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Solid Earth
Discussions

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Interactive
Comment

Interactive comment on "3-D thermo-mechanical laboratory modelling of plate-tectonics" *by* D. Boutelier and O. Oncken

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The referee, Dr. Wouter Schellart, noted 11 points that should be addressed to improve the paper. Below we respond to these 11 points.

Point 1: for completeness we have added the following references:

- Jacoby, W. (1976), Paraffin model experiment of plate tectonics, Tectonophysics, 35, 103-113.
- Jacoby, W., and H. Schmeling (1982), On the effects of the lithosphere on mantle convection and evolution, Physics of the Earth and Planetary Interiors, 29(3-4), 305-319, doi:10.1016/0031-9201(82)90019-X.

- Kincaid, C., and P. Olson (1987), An Experimental Study of Subduction and Slab Migration, Journal of Geophysical Research, 92(B13), 13832-13840, doi:10.1029/JB092iB13p13832.
- Turner, J. (1973), Convection in the mantle: a laboratory model with temperature-dependent viscosity, Earth and Planetary Science Letters, 17(2), 369–374.

Point 2: We refer to the sub-lithospheric mantle as asthenosphere and do not differentiate the asthenosphere from the upper mantle as we neglected the viscosity of both. Our modeling follows from earlier work (Shemenda 1992, Shemenda 1993, Chemenda et al., 2000, Boutelier et al., 2002,2003, 2004) where we focused on the solid interaction of the plates in the subduction zone. The subduction zone is simplified and the asthenosphere is modeled with water. This allows investigating other parameters that influence the mechanics of subduction such as the flexural rigidity of the lower plate. It is an approximation motivated by the fact that the low viscosity of the sub-lithospheric mantle cannot generate large shear traction at the bottom of the lithosphere. Hence, when studying deformation in a limited area around the subduction zone we can ignore the local effect of viscous coupling and replace its larger-scale effect by the action of a piston. A recent study (Bonnardot et al., 2008) confirmed that if the asthenosphere viscosity is below 1×10^{19} Pa.s then the effects of viscous interaction between slab and upper mantle on the dynamics of the arc and back-arc is small and the simplification that we made is reasonable. However, for an investigation on the dynamics of subduction, or when subduction is investigated at the scale of the entire plate or mantle, we must include the viscous coupling between the lithosphere and asthenosphere. This is however the next step in the development of our thermo-mechanical modeling. In the future, we aim to perform dynamic thermo-mechanical experiments. However, there are milestones that we have to reach before this aim can be attained. The first one was going 3D, and we presented this important step-up from our previous models in this study. Next we will have to implement proper viscous interaction between the lithosphere and sub-lithospheric mantle. Finally we will impose constant stress boundary conditions at the back of one lithospheric plate. It is important to note that the order of these milestones cannot be changed. We must go 3D before we implement the viscous interaction because viscous flow is poorly reproduced in a quasi-2D set-up (Boutelier and Cruden, 2008). We cannot do dynamic experiments before the viscous interactions are implemented because a big player would be missing from the force balance at plate scale.

The point made by the reviewer is noted, and we modified the manuscript to acknowledge even more explicitly that the viscous coupling with the sub-lithospheric mantle is presently missing from our modeling. We now introduce the future development of the modeling technique and further strengthen the fact that our present set-up is one milestone in the development towards 3D thermo-mechanical and dynamical modeling experiments.

Point 3: Yes, the proportions are given in weight percent. We now explicitly mention it.

Point 4: We changed the words. The presented experiments are not referred to as 2D experiments but 3D cylindrical experiments. The model sides are presently free since there are large (5 cm) gaps with very low viscosity asthenosphere on both sides of the model lithosphere. In the future, when proper viscosity of the sub-lithospheric mantle is implemented, we will have to face a choice. We can either reduce the plate's width to increase the gaps and have free sides, or we can keep the large plate's width, which allows implementing along-strike variations of the initial conditions, but will not have true free boundary conditions along the sides. We will choose one option or the other depending of whether we are investigating the effects of along-strike variations of the initial conditions or the 3D dynamics of the interaction between the lithosphere and asthenosphere. However, this problem only pertains to the next developmental stage of the experimental set-up and thus we do not wish to expand on it in this study.

Point 5: The Reynolds number is very high in our experiments because the viscosity of water is very low. Since we focused on the deformation of the plates in a kinematic

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framework, the high Reynolds number is not important. Whatever flow is produced in the asthenosphere; it does not influence the plates because of the very low viscosity of the asthenosphere. For future work, we will have to consider the Reynolds number. Following the first two reviews we now introduce the next steps of the development of the experimental set-up. We present the scaling of viscosity derived from the existing scaling of stress and time. To model a sub-lithospheric mantle with viscosity 1×10^{19} to 1×10^{21} Pa. s, we must use fluids with viscosity 2.57 to 257 Pa.s. Using the characteristic length of either 2 cm (thickness) or 40 cm (width), the Reynolds number will be 1.95×10^{-3} to 3.89×10^{-2} for a viscosity of 2.57 Pa.s or 1.95×10^{-5} to 3.89×10^{-4} for a viscosity of 257 Pa.s. With these low values we will be able to properly model the flow patterns in the mantle.

Point 6: We now provide the error margins in table 1.

Point 7: The plate boundary is lubricated with paraffin oil. The thickness is estimated to be ~0.1 mm since the surface is brushed with low viscosity oil before being plated in the tank. We now provide the details of the lubrication process. We also changed the words to make it clear that we assume the shear stress to be zero Pa when the interplate zone is lubricated.

Point 8: α is the dip angle of the interplate surface, and F_p is the pressure force, oriented perpendicular to the interplate surface. Therefore, if α is zero the interplate surface is horizontal and the pressure force is vertical. Thus its horizontal component F_{ph} is zero. If α is 90 then the interplate surface is vertical and the pressure force is horizontal, therefore $F_p = F_{ph}$.

Point 9: This sentence should not be interpreted out of the context. In this paragraph we present how we will investigate the formation of trench-parallel shortening in the Andes. Numerical simulations have revealed that to favor trench-parallel shortening in the centre of the curvature we should not impose a large non-hydrostatic normal stress on the interplate zone. Now, in this study we point out that the compressive non-hydrostatic

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normal stress can be reduced because of the suction exerted by the slab. This is our recipe to reduce the compressive non-hydrostatic normal stress. We add that the reduction should not be too large. Otherwise we would produce trench-parallel tension, which is not bad in itself, but we don't want that if we are trying to model the Andes. The goal is to have stress conditions promoting both trench-perpendicular (testified by the mountain belts) and trench-parallel shortening near the centre of curvature. This is why we do not want to impose stress conditions generating trench-perpendicular tension. We rephrased this in order to make it clearer that this only applies to our goal of investigating the deformation in the central Andes.

Point 10: Yes some scaling factors are the wrong way around. We have corrected the values in the table.

Point 11: We added the experimental time and bulk shortening to each individual image on figures 7, 9, 11 and 12.

Interactive comment on Solid Earth Discuss., 3, 105, 2011.