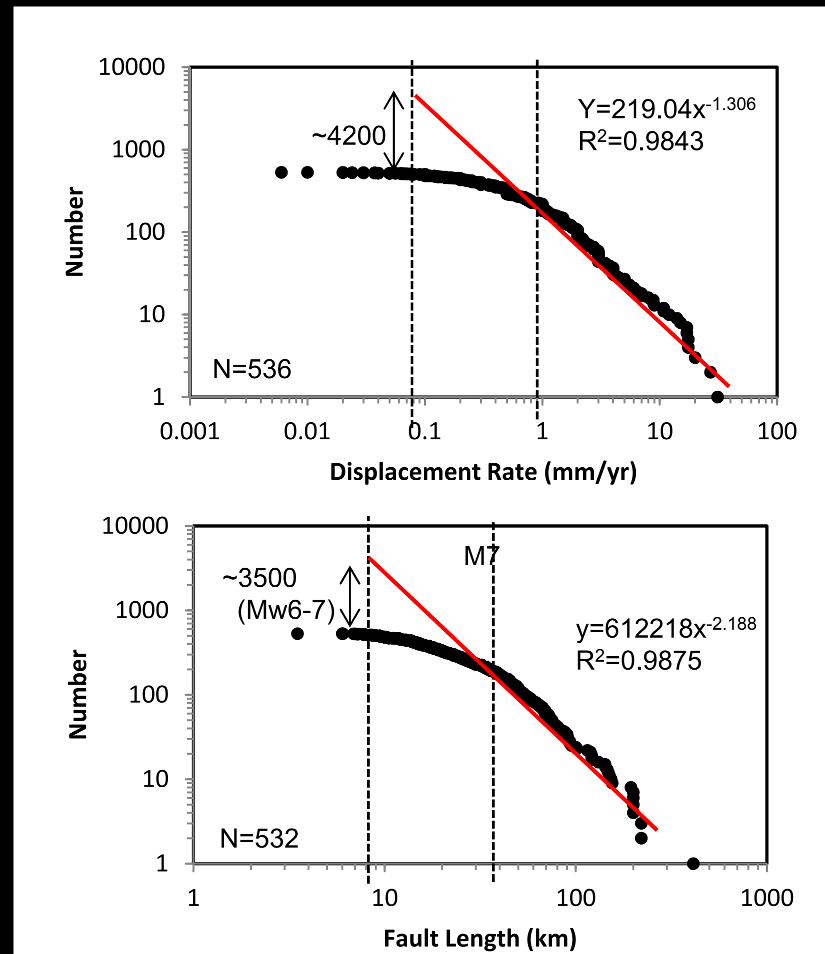
- Paleoseismic trenches well located, well mapped, stratigraphy well dated
  - Error reporting and uncertainty bounds with respect to timing of past seismic events? *(e.g. '2000 yr BP' vs '1500±500 yr BP'?)*
  - Consideration of trench 3-dimensional displacements? Consideration of 'apparent vertical'? 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

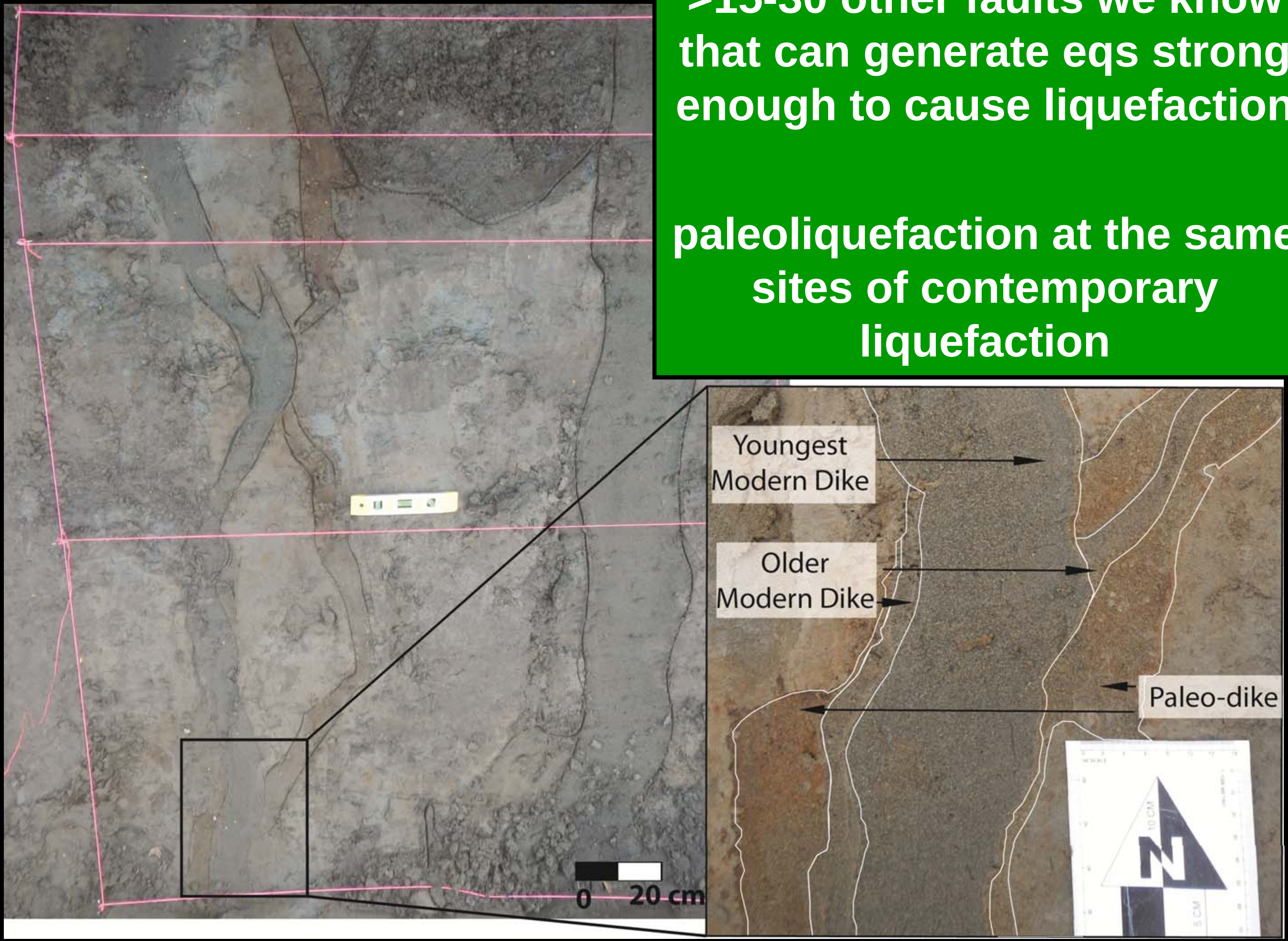


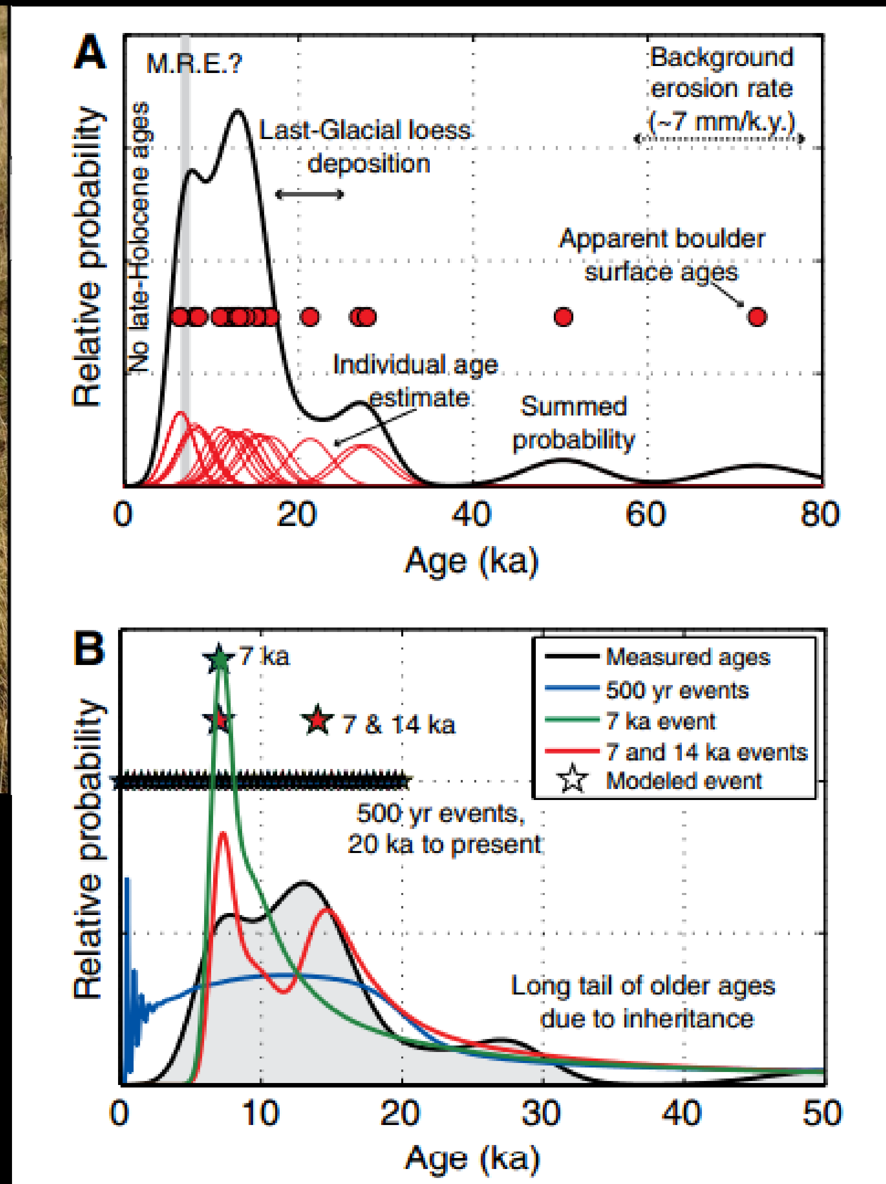
Pettinga et al 2001; Nicol et al 2011

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

>15-30 other faults we know that can generate eqs strong enough to cause liquefaction

paleoliquefaction at the same sites of contemporary liquefaction

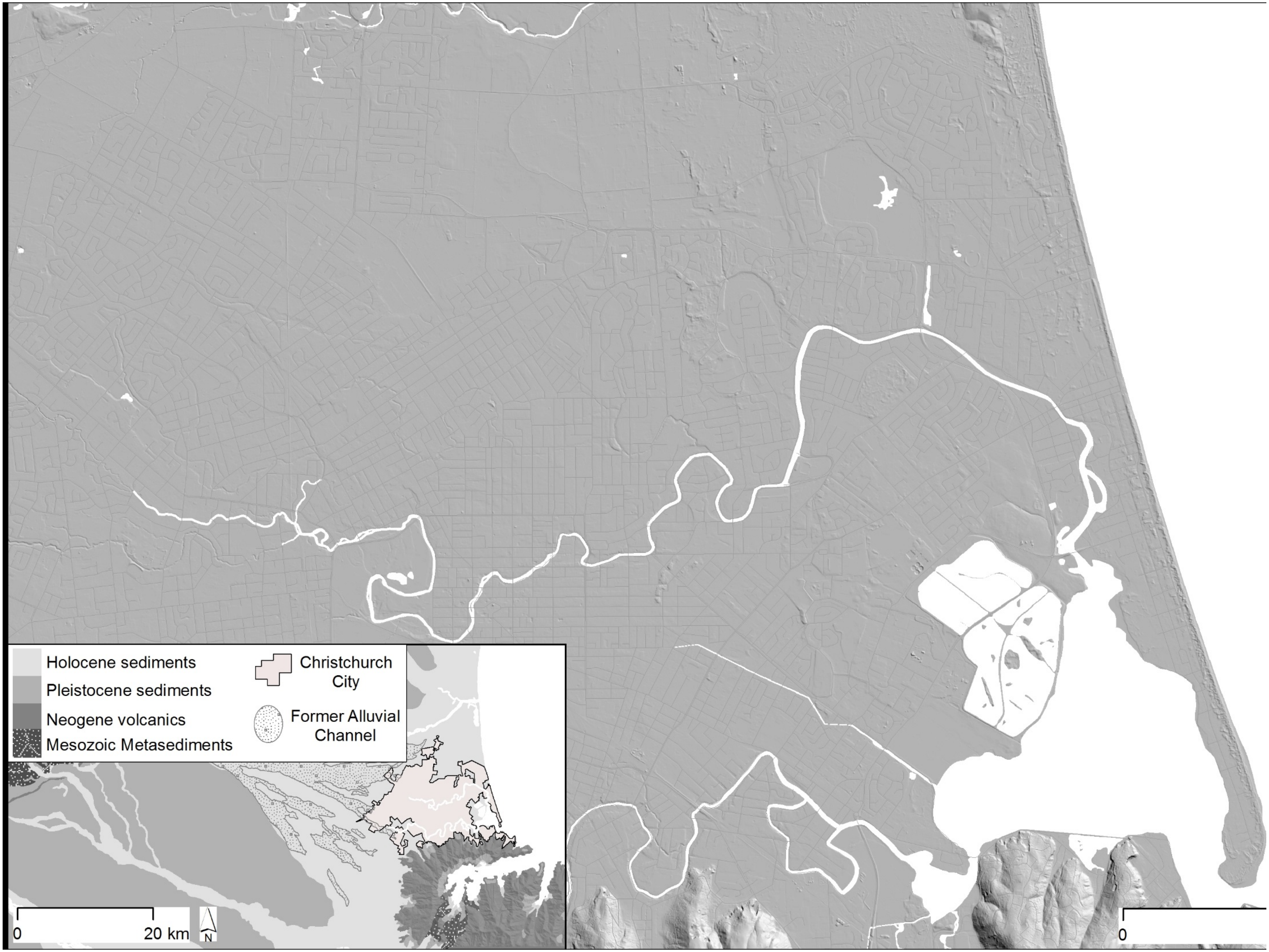




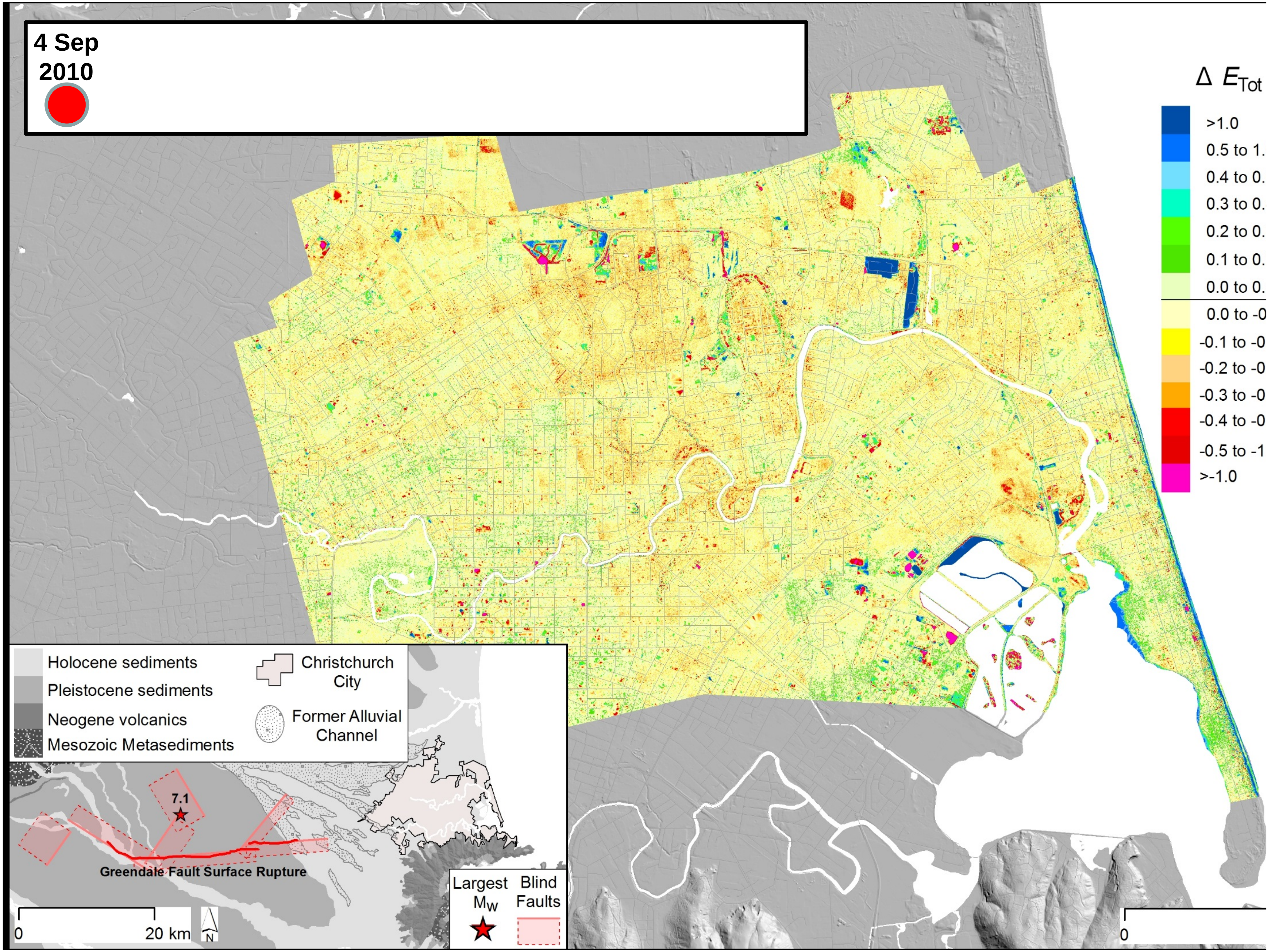
~6 ka hiatus since penultimate rockfall encompasses many earthquakes on largest known sources

Penultimate Greendale Fault event ca. 25 kyr ago, proximal strong shaking RI << nearest source RI identifiable from surface evidence

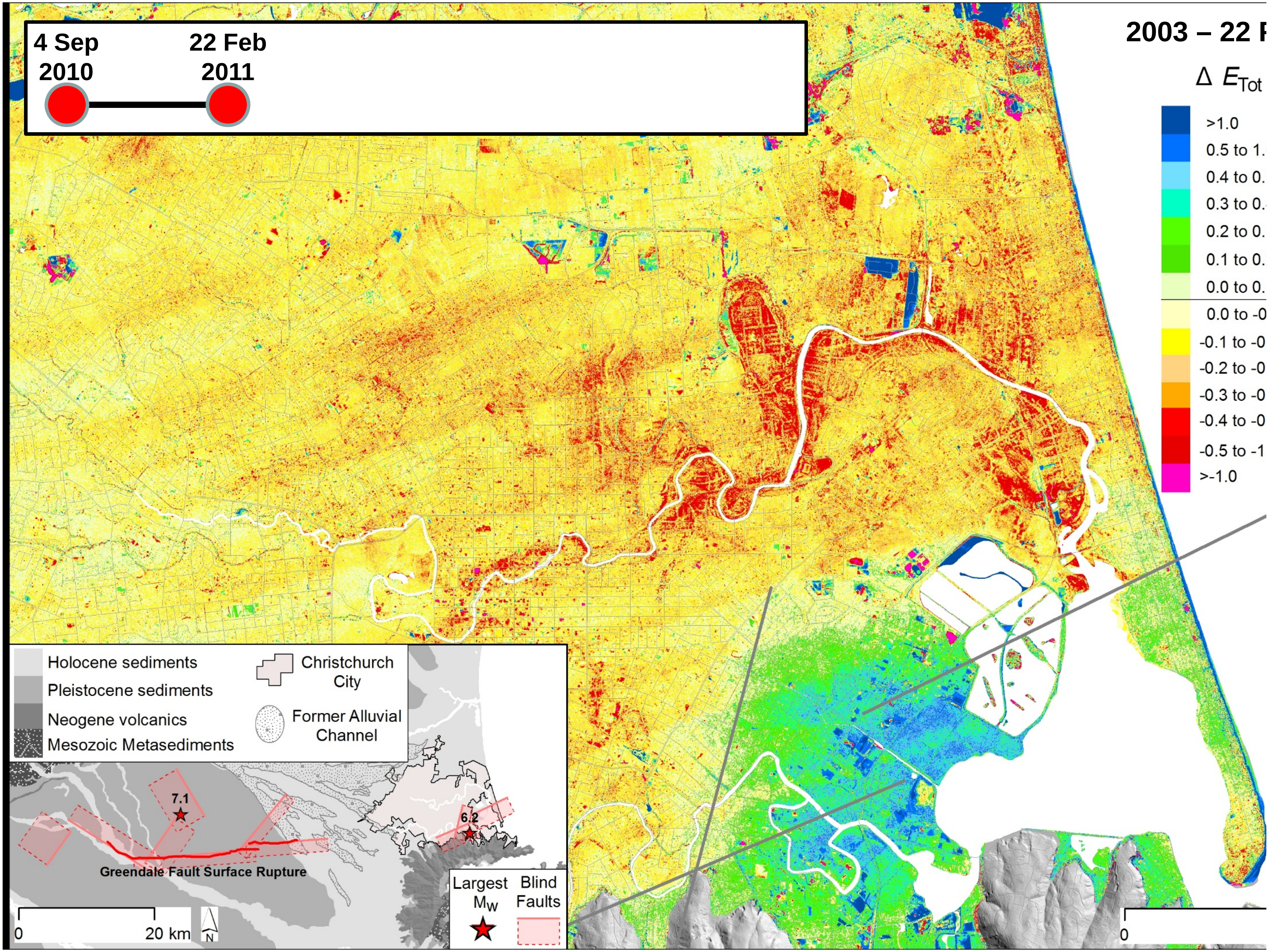
Mackey, B., and Quigley, M., (2014) Strong proximal earthquakes revealed by cosmogenic ^{3}He dating of prehistoric rockfalls, Christchurch, New Zealand, *Geology*

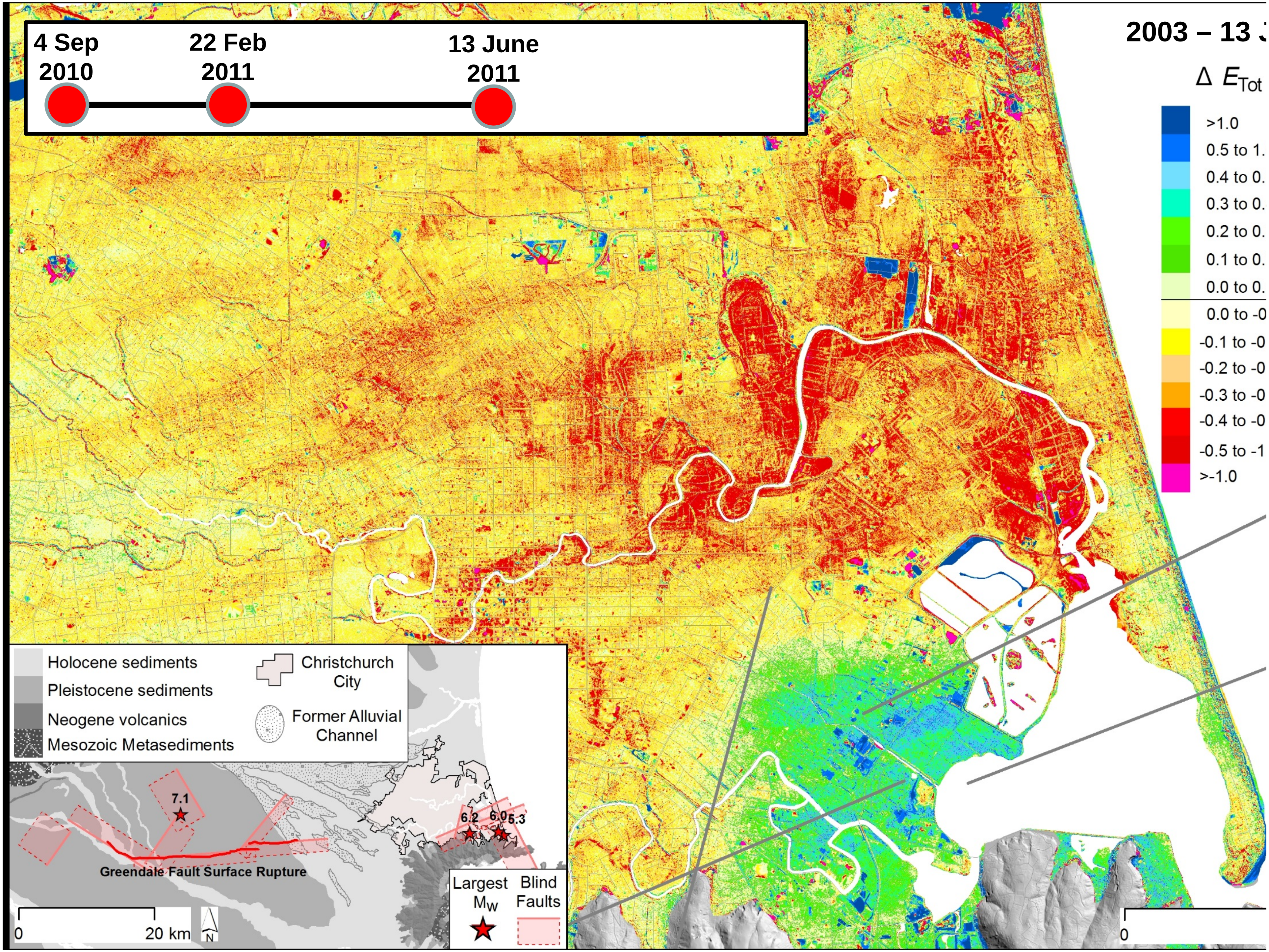


Holocene sediments
Pleistocene sediments
Neogene volcanics
Mesozoic Metasediments
Christchurch City
Former Alluvial Channel
0
20 km
N
0

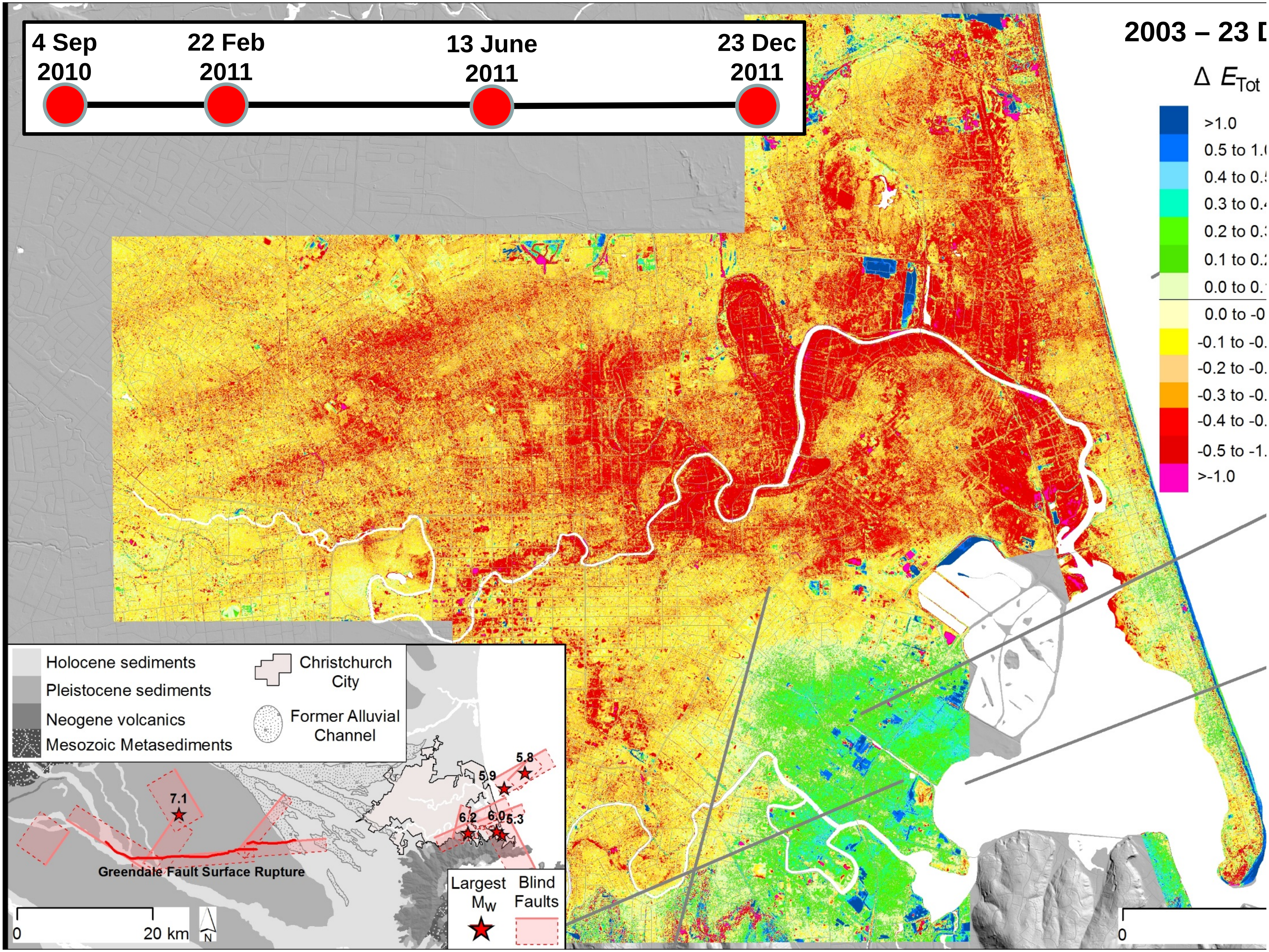


4 Sep
2010
Δ E_{Tot}
>1.0
0.5 to 1.
0.4 to 0.
0.3 to 0.
0.2 to 0.
0.1 to 0.
0.0 to 0.
0.0 to -0
-0.1 to -0
-0.2 to -0
-0.3 to -0
-0.4 to -0
-0.5 to -1
>-1.0
Holocene sediments
Pleistocene sediments
Neogene volcanics
Mesozoic Metasediments
Christchurch City
Former Alluvial Channel
7.1
Greendale Fault Surface Rupture
0
20 km
N
Largest M_W
Blind Faults
0


4 Sep
2010
22 Feb
2011
2003 – 22 F
Δ E_{Tot}
>1.0
0.5 to 1.
0.4 to 0.
0.3 to 0.
0.2 to 0.
0.1 to 0.
0.0 to 0.
0.0 to -0
-0.1 to -0
-0.2 to -0
-0.3 to -0
-0.4 to -0
-0.5 to -1
>-1.0
Holocene sediments
Pleistocene sediments
Neogene volcanics
Mesozoic Metasediments
Christchurch City
Former Alluvial Channel
7.1
6.2
Greendale Fault Surface Rupture
0
20 km
N
Largest M_W
Blind Faults
0



4 Sep 2010
22 Feb 2011
13 June 2011
2003 – 13 J
Δ E_{Tot}
>1.0
0.5 to 1.
0.4 to 0.
0.3 to 0.
0.2 to 0.
0.1 to 0.
0.0 to 0.
0.0 to -0
-0.1 to -0
-0.2 to -0
-0.3 to -0
-0.4 to -0
-0.5 to -1
>-1.0
Holocene sediments
Pleistocene sediments
Neogene volcanics
Mesozoic Metasediments
Christchurch City
Former Alluvial Channel
7.1
6.2
6.0
5.3
Greendale Fault Surface Rupture
Largest M_W
Blind Faults
0
20 km
N
0



4 Sep 2010
22 Feb 2011
13 June 2011
23 Dec 2011
2003 – 23 D
Δ E_{Tot}
>1.0
0.5 to 1.
0.4 to 0.
0.3 to 0.
0.2 to 0.
0.1 to 0.
0.0 to 0.
0.0 to -0
-0.1 to -0.
-0.2 to -0.
-0.3 to -0.
-0.4 to -0.
-0.5 to -1.
>-1.0
Holocene sediments
Pleistocene sediments
Neogene volcanics
Mesozoic Metasediments
Christchurch City
Former Alluvial Channel
7.1
5.8
5.9
6.2
6.0
5.3
Greendale Fault Surface Rupture
0
20 km
N
Largest M_W
Blind Faults
0

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