Mechanical versus kinematical shortening reconstructions of the Zagros High Folded Zone (Kurdistan Region of Iraq)

Marcel Frehner
Daniel Reif
Bernhard Grasemann

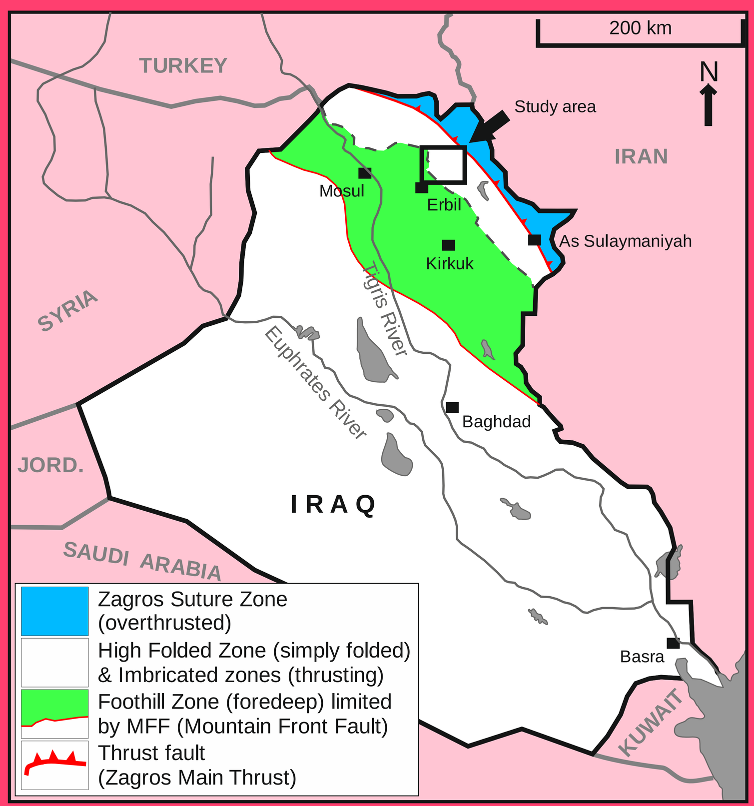
ETH Zurich, Switzerland
University of Vienna, Austria

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

universität wien

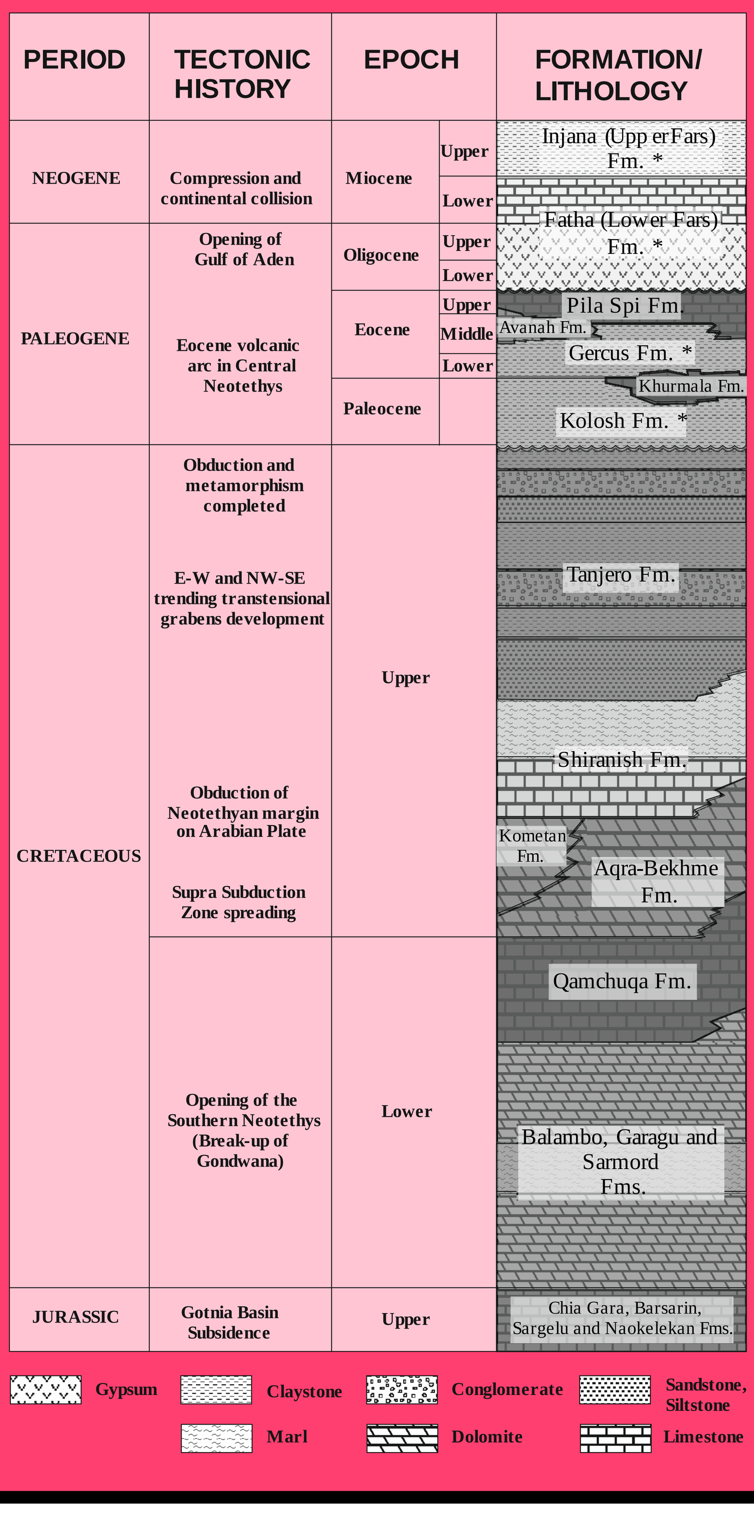
First author contact:
marcel.frehner@erdw.ethz.ch

Geological setting



Position of the study area in the High Folded Zone of the Zagros fold-and-thrust belt.

Stratigraphic column of the study area after Sissakian et al. (1997). Formations containing low-shear-strength layers are denoted by asterisks.



Geological map of the study area after Sissakian et al. (1997) with the positions of the 55.5 km long cross section. The shortening of several short balanced cross-sections is kinematically calculated as (1) 4.5%, (2) 14%, (3) 14%, (4) 15.3%, (5) 16.9%, (6) 14.6%, and (7) 13.5%, which shows an increasing deformation from SW to NE.

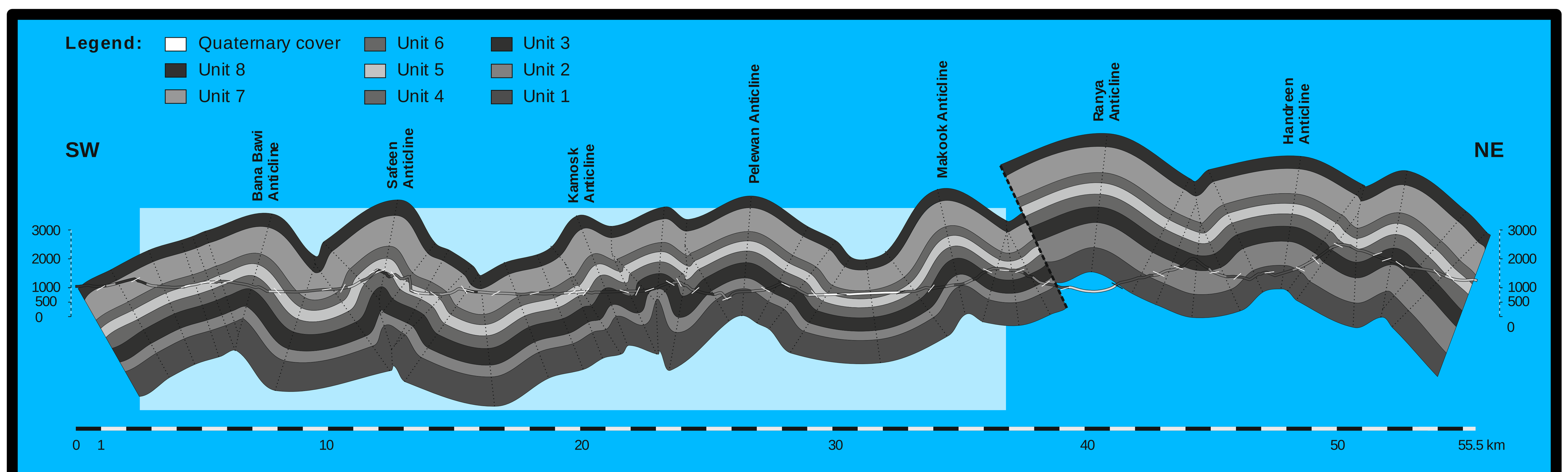
Regional geology

- Precambrian polymetamorphic basement
- 8 im thick sedimentary sequence (starting Late Permian)
- 4 NW-SE striking tectonic zones (Suture Z., Imbricated Z., High Folded Z., Foothill Z.)

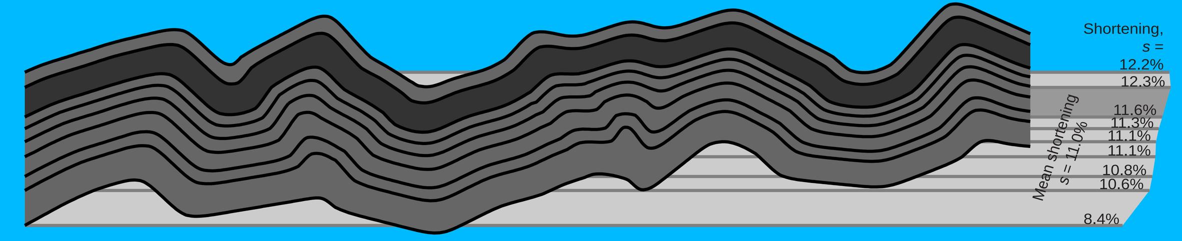
Zagros HFZ

- No major detachment
- No evidence of significant faults
- Dominated by harmonic open folds

Balanced cross-sections



Balanced cross-section constructed from field and remote sensing data using the dip domain method. The location of the cross-section is shown in the geological map. The offset of the thrust fault in the NE part of the cross-section is unknown. The part of the cross-section used in the numerical simulations is highlighted in light blue.



Kinematical unfolding (constant arc length) of the part of the folded profile that is used for the dynamical unfolding simulations.

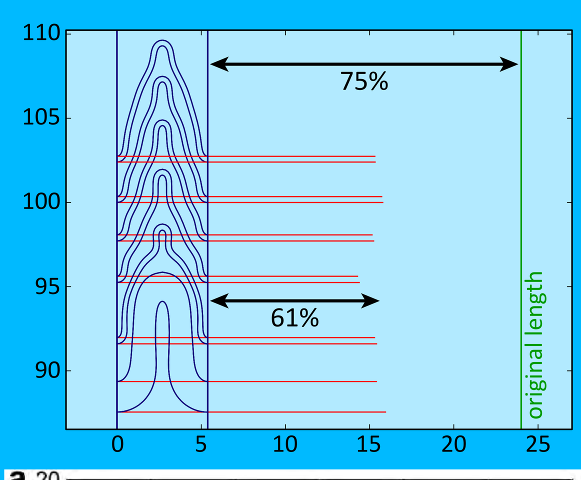
Kinematical shortening estimates:

- Dip domain method using the whole cross-section: 15%
- Constant arc length method using the part without fault: 11%

Drawback of kinematical reconstruction

- Purely geometrical (e.g., constant area, constant arc length)
- Many assumptions
- "No physics"
- "No mechanics"
- Pure-shear shortening and thickening prior to buckling initiation is not included in kinematical reconstruction methods

From Lechmann et al. (2010)

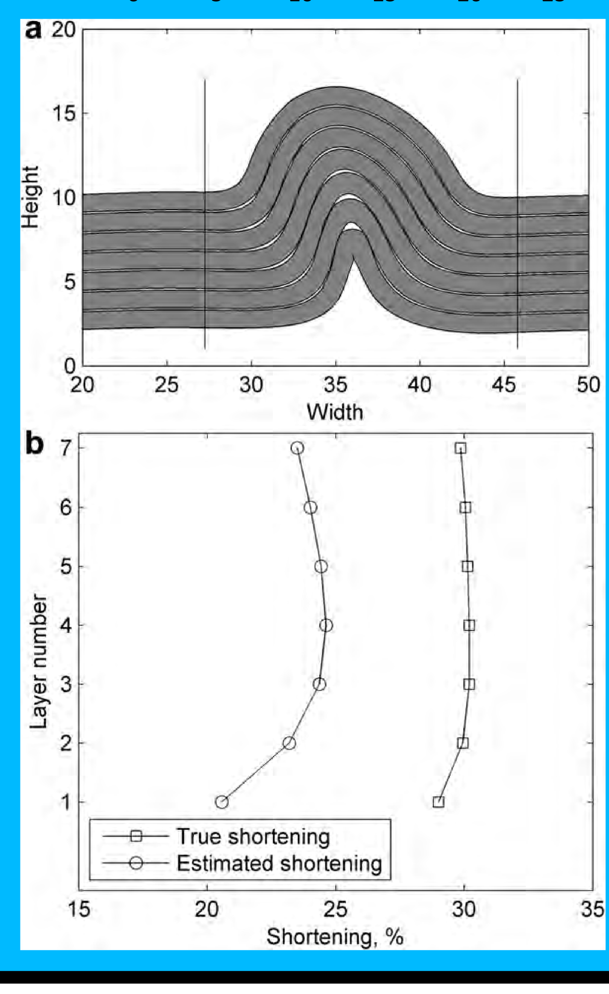


Lechmann et al. (2010)

- Numerical forward simulation of Newtonian buckle folding of multilayers (viscosity ratio 1:50) (green to blue in figure)
- Kinematical constant arc length reconstruction (blue to red)
  - Mismatch between the two: 19% average error

Ghassemi et al. (2010)

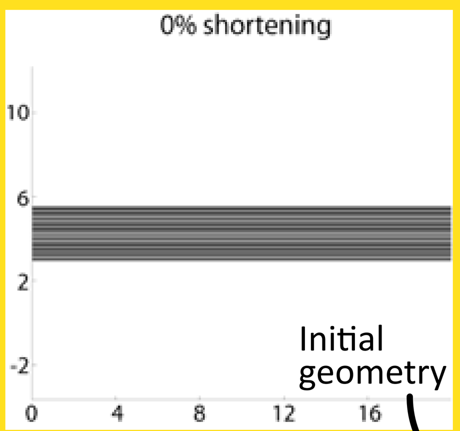
- Numerical forward simulation of power-law (n=5) viscous buckle folding of multilayers (viscosity ratio 1:100)
  - Kinematical constant arc length reconstruction
    - Mismatch between the two: 20% average error



From Ghassemi et al. (2010)

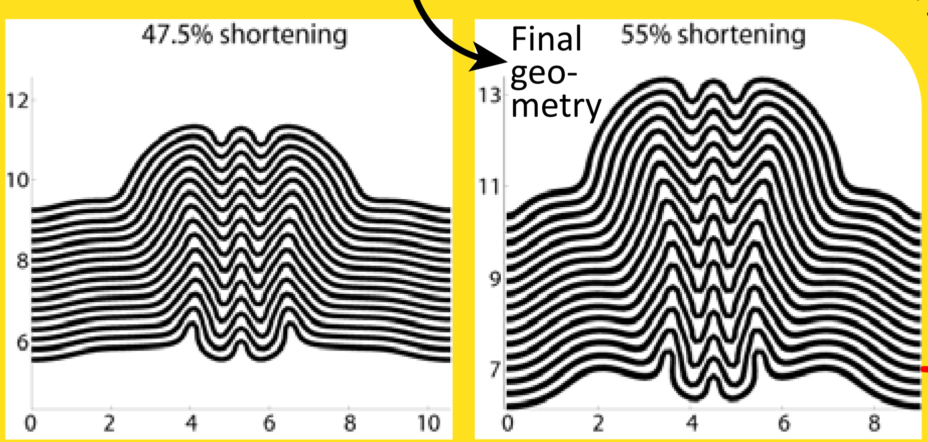
Dynamical unfolding

Basic idea

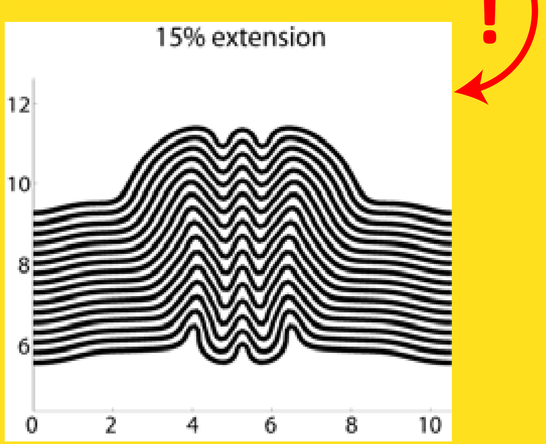


Forward:

- Buckle folding from initial geometry to final fold geometry
- This is the natural folding process.
- In the figure, it is a numerical model.



Figures from S.M. Lechmann



Dynamical unfolding works theoretically in

- 3D for Newtonian media (Schmalholz, 2008) and
- 2D for Newtonian and power-law viscous (n=3) media (Lechmann et al., 2010).

This study is only the second that applies dynamical unfolding to natural folds after Lechmann et al. (2010).

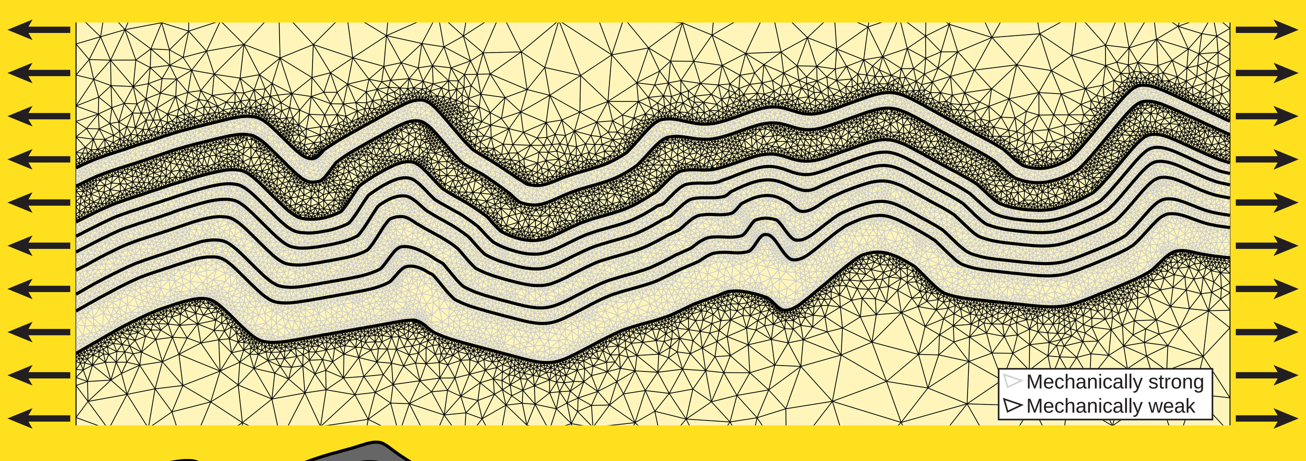
Unfolding:

- Use the present-day (final) fold geometry as the initial setup of a numerical model.
- Apply extensional boundary conditions in the horizontal direction.
- This unfolds the cross-section.
- Dynamic unfolding simulations correspond to a reverse-time simulation.

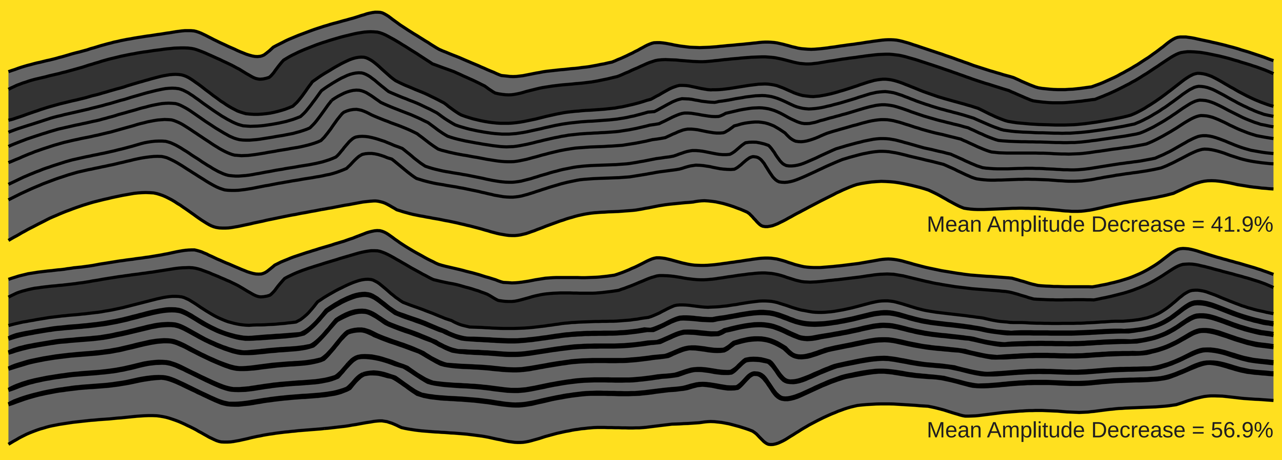
- The numerical approach allows including rheological parameters.
- Dynamical unfolding includes pure-shear thickening prior to buckling initiation.

Application to the Zagros HFZ

Geological section discretized with triangular finite-element mesh:



- *T7/3-elements*
- *Mixed v-p-formulation*
- *Uzawa iteration to enforce incompressibility*
- *Piccard iteration for power-law rheology*
- *Welded interfaces*
- *Interfacial slip conditions: thin weak layers*
- *Viscosity ratio = 1:100*
- *BC's: base: free slip, top: free surface, left and right: constant horizontal strain rate*

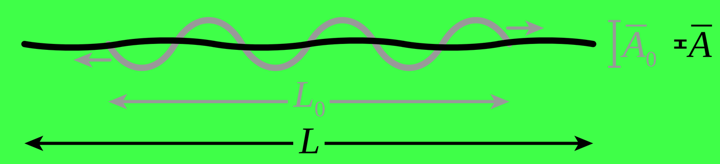


Dynamical unfolding simulations after a horizontal shortening of 11.0% (kinematical shortening estimate), Newtonian rheology, and no basement.

***Upper:** Welded interfaces*
***Lower:** Interfacial slip conditions: Unfolding is more effective!*

Results and Discussion

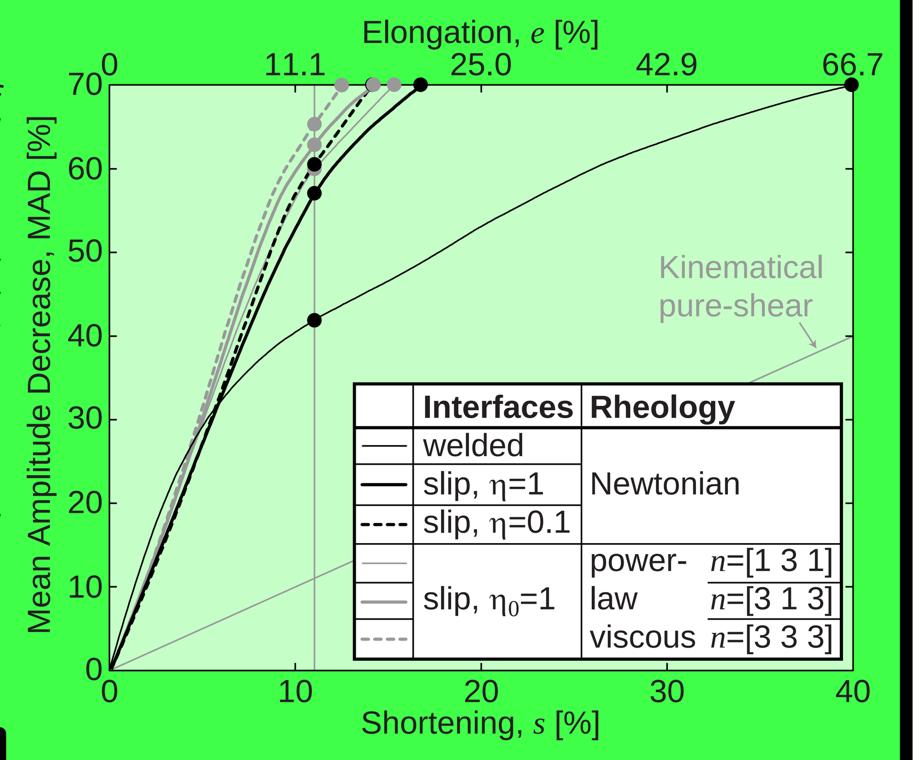
Quantification



Elongation: (during unfolding) $$e = \frac{L - L_0}{L_0}$$

Shortening: (equivalent to elongation, but during forward folding) $$s = -\frac{L_0 - L}{L} = \frac{e}{1+e}$$

Mean Amplitude Decrease: (during unfolding) $$\mathrm{MAD} = -\frac{\bar{A} - \bar{A}_0}{\bar{A}_0}$$

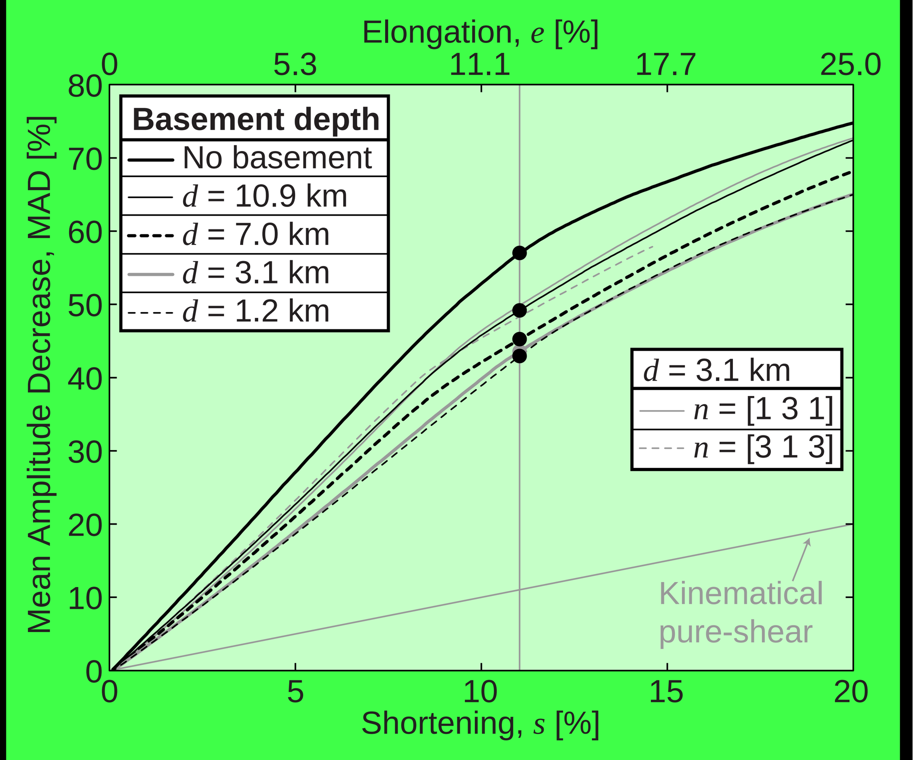


Evolution of the mean fold amplitude during various progressive dynamical unfolding simulations without basement (top) and including a basement at depth d (bottom figure). The thick black line is the same in both figures.

Kinematical pure-shear is equivalent to a dynamical unfolding simulation with no mechanical difference between the layers (MAD = s).

Simulation snapshots corresponding to the thick and the thin black lines in the top figure are shown in the lower-left corner of this poster.

The legend in the top-left corner of the bottom figure corresponds to simulations with a Newtonian rheology.



Conclusions

- Interfacial slip is the most important factor for an efficient amplitude decrease during dynamical unfolding simulations.
- Various power-law exponents increase the efficiency, but only have a second-order effect.
- Detachment folding reduces efficiency of dynamical unfolding simulations.

- Dynamical unfolding helps identify dominant deformation processes.
- Interfacial slip is a key mechanism in the Zagros HFZ.
- Other factors have a small influence on dynamical unfolding results.

Why complete flattening is not (yet) possible

- Issues with the initial model
  - ➡ Quality control for cross-section constructions
- Some natural processes not included in the model
  - ➡ Identify areas of complex processes.

References

Frehner M., Reif D. and Grasemann B., 2012: Mechanical versus kinematical shortening reconstructions of the Zagros High Folded Zone (Kurdistan region of Iraq), Tectonics 31, TC3002.
Ghassemi M.R., Schmalholz S.M. and Ghassemi A.R., 2010: Kinematics of constant arc length folding for different fold shapes, Journal of Structural Geology 32, 755–765.
Lechmann S.M., Schmalholz S.M., Burg J.-P. and Marques F.O., 2010: Dynamic unfolding of multilayers: 2D numerical approach and application to turbidites in SW Portugal, Tectonophysics 494, 64–74.
Schmalholz S.M., 2008: 3D numerical modeling of forward folding and reverse unfolding of a viscous single-layer: Implications for the formation of folds and fold patterns, Tectonophysics 446, 31–41.
Sissakian V.K., Ibrahim E.I. and Al-Waíly I.J., 1997: Geological map of Arbeel and Mahabad Quadrangles, sheets Nj-38-14 and Nj-38-15, State Establishment of Geological Survey and Mining, Baghdad, Iraq.

Acknowledgement
OMV Exploration and Production Company