Some mechanical aspects of collision and extension in the Eastern Alps: the Cretaceous event

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The Austroalpine unit represents at present the highest tectonic element of the Eastern Alps and contains abundant evidence for a continent-continent collisional event of Cretaceous age. Among others, the restored distribution of sedimentary facies within the Northern Calcareous Alps and the metamorphic signature of Cretaceous tectonics argue for a collision-related model to explain the observations.

The Cretaceous evolution of the Austroalpine unit is discussed on the basis of published P-T-t and structural data and numerical model predictions. The latter one provides valuable information on the possible mechanical evolution of collision zones within well defined boundary conditions. Keeping in mind that the geologic record points to continuous convergence during the Cretaceous, the Austroalpine unit seems to have experienced a three-phase tectonic evolution.

The first phase is characterized by crustal thickening that started within cover sequences (Northern Calcareous Alps) of the Austroalpine unit upon closure of the south to southeasterly-located Meliata Ocean as early as Mid Jurassic. Subsequent propagation of the deformation toward the west to northwest successively led to the incorporation of basement units in the subduction-collision process. Maximum pressure (P) and temperature (T) conditions have been estimated to be in the order of 1.8–2.0 GPa and 600–700 °C, respectively. The high-pressure metamorphism took place at ca. 100–95 My. During the major compressional phase, the thermal structure of the lithosphere is controlled by the subduction process such that the isotherms are dragged downward according to the imposed tectonic movement. As a consequence Austroalpine basement (Middle Austroalpine Unit) is emplaced underneath a strong mantle wedge of the overriding plate. The important implication of such a configuration would be that it prevents the already formed eclogites from strictly moving vertically toward shallower crustal levels. Isothermal exhumation of the eclogites could, therefore, have occurred for example by buoyancy driven reverse flow parallel to the subduction zone. During that second phase (ca. 95–90 My)ductile structures like thick shear zones (Plattengneis) or normal faults emphasize vertical shortening of the thickened crust. Major vertical movements related to the isothermal exhumation of the eclogites and the formation of metamorphic domes enforced advective heat transfer upward what results in weakening of the orogenic system.

During this stage of orogeny gravitational forces apparently have been released by ductile flow within lower structural levels. The third phase that covers approximately the time span from 90 My until the end of the Cretaceous is characterized by cooling of the basement and renewed accretion of material (Lower Austroalpine Unit) to the system. This phase coincides with detachment faulting along Upper–Middle Austroalpine interfaces and the formation of sedimentary basins on internal parts of the orogen commencing at ca. 86 My. According to analogue modelling, detachment-type deformation is promoted by the presence of low viscosity layers in the crust. Such a configuration most likely existed during the Late Cretaceous as indicated by the prevalence of extended low-strength regions in the center of the orogen.

The role of rheology in collisional orogenic settings: TRANSALP – a numerical and analogue approach

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We like to introduce a new ALW-project that aims to explore the role of rheology during Cenozoic continent-continent collision in the Eastern Alps. It forms an integral part of the international TRANSALP research programme studying the structure of the lithosphere across the Eastern

Alps through deep seismic profiling. Results of the TRANSALP deep reflection seismic profile together with data from other Earth Science disciplines and an already existing extensive database on the stratigraphic and P-T-t evolution of the Eastern Alps will be used to set up a three-dimensional (3D) numerical model for the collision zone and the adjacent foredeeps. Key questions relate to the influence of rheology on the geometry of the orogen, the topography and strain distribution in time. Dynamic modelling will be used to explore the interplay of lower crustal flow and concomitant brittle upper plate deformation during orogen-parallel extension and lateral escape tectonics and to study the mechanics of lower crustal wedging. Numerical modelling will be complemented by lithospheric-scale analogue modelling.

Emphasis will be put on lateral variations of lithospheric strength and its influence on the evolving geometry and topography of the orogen. Indentation experiments with rheologically stratified indenters will be performed to evaluate conditions for indenter deformation, and its influence on lateral escape tectonics. Thick-skinned analogue experiments will include subduction of the European continental lithosphere underneath that of the Adriatic plate. Computed tomography (CT) recording allows for continuous non-destructive analysis of experiments and the transfer of data to powerful work stations for detailed analysis of the kinematic, structural and topographic evolution of the collision zone. The proposed project represents a new research line that enables the exchange of data between numerical and analogue modelling. Of particular importance will be the feed-back relation between numerical and analogue modelling that complement each other. Comparison, validation and improvement are key aspects of the integrated approach that will lead to a higher precision in quantitative analysis of collision tectonics. On the other hand, process oriented modelling will shed light on the 3D dynamics of collision zones that ultimately control the build-up and destruction of mountain ranges.

Dynamic processes controlling foreland development – the role of mechanical (DE)coupling of orogenic wedges and forelands

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Depending on their position with respect to polarity of the subduction system controlling the evolution of an orogenic wedge, we distinguish between pro-wedge (fore-arc, foreland) and retro-wedge (retro-arc, hinterland) forelands. Flexural foreland basins can develop in retro-wedge domains of Andean-type and in pro- and retro-wedge domains of Himalaya-type orogens.

Whereas the subsidence of retro-wedge foreland basins is largely controlled by the topographic load exerted by the orogenic wedge on the foreland lithosphere, the subsidence of pro-wedge foreland basins is governed by the loads of the orogenic wedge and of the subducted foreland lithospheric slab. Forebulges of purely flexural orogin develop only if the orogenic wedge and the foreland lithosphere are mechanically decoupled. Under conditions of mechanical coupling between an orogenic wedge and its foreland, compressional stresses are transmitted into the latter, inducing reactivation of pre-existing crustal discontinuities and broad crustal and lithosphere scale buckling at distances of up to 1700 km from the collision front. Such stresses can overprint potential pre-existing flexural forebulges or impede or amplify their development. Moreover, depending on the rheological structure of the crust and the thickness of its sedimentary cover, thick- and/or thin-skinned thusts can propagate far into forelands, either destroying pre-existing flexural foreland basins or impeding their development.

Collision-related compressional stresses can be transmitted into pro-wedge forelands during 1) initiation of subduction zones, 2) periods of subduction impediment caused by the arrival of more buoyant crust at a subduction zone, 3) initial collision of an orogenic wedge with a passive margin, and 4) post-collisional over-thickening and uplift of an orogenic wedge and the development of a mantle-back-stop.

Development of intraplate crompressional/ transpressional structures in forelands is indicative for the build-up of collision related stresses, and thus for their strong mechanical coupling