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A combined analytical and experimental study on the formation of sheath folds

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The term ‘sheath fold’ describes a cone-shaped structure with a rounded apex. Such folds can occur in all rock-types and range in size from sub-millimeters to kilometers. They are in many cases associated with shear zones and shear deformation.

Even though sheath folds are three-dimensional structures they are rarely exposed as such. In the field they are more commonly recognized in cross-sections perpendicular to the shear direction where they exhibit eye-structures.

How sheath folds form and how they evolve with increasing strain is still a matter of debate. Several mechanisms for the sheath fold development have been proposed, such as the passive amplification of pre-existing structures, for example buckle folds, or the disturbance of the flow in simple shear by, for example, weak or rigid inclusions.

In this study we trigger the sheath fold development with a slip surface (weak inclusion) embedded in a layered matrix subjected to simple shear. We study the impact of the slip surface orientation, the cross-section location, the viscosity ratio between the layers and the layer thickness on the evolving eye-structures. To address these questions we employ a combined approach of analytical and experimental modeling.

In the analytical model setup we place an elliptical, weak inclusion, acting as a slip surface, in a stiff matrix and apply simple shear of up to γ=10. The analytical model is three-dimensional where the flow around the inclusion is obtained with an adapted external Eshelby solution for incompressible viscous materials in the limit of an elliptical and inviscid inclusion. The evolving structures are visualized by tracking passive marker layers in the matrix. We tested the influence of the initial inclusion orientation (0°, 90°, or 135° with respect to the shear direction) on the development of sheath folds. The analytical model shows that the sheath folds and consequently eye-structures develop irrespectively of the initial inclusion orientation. However, the shapes of the folds depend on the initial slip surface orientation as well as on the applied shear strain.

As the analytical model does not consider a heterogeneous matrix, we designed experimental models to test the effect of mechanical layering (viscosity contrast, layer thickness) on the geometry of the eye-structures. The layered rock was simulated using silicons of different viscosities, in which a slip surface was embedded. The model underwent deformation in a simple shear apparatus to a shear strain of γ=6. To analyze the results we cut the models in serial cross-sections perpendicular to the shear direction. The results show that sheath folds also develop in a layered matrix with a viscosity contrast between the layers from up to 20. The thickness of the layers has a strong impact on the visibility of the eye-pattern.

Results from the analytical and experimental study show that sheath folds form around a slip surface in simple shear. The orientation of the slip surface and the viscosity ratio between the layers play a minor role on the development of the sheath folds, while the layer thickness has a big influence on their visibility. Both models capture the first order observations and variety of shapes in nature.