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Three-dimensional Subduction Kinematics and Dynamics in shallow and deep Mantle Reservoirs

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Subducting slabs provide the main driving force for plate tectonics and mantle flow. The process of subduction has been simulated previously with numerical and physical experiments to investigate different aspects of subduction. The numerical simulations have almost exclusively treated subduction as a two-dimensional process, evidently neglecting complexities that arise from trench-parallel inhomogeneities in the overriding and subducting plate. Physical laboratory simulations of subduction are in this respect more realistic, as they were all conducted in three-dimensional space. However, most simulations had essentially two-dimensional parametric conditions (i.e. no variation in a direction parallel to the trench). First order observations of the Earth's surface, however, tell us that subduction zones are intrinsically three-dimensional due to their curved geometry, due to their limited lateral extent, and due to trench-parallel irregularities on both the subducting and overriding plate. For example, the width of slabs on earth varies considerably, from only a few hundred km (e.g. Calabrian slab and Scotia slab) up to some 6000-7000 km (Northwest Pacific slab and Nazca slab). The lateral (dis)continuity of such slabs is one of the most evident trench-parallel complexities that will have a significant influence on the subduction process and subduction-induced mantle flow. For a number of these slabs, the lateral extremities are defined by distinct sub-vertical edges, which appear to have a major influence on the local mantle flow pattern, as revealed by volcanic rock geochemistry and seismic anisotropy in the mantle.

Three-dimensional numerical and laboratory models have been built to investigate the influence of lateral slab edges on the subduction dynamics and flow processes in the mantle. The experiments model a dense high-viscosity plate (subducting lithosphere) overlying one or two lower-density lower-viscosity layers (sub-lithospheric mantle) confined in a 3D box. The simulations clearly illustrate the added complexity that evolves from simulating the subduction process in three-dimensional space. Results show that hinge-retreat is a natural consequence of subduction of a negatively buoyant slab. The lateral edges of slabs have a profound influence on the effectiveness of mass transfer of mantle material from one side of the slab to the other side. Slab rollback forces flow around the lateral slab edges, which again forces the slab to become convex toward the direction of retreat. This behaviour is observed in both the laboratory and numerical simulations. These results are in agreement with arc – back-arc systems, which generally have a convex shape towards the subducting plate side and for which mantle anisotropy suggests that mantle material flows around the lateral slab edges. Results will be presented showing subduction simulations for restricted mantle flow in a 670 km deep upper mantle reservoir and subduction simulations in deeper mantle reservoirs up to 2900 km deep.