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The theory of dynamic Coulomb wedge and its application to great subduction earthquakes

Kelin Wang (1,2) and Yan Hu (2)

(1) Geological Survey of Canada, Sidney, BC, (2) University of Victoria, BC, Canada (kwang@nrcan.gc.ca)

Submarine wedges at subduction zones are usually modeled using the classical theory of critically tapered Coulomb wedge which describes a long-term average state of stress. However, stress changes in subduction earthquake cycles are of fundamental importance to wedge mechanics. Building on the Coulomb-plasticity of the classical Coulomb wedge theory, we assume an elastic – perfectly Coulomb-plastic rheology and develop the theory of dynamic Coulomb wedge. The new theory postulates that the actively deforming outer wedge overlies the updip velocity-strengthening part of the subduction fault, and the less deformed inner wedge overlies the megathrust seismogenic zone. To the first order, the outer wedge switches between critical and stable states in earthquake cycles. During a great earthquake, sudden increase in fault stress (due to velocity-strengthening) and pore fluid pressure drives the outer wedge into a compressively critical state, causing accretion, thrust deformation, and even basal erosion. The outer-wedge geometry is thus controlled by the peak stress of the velocity-strengthening part of the subduction fault achieved in largest earthquakes. After an earthquake, the outer wedge returns to a stable state, with basal stress and fluid pressure decreasing with time. With a high enough surface slope such as at many margins dominated by basal erosion, interseismic stress relaxation may turn the outer wedge into an extensionally critical state, resulting in normal faulting. The inner wedge experiences stress changes opposite to the outer wedge but stays in the stable regime throughout the earthquake cycles, acting as an apparent backstop and providing a stable environment for the formation of forearc basins. The new theory explains a range of previously unexplained observations and provides many testable predictions regarding the dynamics of submarine wedges and the megathrust seismogenic zone.