Lithosphere-asthenosphere transition tracked in models of plate and mantle dynamics: the “constant-velocity plate” deforms at its base

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If the lateral limits of tectonic plates are well mapped by seismicity, the bottom boundary of the uppermost rigid layer of the Earth, comprising both crust and shallow mantle, remain elusive. A lithospheric plate can be viewed as a cold, rigid, undeformed and/or translating block, which relates to different physical fields, i.e. temperature, viscosity, strain rate and velocity. Their variation with depth are here investigated in thermo-mechanical models, either in a transient subduction or in a steady-state plate-driven set-up, with mantle rheology derived olivine plastic creeps. We propose three different definitions of lithosphere-asthenosphere boundaries (LAB), associated to either temperature (1300 K), strain rate (10-16 s-1). or horizontal velocity (0.5% departure from surface velocity). The depths of these 3 LABs are distinct from one another and the base of the “constant-velocity” plate deforms in continuity with the underlying asthenosphere mantle. If the thermal structure has a major control on the three LABs, the surface plate velocity, the asthenosphere flow geometry and magnitude also influence the velocity- and strain rate-defined LABs. The thickening of the “constant-velocity“ plate with increasing surface velocity is interpreted as a thicker mantle layer dragged by a larger surface plate motion. The mechanical transition from lithosphere to asthenosphere also adjusts to mantle dynamics, and this transient behaviour has implications for mass transport within the Earth's mantle. We discuss how various set of data may constrain, or not, thermo-mechanical mantle fields, given that most of the observables (e.g. seismic velocities or anisotropy) suffer from temporal integration and/or spatial averaging. We conclude that the “constant-velocity plate” is the most relevant definition for the lithosphere when addressing mantle mass transfers, even if it is the least likely to be constrained by geophysical data.

Mots-Clés : thermo-mechanical models ; plate-driven mantle flow ; lithosphere-asthenosphere transition ; constant-velocity plate