Review of the PhD Thesis
The role of rheology and water in the deformation of subducting slabs
by Jakub Pokorný

Subduction dynamics is one of the critical challenges in contemporary geodynamical studies. Jakub Pokorný's thesis focuses on the role of complex non-linear rheology in the dynamics of subducting plates and aims also to explain some of the constraints revealed by recent seismological research in subduction zones.

The first part of the thesis includes the Introduction, a chapter focusing on the mechanical properties of the oceanic lithosphere with special attention to the roles of hydration and dehydration, and a subsequent chapter summarizing the system of equations that mathematically represent the physics of lithospheric subduction. This section is followed by three chapters published as separate articles in respected international journals. The sixth chapter presents unpublished results regarding the role of water, and the thesis concludes with a brief summary of findings.

The clear necessary condition for obtaining reasonable models of subduction dynamics is that the equations studied must express the fundamental physical laws of conservation, along with the mechanical properties of the lithosphere as defined by mineral physics. I believe that the system of equations described in Chapter 2 of the thesis is correct, but I would like to see more details regarding the numerical approach to the studied system of partial differential equations, such as:

Q1 *What type of finite elements were used, and how is the remeshing executed during the time evolution of the models being studied?*

Chapter 3 provides a detailed examination of the mechanical lubricating properties of the oceanic crust in the context of subduction. I greatly appreciate the systematic approach taken to explore this significant phenomenon. Rather than addressing all the results obtained, I will focus on several points that remain unclear to me:

Q2 *What is the effect of shear heating at the contact surfaces of the plates? I am also interested in the evolution of surface heat flow, although this topic falls outside the scope of the study presented in this chapter.*

Q3 *The viscosity of the decoupling layer is artificially increased at a depth of 150 km. Have you tested whether this increase affects the results?*

Q4 *Is there any physical significance to the exponent* n_y *in equations (2.11) and (3.3)? Is the choice of* $n_y = 10$ *based on specific numerical requirements?*

At the end of this paragraph, I would like to highlight that the pioneering studies in our department concerning the role of weak crust were conducted by Martin Kukačka two decades ago. Although his models lacked sophistication and were stationary, he provided valuable insights. Notably, he determined the unspecified position of the crust through the value of the stream function. Despite these differences, his conclusions regarding the relationship between the lubrication effect of the oceanic crust and the dip angle of the subducting lithosphere align closely with the findings presented in this thesis. I believe it is important to acknowledge his contributions in this context.

Chapter 4 seeks to address whether the seismically observed abrupt change in the stress regime within the subducting lithosphere of the Tonga region, occurring at a depth of 660 km, is primarily driven by bending forces acting on the relatively strong, cold lithosphere, or by buoyancy effects caused by a phase transition at that depth. The models indicate that bending forces are the predominant factor. However, I have some queries:

Q5 *I do not understand why metastable phases and grain-size weakening, which could potentially affect the strength of the lithosphere, were not included in the model. Was this omission due to numerical limitations? Additionally, I am unclear about the note on page 70 regarding the models of Fukao and Obayashi (2013).*

The analysis of lithospheric buckling resulting from sufficiently high velocities of subducting plates and their subsequent deceleration in the mantle is presented in Chapter 5. Both models that allow rollback and those that prohibit it can lead to buckling. This buckling is related to the periodically fluctuating plate velocities, which may provide a physical explanation for the recently observed oscillations in Indian plate velocities. The deceleration of the subducting plate is influenced by both mantle rheology and the phase transition occurring at a depth of 660 km. In this study, the rheological model is considered robust, as defined in Table 5.1, that may rise a question:

Q6 *What are your thoughts on the uncertainties in the determination of lower mantle viscosity and their potential impact on subtle subduction models such as those presented in this chapter?*

In Chapter 6, the author highlights the sensitivity of crustal rheology to hydration, demonstrating that this sensitivity can lead to dynamic effects that were examined in previous models, where the crust's ad hoc viscosity was considered. Notably, interesting new models emerge when water released from the crust hydrates the mantle accretionary wedge. However, there are several points that remain unclear to me:

Q7 *How does the water flux influence the energy balance?*

Q8 *Why does the sum of bound water, free water, and surface water flux, as shown in Fig. 6.3, decrease over time?*

Q9 *Will you address models that consider hydration in the rest of the upper mantle?*

Additionally, the author has included a simple kinematic model in the Appendix to illustrate the mechanisms of water transport.

Summary: This thesis presents the results of extensive and sophisticated research that addresses a range of geodynamic issues related to the subduction of oceanic lithosphere. A significant portion of the research has been published in reputable international journals. I also commend the author for drawing motivation from seismic observations in his research. The results clearly demonstrate his capacity for creative scientific inquiry.

I strongly recommend that Jakub Pokorný be awarded the PhD degree.

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