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Earthquake supercycle in subduction zones controlled by the downdip width of the seismogenic zone

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Supercycles describe a long-term cluster of megathrust earthquakes that consist of partial ruptures before a complete failure of a subduction zone segment (Sieh et al. 2008, Goldfinger et al. 2013). The controls on supercycles remain unclear, although structural or fault frictional heterogeneities were proposed (Sieh et al. 2008). We recognize that supercycles have been suggested in those subduction zones (Sieh et al. 2008, Goldfinger et al. 2013, Metois et al. 2014, Chlieh et al. 2014) for which the seismogenic zone downdip width is estimated (Heuret et al. 2011, Hayes et al. 2012, Hayes et al. 2013) to be larger than average.

Here we assess this potential link between the seismogenic zone downdip width and supercycles. For this purpose we use the continuum-based seismo-mechanical model of megathrust earthquake cycles in subduction zones (Van Dinther et al. 2013), which was validated through a comparison against scaled analogue subduction experiments (Corbi et al. 2013). The two-dimensional numerical model setup consists of a visco-elastic wedge underthrusted by a rigid plate and a frictional boundary layer simulating the megathrust. In this boundary layer, we evaluate a non-associative Drucker-Prager plasticity with pressure dependent yield strength and a strongly rate-dependent friction formulation. The velocity-weakening seismogenic zone with a downdip width W is limited up-and downdip by velocity-strengthening regions.

In our numerical models, an increasing seismogenic zone downdip width leads to a transition from ordinary cycles of similar sized complete ruptures to supercycles. For supercycles in wide seismogenic zones, we demonstrate how interseismic deformation accompanied by partial ruptures effectively increases the stress throughout the seismogenic zone until a crack-like superevent releases most of the accumulated stresses. Our findings suggest that supercycles are more likely to occur in subduction zones with a large seismogenic downdip width due to a larger potential strength excess. It takes longer and more events to reach a critical stress state in the center of wider seismogenic zones.

We conclude that such stress evolution along the dip of a wide seismogenic zone is the simplest mechanism governing supercycles. Our results show that earthquake size variability during a supercycle can be purely explained by the along-dip evolution of stress heterogeneities within an up- and downdip bounded homogeneous seismogenic zone. Additional a priori complexities, like previously suggested structural or frictional heterogeneities (Sieh et al. 2008) are not required to generate supercycles, although they are expected to complicate our simplest explanation of supercycles. We suggest that larger than thus far observed earthquakes could occur as part of a supercycle in subduction zones with a large seismogenic zone downdip width.