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Shocks in a box - Analogue simulations of the seismic cycle in subduction settings

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Active continental margins are announced disaster hotspots where destructive megathrust earthquakes nucleate deep below the coast, propagate offshore along the plate interface and send tsunamis back to the coast and over the ocean. During the last decade, increasingly sophisticated geodetic techniques have been developed to allow monitoring of active surface deformation in subduction settings. To provide insight into the mechanisms of subduction thrust earthquakes and associated surface movements, this study analyses elastic and permanent forearc deformation at the scale of the seismic cycle featuring analogue simulation. The simulations include rate- and state-dependant frictional-elastic and viscoelastic rheologies and are monitored by a high spatio-temporal resolution image acquisition and correlation system.

Analogue subduction thrust earthquakes induce landward tilting of the forearc along a trench-parallel axis located above the downdip end of the seismogenic zone. Forearc tilting results in coseismic subsidence of the coastal area and uplift of the shelf or slope region consistent with existing empirical models inferred from aftermaths of historical megathrust earthquakes. The localization of coseismic seafloor uplift - and thus the tsunamigenic potential - is controlled by the upper limit of the earthquake rupture. Interseismic displacement vectors indicate landward translation and subsidence of the shelf region above the seismogenic zone and shortening of the coastal area consistent with elastic dislocation models. Forearc backthrusts may localize long-term, permanent shortening and uplift of a coastal cordillera above the downdip end of the seismogenic zone. We thus speculate that the long-term morphological evolution of the active margin is controlled at least partly by the short-term mechanics. Backthrust activity tends to increase during the interseimic period but is choked during the co-

seismic stage, in which the forearc acts as an elastic continuum. This led us speculate further that in turn long-term active discontinuities have only minor influence on the short-term deformation pattern. Across the continental margin, co- and interseismic deformation thus interfere in a positive or negative way to shape its long-term geometry over several seismic cycles.

Compared with frictional experiments using a ring shear tester, the simulations suggest that the self-similarity of earthquakes is not due to the nonlinearity of the deformation laws but is a result of the kinematic complexity of the fault systems. Characteristic analogue earthquakes occur exclusively in highly constrained systems with fixed fault geometry and constant loading rate and pressure, as realized in the ring shear tester. In systems with higher degree of freedom (either in fault boundary conditions or deformation partitioning), simulated earthquakes obey power-law frequency-size relationships with transient slip- or time-predictable recurrence. We therefore hypothesize that earthquake statistics are controlled by extrinsic rather than by intrinsic system parameters.

Land-based and recently seafloor-based geodetic monitoring programmes are under way in many parts of the world; however, this new record provides only snap shots of the seismic cycle as yet. Along with seismic cycle modelling it may offer new opportunities of earthquake prognostics and hazard assessment.