Strike-Slip Enables Subduction Initiation Beneath a Failed Rift: New Seismic Constraints from Puysegur Margin, New Zealand

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Critical ingredients and conditions necessary to initiate a new subduction zone are debated. General agreement is that subduction initiation likely takes advantage of previously weakened lithosphere and may prefer to nucleate along pre-existing plate boundaries. To evaluate how past tectonic regimes and lithospheric structures might facilitate underthrusting and lead to self-sustaining subduction, we present an analysis of the Puysegur Margin, a young subduction zone with a rapidly evolving tectonic history.

The Puysegur Margin, south of New Zealand, currently accommodates convergence between the Australian and Pacific plates, exhibits an active seismic Benioff zone, a deep ocean trench, and young adakitic volcanism on the overriding plate. Tectonic plate reconstructions show that the margin experienced a complicated transformation from rifting to seafloor spreading, to strike-slip motion, and most recently to incipient subduction, all in the last ~45 million years. Details of this tectonic record remained incomplete due to the lack of high-quality seismic data throughout much of the margin.

Here we present seismic images from the South Island Subduction Initiation Experiment (SISIE) which surveyed the Puysegur region February-March, 2018. SISIE acquired 1252 km of deep-penetrating multichannel seismic (MCS) data on 7 transects, including 2 regional dip lines coincident with Ocean Bottom Seismometers (OBS) deployments which extend (west to east) from the incoming Australian plate, across the Puysegur Trench and Puysegur Ridge, over the Solander Basin and onto the continental Campbell Plateau margin.

We integrate pre-stack depth migrated MCS profiles with OBS tomography models to constrain the tectonic development of the Puysegur Margin. Based on our results we propose the following
Cenozoic evolution: (1) The entire Solander Basin contains thinned continental crust which formed from orthogonal stretching between the Campbell and Challenger plateaus during the Eocene-Oligocene. This phase of rifting was more pronounced to the south, producing thinner crust with abundant syn-rift volcanism across a wider rift-basin, in contrast to the relatively thicker crust, moderate syn-rift volcanism and narrower rift basin in the north. (2) Strike-slip deformation subsequently developed along Puysegur Ridge, west of the locus of rifting and within relatively unstretched continental lithosphere. This young strike-slip plate boundary translated unstretched crust northward causing an oblique continent-collision zone, which led to a transpressional pattern of distributed left-stepping, right-lateral faults. (3) Subduction initiation was aided by large density contrasts as oceanic lithosphere translated from the south was forcibly underthrust beneath the continent-collision zone. Early development of oblique subduction generated modest and widespread reactivation of faults in the upper plate. (4) Present-day, the Puysegur Trench shows a spatiotemporal transition from nearly mature subduction in the north to a recently initiated stage along the southernmost margin, requiring a southward propagation of subduction through time.

Our new seismic images suggest subduction initiation at the Puysegur Margin was assisted by inherited buoyancy contrasts and structural weaknesses that were imprinted into the lithosphere during earlier phases of continental rifting and strike-slip along the developing plate boundary. The Puysegur Margin demonstrates that forced nucleation along a strike-slip boundary is a viable subduction initiation model and should be considered throughout Earth's history.