Evolving sensitivity of tremor to tidal stress during and between large ETSs in Cascadia: Implications for deep fault properties

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Solid Earth and ocean tides generate tiny stress changes that strongly modulate slow slip and tremor on deep plate boundaries. Analysis of tidal influence on tremor during large ETS in the Cascadia subduction zone (Houston 2015 Nature GeoScience) finds that the sensitivity of tremor to tides increases markedly over the several days of tremor and slip at a spot, and is an exponential function of tidal stress. Furthermore, a direct *in situ* image of the Coulomb sliding line shows intrinsic friction <~0.1, far lower than lab values (see Figure). A strength-threshold model for failure, in which slip and tremor occur when tidally-modulated stress exceeds strength (drawn from a random distribution), can explain the evolving, increasing, exponential sensitivity to tides during ETS. In the context of rate-state friction, the degree of tidal sensitivity implies near–lithostatic pore pressures for typical rate-state parameter choices.

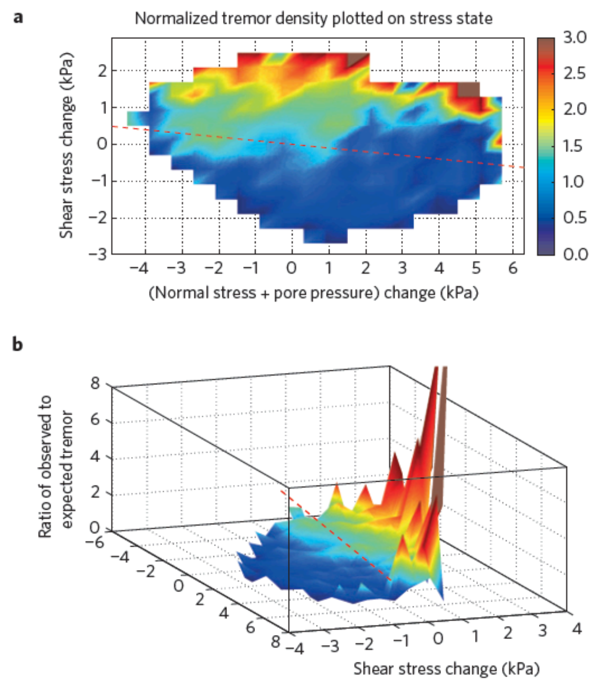

Figure 3 | Influence on tremor of shear versus normal stress changes. **a**, Ratio of observed-to-expected tremors (late group) plotted in effective-normal-stress versus shear-stress space. Effective normal stress is normal stress plus pore pressure from Model 1 with $B = 0.5$ (see equation (1)). Expected number of tremors is based on the time the fault occupies that stress state. Stress bins do not overlap. Positive normal stress is tensile. Dashed red line has slope −0.1, indicating a very shallow slope of the Coulomb sliding line—that is, low intrinsic friction. **b**, 3D perspective view of **a**, showing its exponential character.

Extending analysis to the entire slow slip "seismic cycle" including periods between large ETS shows that tidal response also evolves between ETS - decaying over the first quarter of the cycle to low values then climbing back up in the second half of the cycle towards the strong response that occurs late during the ETS. To extend the model for threshold failure strength, I posit that after the stress and strength drop of an ETS, stress rebuilds linearly by tectonic loading, whereas strength rebuilds as the logarithm of time (Vidale et al, 1994). Model stress and strength diverge the most midway through the cycle, the period when tidal sensitivity is observed to be weakest. Tidal stresses are more effective in triggering tremor later in the cycle as linearly-growing stress draws near logarithmically-growing strength. This model broadly fits the observed evolution of tidal response during and between large ETSs.

However, tidal sensitivity, ETS initiation, and tremor/LFE clustering are also affected by down-dip position (e.g., Wech and Creager 2011). Incorporating this effect into strength-threshold models may constrain how properties such as pressure, temperature, or permeability evolution vary down dip, and shows the value of integrating lab constraints, theory, and observations.

The evolution of tremor's tidal sensitivity over the slow slip seismic cycle illuminates the competition between healing on the plate interface and reloading with tectonic stress, and can help constrain, and even monitor, physical conditions on deep subduction zones.