Seafloor and Subseafloor Monitoring of Slow Slip at the Northern Hikurangi Margin

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Slow slip events offshore the northern Hikurangi margin occur at shallow depths of <5-15 km approximately every eighteen months just offshore Gisborne, New Zealand. They typically last 1-2 weeks, producing horizontal displacements of up to 3 cm at onshore cGPS sites. The unusually close proximity of the Gisborne SSEs to the seafloor is in distinct contrast to Cascadia and southwest Japan where SSEs are at >30-40 km depth. Due to large slip and shallow depths, **vertical seafloor displacements in SSEs offshore Gisborne are expected to be 1-3 cm or more, much larger than for Cascadia SSEs.** The close proximity of north Hikurangi SSEs to the seafloor makes this region an ideal location for ***near-source*** monitoring of variations in deformation, seismicity, fluid pressure, fluid geochemistry, and temperature through multiple SSE cycles using a network of seafloor and subseafloor instruments. **To this end, we advocate the development of an integrated network of seafloor and subseafloor observatories** (Fig. 1)**.** The seafloor component should include ocean bottom seismometers (OBS) and absolute pressure gauges (APG; to measure vertical deformation). Borehole observatories would be focused on monitoring hydrogeological, thermal, geochemical, and deformation (via tilt, pore pressure, & flow rates) variations throughout multiple SSE cycles (see Hikurangi drilling white paper).

Seafloor OBS and Absolute Pressure gauges. The primary aim of a seafloor-based network of OBS and APG is to **improve our knowledge of the distribution of slow slip and related seismicity beneath the offshore region**. Specific goals are: **(1)** Determine the spatial distribution of SSE slip using vertical deformation data from the APGs. Based on recently recovered APG data from Cascadia, we expect to resolve vertical deformation signals of 0.5 cm and larger; **(2)** Identify and precisely locate seismicity and tremor related to SSEs at the offshore northern Hikurangi subduction margin, and assess the spatial and temporal relationship to SSE slip; **(3)** Passive source imaging with OBS to improve earthquake locations and inferring properties of the plate interface and surrounding crust in the SSE region. If we find that slow slip propagates all the way to the trench (Fig. 2), this will have major implications for our knowledge of the range of physical environments that promote SSE behavior, and could also open the possibility of shallow drilling into the SSE source area using less costly riserless drilling.

Sub-seafloor observatories. The primary goals of the borehole observatories are***:*** **(1)** Monitor temporal variations in pore fluid pressure, fluid geochemistry and flow rate within the shallow subduction thrust (near the trench) and upper plate throughout the SSE cycle. These data will quantify ambient pore pressure, provide information about potential links between hydraulic and geochemical transients and SSEs, and constrain the source region of fluids that may be mobilized through permeability enhancement associated with SSEs (e.g., Solomon et al., 2009; Davis et al., 2011). **(2)** Deployment of a string of thermistors in the boreholes will enable determination of ambient temperatures, evaluation of the thermal regime of shallow slow slip, as well as variations in temperatures throughout the SSE cycle. **(3)** Document formation pressure response to known tidal loading to constrain formation compressibility and hydraulic diffusivity (e.g., Wang and Davis, 1996). **(4)** Borehole tiltmeter, pore pressure, and flowmeter data (with the latter two used as a proxy for strain) can be integrated within the broader framework of OBS and APG deployments at north Hikurangi to provide key information on the spatial and temporal distribution of slip in SSEs on the shallow subduction thrust (Fig. 2).

In a pilot study, the University of Tokyo has recently recovered two OBS+APG offshore Gisborne (led by Kimi Mochizuki). A larger deployment of OBS and APG has been recently proposed to NSF and Japanese funding agencies (Fig. 1) for 2014. This proposed deployment is intended to capture deformation and seismicity related to a large SSE offshore Gisborne that is expected to occur sometime in 2014 (based on past behavior of SSEs there). We are in the process of developing proposals for observatory equipment to be installed in boreholes as part of IODP proposal 781A-Full (see white paper on Hikurangi margin drilling). To fully integrate the results from seafloor observations (OBS, APG) with those from the borehole observatories, we advocate deployment of a network of OBS and APG instruments at the same time that the borehole observatories are operating. Combined interpretation of data from these two complementary networks will greatly improve the spatial resolution of the distribution of slip and seismicity. The borehole observatories on their own will also reveal how physical properties such as fluid chemistry, pressure, temperature, and fluid flux (both above the SSE source and within the frontal thrust) vary through the SSE cycle.

References:

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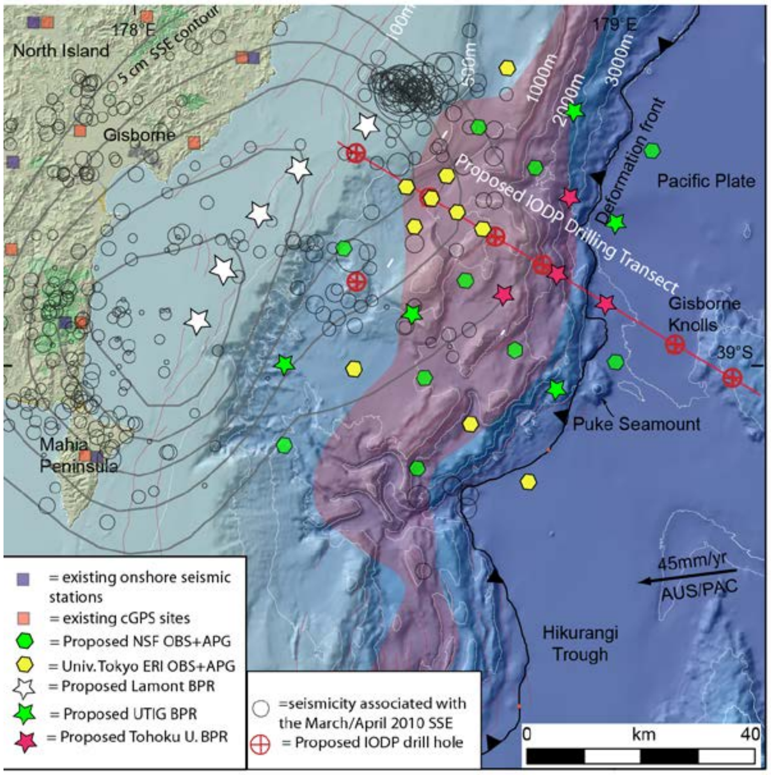

Figure 1. Bathymetry of the northern Hikurangi margin, IODP drilling transect (proposal 781A-full, red line), and a proposed 2014 deployment of OBS and APG (hexagons and stars). Purplish-red transparent area on mid slope is the envelope of viable riser drilling targets that would intersect the subduction interface. See key at lower left explaining the symbols on the figure. The gray contours indicate slip on the subduction interface in the March/April 2010 SSE offshore Gisborne, New Zealand (Wallace and Beavan, 2010); contour intervals are 30 mm, the starting (outermost) contour is 30 mm, innermost contour is 150 mm. Black circles are seismicity associated with the March/April 2010 SSE.

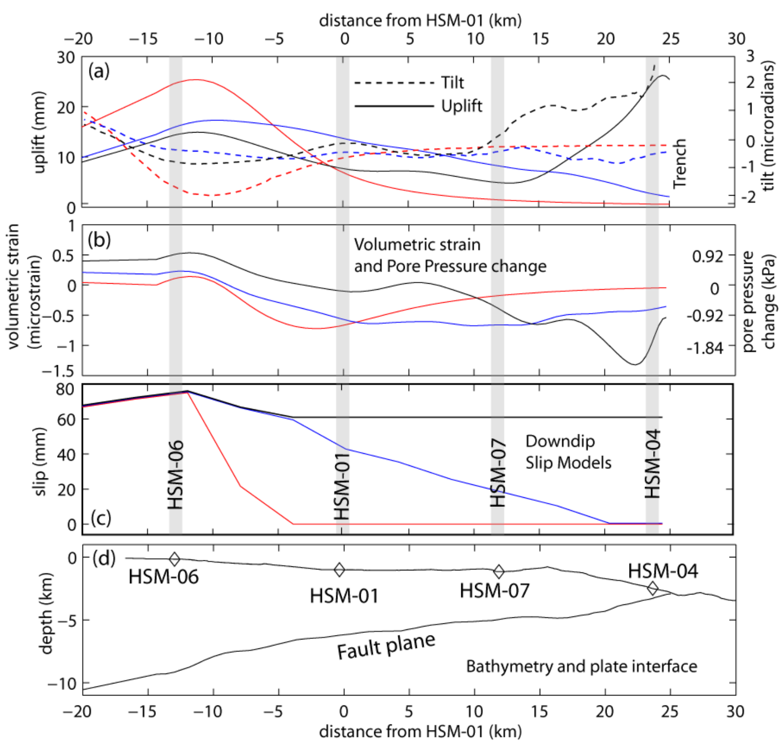

Figure 2. Forward elastic, half space dislocation models of 3 different SSE slip scenarios shown in (c). Tilt and uplift (a) are calculated at the seafloor and volumetric strain (b) is estimated for 300 mbsf. If conditions within the sediments are undrained there is a linear relationship between pore pressure (Pf) and volumetric strain, scaled by the bulk modulus (Ge and Stover, 2000). We assume a bulk modulus of 6.5 GPa, consistent with bulk moduli estimated for upper plate wedge sediments offshore Costa Rica (Gettemy and Tobin, 2003). Note that observed Pf change related to a similar-sized SSE offshore Costa Rica were much larger (~40 kPa) than we predict here. Thus, we suspect that we may be underestimating the influence of the volumetric strain on Pf change, and the actual signals could be even larger than shown here. Note the blue slip model is similar to our best-fitting slip from the March, 2010 SSE.