3D fold growth in transpression

(Paul Niggli Medal Lecture)

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Geological folds in transpression are inherently 3D structures; hence their growth and rotation behavior is studied using 3D numerical finite-element simulations (Figure 1). Upright single-layer buckle folds in Newtonian materials are considered, which grow from an initial point-like perturbation due to a combination of in-plane shortening and shearing (i.e., transpression with convergence angle α). The resulting fold growth exhibits three components (Figure 2):

1. Fold amplification (vertical): Growth from a fold shape with low limb-dip angle to a shape with larger limb-dip angle.

2. Fold elongation (parallel to fold axis): Growth from a dome-shaped (3D) structure to a more cylindrical (2D) structure.

3. Sequential fold growth (perpendicular to axial plane): Growth of new anti- and synforms adjacent to the initial isolated fold.

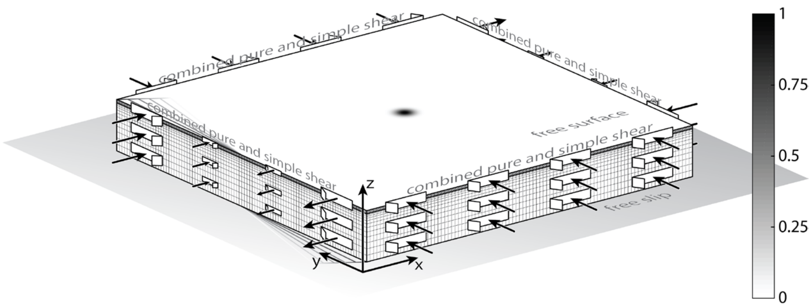

Figure 1. Finite-element model setup and boundary conditions. A higher-viscosity layer is resting on a matrix layer. Gray levels represent the initial Gaussian topography.

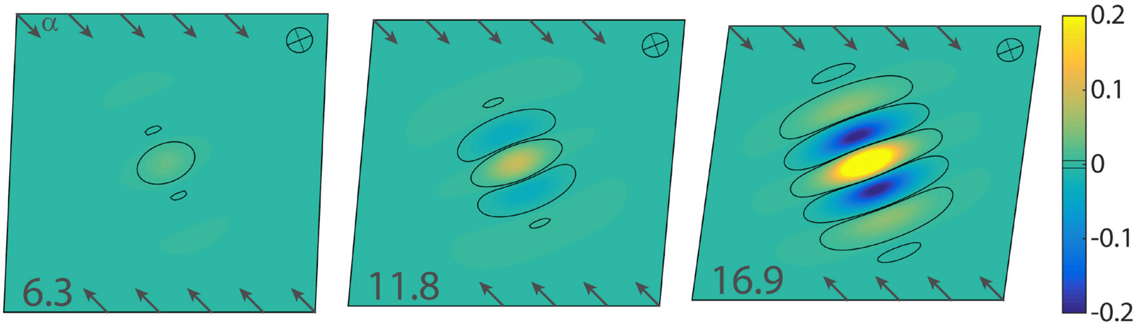

Figure 2. Top view of example numerical simulation with convergence angle α=45°. Background strain, ε_{bg} (given in %) is increasing from left to right. Colors represent the vertical fold amplitude; black contour lines mark half the initial value (A_0/2) defining the individual sequential folds. Each upper-right corner shows the horizontal strain ellipse with its major and minor axes.

Generally, the numerical simulations show that the fold growth rates are smaller for shearing-dominated than for shortening-dominated transpression. In spite of the growth rate, the folding behavior is very similar for the different convergence angles and similar to the previously studied pure-shear case (Frehner, 2014). In particular, the two lateral directions always exhibit similar growth rates implying that the bulk fold structure always occupies a roughly circular area.

Fold axes are always parallel to the major horizontal principal strain axis (λ_{max}, i.e., long axis of the horizontal finite strain ellipse, Figure 2 & 4), which is initially also parallel to the major horizontal instantaneous stretching axis (ISA_{max}). After initiation, the fold axis rotates with λ_{max} (Figure 2 & 4). Sequential folds appearing later do not initiate parallel to ISA_{max}, but parallel to λ_{max}, i.e. parallel to the already existing folds, and also rotate with λ_{max}. Therefore, fold axes are not passive material lines and hinge migration takes place as a consequence.

The numerical results are used to explain the fold axis rotation data of the transpressional analog models of Leever et al. (2011). The model fits the data very well confirming the fold axis rotation with λ_{max}.

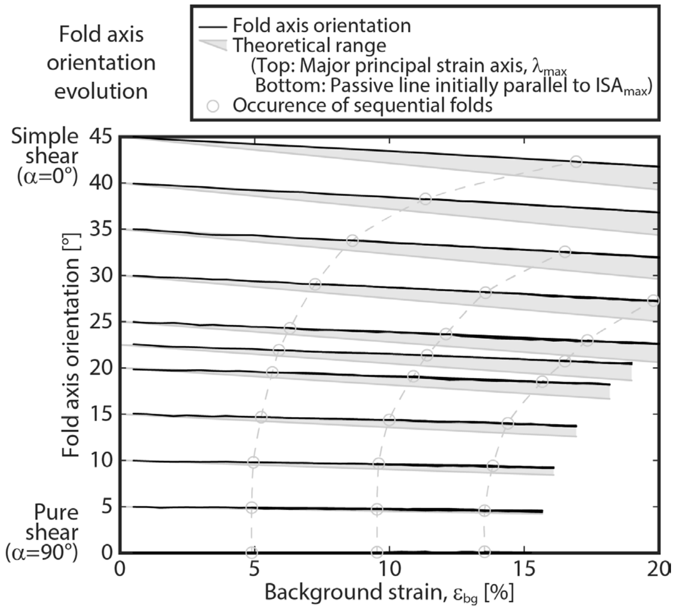

Figure 4. Evolution of fold axis orientation in top view of all individual sequential folds (individual anti- and synforms; black lines) with increasing background strain, ε_{bg}, and for different convergence angles (from α=0°, simple shear to α=90°, pure shear). Gray areas: theoretical range of fold axis orientation (Fossen et al., 2013).

ACKNOWLEDGEMENTS
I thank the Paul Niggli Foundation and the Swiss Society of Mineralogy and Petrology for awarding me with this medal. As this is the medal lecture, I will allow myself to begin the presentation with a short overview of my past research, for which I receive the Paul Niggli Medal.

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