The New Zealand region: A key natural laboratory for studying subduction initiation

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Themes addressed: 4.6. What are the physical and chemical conditions that control subduction zone initiation and the development of mature arc systems?

Key types of data/infrastructure: Active and passive source seismic experiments, deep sea drilling, onshore outcrop data, seismic stratigraphy, geochemical analysis and geodynamic modeling.

Subduction initiation is a vital, but poorly understood phase of the plate tectonic cycle. Computational studies and interpretation of the Mesozoic and later plate tectonic history suggest that subduction initiation profoundly alters the force balance on plates [1,2]. If that is the case, then our picture of the dynamics of plate tectonics is incomplete. If we hope to make fundamental advances in understanding the forces driving and resisting plate motions, then a detailed picture of subduction initiation is needed. The geodynamic force balance and the tectonic conditions likely evolve quickly during subduction initiation (over several millions of years) and magmatic and structural processes can overprint earlier geological events. Nearly half of all presently active subduction zones initiated during the Cenozoic [2], and thus provide multiple opportunities to better understand the process through geophysical and geological studies. The New Zealand region contains examples in different phases of evolution, from juvenile (in the case of Puysegur) to fully developed (Tonga-Kermadec, Hikurangi/Taupo).

Puysegur. To find key evidence to constrain geodynamic processes, we must study a subduction zone that has *partially proceeded* through the nucleation stage. Existing geological and geophysical evidence suggest that the Puysegur Trench and Ridge (Figure 1) just south of New Zealand is slowly transitioning from a forced to a self-sustaining subduction system. The Puysegur region could be a natural laboratory to study the kinematics of this vital phase of plate tectonics, potentially uniquely so in the world, especially in terms of its well-constrained convergence history [3]. Many of the constraints on dynamics can be determined by further field work and analysis.

Puysegur is a region ideally suited to constrain geodynamic processes of subduction initiation because of (1) a clear association between submarine and subaerial geomorphological indicators and geophysical structure; (2) a well constrained plate convergence history; (3) onshore and offshore targets for detailed hypothesis testing; and a (4) juvenile island arc.

Existing marine geophysical surveys of Puysegur are sparse but suggest that the vertical motions are partially caused by the newly subducting lithosphere and thickening crust [4]. All models of subduction initiation (either conceptual or mechanical) have the thrust interface nucleating and growing. State-of-the-art surveys (Figure 2) could help distinguish between competing scenarios for subduction initiation (including if the new subduction interface is on a new fault or an old fracture zone). Modern MSC surveys with a 6 km streamer could image the nascent dipping plate boundary in this region. Detailed marine geophysical surveys of the Puysegur Trench and Ridge could be mounted to test the hypothesis that this incipient subduction zone is slowly making a transition from a forced to a self-sustaining state. The *R/V Marcus Langseth* is an ideal platform to carry out seismic refraction, with OBSs, and multi-channel seismic surveys to collect structural and geological tests on geodynamic models. For example, refraction lines would be used to constrain the crustal thickness and velocities of the lower crust and upper mantle, whereas MCS lines would reveal the velocity and structure of the upper crust (Figure 2). Appropriately designed MCS surveys could be linked to the detailed sequence stratigraphy already completed closer to New Zealand. Moreover, substantially thermochronology has already been completed onshore that shows the detailed space-time pattern of rock uplift associated with SI in the onshore Fiordland segment of Puysegur [5].

Tonga-Kermadec. Tonga-Kermadec subduction may have initiated in the Eocene, associated with a change in Pacific Plate motion. Recently, seismic-reflection and rock-sample data have been used to propose that the first-order physiography of the New Caledonia Trough and Norfolk Ridge formed in Eocene and Oligocene time, and was associated with the onset of subduction and back-arc spreading at the Australia-Pacific plate boundary [6]. The analysis suggests permanent subsidence of the New Caledonia Trough and transient uplift of Lord Howe Rise during Eocene and Oligocene initiation of Tonga-Kermadec subduction [6].

North Island (Hikurangi/Taupo) Further south of Tonga-Kermadec, subsidence curves from oil wells in central North Island, New Zealand show a rapid (~0.2 mm/y for 7 my) and regional subsidence in the Late Oligocene [7]. This event has been interpreted to represent subduction initiation in the New Zealand region, but the link, if any, to subsidence in the New Caledonia trough 1000 km to the north is not clear. Furthermore, the Northland region of North Island has extensive ophiolite outcrops also tied to the subduction initiation process [8]. The east-west Miocene subduction zone is expressed by a distinct magmatic arc, and this subduction system evolved into the current north-south Taupo-Hikurangi subduction zone (e.g., Nicol et al., 2007).

In conclusion, New Zealand should be a GeoPRISMS focus site: it not only has the best modern example of subduction initiation (Puysegur), but also a rich Cenozoic stratigraphic and volcanic history of the processes involved. Furthermore, all these modern and Cenozoic examples are relatively understudied but easily accessible.

References. 1. R. J. Stern, **EPSL**, *226*, 275-292, 2004; 2. M. Gurnis, et al., **Geochem., Geoph., Geosys, 5**, Q07001, doi:10.1029/2003GC000681, 2004. 3. Sutherland, R., et al., **New Zealand J. Geol. Geophys, 49**, 131-1494, 2006; 4. C. Massell, et al., **J. Geophys. Res., 105**, 13,457–13,480, 2000. 5. R. Sutherland, et al., **Geosphere**, **5**, 409-425, 2009. 6. R. Sutherland, et al., **Tectonics, 29**,1-16, 2010. 7. Stern, T., and Holt, W. E., **Nature, 368**, 233-236, 1994) 8. Whattam, S.A., *et al*., **EPSL, 250**, 606–632, 2006. 9. Nicol, A., *et al*., **Tectonics, 26** (4), 2007.

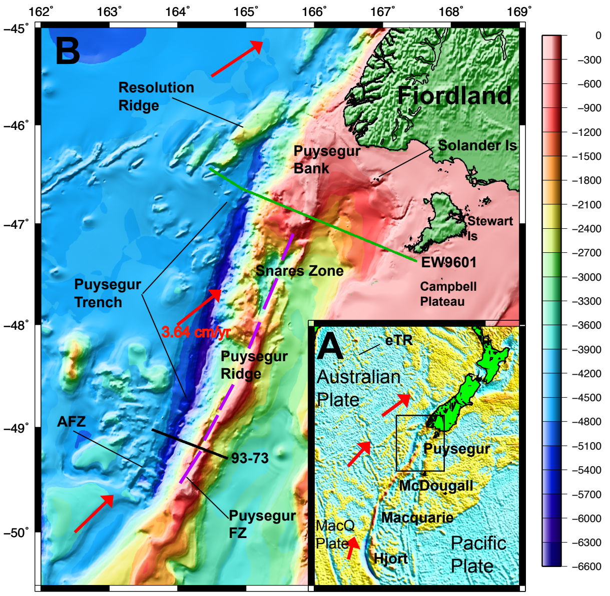

Figure 1. A. Location of the Puysegur region (black rectangle). B. Bathymetry (scale bar is depth in meters) of the Puysegur Ridge and Trench region just to the south of the South Island of New Zealand. The sector denoted Puysegur Trench has experienced active subduction. Bathymetry assembled by NIWA from a variety of surveys. In both A and B, the red arrows are the relative motion of AUS or MACQ with respect to fixed PAC from the MORVEL present day plate model. The ideal location to test models of subduction initiation is within the Snare Zone. The feasibility of collecting seismic data to test geodynamic models, including imaging the top of the down going slab as it first penetrates into the mantle is shown in the Next Figure. In all probability this is the only region on the planet where we can capture a subduction zone evolving from a forced to a self-sustaining state.

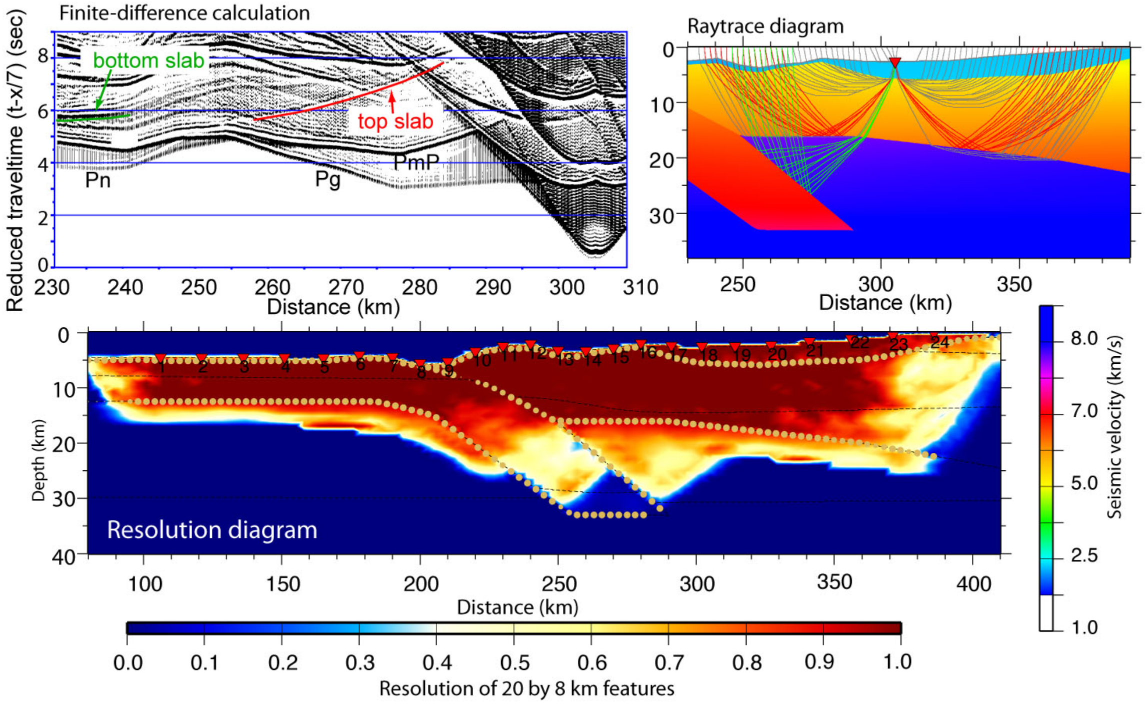

Figure 2. Feasibility tests showing how an active source seismic experiment with an OBS array across the Puysegur Trench (see Fig 1) could measure the top of the slab in the nucleating trench as well measure the thickness of the crust. Such parameters could constrain the dynamics of SI. This is the only location on the planet where a slab has partially nucleated with a clear plate tectonic and geological history -- making it a critical target for the GeoPRISMS program.