

# *On the Uses of Earthquakes*

*“Civilization exists by geological consent,  
subject to change without notice!”*

*– Will Durant*

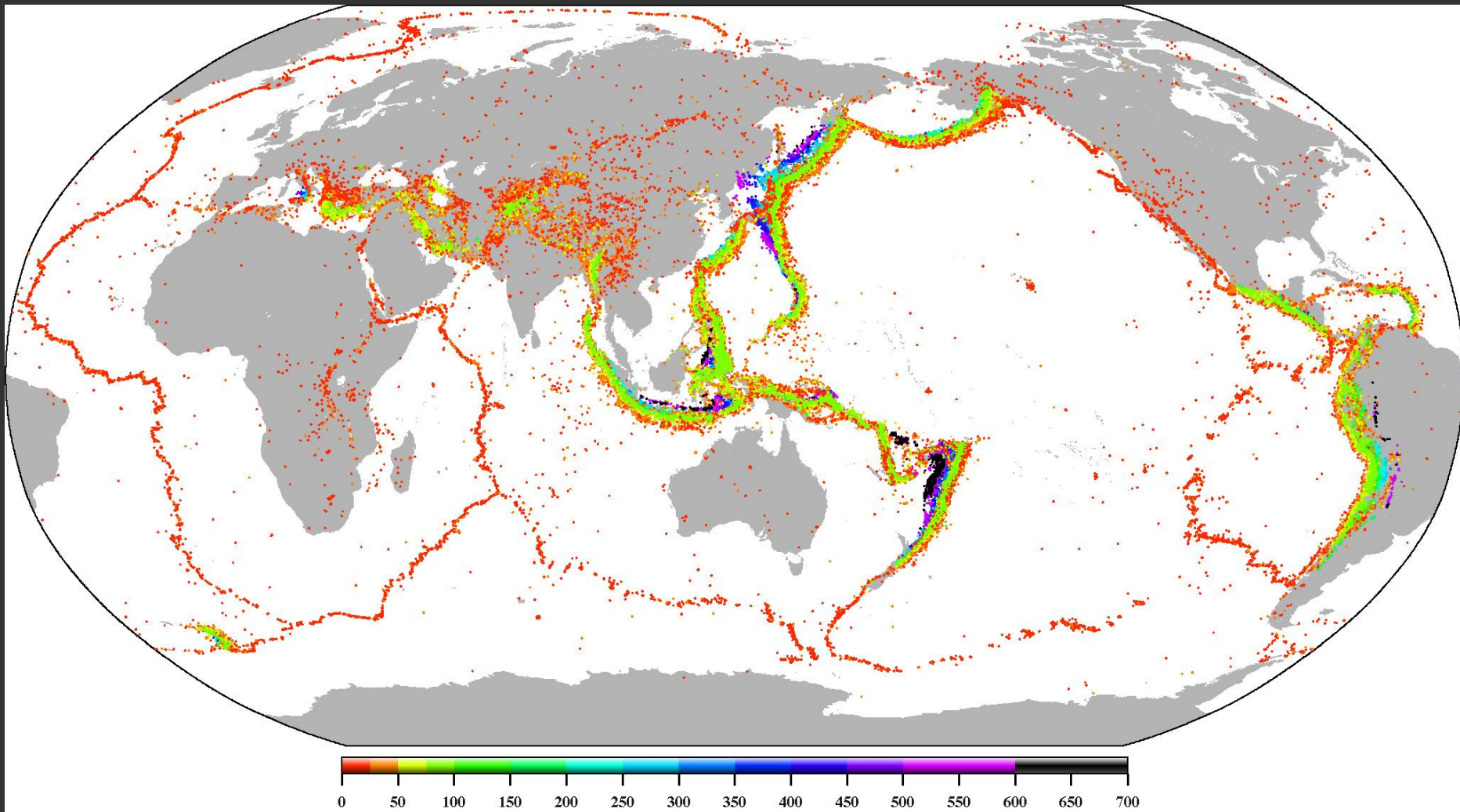
*TE WAI POUNAMU*

*c. 40 mm/yr*

*“What unknown affinity  
Lies between Mountain and Sea  
In country crumpled like an unmade bed”*

*- Arawata Bill – Denis Glover*

# *Major Plate Boundaries Defined by EQ Activity*

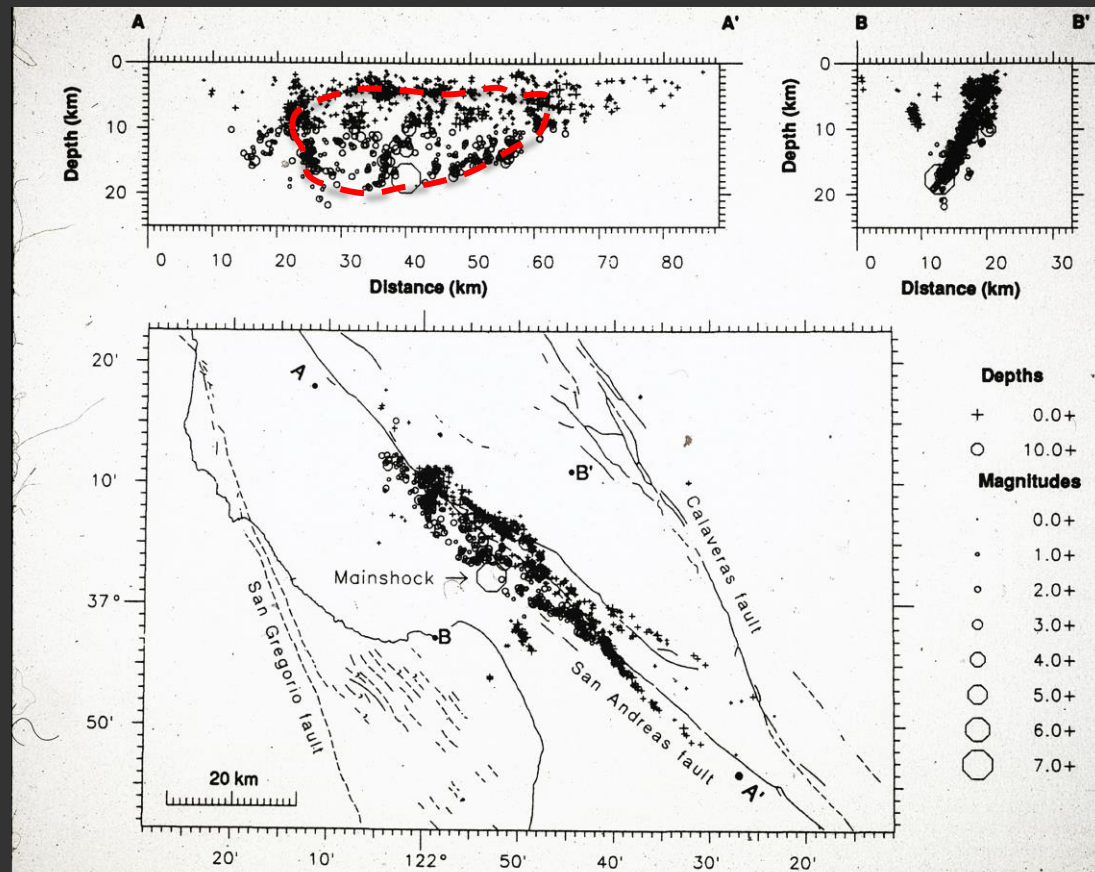




# Earthquake Ruptures are not 'Fly-Spots'!

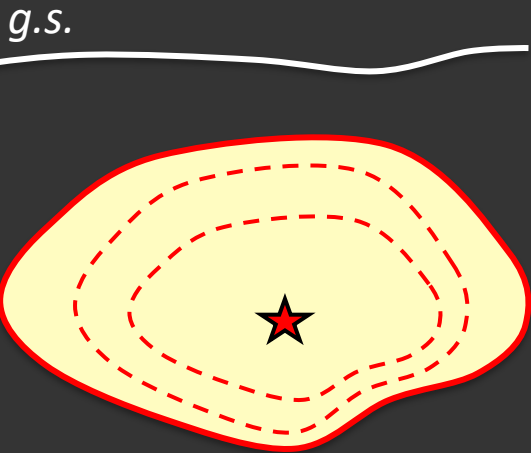
e.g. 1989 M6.9 Loma Prieta  
Mainshock-Aftershock  
Sequence)

Magnitude depends on  
RUPTURE AREA



**EQ SCALING** (circular  
ruptures  
with  $\Delta\tau = 3 \text{ MPa}$ )

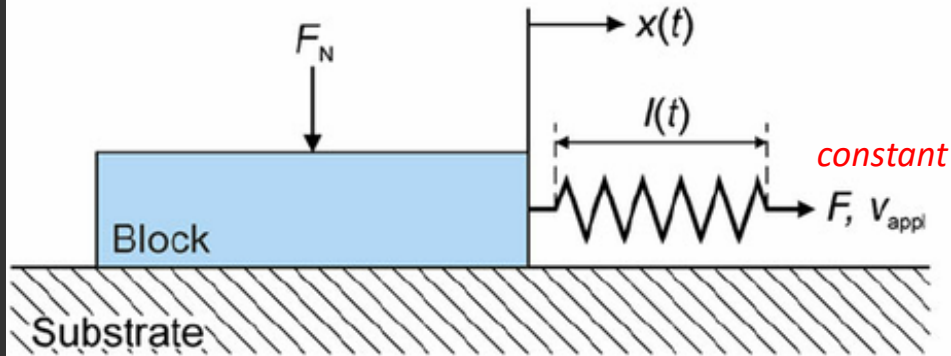
EARTHQUAKE MAGNITUDE	AVERAGE SLIP	RUPTURE DIMENSION	NZ FREQUENCY
M8	~3 m	~100 km	~0.01 /yr
M7	~1 m	~30 km	~0.1 /yr
M6	~30 cm	~10 km	~1 /yr
M5	~10 cm	~3 km	~10 /yr
M4	~3 cm	~1 km	~100 /yr
M3	~1 cm	~300 m	~1000 /yr
M2	~3 mm	~100 m	~10,000 /yr
M1	~1 mm	~30 m	~100,000 /yr





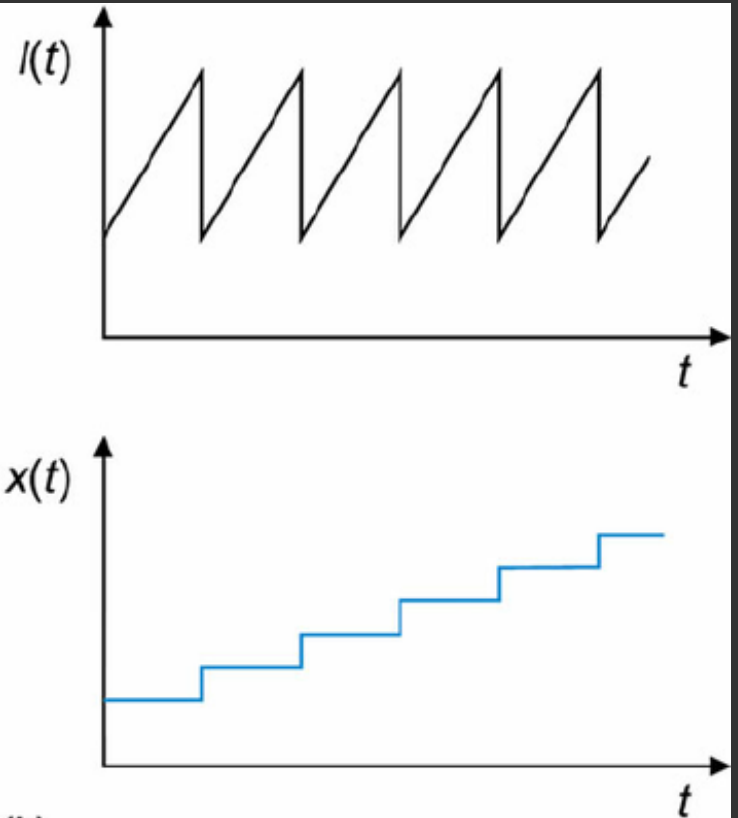
# *EQs - Frictional Instability on Faults*

*Inside a Seismologist's Head*  
- **block slider**



*frictional 'stick-slip' instability*

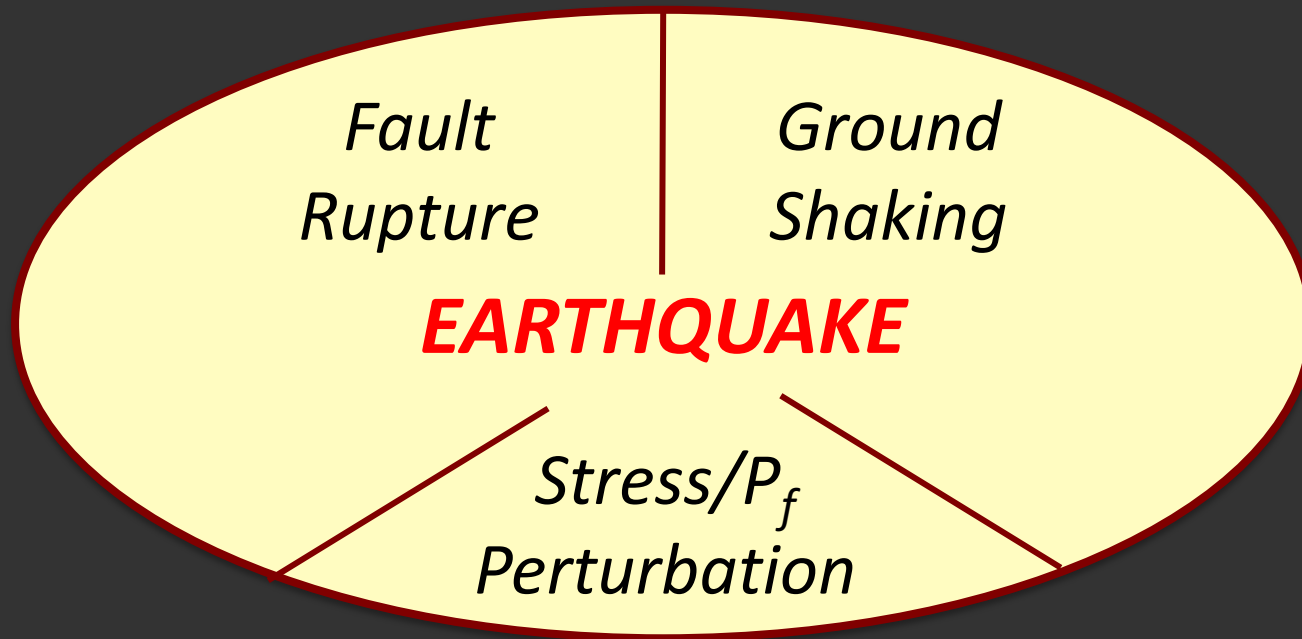
(a)



(b)

# EARTHQUAKES

mostly produced by *increments of shearing displacement along existing faults*



# EARTHQUAKE

## GROUND SHAKING

### MASS MOVEMENT

- landslides
- rock-falls
- avalanches

### SEDIMENTATION

- slumping
- debris flows
- turbidites
- seismites

### CONSOLIDATION

- compaction
- liquefaction
- spreading

## FAULT RUPTURE

### INCREMENTAL TECTONICS

- mountain building
- basin subsidence

### INCREMENTAL DEFORMATION

- fault rocks
- fold growth
- subsidiary faulting  
and fracturing

### GEOMORPHIC INCREMENTS

- scarp formation
- river downcutting
- coastal change
- ponding

## STRESS CHANGE

( $\Delta\sigma$ ,  $\Delta\tau$ ,  $\Delta P_f$ )

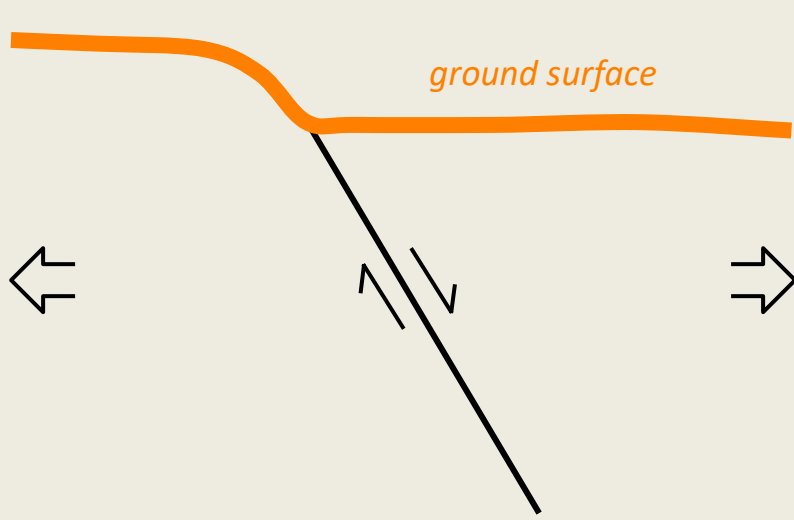
REDISTRIBUTION OF  
STRESS / STRAIN  
HETEROGENEITIES

**PERMEABILITY  
ENHANCEMENT**

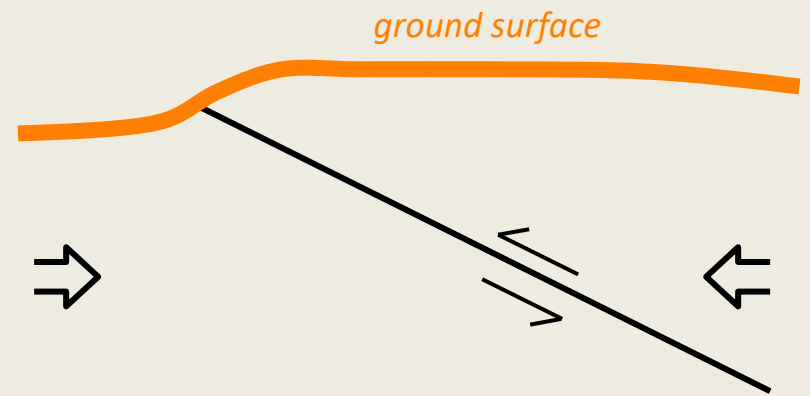
- ### INCREMENTAL FLUID FLOW
- diagenetic, hydrothermal,  
hydrocarbon, metamorphic,  
magmatic fluids
  - hydrothermal deposition
  - oil-gas migration



# Three Basic Types of Fault

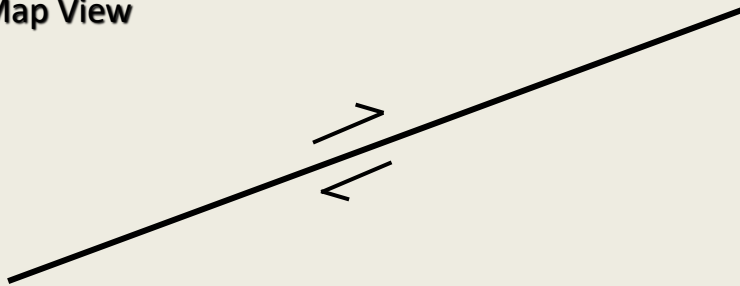


**NORMAL FAULT** from horizontal extension



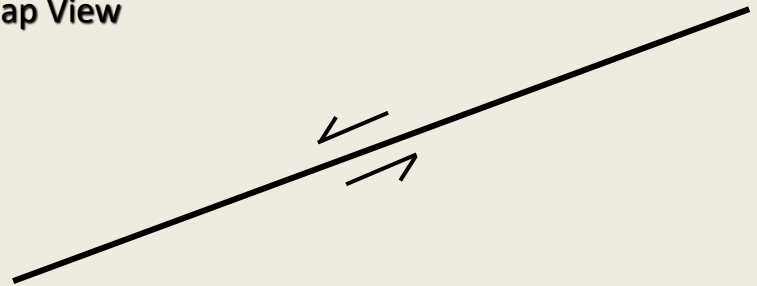
**THRUST FAULT** from horizontal compression

Map View



**Dextral STRIKE-SLIP FAULT** (sideways motion)

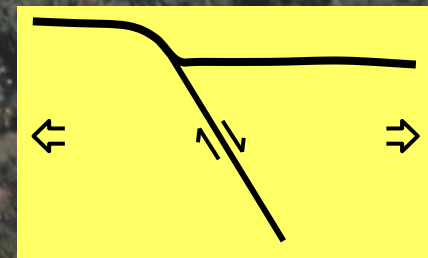
Map View



**Sinistral STRIKE-SLIP FAULT** (sideways motion)

*1983 M7.2 Borah Peak, Idaho, EQ*

*- one increment of mountain building  
on a range-bounding normal fault*





## *Normal Fault Scarp – 1987 M6.5 Edgecumbe Earthquake*





*1999 M7.6 Chi-Chi, Taiwan, EQ*  
*- rupture of a thrust fault*



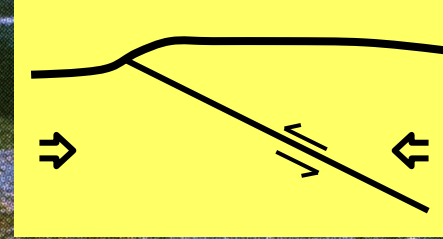


# Wufeng School



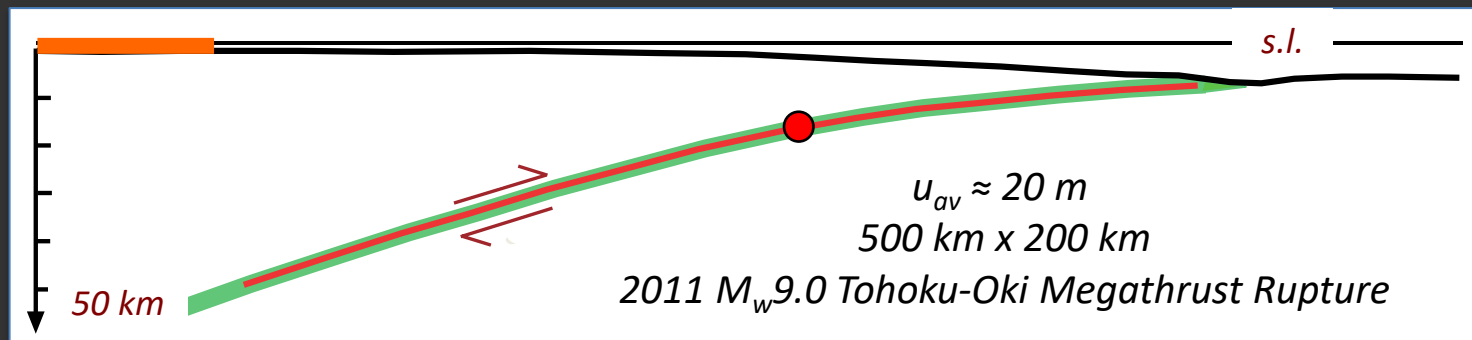
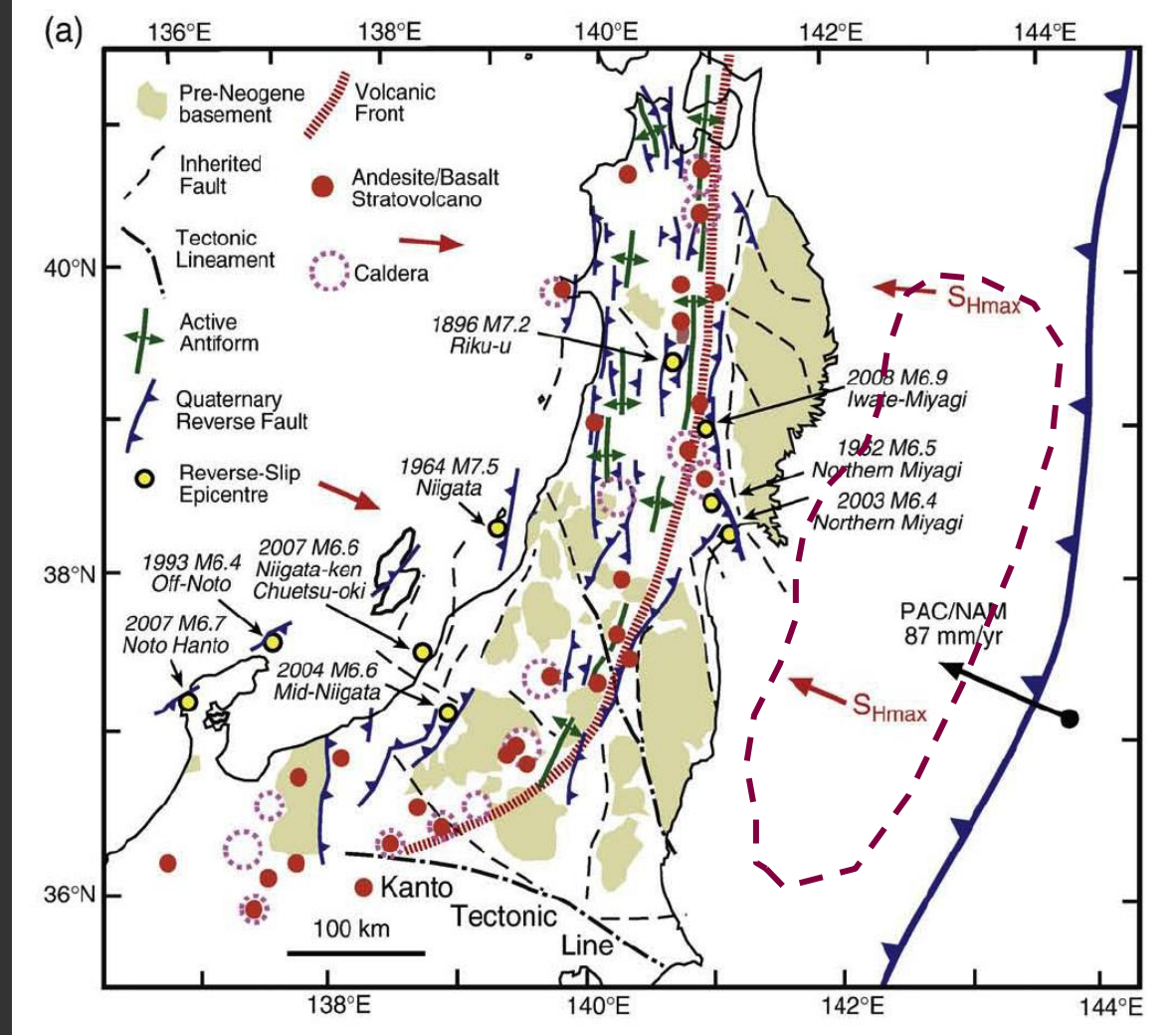


*1999 M7.6 Chi-Chi, Taiwan, EQ  
- rupture of a thrust fault*

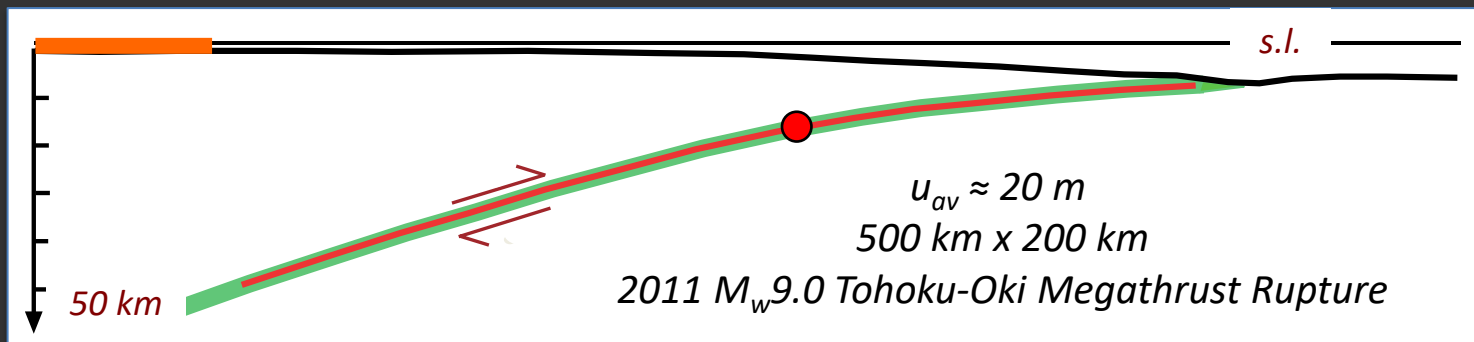




# 2011 M9.0 Tohoku-Oki MEGATHRUST Rupture, northern Japan



# 2011 M9.0 Tohoku-Oki, Japan, MEGATHRUST Rupture





# *Inundation of the Sendai Coastal Plain*



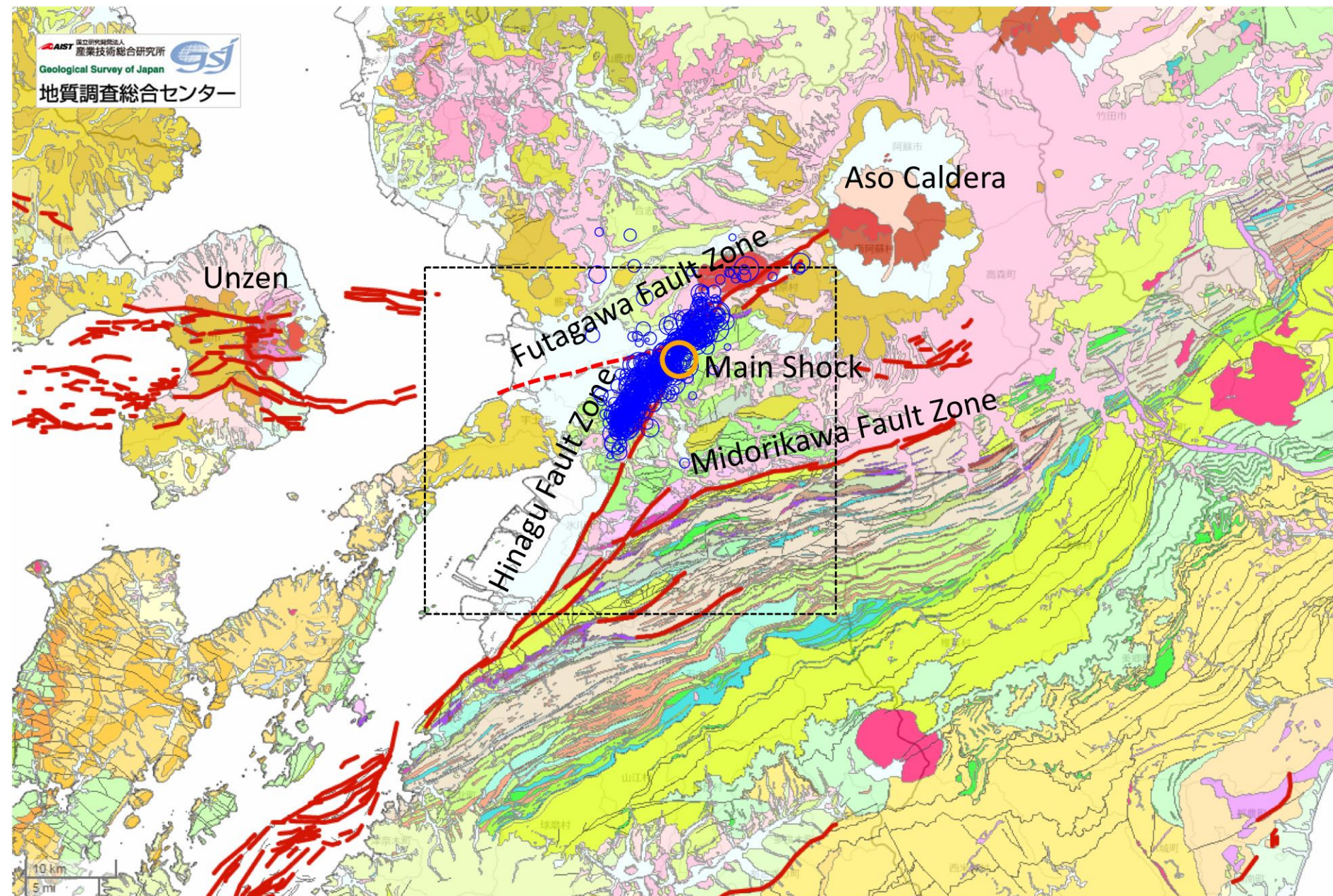


# *Sendai Plain –Post-Tsunamai*





# 2016 Kumamoto, Kyushu, EQ Sequence





*April 16, 2016 M7.1 Kumamoto, Kyushu  
Dextral Strike-Slip Rupture*





*1999 M7.6 Chi-Chi, Taiwan, earthquake  
- strike-slip splay rupture*





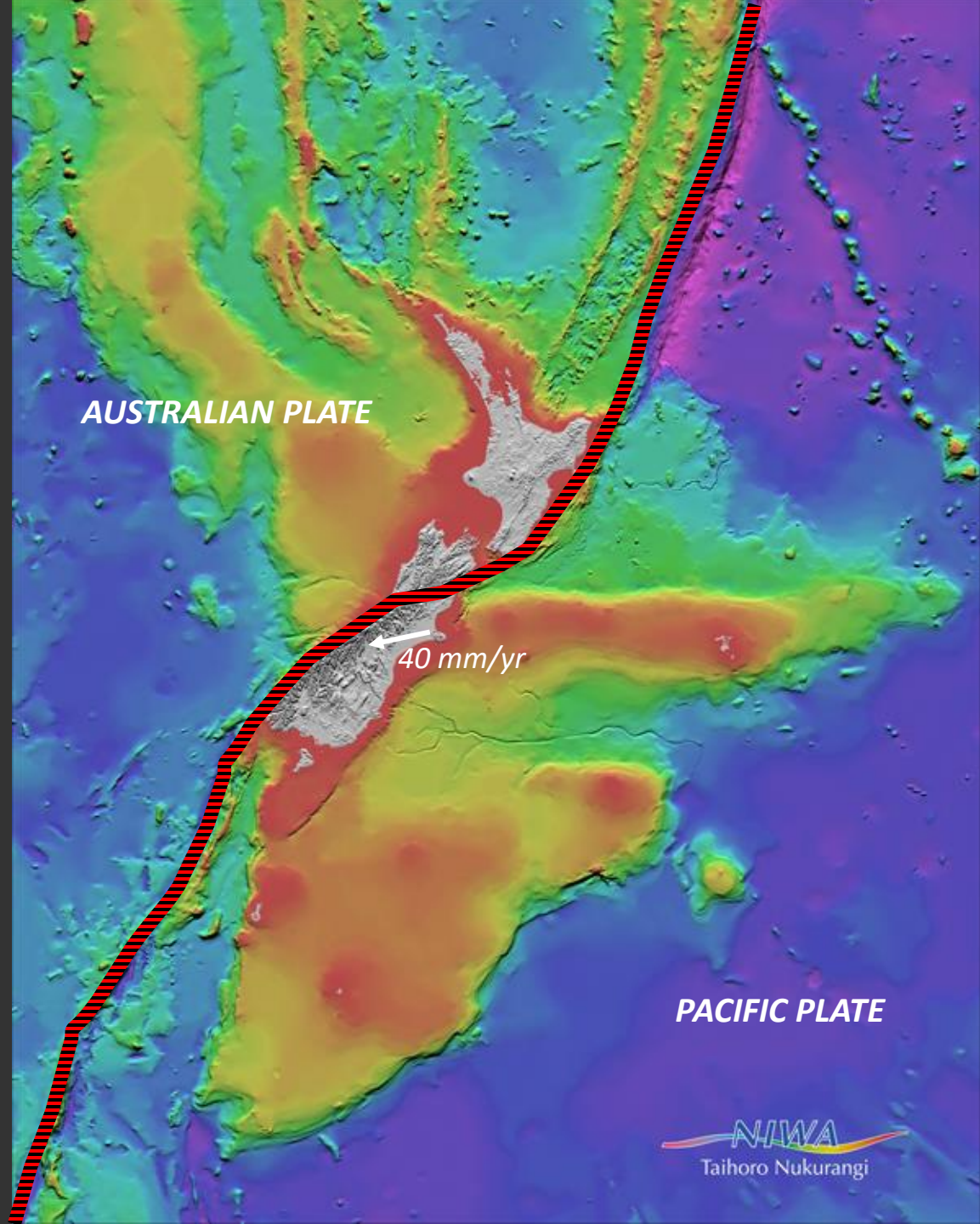
*2011*  
*Greendale Fault Rupture*



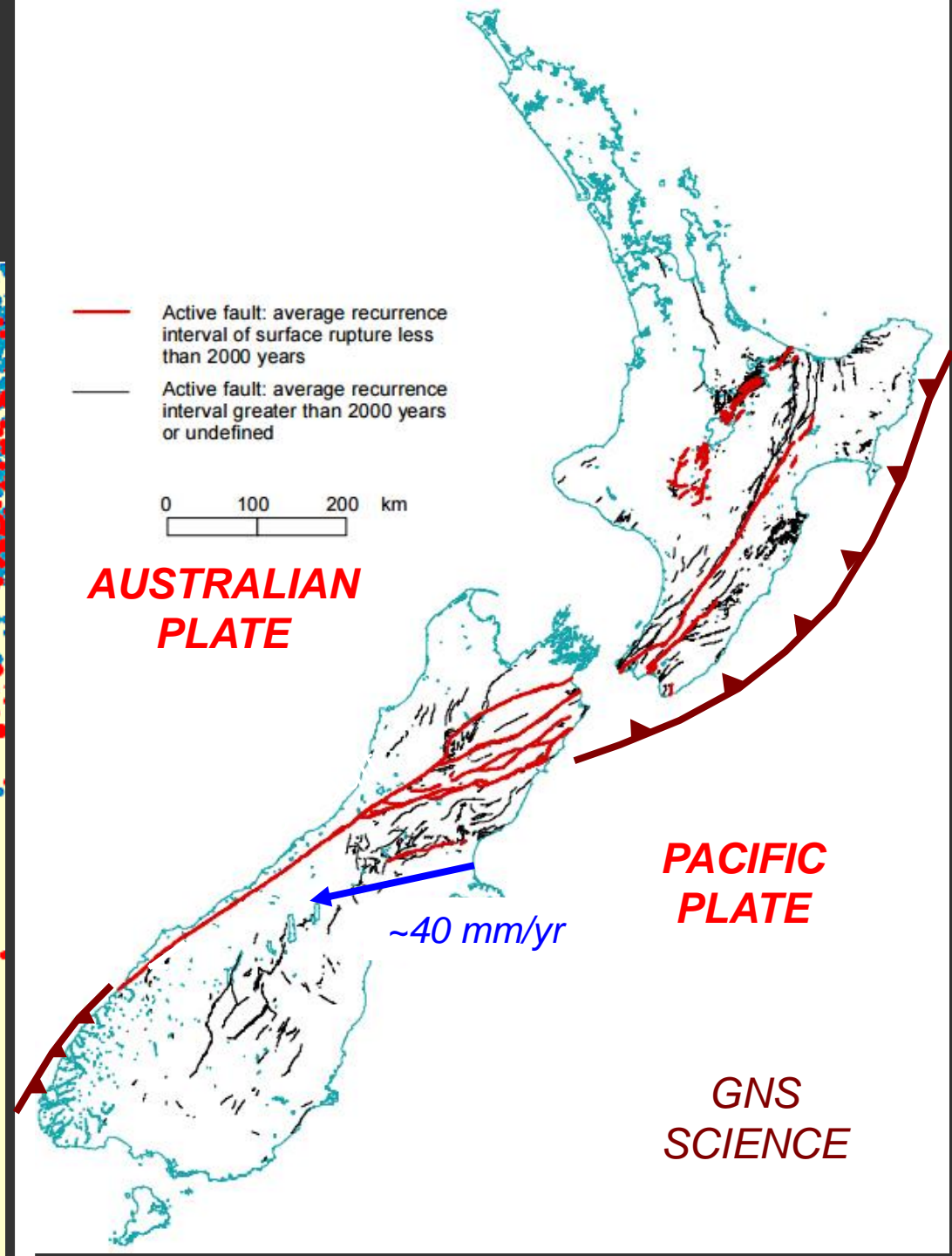
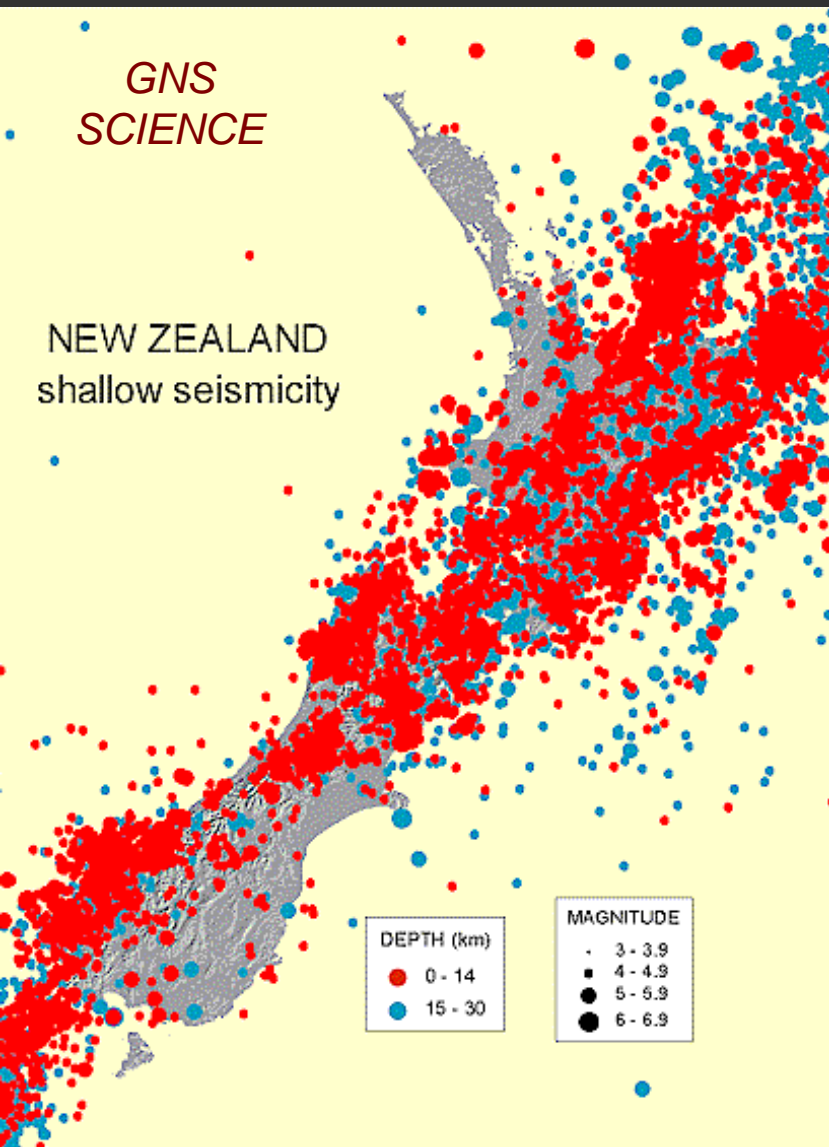


# WHY IS NEW ZEALAND?

*South Island is an emergent landmass ONLY because it is being **actively shortened by distributed earthquake faulting** associated with the Pacific / Australia plate boundary*



# Active Faults and Seismicity Defining the New Zealand Plate Boundary





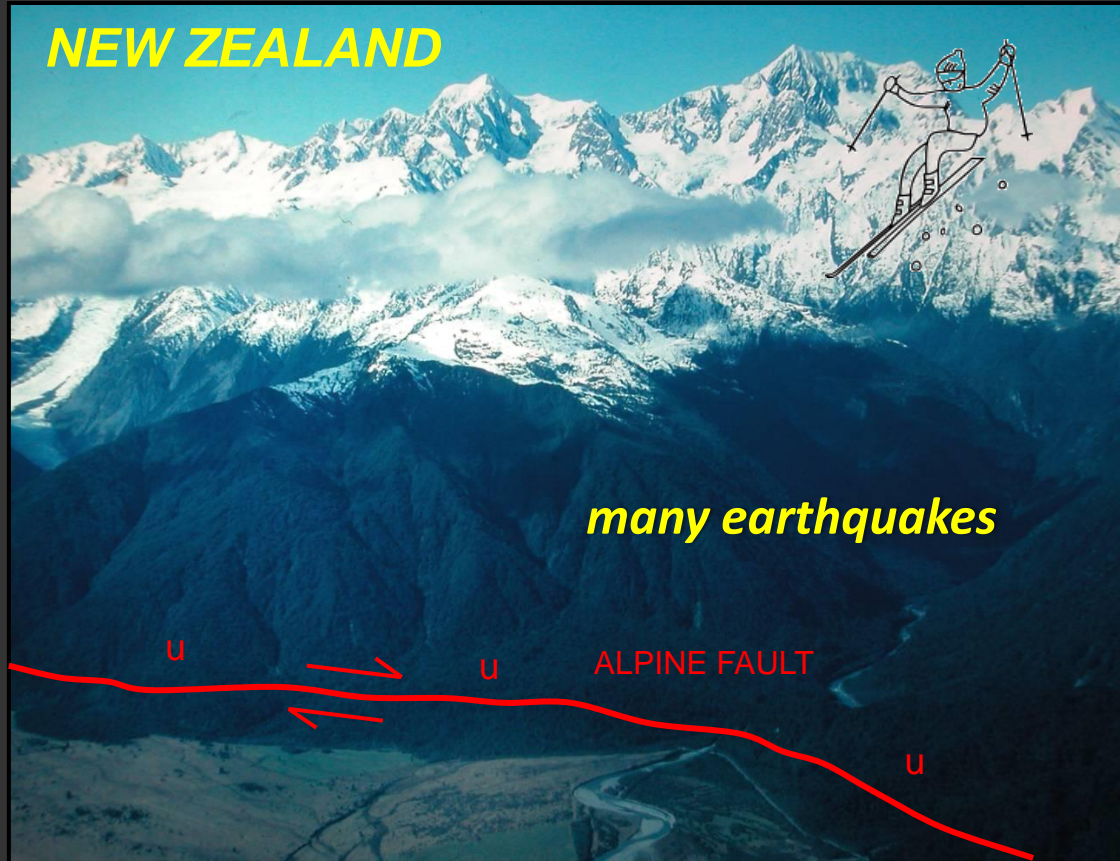
## OLD ZEELAND

*few earthquakes*



# Tectonic Tempo

## NEW ZEELAND



*many earthquakes*

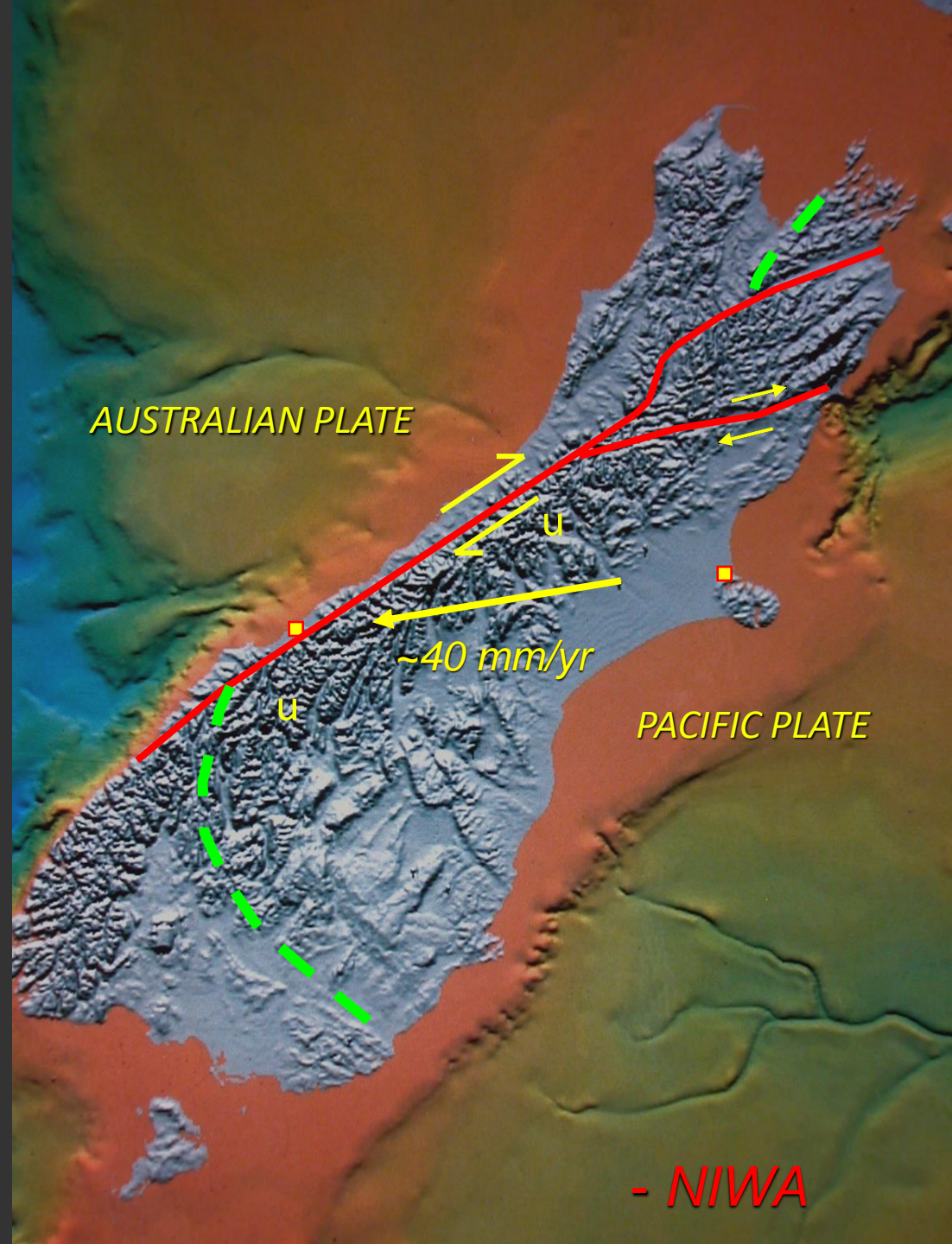
### ALPINE FAULT

- last rupture c. 1717 AD
- rupture length  $\sim 350$  km
- dextral slip  $\sim 8$  m
- $7.8 < M < 8.0$
- recurrence  $330 \pm 70$  yrs?



## ***WHY ARE THE SOUTHERN ALPS?***

***The South Island is an  
emergent landmass  
ONLY because it is being  
actively shortened by  
distributed earthquake  
faulting associated with  
the Pacific / Australia  
plate boundary***





# Alpine Fault - Gaunt Creek 1977

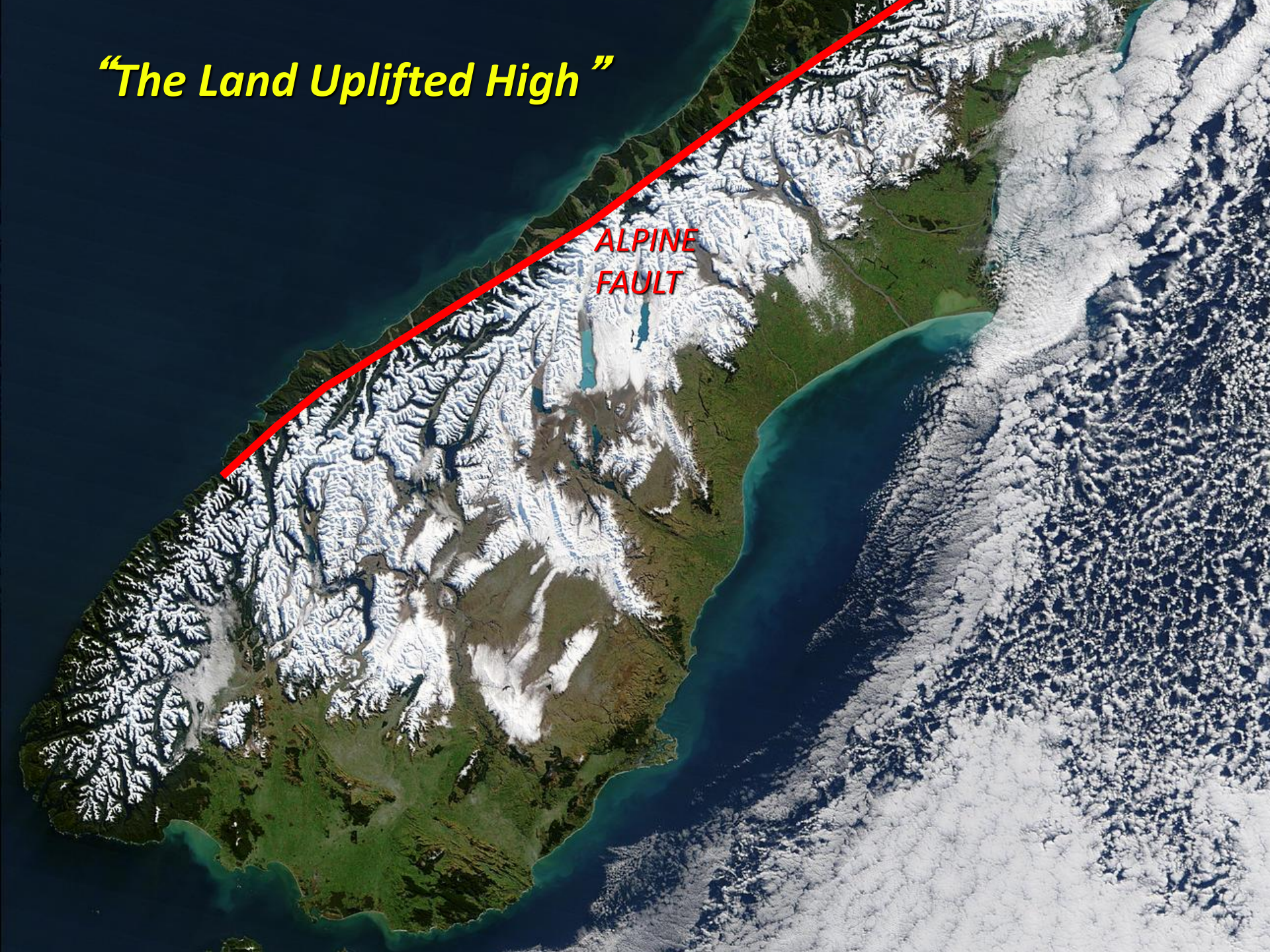


- *last rupture c. 1717 AD*
- *rupture length ~ 350 km*
- *dextral slip ~ 8 m*
- *$7.8 < M < 8.0$*
- *recurrence  $330 \pm 70$  yrs?*



# ***“The Land Uplifted High”***

**ALPINE  
FAULT**





# Why is Wellington?

- the EQ Catch 22

## Wellington Fault

$L \sim 75 \text{ km}$

$\text{Slip} \sim 5 \text{ m}$

$\text{Slip-rate} \sim 6\text{-}7 \text{ mm/yr}$

$M \sim 7.6$

$\text{R.I.} \sim 750 \pm 250 \text{ yrs}$

1 Wellharb  $\approx 1 \text{ km}^3$

*Risk = Hazard x Vulnerability*

Photo - Lloyd Homer



# Why is the Basin Reserve?







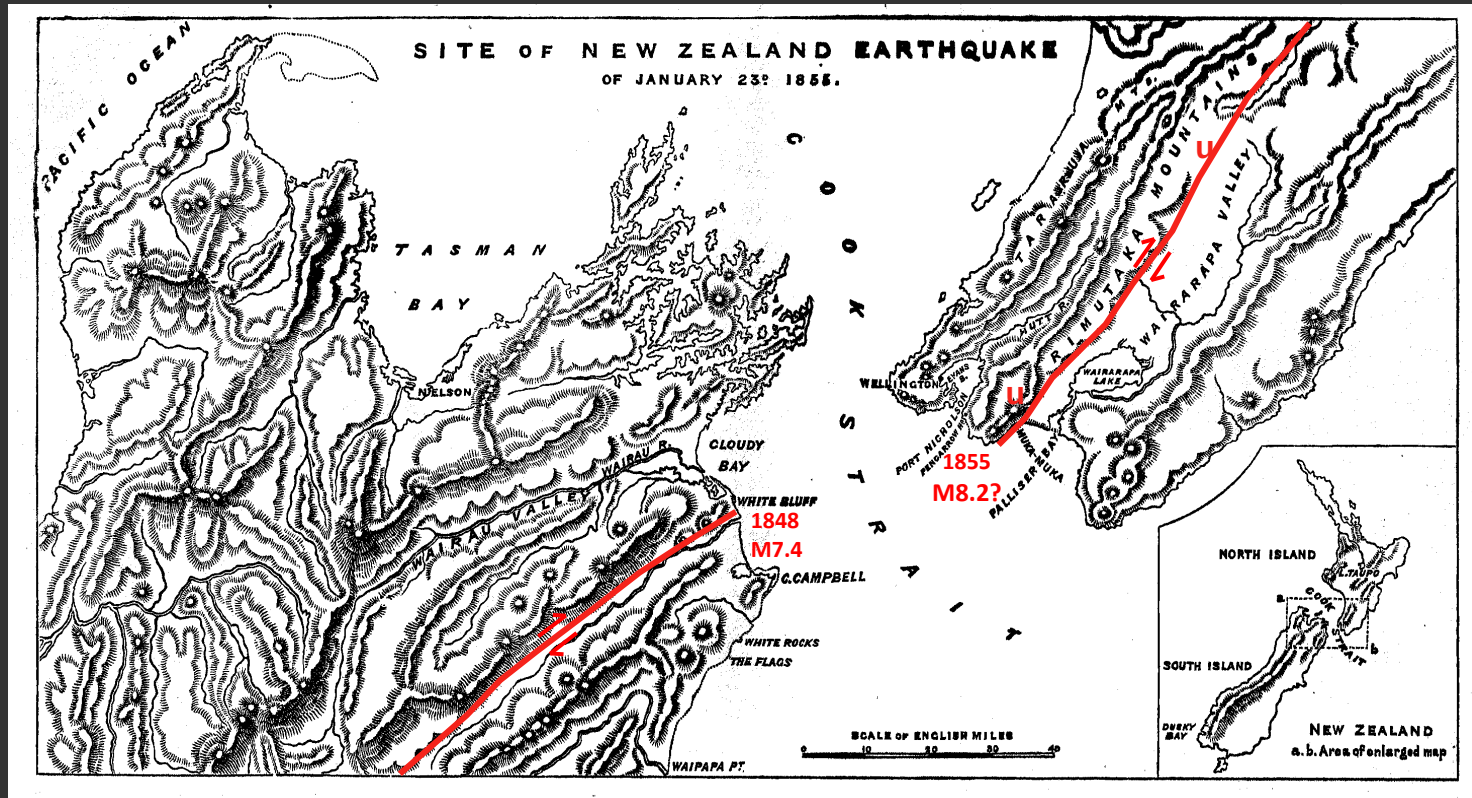
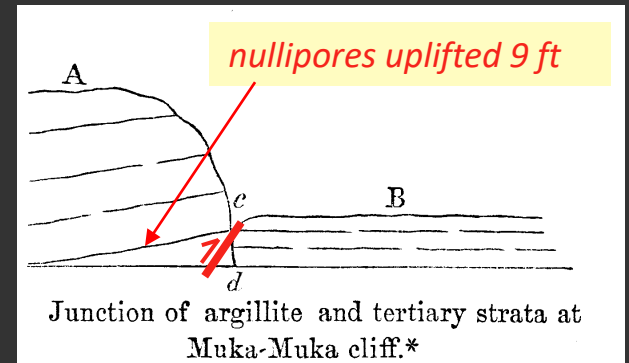
# A Well-Planned City?

## 1840





# Earthquake in New Zealand - Permanent Upheaval and Subsidence of Land - A Fault Produced in the Rocks





# 1855 EQ Rupture SW of Featherston

- $M_w$  8.2 ?
- length c. 145 km?
- reverse slip < 3 m
- (dextral strike-slip < 18 m)!!

*- first recognition, world-wide,  
of the association between an  
earthquake and an increment  
of fault displacement*

*- Charles Lyell (1868)*



Photo - Lloyd Homer



Charles Lyell  
(1797-1875)

## *Principles of Geology*

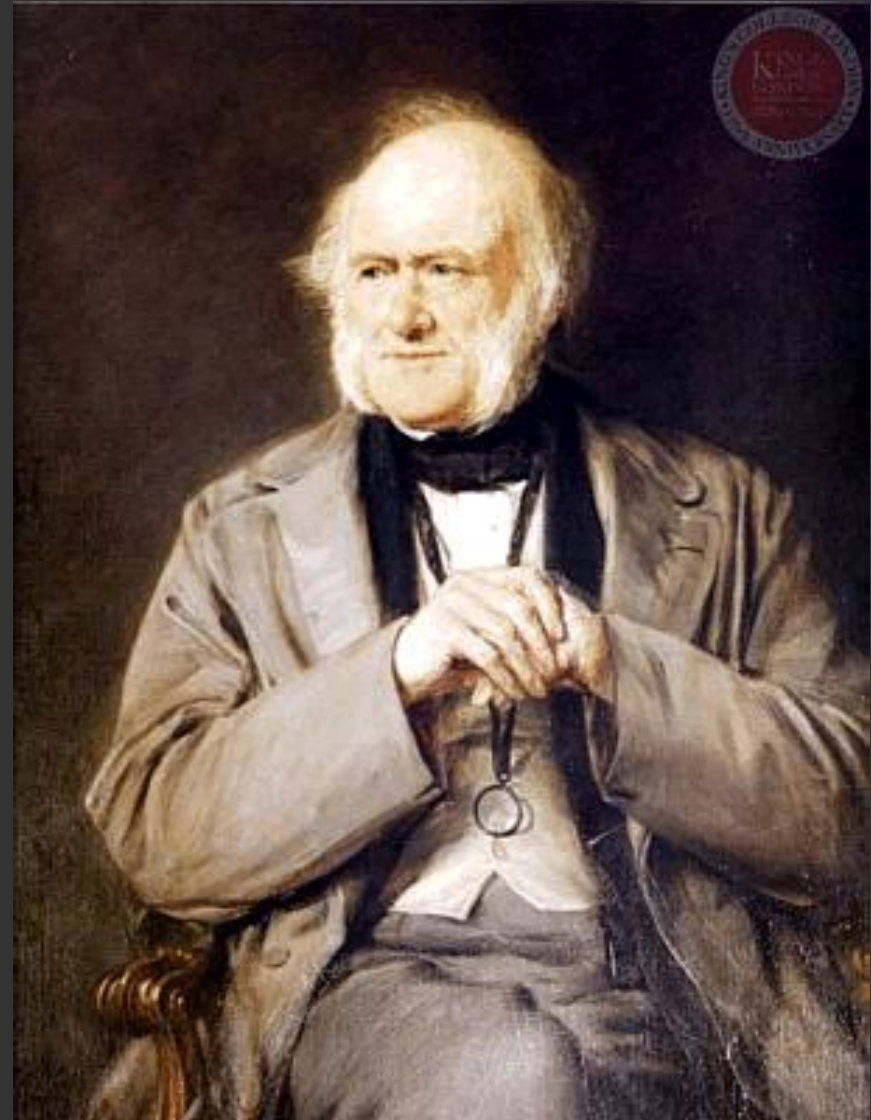
1st edn. 1830-33

10th edn. 1868

*“The Present is the Key to the Past.”*

*“The geologist has rarely enjoyed so good an opportunity as that afforded him by this convulsion in New Zealand, of observing one of the steps by which those great displacements of the rocks called ‘faults’ may in the course of ages be brought about.”*

- based on correspondence with Frederick Weld,  
Walter Mantell, and Edward Roberts (Royal Engineer)





*Hydrothermal Mineralisation Hosted in Ancient Fault Zones  
(e.g. Macraes Mine, Otago - Au-Quartz Veining in a Thrust Fault  
exhumed from base of the seismogenic zone at c. 10-15 km depth)*



*Macraes Gold Content (c. 200 tonnes) requires  
episodic flow of 2-20 Wellharbs of c. 300 °C  
hydrothermal fluid*





*hanging-wall shear*



## *Thrust-Hosted Au-Quartz Vein, South Africa*



*Ruptures create transitory PERMEABILITY!*



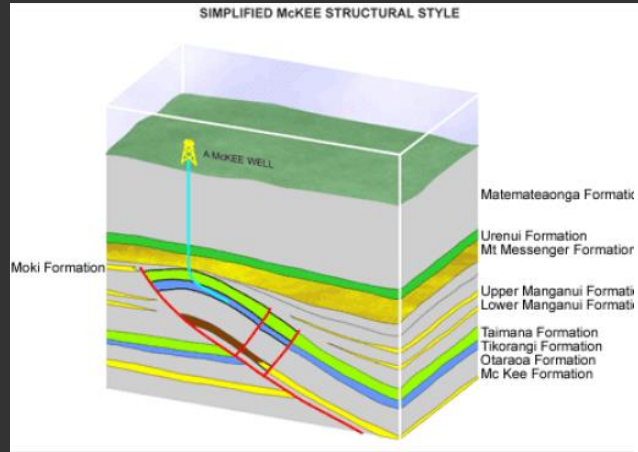
*Mixed Hydrothermal/Hydrocarbon Flow Along a Normal Fault  
Monterey Formation, Santa Barbara*



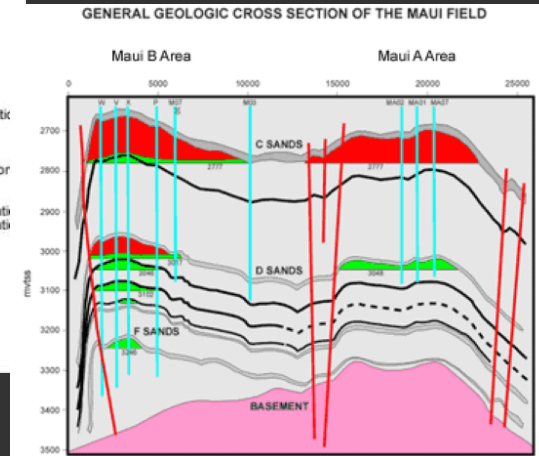


# Taranaki Basin Reservoir Structures

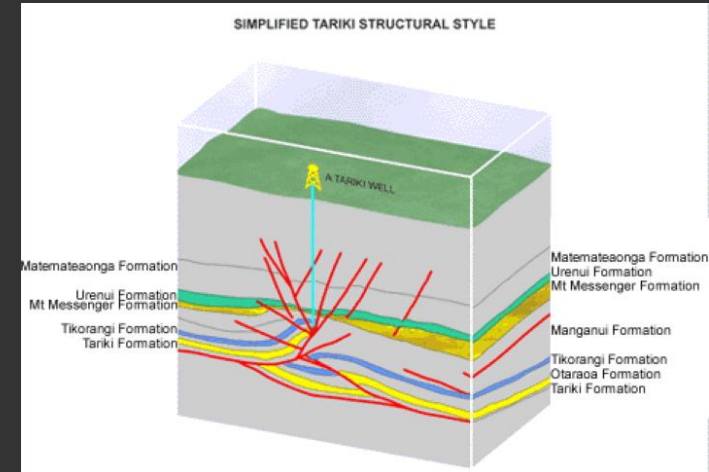
SIMPLIFIED McKEE STRUCTURAL STYLE



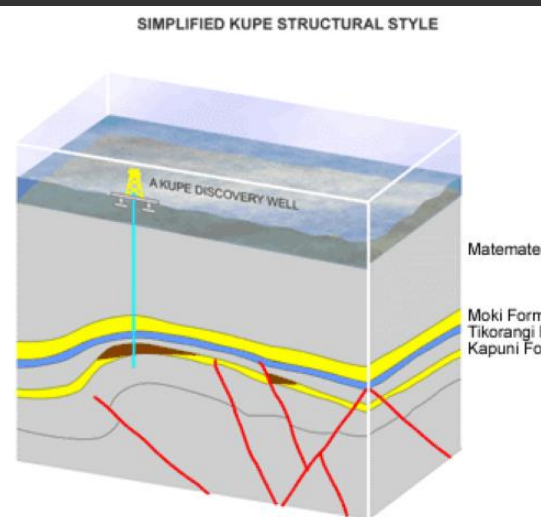
GENERAL GEOLOGIC CROSS SECTION OF THE MAUI FIELD



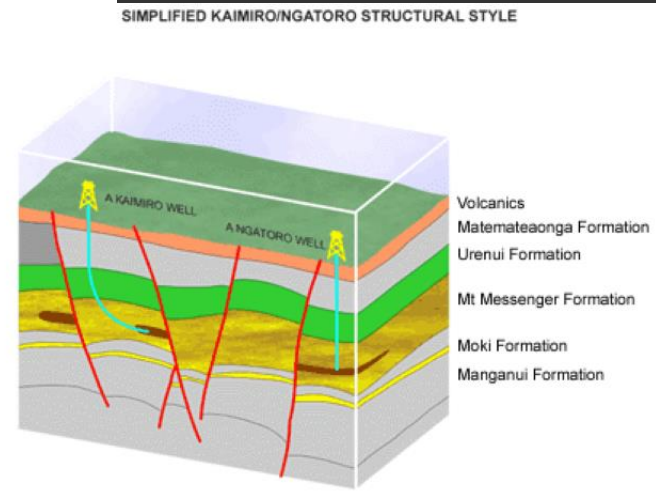
SIMPLIFIED TARIKI STRUCTURAL STYLE



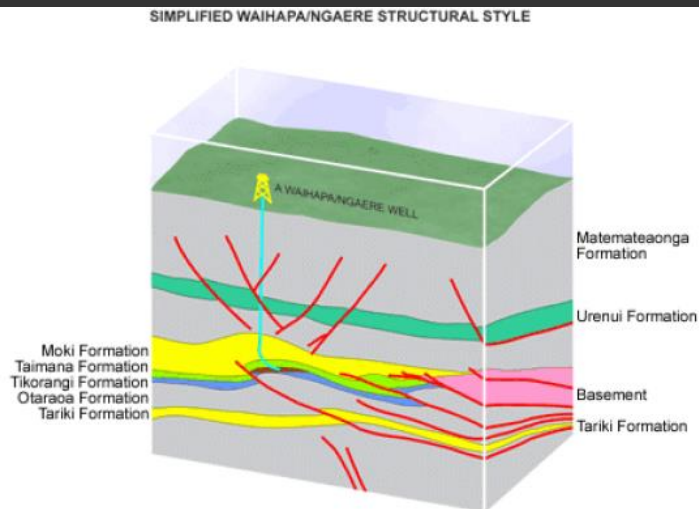
SIMPLIFIED KUPE STRUCTURAL STYLE



SIMPLIFIED KAIMIRO/NGATORO STRUCTURAL STYLE



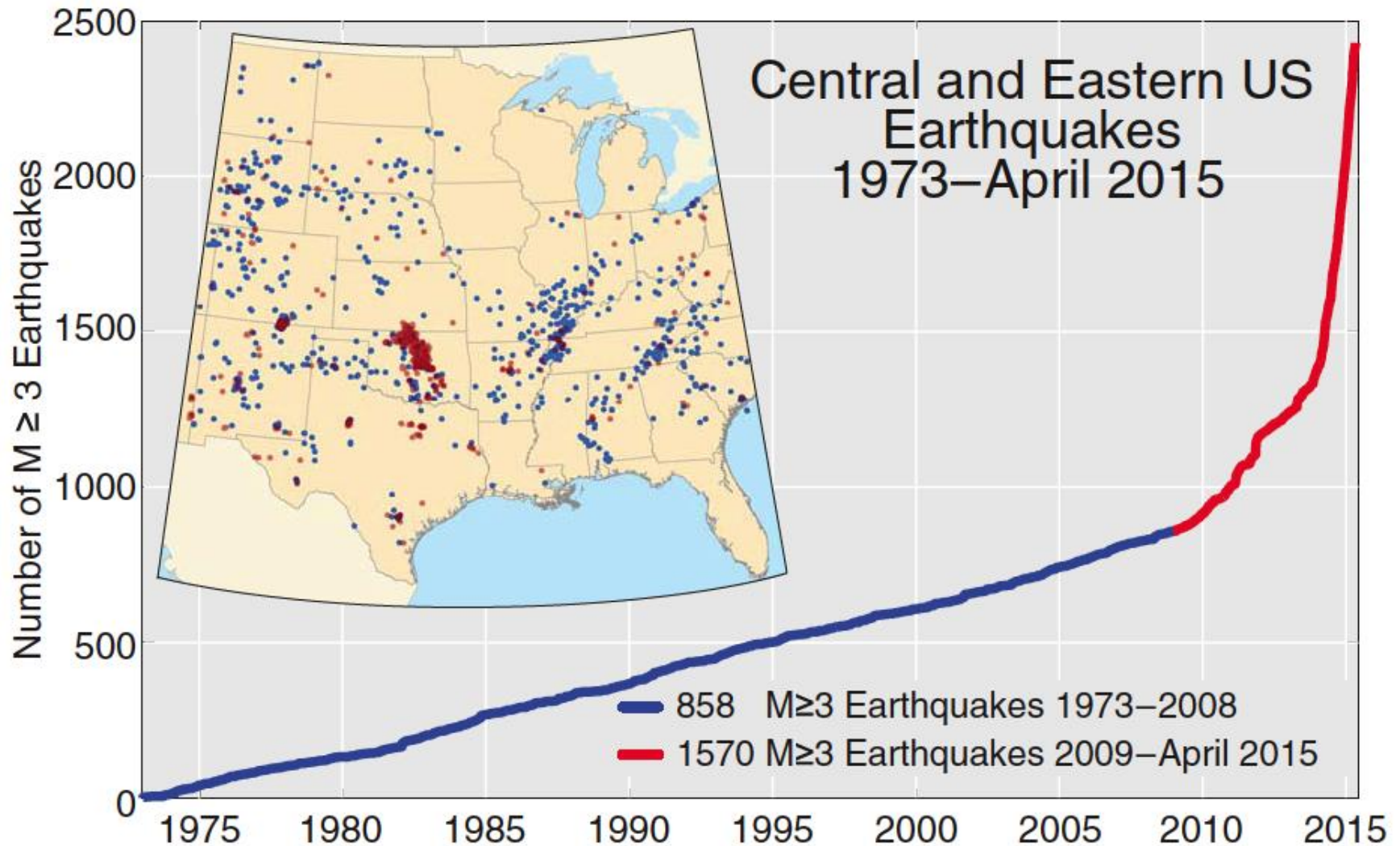
SIMPLIFIED WAIHAPA/NGAERE STRUCTURAL STYLE



Crown Minerals website

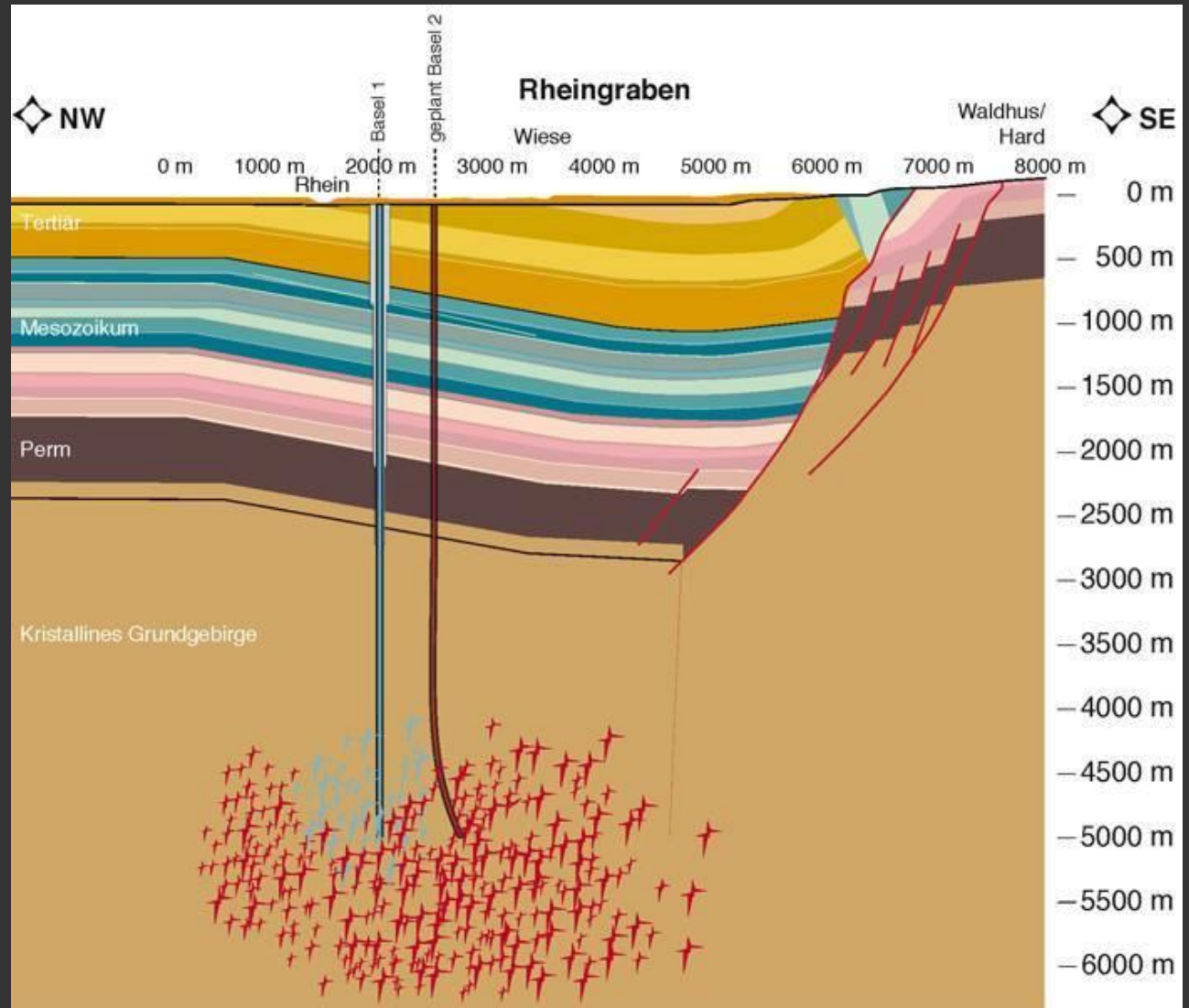


# *Post-2009 Accelerated Seismicity*





# Heat Mining – Rhine Graben

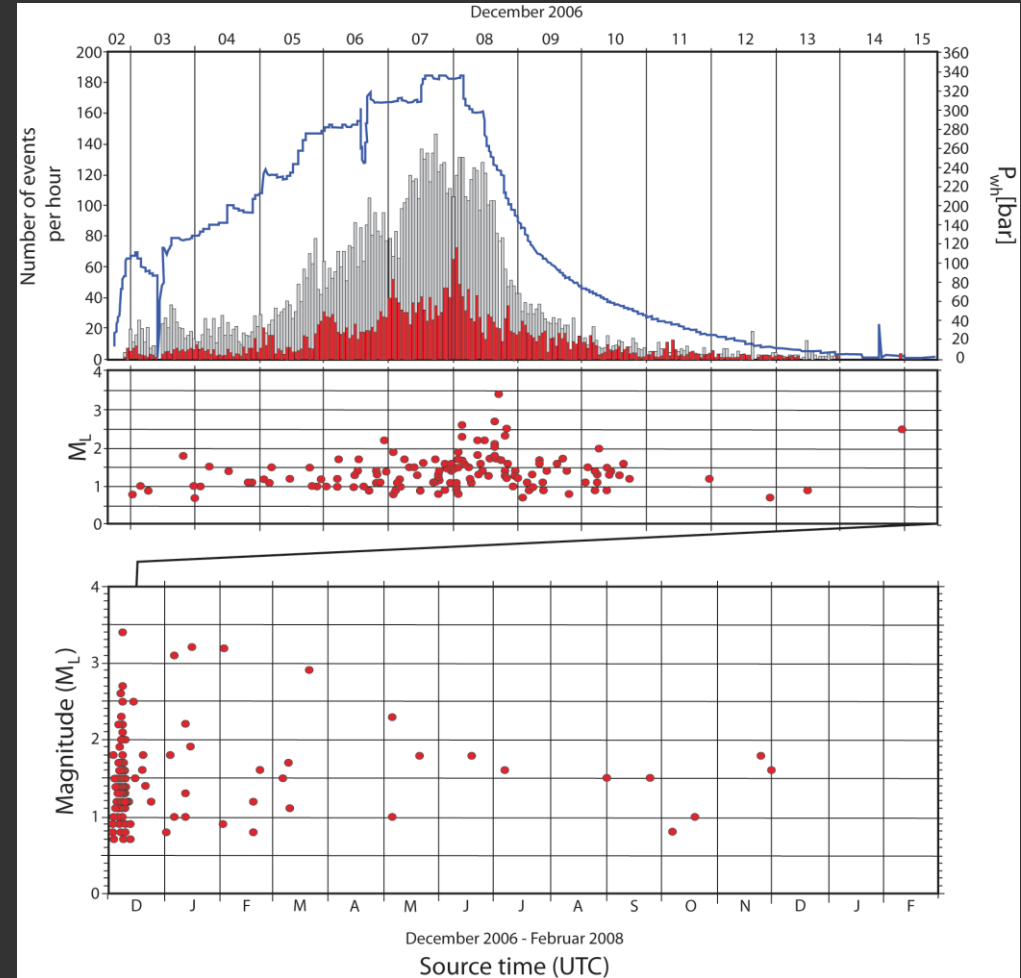


*'High' Continental  
Geothermal Gradient  
30-60 °C/km*



# Basel EGS – 2006-2008

11,500 m<sup>3</sup> injected in 1 week



Deichmann & Giardini, 2009: SRL, 80, 784-798



Basel, 1356 –  $6.0 < M < 7.1$







ΓΝΩΣ ΤΗΝ ΓΕΩΛΟΓΙΑΝ



***KNOW THY FAULTS!***





# Alpine Fault EQ Recurrence

Dextral slip per EQ  $\sim 8$  m

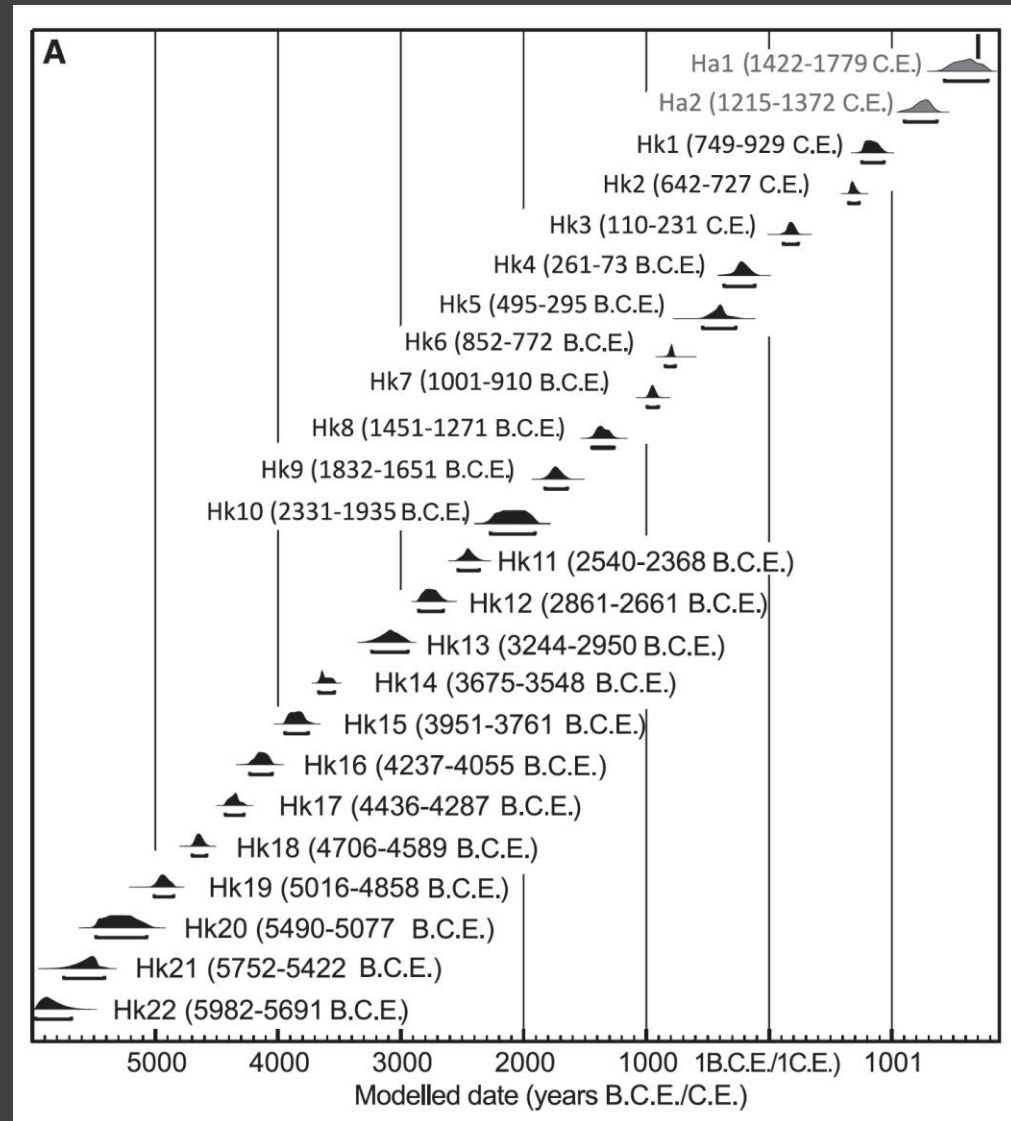
Time-averaged dextral slip-rate  $\sim 25$  mm/yr

R.I.  $\sim 320$  years

## Haast – Hokuri Ck.

- 8000 year record of Large EQs in sediments
- 24 major ruptures over 8000 years
- Average R.I.  $\sim 330$  years

**Last AF EQ  $\sim 1717$  A.D.**  
**- 304 yrs ago**



Berryman et al., 2012:  
*Science* 336, 1690-1693





**LARGE FLUID  
VOLUMES**

**$> 1 \text{ km}^3 \text{ H}_2\text{O}$  per  
km strike-length**



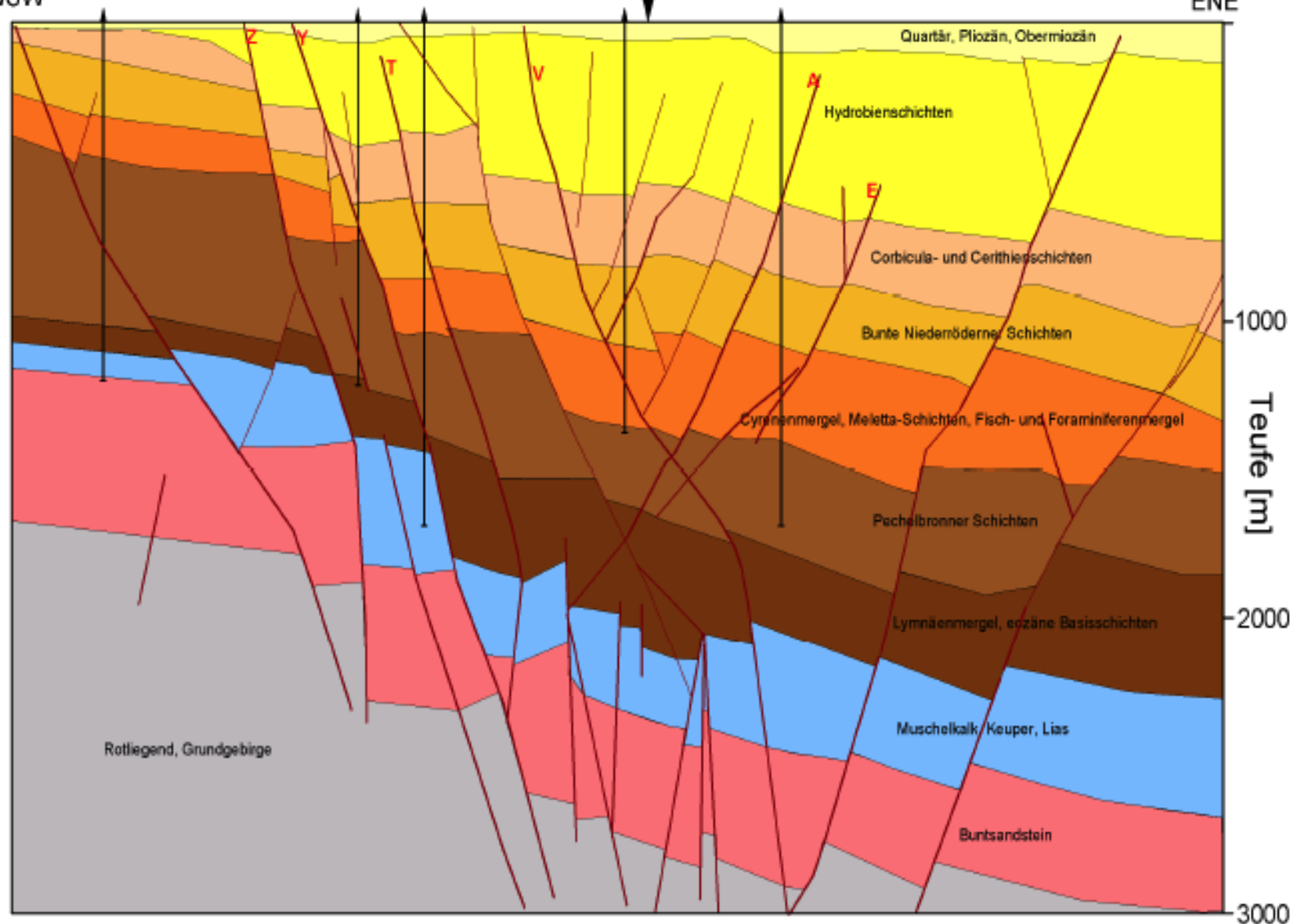




WSW

Bohrplatz, projiziert

ENE

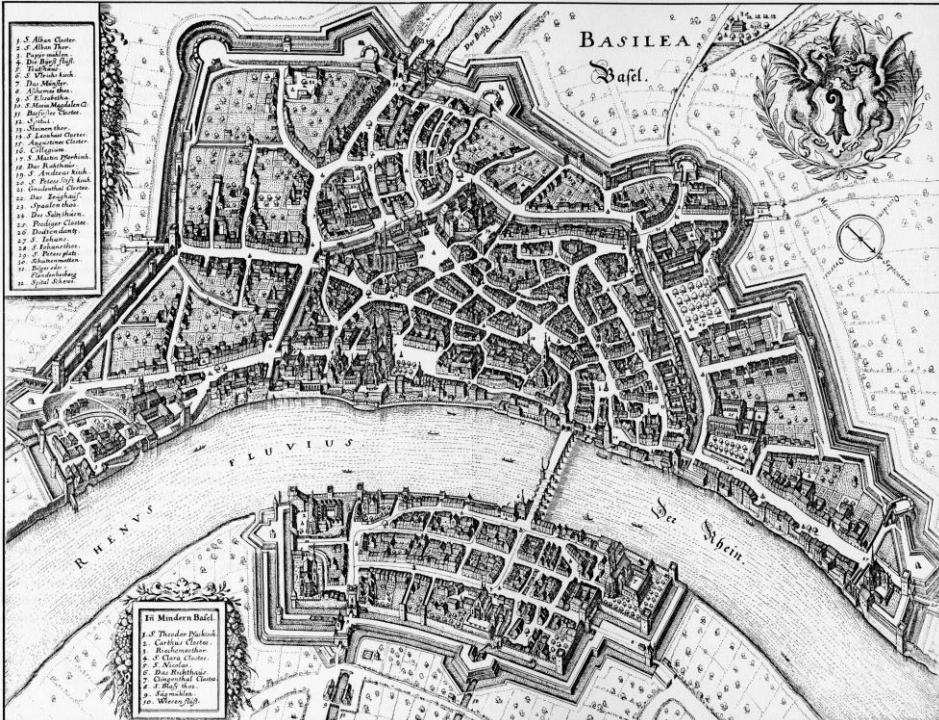




*April 16, 2016 M7.1 Kumamoto, Kyushu  
Dextral Strike-Slip Rupture*





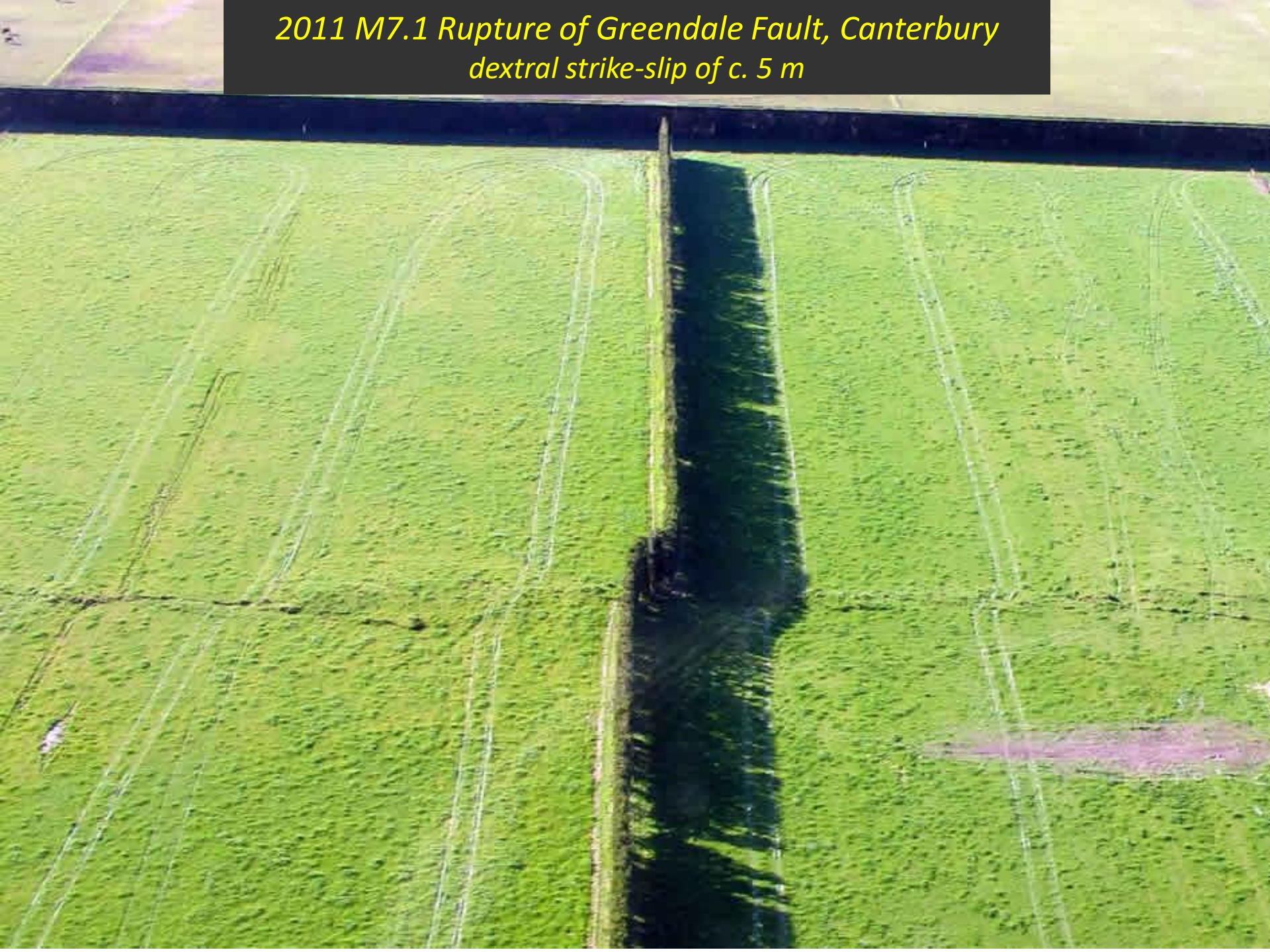


## Basel, Switzerland





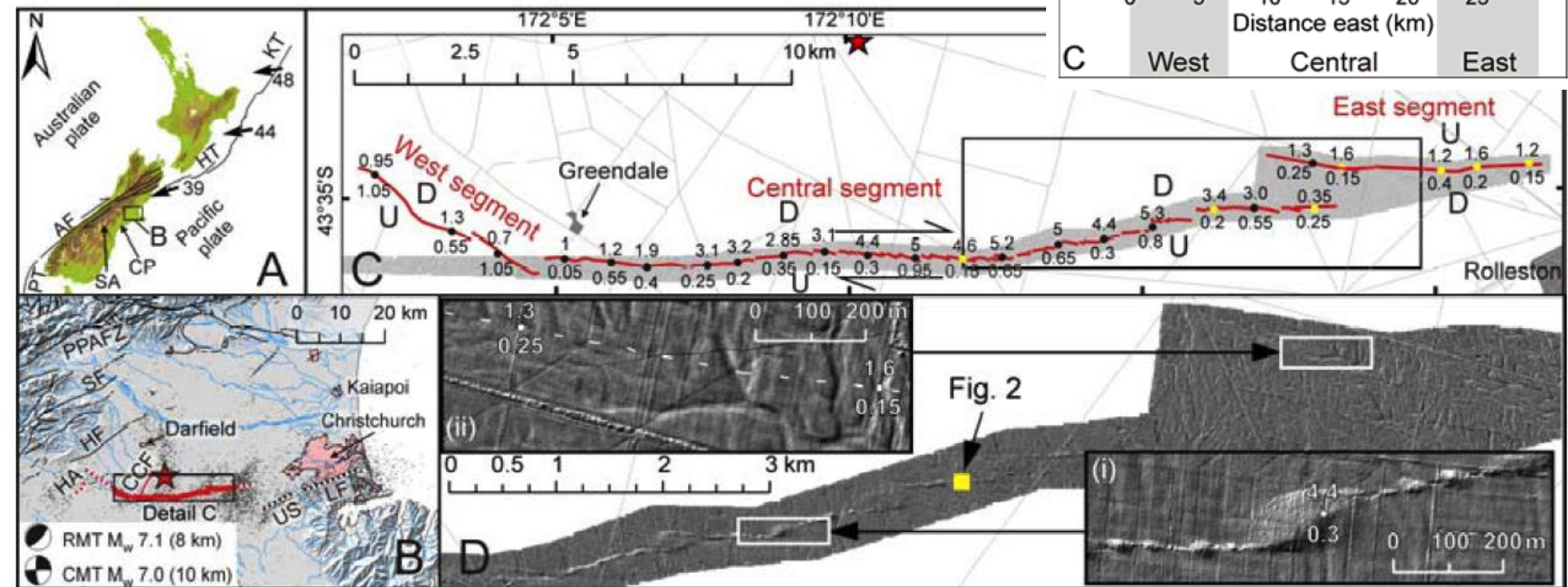
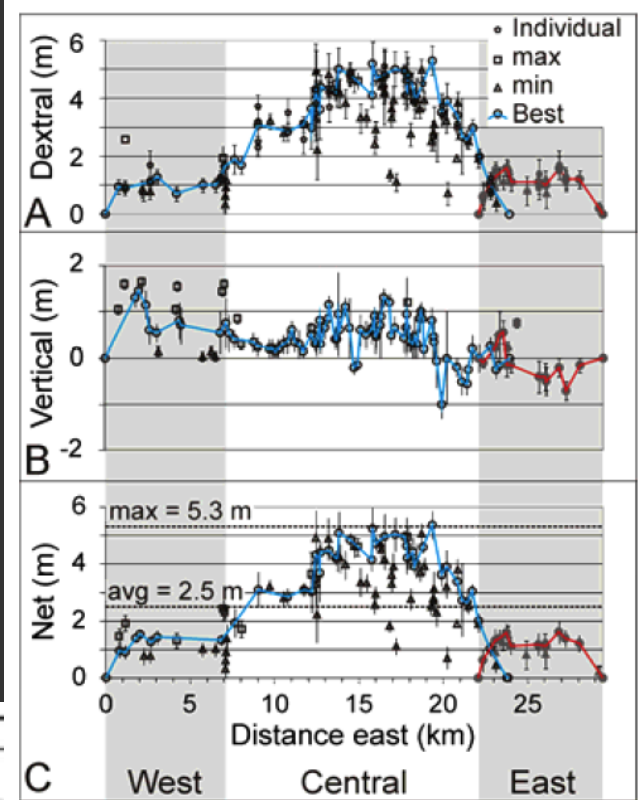
*2011 M7.1 Rupture of Greendale Fault, Canterbury  
dextral strike-slip of c. 5 m*





# Surface Displacement Along The Greendale Fault Rupture

Quigley et al. 2011





# *Inundation of the Sendai Coastal Plain*





# *Sendai Plain –Post-Tsunamai*



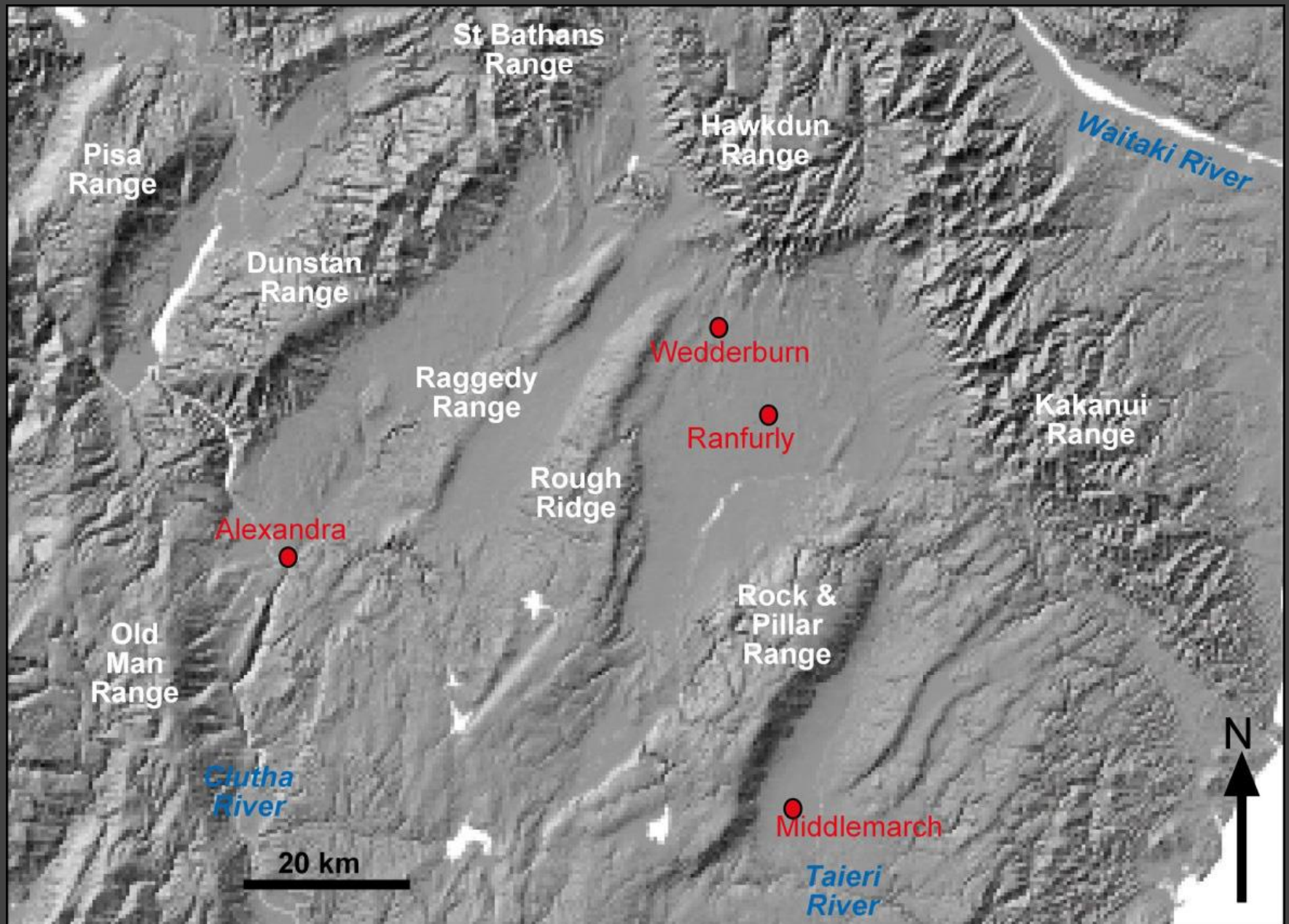


## *Clyde Dam, Clutha River*





# Central Otago



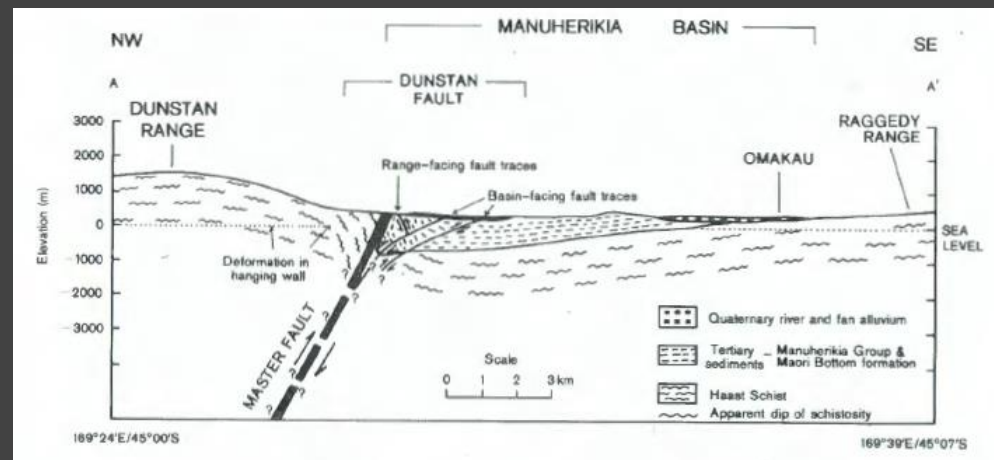
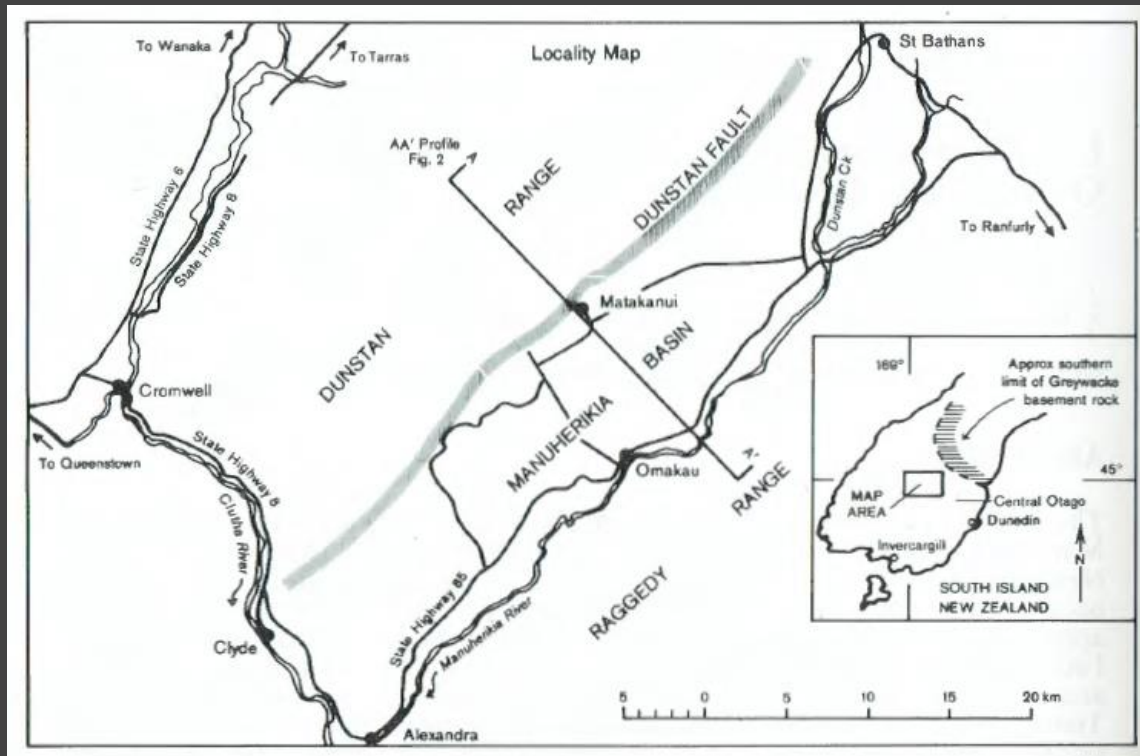


# *Clyde Dam, Clutha River*



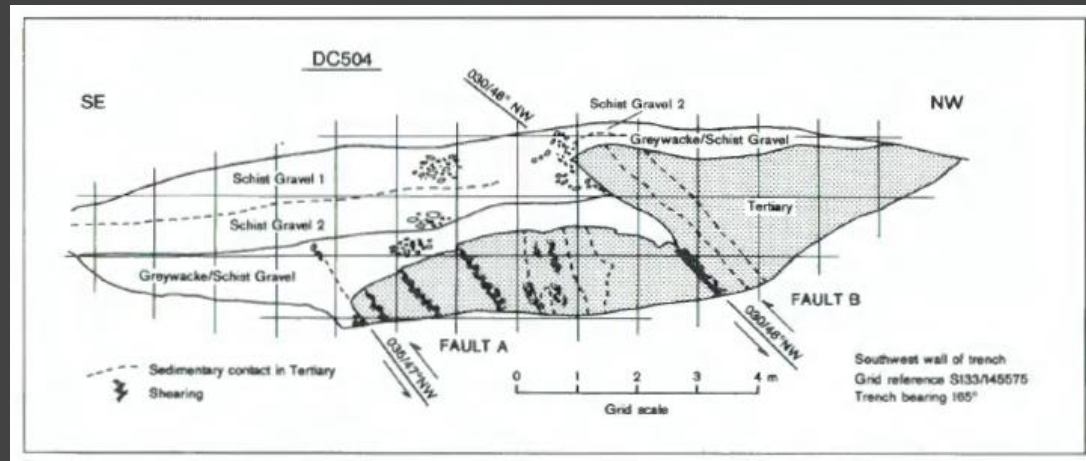
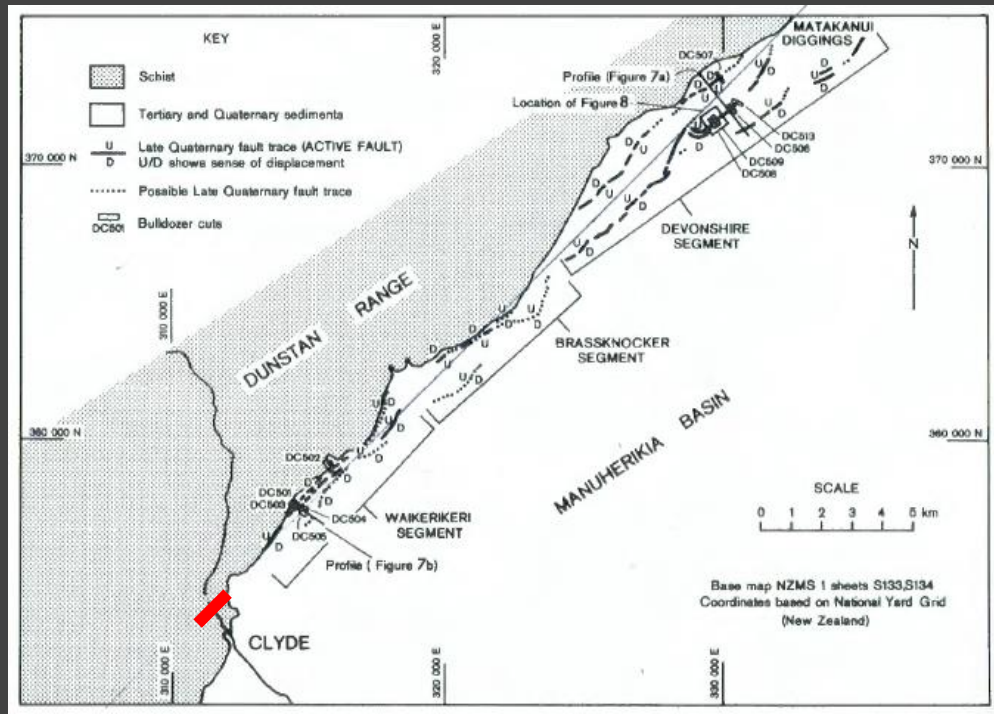


# Dunstan Range-Front Fault





# Dunstan Range-Front Fault





# Dunstan Range-Front Fault

