crustal structure experiment beneath Wairarapa - Wellington area: results from SAHKE

Tim Stern and SAHKE team*

* VUW, GNS, University of Southern California, University of Tokyo (Japan)

SAHKE = Seismic Array on the HiKurangi margin Experiment
Talk Plan

- Plate boundaries & earthquakes
- Little faults, Big faults and
- Megathrusts
- SAHKE and what goes on beneath the Wairarapa
Japanese Subduction Zone – similar to what we see under eastern North Island
NZ earthquakes: the $ cost
=> $500 mill / y
Faults

Hazards

Colours represent peak ground acceleration expected at 10% probability in 50 years.

Figure courtesy of GNS Science.
Canterbury Earthquakes: New Fault?
Cook Strait Fault aftershocks, July 2013

- = faults

- Epicenter of after-shock

Locations:
- Blenheim
- Seddon
- London Hills Fault
- Wellington Fault

The map shows a concentration of aftershocks in the Cook Strait area, with a focus on the Wellington Fault and London Hills Fault. The epicenters of the aftershocks are marked by orange circles.
Red: Crustal earthquakes  
$M \geq 2$, 2000 to 2009

Blue: Shallow earthquakes  
$6 \leq M < 7$, 1930 to the present, no aftershocks.

One every two years.

Was the February 22, ChCh, $M 6$ earthquake particularly unusual?
NZ earthquakes: > Mag 7

Red highlight => associated with known active fault
Probabilistic Hazard in Japan

=> Most damaging eqs (since 1979) occur in low risk areas
Problem for seismology in general

Record is too short for prediction

Great (M > 8) Earthquakes Since 1900

- Chile 1960
- Alaska 1964
- Sumatra 2004
- Japan 2011
- Chile 2010
- Russia 1952
- Alaska 1965
- Ecuador 1906

Data: USGS
Science of Earthquakes

- **Statistics**
  - After shocks with time
  - Number of shocks with specific magnitudes
  - Forecasts

- **Physics**
  - Geophysical exploration
  - Geology of fault zones.
  - Measurements of rupture rates
Pacific-Australia Plate Boundary Zone

- Pacific Plate
- Australian Plate
- Pacific-Australia Plate Boundary Zone
- 30 mm/yr
- 40 mm/yr
- 50 mm/yr

- Australian Plate
- Pacific Plate
- Continental crust
The SAHKE project

- Asthenospheric mantle - semi-fluid
- Subducting plate - cold, heavy mantle - Elastic
- AUSTRALIAN PLATE
- PACIFIC PLATE
- Crust – light and brittle

SAHKE Line

Tasman Sea

WELLINGTON
GPS observations over 10 years

Vectors showing velocity (mm/y)

GPS => Major advance in our understanding of earthquakes
The “Wellington problem”
MED spec seismic lines

MED( MBIE) Exploration~ $30 m since 2005 “Spec-seismic” data
69000 offshore “sound sources” from 3200 km of ship profiles
SAHKE3 MCS TRANSECT

Subsidence since 4 Ma
most since 2 Ma

Processed by Geotrace, supplied courtesy of MED
Drowned topography and onlap in the Marlborough Sounds.
Seismic Reflection data reveals hidden and buried Mountain Range, north of Marlborough Sounds. “Northern Alps”

=> semi-Alpine mtn range ~1800 m high
~ 20 km

1800 m
SAHKE II: Seismic Array Hikurangi Experiment

2011 SAHKE Experiment

835 seismic stations deployed at 100 m spacing (277 3-component and 558 vertical sensors) ~ 1400 seismographs

http://juliansrockandiceblog.blogspot.com/2011_05_01_archive.html
SAHKE II: Seismic Array
Hikurangi Experiment

2011 SAHKE Experiment

835 seismic stations deployed at 100 m spacing
(277 3-component and 558 vertical sensors)
12 x500 kg explosive sources
Crew of > 60 people
12 months planning
3 weeks fieldwork
Top panel – Data from shots _ a sort of X-ray
Bottom panel: model of structure and earthquake locations

Henrys et al, 2013
Green rock = sediment rafted in and ‘underplated’

Henry et al (G-cubed, 2013)
East Cape:
Note: the same mound of sediment on top of plate

Bassett et al. G^3, 2010
Tohoku EQ Mag. 9 at depth of 24 km.

Oceanic crust (2900 kg/m$^3$) = 7km thick
Plate interface ~ 24 km deep under Kapiti

Oceanic crust ~ 12 km thick - buoyant

GeoNet Earthquake catalogue
Difference between Japan and NZ: a proposal

Honshu, Japan

- Large elastic strain
- A few big slips with large (M9) earthquakes

North Island, New Zealand

- 'Asperity'
- Build up on subduction zone - 'bleeds' off strain to surface with many small slips (M7-8)
What does the WW Fault do under the land surface?

Tauherenikau River: Geophysics Field trip for VUW students
West Wairarapa fault is steep at surface then shallows at depth: => large Mag events for rupture length
Henrys et al (G-cubed, 2013)
Green rock = sediment rafted in and ‘underplated’
Isostatic Gravity
Free-air gravity (offshore)

Process for a broad, coeval, subsidence & uplift?
Weight of Subducted slab

Whanganui

100-200 km

Wairarapa

Outer High: In Topography and gravity
Horizontal stress from collision

Enhanced Outer High: In Topography and gravity

Weight of Slab
Numerical modelling:

Apply principles of mechanical engineering to the earth

Max upwarp ~ 1000 m (east Wairarapa).

In-plane stress

Flexure of plate with $T_e = 30$ km
And in plane-stress = 170 MPa
Wellington –Wairarapa setting

Image the base of the plate with seismic reflections- 100 km depth
Summary

- Subduction is very shallow under the Wairarapa
  - SAHKE => much better understanding of Wairarapa Faults

* Stress release valves from the mega-thrust ? (mag 7-8 events)

* Subsidence in offshore Kapiti and uplift in Wairarapa appear to be mechanically linked
Blow out from 1.4 tonne shot

In 50 m deep holes cased with 8 inch diameter steel
Henry's et al., 2013
Re-Enhanced Outer High: In Topography and gravity

Horizontal stress from collision

Weight of Slab

Torque