Fold axis rotation during transpressional folding: Insights from numerical modeling and application to the Zagros Simply Folded Belt

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Introduction

Transpression is a combination of strike-slip deformation and shortening orthogonal to the deformation zone. Transpressional structures generally form in response to obliquey convergent plate motions. Whereas transpression in the upper crust is dominantly accommodated by faulting, viscous parts of the lithosphere accommodate transpression dominantly by folding. In some cases, transpressional strain is geographically partitioned (Tikoff and Teyssier, 1994) between a strike-slip domain lacking major shortening structures and a neighboring pure-shear domain (e.g., fold-and-thrust belt) lacking major strike-slip structures.

Transpressional folding is inherently 3D; hence the growth and rotation of folds during transpression as a function of the convergence angle is investigated using 3D numerical finite-element models (Figure 1; Frehner, in press). The studied model setup comprises upright single-layer buckle folds in Newtonian materials, which grow from an initial point-like perturbation due to a combination of in-plane shortening and shearing (i.e., transpression).

Results

The numerical study suggests that fold axes are always parallel to the major horizontal principal strain axis (λ_{max}), and that sequential folds appearing later form parallel to already existing folds and rotate with the major horizontal principal strain axis with increasing strain. This suggests that fold axes are not passive material lines and that fold hinge migration occurs during transpression.

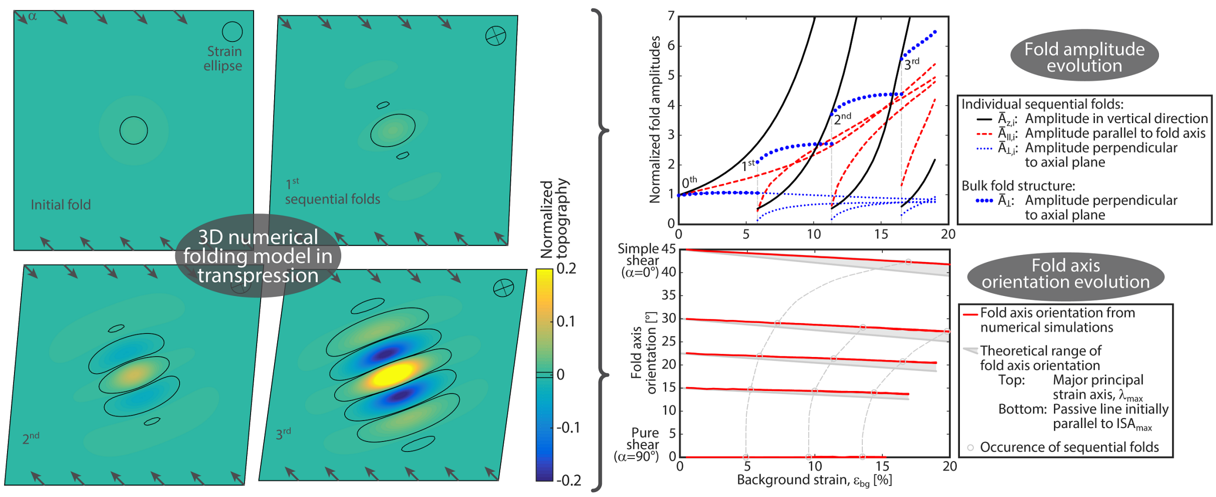

Figure 1: Graphical abstract of main results. Left: Top view snapshots of example simulation with a convergence angle, α=45°. With increasing background strain, the fold structure grows in all three dimensions. Top right: From the numerical simulation the fold amplitude evolution is calculated in three directions: vertical (fold growth), parallel to the fold axis (fold elongation) and perpendicular to the axial plane (sequential fold growth). Bottom right: Fold axis orientation in map view with increasing background strain for different convergence angles (α=0°–90°). For all cases, the fold axis is always parallel to the major principal strain axis, λ_{max}; hence it is not a passive marker line.

Because the fold axis is always parallel to λ_{max}, there is an analytical triangular relationship between the convergence angle, the amount of strain, and the fold axis orientation. If two of these values are known, the third can be determined. Importantly, this relationship is independent of the viscosities and viscosity ratios involved in the folded layers.

Application to the Zagros Simply Folded Belt

For the Zagros Simply Folded Belt (ZSFB) in NE Iraq, the far-field convergence angle (from GPS; Vernant and Chéry, 2006) is α=35°. Strain is partitioned between the ZSFB and the bounding fault system. However, the degree of partitioning is disputed, ranging from full partitioning (α=90° in the ZSFB; Talebian and Jackson, 2004) to intermediate partitioning (α=60° in the ZSFB; Vernant and Chéry, 2006). Zero strain partitioning (α=35° in the ZSFB) is unrealistic because some strike-slip movement along the MZT-MRF-system is clearly documented (Talebian and Jackson, 2002).

The above mentioned triangular relationship is applied to the Zagros fold-and-thrust-belt to estimate the degree of strain partitioning between the ZSFB and the bordering strike-slip fault-system (Figure 2). Despite some data scatter, the orientation of the majority of fold axes indicates a convergence angle within the ZSFB of α=60°–90°, confirming the proposed range. However, the data covers this entire range; hence it is not clear which end-member model is more appropriate.

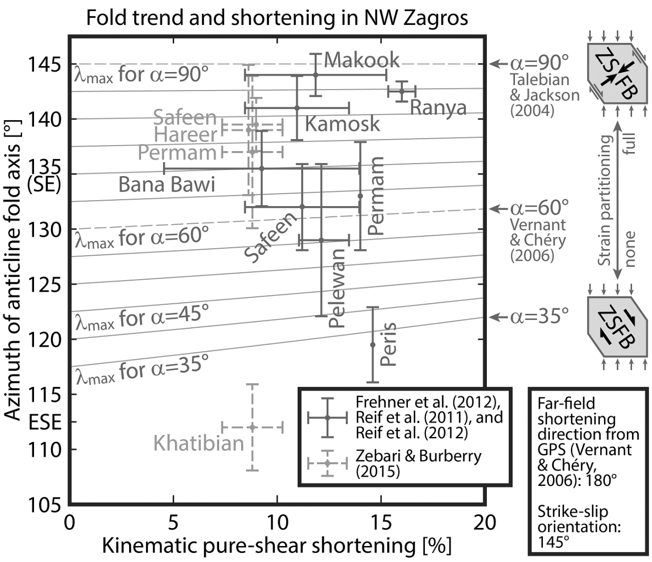

Figure 2: Fold axis orientations plotted versus kinematic strain estimates of anticlines in the ZSFB (NE Iraq). In the background, the theoretical fold axis orientation, λ_{max}, is plotted for different convergence angles. End-member convergence angles are sketched on the right based on the far-field shortening direction and strike-slip fault orientation; they are 90° (pure shear) for full strain partitioning and 35° for zero strain partitioning.

References

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Keywords

Buckle folds, Transpression, Fold growth, Hinge migration, Fold rotation, Zagros fold-and-thrust-belt