Comparing global mantle models: from mapping to hypotheses testing

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Seismic tomography shows that subducted oceanic lithosphere deforms in a complex variety of ways as it descends through the mantle. To understand better the mechanisms of this deformation, I study the dynamics of thin viscous sheets of arbitrary shape subject to arbitrary loading. An analytical "shallow sheet" scaling analysis reveals that two distinct types of deformation can occur, depending on the sheet's principal curvatures and the wavenumbers of the applied load: an "inextensional" (bending) mode and a "membrane" (stretching) mode. In general, high curvature favors membrane deformation, whereas low curvature favors inextensional deformation. By using the scales revealed by the shallow-sheet analysis together with asympotic expansions in powers of a small slenderness parameter, I reduce the three-dimensional viscous flow equations to a set of equivalent two-dimensional equations for the velocity of the sheet's midsurface. General nonorthogonal coordinates are employed, which allows the use of a Lagrangian grid that deforms with the sheet. The set of "thin-sheet" equations is completed by kinematic evolution equations for the sheet's shape (metric and curvature tensors) and thickness. Numerical solutions of the equations for gravity-driven deformation show that the inextensional mode has a boundary-layer character, and that compressive membrane states are inherently unstable to buckling instabilities. A model for a two-dimensional viscous jet falling onto a rigid plate exhibits steady periodic folding, the frequency of which varies with the jet's height and extrusion rate in a way similar to that observed experimentally. A simple model for subduction, in which a thin sheet extruded horizontally deforms under its own weight, exhibits "trench rollback" at a rate comparable to those observed on earth.