Predicting and reducing the impacts of future earthquakes

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ICSU Auckland, Sept 3, 2014

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

EQC EARTHQUAKE COMMISSION
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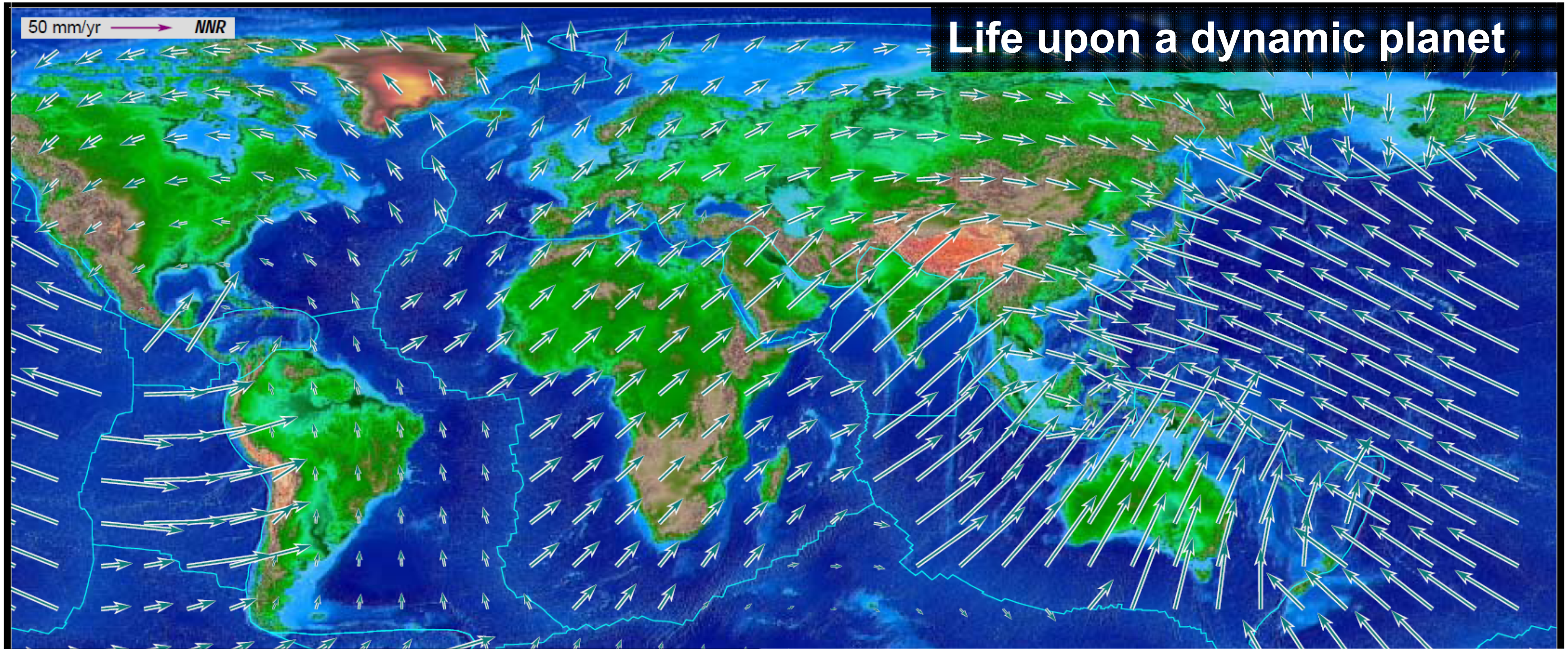
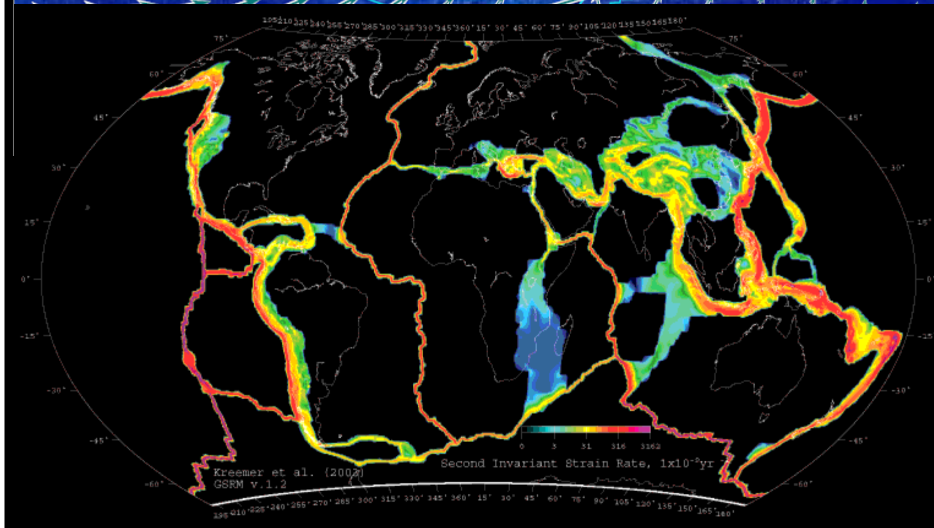
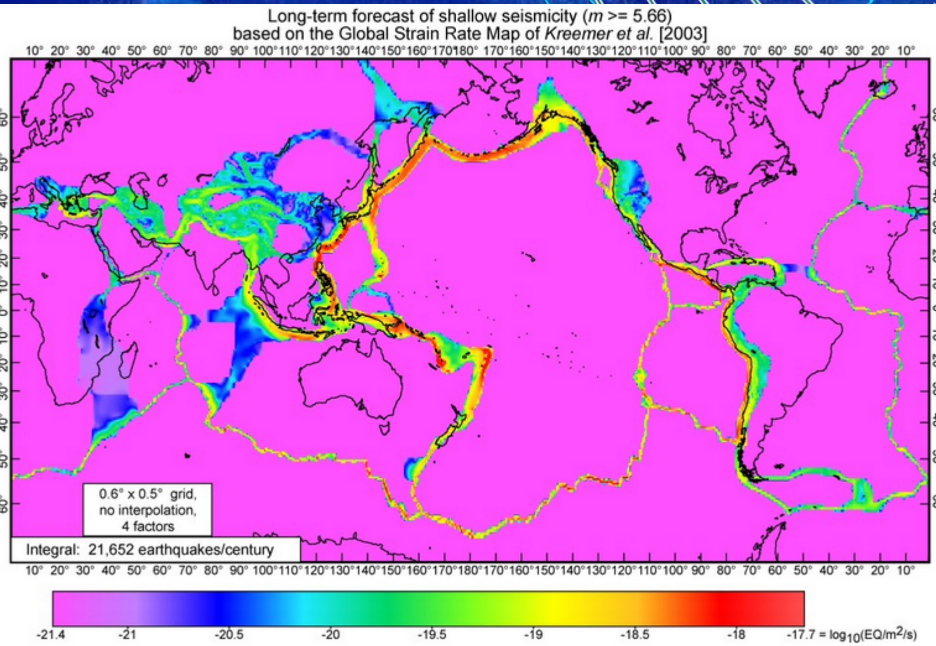
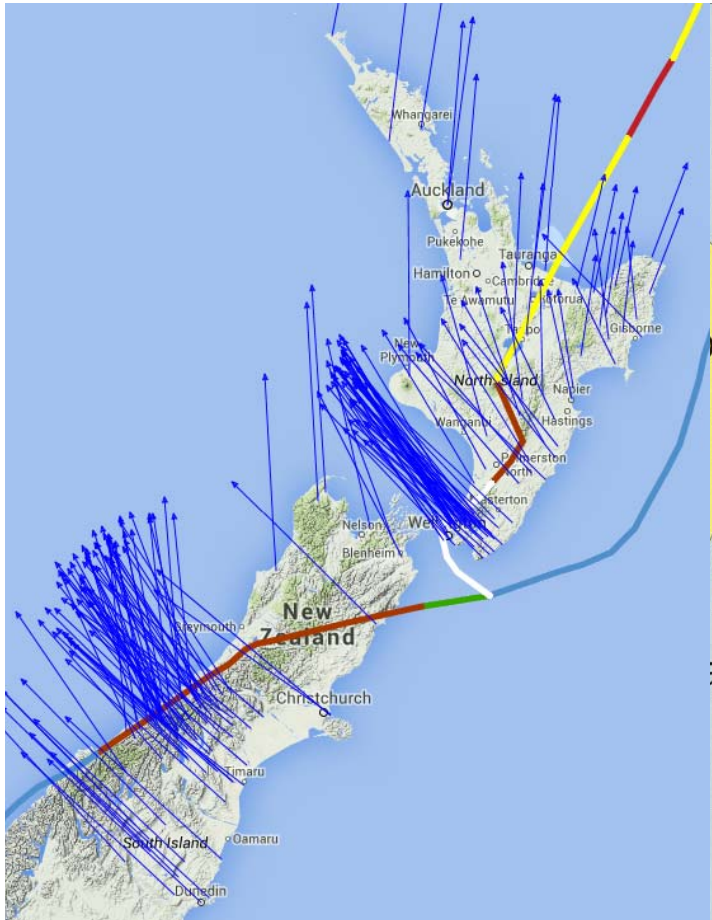
Life upon a dynamic planet

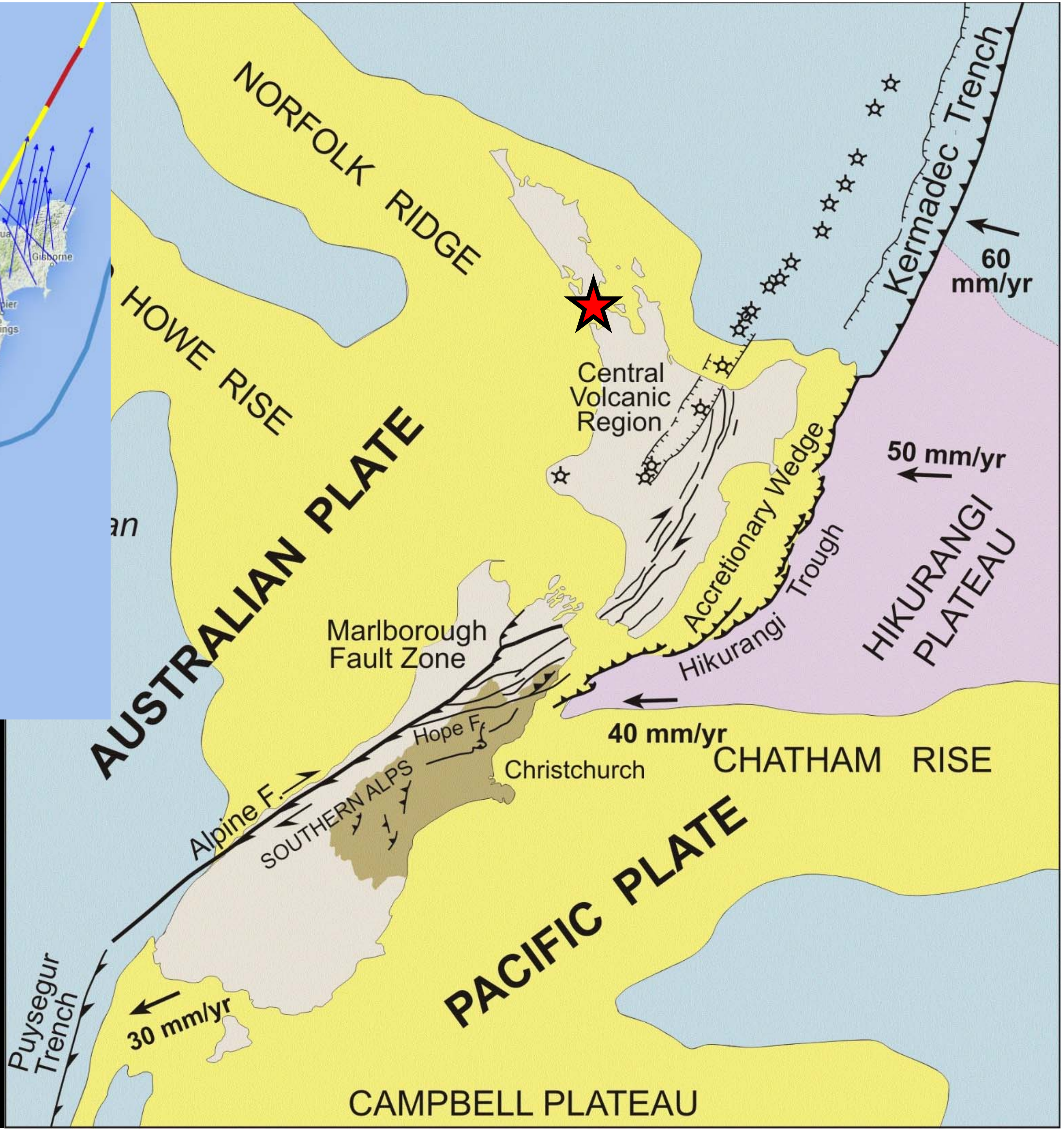




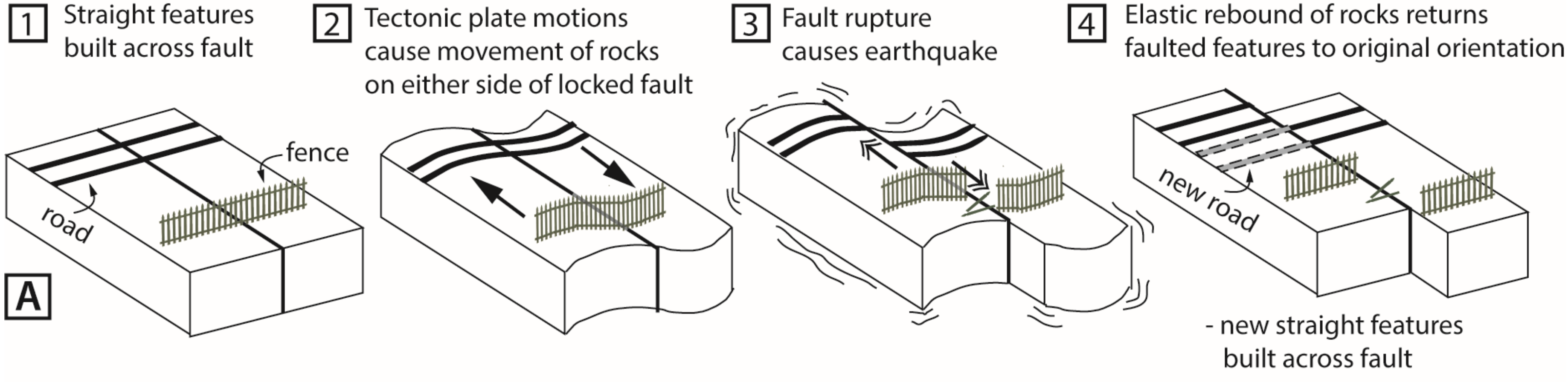


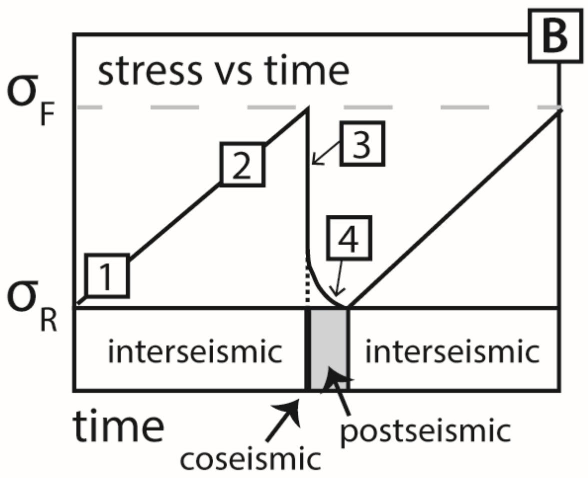
Kreemer et al., 2003; Bird et al 2010; UNAVCO





Life on a tectonic plate boundary





The earthquake cycle

Elastic rebound on the Hope Fault in the 1888 Amuri earthquake

Photo of son with laterally displaced fenceline: Alexander McKay geologist

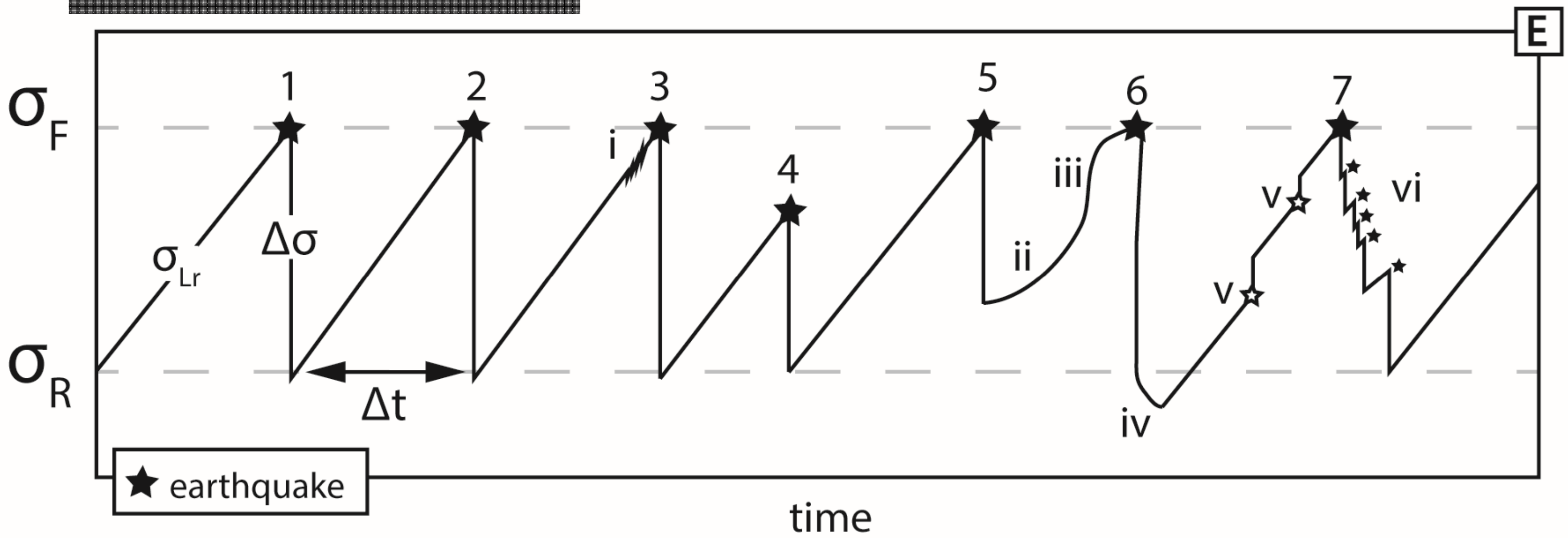
Geologic investigations:

Earthquakes don't keep on a tight schedule, aren't always the same magnitude, and some faults are better behaved than others

Hornblow, Quigley, et al in review

Complex interactions within fault networks, temporal and spatial changes in fault properties and fluid pressures, changes in stress loading rates, multitude of earthquake triggering mechanisms challenge our ability to predict* earthquakes

THE REALITY

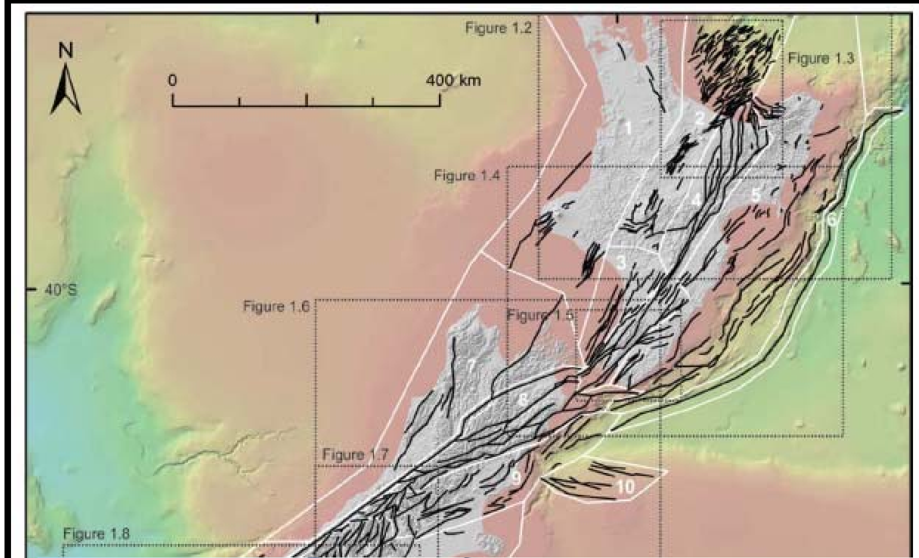


*specification of the time, location (including depth), and magnitude of future earthquakes in a specified area within stated confidence limits

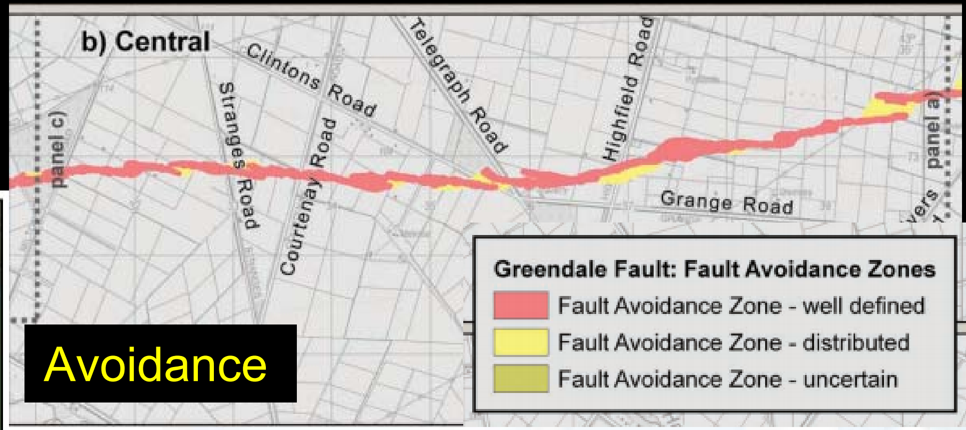
**no reliable short-term earthquake prediction scheme presently exists, and many scientists believe that eq prediction at a confidence level required for evacuations or other short-term measures will never be possible

Quigley and Duffy, 2014

So what can science do?



Acknowledgement of data incompleteness and need for well built structures



Avoidance

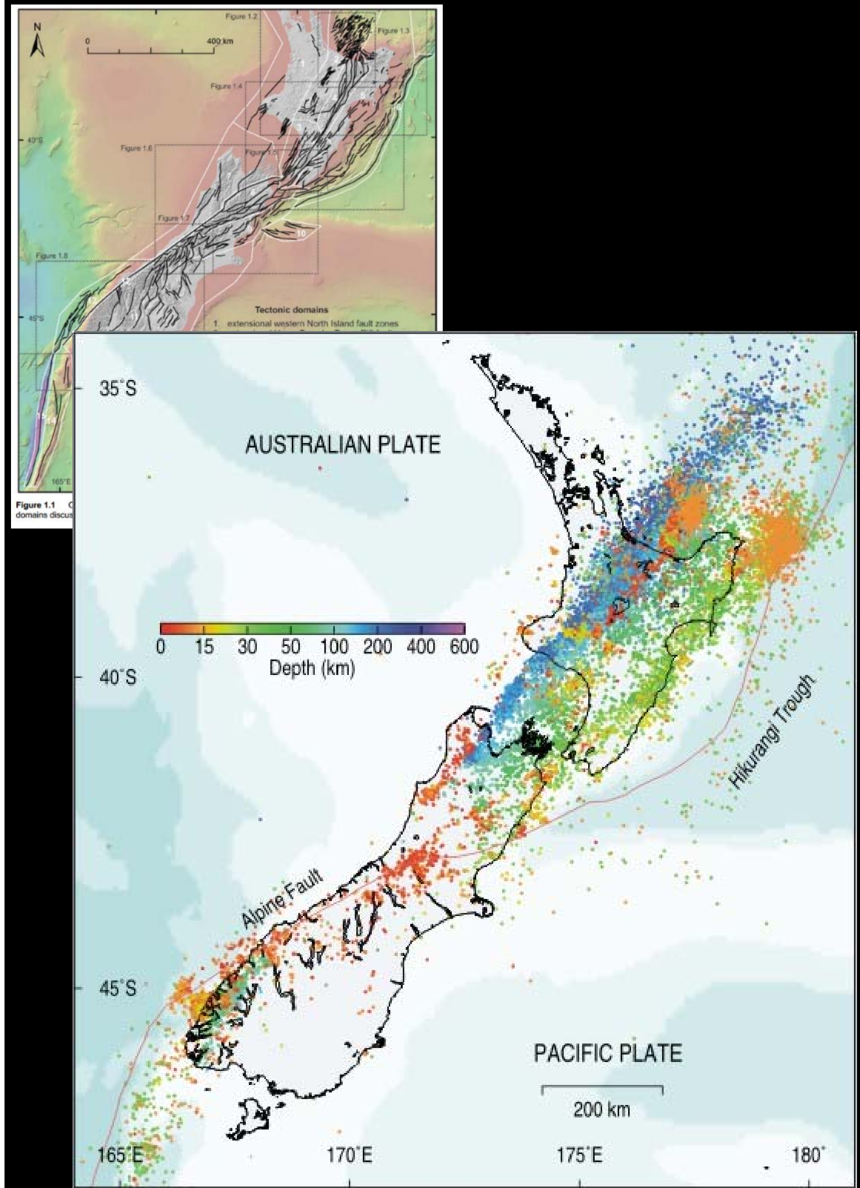
Mitigation

Earthquake science informing policy:

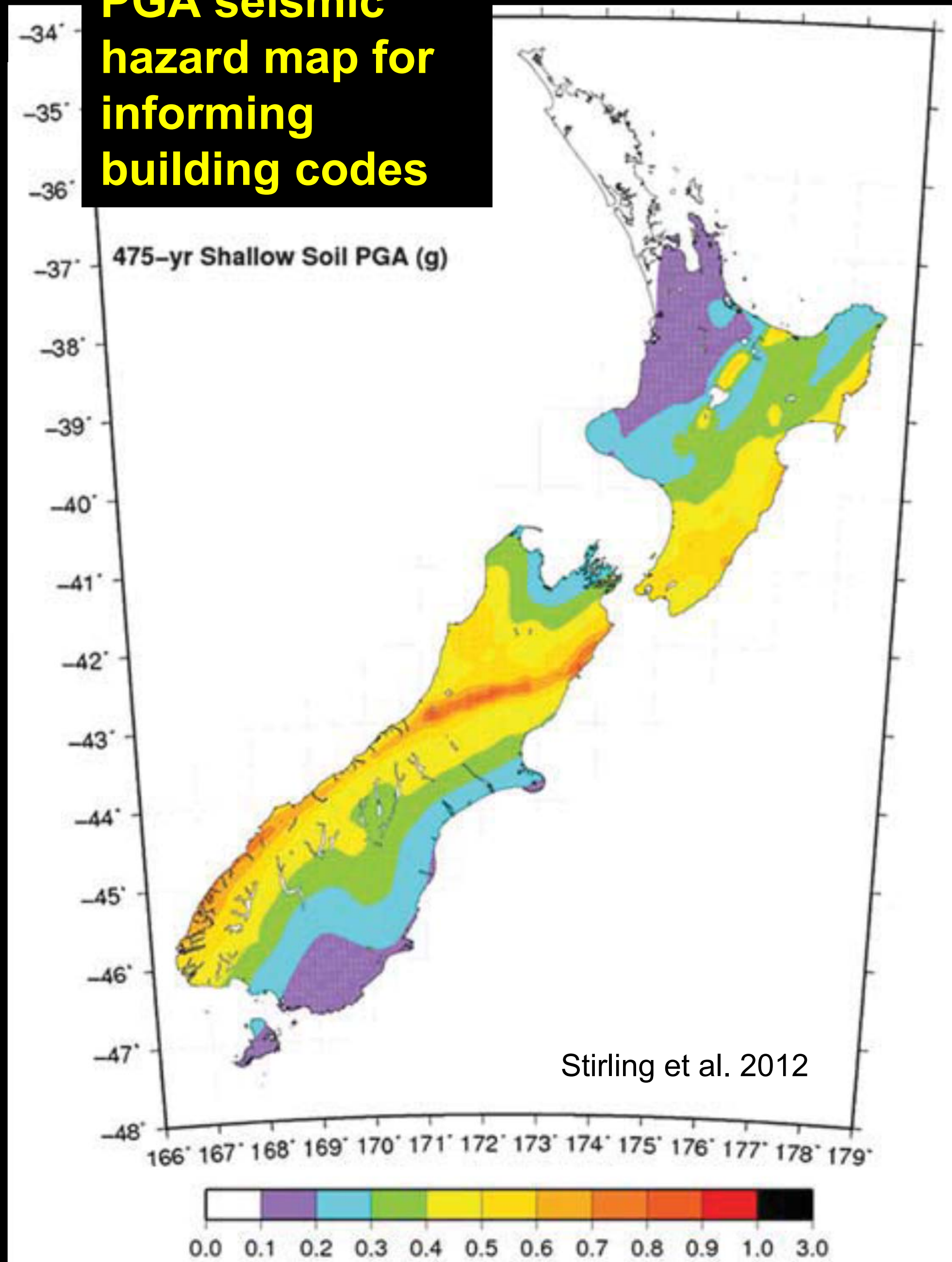
Reducing the impacts of future earthquakes

USGS; Villamor et al., 2012

Earthquake science informing policy:
Reducing the impacts of future earthquakes

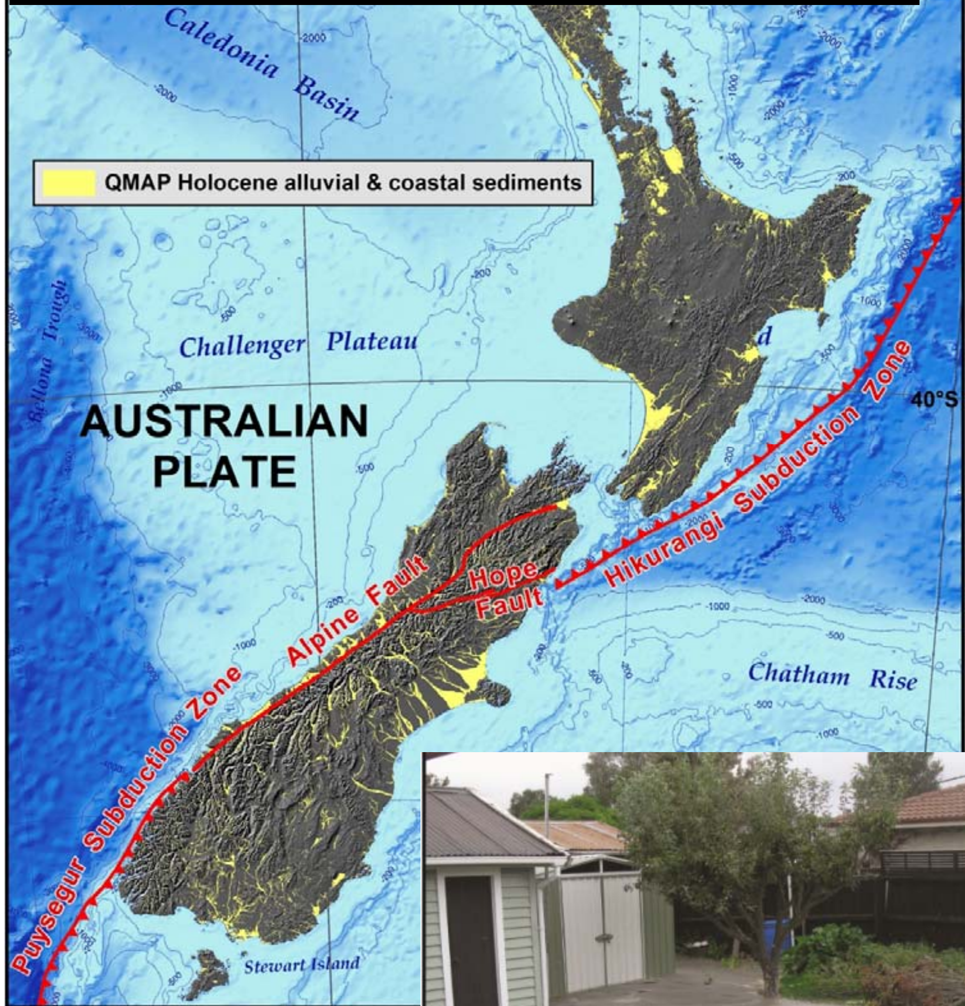


PGA seismic hazard map for informing building codes

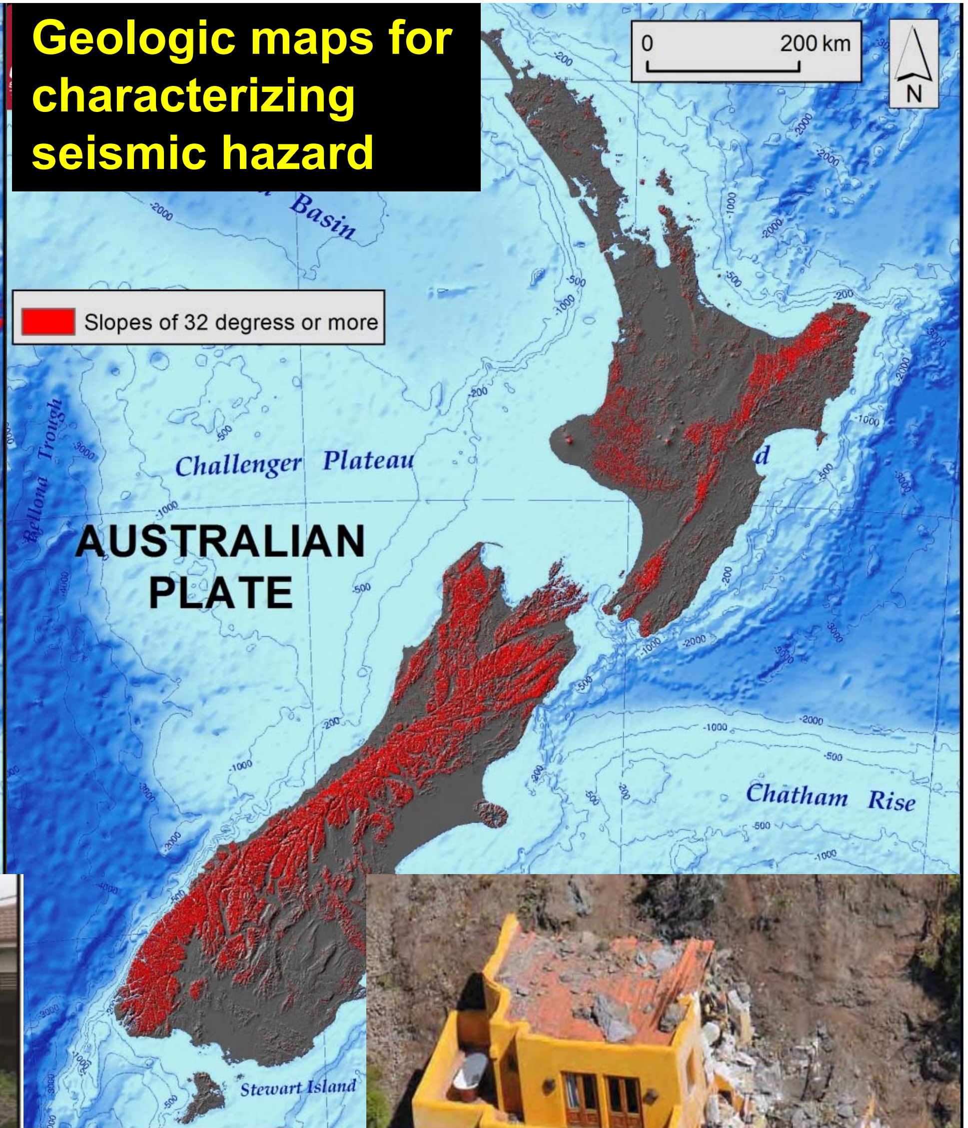


Stirling et al. 2012

Earthquake science informing policy:
Reducing the impacts of future earthquakes



Geologic maps for characterizing seismic hazard

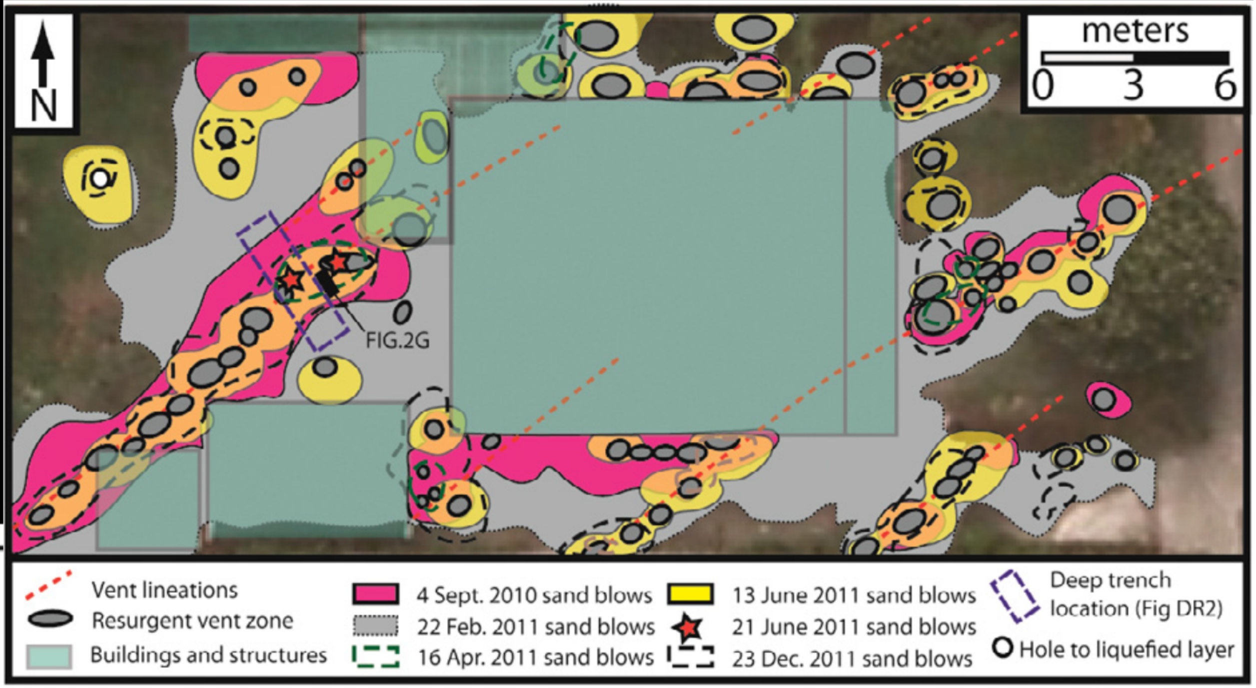


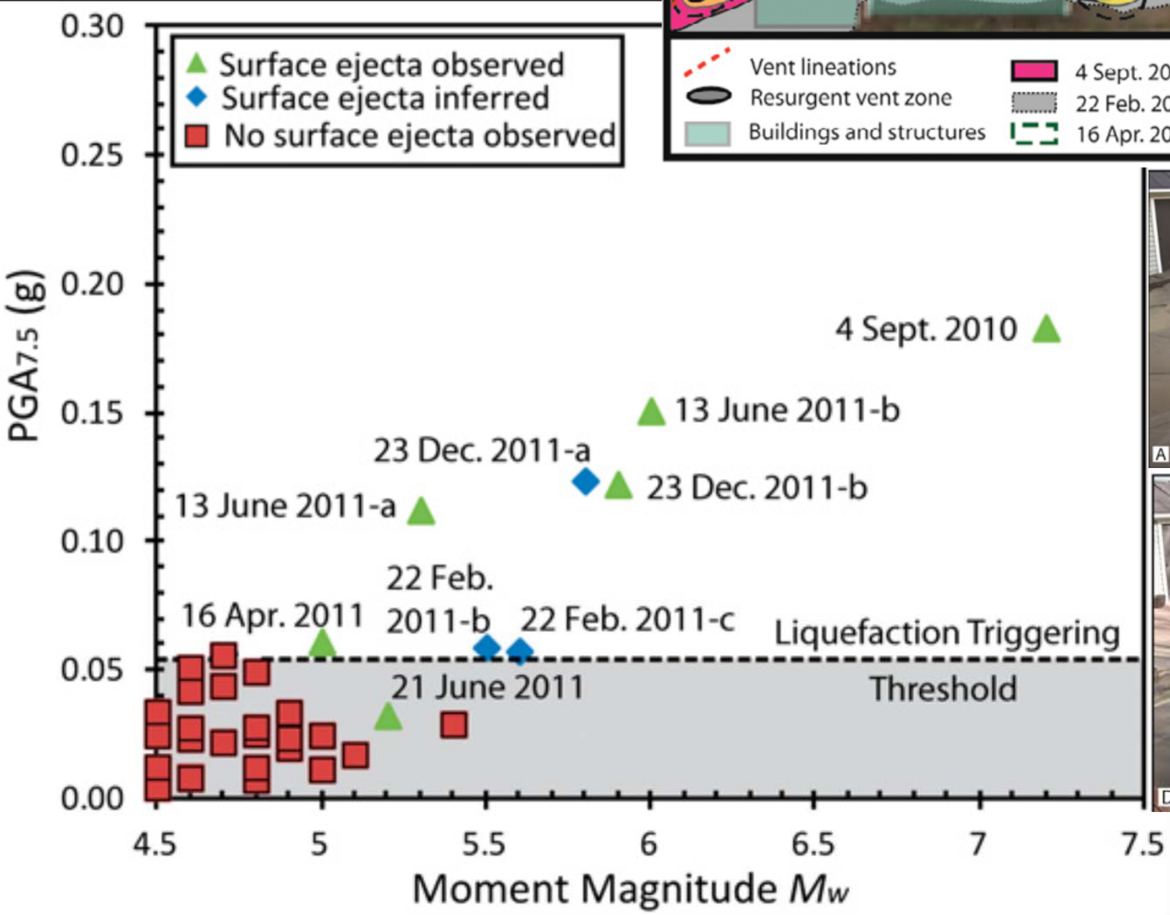
Liquefaction

Courtesy GNS Science
Quigley et al. 2013

Rockfall

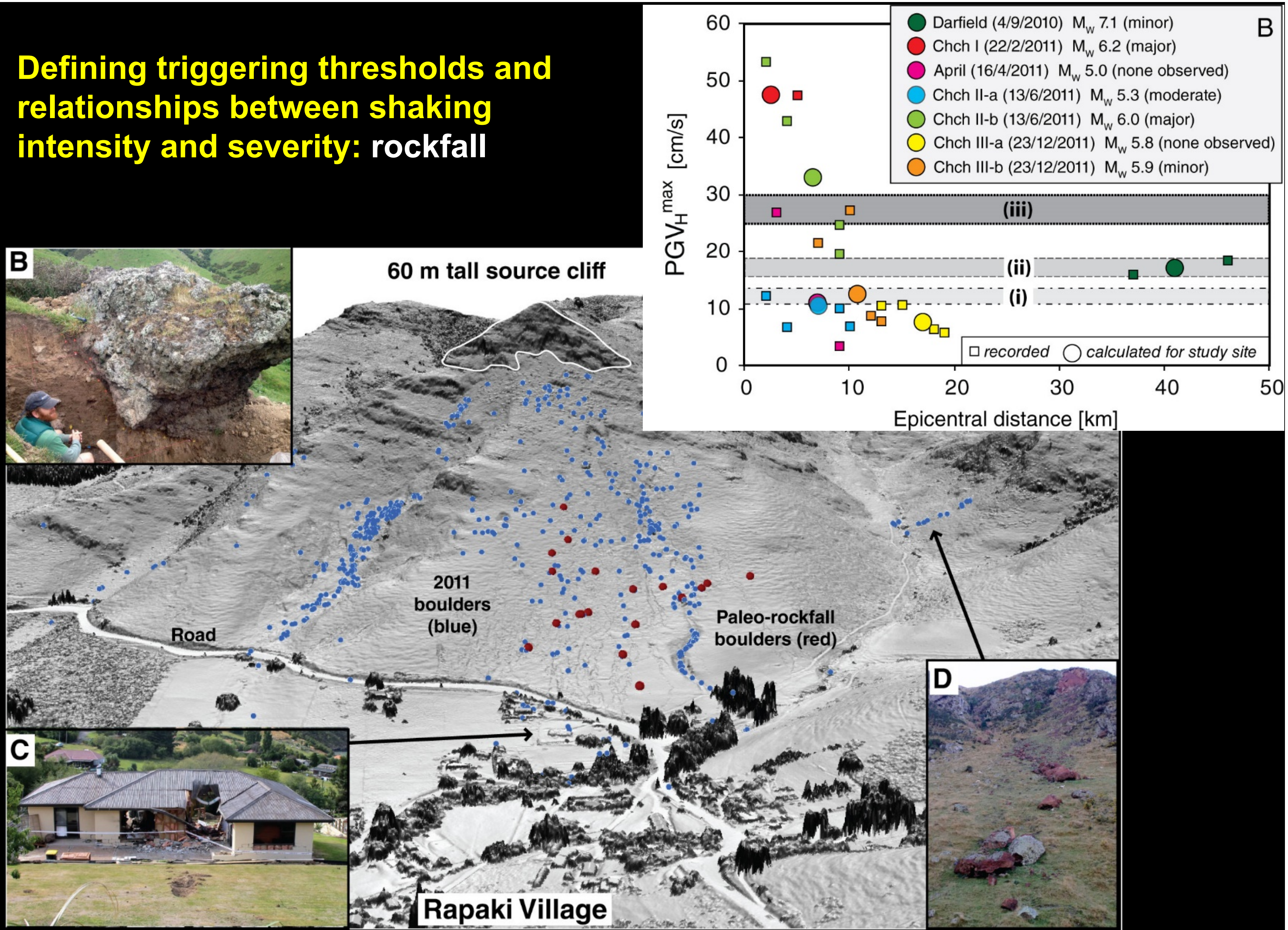
Defining triggering thresholds and relationships between shaking intensity and severity: liquefaction



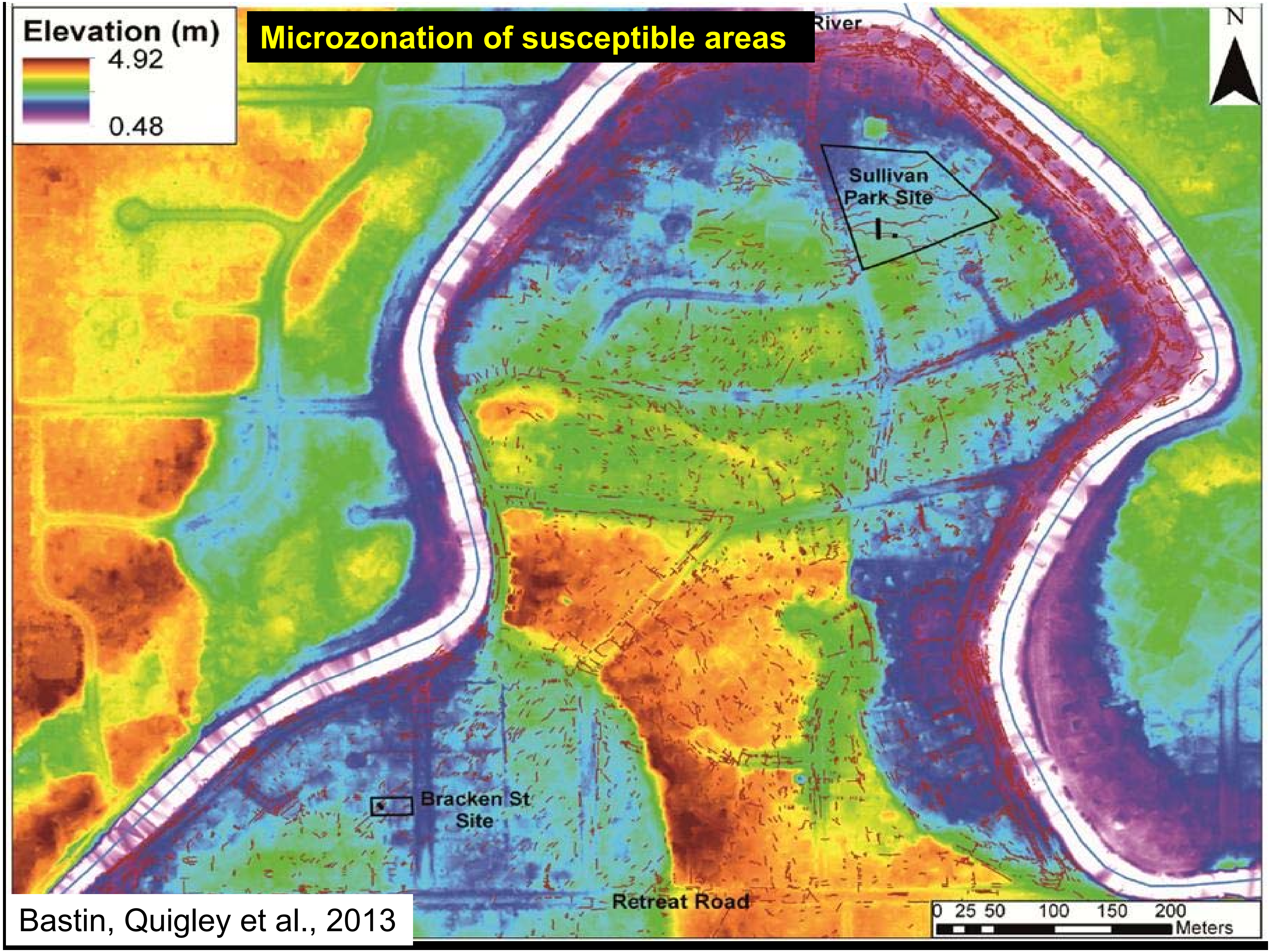


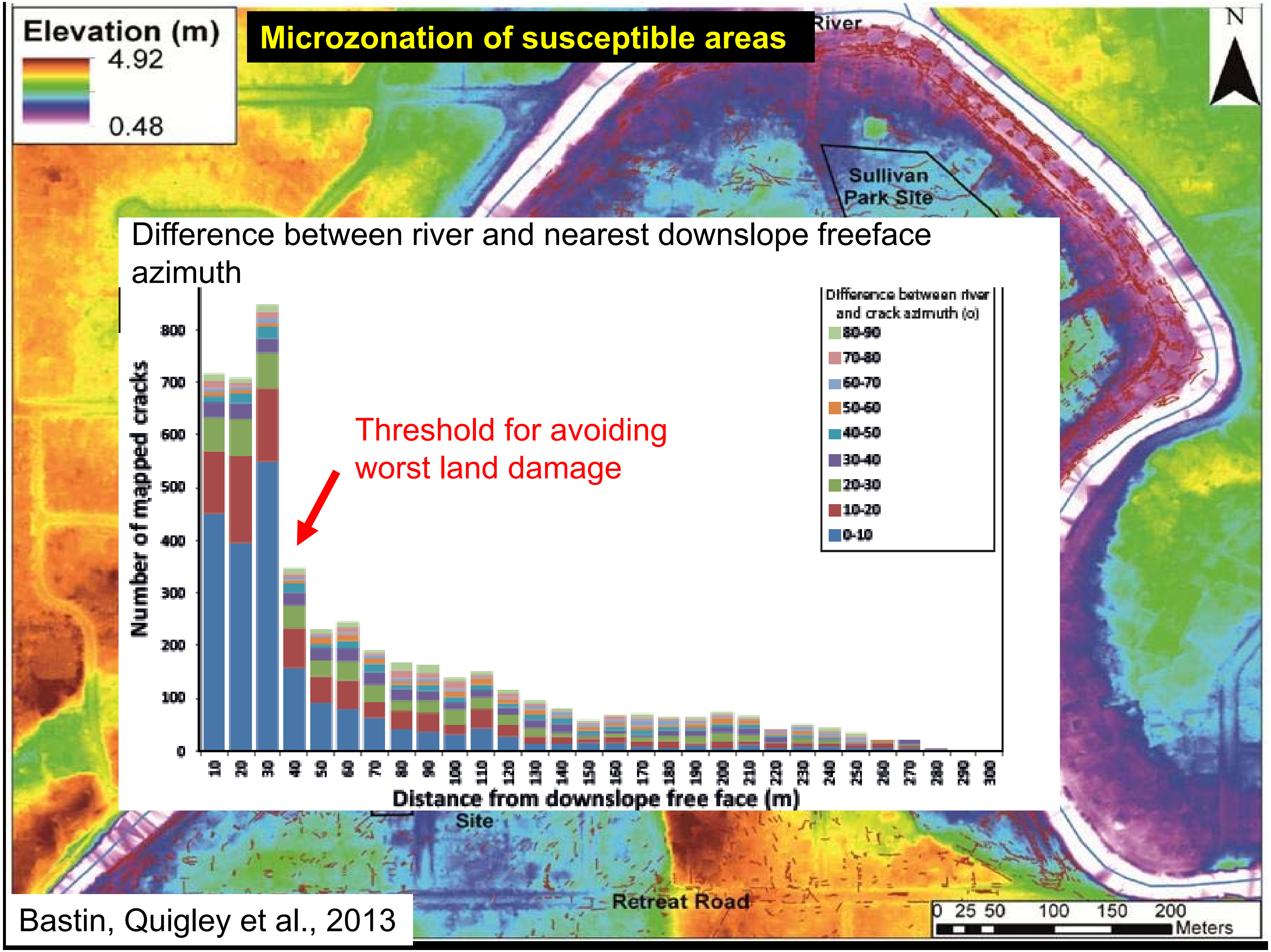
Quigley et al. 2013 Geology

Defining triggering thresholds and relationships between shaking intensity and severity: rockfall



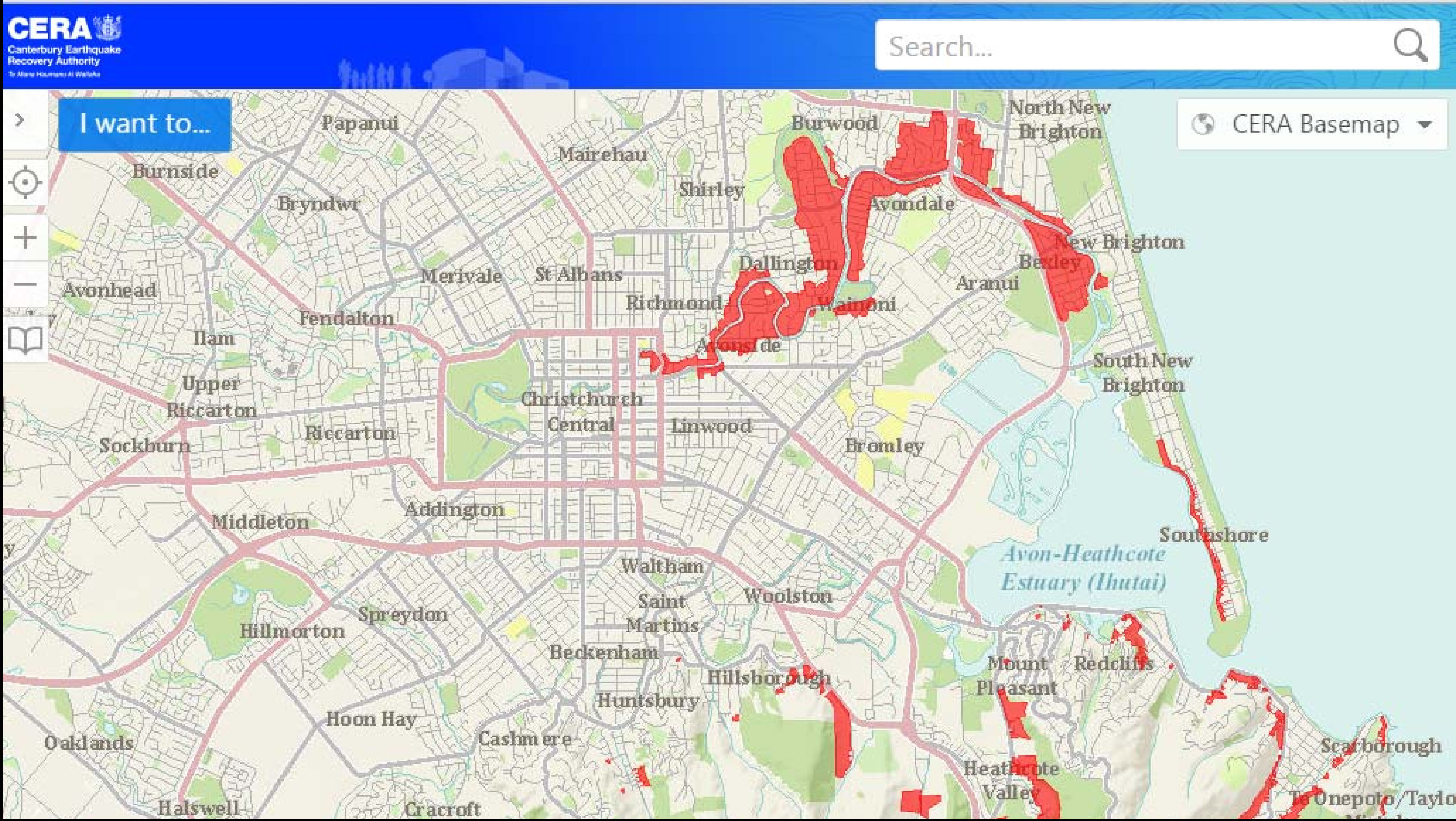
Mackey and Quigley. 2014 Geology


Microzonation of susceptible areas
Elevation (m)
4.92
0.48
River
N
Sullivan Park Site
Bracken St Site
Retreat Road
0 25 50 100 150 200
Meters
Bastin, Quigley et al., 2013


Microzonation of susceptible areas
Elevation (m)
4.92
0.48
River
Sullivan Park Site
Difference between river and nearest downslope freeface azimuth
Threshold for avoiding worst land damage
Number of mapped cracks
Distance from downslope free face (m)
Difference between river and crack azimuth (o)
80-90
70-80
60-70
50-60
40-50
30-40
20-30
10-20
0-10
Site
Retreat Road
0 25 50 100 150 200
Meters
N
Bastin, Quigley et al., 2013

Earthquake science informing policy:

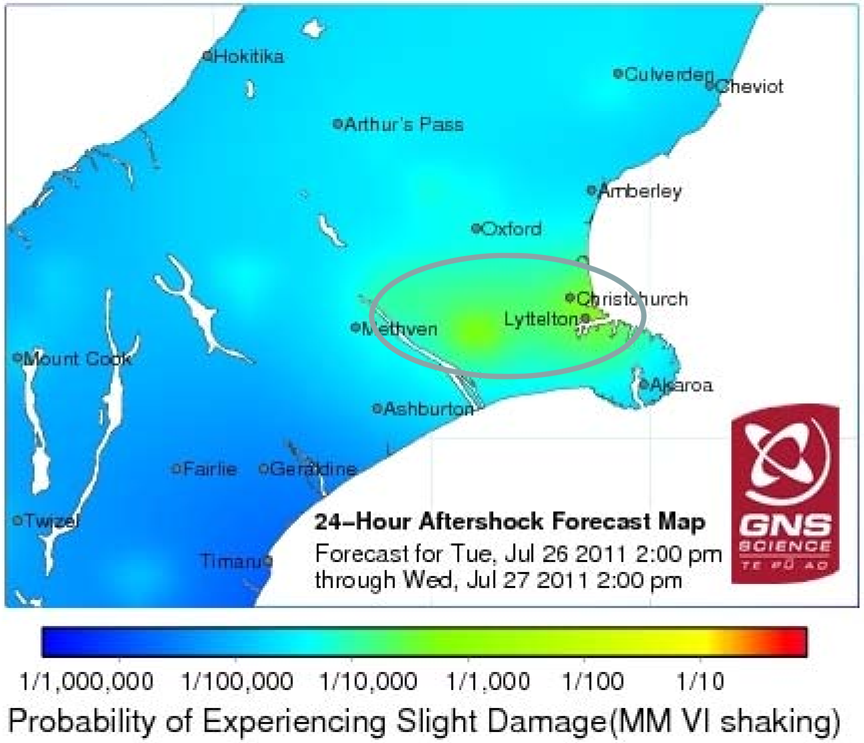
Reducing the impacts of future earthquakes



Land rezoning due to (1) unacceptable life safety risk (rockfalls), (2) unfeasible duration, logistical and financial issues with land repair, and uncertainty that remediation would satisfactorily reduce the risk of future liquefaction

Operational earthquake forecasting

-Publically available
-Continuously updated
-Multiple timescales

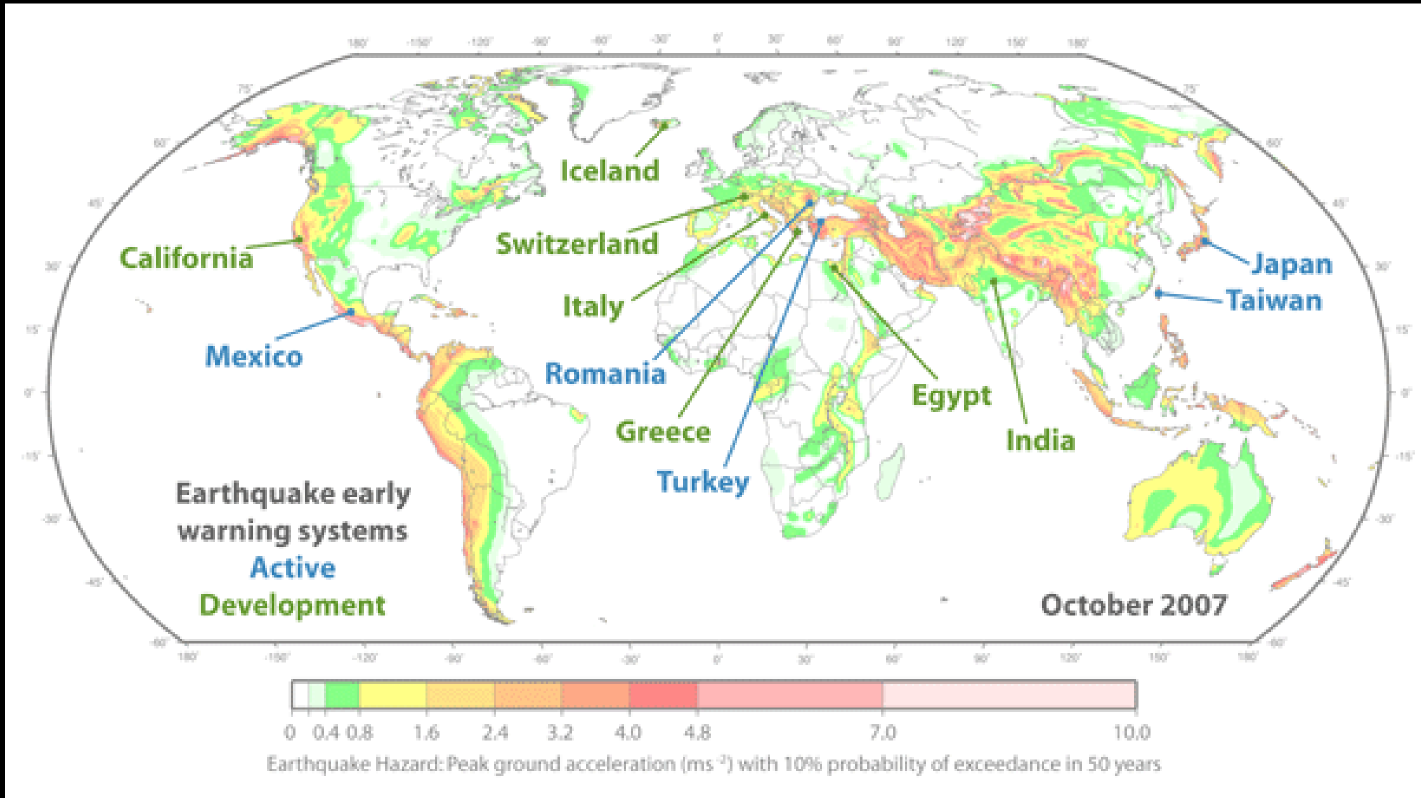


MM 6 = felt by all, objects fall from shelves, some furniture moved on smooth floors, very unstable furniture overturned, slight damage to unreinforced masonry and some damage to chimneys

	Canterbury region long-term probabilities					
	One month: July 15 2011 - August 14 2011			One year: July 15 2011 - July 14 2012		
Magnitude range	Expected range	Expected average	Probability	Expected range	Expected average	Probability
5.0 - 5.4	0 - 2	0.39	32%	0 - 5	1.9	85%
5.5 - 5.9	0 - 1	0.12	11%	0 - 3	0.9	45%
6.0 - 6.4	0 - 1	0.04	4%	0 - 1	0.2	15%
6.5 - 6.9	0 - 1	0.01	1%	0 - 1	0.07	7%
7.0 - 7.9	0 - 1	0.005	<1%	0 - 1	0.02	2%

This table was last updated on July 22 2011

Technology outracing earthquakes:
earthquake early alarm

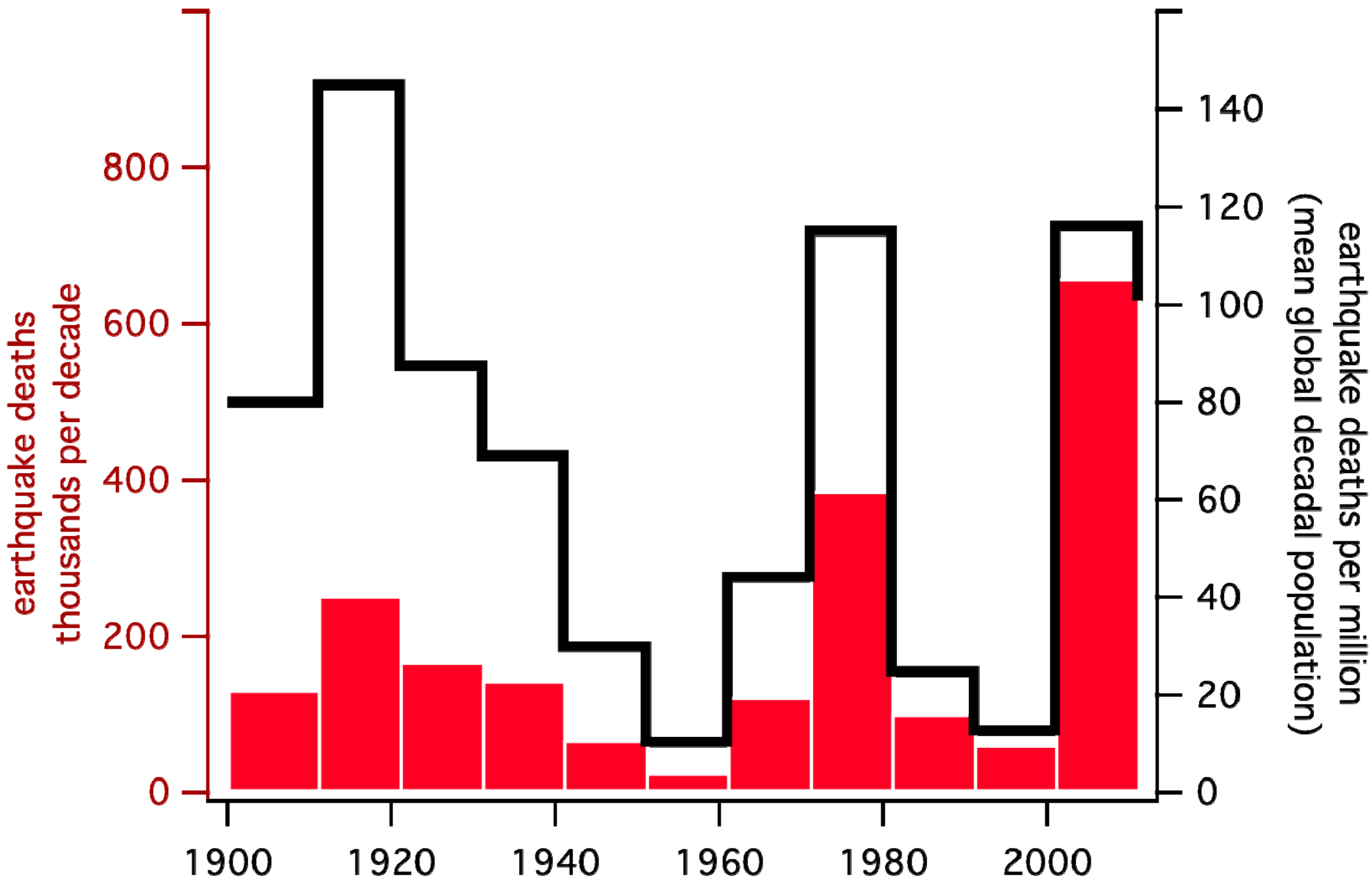


Stop trains, stop medical procedures, cut power, open fire station garages, prepare public for shaking

http://www.elarms.org/front/eewGlobal.php

Challenges

Despite significant scientific and technological advances,
global earthquake fatalities are not decreasing
(modified from Bilham, 2010)



Individual earthquakes continue to have high death tolls

Huge variation in fatalities for a given magnitude

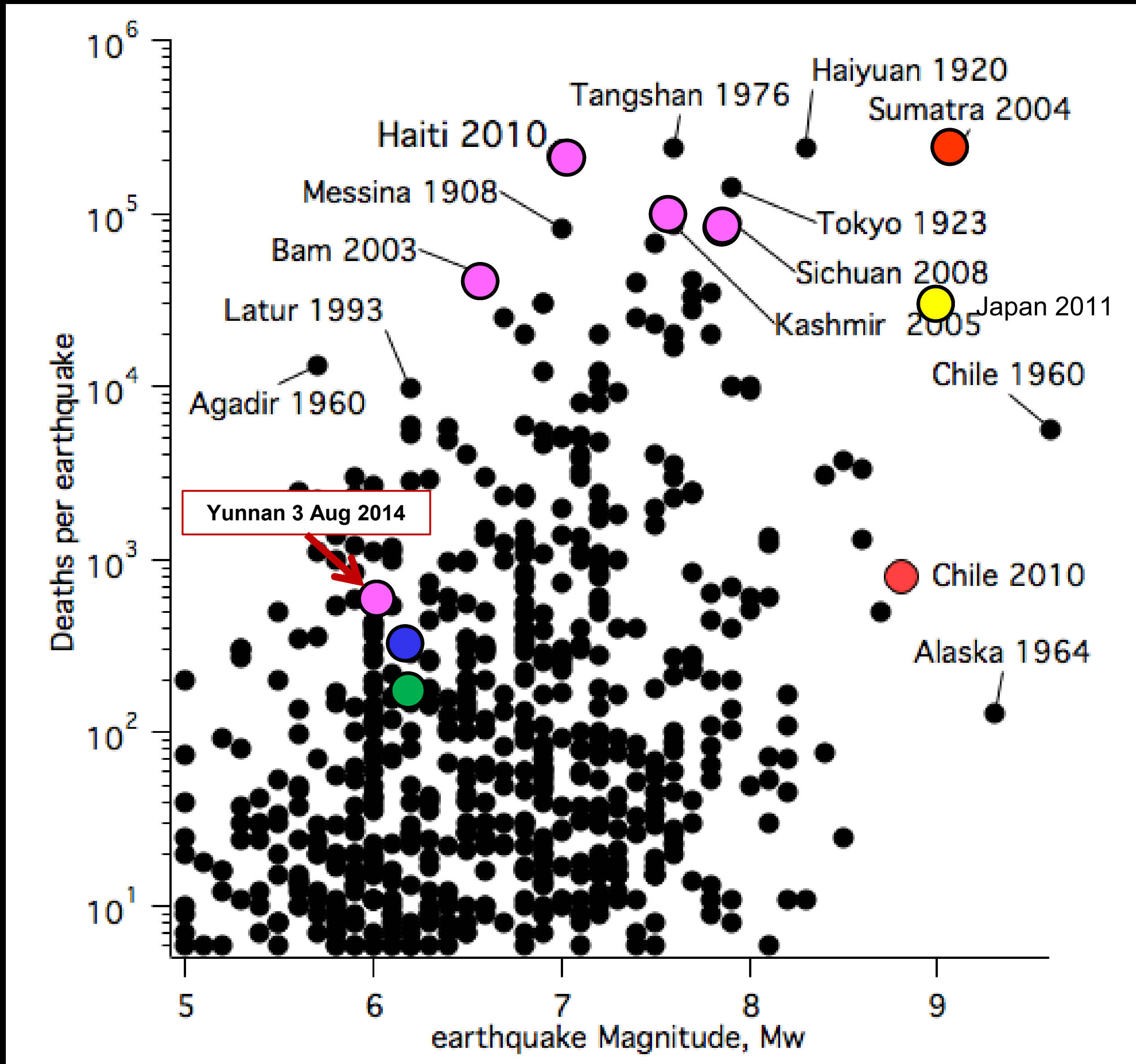
Earthquakes on unidentified faults

Notable quakes last decade (~630,000 deaths)

Previously unidentified fault

L'Aquila 2009

Christchurch 2011



Modified from Bilham 2010

Earthquakes hit poorest countries the hardest (fatalities and finances)

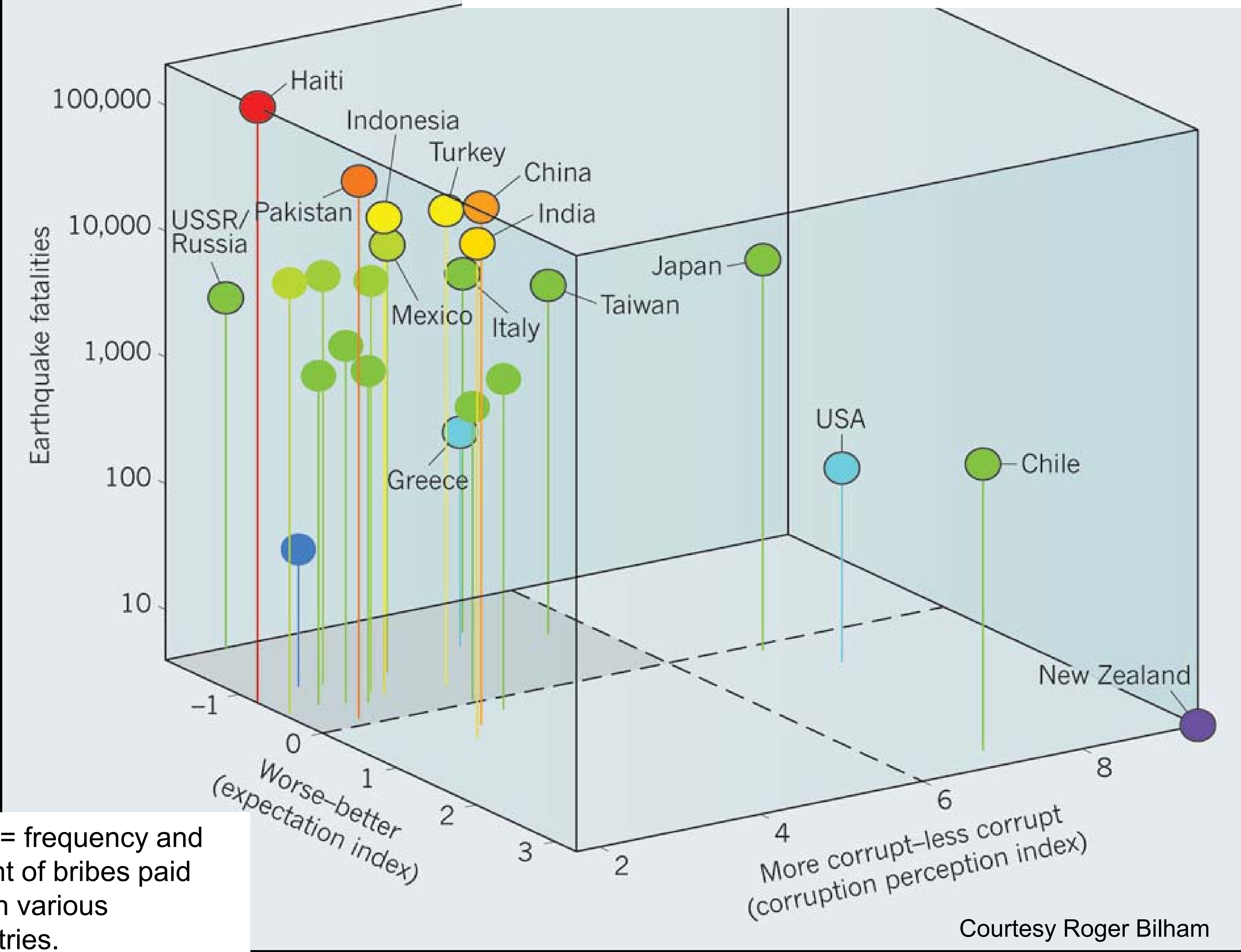
Deadliest natural disasters since 1970
As a proportion of population

Rank	Country	Year	Description	Killed	Deaths per million inhabitants	Damages (US Millions, 2009)	Damages (% of GDP)
	Haiti	2010	Earthquake	150,000 - 250,000	15,000 - 25,000	7,200 - 8,100	104% - 117%
1	Nicaragua	1972	Earthquake	10,000	4,046	4,325	102.0%
2	Guatemala	1976	Earthquake	23,000	3,707	3,725	27.4%
3	Myanmar	2008	Cyclone Nargis	138,366	2,836	4,113	*n.a.*
4	Honduras	1974	Cyclone Fifi	8,000	2,733	2,263	59.2%
5	Honduras	1998	Cyclone Mitch	14,600	2,506	5,020	81.4%
6	Sri Lanka	2004	Tsunami*	35,405	1,839	1,494	7.0%
7	Venezuela	1999	Flood	30,005	1,282	4,072	3.5%
8	Bangladesh	1991	Cyclone Gorki	139,252	1,232	3,038	6.4%
9	Solomon Is	1975	Tsunami	200	1,076	n.a.	*n.a.*
10	Indonesia	2004	Tsunami*	165,825	772	5,197	2.0%

*Indian Ocean Tsunami caused a total of 226,000 deaths over 12 countries.
n.a. Not available
Source: Authors' calculations based on EM-DAT and WDI databases.

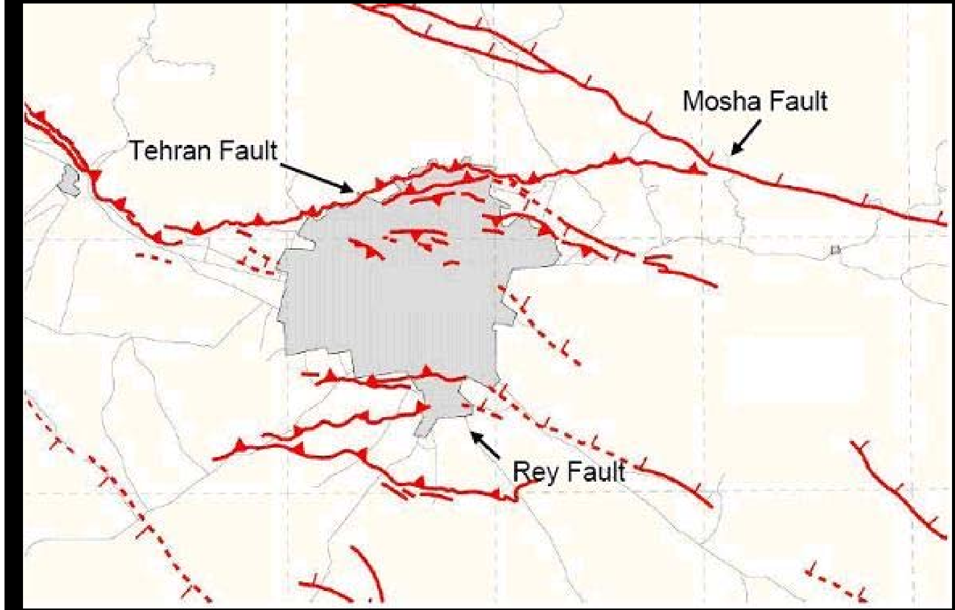
Event	Country	Year	% of GDP	Deaths (per million people)
Christchurch EQ	New Zealand	2010-2011	8%	182 (41/million)
Great East Japan EQ + tsunami	Japan	2011	3-5%	>23,000 (180/million)

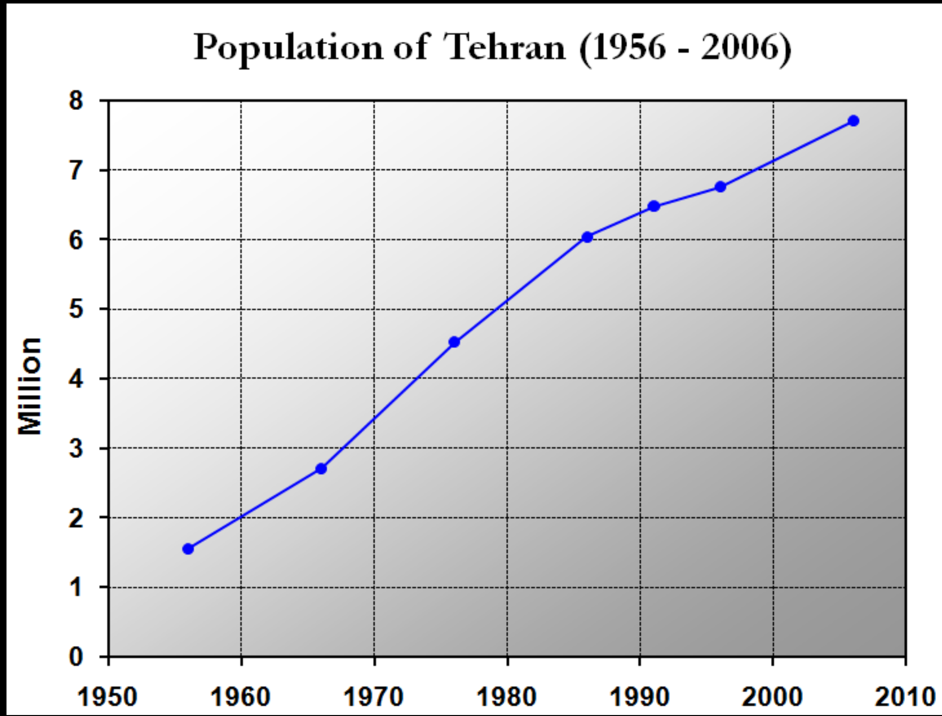
Countries with more perceived corruption tend to fare worse than expected in earthquakes



CPI = frequency and extent of bribes paid within various countries.

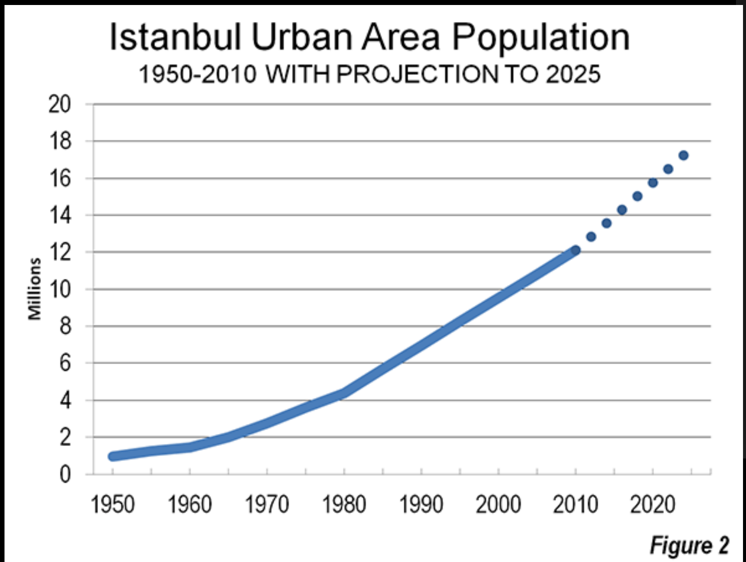
Courtesy Roger Bilham





Expanding cities are increasing vulnerability and life and financial risk

Tehran, Iran: a metropolis above active faults with a legacy of earthquake destruction



Istanbul, Turkey: a metropolis adjacent to a seismic gap on the North Anatolian Fault

Cultural shifts are increasing earthquake risk

East Timor

Managing the message and conducting science at 'media pace' is a massive challenge

Italy earthquake experts charged with manslaughter

Risks commission members to face trial over failure to give sufficient warning about L'Aquila earthquake in 2009

David Batty and agencies
The Guardian, Thursday 26 May 2011
Article history

ScienceInsider
Breaking news and analysis from the world of science policy

Japan's Earthquake Off the (Seismic Risk) Map

by Dennis Normile on 11 March 2011, 9:51 AM | Permanent Link | 20 Comments

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TOKYO—The most surprising thing about the magnitude-8.9 earthquake that hit Japan today is that it was a surprise. Despite what may be the world's most intensive effort to map faults and assess risks by a notoriously earthquake-prone and earthquake-conscious nation, such a strong quake was not anticipated for the region, says University of Tokyo

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12 August 2010 Last updated at 08:11 GMT

Haiti quake was caused by previously unknown fault

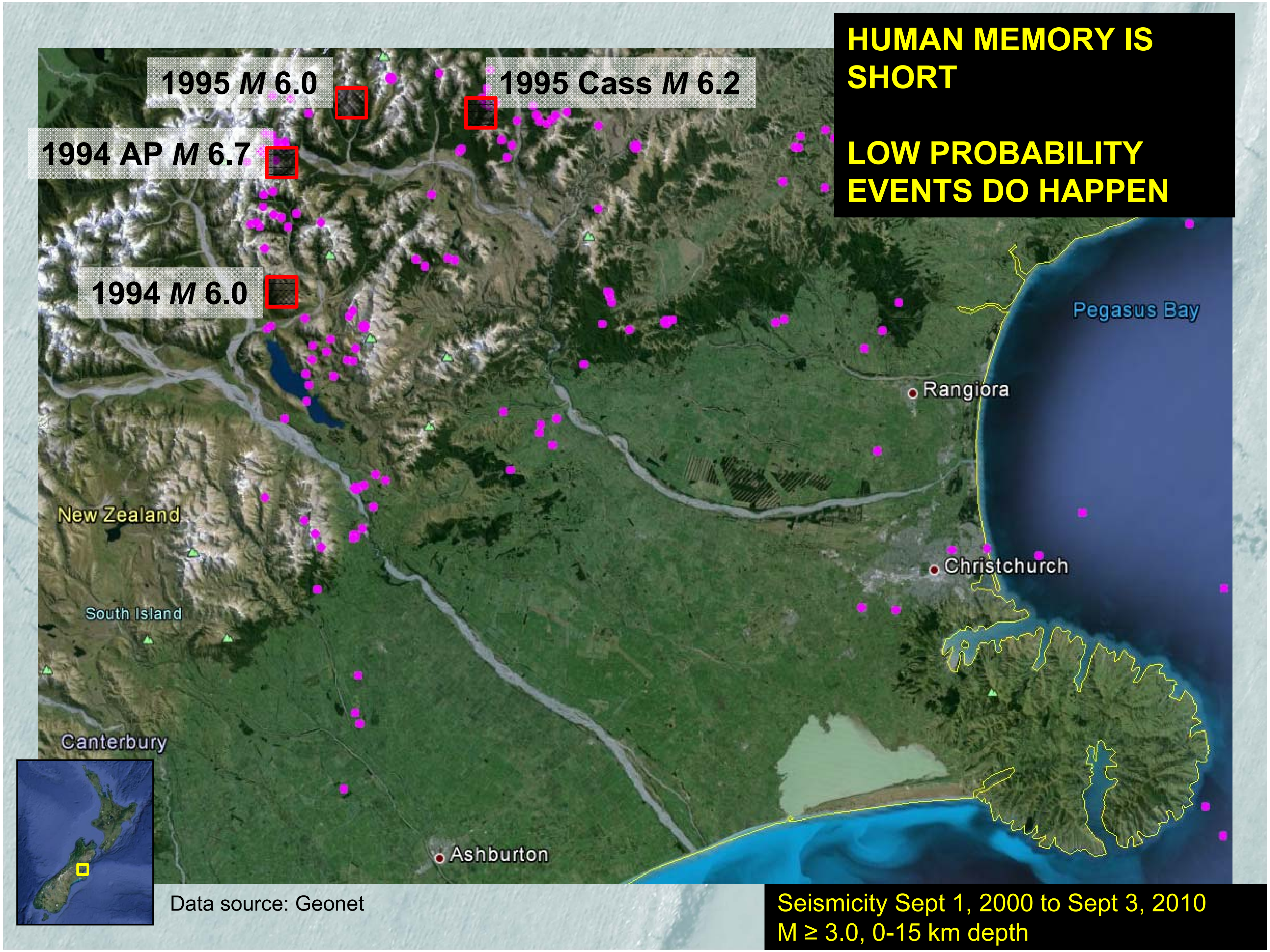
By Victoria Gill
Science reporter, BBC News

The 2010-2011 Canterbury Earthquake Sequence

Lessons we've (re)learned

HUMAN MEMORY IS SHORT

LOW PROBABILITY EVENTS DO HAPPEN



Data source: Geonet

Seismicity Sept 1, 2000 to Sept 3, 2010
M ≥ 3.0, 0-15 km depth

HUMAN MEMORY IS SHORT

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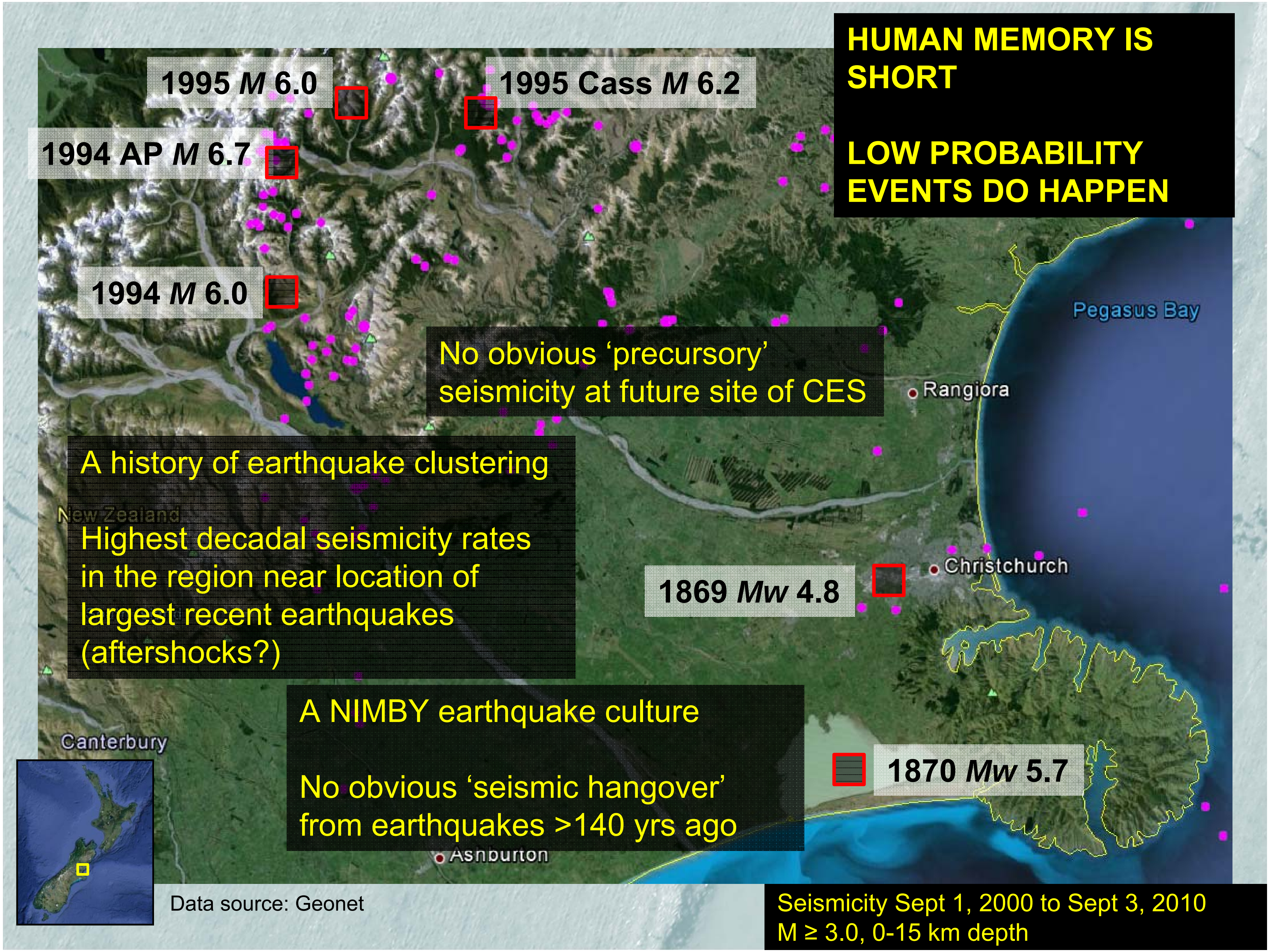


No obvious 'precursory' seismicity at future site of CES

A history of earthquake clustering

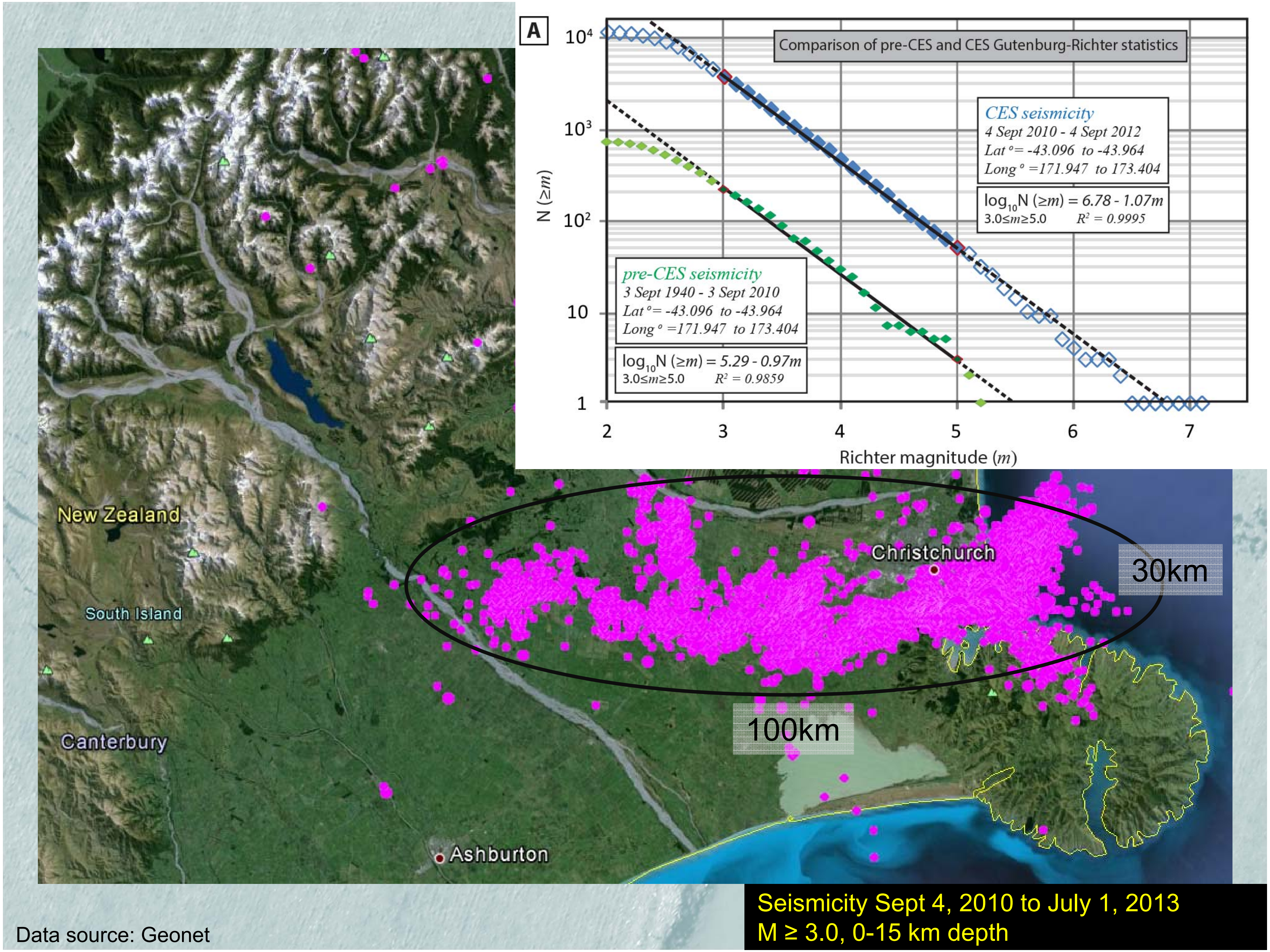
Highest decadal seismicity rates in the region near location of largest recent earthquakes (aftershocks?)

A NIMBY earthquake culture

No obvious 'seismic hangover' from earthquakes >140 yrs ago

Data source: Geonet

Seismicity Sept 1, 2000 to Sept 3, 2010
M ≥ 3.0, 0-15 km depth


A
Comparison of pre-CES and CES Gutenberg-Richter statistics
CES seismicity
4 Sept 2010 - 4 Sept 2012
Lat ° = -43.096 to -43.964
Long ° = 171.947 to 173.404
$\log_{10} N (\geq m) = 6.78 - 1.07m$
$3.0 \leq m \geq 5.0$ $R^2 = 0.9995$
pre-CES seismicity
3 Sept 1940 - 3 Sept 2010
Lat ° = -43.096 to -43.964
Long ° = 171.947 to 173.404
$\log_{10} N (\geq m) = 5.29 - 0.97m$
$3.0 \leq m \geq 5.0$ $R^2 = 0.9859$
$N (\geq m)$
Richter magnitude (m)
New Zealand
South Island
Canterbury
Christchurch
Ashburton
30km
100km
Seismicity Sept 4, 2010 to July 1, 2013
M ≥ 3.0, 0-15 km depth
Data source: Geonet

Earthquake comparisons: Counting the costs

	4 September 2010	22 February 2011	13 June 13 2011	23 December 2011
Mag (M_w)	7.1	6.2	6.0	5.9
Epicentre[1]	30 km W	10 km SE	10 km SE	10 km E
Time[2]	4:36 am	12.51 pm	2.20 pm	3.18 pm
Max PGA[3]	0.6g (0.3g CBD)	2.2g (0.8g CBD)	2.2g (0.4g CBD)	0.96g[4] (0.25g CBD)
Casualties	0 fatalities	185 fatalities	0 fatalities	0 fatalities
Building Damage	To older brick & URM	All pre-1970s & several modern buildings with eccentric design	Further residential damage in Port Hills & already damaged CBD buildings	Minor, but several instances of progressive failure
Liquefaction	Widespread in eastern suburbs	Extreme damage in many eastern Christchurch suburbs	Further damage in eastern Christchurch suburbs	Minor damage in eastern Christchurch suburbs
Cost[5]	4-5 billion	15-20 billion	c. 1.5 billion	c. 26 million

Loss of life and most damage occurred in an 'aftershock' on a previously unknown 'blind' fault

Most fatalities in two building collapses – building stock performed well from life safety perspective but poorly from a 'post-event functionality' perspective

Berryman, 2012

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Building Damage	To older brick & URM	All pre-1970s & several modern buildings with eccentric design	Further residential damage in Port Hills & already damaged CBD buildings	Minor, but several instances of progressive failure
Prob	**1/475 yr**	**1/12,000 yr**	**1/1,000 yr**	**1/300 yr**
%	0.2	0.008	0.08	0.3
Cost[5]	4-5 billion	15-20 billion	c. 1.5 billion	c. 26 million

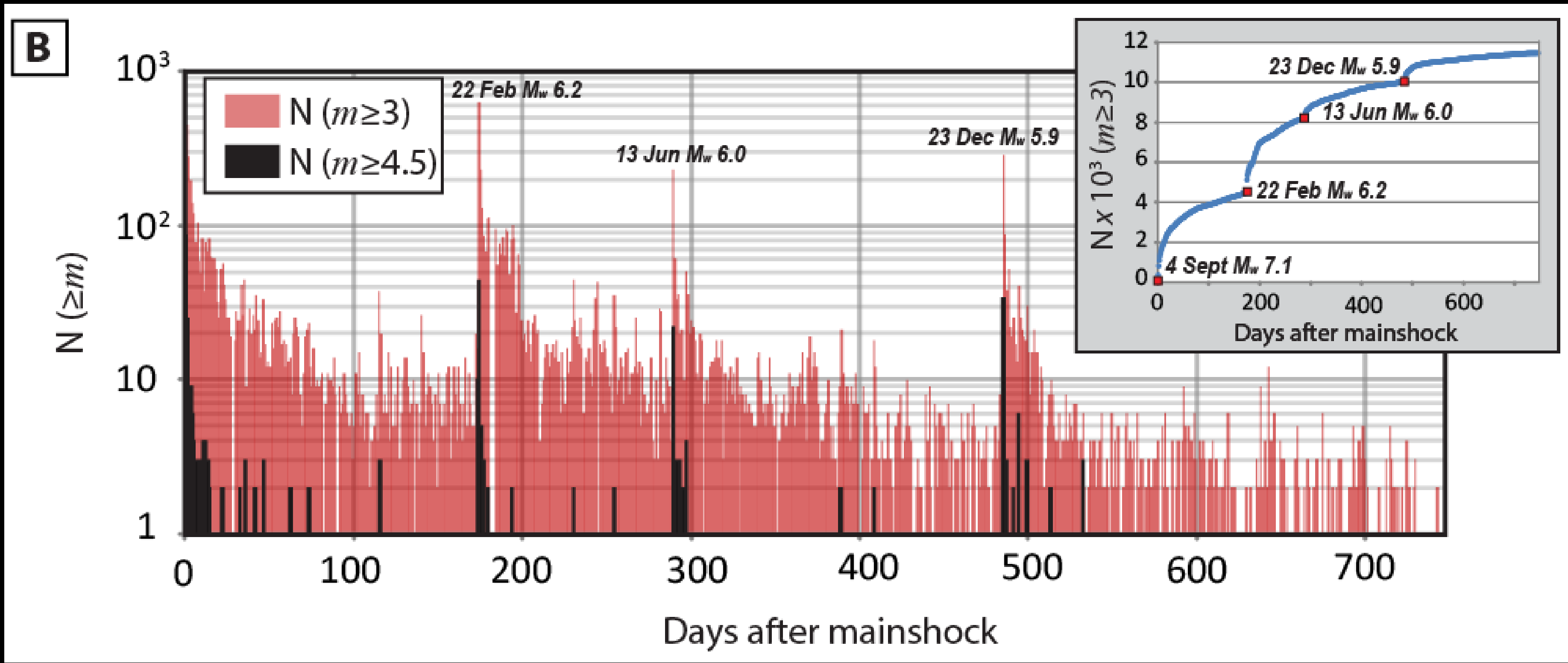
Notes:

EARTHQUAKES CLUSTER IN TIME AND SPACE, AND SIGNIFICANTLY MODIFY SHORT-TERM HAZARD FROM BACKGROUND

The importance of discussing 'relative probability change' in addition to absolute probabilities

Berryman, 2012

The most likely time for a damaging earthquake to occur is immediately after a damaging earthquake has occurred

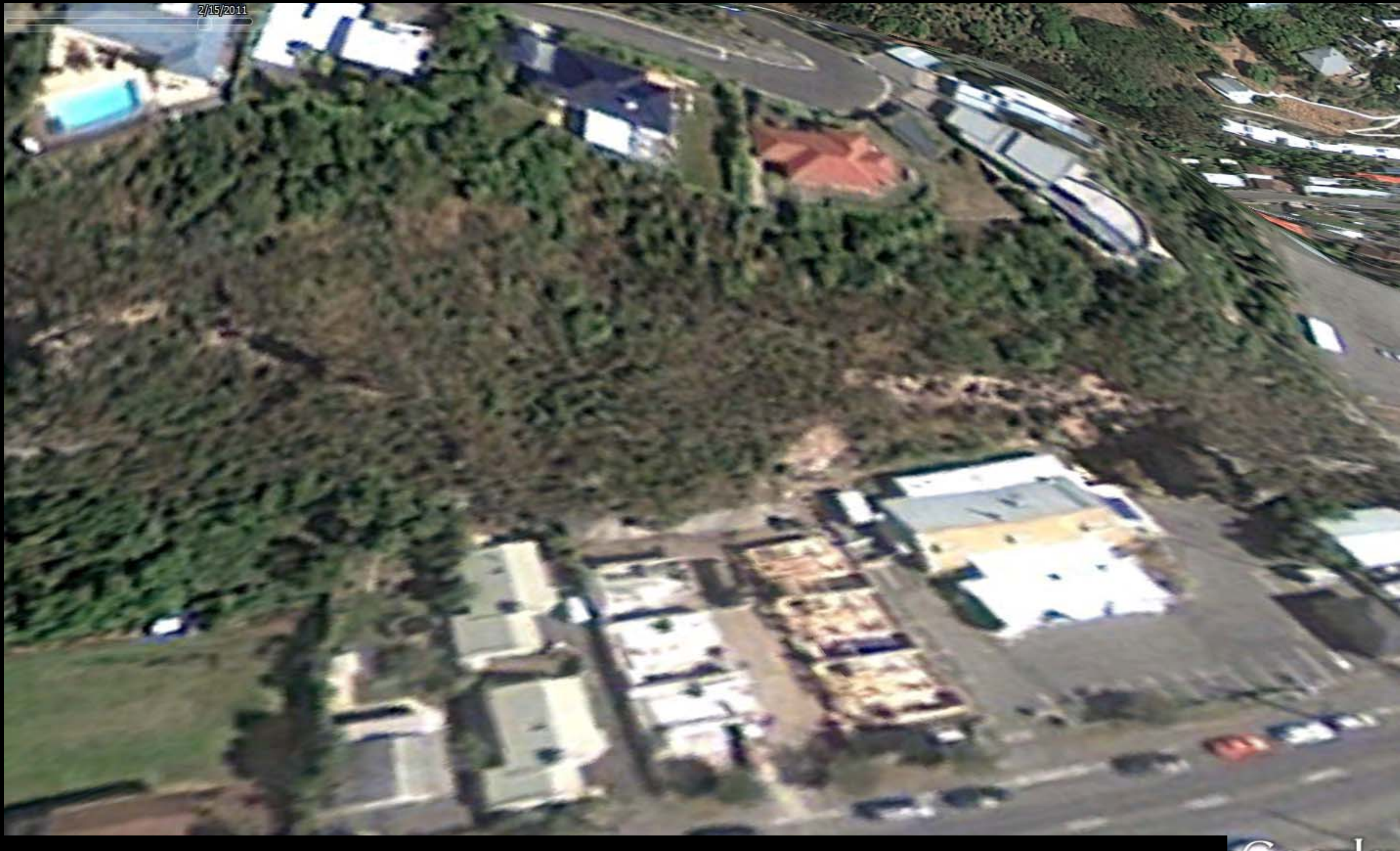


Search and rescue, building inspections, land use planning

Quigley et al, 2014

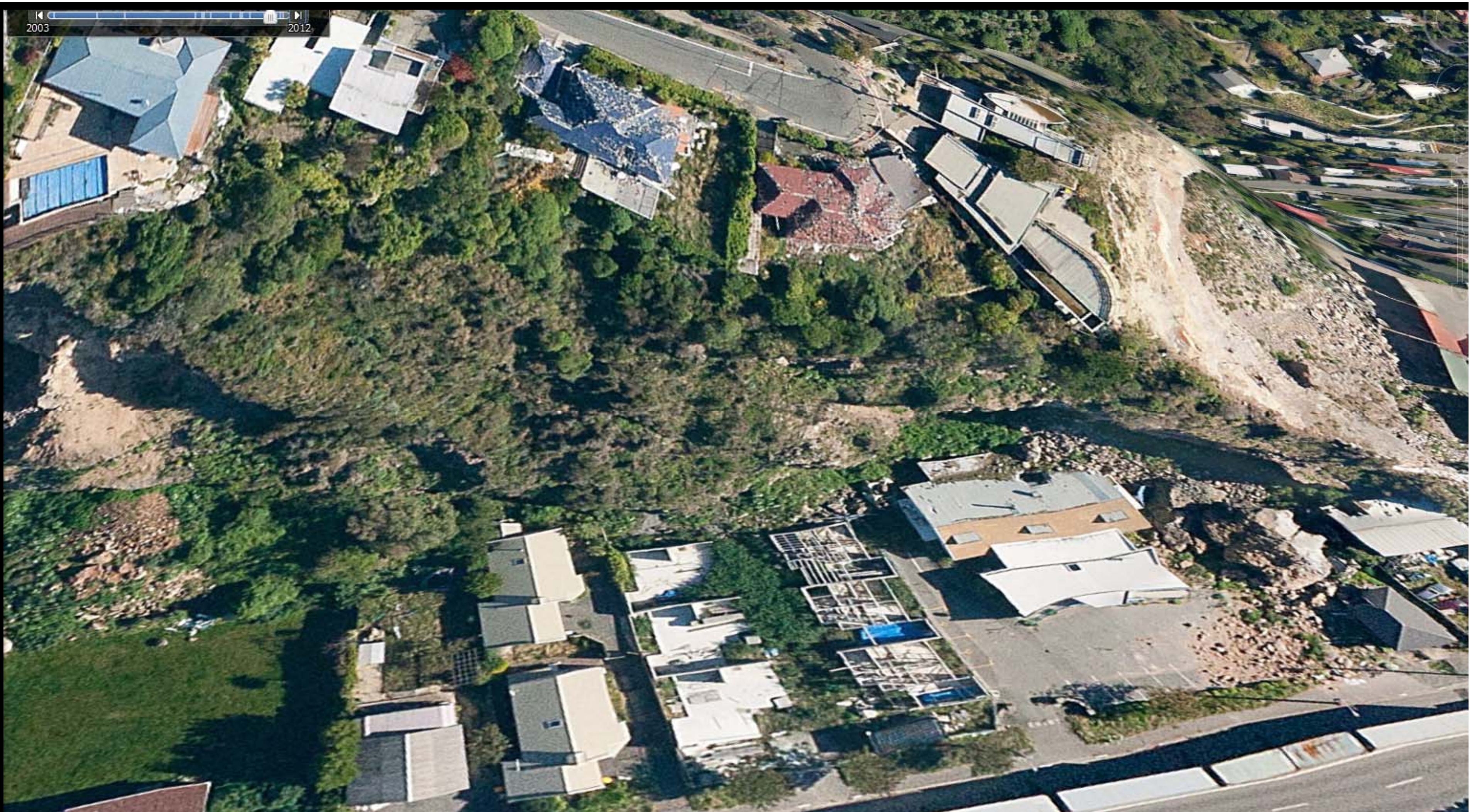
The most likely time for a damaging earthquake to occur is immediately after a damaging earthquake has occurred

Immediately post-Sept earthquake, Sumner



The most likely time for a damaging earthquake to occur is immediately after a damaging earthquake has occurred

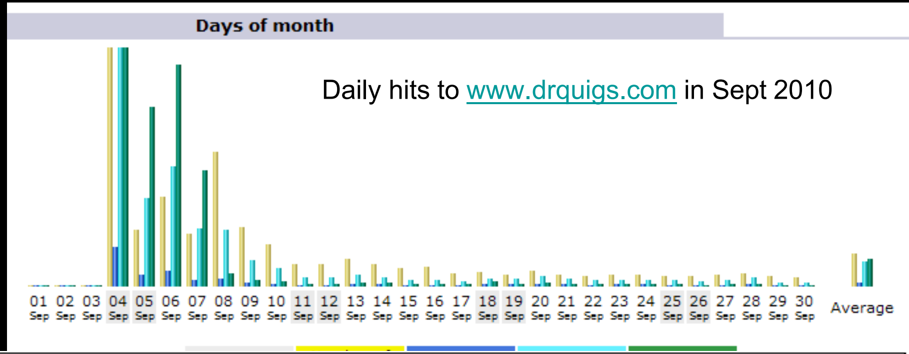
Post-Sept earthquake, pre-Feb earthquake, Sumner

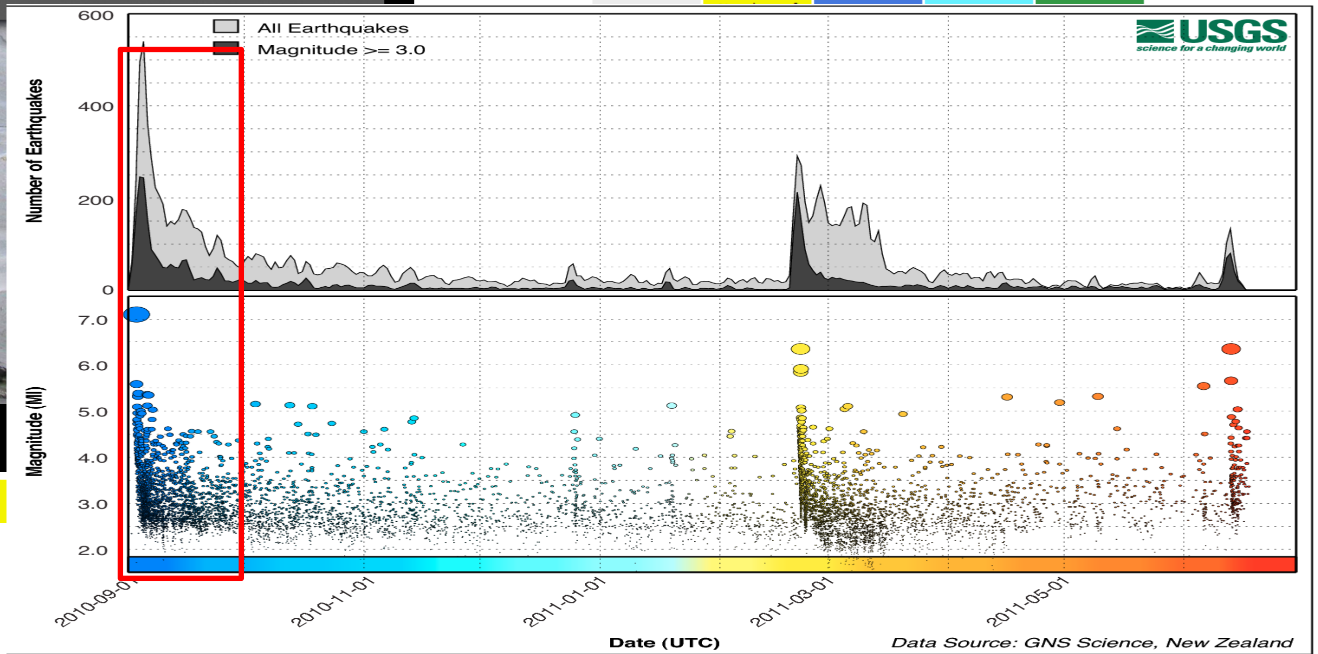


The most likely time for a damaging earthquake to occur is immediately after a damaging earthquake has occurred

Post-Sept, June, Dec earthquakes, Sumner

Societal interest in earthquake science peaks immediately after the earthquake and decays exponentially in parallelism with aftershock activity





Month	Unique visitors	Number of visits			
Jan 2010	178	466			
Feb 2010	318	569			
Mar 2010	213	544			
Apr 2010	455	782			
May 2010	266	778			
Jun 2010	728	1,765	57,578	65,245	8.96 GB
Jul 2010	480	1,147	13,773	21,615	3.58 GB
Aug 2010	533	1,645	12,322	25,740	3.57 GB
Sep 2010	29,630	41,967	335,660	2,310,042	136.92 GB
Oct 2010	5,505	9,648	61,221	311,347	5.34 GB
Nov 2010	3,862	8,550	55,260	194,222	6.54 GB
Dec 2010	3,466	7,687	44,916	91,802	6.08 GB
Total	45,634	75,548	662,062	3,140,276	178.36 GB

Science of science communication:
Positive covariance of website hits with earthquake frequency – magnitude variations

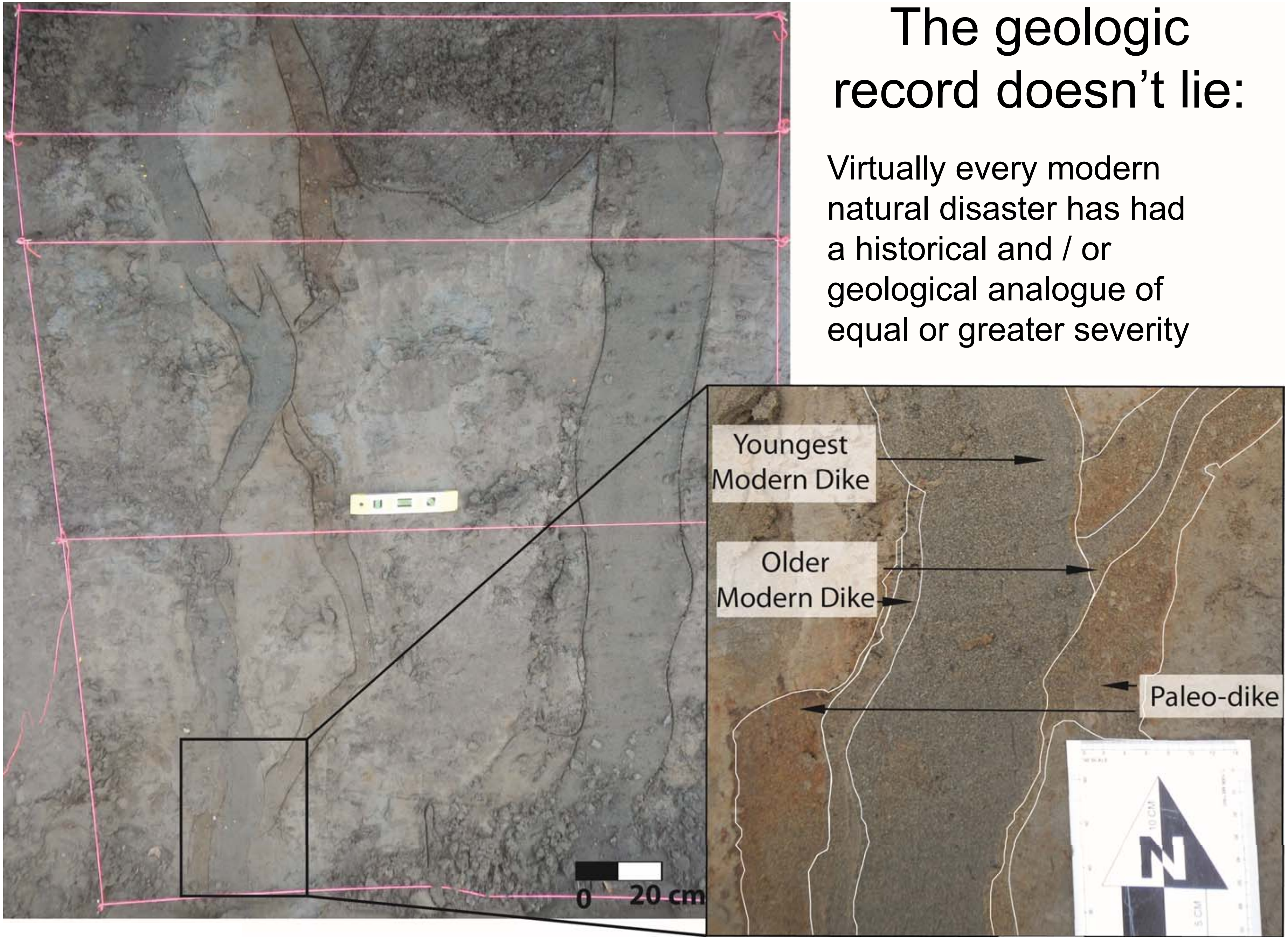
The geologic record doesn't lie:

Signs of future failure are often evident in the landscape

http://www.abc.net.au/news/image/2756902-3x2-940x627.jpg

The geologic record doesn't lie:

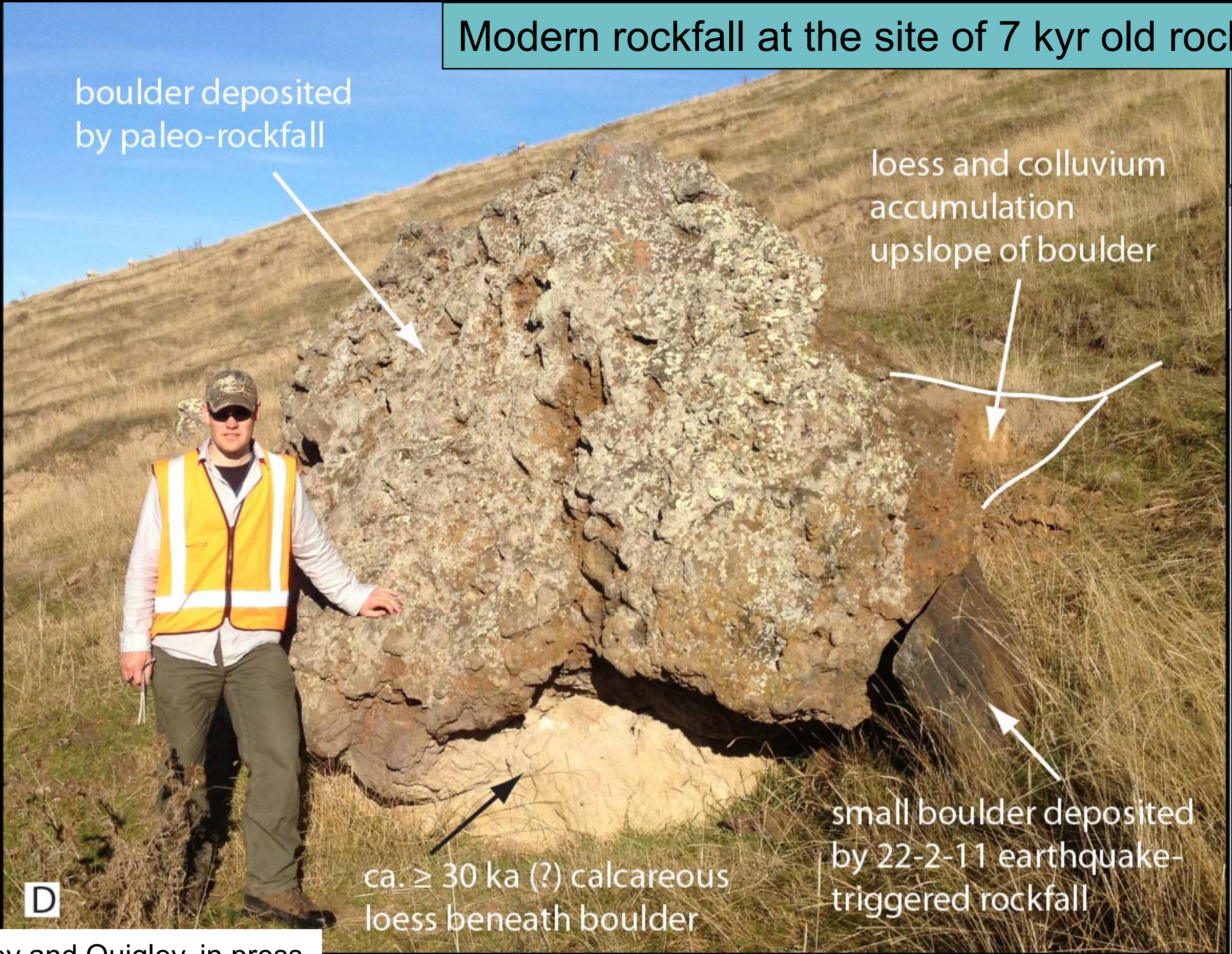
Virtually every modern natural disaster has had a historical and / or geological analogue of equal or greater severity



Bastin et al., 2013

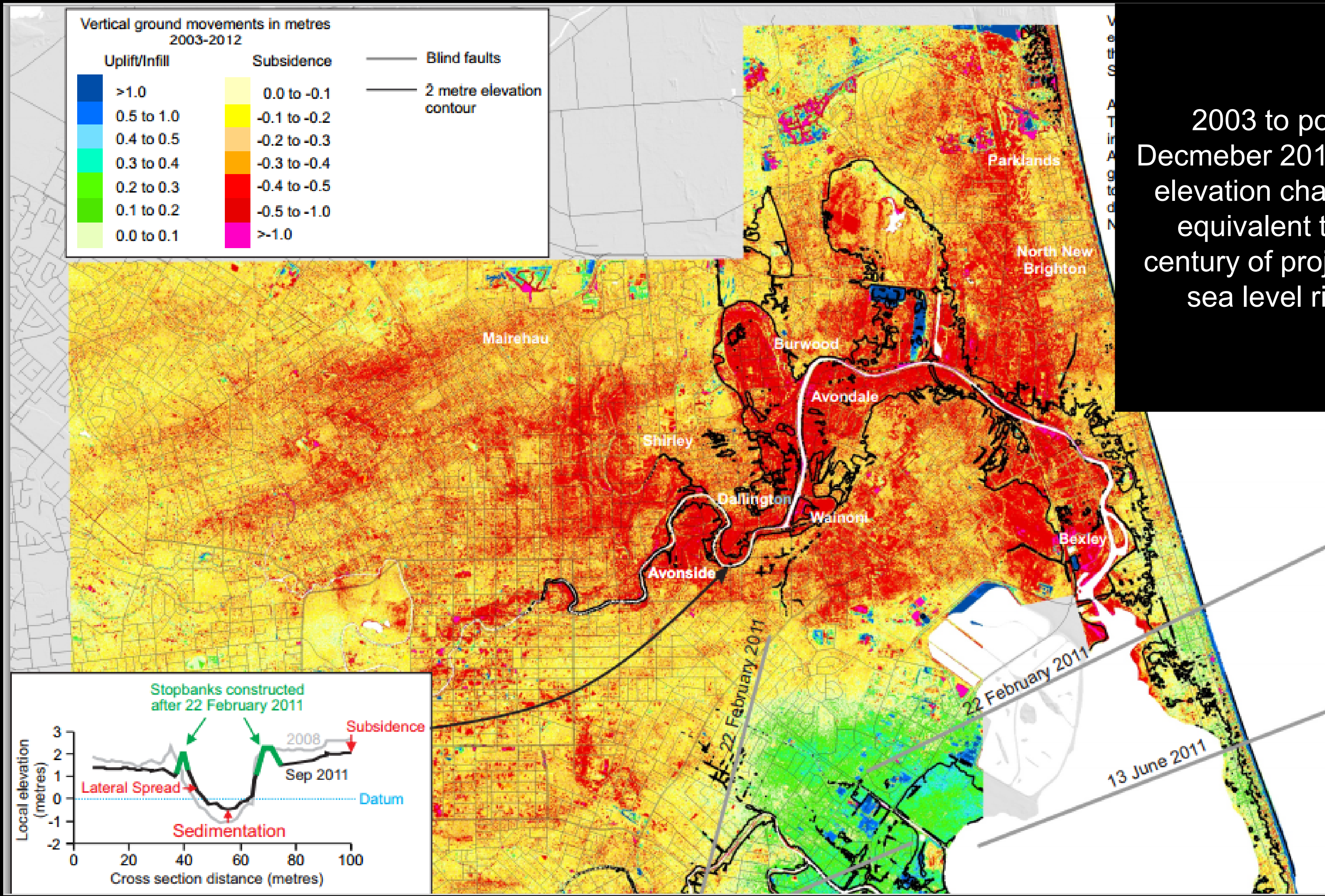
The geologic record doesn't lie:

Modern rockfall at the site of 7 kyr old rockfall



Mackey and Quigley, in press

Earthquakes influence other hazards



2003 to post Decmeber 2011 land elevation changes equivalent to a century of projected sea level rise

Hughes, Quigley et al, in press

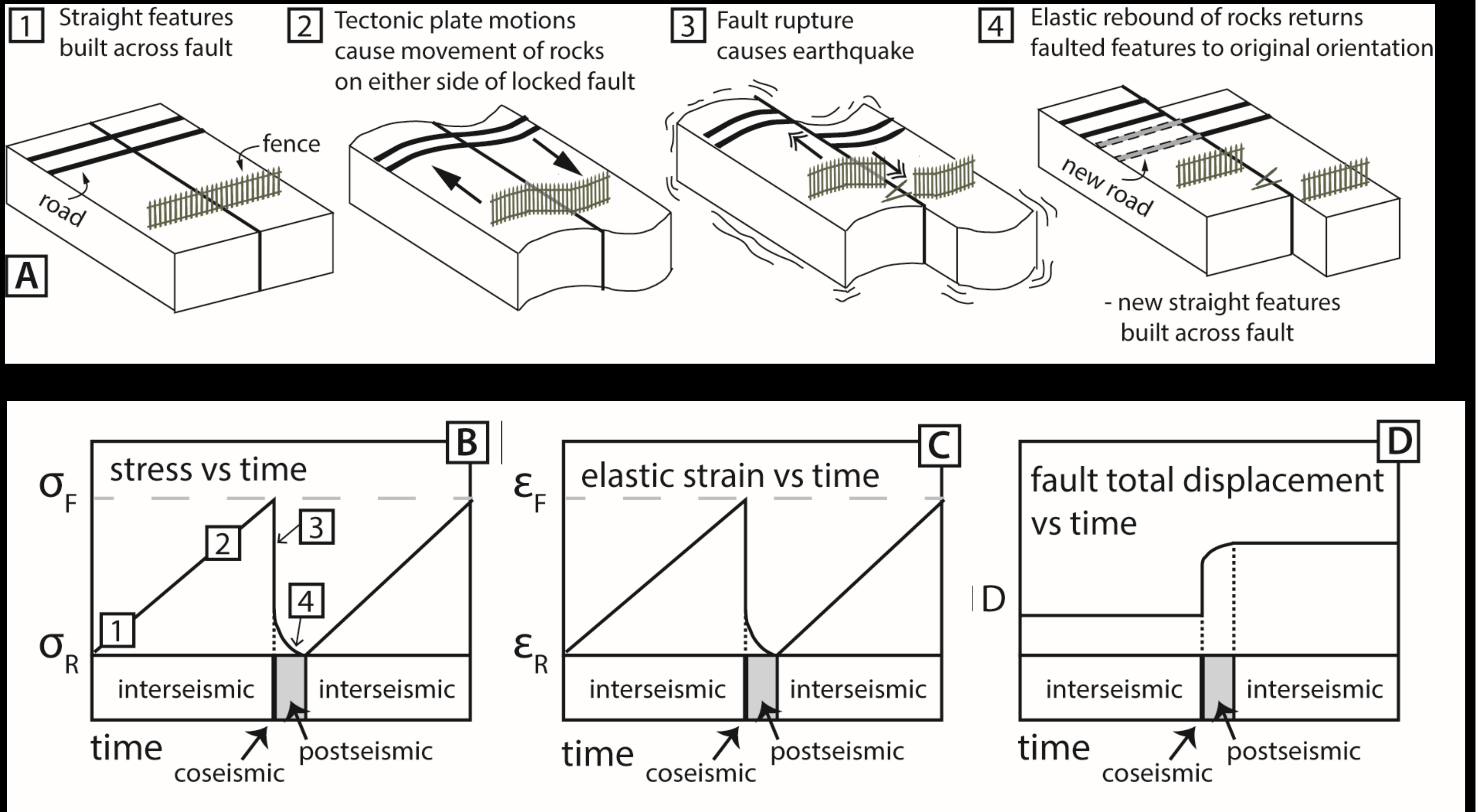
Conclusions

- Global earthquake fatalities are increasing despite advances in earthquake science and engineering
- Fatalities and loss will continue to increase due to population growth and increased exposure, and poor building materials and design
- Earthquake prediction *senso stricto* is unlikely. However the impacts of earthquakes can be predicted.
- Scientists can help inform land planning decisions that can save lives and reduce financial loss in future earthquakes
- ‘Cheap’ alternatives to earthquake-strengthening exist and could be tailored and integrated into diverse cultures

Conclusions

- Scientists must engage directly with policy makers (top-down) AND the general public (bottom-up) if major changes are to be made
  - Land use planning
  - Insurance
  - Perception of the value of science in disaster risk reduction
  - Building codes

[redacted]



The earthquake cycle

Characteristic, predictable earthquakes?