SHIRE Project Summary

Overview. We propose an interdisciplinary, multinational collaborative program involving the USA, New Zealand, Japan and the UK to evaluate system-level controls on processes that govern both slip behavior and long-term deformation at subduction zones. We focus on the Hikurangi margin in New Zealand, where GPS data show a transition in slip behavior from predominantly stick-slip in the south to aseismic creep in the northern North Island, and where a wide range of subduction-related processes and characteristics vary along-strike. We aim to rigorously investigate the feedbacks between plate interface slip behavior, solid and fluid mass fluxes, and manifestations of plate boundary mechanics in the long-term geological record that likely reflect common driving processes linking forearc uplift, sediment transfer and underplating, plate boundary strength, and seismogenesis. We will address this important problem through an integrated approach combining large-scale seismic imaging, paleoseismology, and geomorphology, focused through the lens of state-of-the-art numerical modelling. First, we will investigate present-day to long-term (>10,000 years) deformation styles of the Hikurangi margin by integrating paleoseismological studies with ongoing geodetic modeling. To characterize the physical attributes of the subducting Pacific plate and the North Island forearc, and the influence of these on plate interface slip behavior and long-term forearc deformation, we will collect seismic reflection and refraction data onshore and offshore New Zealand. Marine and land-based active-source seismic data will show the crustal structure of the incoming and overriding plates and subduction thrust character from the trench to the mantle wedge corner. The new constraints on physical properties and deformation will be integrated via a suite of numerical modeling studies that test a set of focused hypotheses explaining controls on subduction thrust slip behavior and long-term margin evolution.

Intellectual Merit. The physical processes dictating the spectrum of fault slip modes (spanning destructive earthquakes to slow slip events and aseismic creep) and the links between these behaviors and long-term morphotectonic evolution of subduction systems are not understood. There is a fundamental need to address this important problem with an integrated, system-level approach combining geodynamical modeling with high-quality geophysical and geological constraints on subduction margin characteristics. We will test the following hypotheses in this project: 1) High fluid pressure on the megathrust reduces effective normal stress, promoting stable sliding and/or failure in repeating slow slip events; 2) Rough subducting seafloor promotes aseismic creep associated with heterogeneously distributed pore pressure, stress, and frictional behavior along the plate interface; 3) Subduction of thickened Hikurangi Plateau crust drives both long-term uplift of the forearc and increased normal stress across the plate interface; 4) Both the locations of slow slip events and forearc uplift are related to underplating of sediment to the lower crust of the overriding plate; and 5) The distribution of stick-slip vs. creep behavior persists through many seismic cycles. The existing data show along-strike trends in the structure and behavior of the Hikurangi margin that make it the ideal location for such a quantitative analysis of physical controls on the short- and long-term dynamics of the Hikurangi system.

Broader Impacts. The devastating March 2011 M9 Tohoku-Oki earthquake highlighted the need to understand processes that produce great megathrust earthquakes and tsunami. Our results will mitigate risk in NZ and elsewhere by improving knowledge of physical controls on subduction earthquakes. This project involves strong international collaboration with New Zealand, Japanese, and UK partners, enabling leveraging of resources and providing cross-national scientific training for students and young scientists in the US, NZ, and in Japan. The highly visible field experiments within this project offer outstanding science outreach opportunities in east coast North Island communities: ship tours, lectures, and educational activities will be coordinated with the East Coast LAB in NZ. An REU organized by CSU Pomona, will provide US undergraduates unique overseas field and research experiences. USC and UTIG graduate students will experience large-scale active-source seismic experiments. Our project provides professional training for a post-doctoral scientist and NSF funding for early-career female co-PI Pilarczyk.

Hikurangi 3D Project Summary

Overview. We propose to use the *R/V Langseth* to acquire an open-access 3D seismic reflection data set in a 15 x 60 km area offshore New Zealand's Hikurangi trench and forearc. Here the subduction thrust slips predominantly in well-documented transient slow slip events (SSEs) rather than large stick-slip earthquakes. These data will give our community the first high-resolution images and seismic attributes of a transient-slip plate boundary megathrust identified by both the GeoPRISMS and IODP communities as an important point of comparison to predominantly locked subduction thrusts such as Nankai, Tohoku, Cascadia, and Costa Rica. Seismic attributes linked to high fluid pressures are a promising indicator of conditions favorable for SSEs, but the N. Hikurangi margin is the only subduction zone in the world where well-documented SSEs occur at 5-10 km depth (vs. typical 25- 50 km depths) – shallow enough for detailed seismic imaging and seismic attribute measurements. Furthermore, the unusually shallow SSEs coincide with inferred thick packages of sediment subducting with seamounts. Unfortunately variability in upper plate structure seen in 2D profiles distorts images of the upper plate, plate boundary, and subducting sediment to the extent that interpretation of 2D images is equivocal and incomplete. We propose to acquire 3D seismic images and attributes that will enable us to remove distortion and provide an unprecedented opportunity to accurately document the structural, stratigraphic, and hydrogeologic conditions that lead to generation of SSEs along a subduction megathrust. International collaborative experiments are now funded to record Langseth shots during 3D acquisition and develop the first ever high-resolution 3D velocity models across a subduction zone using 3D full-waveform inversion, which will overlap and extend beyond the 3D volume (see letters from Japan, UK, and New Zealand-based scientists).

Intellectual Merit. Slip on plate boundary faults associated with recorded earthquakes typically fails to account for all of the expected plate motion predicted by geodetic methods or global models. One of the most exciting advances in the last decade is the recognition and documentation of transient SSEs as another mode to accommodate plate convergence at subduction margins. SSEs have now been documented by continuous GPS arrays in Cascadia, Costa Rica, Japan, New Zealand and other subduction zones, showing repetitive SSEs occurring over days to months separated by several months to a few years or more. SSEs often occur down dip from a part of the plate boundary characterized by full or partial locking and earthquake rupture. SSEs offer an opportunity to understand the full spectrum of fault dynamics ranging from aseismic creep to earthquake rupture, as SSEs release stress through previously unknown mechanisms. Current numerical models suggest SSEs occur in zones of very high pore fluid pressures. These conditions generate characteristic seismic reflection responses, such as anomalously high-amplitude reversed-polarity reflections and horizontal bands of high reflectivity. However attenuation and signal degradation limits such seismic analysis to shallow targets. We propose to investigate the SSEs in the Hikurangi margin because its comparatively shallow depth allows for high resolution 3-D imaging and robust analyses of seismic attributes.

Broader Impacts. This project addresses the mechanics of subduction thrusts, the conditions that lead to the wide variety of slip behaviors, and it will be the ***first-ever*** 3D seismic dataset acquired over a subduction thrust dominated by aseismic creep. This survey will benefit a large, international pool of researchers by providing both (a) a critical geophysical dataset for planned IODP non-riser and proposed riser drilling, as well as (b) a centerpiece of field data acquisition for one of the three GeoPRISMS SCD focus areas. Results will be far reaching for characterizing the seismic and tsunami hazards to global populations posed by subduction thrusts. The strong international collaboration involving the US, NZ, UK, and Japan will foster broad transfer of knowledge. We will recruit two students in addition to the students from the collaborating institutions and early-career researcher J. Kluesner who will have hands-on field experience with 3D seismic data acquisition leading to numerous international collaborations for all participants and many future student thesis projects.