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Rheological effects on slab stagnation and trench rollback

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Trench rollback has been a widely discussed phenomenon in recent years, and multiple studies have concentrated on various parameters that may influence trench migration and related aspects of slab deformation in the (upper) mantle. Here we concentrate on the effects of rheology in controlling the rollback and associated stagnation of slabs in the transition zone. We perform numerical simulations of slab evolution in a 2D Cartesian model with strongly nonlinear rheology combining diffusion creep, dislocation creep and a power-law stress limiter. Decoupling of the subducting and overriding plates is facilitated by a low-viscosity crustal layer prescribed on top of the subducting plate. We investigate models with the age of the subducting plate varying between 70 Myr and 150 Myr at the trench. We study the effects of the yield stress of the stress-limiting rheology (0.2–1 GPa) and of the crustal strength. We demonstrate that retrograde trench migration develops in most models considered, regardless of the subducting plate age or prescribed strength. Rollback then mostly produces slabs that are horizontally deflected at the 660-km phase boundary and remain subhorizontal at the bottom of the transition zone. Slab morphologies are in agreement with stagnant, horizontally deflected structures reported in the transition zone by seismic tomography. Furthermore, if the strength of the slab is limited to less than 0.5 GPa, the slab experiences a significant amount of horizontal buckling. Both subducting plate velocity and trench rollback velocity then exhibit periodic time variations with dominant periods of around 20 Myr with rollback velocity maxima occurring at plate velocity minima and vice versa. These oscillations are reflected also in dip-angle variations that may further influence, for example, the exhumation of high-pressure metamorphic rocks. The amplitude of the rollback velocity is sensitive to several model parameters. As one might expect, it increases with the age of the subducting plate, thus reflecting its increasingly negative buoyancy. On the other hand, rollback velocity decreases if we increase the viscosity of the crust and strengthen the coupling between the subducting and overriding plates. High friction on the contact between the subducting and overriding plates may even result in slabs penetrating into the lower mantle after a period of temporary stagnation. Also, the reduction in extra negative buoyancy associated with the 410-km exothermic phase transition suppresses trench rollback. The interpretation of the effects that control slab rollback and stagnation may be rather complex in strongly nonlinear rheological models, where, for example, the buoyancy effects may be counteracted by associated yield-stress weakening.