

# Scaling of Free Subduction on a Sphere

- Neil M. Ribe  
Laboratoire FAST, Université Paris-Saclay, CNRS, Orsay, France  
neil.ribe@universite-paris-saclay.fr
- Alexander Chamolly  
Institut Pasteur, Université de Paris, CNRS, Paris, France
- Gianluca Gerardi  
MINES ParisTech, PSL Research University, Fontainebleau, France
- Stéphanie Chaillat  
Lab POems, ENSTA-UMA, Palaiseau, France
- Zhong-hai Li  
Key Laboratory of Computational Geodynamics, University of Chinese Academy of Sciences, Beijing, China

Because Earth’s tectonic plates are doubly curved shells, their mechanical behavior during subduction can differ significantly from that of flat plates. We use the boundary-element method (BEM) to study free (gravity-driven) subduction in axisymmetric and 3-D geometry, with a focus on determining the dimensionless parameters that control the dynamics. The axisymmetric model comprises a shell with thickness  $h$  and viscosity  $\eta_1$  subducting in an isoviscous planet with radius  $R_0$  and viscosity  $\eta_2$ . The angular radius of the trench is  $\theta_t$ . Scaling analysis based on thin-shell theory reveals two key dimensionless parameters: a ‘flexural stiffness’  $St = (\eta_1/\eta_2)(h/l_b)^3$  that is also relevant for flat plates, and a new ‘dynamical sphericity number’  $\Sigma_D = (l_b/R_0) \cot \theta_t$  that is unique to spherical geometry. Here  $l_b$  is the ‘bending length’, or the sum of the lengths of the slab and of the seaward flexural bulge. The definition of  $\Sigma_D$  implies that the dynamical effect of sphericity is greater for small plates than for large ones; we call this the ‘sphericity paradox’. By contrast, the purely geometric effect of sphericity is opposite, i.e. greater for large plates than for small ones. The dynamical and geometrical effects together imply that sphericity significantly influences subduction at all length scales. We confirm the scaling analysis using BEM numerical solutions, which show that the influence of sphericity on the slab sinking speed (up to a few tens of percent) and on the hoop stress (up to a factor of 2-3) are largest for small plates such as the Juan de Fuca, Cocos and Philippine Sea plates. We next study a 3-D model comprising a plate bounded by a ridge and a semicircular trench subducting in a three-layer earth consisting of an upper mantle, a lower mantle and an inviscid core. We examine the linear stability of the shell to longitudinal perturbations corresponding to buckling, and determine a scaling law for the most unstable wavelength that we compare with the observed shapes of northern/western Pacific trenches.