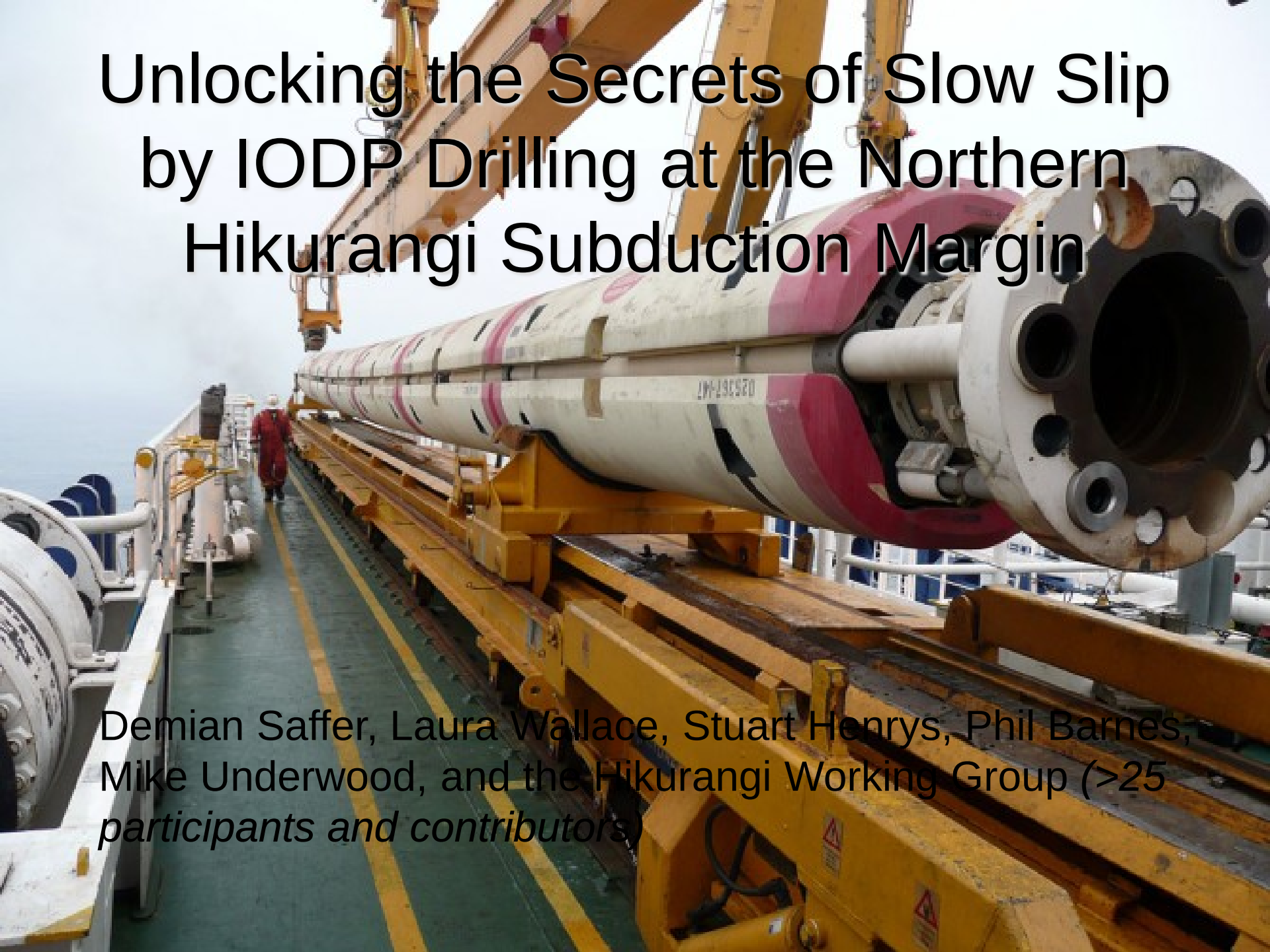
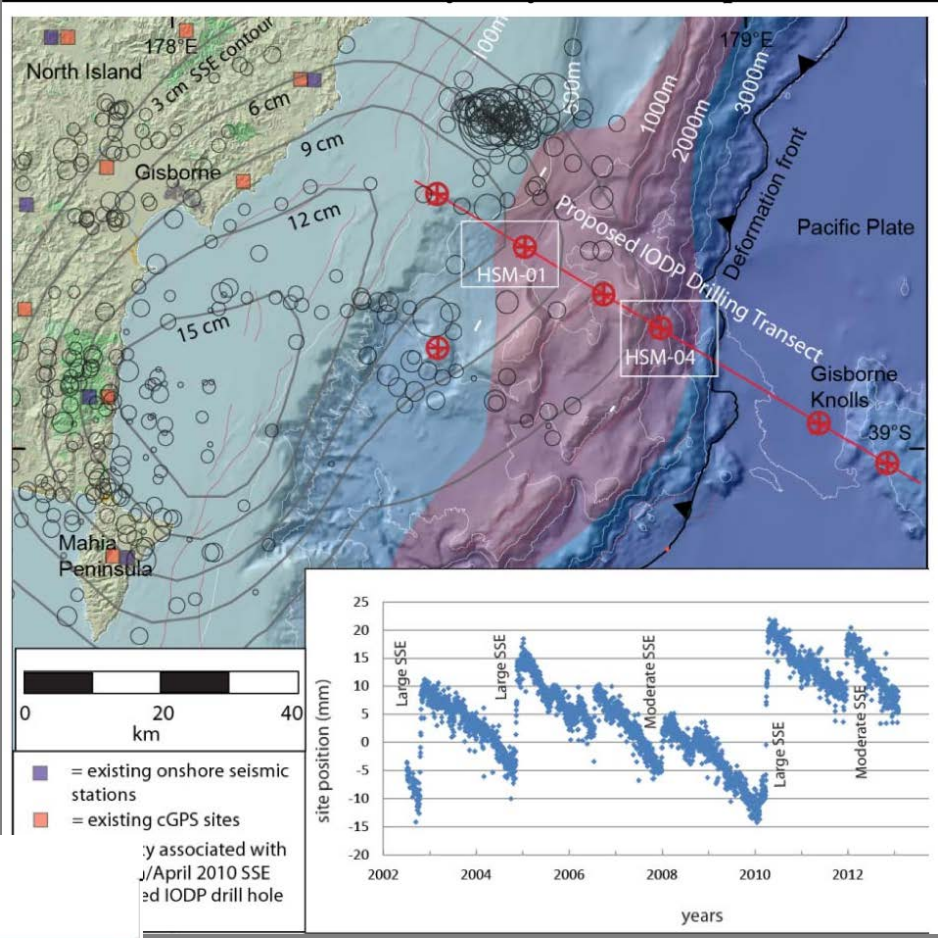
Unlocking the Secrets of Slow Slip by IODP Drilling at the Northern Hikurangi Subduction Margin

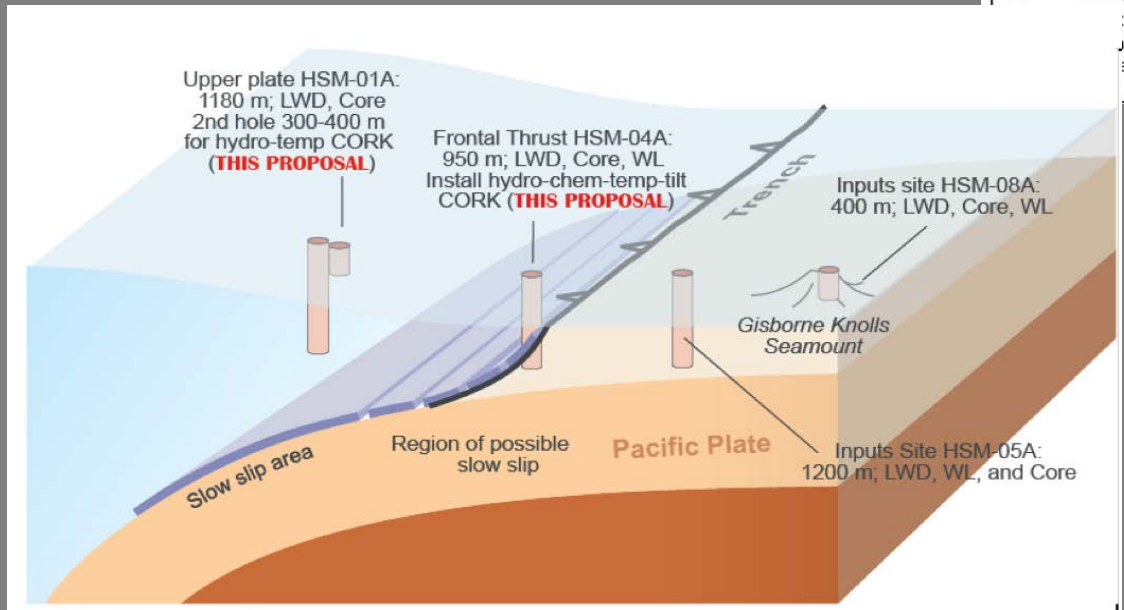


Demian Saffer, Laura Wallace, Stuart Henrys, Phil Barnes, Mike Underwood, and the Hikurangi Working Group *(>25 participants and contributors)*

IODP Complex Drilling Project at Hikurangi Margin

- Focus on Slow Slip Events
- Two IODP proposals: riserless & riser submitted 2011-2013
- NSF Observatory proposal submitted Aug, 2014
- Wide range of complementary efforts underway or proposed (seismic, heat flow, etc…)





IODP New Science Plan and GeoPRISMS science themes are highly complementary:

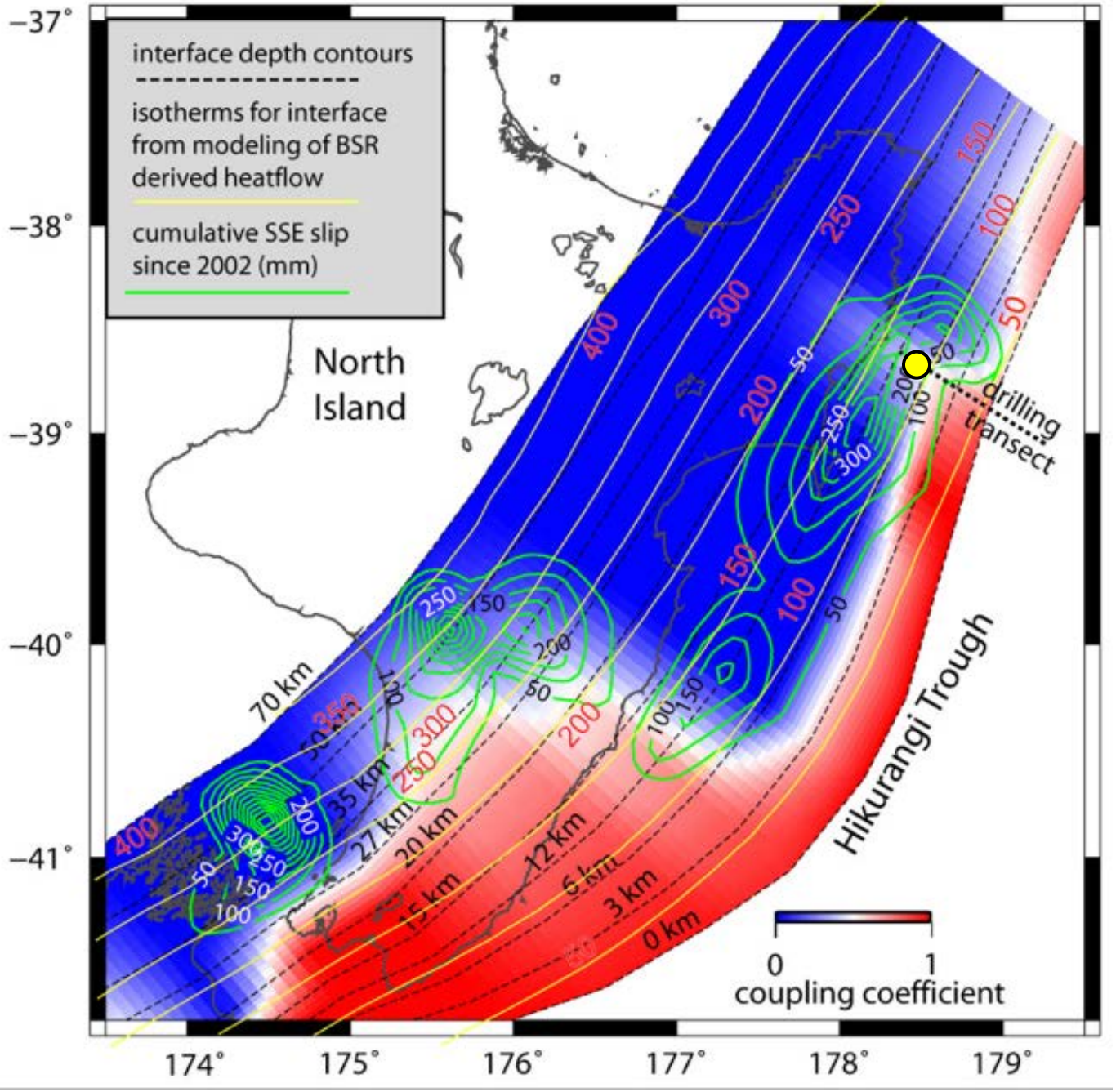
- *"Earth In Motion"* Theme includes: subduction megathrust behavior, volcanic activity, feedbacks between climate, deformation, sedimentation (parallels to Breakouts #2,3,4).

- "*Earth Connections*" Theme includes: subduction initiation, fluxes of mass & volatiles, growth of arcs (Breakouts #1-2)

Unlocking the secrets of slow slip by drilling at the N. Hikurangi subduction margin

- **781-MDP** "Umbrella Prop";
- **781A-Full**: Riserless drilling to ***log, sample*** and ***monitor*** the forearc and subducting plate (Saffer, Barnes, Wallace, Henrys, Underwood, Torres et al.)
  - Submitted October, 2011; Sent for external review
  - Forwarded from PEP with "Excellent" ranking
  - EPSP approval of primary & alternate sites, May 2014
  - Eligible for scheduling, possible 2017 timeframe

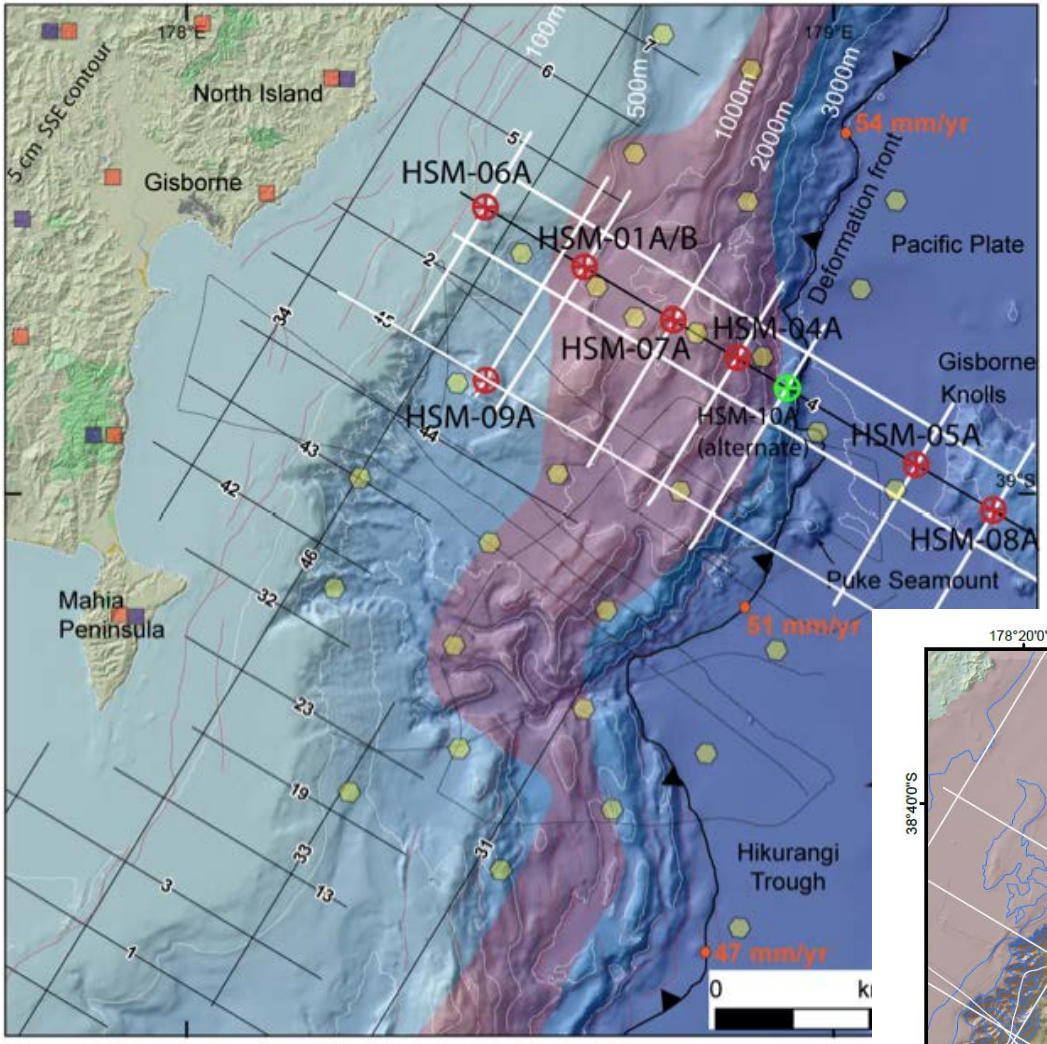
- **781-B-Full**: Riser drilling to intersect the plate interface (Wallace, Ito, Henrys, Barnes, Saffer, Kodaira, Tobin, Underwood, Bangs, Fagereng, Savage, Ellis, et al.)
  - Submitted April, 2013
  - Forwarded to Chikyu implementation board (CIB) Jan, 2014 with "Excellent" ranking


interface depth contours
isotherms for interface from modeling of BSR derived heatflow
cumulative SSE slip since 2002 (mm)
North Island
drilling transect
Hikurangi Trough
70 km
35 km
27 km
20 km
12 km
6 km
3 km
0 km
0
1
coupling coefficient
−37°
−38°
−39°
−40°
−41°
174°
175°
176°
177°
178°
179°

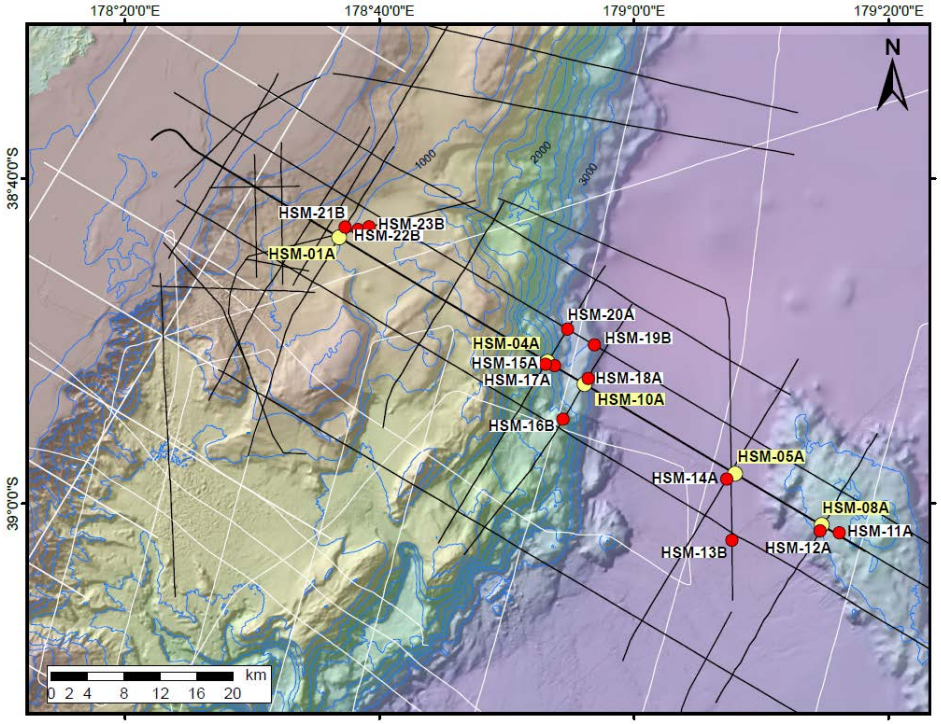
Overarching Questions Addressed by Drilling

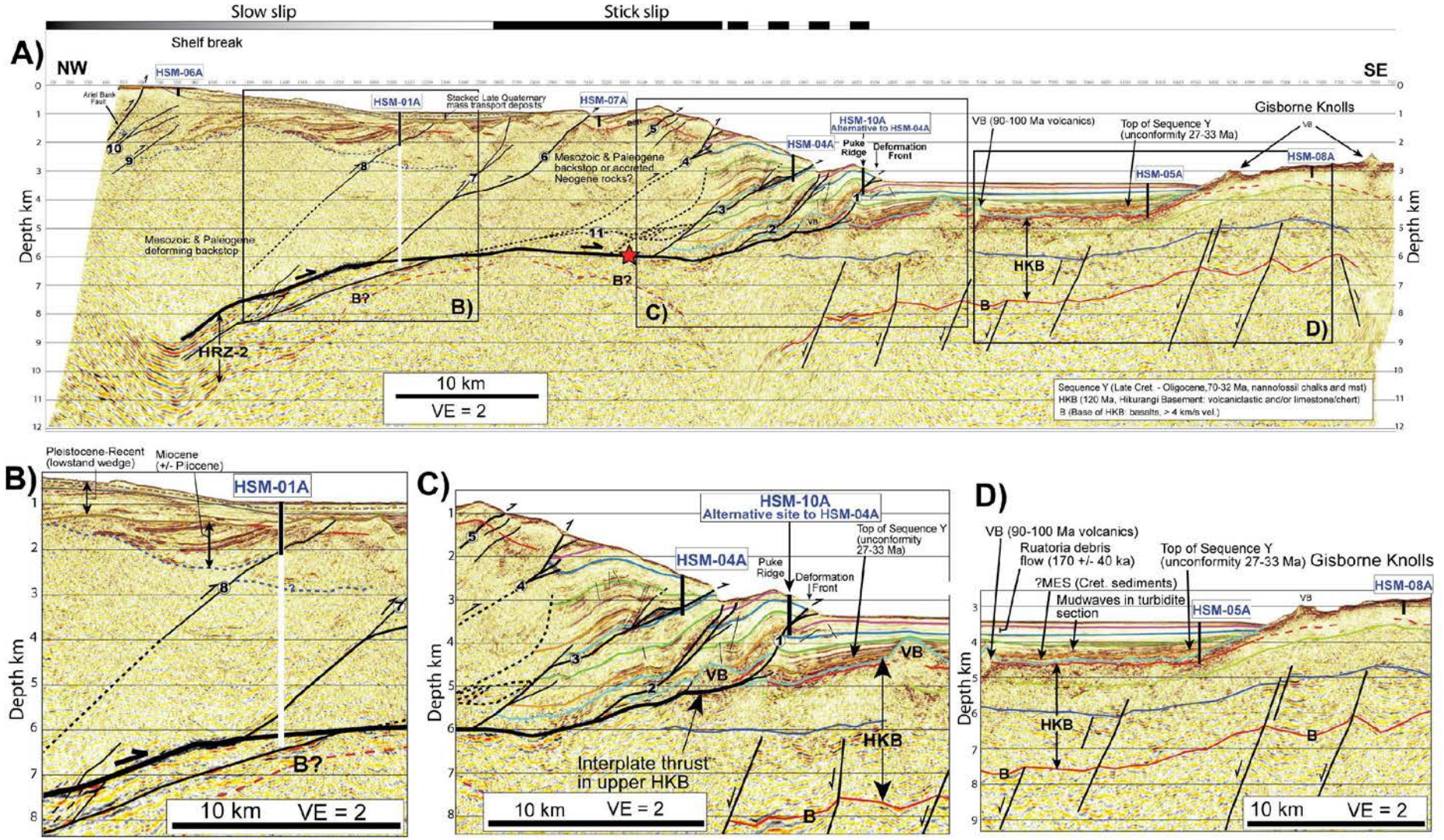
- *Hypothesis #1: Slow slip events occur within a conditionally stable frictional regime.*
- *Hypothesis #2: Slow slip events occur in regions of near-lithostatic fluid pressures, driven by mineral dehydration reactions.*
- *Hypothesis #3: The environments that host episodic slow slip are not restricted to a specific pressure or temperature range.*
- *Hypothesis #4: There is a continuum of duration and magnitude characteristics of SSEs and slow seismic behavior.*
- *Hypothesis #5: Subduction interfaces dominated by aseismic slip are structurally distinct from those that fail in large magnitude EQ, and are characterized by a thick zone of distributed shearing.*

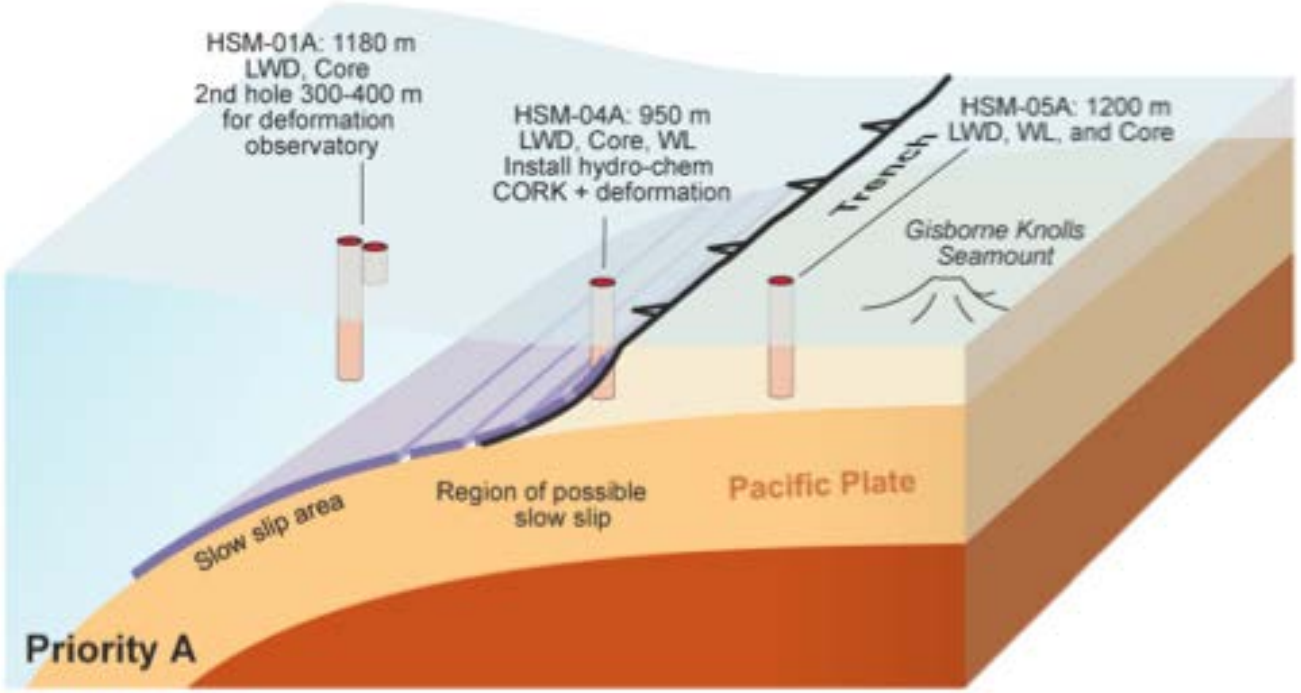
Proposed drilling transect



Proposed sites and alternates. Most of these have been approved by EPSP



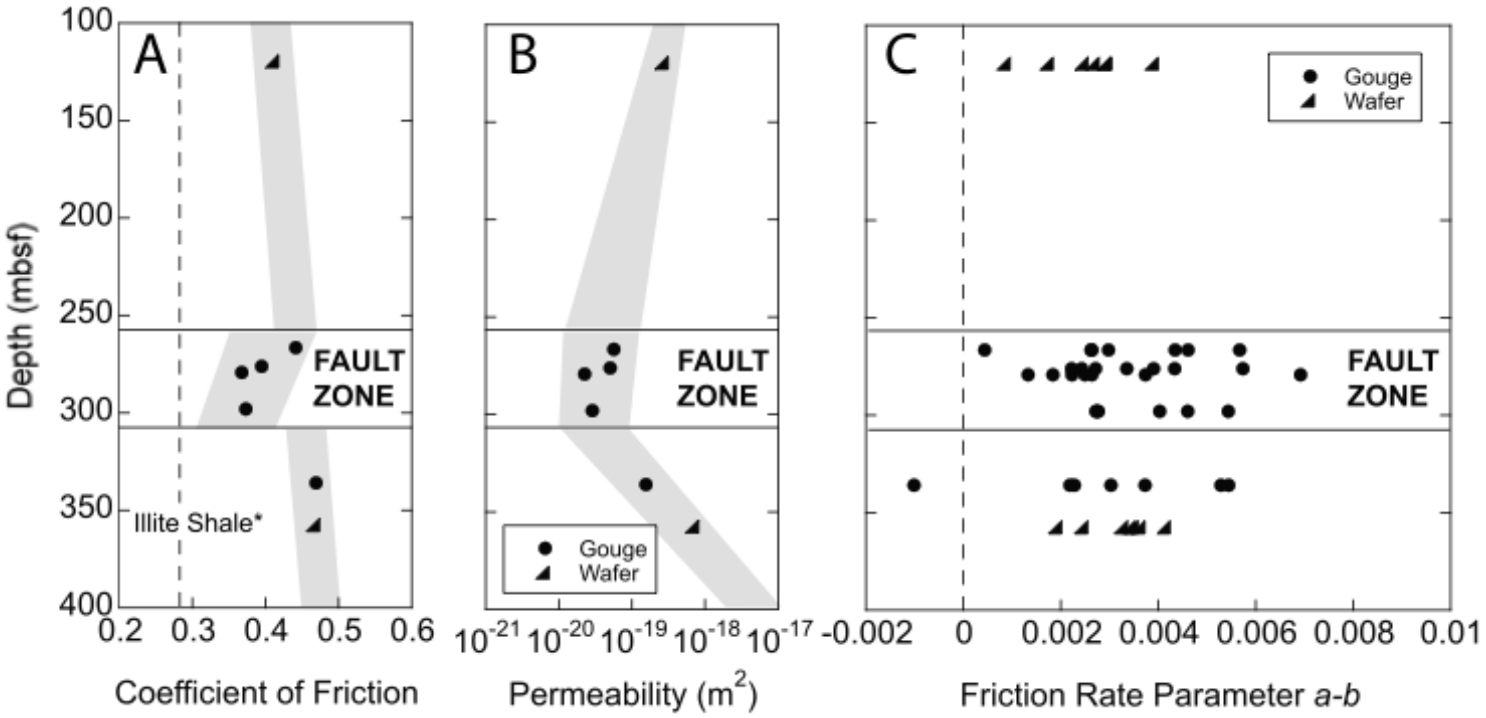

Slow slip
Stick slip
A)
Shelf break
NW
SE
HSM-06A
Ariel Bank Fault
HSM-01A
Stacked Late Quaternary mass transport deposits
HSM-07A
HSM-10A
Alternative to HSM-04A
HSM-04A
Puke Ridge
Deformation Front
VB (90-100 Ma volcanics)
Top of Sequence Y (unconformity 27-33 Ma)
Gisborne Knolls
HSM-05A
HSM-08A
Mesozoic & Paleogene backstop or accreted Neogene rocks?
Mesozoic & Paleogene deforming backstop
HKB
B
B?
HRZ-2
B)
C)
D)
Depth km
10 km
VE = 2
Sequence Y (Late Cret. - Oligocene,70-32 Ma, nannofossil chalks and mst)
HKB (120 Ma, Hikurangi Basement: volcaniclastic and/or limestone/chert)
B (Base of HKB: basalts, > 4 km/s vel.)
B)
Pleistocene-Recent (lowstand wedge)
Miocene (+/- Pliocene)
HSM-01A
B?
10 km VE = 2
C)
HSM-10A
Alternative site to HSM-04A
Top of Sequence Y (unconformity 27-33 Ma)
HSM-04A
Puke Ridge
Deformation Front
VB
HKB
Interplate thrust in upper HKB
B
10 km VE = 2
D)
VB (90-100 Ma volcanics)
Ruatoria debris flow (170 +/- 40 ka)
Top of Sequence Y (unconformity 27-33 Ma)
Gisborne Knolls
?MES (Cret. sediments)
Mudwaves in turbidite section
HSM-05A
HSM-08A
HKB
B
10 km VE = 2



- **Inputs sites**: Log & Core to characterize composition, thickness, state, phys. props of incoming sed & basement
- **Shallow fault** (750 m): Log & core to characterize plate boundary in updip region of SSE zone. Install observatory to monitor pore pressure & fluid geochemistry.
- **Shallow observatory** on lower slope: Drill to ~300-400 m, case, install simple "geodetic" observatories.
- **Pilot hole** for riser drilling to SSE source region.

Logging and Coring:

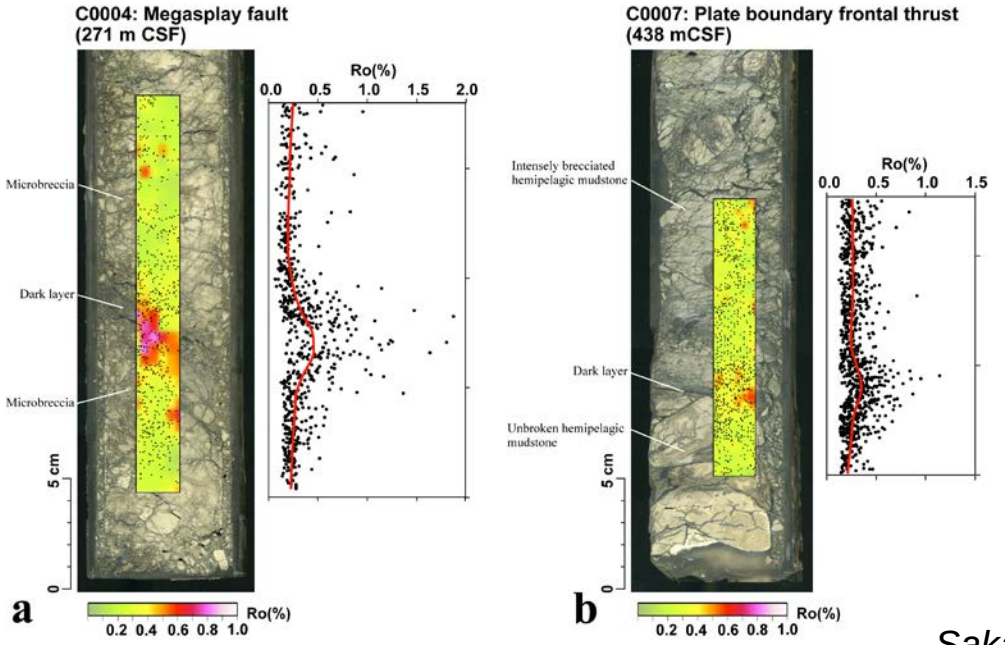
- → Lithologies and composition
- → Frictional properties of fault rock
- → Fault zone architecture
- → Physical properties (porosity, permeability, Vp, etc…)
- → In situ pore pressure and stress estimates (indirect)



Ikari et al., 2009

Logging and Coring:

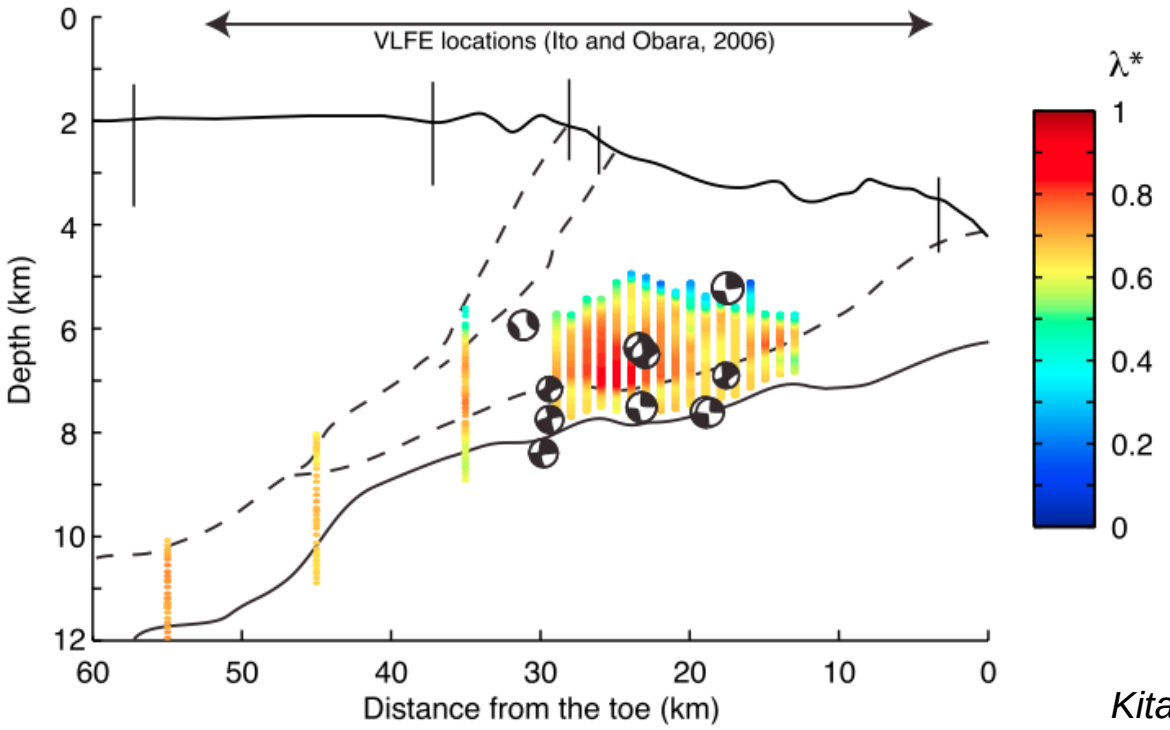
- → Lithologies and composition; shallow thermal gradient
- → Frictional properties of fault rock
- → Fault zone architecture
- → Physical properties (porosity, permeability, Vp, etc…)
- → In situ pore pressure and stress estimates (indirect)



Sakagucji et al., 2010

Logging and Coring:

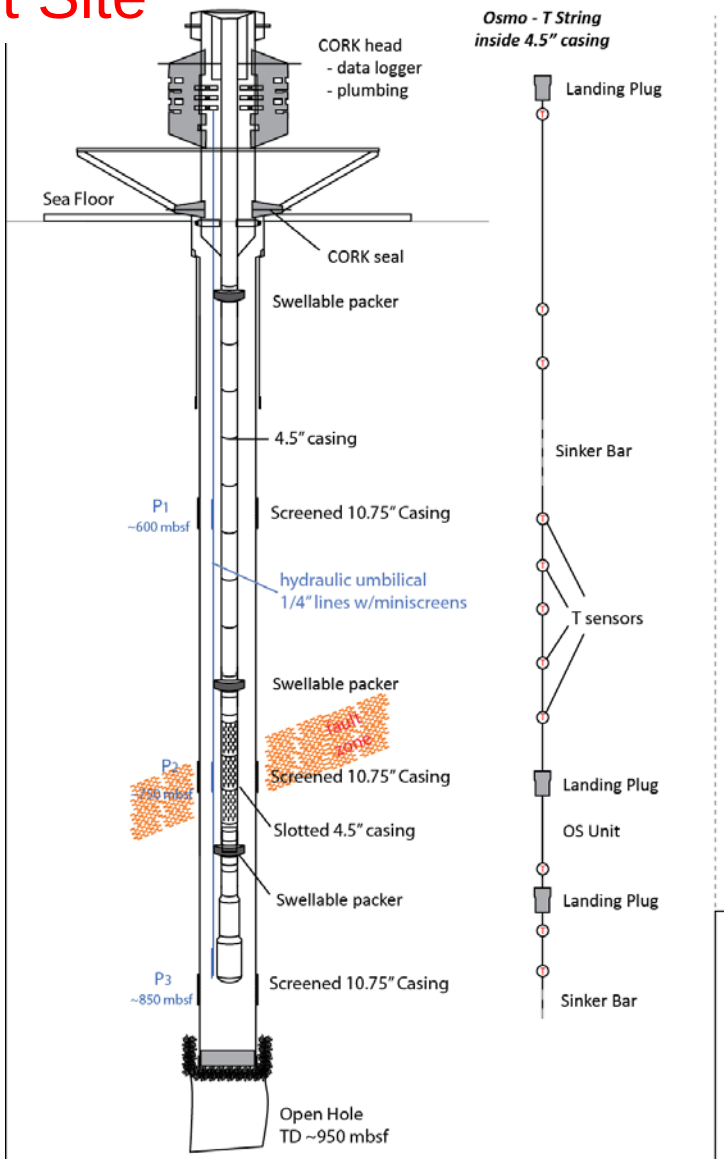
- → Lithologies and composition
- → Frictional properties of fault rock
- → Fault zone architecture
- → Physical properties (porosity, permeability, Vp, etc…)
- → In situ pore pressure and stress (direct & indirect)



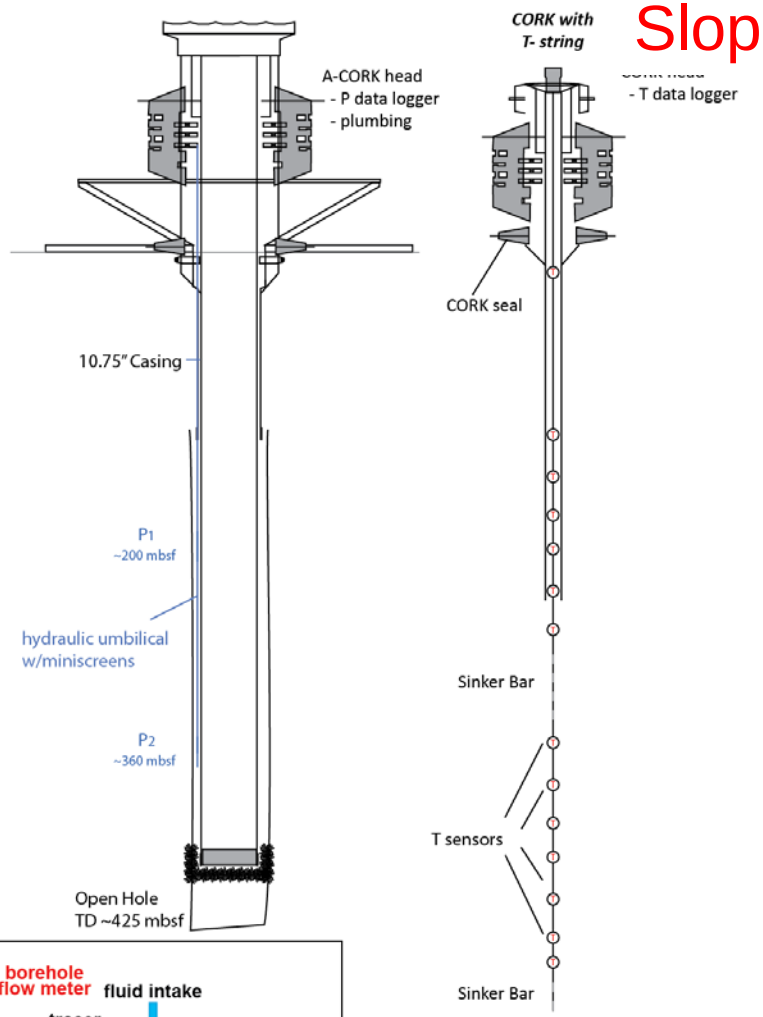
Kitajima & Saffer, 2012

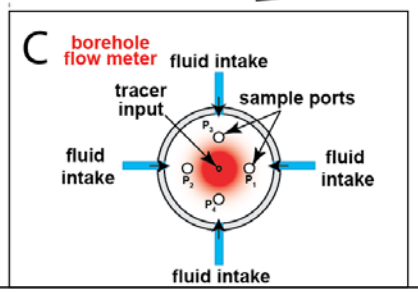
Proposed Borehole Observatories

Fault Site



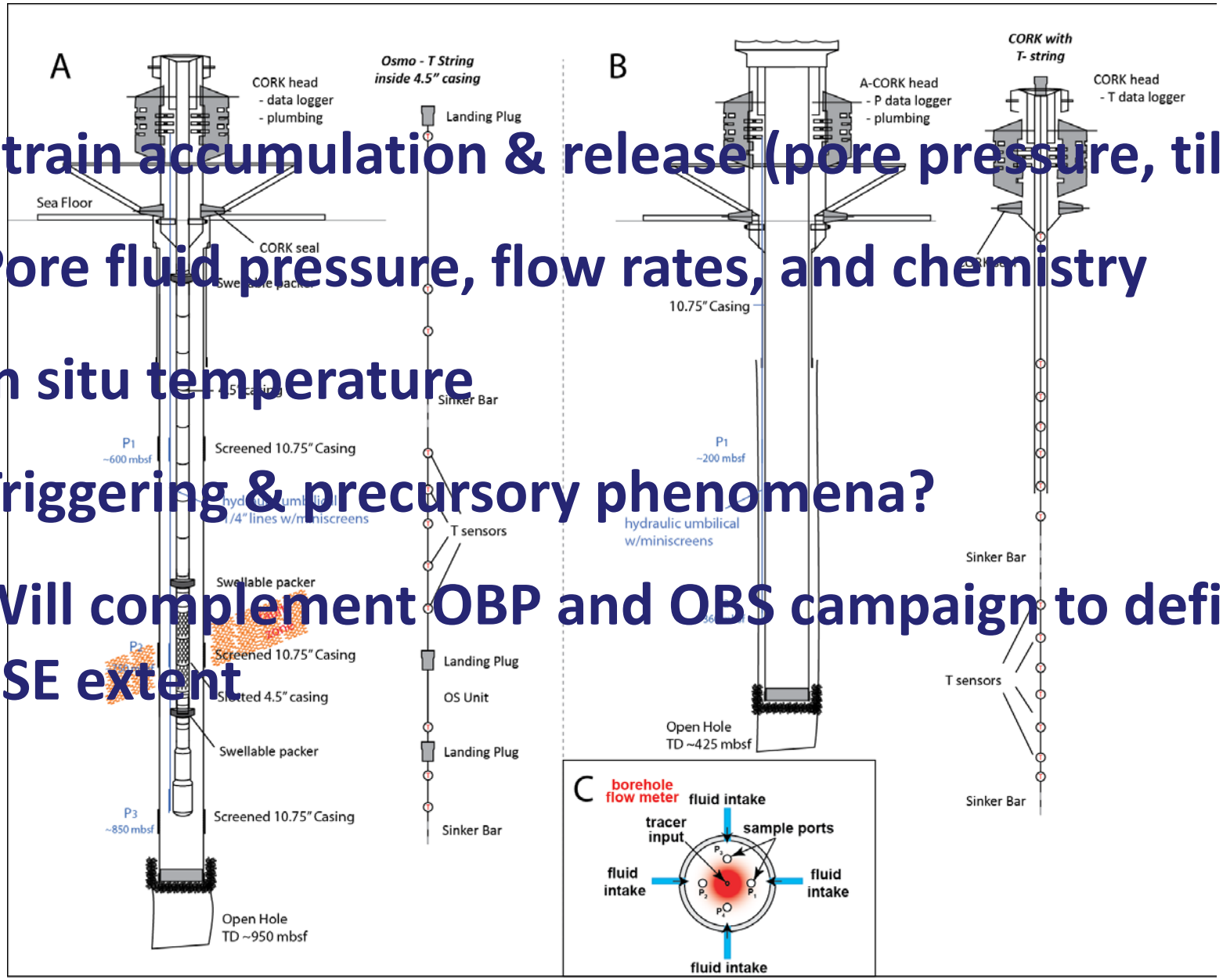
Slope Site





Proposed Borehole Observatories

- Strain accumulation & release (pore pressure, tilt)
- Pore fluid pressure, flow rates, and chemistry
- In situ temperature
- Triggering & precursory phenomena?
- Will complement OBP and OBS campaign to define SSE extent



Example from Nankai Trough: Response to the March 2011 Tohoku EQ:

- *dynamic response*
- *static P change (strain)*
- *permeability change?*