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Fault zone structure and seismic reflection characteristics in zones of slow slip and tsunami earthquakes

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Over the last couple of decades we have learned that a whole spectrum of different fault slip behaviour takes place on subduction megathrust faults from stick-slip earthquakes to slow slip and stable sliding. Geophysical data, including seismic reflection data, can be used to characterise margins and fault zones that undergo different modes of slip. In this presentation we will focus on the Hikurangi margin, New Zealand, which exhibits marked along-strike changes in seismic behaviour and margin characteristics. Campaign and continuous GPS measurements reveal deep interseismic coupling and deep slow slip events (∼30-60 km) at the southern Hikurangi margin. The northern margin, in contrast, experiences aseismic slip and shallow (<10-15 km) slow slip events (SSE) every 18-24 months with equivalent moment magnitudes of Mw 6.5-6.8. Updip of the SSE region two unusual megathrust earthquakes occurred in March and May 1947 with characteristics typical of tsunami earthquakes. The Hikurangi margin is therefore an excellent natural laboratory to study differential fault slip behaviour.

Using 2D seismic reflection, magnetic anomaly and geodetic data we observe in the source areas of the 1947 tsunami earthquakes i) low amplitude interface reflectivity, ii) shallower interface relief, iii) bathymetric ridges, iv) magnetic anomaly highs and in the case of the March 1947 earthquake v) stronger geodetic coupling. We suggest that this is due to the subduction of seamounts, similar in dimensions to seamounts observed on the incoming Pacific plate, to depths of <10 km. We propose a source model for the 1947 tsunami earthquakes based on geophysical data and find that extremely low rupture velocities (c. 300 m/s) are required to model the observed large tsunami run-up heights (Bell et al. 2014, EPSL). Our study suggests that subducted topography can cause the nucleation of moderate earthquakes with complex, low velocity rupture scenarios that enhance tsunami waves, and the role of subducted rough topography in seismic hazard should not be under-estimated.

2D seismic reflection data along the northern Hikurangi margin also image thick (c. 2 km) high-amplitude reflectivity zones (HRZ) coinciding broadly with the source areas of shallow SSEs. The HRZ may be the result of high-fluid content within subduction sediments, suggesting fluids may exert an important control on the generation of SSEs by reducing effective stress (Bell et al. 2010, GJI). However, this hypothesis remains untested. In this presentation, using synthetic models, we will discuss planned future applications of an advanced seismic imaging technique called Full-waveform inversion, integrated with drilling, at subduction margins like Hikurangi to recover fault physical properties at high-resolution in 3D to examine the properties of heterogeneous fault zones.