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Stored elastic strain energy and energy release in subduction zones. Experimental investigation on fault materials.

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The energy budget is a key parameter to investigate earthquake mechanics. However, our knowledge about the amount of elastic strain stored in the seismogenic volume and the energy released during an earthquake is limited by: (1) the observational time (orders of magnitude shorter that the recurrence time of moderate to large earthquakes); (2) the paucity of historical records and the scarcity of instrumental coverage; (3) the availability of only indirect measures (e.g., from seismic and GPS inversion at the surface); (4) the lack of sound estimates about the energy dissipated in on-fault and off-fault processes during earthquakes.

One way to reduce the observational time and enlarge the number of observations is the experimental simulation. Experiments provide a quite robust reproduction of seismic source processes, confirmed by geological evidence (experimental fault products are very similar in many cases to natural ones) and guarantee a control on the environmental and loading conditions of the simulated fault. In particular, experiments performed with high velocity frictional apparatuses (so imposing slip and slip rates typical of moderate to large in magnitude earthquakes), a number of constraints have been retrieved regarding the energy dissipated during seismic slip (on-fault processes) and, to some extent, the energy required to propagate seismic slip (i.e. fracture energy).

To acquire more information and shed light on the capability of fault zone rock materials and the wall rocks to store elastic strain and release it in different forms (seismic waves, grain size reduction frictional heat, etc.), we performed experiments with a rotary shear apparatus (the stiffness of the machine simulates the wall rock stiffness) by controlling the normal stress acting on the experimental fault and (1) observing the evolution of shear stress under steps in the slip rate and (2) observing the spontaneous evolution of slip and slip rate as the shear stress is increased stepwise (e.g. with steps of 0.1 MPa every 100 s).

We tested wet non-cohesive materials (clay rich gouges) representative of fault materials that are thought to characterize the actual subducting interface in the shallow portions of the accretionary prism and fault materials (silty clay gouges and carbonatic oozes) from Costa Rica IODP expeditions 334 and 344. These experiments allowed us to measure the initial, the dynamic and residual shear stresses at different stages of the seismic cycle which are essential to compute the energy budget.

Our experiments revealed that fault materials at the shallow portions of the accretionary prism can store a relatively large amount of elastic strain energy, largely depending on the water content, but enough to promote seismic slip propagation when stimulated by a perturbation in the loading conditions.

These experiments may contribute to our understanding of fault stability and the likelihood that seismic slip can propagate up to the trench, an observation that since the M9 Tohoku Oki 2011 earthquake is puzzling our current understanding of earthquake mechanics.