**Three-dimensional seismic imaging of slow slip zones along the northern Hikurangi margin**

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Subduction margins produce the largest and most destructive earthquakes and tsunami on Earth. Understanding the mechanics of fault slip behaviour on subduction thrust interfaces is critical to understand earthquakes and mitigate seismic hazards. Recent detection of slow slip and its associated seismic phenomena (such as non-volcanic tremor, low-frequency and very-low frequency earthquakes) has transformed our understanding of possible fault slip behaviour (e.g., Ide et al., 2007), which exposes the need to investigate the full range of slip behavior to fully understand deformation mechanisms and rheology on subduction megathrusts.

The mechanisms responsible for slow slip are poorly known, but focus has turned to the role of high-fluid pressure as a controlling factor. Progress in understanding the physical mechanisms behind slow slip will require a combination of detailed seismic imaging, passive seismic monitoring and more direct sampling and measurement of material in the SSE (slow slip earthquake) regions (via ocean drilling) throughout the SSE cycle. However, most well-documented subduction SSEs (Cascadia, southwest Japan, Mexico, Alaska) occur at 25-50 km depth and pose significant challenges for detailed seismic imaging and are impossible for drilling. One notable exception to this lack of access is the northern Hikurangi margin, New Zealand, where SSEs occur approximately every two years at <5-15 km depth, at the down-dip transition from stick-slip to aseismic creep on the Hikurangi subduction thrust. Northern Hikurangi SSEs (see figure) typically last 1-2 weeks and produce slip on the subduction interface equivalent to an Mw 6.3-6.8 earthquake (Wallace and Beavan, 2010). The extremely shallow depth of the northern Hikurangi SSEs permits detailed remote geophysical sensing studies of the physical properties of the interface in the SSE source area, and offers the possibility of calibrating these properties by direct sampling of material in the SSE source area with offshore drilling methods.

In the last couple of years an international group of scientists has assembled to explore and develop strategies to investigate emerging hypotheses about the structures and physical conditions that control a spectrum of slip behaviour along the Hikurangi subduction thrust. The Hikurangi margin exhibits behaviours along the north island of New Zealand that range from regularly repeating slow slip events (SSEs) in the north to full locking and stick-slip in the south. Recent geophysical studies and emerging hypotheses make this a compelling setting to investigate the conditions and processes that control slip behaviour on the subduction thrust. Following a preliminary workshop in May 2010 and a large workshop in Aug. 2011, an international team of scientists has begun planning a broad range of experiments, including IODP drilling, to address slip behaviour along the Hikurangi margin. A description of drilling plans, including riserless drilling and monitoring (781A-Full), and deep riser drilling to ~6 km depth (to be submitted to IODP April 2013) are described in a separate white paper (**Unlocking**

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

## A 3D seismic imaging program for the Hikurangi margin

As plans for potential deep drilling evolve, the need to acquire 3D seismic reflection data to further constrain structures and material properties along the Hikurangi margin is evident. These data would allow us to expand hypotheses and develop targets for further investigation. Three-dimensional seismic imaging in the last two decades have demonstrated that is a highly effective tool for mapping fault systems within structurally complex subduction zone settings. Integration of 3D seismic results with ground truthing from drilling is by far the most effective tool for characterizing fault geometry and rock properties that approach the scale of fault slip regions.

We plan to submit proposals to use the R/V Langseth for a 3D survey of the northern Hikurangi margin along the proposed drilling transect. The 3D survey will be designed from existing 2D seismic reflection data in the proposed drilling area. In recent years, a community of largely New Zealand scientists have surveyed the Hikurangi margin extensively with 2D seismics (see figure for location of 2-D seismic lines surveyed at northern Hikurangi in 2005) and swath bathymetry (including SIMRAD multi-beam data) with funding from the New Zealand science funding agencies and government departments. The 2-D MCS data from the offshore northern Hikurangi margin reveal a zone of high-amplitude reflectivity near the subduction interface, 5–15 kilometers below the seafloor, that coincides with geodetically determined SSE source areas (Bell et al., 2010). These high-amplitude reflective zones (HRZs) are interpreted to correspond to fluid-rich sediments, suggesting that high fluid pressures may play an important role in the occurrence of SSEs at the northern Hikurangi margin. In addition to imaging the SSE source area and associated HRZ, the proposed survey also offers an opportunity to image the seamount asperity associated with a 1947 tsunamigenic earthquake on the subduction interface, adjacent to and updip of the SSE source area (see figure). The ability to contrast the properties of the interface in the seamount asperity region (unstable frictional regime) with the surrounding slow slip area (conditionally stable regime) could give important insights into the processes and properties that control the occurrence of earthquakes vs. slow, aseismic slip. Because of both the local interest and the growing international interest in the Hikurangi margin as a setting for this world class problem, we plan to seek funding for the Langseth acquisition from New Zealand, NSF and other international funding agencies.

Survey plans are still preliminary and will not be complete until proposals are submitted, but we envision a 3D survey of ~ 45 days, covering an area of approximately 20 x 50 km, acquired in coordination with another OBS program outlined in a separate white paper. The primary goal would be to image the geometry and reflective properties of the plate boundary fault from the trench across the strongly coupled regions and into the slow-slip patches, to a down dip depth of ~ 10 km. Two-dimensional seismic profiles show high amplitude reflections from the plate interface down to ~10 km. The 3D survey would also map structures and material properties within the overriding plate to examine deformation and the potential plumbing system of the overriding plate. The survey would be centered along the proposed drilling transect as described in the drilling proposal 781A-Full. A 3D seismic survey would be best in the southern summer when the weather in New Zealand is relatively calm.

**Summary of plans**:

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| Proposal Type: | "Community" including US and Foreign participants |
| US Funding Agency: | NSF and other non-US sources |
| Approx. number of ship days: | 60 (but still very uncertain) 3D |
| Equipment: | 3D seismic reflection |
| Time of year for operations: | Southern summer |
| Anticipated submission deadline: | Aug 15, 2013 NSF-OCE deadline |
| Links to other Programs: | IODP and NSF-GeoPRISMS |

## References


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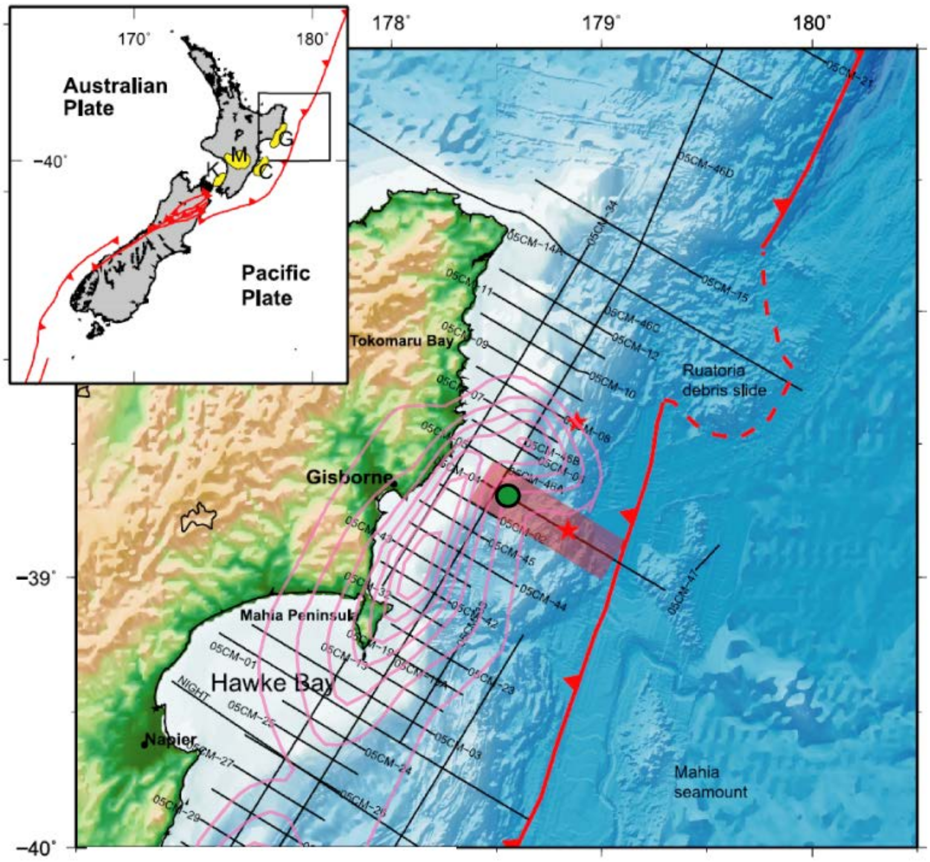


*Figure 1. Location of the east coast North Island study region offshore Gisborne modified from Bell et al. (2010). Black lines are most recent 2005 seismic survey lines shot by the NZ Ministry of Econ. Development and consisted of ca. 2800 km of 2-D seismic reflection data including 33 dip and 6 strike profiles. Streamer length varied from 12 km to 4 km, with record lengths of 12 s to 8 s two-way travel time (TWT) and shot intervals of 37.5 m to 25 m using a 4140 cubic inch, 2000 psi air gun source. Pink contours show the areas slow slip since first recorded in 2002 (Wallace and Beavan, 2010). Topography and bathymetry are from ETOPO2 and swath bathymetry has been merged where available. Green dot shows proposed offshore drilling location to access the SSE source area on the interface at ~5 km sub- seafloor. Red toothed line is approximate frontal thrust at accretionary wedge toe and red stars show 1947 tsunami earthquakes locations (Doser and Webb, 2003). Inset is a summary of New Zealand regional tectonics. Yellow patches indicate areas of recorded slow slip (Wallace and Beavan, 2010). K = Kapiti, M = Manawatu, C = Cape Kidnappers and G = Gisborne slow slip events. The red shaded rectangle is the approximate extent of intended 3D MCS survey.*