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Time-variable stress transfer across a megathrust from seismic to Wilson cycle scale

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During the lifetime of a convergent plate margin stress transfer across the plate interface (a megathrust) can be expected to vary at multiple timescales. At short time scales (years to decades), a subduction megathrust interface appears coupled (accumulating shear stress) at shallow depth (seismogenic zone <350°C) in a laterally heterogeneous fashion. Highly coupled areas are prerequisite to areas of large slip (asperities) during future earthquakes but the correlation is rarely unequivocal suggesting that the coupling pattern is transient during the interseismic period. As temperature, structure and material properties are unlike to change at short time scales as well as at short distance along strike, fluid pressure change is invoked as the prime agent of lateral and time-variable stress transfer at short time (seismic cycle) scale and beyond. On longer time scales (up to Wilson cycles), additional agents of time-variable stress change are discussed.

Shear tests using velocity weakening rock analogue material suggest that in a conditionally stable regime the effective normal load controls both the geodetic and the seismic coupling (fraction of convergence velocity accommodated by interseismic backslip/seismic slip). Accordingly seismic coupling decreases from 80% to 20% as the pore fluid pressure increases from hydrostatic to near-lithostatic. Moreover, the experiments demonstrate that at sub-seismic cycle scale the geodetic coupling (locking) is not only proportional to effective normal load but also to relative shear stress. For areas of near complete stress drop locking might systematically decrease over the interseismic period from >80-95 % shortly after an earthquake to backslip at significant fractions of plate convergence rate (<5-45 % locking) later in the seismic cycle. If we allow pore fluid pressures to change at sub-seismic cycle scale a single location along a megathrust may thus appear fully locked after an earthquake while fully unlocked before an earthquake. The mechanisms and timescales of fluid pressure changes along a megathrust are yet to be explored but a valid hypothesis seems to be that non-volcanic tremor and slow slip below the seismogenic zone represent short term episodes of metamorphic fluid infiltration into the shallow megathrust. A megathrust fault valve mechanism clocked by the greatest earthquakes then accounts for cyclic fluid pressure build up and drainage at sub-seismic cycle scale.

As pore pressure dynamics are controlled primarily by permeability which in turn is controlled by structure and material properties, then more long term coupling transients associated with structural evolution of the plate margin can be implied. Fluid controlled transients might interfere with transients and secular trends resulting from changes in material strength and plate tectonic forces over the Wilson cycle resulting in a multispectral stress-transfer pattern associated with convergent margin evolution. Because of the viscous damping effect of the underlying asthenosphere, however, only longterm transients (periods >1-10 ka) are transmitted into the engaged plates. We therefore speculate that the multispectral nature of stress transfer across a megathrust filtered through the asthenosphere explains transient fault activity in some intraplate settings.