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Numerical models of sheath fold development in rheologically heterogeneous rocks of the Cima Lunga-Adula shear zone (Central Alps)

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Highly curvilinear folds develop during simple shear deformation due to perturbations in the velocity field around the inclusion heterogeneity. In the field, such structures may be recognized at the micro- and meso-scale within high-strain crustal-scale shear zones. However, at scarce outcrop conditions, fragments of these structures are often interpreted as generated by poly-phase deformation. The structural history becomes even more complex when the deformation within the inclusion is considered. In this inclusion-matrix deformation system, two end-member regimes has been already investigated: (i) a weak ellipsoidal inclusion that acts as a slip surface over which sheath folds develop and (ii) a rigid ellipsoidal inclusion that rotates within the matrix generating sheath folds in the back of the rotating ellipse in direction of the shearing. Between these two end-members, understanding the clast-matrix deformational regime is not trivial and the genesis of sheath fold is unexplored.

We employed 3D numerical models to study fold structure evolution around an ellipsoidal inclusion within a matrix during simple shear. Both inclusion and matrix were homogeneous and isotropic, and had linear viscous rheologies. We tested models with different (i) initial inclusion aspect ratio, (ii) viscosity ratio between the inclusion and the matrix, and (iii) strain. We identified three main deformation regimes that are closely related with the behaviour of the inclusion. In the first regime, the inclusion experiences massive stretching. In the second regime, we observe oscillatory motion of the principal inclusion axes and the deformation of the material lines within inclusion periodically changes from shortening to stretching conditions. In the third regime, principal inclusion axes rotate. The material lines within inclusion, similar as in the second regime, experience cyclic stretching and shortening, however, the amount of extension and shortening is significantly smaller. The transition between regimes is dependent of both initial inclusion aspect ratio and viscosity ratio. The first regime is characteristic for inclusions with small viscosity ratio. With increasing viscosity ratio, the regime changes to the second and eventually to the third. The change occurs at lower viscosity ratio for models with larger initial inclusion aspect ratio than for smaller once. All the models developed sheath folds around the inclusions.

The results of our simulations were compared with the deformation pattern derived from a main shear zone of the Cima-Lunga in the Central Alps. In the field, the elongated high-pressure

ultramafic bodies are surrounded by folded amphibolite-facies paragneisses that locally depict sheath folds. The internal structures of ultramafic bodies are characterized by recumbent, sub-isoclinal folds and folded boudinaged mafic layers that suggest internal changes in stress direction. In a selected ultramafic body elongated sub-parallel to the shearing direction and with an aspect ratio $a/c=3$ and $b/c=2$, we estimate from a mafic boudinaged layer subparallel to the a/c axis a minimum stretching of 40%. This field data allowed us to establish that the viscosity ratio of the ultramafic body to the paragneisses at the time of the deformation of the shear zone was in the range of 4-11 and the strain was $\gamma > 13$.