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Seismotectonic evolution of subduction zone forearcs - insights from analogue earthquake experiments

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We present results of the deformation analysis of granular elastic-plastic wedges overlying a rate-state frictional interface reminiscent to subduction zone forearcs. Longterm compressional unstable wedges deform dominantly plastic (“plastoelastic”) to reach a stable geometry by fault controlled accumulation of shortening. Longterm stable wedges deform dominantly elastic (“elastoplastic”) with a more diffuse strain pattern. The change from plastoelastic to elastoplastic behaviour is associated with an increase in seismic moment release rate. This is mainly due to a decrease in earthquake recurrence time and presumably controlled by an increased loading rate and normal load.

Both plastoelastic and elastoplastic wedges show a morphotectonic evolution which is transient at the timescale of the megathrust seismic cycle. This evolution reflects stress changes related to “transient singularities” controlled by the velocity dependent frictional behaviour along the megathrust. Accordingly, a morphotectonically segmented forearc evolves over tens of seismic cycles with a minor deformed domain above the seismogenic velocity weakening zone enclosed by contractional domains overlying the aseismic velocity strengthening parts of the megathrust. Coseismic compression at the updip limit of the seismogenic zone is relaxed by shallow postseismic afterslip and/or plastic shortening of the outer wedge causing the longterm formation of a trench slope break or outer arc high. Interseismic compression at the downdip limit of the seismogenic zone drives plastic shortening in the coastal region resulting in longterm uplift of a forearc high. The area above the seismogenic zone remains relatively undeformed in plastoelastic wedges where internal deformation of the outer wedge is the dominant postseismic stress relaxation mechanism and results in a plateau-like deep sea terrace. In elastoplastic wedges, shallow afterslip is the dominant mode of postseismic stress relaxation. It may interfere with interseismic tectonic reloading resulting in finite extension and seaward tilting of the area above the seismogenic zone. This process may involve basin formation.

Our seismotectonic simulations have potential implications for seismic hazard assessment in subduction settings based on morphotectonic features. They suggest that (1) the morphotectonic segmentation mirrors transient singularities delineating the seismogenic zone at depth, (2) longterm deformation rates are inversely correlated with rates of seismic moment release, and that (3) internal deformation of the outer wedge relaxes stored elastic energy thus decreasing the risk for tsunami earthquakes.