

Abstract: The process of subduction, a key driver of plate tectonics, has been intensively studied over the past few decades. Understanding the complex mechanisms that control subduction dynamics is essential for comprehending slab fate in the transition zone, stress distribution associated with deep seismicity, water transportation, but also changes in plate motions driven by variations in slab sinking speed. Previous studies have shown that the combined effects of the rheology of crust and mantle and phase transitions control the deformation of the subducting lithosphere in the deeper parts of the Earth's mantle. In this thesis, we use numerical modeling of subduction to further elaborate on the material properties that influence subduction.

It has been previously shown that magnitude of constant crustal viscosity plays an important role in the slab behavior. Here we build on these findings and concentrate on the impact of nonlinear crustal rheology. We find that there is a feedback between slab velocity and nonlinear crustal viscosity that enhances transient nature of slab behavior and eventually facilitates slab penetration to the lower mantle after a temporary period of stagnation in the transition zone (TZ). Further, we evaluate the effects of water present in the oceanic crust. We show that besides the direct weakening of initially wet crust, subduction is further accelerated through weak hydrated mantle wedge. On the other hand, low density of wet crustal material might reduce plate velocity considerably especially in early stages of subduction.

In the application part, we explain the unusual stress orientations associated with deep earthquakes in the Tonga region. We show that the direct buoyancy effects from the phase transition at 660 km depth are overprinted by forces related to slab bending. Change in stress orientation occurs as the slab, temporarily deflected by the 660 km phase transition, penetrates the lower mantle, tightening the fold in the flat-lying part. This behavior is seen in cold slabs with the viscosity interface shifted from 660 km to 1000 km depth. Finally, we link slab deformation in TZ with surface plate motions. We find that buckling in the TZ causes rapid plate velocity oscillations of the Indian plate, as recently indicated by plate reconstructions. We show that the amplitude and period of these oscillations are controlled by the average subduction velocity and space available in the TZ.