Record of slow slip instabilities in rocks: the role of silica redistribution in the behavior of subduction interfaces

*Donald M Fisher[1], Andrew Smye[1], Chris Marone[1], Asuka Yamaguchi[2]

1. Department of Geosciences, Penn State University, 2. Atmosphere and Ocean Research Institute, The University of Tokyo

We present observations from nine regional fault zones exposed in the ancient, sediment-dominated Kodiak and Shimanto accretionary complexes. There are characteristics common to all these examples that suggest a record of slow slip instabilities that deform the underthrusting footwall at a range of depths within and around the seismogenic zone. These fault zones, in some cases 10's of m's thick, have a block-and-matrix fabric but are structurally systematic, with evidence for a compactive strain path and simple shear along a web-like array of scaly slip surfaces in fine-grained lithologies. These slip-related microstructures are coincident with silica redistribution, with silica depletion along slip surfaces and precipitation of quartz and other silicates in veins within coarser clasts and along extensional jogs in slip surfaces.
The fault rocks contain several features that suggest a record of slow slip and quasi-dynamic fault motion: 1) scaly shears represent locations of diffusive mass transfer, suggesting linear viscous flow, a rheology favored by low strain rates, 2) there is clear evidence for repeated antitaxial and syntaxial cracking and sealing, in some examples directly related to slip on shear surfaces—an observation that is consistent with slip instabilities as it requires cyclic behavior rather than continuous creep, 3) the zone of deformation is wide, indicative of distributed shearing on many slip surfaces, with large slip distances and a strain hardening process on individual features, and 4) small (10's of microns) magnitudes of slip during cracking and slip.
We propose a conceptual model for propagating, slow ruptures that move at rates dictated by shear processes within a zone of finite thickness. The fault rocks suggest that stress rises at the propagating front of a slow slip instability, leading to quasi-plastic failure in the form of scaly slip surfaces in the footwall. Development of slip surfaces represents a weakening mechanism due to loss of cohesion or alignment of phyllosilicates, but each slip surface subsequently hardens because of increases in normal stress associated with hydrofracturing or by the activation of a hardening mechanism such as pressure solution and ensuing reduction in fracture porosity. Thus, the development of a distributed scaly foliation and vein system leads to initial softening but has an inherent stabilization mechanism for putting on the breaks and keeping things slow.
Based on these observations, we construct a kinetic model to estimate the time required to seal fractures. This model accounts for the interplay between spatial gradients in chemical potential and pressure within a vein-rock system. Vein sealing is driven by diffusive redistribution of Si from solid-solid surfaces to undersaturated veins. The model predicts that healing of cracks in subduction zones occurs on secular time scales. Temperature exerts a primary control on healing rate and variations in the temperature structure of different convergent margins leads to a wide variability in sealing times. Correlation between plate age and the b-value of earthquake size distributions could reflect temperature through the kinetics of reactions and the healing rates of fractures. The evidence from ancient rocks for stress cycling, repeated fracturing, and thermally activated crack healing in underthrusting sediments could play an important role in modulating the behavior of the footwall of the subduction interface, and the spatial roughness in this behavior for different subduction zones could be an important control on seismicity.

Keywords: Slow slip, silica kinetics, earthquakes

