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The geology of slip-to-the-trench in Central America

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Coseismic slip-to-the-trench, which occurred during Mw9 Tohoku-Oki earthquake, raises strong questions for the previously widely accepted paradigm of an aseismic nature of subduction megathrusts at shallow depths. In the new conceptual model, the frontal part of the subduction megathrust can support slip speeds that range from plate convergence rates (mm/yr) to co-seismic slip rates (m/s). The investigation of the conditions that favour slip-to-the-trench requires addressing a complex interplay of processes along the first ∼10 km of the subduction plate interface.

To investigate the frontal megathrust's co-seismic behaviour we have focussed on the geological framework for the development of the subduction megathrust. We combine friction experiments, energy balance calculations for rupture propagation, and numerical modelling for the elastic stress build up. Our area of investigation is the Middle America Trench offshore Costa Rica, where recent ocean drilling has provided both constraints on the geometry of the frontal part of the megathrust and samples of the lithologies involved in the megathrust itself. The incoming plate sediments consist of Miocene biogenic oozes and late Miocene-Pleistocene silty clays. Drilling has resolved the position of the basal decollement to lie within the biogenic oozes. Friction experiments show that when wet, silty clays and biogenic oozes are both slip-weakening at sub-seismic and seismic slip velocities. Oozes are stronger than silty clays at slip velocities of less than or equal to 0.01 m/s, and wet oozes only become as weak as silty clays at a slip velocity of 1 m/s. We therefore suggest that the geological structures found offshore from Costa Rica were formed during seismic slip-to-the-trench events. Sliding friction alone, however, does not control the onset of slip during an earthquake. To further explore whether the carbonate-rich oozes can accumulate sufficient elastic energy to slip seismically, we used the slip experiment data to estimate the energy available for seismic faulting and seismic radiation. From our results we conclude that oozes can accumulate larger strain energies than silty clays and are also velocity weakening. In this scenario oozes are capable of accumulating elastic strain to produce a locked patch on a plate interface at shallow depth. We have also performed numerical modelling - 2D viscoelastic finite elements with contrasting 'ooze' and 'clay' material properties – to explore whether, given the stratigraphic and geometrical characteristics of the incoming plate sediments at the trench, elastic strain can accumulate in the oozes, or if instead it will be completely released by creep in its adjacent weaker silty clays. Numerical experiments suggest this becomes possible when the fault units have geologically observed geometrical complexity.

These lines of inquiry concerning the forearc toe offshore SE Costa Rica converge to the conclusion that that, here, the megathrust was active during transient high slip-rates (i.e. rates only possible during earthquake slip to the trench). The geological investigation of historical occurrences of co-seismic slip to the trench can help to better assess hazards at subduction zones, and should be investigated globally.