THE SPECTRUM OF MEGATHRUST SLIP BEHAVIOR AT THE HIKURANGI SUBDUCTION MARGIN, NEW ZEALAND

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Acknowledgements

GNS Science: John Beavan, Kate Clark, Ursula Cochran, Stephen Bannister, Bill Fry, Martin Reyners, Susan Ellis, Charles Williams, Donna Eberhart-Phillips, Ian Hamling, Agnes Reyes, Nicola Litchfield, Kelvin Berryman, Dan Barker, Stuart Henrys, Rupert Sutherland

NIWA: Phil Barnes, Joshu Mountjoy

LDEO: Spahr Webb, and the LDEO OBS team

UCSD: Noel Bartlow

Imperial College, London: Rebecca Bell

Kyoto University: Yoshihiro Ito

Tokyo University: Kimi Mochizuki

Tohoku University: Ryota Hino

Penn State: Demian Saffer

Cardiff University: Ake Fagereng

UCSC: Susan Schwartz

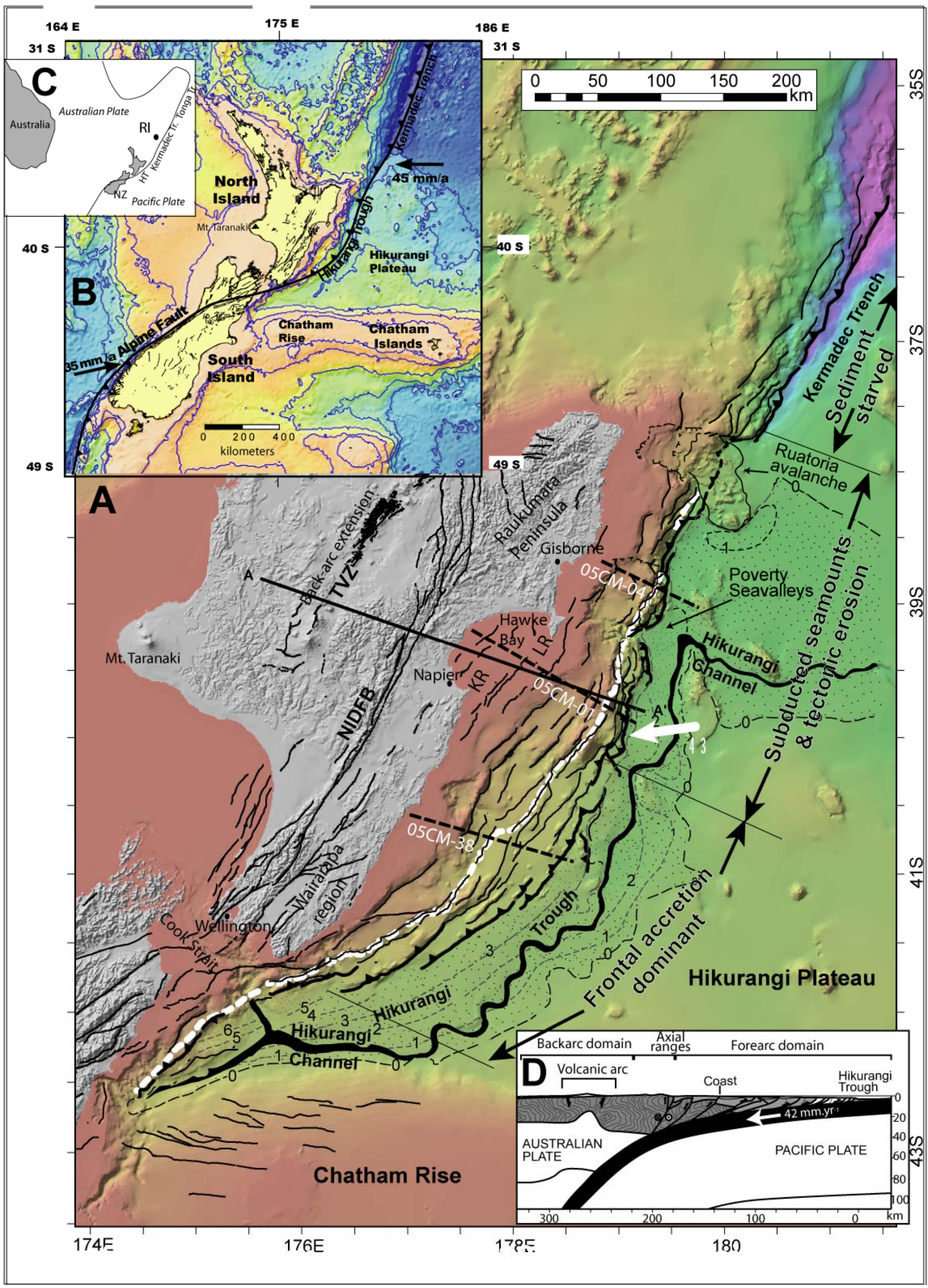
CU-Boulder: Anne Sheehan

What are the physical controls on the spectrum of slip behaviors we observe at megathrusts?

- Intro to Hikurangi margin tectonics, interseismic locking and slow slip
- New results on shallow megathrust slip behavior from the HOBITSS project
- What might control the along strike variations in Hikurangi slip behavior that we observe, and how might we apply these lessons to other settings?

The Hikurangi subduction margin

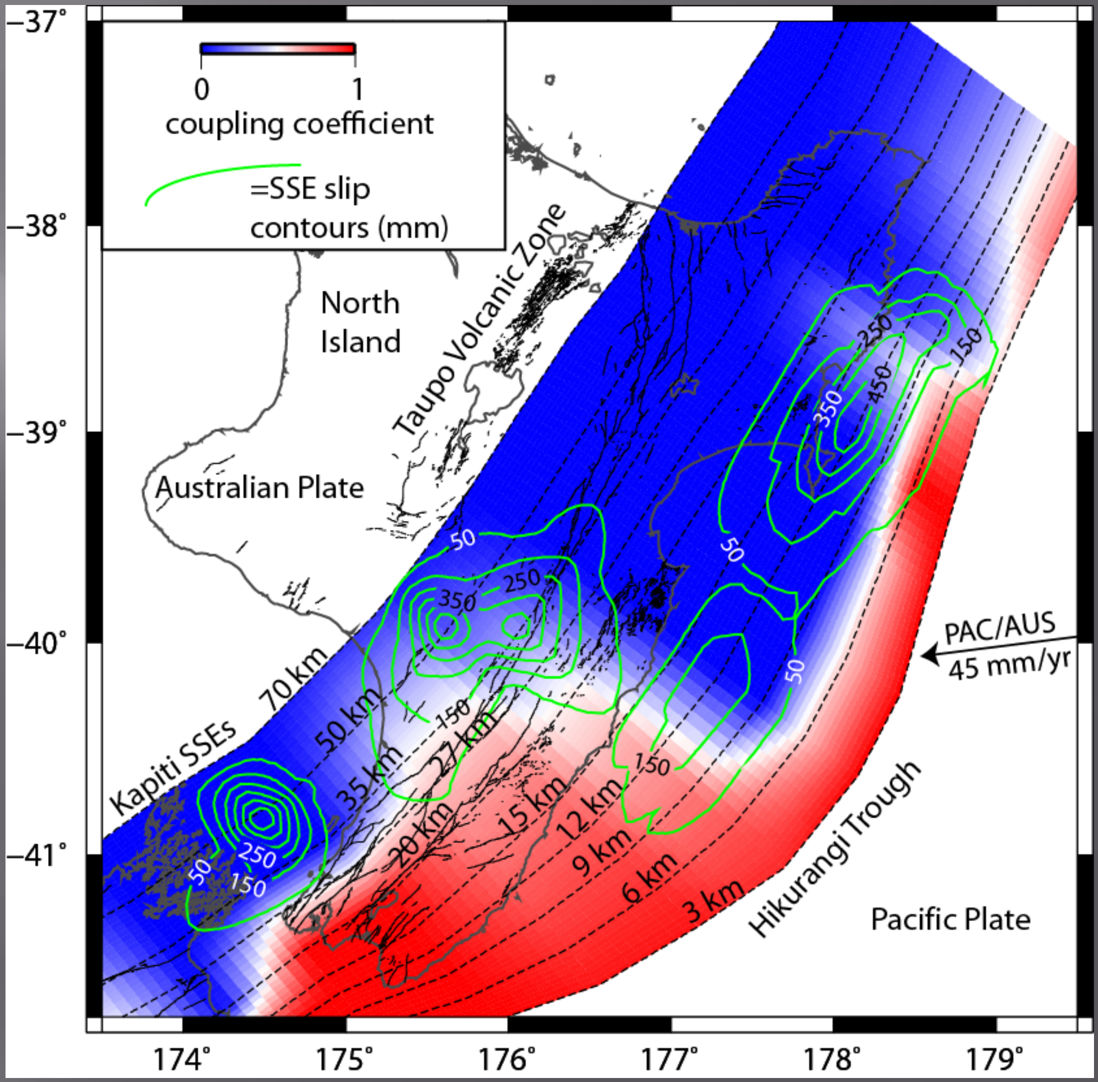
- The Hikurangi Plateau (a Cretaceous oceanic Plateau) is being subducted at the Hikurangi Trough
- Plate motion is oblique, and is partitioned all along the margin via strike-slip faults and clockwise rotation of the margin.
- Active back-arc rifting occurs in the central North Island (in the Taupo Volcanic Zone)
- The southern Hikurangi margin has a well-developed accretionary wedge, while the northern portion of the margin is dominated by tectonic erosion and seamount subduction.
- The sediments on the lower plate are much thicker at the southern Hikurangi margin, due to sedimentation being funnelled along the Hikurangi channel from the South Island



Interseismic coupling on the Hikurangi megathrust

- Campaign GPS reveals the distribution of interseismic coupling on the megathrust at Hikurangi
- There is deep coupling in the south, while aseismic creep dominates in the north
- cGPS shows that slow slip mostly follows the down-dip limit of interseismic coupling

Green contours : total SSE slip 2002-2012

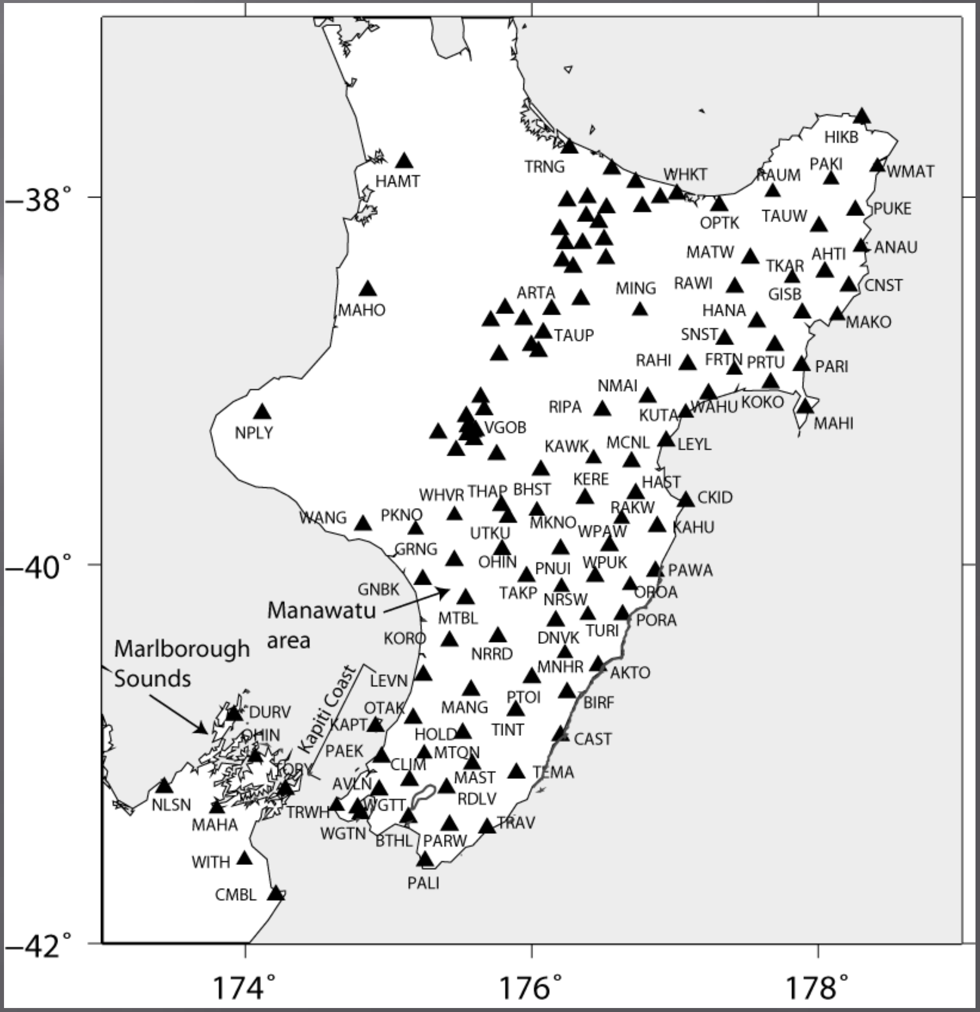


Wallace, et al., 2004; 2012a, b; Wallace and Beavan, 2010

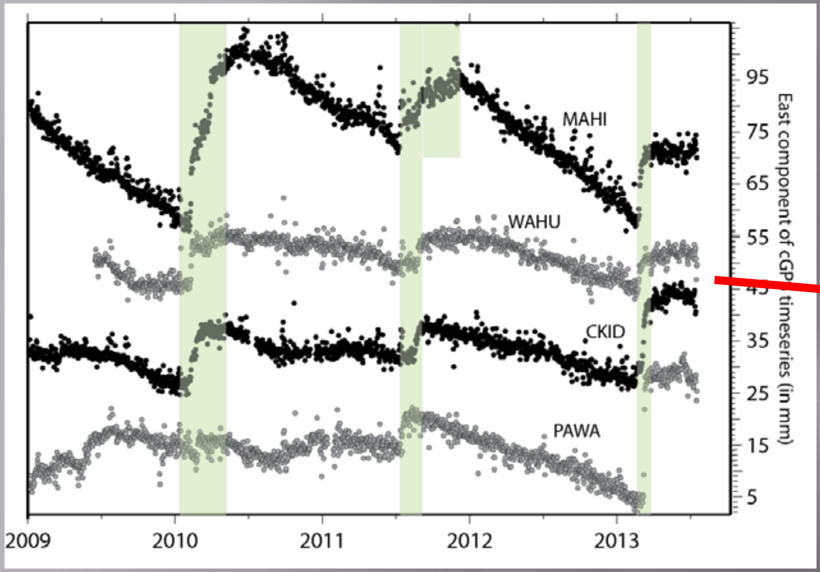
Continuous GPS to monitor slow slip

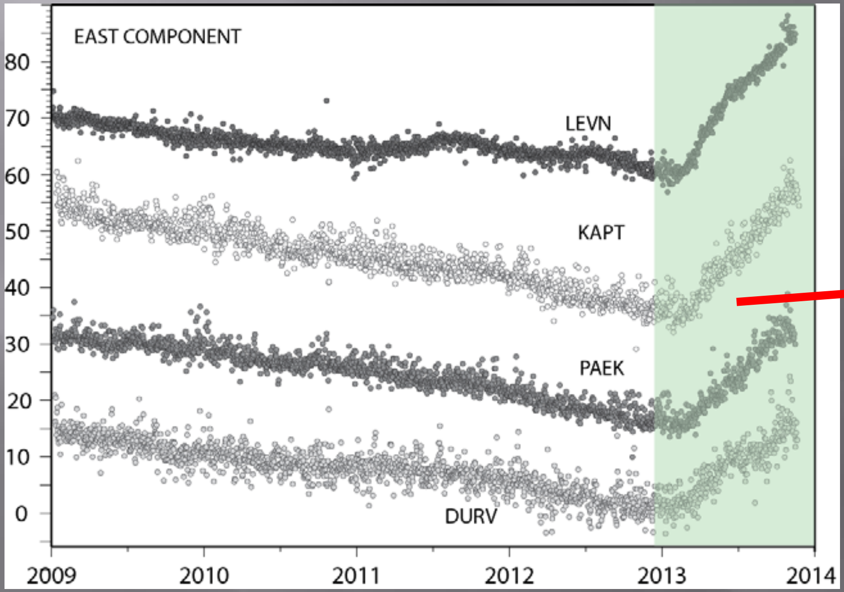
Since 2002, we have observed more than 20 distinct slow slip events at CGPS sites in the North Island

Current CGPS network configuration
Data available at www.geonet.org.nz

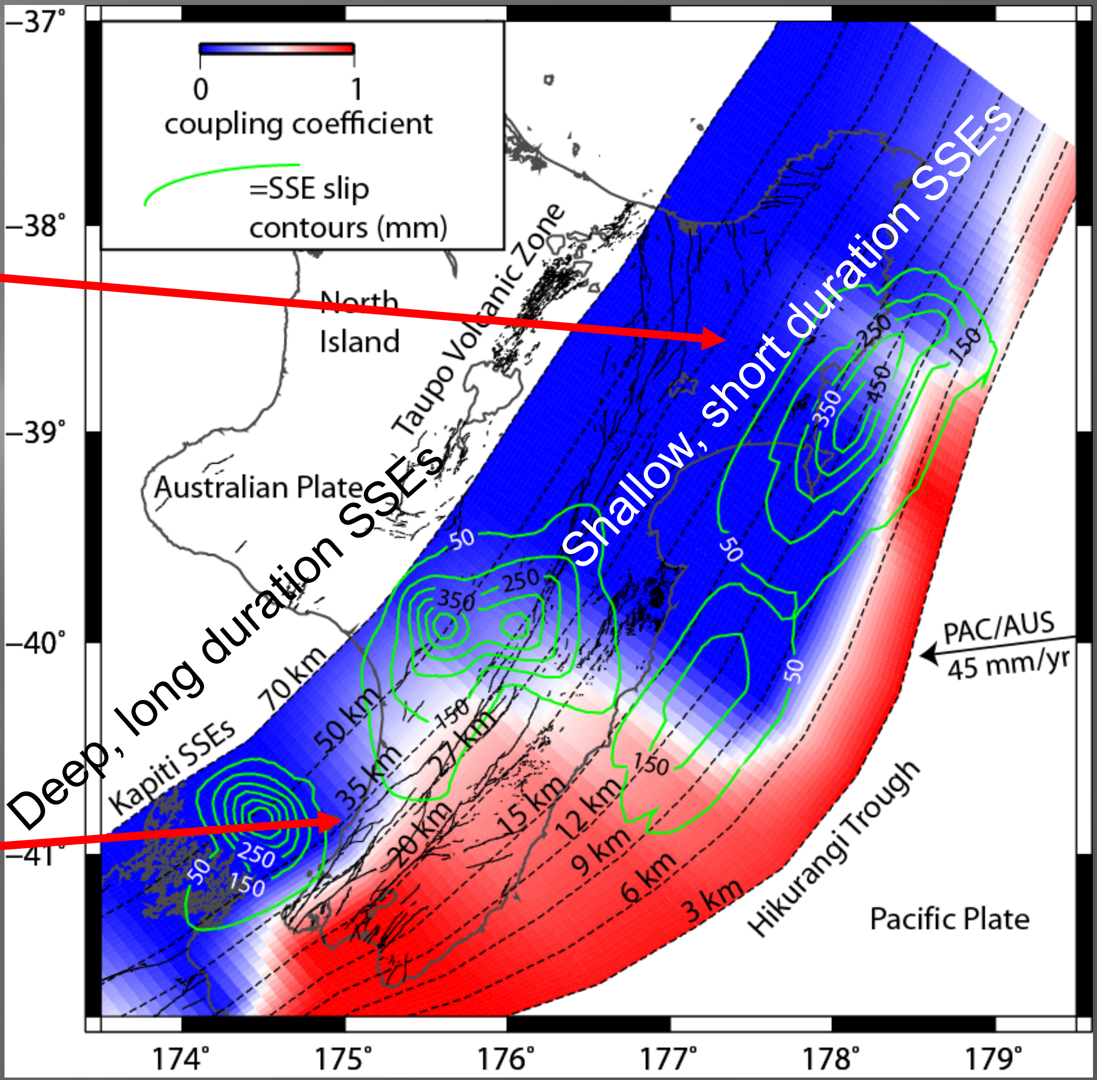


Slow slip at Hikurangi varies strongly from N to S



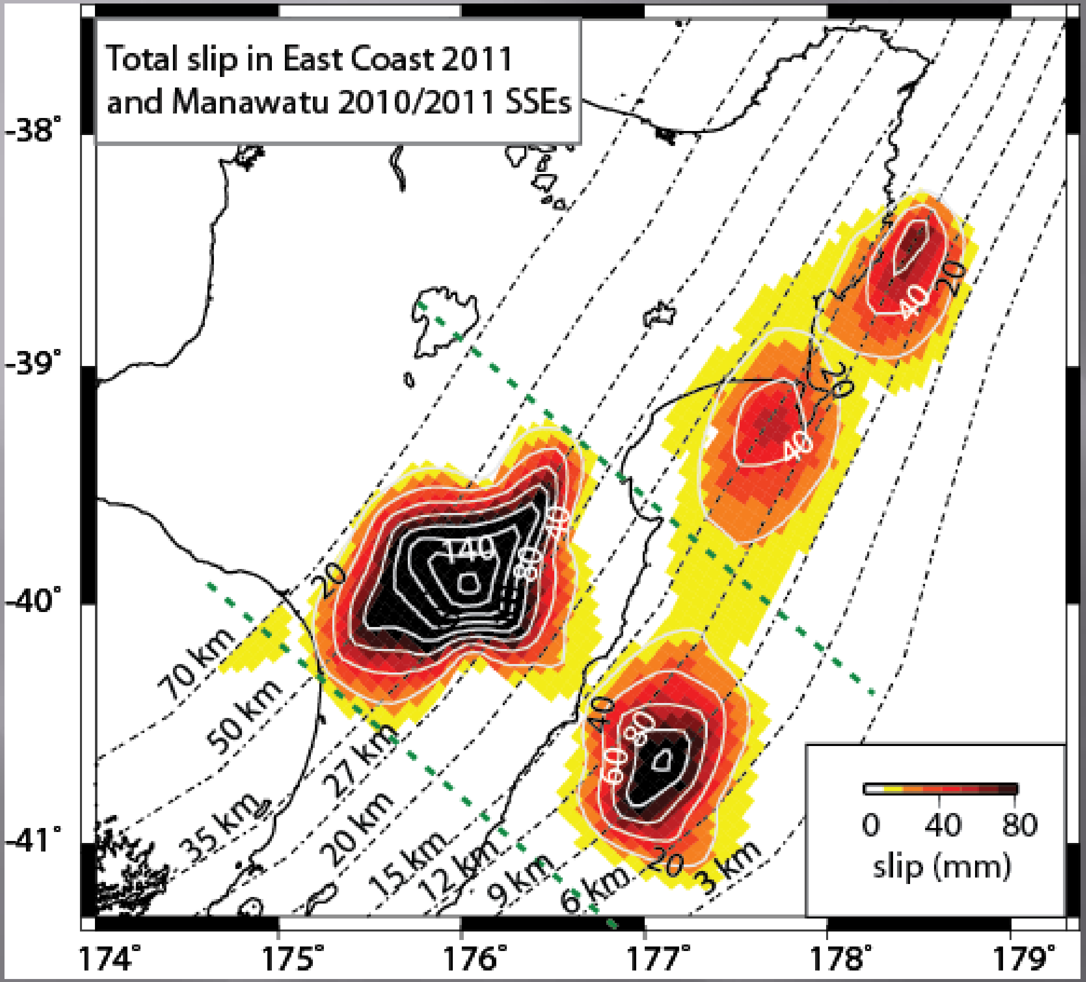


Large cGPS displacements of up to 3-4 cm



Green contours show cumulative slow slip between 2002 and 2012

At central Hikurangi, much of the interface undergoes slip in slow slip events



Total slip during a 2010/2011 sequence

Wallace, et al., 2012, JGR

A huge depth range (<10-60 km) of the central Hikurangi interface slipped during a 2010/2011 SSE sequence

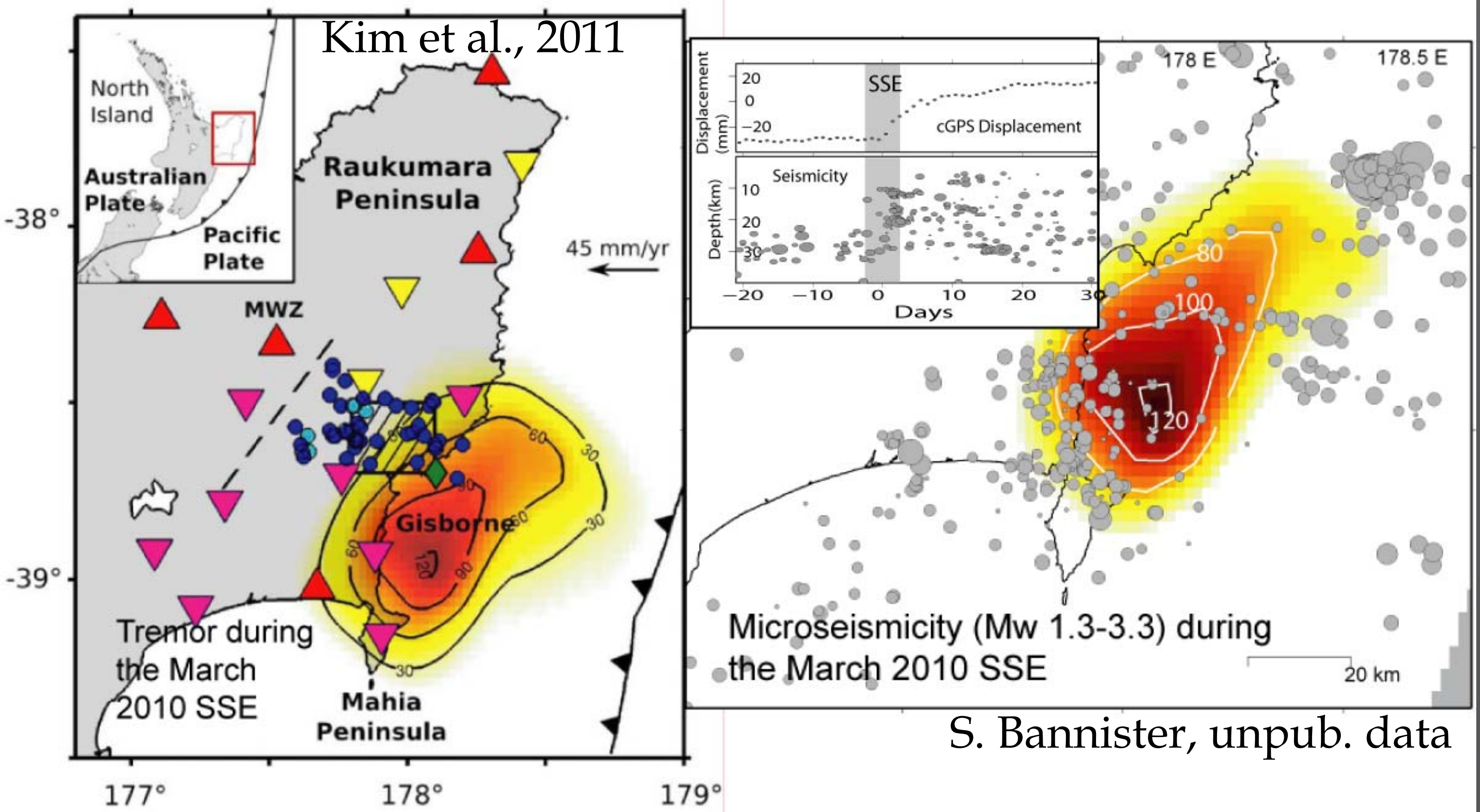
This suggests that the physical conditions conducive to slow slip events may actually be very broad

MORE ON NZ SLOW SLIP:
Stay tuned for Noel Bartlow’s talk on the deep Hikurangi SSEs later today…

See Lada Dimitrova’s poster on a new approach to NZ and Cascadia cGPS timeseries inversions

Seismicity and SSEs at North Hikurangi

Abundant microseismicity and some possible tremor accompanying slow slip



Kim et al., 2011

Tremor during the March 2010 SSE

Microseismicity (Mw 1.3-3.3) during the March 2010 SSE

S. Bannister, unpub. data

Tremor not as ubiquitous at Hikurangi compared to Cascadia and SW Japan—microseismicity is more important in NZ SSEs. This is similar to Boso Peninsula (central Japan) and Ecuador SSEs

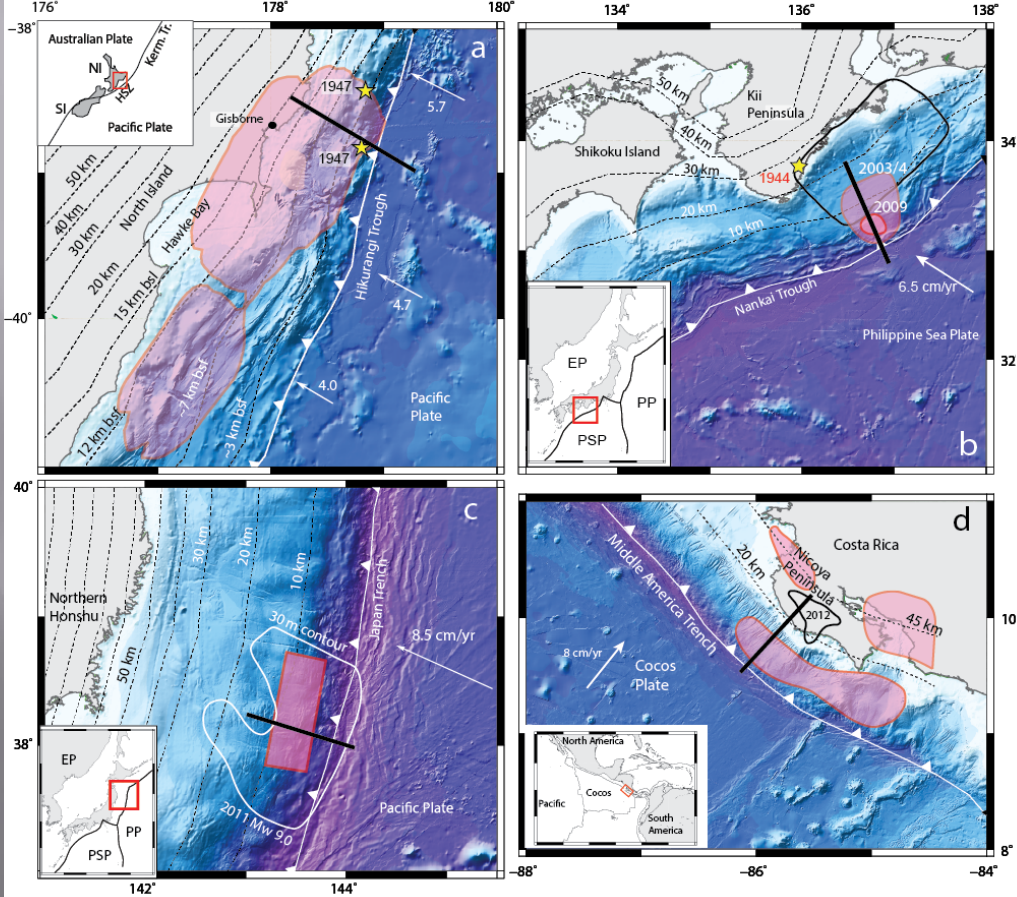
New Zealand slow slip has many analogues

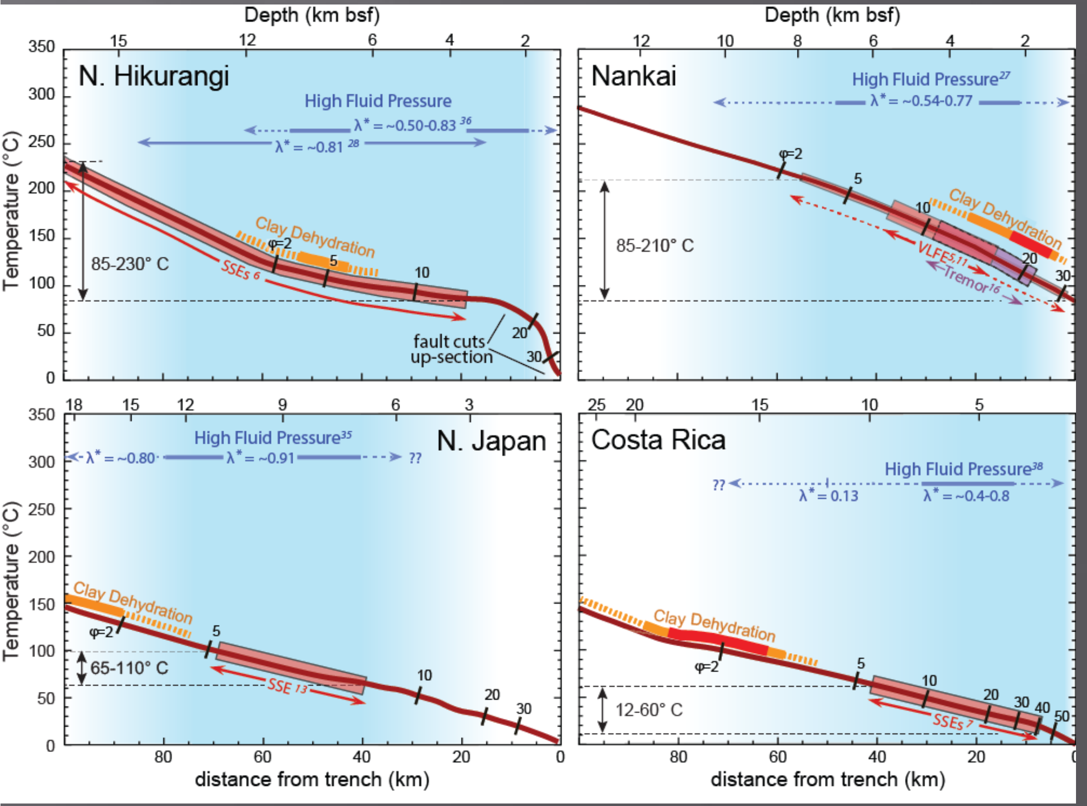
- Deep (>20-30 km), long duration (1 year or more), large (Mw ~7.0) SSEs similar to southern Hikurangi occur in Guerrero (Mexico), the Bungo Channel (SW Japan), Tokai (central Japan), and Alaska

- Shallow (<20 km), short duration (weeks) SSEs similar to north Hikurangi occur at Boso Peninsula (central Japan), Costa Rica, Ecuador, and Ryukyu Islands. Many of these shallow SSE locales are typically associated with bursts of microseismicity (rather than tremor)

A focus on shallow SSEs

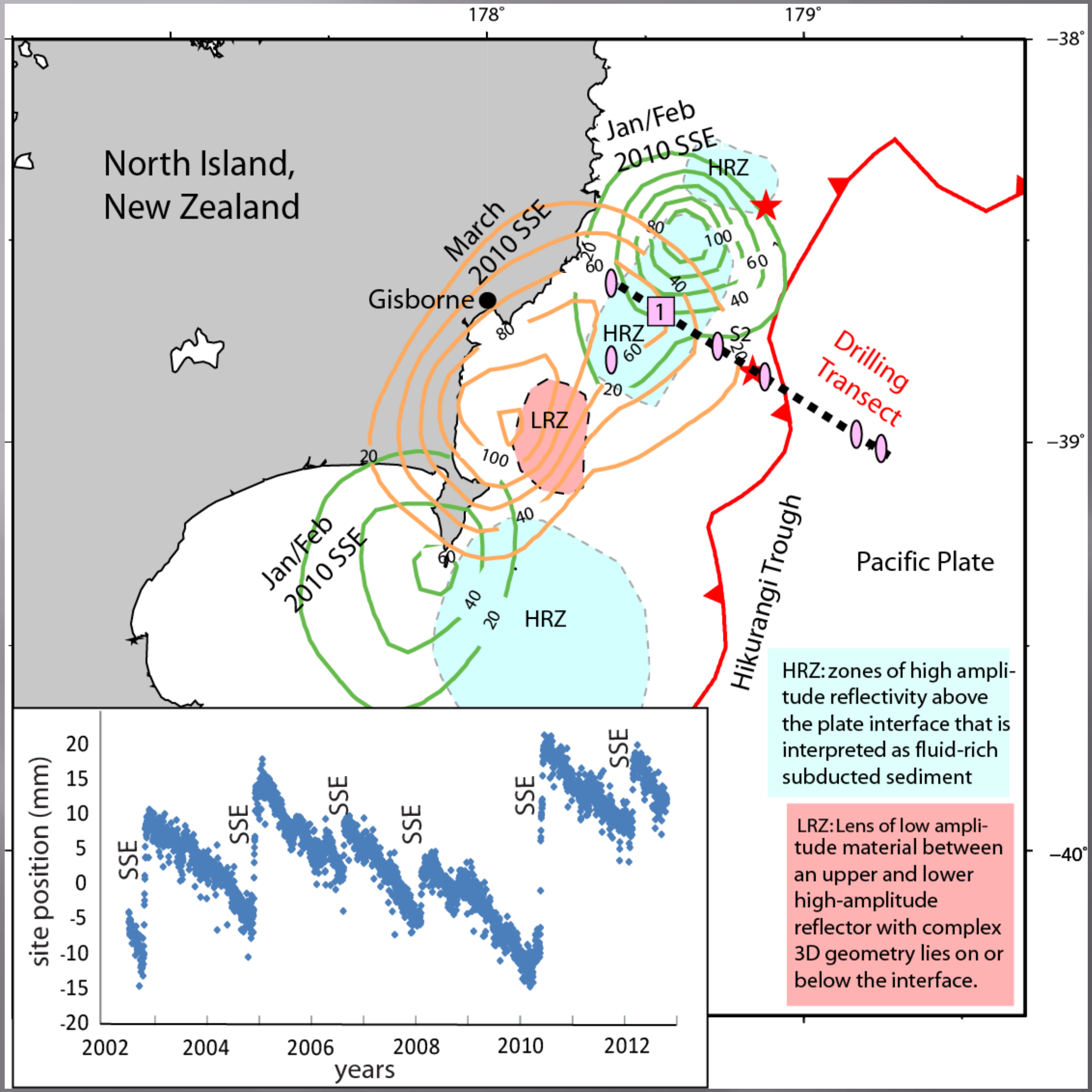
High fluid pressures and heterogeneities on incoming plate are likely a major control on shallow SSEs





Saffer and Wallace, Nature Geoscience, 2015

Shallow slow slip (<5-15 km depth) at north Hikurangi is the target of numerous investigations



HRZ: zones of high amplitude reflectivity above the plate interface that is interpreted as fluid-rich subducted sediment

LRZ: Lens of low amplitude material between an upper and lower high-amplitude reflector with complex 3D geometry lies on or below the interface.

North Hikurangi SSEs are the shallowest well-documented SSEs on Earth.

These SSEs recur every one to two years

Accessibility of the SSE source area makes this one of the best locales in the world to investigate mechanisms behind SSE processes

Efforts include: seafloor geodetic and OBS studies (NSF-funded HOBITSS), heatflow acquisition (NSF-funded STINGS; 2015), planned IODP drilling (2018), and proposed 3D seismic

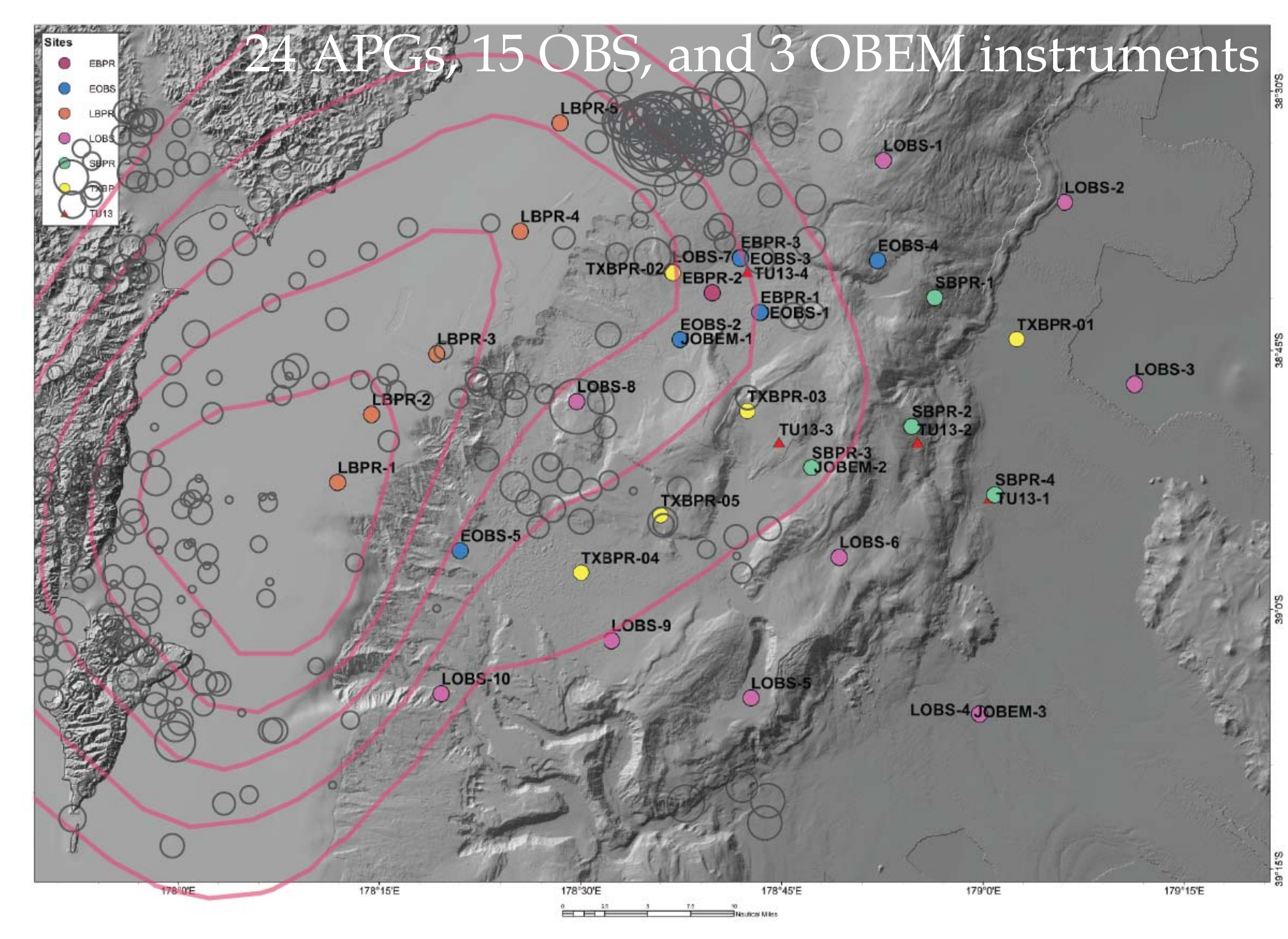
North Hikurangi SSEs occur where high amplitude reflectivity is observed (Bell et al., 2010, EPSL)

NSF-funded HOBITSS: "Hikurangi Ocean Bottom Investigation of Tremor and Slow Slip"

Instruments belonged to LDEO, UTIG, Univ. Tokyo, Tohoku Univ., and JAMSTEC

They were deployed in May 2014 with NZ's R/V Tangaroa, and were recovered using the R/V Revelle in late June 2015

Seafloor geodesy using absolute pressure gauges to reveal the vertical deformation in SSEs. OBS for tremor, seismicity, and passive imaging of SSE source

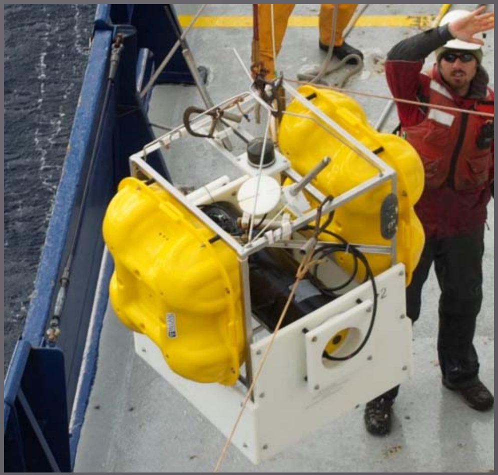

24 APGs, 15 OBS, and 3 OBEM instruments

USA PIs: Laura Wallace, Spahr Webb, Susan Schwartz, Anne Sheehan,
Japan PIs: Yoshihiro Ito, Kimihiro Mochizuki, Ryota Hino, Hiroshi Ichihara

Instruments used


10 LDEO BB OBS, 7 WITH APG


5 LDEO BPRs

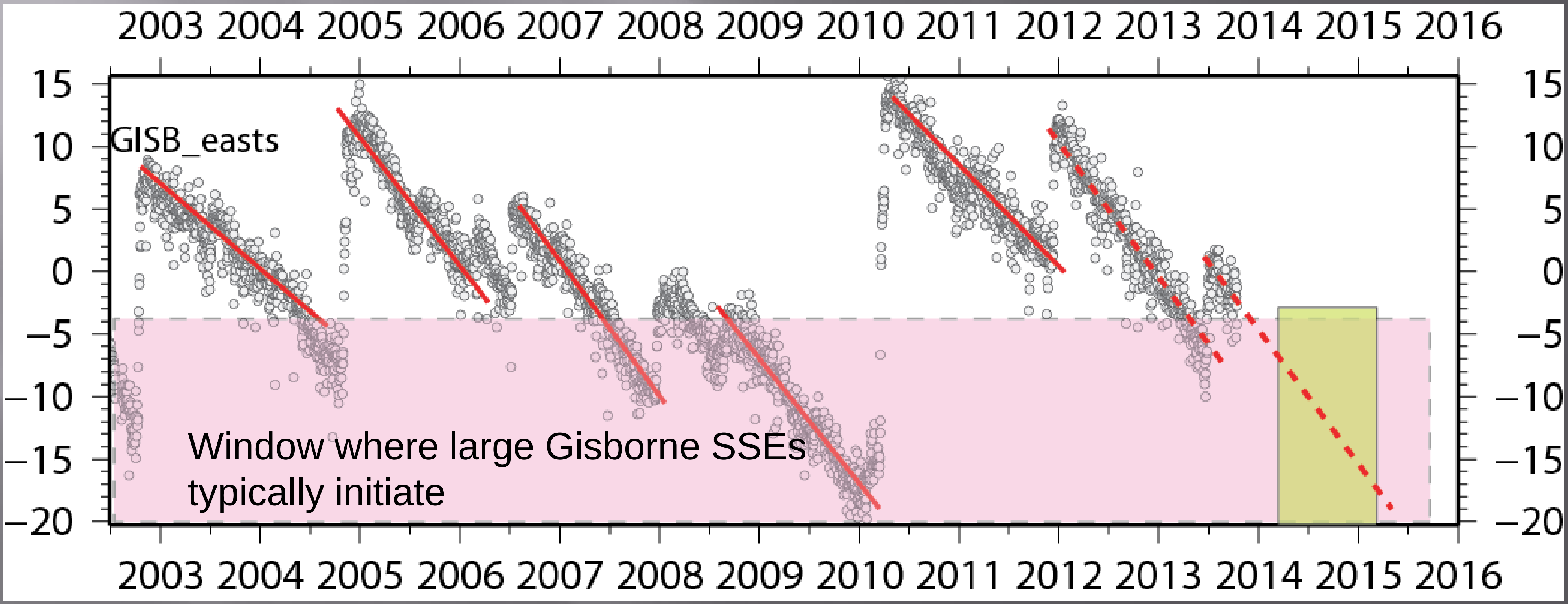

5 UTIG BPRs


4 Tohoku University BPRs

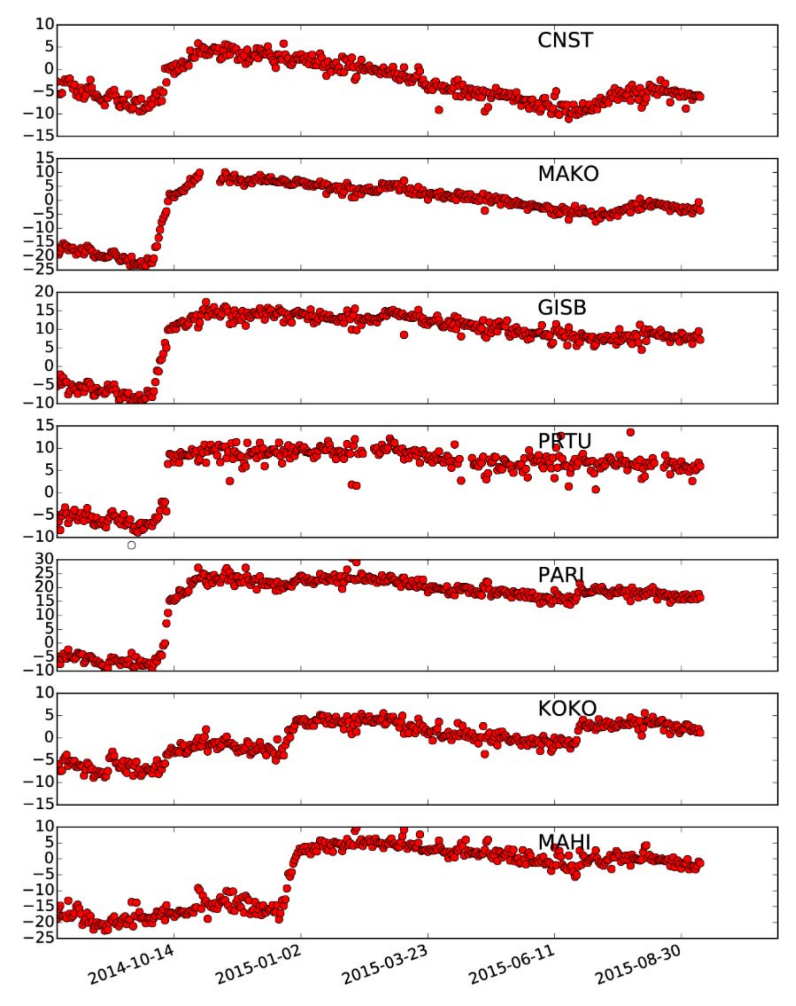

5 Univ. Tokyo Short period OBS, 3 BPRs


3 JAMSTEC OBEM

SSEs recur here every 1-2 years, with very large ones every 4-5 years. 2014/2015 looked to be a prime window for catching a big one

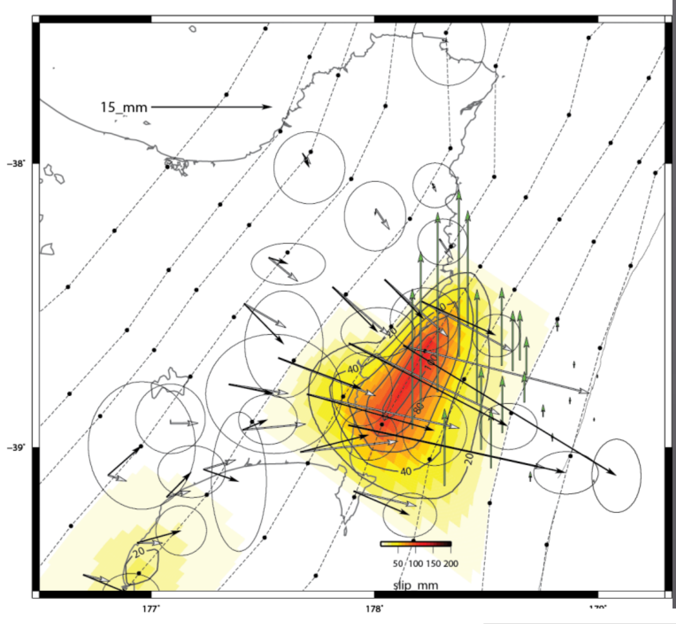


Two VERY large slow slip events occurred beneath HOBITSS in Sept/Oct and late Dec 2014!

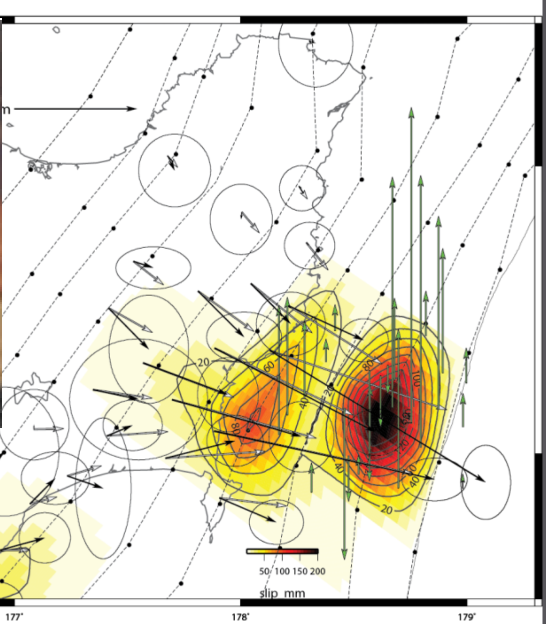


Horizontal displacement onshore >3 cm

Expected vertical deformation at offshore APG network is 1-4 cm, and should be easily detectable

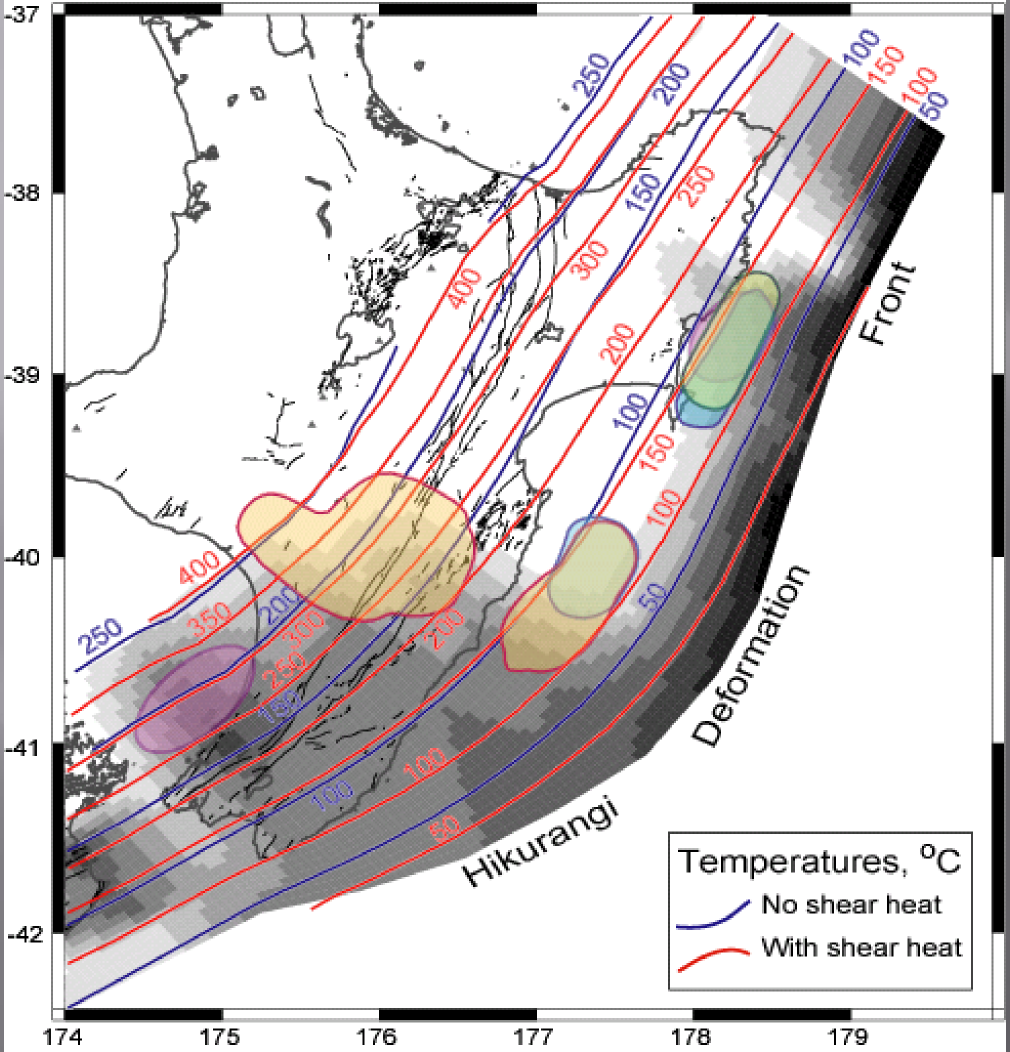


Two SSE slip models fit the GPS data well, with VERY different offshore predictions



What controls the along strike variations in distribution of slow slip and interseismic coupling at the Hikurangi margin?

Hikurangi slow slip and coupling cannot be explained by a simple temperature-based model

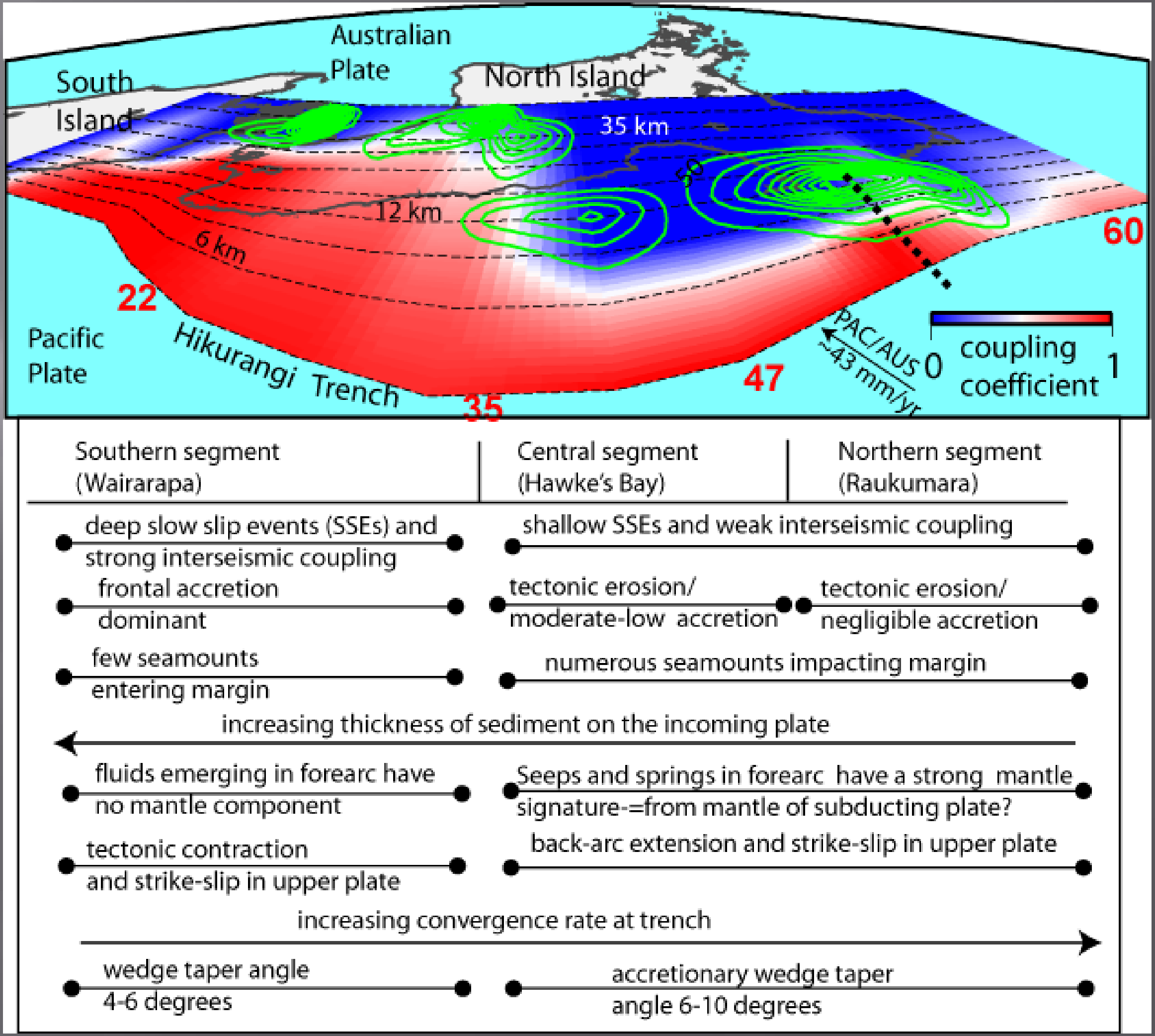


McCaffrey, Wallace, Beavan, Nature Geoscience (2008)

What other parameters might control the abrupt change in depth of the down-dip limit of the seismogenic zone that we observe?

There are a number of margin characteristics that vary in concert with megathrust behavior

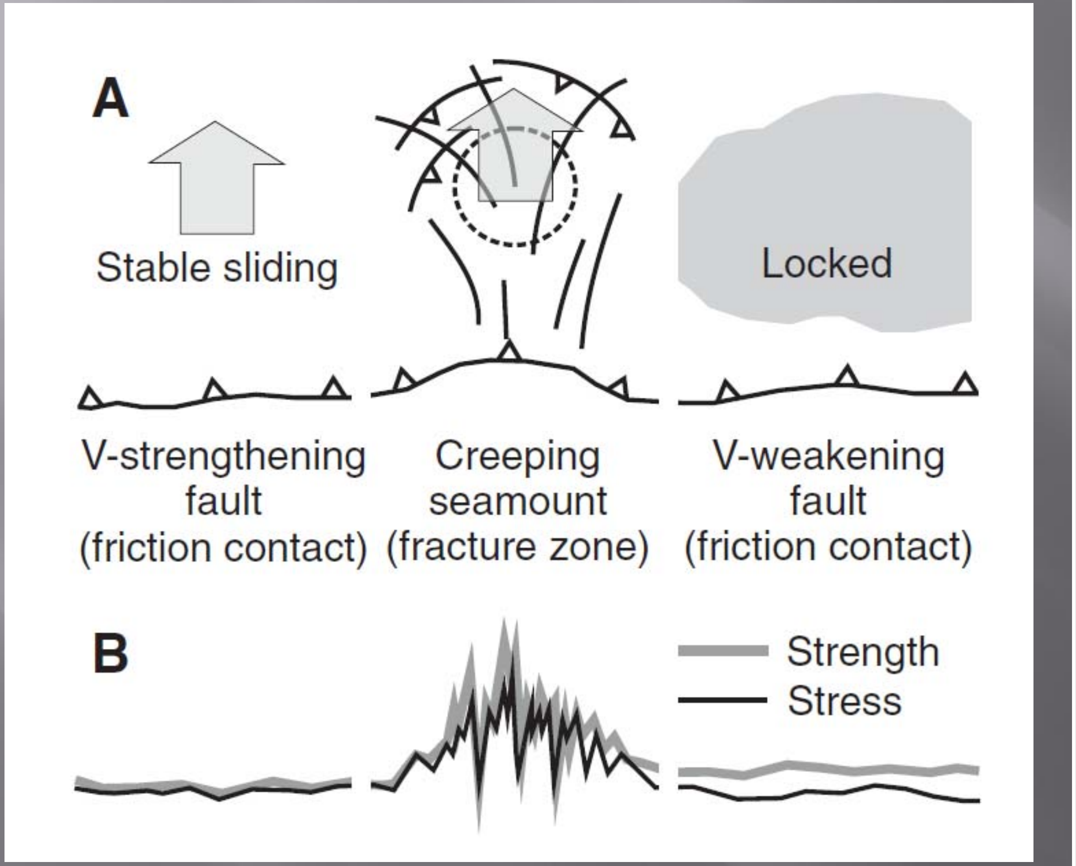
These include:
(1) a shift from an accretionary to erosional offshore margin
(2) A northward decrease in thickness of sediment on the incoming plate
(3) A larger number of seamounts protruding above the sedimentary cover in the north vs. south
(4) An along-strike change from back-arc rifting to upper plate contraction
(5) Major change in the geochemistry and volume of fluids emerging at the onshore forearc
(6) Northward increase in convergence rate
(7) Change in Vp/Vs and Qp in the upper plate and near the interface



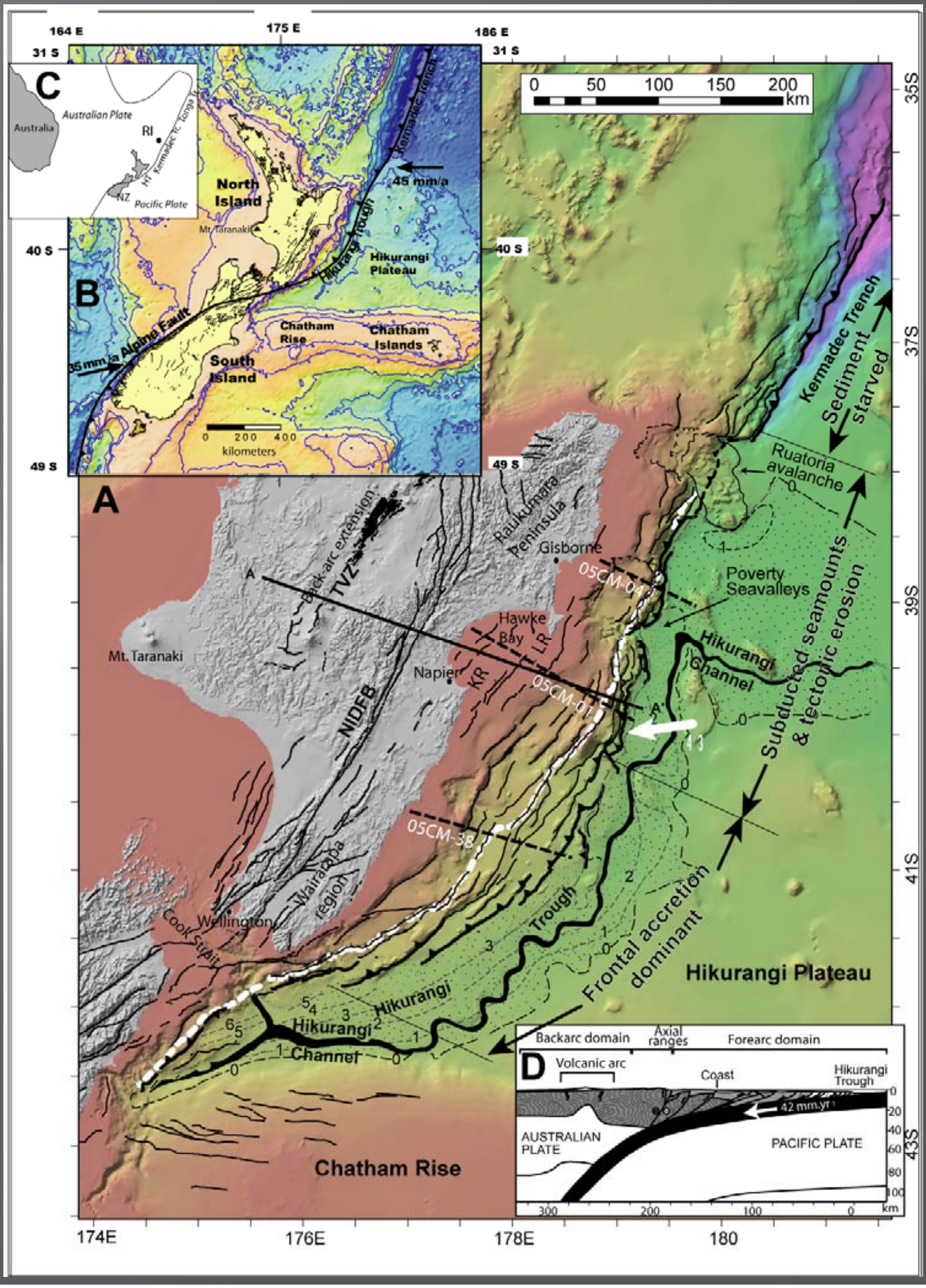
Southern segment (Wairarapa)	Central segment (Hawke's Bay)	Northern segment (Raukumara)
deep slow slip events (SSEs) and strong interseismic coupling	shallow SSEs and weak interseismic coupling	
frontal accretion dominant	tectonic erosion/ moderate-low accretion	tectonic erosion/ negligible accretion
few seamounts entering margin	numerous seamounts impacting margin	
← increasing thickness of sediment on the incoming plate		
fluids emerging in forearc have no mantle component	Seeps and springs in forearc have a strong mantle signature-=from mantle of subducting plate?	
tectonic contraction and strike-slip in upper plate	back-arc extension and strike-slip in upper plate	
increasing convergence rate at trench →		
wedge taper angle 4-6 degrees	accretionary wedge taper angle 6-10 degrees	

How do these characteristics influence the along-strike variations in megathrust behavior?

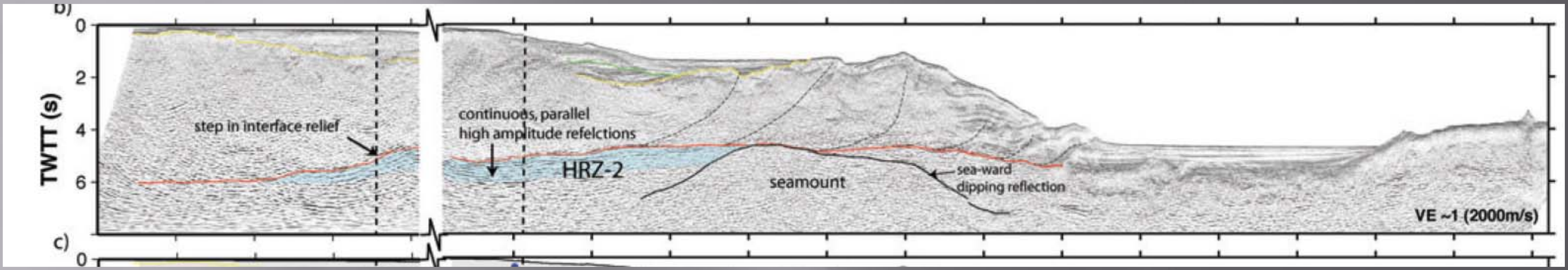
Does a smooth vs. rough incoming plate influence interseismic coupling and SSE variations at Hikurangi?

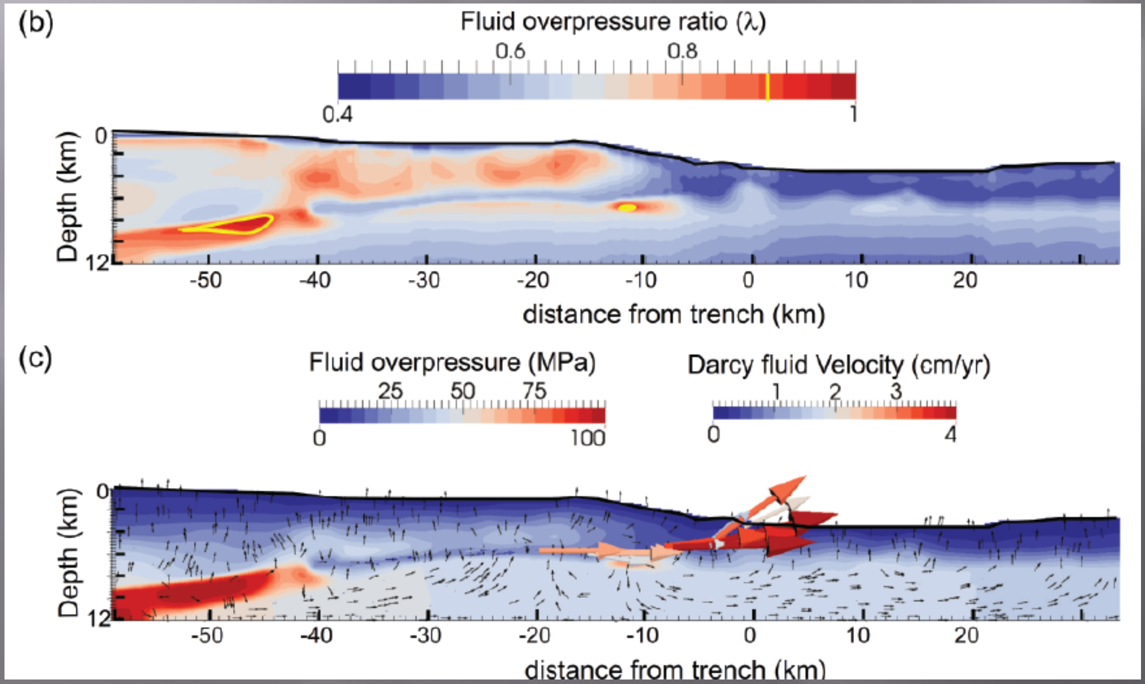


Wang and Bilek, 2011



Subducting, underplating sediments and seamounts: how do these influence fluid pressure and slip behavior?



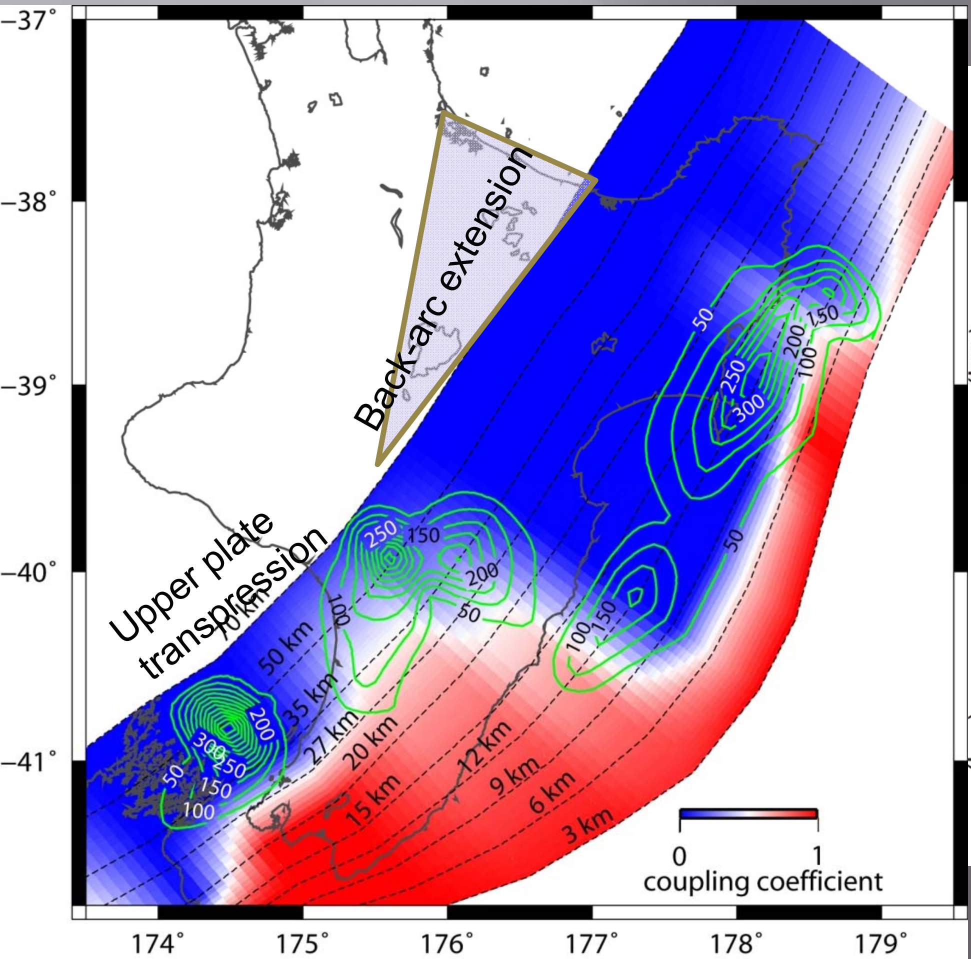


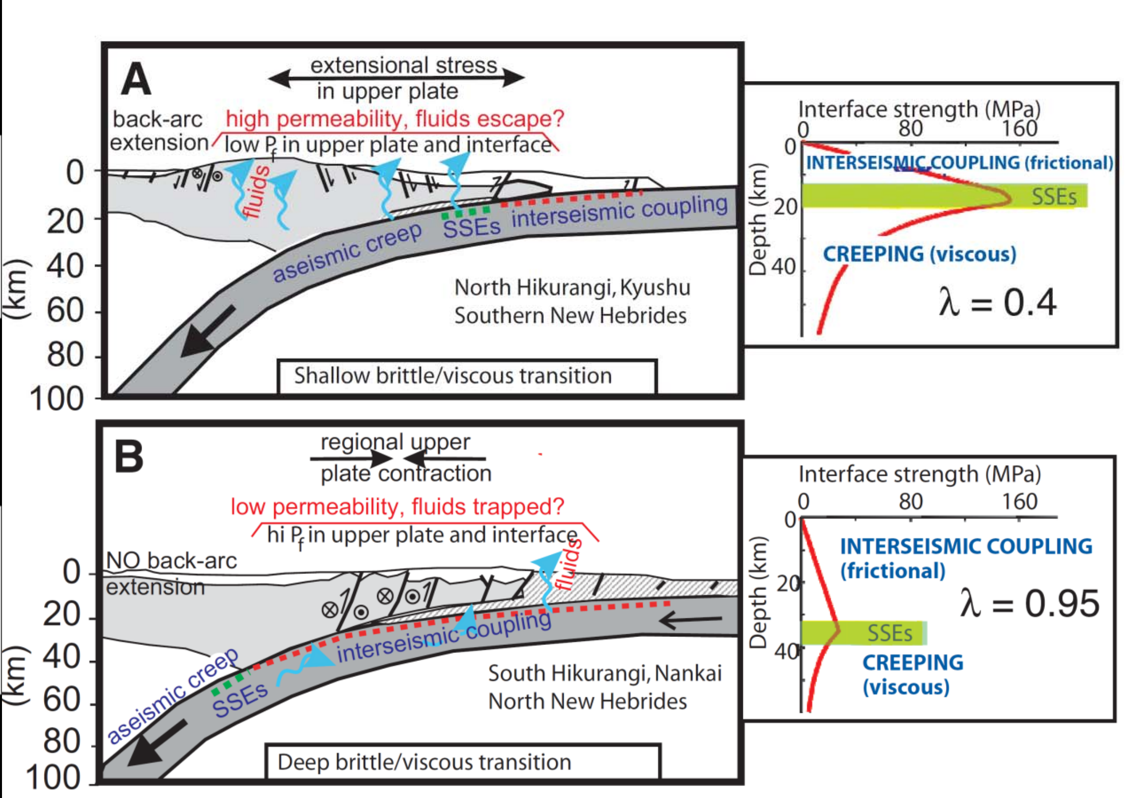
Ellis et al., GJI, 2015

Do high fluid pressures from subducted, underplated sediments promote slow slip events and aseismic creep? What role do seamounts play in this? (Bell et al., 2010, GJI)

Stay tuned for next talk by Susan Ellis!

Does the along-strike change in upper plate tectonic stress state influence depth of interseismic coupling and slow slip?





Similar relationships between coupling and upper plate tectonics observed in SW Japan and Vanuatu

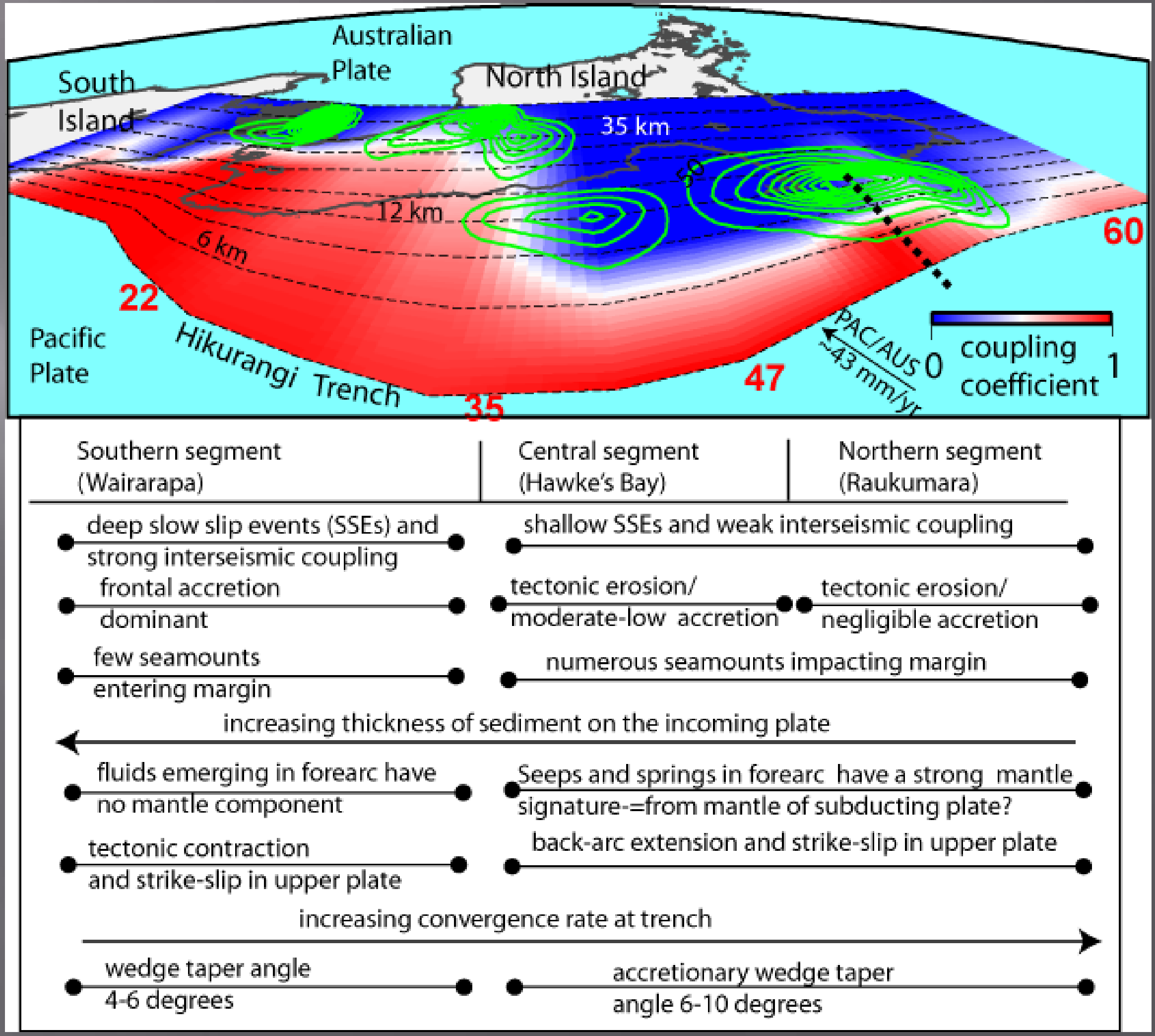
Fagereng and Ellis, EPSL, 2009
Wallace, Fagereng, Ellis, 2012, Geology

The Hikurangi margin is a compelling natural laboratory to resolve the physical controls on megathrust behavior

Which of these parameters is the smoking gun?

(?)

Or, are there multiple smoking guns that feedback on each other in a complex way?



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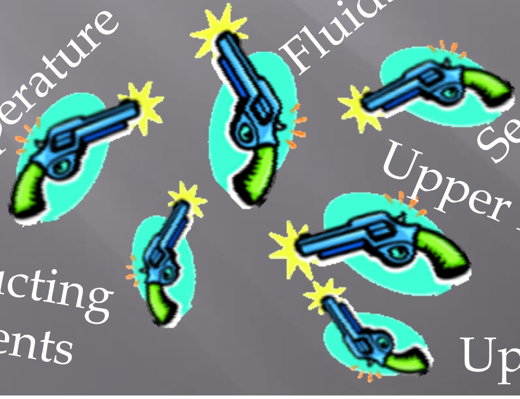
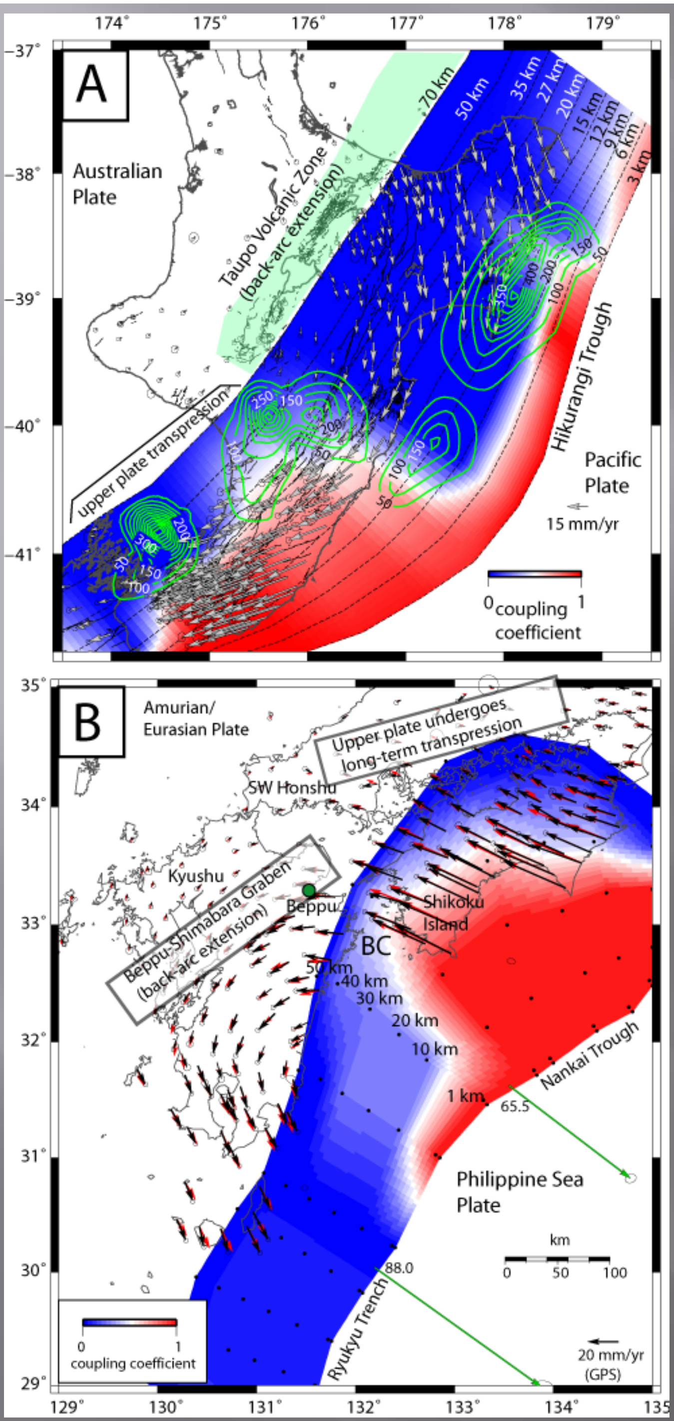


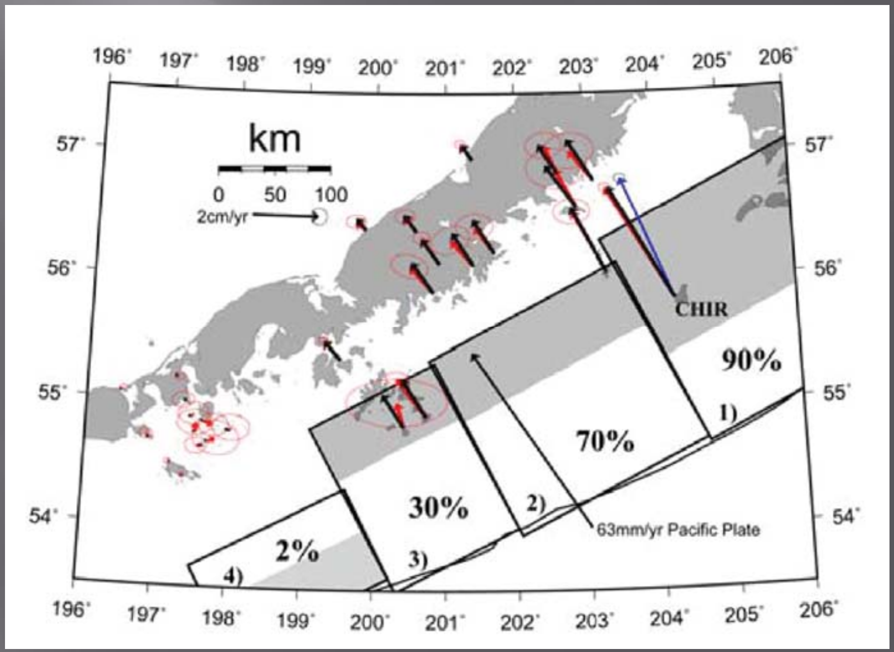
To really answer these questions we need to treat this as a COMPLETE SYSTEM



Wallace, Fagereng, Ellis, 2012

Comparative studies are needed

Similar along-strike variations in slip behavior are also observed in SW Japan and the Shumagins, Alaska. We need to undertake comparative studies of these margins to distinguish the common factors that may be controlling these changes



Shumagins (Fournier and Freymueller, 2007)