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Thermal structure of arc lithosphere in subduction zones: Plate thinning by small-scale convection enhanced in a wet mantle wedge

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The small-scale convection occuring at the lithosphere-asthenosphere boundary has been suggested to regulate the thickness of old oceanic lithosphere and to be able to thin the thickened root of continental lithosphere after a collision episode. Small-scale convection could also occur in the mantle wedge of a subduction zone. The fluids expelled during subducting slab dehydration are likely to wet asthenospheric rocks and decrease there mantle viscosity, even for very small amounts of absorbed water. We present a numerical study of this process. Our thermomechanical model combines a non-Newtonian viscous rheology and a pseudo-brittle rheology, as a function of depth, temperature and stress, both for an oceanic crust and the mantle.

We model subduction by imposing constant plate velocity far away from the subduction area. The released water comes from the oceanic crust, and the altered (serpentinized) peridotite of the slab. Slab dehydration and water transfers are computed all over the subduction zone thanks to pressure-temperature-time paths, by using accurate phase diagrams for water-saturated mantle peridotite and a gabbroic crust. Transition phases are supposed to be not metastable. This leads to a ca. 200 km wide hydrated mantle wedge for a 5 cm/yr convergence rate and a 100 Myr old subducting lithosphere. We parameterize the asthenosphere strength reduction in the presence of water and study how it affects the small-scale convection intensity and the thinning degree of the upper lithosphere in the arc region. Numerical simulations show that, as we increase the hydrous strength reduction of hydrated mantle wedge rocks, between 10 and 350, first, the final thickness of the damp arc lithosphere significantly decreases (equilibrium thickness encompassed between 42 and 14 km), and second, the characteristic time of lithosphere thinning decreases (from 63 to 20 Myr). Both results are in a good agreement with the analytical scaling laws we derived to explain the numerical models. This mechanism of arc lithosphere thinning might explain the thermal structure of hot backarcs where no significant spreading has been recorded. However, the high characteristic times of thermal erosion that we simulate may question the relevance of applying this model in subduction systems not older than a few tens of Myr. We will thus discuss how alternative rheological models of water content-dependence of mantle viscosity could affect our results.