Stress-cycle driven evolution of faulting in a plate boundary transition zone

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Upper plate faults along the Cascadia subduction margin of North America go through a 3 stage evolution over millions of years as a consequence of the migrating Mendocino Triple Junction (MTJ). Initially, NE-directed cyclic shortening produced by the Cascadia subduction earthquake cycle drives reverse dip-slip motion on trench-parallel faults. As the triple junction moves north, NNW-shortening associated with the Mendocino Crustal Conveyor (MCC, Furlong & Govers, 1999) is superimposed on the cyclic subduction-earthquake-cycle regional stress field. As the triple junction migrates further north, and these faults transfer from the subduction to transform plate boundary, they become part of the San Andreas system and are loaded by right-lateral shear. In this work we investigate how the faulting behavior in northern California evolves through time from first being driven by cyclic subduction zone stresses (superimposed on a NNW-oriented shortening field) to eventually forming the primary structures within a dominantly strike-slip stress regime.

We decompose the observed horizontal GPS velocity field in southern Cascadia to determine a subduction coupling component and a NNW-directed displacement component to separate the subduction cycle effects from other tectonic effects on the behavior of upper plate faulting and its evolution through time. Since the MCC processes acts over millions of years, we assume that the effects associated with the NNW-directed signal can be represented by a constant stress field over subduction earthquake cycle timescales. Early in the subduction earthquake cycle, the principal stresses north of the MTJ are oriented in this NNW-SSE direction and rotate clockwise as the subduction component increases. This stress cycle then resets following each large megathrust event. Coulomb stress analyses indicate that the cyclic nature of the regional stress field, changes the likelihood of faulting and slip behavior on faults in southern Cascadia over time intervals of 100s of years. Trench-parallel faults are most likely to exhibit right-lateral or oblique motion early in the seismic cycle, however by ~100-200 years following a megathrust event, they are more likely to exhibit reverse dip-slip motion as the stress effects from the subduction component increase.

Though the NNW-oriented displacement field is assumed to be temporally constant over subduction earthquake cycle timescales, the spatial extent of this deformation field constrains strain localization within the upper plate. For example, a steep decrease in GPS velocities from SW to NE in southernmost Cascadia indicates right-lateral strain is accumulating adjacent to the relatively rigid Klamath Mountain Province. This region of localized right-lateral shear coincides
with the location of the development of several regional-scale right-lateral strike slip faults. We hypothesize these faults, formed within the subduction regime, evolve to become regional-scale 'San Andreas-type' plate boundary faults. Understanding the implications of such time- and space-variable stress regimes provides insight into interpreting geologic estimates of the slip history of faults along the Cascadia and northern San Andreas margins of North America, and also a framework for understanding how a new plate boundary develops following a major change in plate interaction.