Locking, creep and the rock record of plate interfaces and fluids

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A number of recent studies have suggested that the interseismic locking degree inverted from geodetic data at convergent plate boundaries may be closely related to slip distribution of subsequent megathrust earthquakes as found for the Maule 2010 and Tohoku 2011 earthquakes. The physical nature of locking, however, remains a matter of debate, just as the associated increasingly observed features such as creep transients and non-volcanic tremor. Linking geophysical and geodetic data collected from recent earthquakes along the Chilean plate boundary and the rock record of the ancient entirely exposed plate interface in the European Alps provides a coherent image of the processes controlling creep, seismogenic rupture and transients along the seismogenic part of a plate interface.
Seismic, seismological and geodetic data collected from the southern part of the Maule 2010 earthquake rupture zone allow identifying the spatial variability of pore fluid pressure and effective stress along the plate interface zone. The reflection seismic and the seismological data exhibit well defined changes of reflectivity and Vp/Vs ratio along the plate interface that can be correlated with different parts of the coupling zone as well as with changes during the seismic cycle. High Vp/Vs domains, identified as zones of elevated pore fluid pressure, spatially correlate with lower locking degree, and exhibit higher background seismicity as expected for partly creeping domains. In turn, unstable slip associated to a higher degree of locking is promoted in lower pore fluid pressure domains. In the gradient zone towards deeper domains locking and the elevated Vp/Vs-ratio gradually decrease to low values and are largely coincident with aftershock clusters and a concentration of geodetically recorded afterslip bursts following the Maule earthquake. We show that variations of pore pressure at the plate interface control locking degree variations and therefore coseismic slip distribution of large earthquakes. Finally, we speculate that pore pressure increase during the terminal stage of a seismic cycle to close to lithostatic pressure with an equivalent reduction of effective strength may be as relevant for earthquake triggering as stress loading from long-term plate convergence.
The rock record of the deeper parts of a former seismogenic subduction thrust corroborates the dominant role of high pore fluid pressures with very low effective stresses also identified with paleopiezometry. In addition, competing fabric styles varying from solution-precipitation creep to brittle fracture, involving also the formation of pseudotachylites, clearly indicate repeated transient changes in shear strain rate in the subduction channel rocks over more than 10 orders of magnitude. Finally, analyzing the scaling properties of the various styles of seismic slip to slow creep and converting theses to properties potentially observable in the rock record, we note that several strain rate regimes are distinguishable separating normal earthquakes from a group of slower features –such as slow slip, afterslip, transient creep etc. –and a final one of creep at convergence rates. At present, it appears not possible to differentiate between the various modes of accelerated slip below seismic speeds to be assigned diagnostic fabric types. Hence, the physical nature of these differences and the factors controlling them continue to be enigmatic.

