

How do subduction zones end?

Simon Lamb¹, Martha Savage¹, Tim Stern¹, John Townend¹, Paul Denys²—other collaborators also welcome

¹ *Institute of Geophysics, Victoria University of Wellington, Wellington, New Zealand;*

² *School of Surveying, University of Otago, Dunedin, New Zealand*

Simon.Lamb@vuw.ac.nz

Subduction is a fundamental part of plate tectonics that accommodates most of the plate convergence required by motion on a planet with a constant size. Theoretical models show that the large forces required for initiation of subduction zones are difficult to sustain on a real Earth. Thus, most subduction zones are likely to form by lateral propagation at their ends. In addition, the ends of subduction zones often exhibit complex tectonic, as well as being the places where large subduction thrust earthquakes initiate or terminate.

The New Zealand plate-boundary is unique in containing two ends of subduction zones, as well as a rapidly rotating hinge where one segment of a subduction system is rotating relative to another (Fig. 1)¹. All these features lie beneath, or are exposed, onshore. Thus, the northern edge of the subducted Australian plate, along the Puysegur subduction zone, occurs beneath southern South Island, whereas the southern edge of the subducted Pacific plate lies beneath northern South Island. A hinge between the rapidly rotating Hikurangi subducting margin and the more stable Tonga-Kermadec subduction zone cuts through Northeastern North Island. Finally, deep Benioff zones beneath all these regions provide an excellent geometry for seismic probing of the overlying lithosphere with passive source seismology (Fig. 1). The fundamental problem here is the difference in behaviour of oceanic and continental lithosphere in zones of plate convergence. Thus, the along strike end of a subduction zone usually occurs at a transition between negatively buoyant oceanic and buoyant continental lithosphere. These transitions are likely candidates for regions where continental crust can be locally subducted to great depth, ultimately to rise rapidly to the surface giving rise to ultra-high pressure rocks in some core complexes.

We propose using New Zealand as a natural laboratory to study the dynamics and kinematics of subduction termination, and its implications for subduction propagation and initiation. Such a study would focus on the detailed deep lithospheric structure of these regions, in the context of the active surface kinematics and longer term geological and plate tectonic evolution.

The shape of the New Zealand landmass and its position relative to the subduction zone make it a favourable place to carrying out deep geophysical imaging of subduction. There have been a number of deep crustal transects across the width of the plate boundary zone, both in the parts where there is subduction (NIGHT², SAHKE³) and continental convergence (SIGHT⁴). There have also been some arrays of passive broadband seismometers at the ends of the South Island. (e.g., Marlborough⁵, Fiordland⁶, triggered instruments only), but none of these deployments has targeted or overlapped much with the transition areas between subduction and transpression. There is a dense array of permanent seismic and GPS stations (GeoNet) in

North Island, but these stations are more sparse in South Island (Fig. 2). We propose capitalizing on the existing seismic work, augmenting it with extra deep lithospheric soundings to form 3-D lithospheric arrays in three critical regions across where there will be major changes in lithospheric structure. We refer to these as the Puysegur Array (PA), Marlborough Array (MA), and Raukumara Array (RA). They will cover their respective regions with two-dimensional arrays as densely as can be managed within likely funding constraints (e.g., approximately 100 broadband seismometers each), such as the piggy-back arrays operating on the US Earthscope arrays. Joint international proposals should be prepared to carry out the projects, likely to be run in stages to allow results of earlier studies to inform the planning of the later ones.

The project would include:

- Deep crustal and mantle probing using seismic and other geophysical stations spanning the edges of the Puysegur and Hikurangi margins (PA and MA), using active and passive source seismology.
- In addition to determining the velocity structure, there would be detailed studies of microseismicity and anisotropy and resistivity.
- Densification of continuous GPS in these regions to monitor crustal motions and slow earthquakes and tremor activity. A dense array on the Alpine Fault near the PA array has found tremor⁷, however no cGPS is available yet to see if slow slip is occurring nearby.
- Dynamical modeling of the evolution of the edges of subduction zones

References:

- 1 Cande, S. C. & Stock, J. M. Pacific-Antarctic-Australia motion and the formation of the Macquarie Plate. *Geophys. J. Int.* **157**, 399-414 doi:310.1111/j.1365-1246X.2004.02224.x. (2004).
- 2 Stern, T. *et al.* Crust-mantle structure of the central North Island, New Zealand, based on seismological observations. *Journal of Volcanology and Geothermal Research* **190**, 58-74 (2010).
- 3 Henrys, S. *et al.* SAHKE geophysical transect reveals crustal and subduction zone structure at the southern Hikurangi margin, New Zealand. *G-cubed submitted* (2013).
- 4 Okaya, D. A., Henrys, S. & Stern, T. Double-sided onshore-offshore seismic imaging of a plate boundary: "supergathers" across South Island, New Zealand. *Tectonophysics* **355**, 247-263 (2002).
- 5 Wilson, C. K., Jones, C. H., Molnar, P., Sheehan, A. F. & Boyd, O. S. Distributed deformation in the lower crust and upper mantle beneath a continental strike-slip fault zone; Marlborough fault system, South Island, New Zealand. *Geology* **32**, 837-840 (2004).
- 6 Gledhill, K. R. & Savage, M. K. Seismic anisotropy above the Fiordland subduction zone, New Zealand. *Seismological Research Letters* **73**, 222 (2002).
- 7 Wech, A. G., Boese, C. M., Stern, T. A. & Townend, J. Tectonic tremor and deep slow slip on the Alpine Fault. *Geophys. Res. Lett.* **39**, doi:10.1029/2012gl051751 (2012).

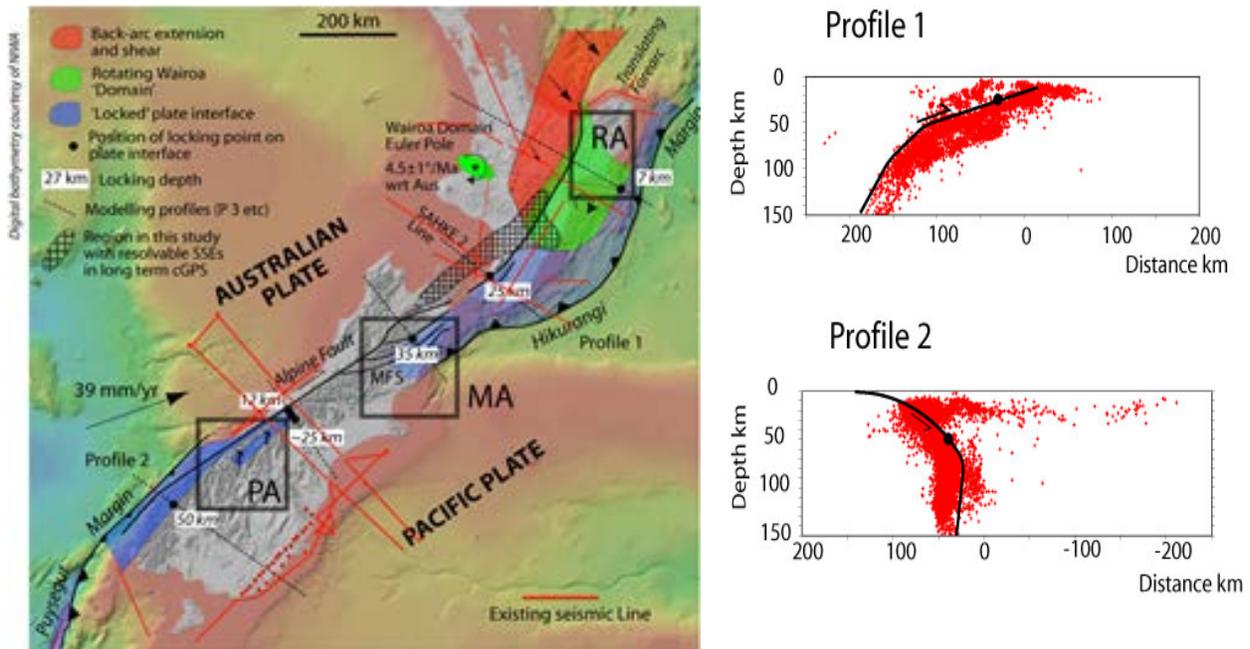


Figure 1. Left : Bathymetric map of the New Zealand plate boundary zone, showing the main edges of the locked portions of the plate interface and also the rapidly rotating 'Wairoa Domain' in the northern part, as well existing deep seismic lines/transects. Boxes show areas of deep geophysical arrays (PA, MA, RA, see text) spanning regions where subduction changes markedly or terminates. Right : Profiles 1 and 2 show geometry of subducted slab in the Hikurangi and Puysegur subduction zones.

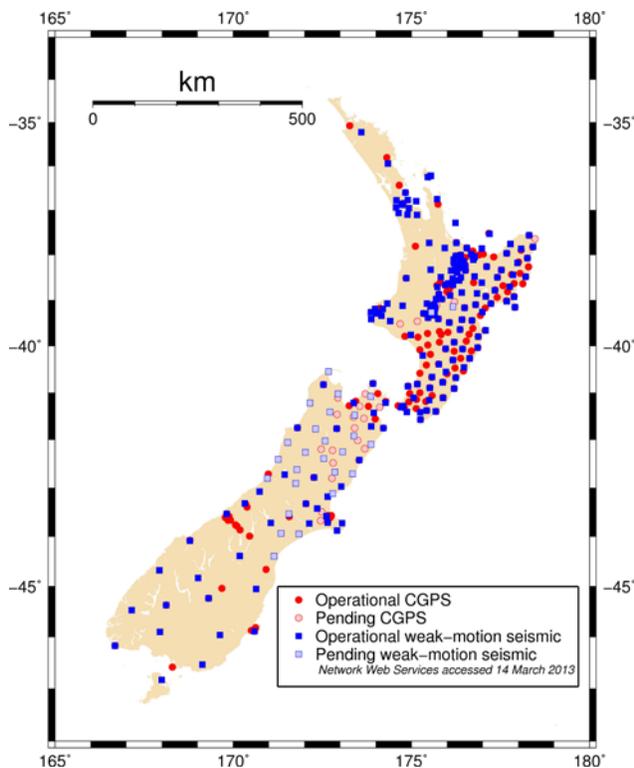


Figure 2. Operating and proposed permanent GeoNet cGPS and seismic stations in New Zealand.