Viscous overthrusting versus folding: 2D numerical modeling and application to the Helvetic and Jura fold-and-thrust belts

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The geometry of the Helvetic and Jura fold-and-thrust belts has been studied in detail since more than 100 years. However, the dynamics of the combined folding and thrusting are still incompletely understood. Two types of nappes have been described in the Alps: fold nappes and thrust nappes. While fold nappes are characterized by continuous sedimentary layers that can be traced back to their root (parautocthonous), thrust nappes exhibit a basal thrust (allochtonous). Detailed mapping in the Alps has shown that the tectonic style can vary laterally from fold to thrust type. Moreover thrust planes in the Helvetic nappe system and in the Jura are often folded and thrust nappes often exhibit considerable internal ductile deformation. It has been proposed that the pre-Alpine stratigraphy, especially the alternation between shales (weak) and limestone (strong), control the tectonic style of the nappes in the Helvetic and Jura fold-and-thrust belts.

We use 2-D numerical simulations of viscous flow to simulate the layer-parallel shortening of a strong viscous layer embedded in a weak viscous matrix, and above a flat detachment plane. A thin weak zone exists initially in the layer representing an initial discontinuity (e.g. thrust plane). We investigate systematically the control of (1) the ratio of the layer thickness to the matrix thickness (between the layer and basal detachment), (2) power-law versus linear viscous rheology and (3) the viscosity ratio between layer and matrix, on the deformation style. When the matrix is linear viscous, only thickening or folding of the layer occurs. When the matrix is power-law viscous (n=5), deformation occurs mainly by folding when the thickness ratio is >~1 and the viscosity ratio is >~10. Overthrusting of the layer occurs when the viscosity ratio is >~100 and the thickness ratio is <~1. Both overthrusting and folding can occur simultaneously for thickness ratios >~1 and viscosity ratios >~50.

Our simulations show that overthrusting is mechanically possible during dominantly viscous flow. The results support the interpretation that many structures in the Helvetic and Jura fold-and-thrust belt resulted from an effectively and dominantly ductile deformation. The results further show that for the same rheology but varying thickness ratio the deformation style can vary from folding-dominated to overthrusting-dominated, which is in agreement with observations in the Helvetic and Jura fold-and-thrust belts.

Orogen-parallel exhumation and topographic gradients east of the Tauern window: a possible clue for shear strength at depth and intra-orogenic raft tectonics

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The interplay of indentation by the Southalpine indenter, surface uplift and exhumation of the Tauern window characterizes the post-collisional Late Oligocene to recent evolution of the central sectors of the Eastern Alps. Strong Miocene E-W extension, basement subsidence in the Pannonian realm and surface uplift in the Tauern window area created an E-W topographic and exhumation gradient allowing the brittle upper crust to move along the mid-crustal ductile decollément level towards the east. The purpose of this study is to estimate the critical topographic angle of the brittle upper crust to move along the basal viscous layer. Subject of research is the area between the viscously behaving Penninic zone of the eastern Tauern Window and the brittle-behaving Austroalpine basement units with its Neogene basins on top. We use published apatite fission track (AFT) and (U-Th)/He data from two sections of the Hohe Tauern to the east to constrain the E-W exhumation gradient. We also consider partitioning of translation of the Austroalpine crust by ca. ENE-trending orogen-parallel Oligocene faults separating the Hohe Tauern from the Northern Calcareous Alps, respectively the combined Hohe Tauern/Niedere Tauern block from the Nock/Gurktal/Murau Mts. domains. For comparison, we include an E-W section along the southern Northern Calcareous Alps and sections along the SEMP and Mur fault zones. Assuming a thermal gradient of 30 ºC/km, we find a similar gradient of ca. 0.04 for both basement sections. This low gradient is close to a gradient typical for viscous material with low shear strength. These relationships imply that gravitational collapse alone might be sufficient to explain the eastward motion of the brittle Austroalpine crust over a thick viscous layer. Flow above a low-friction viscous layer also explains the eastward tilting of blocks like the Saualpe and Koralpe blocks along antithetic high-angle normal faults. Together, the area east of the Tauern window could be explained by intra-orogenic raft tectonics.

Deformation within a subduction channel at eclogite facies conditions and consecutive exhumation: The Eclogite Zone of the Tauern Window, Austria

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Many recent models for the exhumation of subducted oceanic crust assume corner flow in a subduction channel and exhumation of the very dense metabasites, i.e. eclogites, within a buoyant melange of serpentinites or metasediments. The Eclogite Zone of the Tauern Window represents a paleo-subduction channel in the Eastern Alps, which formed during the subduction of the Penninic ocean beneath the Adriatic continent in the Tertiary. It comprises metasediments as well as large metabasite lenses. Since serpentinites are very rare and occur only in small patches in the western Tauern Window, the metasediments are likely to be the buoyant medium for the exhumation of the eclogites. The Eclogite Zone was exposed to P/T-conditions of 20 - 25 kbar and 600±30°C and exhumed in a very short time span of 1 - 2 Ma. Most of the deformation of this rapid exhumation was presumably concentrated in the metasediments almost exclusively displaying the retrograde mylonitization. This is due to the rheological weakness of gneisses, schists, and marbles in comparison to the metabasites. In addition, the large strains required for exhumation caused a penetrative amphibolite to greenschist facies overprinting. Although only weakly deformed, the metabasites show almost the complete deformation history comprising localized eclogite facies shear zones and the whole amphibolite to greenschist facies deformation sequence during exhumation. The foliation consistently dips to the SSE with 70-85° demonstrating the long-standing operation of this shear plane orientation. However, the omphacite stretching lineation plunges SW, while the hornblende stretching lineation is WSW-plunging to sub-horizontally W-trending.

The structural field mapping is completed by microstructural analyses and crystallographic preferred orientation (CPO) measurements. The variable foliation intensity corresponds to a wide range of CPO intensities. In eclogites indicative of dynamic recrystallization of omphacite and garnet, omphacite exhibits a pronounced CPO. Weaker CPOs of other eclogite samples reveal strain gradients and localized deformation. Occasionally, the hornblende CPO mimics the omphacite CPO arguing for a static overprint. In contrast, differing omphacite and hornblende CPOs indicate ongoing deformation during exhumation. The metasedimentary rocks show a strong mica foliation with a pronounced muscovite CPO. The quartz CPO in the metasediments indicates simple shear deformation with top to the NE sense of shear.