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Seismic slip propagation at shallow depth in subduction zones earthquakes: an experimental study on Costa Rica and north Sumatran subduction zone input materials

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Our knowledge of the mechanics of subduction zone megathrust earthquakes is hindered by the the limited number of observations due to the large discrepancy between the observational time and the earthquakes recurrence time, to lacking historical records and to the scarcity of instrumental coverage. Moreover, seismic and GPS inversions rely on indirect measurements which are taken away from the seismic source implying a limited knowledge of the elastic strain energy accumulated in the host rocks surrounding the fault before seismic slip and on the energy partitioning between on-fault and off-fault dissipative processes during seismic slip. Experiments allow us to decrease the observational time, increase the number of observations and control the boundary conditions. In particular, experiments performed with high velocity frictional apparatuses, which impose slip and slip rates typical of moderate to large magnitude earthquakes, provide a quite robust reproduction of on-fault seismic processes as attested by the similarity between the experimental and natural fault products.

We tested materials sampled via scientific drilling in the sediment input to Costa Rican and north Sumatran subduction zones (IODP Exp. 334 and 362, respectively). In the case of Costa Rica these materials were sampled just a few km from the deformation front and drilling the toe of the system reveal that they build a small accretionary wedge at the front of an otherwise active erosional margin and may contain information about its past seismo and tsunamigenic history. In the case of Sumatra these materials were sampled at about 200 km from the deformation front and, although they are the same that are currently deforming in the shallow portions of the subducting interface, they may underestimate future diagenesis. To estimate the available energy to propagate seismic slip and respectively back - and fore - ward trace the history of the two subduction zones we performed experiments with a rotary shear apparatus on gouge layers made of the aforementioned materials: (1) under room humidity and temperature conditions; (2) controlling the normal stress, representative of depth < 1 km (i.e. 5 and 15 MPa), (3) observing the evolution of shear stress during a step at 10 μm/s slip rate, (4) observing the spontaneous evolution of slip and slip rate as the shear stress is increased stepwise and (5) observing the evolution of shear stress at constant 1 m/s slip rate for few meters of slip.

The experiments allow us to achieve constraints on the energy dissipated during seismic slip in on-fault processes, including the available energy to propagate seismic slip (i.e. shear fracture energy). The experiments revealed that fault gouges at the shallow portions of the accretionary prism can store a relatively large amount of elastic strain energy, enough to promote seismic slip propagation when loaded near to the reactivation shear stress. The experiments may contribute to our understanding of fault stability and, in particular, to the debate on the possibility that seismic slip can propagate up to the trench during megathrust earthquakes, as proposed for the 2011 Tohoku-Oki Mw 9.0 earthquake.