Imaging the Southern Hikurangi Margin locked subduction interface and upper plate by passive and active seismic and magnetotelluric arrays

Stuart Henrys[1], David Okaya[2], Hiroshi Sato[4], Tim Stern[3], Marth Savage[3], John Townend[3], Grant Caldwell[1], Wiebke Heise[1], Stephen Bannister[1], Bill Fry[1], Rupert Sutherland[1], Aaron Wech[1]

[1]GNS Science, Lower Hutt, New Zealand; [2]University of Southern California; [3]Victoria University of Wellington; [4]Earthquake Research Institute, University of Tokyo

s.henrys@gns.cri.nz

Subduction zones produce the largest earthquakes and tsunamis on Earth, as evidenced by the 2011 Tohoku Mw 9.0 earthquake (Simons et al., 2011) and 2004 Sumatra Mw 9.3 earthquake (Ammon et al., 2005; Lay et al., 2005). The fault slip behaviour on subduction thrust faults varies greatly between subduction zones, and along-strike at the same subduction zone. The Hikurangi subduction system in North Island, New Zealand, has not experienced a M8+ megathrust earthquake in historical times but, exhibits a range of slip conditions, from aseismic to strongly coupled, with strain release by coseismic, slow slip, and repeating microseismic events (Wallace et al., 2010). Multi-disciplinary studies reveal the complex interplay between upper and lower plate structure, subducting sediment, thermal effects, regional tectonic stress regime, and fluid pressures all contribute to interface behaviour (Wallace et al., 2010). The fact that the locked part of the interface is under land makes this region an ideal location to target a range of geophysical observations to determine physical parameters that control locking on the Hikurangi plate interface and to determine geometrical relationships with upper crustal faults.

We undertook a controlled-source and passive (earthquake) seismic imaging experiment in the Wellington region in 2009-2011 (Henrys et al., submitted). The Seismic Array HiKurangi Experiment (SAHKE, Fig. 1) imaged the plate interface beneath southern North Island with onshore-offshore marine active-source seismic data from three sides, onshore shots, and local and teleseismic earthquakes. Onshore-offshore wide-angle seismic-reflection and refraction data constrain a detailed 2D tomographic model of P-wave structure across a transect of the southern Hikurangi margin orthogonal to the Australia/Pacific plate boundary. This model places constraints on key parameters such as Moho geometry, subducting slab geometry and forearc structure, which may modulate the location of plate coupling. Furthermore recent magnetotelluric (MT) data shows that an electrically conductive layer of underplated sediment is present at the interface in the weakly coupled region (Heise et al., 2012) but may be absent in the locked region.

The relationship of locked zone properties to upper crustal structures and seismicity together with the relationship to slow slip events that occur down dip of the locked zone, however, remain unknown. The existing SAHKE data were not designed to capture this level of detail nor is the regional GeoNET seismic networks capable of detecting seismicity associated with SSEs. Specifically we advocate complimentary seismic and MT observations (Fig) that include: **(1)** Reoccupying the temporary SAHKE transect 3C stations for a 12 -18 month period comprising 300 stations spaced 300 m apart; **(2)** augmenting this 2D array with small 3D (100 m spacing) and large regional (10 km spacing) arrays; **(3)** instrument some of the 50 m SAHKE shot holes with borehole seismographs; **(4)** complete E-W MT profile co-located with the SAHKE transect and collect lines perpendicular to the subduction margin; **(5)** acquire high-resolution seismic reflection lines across accessible parts of the lower North Island that cross Wellington and Wairarapa Faults .

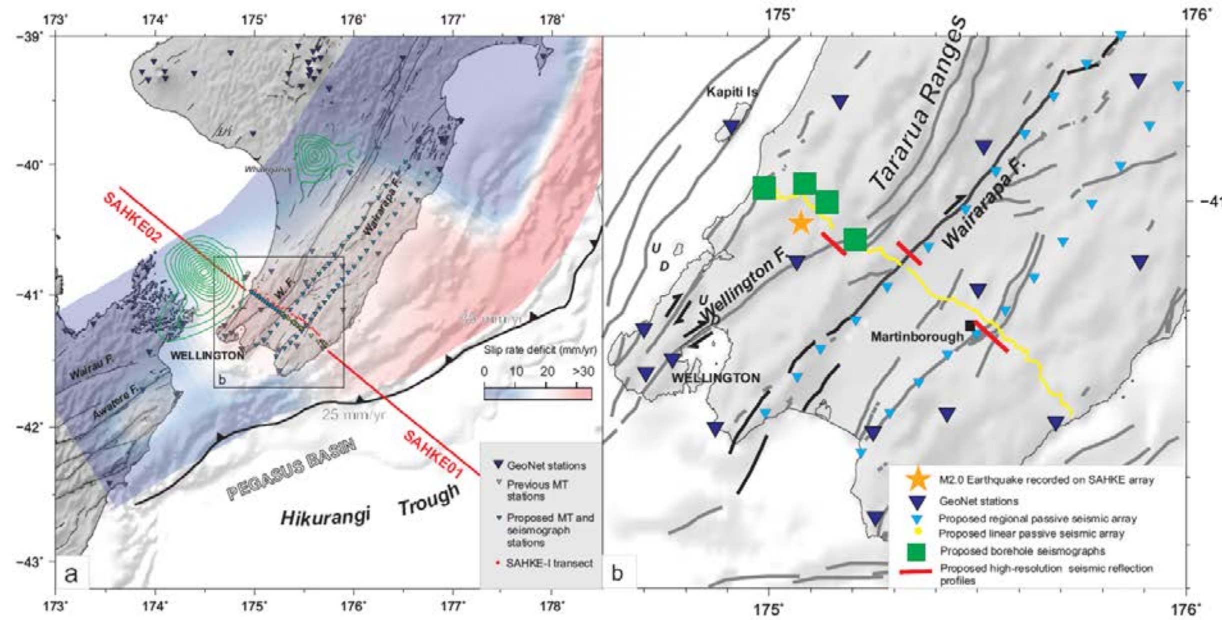

*Figure 1. Tectonic setting showing major active faults of the southern North Island of New Zealand and location of SAHKE experiments. (**a**) Slip rate deficit distribution at the plate interface (Wallace et al., 2012). Green contours show cumulative slip (mm) in slow-slip events (SSEs) during 2002-2010. Red regions are where the plate interfaced is locked.. SAHKE01 and SAHKE02 (red lines) recorded onshore by the transect deployment (red dots). Inverted blue triangles indicate the locations of permanent National Network and Wellington regional network monitored by GeoNet. Thin black lines denote active faults: W.F.=Wellington fault. previous MT stations (green inverted triangles) and proposed (blue) together with regional passive seismograph. Numbers indicate convergence rate at the Hikurangi Trough (in mm/yr) (Wallace et al., 2012). (**b**) Location of proposed linear passive seismometer array (yellow points; space 300 m apart) co-located with stations deployed during SAHKE. Green filled boxes show the locations of the 4 borehole seismographs. Blue inverted triangles proposed regional seismograph array and MT stations. Orange star is location of M2.0 earthquake located at 26 km depth and recorded on SAHKE array (Fig. 2).*

The closely spaced seismic arrays will allow passive imaging array techniques to be applied to the earthquake data and enable us to explore down dip variation in fault properties. For example a M2.0 located at 26 km depth beneath the SAHKE array is shown in Fig. 2. The hypocenter is just above the slab interface and the array has successfully captured reflected P and S-wave slab phases. The regional seismic array will allow us to investigate the along strike changes in seismicity and whether this relates to the transition from locked to unlocked part of the plate interface. Borehole seismometers should allow us to improve detection threshold of local earthquakes, improve our chances of finding and locating micro-seismicity and tremor, and potentially provide information on the relationship of SSEs and seismicity. High resolution seismic reflection data will be integrated with SAHKE data to improve knowledge of the geometry of upper crustal faults that splay from the subduction interface. Finally MT data will be used to construct a 3D conductivity image of the locked plate interface and compared to the P-wave velocity and seismic images.

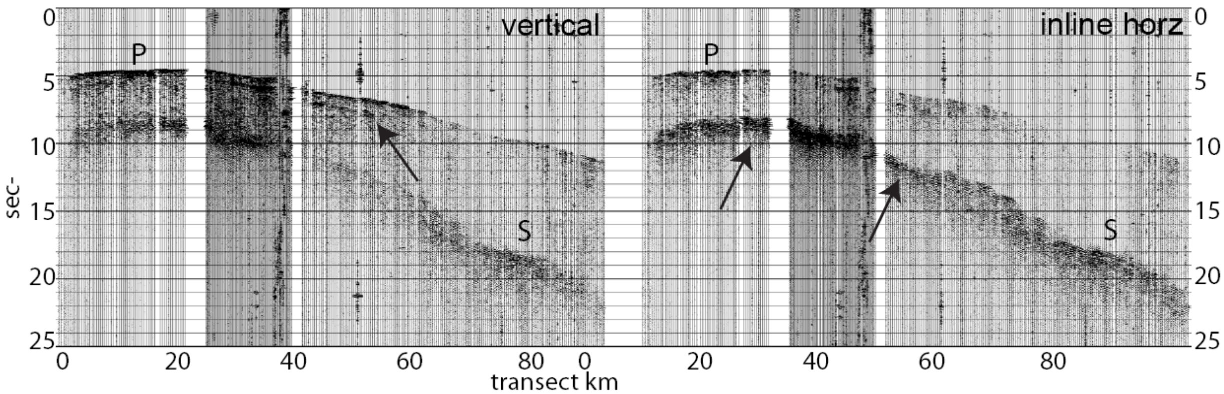

Figure 2. Local earthquake collected into SAHKE transect. 3-C stations have 300 m spacing with 150 m densification in the middle. Magnitude 2.0 earthquake is at 26 km depth, just above the slab interface. Sharp secondary P event may be associated with interface or subduction-related structure at base of overlying plate. S-waves exhibit lateral variation in first and secondary (coda) waveform character. Heterogeneity in overlying plate affects arrival times.

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