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Slab stagnation and buckling in the mantle transition zone: Rheology, phase transition, trench migration, and seismic structure

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Subducting slabs may exhibit buckling instabilities and consequent folding behavior in the mantle transition zone for various combinations of dynamical parameters, accompanied by temporal variations in dip angle, plate velocity, and trench retreat. Parameters governing such behavior include both viscous forces (slab and mantle rheology) and buoyancy forces (slab thermal structure and mineral phase relations). 2D numerical experiments show that many parameter sets lead to slab deflection at the base of the transition zone, typically accompanied by quasi-periodic oscillations (consistent with previous scaling analyses) in largely anticorrelated plate and rollback velocities, resulting in undulating stagnant slabs as buckle folds accumulate subhorizontally atop the lower mantle. Slab interactions with mantle phase transitions are important components of this process (Bina and Kawakatsu, 2010; Čížková and Bina, 2013).

For terrestrial parameter sets, trench retreat is found to be nearly ubiquitous, and trench advance is quite rare – due to both rheological structure and ridge-push effects (Čížková and Bina, 2013). Recent analyses of global plate motions indicate that significant trench advance is also rare on Earth, being largely restricted to the Izu-Bonin arc (Matthews et al., 2013). Consequently, we explore the conditions necessary for terrestrial trench advance through dynamical models involving the unusual geometry associated with the Philippine Sea region.

Detailed images of buckled stagnant slabs are difficult to resolve due to smoothing effects inherent in seismic tomography, but velocity structures computed for compositionally layered slabs, using laboratory data on relevant mineral assemblages, can be spatially low-pass filtered for comparison with tomographic images of corresponding resolution. When applied to P-wave velocity anomalies from stagnant slab material beneath northeast China, model slabs which undulate due to compound buckling fit observations better than a flat-lying slab (Zhang et al., 2013). Earthquake hypocentral distributions and focal mechanisms may provide clearer insights into slab buckling, as they appear to vary systematically across regions of slab stagnation (Fukao and Obayashi, 2013). Stress fields computed from our dynamical models may help to illuminate such observations.

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