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Viscosity in transition zone and shallow lower mantle - Insight from numerical models of subduction

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A viscosity profile throughout the upper 1000 km of mantle is far from being well known. Different models were proposed to find the best-fit viscosity distribution based on the imposition of different sets of constraints (e.g. geoid, Haskell, tomography model). There are some common factors in all the possible profiles: 1) there seems to be a sharp viscosity increment between transition zone (TZ) and lower mantle (LM) and 2) a slow increase in viscosity with depth in the first hundreds of km of LM.

The positive Clapeyron slope associated with the olivine-spinel phase transition at ∼410 km favors that the cold slab can go through it, accelerating the subduction process. The opposite situation occurs on the spinel-perovskite phase transition at ∼660 km, where the Clapeyron slope is negative and inhibits or slows the subduction. Whether the slab is able to sink beyond this boundary depends, not only on the value of the Clapeyron slope, but also on other factors like absolute velocities of the plates, viscosity of the underlying mantle (TZ and LM) and discontinuities in its distribution, among others.

In this set of experiments, we represent the viscosity profile of TZ and LM in a simplified way by means of two parameters: viscosity in TZ and viscosity step at the spinel-perovskite phase transition.

We used a coupled elasto-visco-plastic thermomechanical numerical model based on code SLIM-3D to run all experiments. The model has true free surface and elastic deformation is included. Realistic rheology was applied to the subducting and overriding plates as well as the upper mantle. In this part of the model, viscosity is stress and temperature dependent. Three different types of creep (diffusion, dislocation and Peierls) are included. In particular, Peierls creep plays a key role to reduce stress in the deep cold slab.

From our results we can conclude that the most reasonable range of viscosity values for the TZ would be $(3*10^{20} - 10^{21})$ Pa s. A value of $3*10^{21}$ is too high to allow a subducting slab to penetrate into the LM with a reasonable velocity if a viscosity step is present. The same situation arises if the viscosity step is greater than 10, in which case most of the times a piling up of material next to the LM or flat slabs can be seen, but no direct penetration. It should also be noted that, for higher jumps, viscosity in LM would be too large under certain combinations. A substantial reduction of the Clapeyron slope at the 660 km boundary did not help to enhance subduction and showed only a small influence over the evolution of the slab.

On the other hand, when viscosity in TZ is significantly lower than $3*10^{20}$ Pa s slab accelerates to more than 30 cm/yr while (or before) penetrating the TZ, a phenomenon that is rarely seen in nature. If viscosity step is not present, exaggerated or very high velocity values are also obtained for the most reasonable viscosity. The best results were obtained with a step around 5. Even if overriding velocity can change the style of subduction toward more flattened slab, it cannot much reduce the exaggerated velocities obtained with the low values of both variables.

With a viscosity of $3*10^{20}$ Pa s in TZ, a step between 5 and 10 gives the best velocity patterns, considering that this is a case of fast subduction. If viscosity is 10^{21} Pa s, the step between TZ and LM should be smaller than 5 in order to get reasonable subduction velocities.