Unlocking the Secrets of Slow Slip by Scientific Drilling at the Northern Hikurangi Subduction Margin, New Zealand

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Slow slip events (SSEs) involve transient aseismic slip across a fault (lasting weeks to months) at rates intermediate between plate-boundary displacement rates and the slip velocity required to generate seismic waves. The importance of these events as a mode of fault slip was unknown prior to the advent of dense, plate-boundary-scale geodetic networks during the last decade. Observations of SSEs and associated seismic phenomena at several subduction megathrusts have ignited a dynamic and exciting field of research in seismology and plate boundary fault mechanics. SSEs appear to bridge the gap between typical earthquake behavior and steady, aseismic slip on faults, but the governing physical mechanisms, rock properties, in situ conditions, and the relationship of these events to destructive, seismic slip on subduction thrusts are poorly known. This deficiency in our understanding is due partly to the fact that most well-studied subduction zone SSEs (Cascadia, southwest Japan) are too deep for high-resolution imaging or direct sampling of the source region. **A notable exception is the northern Hikurangi subduction margin, New Zealand, where well-characterized SSEs occur every 1-2 years, over a period of 2-3 weeks at depths of only <5-15 km below the seafloor** (Fig. 1). SSEs at northern Hikurangi are, therefore, shallow and frequent enough to sample, log, and monitor in the near field over several cycles of strain accumulation and release.

The Multi-phase Drilling Project proposal "**Unlocking the Secrets of Slow Slip by Drilling at the Northern Hikurangi Subduction Margin, New Zealand"** (781-MDP) outlines a plan for IODP drilling to discern the mechanisms of subduction zone SSEs by a transect of both riserless and riser drilling and borehole observatories above the SSE source and on the incoming plate (Fig. 2). The proposal for riserless operations (781A-Full) was submitted in October 2011. 781A-Full was forwarded by the IODP Proposal Evaluation Panel (PEP) with an "Excellent" rating and is now eligible for scheduling on *JOIDES Resolution*. A proposal for the riser operations will be submitted to IODP by 1 April 2013.

The riserless boreholes are designed to address three fundamental scientific objectives: (1) characterize the *state* and *composition* of the incoming plate and shallow plate boundary fault near the trench, which comprise the protolith and initial conditions for fault zone rock at greater depth; (2) characterize material properties, thermal regime, and stress conditions in the upper plate above the SSE source region; and (3) install borehole observatory instruments to monitor a transect of holes above the SSE source, to measure temporal variations in deformation, fluid flow, and seismicity.

For the riser drilling phase, we propose a single borehole to intersect the plate interface 5.5-5.8 km below the seafloor, to collect samples, geophysical logs, and downhole measurements across the subduction megathrust fault *where SSEs are occurring*. Our drilling strategy is also designed to take advantage of scientific opportunities on the way to the subduction interface, including a temporary observatory ~1.5 km above the SSE source, to be in place between drilling phases (Fig. 2). The deep borehole is required to address three fundamental scientific objectives: (1) reveal the composition, mechanical properties, and structural characteristics of the slow slip source zone; (2) characterize hydrological properties, thermal regime, and in situ stress conditions within the SSE source region, and (3) determine hydrological properties, thermal regime, and stress conditions within the upper plate above the SSE source.

Together, the data from our proposed program of riserless and riser drilling will test a suite of hypotheses and answer outstanding questions about the fundamental mechanics of faults and occurrence of slow slip events. **(1)** Are SSEs associated with elevated fluid pressures, and if so, what is the source of the fluids? **(2)** What are the roles of fault strength and frictional properties in facilitating slow slip? **(3)** What is the fault zone architecture associated with slow slip, and does slow slip occur over a broad shear zone or discrete slip zone? **(4)** Which lithologies host slow slip, and do they promote conditional frictional stability? If so, do both fast seismic slip and slow aseismic slip occur in the same location on the interface? **(5)** Do slow slip events propagate all the way to the trench? **(6)** How do fluid chemistry, pore pressure, temperature, and fluid flux (near the surface and at the SSE source) vary in response to SSEs, and vice versa? **(7)** Does temperature influence the down-dip limit of the seismogenic zone and the depth to slow slip events?

Most importantly, drilling into the aseismically creeping northern Hikurangi margin constitutes an ***ideal counterpart*** to deep riser drilling into the Nankai trough seismogenic zone, which is ongoing. If both subduction margins are eventually drilled, holistic comparisons of cores and logs between the two end-member locations will help to ***solve the mystery of why some subduction zones lock up and rupture in Great earthquakes (e.g., Nankai), while others are dominated by aseismic creep (e.g., North Hikurangi).***

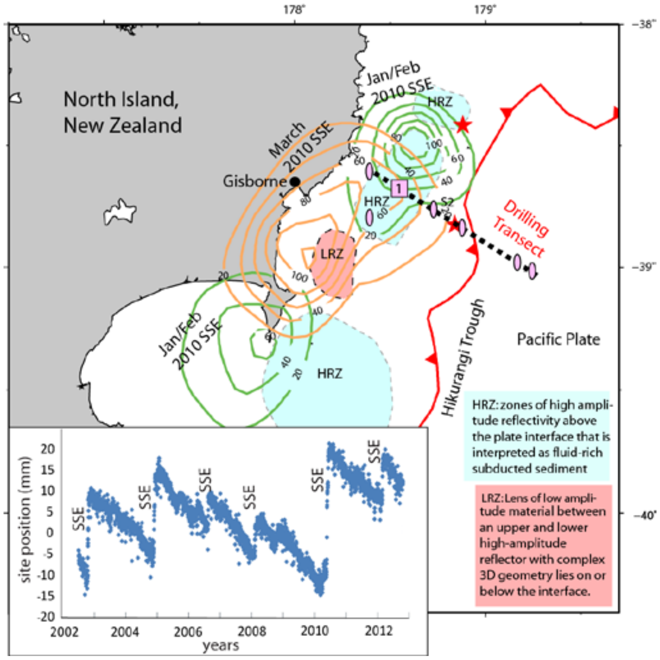

Figure 1. Tectonic setting and location of slip (colored contours) on the subduction interface in a sequence of SSEs in 2010. Black dashed line with pink ellipses shows the location of the proposed riserless drilling transect (proposal 781A-Full), while the pink square (labeled "1") shows the proposed riser drillsite to intersect the SSE source at 5.5-5.8 km bsf. Inset figure in lower left shows the east component of the position timeseries for a cGPS site near Gisborne to demonstrate the repeatability of SSEs since they were first observed in 2002.

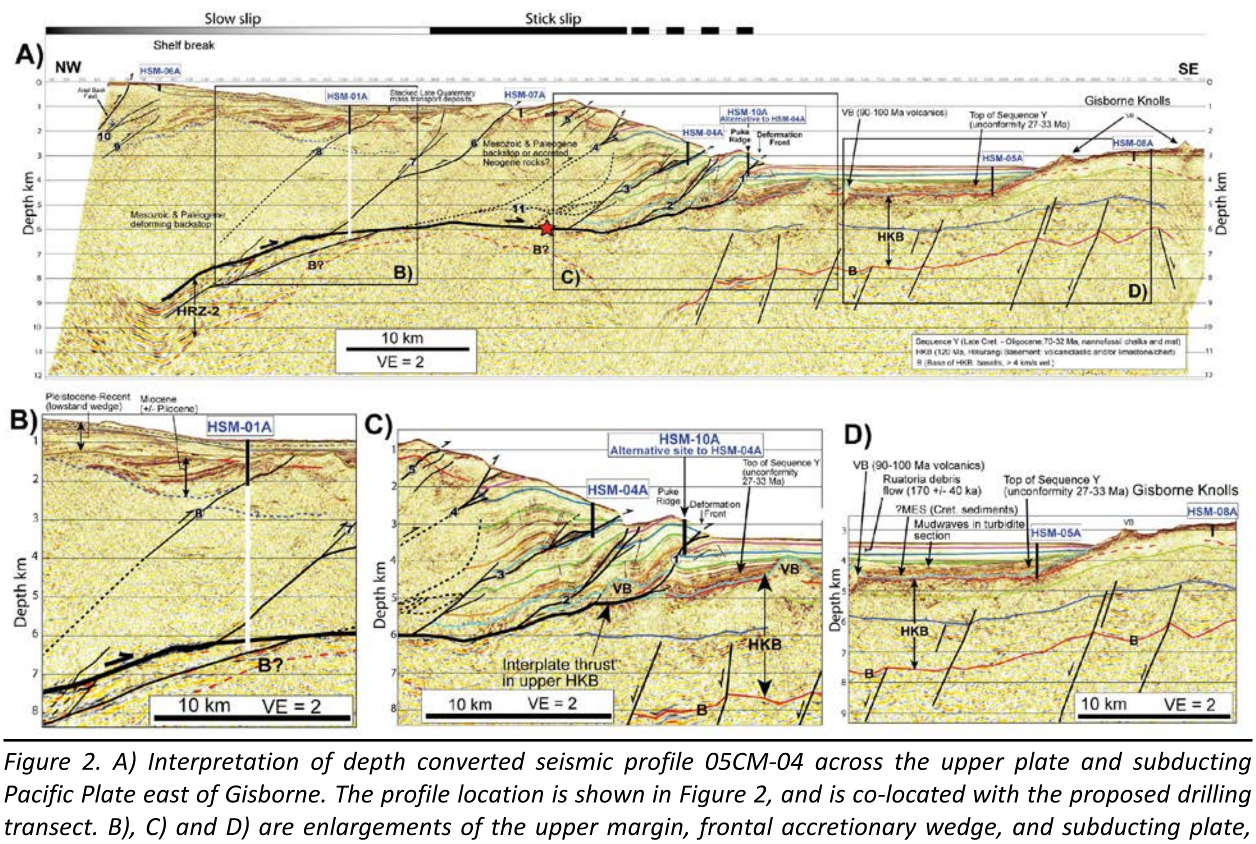

Figure 2. A) Interpretation of depth converted seismic profile 05CM-04 across the upper plate and subducting Pacific Plate east of Gisborne. The profile location is shown in Figure 2, and is co-located with the proposed drilling transect. B), C) and D) are enlargements of the upper margin, frontal accretionary wedge, and subducting plate, respectively. The bold black fault is the subduction interface. The stratigraphy of the subducting Hikurangi Plateau sequence is inferred from correlations to seismic reflection and ODP borehole (1123, 1124) data from east of the trench. Note that at the deformation front, the plate interface is developing in the upper part of the Hikurangi Plateau basement sequence (HKB). The high-amplitude reflectivity zone above the interface (HRZ) labeled on 1, and the red star shows the location of the March 1947 tsunami earthquake.