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Lithospheric-scale Analogue Modelling of Bi-polar Continental Subduction: Implications on the Alpine Crustal Deformation

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Tomographic images from the Alps reveal southeasterly-directed subduction of the European mantle lithosphere in the central Alps and a north-easterly dipping subduction of the Adriatic mantle lithosphere underneath the Eastern Alps. We studied the deformation and surface expression of this lateral change in subduction polarity by using lithospheric-scale physical models. The parameter space investigated for uni-polar and bi-polar subduction systems of the continental lithosphere invoke: (a) the weakness of the plate interface, (b) the width of the transition zone between the oppositely dipping slabs and (c) the angle between the plate boundaries and the shortening direction.

The results of the analogue experiments show that upper crustal deformation initiated at the plate interface by the formation of a pop-up structure. In case of a vertical plate boundary no subduction or thrusting of the lower lithosphere occurred, instead the lithosphere was affected by large-scale folding coinciding with upper crustal thrusting. An inclined plate boundary resulted in lithosphere-scale thrusting and a significant amount of Moho displacement. The downgoing plate suffered upper crustal thrusting and the development of a foredeep basin. The thickness of the weak-zone interface plays a key role in the amount of continental subduction, and consequently on the onset of intraplate deformation, which occurs only after the weak interface is consumed or sufficiently thinned. However, a significant amount of mantle lithosphere subduction beneath a symmetrical wedge takes place only if the lower crust is weak enough to allow crust-mantle decoupling.

From the second series of bi-polar subduction it can be observed that the first pop-up structure is laterally continuous pointing out its independence on the vergence and obliquity of subduction. Ongoing deformation lead to the formation of a second pop-up structure on the downgoing plates resulting in lateral asymmetry and the development of a narrow transition zone. Experiments including oblique subduction show also wrench fault patterns between slightly rotated pop-ups. Cross sections illustrate an asymmetry in the upper crustal wedge with a clear pro- and retro- side. However, a wide and symmetrical orogen overlying a vertical slab of mantle lithosphere is characterizing the zone of subduction polarity change. The width of this symmetrical domain matches the width of the predefined transition zone between the oppositely dipping slabs. Oblique subduction resulted in space problems and finally to a collision between both slabs at depth.

Our modelling results can be compared with the crustal and lithosphere-scale structure of the Alps, where the orogenic wedge in the Western Alps is asymmetric and a relatively large pro-wedge overlays the downgoing European plate. Eastwards, the upper crustal deformation is more symmetrically distributed above both colliding plates, and the orogen widens reaching maximum values along the TRANSALP profile. Hence, lateral variations of the crustal architecture (symmetry of mountain belts) may be indicative for changes in the subduction polarity of the lower lithosphere.