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The neutral lines in buckle folds

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The concept of the neutral line in a buckle fold is fundamental in structural geology. The neutral line divides the outer arc of a fold where layer-parallel extension occurs from the inner arc where layer-parallel compression occurs. Indeed, in nature outer-arc-extension-structures, such as mode 1 fractures normal to the layer, and inner-arc-compression-structures, such as enhanced cleavage development or pressure solution, can be observed.

In the past, the neutral line has often been used for the kinematic construction of folds. The technique that has been used is called neutral line folding or tangential longitudinal strain folding and the fold is constructed from a given neutral line geometry. One of the necessary and fundamental assumptions for these fold construction techniques is that the neutral line is continuous along the folded layer.

In this study, the neutral line is calculated for the first time in a mechanically calculated fold, rather than in a kinematically constructed one. The finite element method is used to numerically buckle an individual layer and a multi-layer sequence with Newtonian viscous rheology. The strain distribution resulting from the numerical simulations is used to calculate the neutral line. The findings of this study are:

1. Two neutral lines have to be distinguished, the finite neutral line and the incremental neutral line. The former is the zero-contour line of the finite layer-parallel strain, the latter is the zero-contour line of the strain rate.

2. Both neutral lines are not continous along the folded layer, but terminate at the bottom or top interface of the layer.

3. The neutral lines start to develop at the hinge point at the outer arc and first encircle a small area at the outer arc. They move through the layer and, in a late stage of the folding process, encircle a small area at the inner arc.

4. The incremental neutral line develops first and then moves through the layer ahead of the finite neutral line.

5. The finite neutral line does not always develop, depending on the viscosity contrast between the folded layer and the surrounding matrix and on the initial perturbation of the layer. The incremental neutral line always develops when folding is strong enough.

6. In a multi-layer folding scenario, the neutral lines in the individual layers develop differently and in a complex way.

The development of some fold-related structures (e.g., fractures) depends on the momentary state of the fold, others (e.g., cleavage) depend on the folding history. Therefore, the new findings of this study are of great relevance when interpreting fold-related structures, such as outer-arc-extension-structures and inner-arc-compression-structures. Also, this study shows that fundamental assumptions of kinematic fold constructions, such as tangential longitudinal strain folding or neutral line folding, are wrong.