THREE-DIMENSIONAL HYDRODYNAMIC NUMERICAL MODELLING OG FOLD NAPPE FORMATION, BASEMENT-COVER DEFORMATION AND SLAB DETACHMENT WITH APPLICATIONS TO THE HELVETIC NAPPE SYSTEM (W SWITZERLAND)

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Summary

Many three-dimensional (3-D) structures in rock, which formed during the deformation of the Earth's crust and lithosphere, are controlled by a difference in mechanical strength between rock units and are often the result of a geometrical instability. Such structures are, for example, folds, pinch-and-swell structures (due to necking) or cuspate-lobate structures (mullions). These structures occur from the centimeter to the kilometer scale and the related deformation processes control the formation of, for example, fold-and-thrust belts and extensional sedimentary basins or the deformation of the basement-cover interface. The 2-D deformation processes causing these structures are relatively well studied, however, several processes during large-strain 3-D deformation are still incompletely understood. One of these 3-D processes is the lateral propagation of these structures, such as fold and cusp propagation in a direction orthogonal to the shortening direction or neck propagation in direction orthogonal to the extension direction. Especially, we are interested in fold nappes which are recumbent folds with amplitudes usually exceeding 10 km and they have been presumably formed by ductile shearing. They often exhibit a constant sense of shearing and a non-linear increase of shear strain towards their overturned limb. The fold axes of the Morcles fold nappe in western Switzerland plunges to the ENE whereas the fold axes in the more eastern Doldenhorn nappe plunges to the WSW. These opposite plunge directions characterize the Rawil depression (Wildstrubel depression). The Morcles nappe is mainly the result of layer parallel contraction and shearing. During the compression the massive limestones were more competent than the surrounding marls and shales, which led to the buckling characteristics of the Morcles nappe, especially in the north-dipping normal limb. The Doldenhorn nappe exhibits only a minor overturned fold limb. There are still no 3-D numerical studies which investigate the fundamental dynamics of the formation of the large-scale 3-D structure including the Morcles and Doldenhorn nappes and the related Rawil depression. We study the 3-D evolution of geometrical instabilities and fold nappe formation with numerical simulations based on the finite element method (FEM). Simulating geometrical instabilities caused by sharp variations of mechanical strength between rock units requires a numerical algorithm that can accurately resolve material interfaces for large differences in material properties (e.g. between limestone and shale) and for large deformations. Therefore, our FE algorithm combines a numerical contour-line technique and a deformable Lagrangian mesh with re-meshing. With this combined method it is possible to accurately follow the initial material contours with the FE mesh and to accurately resolve the geometrical instabilities. The algorithm can simulate 3-D deformation for a visco-elastic rheology. The viscous rheology is described by a power-law flow law. The code is used to study the 3-D fold nappe formation, the lateral propagation of folding and also the lateral propagation of cusps due to initial half graben geometry. Thereby, the small initial geometrical perturbations for folding and necking are exactly followed by the FE mesh, whereas the initial large perturbation describing a half graben is defined by a contour line intersecting the finite elements. Further, the 3-D algorithm is applied to 3-D viscous nacking during slab detachment. The results from various simulations are compared with 2-D resulats and a 1-D analytical solution.