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A regime diagram for subduction dynamics from thermo-mechanical models with a mobile trench and an overriding plate

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The penetration or stagnation of subducted slabs in mantle transition zone and lower mantle influences Earth's thermal, chemical and tectonic evolution. Yet, the mechanisms responsible for the wide range of observed slab morphologies within the transition zone remain debated. Here, we investigate how downgoing and overriding plate ages controls the interaction between subducted slabs and mantle transition zone. We use 2-D thermo-mechanical models of a two-plate subduction system, modeled with the finite-element, adaptative-mesh code Fluidity. We implement a temperature- and stress-dependent rheology, and viscosity increases 30-fold from upper to lower mantle. Trench position evolves freely in response to plate dynamics. Such an approach self-consistently captures feedbacks between temperature, density, flow, strength and deformation. Our results indicate that key controls on subduction dynamics and slab morphology are: (i) the slab's ability to induce trench motion; and (ii) the evolution of slab strength during sinking. We build a regime diagram that distinguishes four subduction styles: (1) a "vertical folding" mode with stationary trench (young subducting plates, comparatively old overriding plates); (2) slabs that are "horizontally deflected" along the 660-km deep viscosity jump (initially young subducting and overriding plates); (3) an inclined slab morphology, resulting from strong trench retreat (old subducting plates, young overriding plates); and (4) a two-stage mode, displaying bent (rolled-over) slabs at the end of upper-mantle descent, that subsequently unbend and achieve inclined morphologies, with late trench retreat (old subducting and overriding plates). We show that all seismically observed slab morphologies can arise from changes in the initial plates ages at the onset of subduction.