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Overriding plate deformation and its energy dissipation in three-dimensional subduction models

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Analogue and numerical models of subduction have been used to investigate overriding plate deformation during subduction. However, most models either exclude an overriding plate or impose an external force/velocity. Here, we present three-dimensional buoyancy-driven laboratory subduction models including an overriding plate to study the progressive deformation of the overriding plate during subduction. Considering there is uncertainty in the effective viscosity ratio between the subducting plate and sub-lithospheric upper mantle (η_{SP}/η_{UM}), a variability in overriding plate thickness (T_{OP}), and complexity of the far-field plate boundary conditions in natural subduction zones, we investigate models in which we vary $\eta_{SP}/\eta_{UM}$from 157 to 560, T_{OP} from 1.0 cm to 2.5 cm (scaling to 50-125 km in nature), and far-field plate boundary conditions of the overriding plate and subducting plate. Our results show that the variability of these three parameters has an influence on the patterns of overriding plate deformation. Furthermore, we have used the subduction models to quantify the force (F_{OPD}) that drives overriding plate deformation and the involved energy dissipation rate (Φ_{OPD}) during such deformation, and we compare them with the negative buoyancy (F_{BU}) and the total potential energy release rate (Φ_{BU}) of the subducted slab, respectively. In our models of narrow subduction zones (15 cm in experiment, scaling to 750 km in nature) the overriding plate always experiences overall extension during trench retreat. Overall, F_{OPD}/F_{BU} has average values of 0.5-2.5%, with a maximum of 5.0% and Φ_{OPD}/Φ_{BU}has average values of 0.10-0.30%, with a maximum of 0.70%, which indicate that only a small portion of the negative buoyancy of the subducted slab is used to deform the overriding plate and an even smaller percentage of the slab's potential energy is consumed during overriding plate deformation. In addition, our results show that 2-30% of the overriding plate energy dissipation is dissipated in the forearc region and 14-42% in the region of maximum backarc extension. Finally, our calculated force to deform overriding plate is of comparable magnitude as the ridge push force in nature.