Neutral lines in buckle folds

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The neutral line is a fundamental concept in structural geology. It 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 extensional fractures normal to the layer, and inner-arc-compression-structures, such as enhanced cleavage development or pressure solution, can be observed.

In the past, folds have often been constructed kinematically from an assumed neutral line geometry (i.e., tangential longitudinal strain or neutral line folding). 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. From the numerically calculated strain distributions two neutral lines can be calculated:

1. The incremental neutral line (zero-contour line of the strain rate)
2. The finite neutral line (zero-contour line of the finite layer-parallel strain)

The former develops first and then moves through the layer ahead of the latter. The results show that both neutral lines are not continuous along the folded layer, but terminate at the bottom or top interface of the layer. They start to develop in the hinge area and first encircle a small area at the outer arc. They move through the layer from the outer towards the inner arc and encircle a small area at the inner arc in a late stage of the folding process. For some cases, depending on the viscosity ratio between layer and matrix and on the initial perturbation of the layer, the finite neutral line does not develop at all. However, the incremental neutral line always develops when folding is strong enough.

For multi-layer folding, the neutral lines in the individual layers develop differently and in a much more complex way compared to the single-layer case. The new understanding of the dynamics of the two neutral lines is discussed in light of interpreting fold-related structures, such as outer-arc-extension-structures and inner-arc-compression-structures, because their development depends either on the momentary state of the fold (e.g., fractures) or on the folding history (e.g., cleavage, pressure solution).