# Buckle fold growth in the western Northern Calcareous Alps fold-and-thrust belt of Austria – finite element modelling and field observations


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# Background

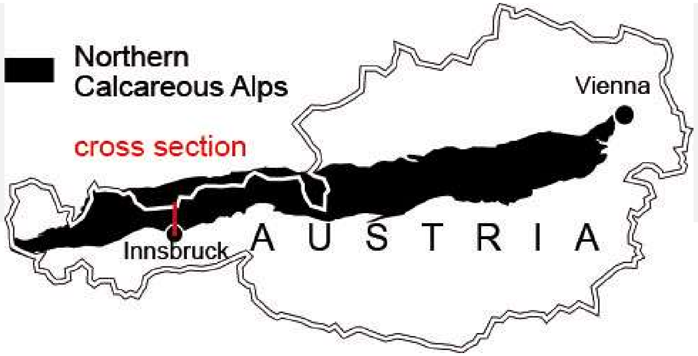
This research investigates the behavior of thrust sheets using an example from the western Northern Calcareous Alps (NCA) fold-and-thrust belt.

The structures above the major thrust (Karwendel thrust Fig. 1) in the Karwendel mountains gave the initial motive.

The Karwendel thrust runs for kilometers along the evaporitic Reichenhall-Haselgebirge décollement.

The thrust has the geometry an upper footwall flat in a fault-bend fold. The large scale folds formed most probably by buckling (Kilian and Ortner, 2019).

# Key cross section



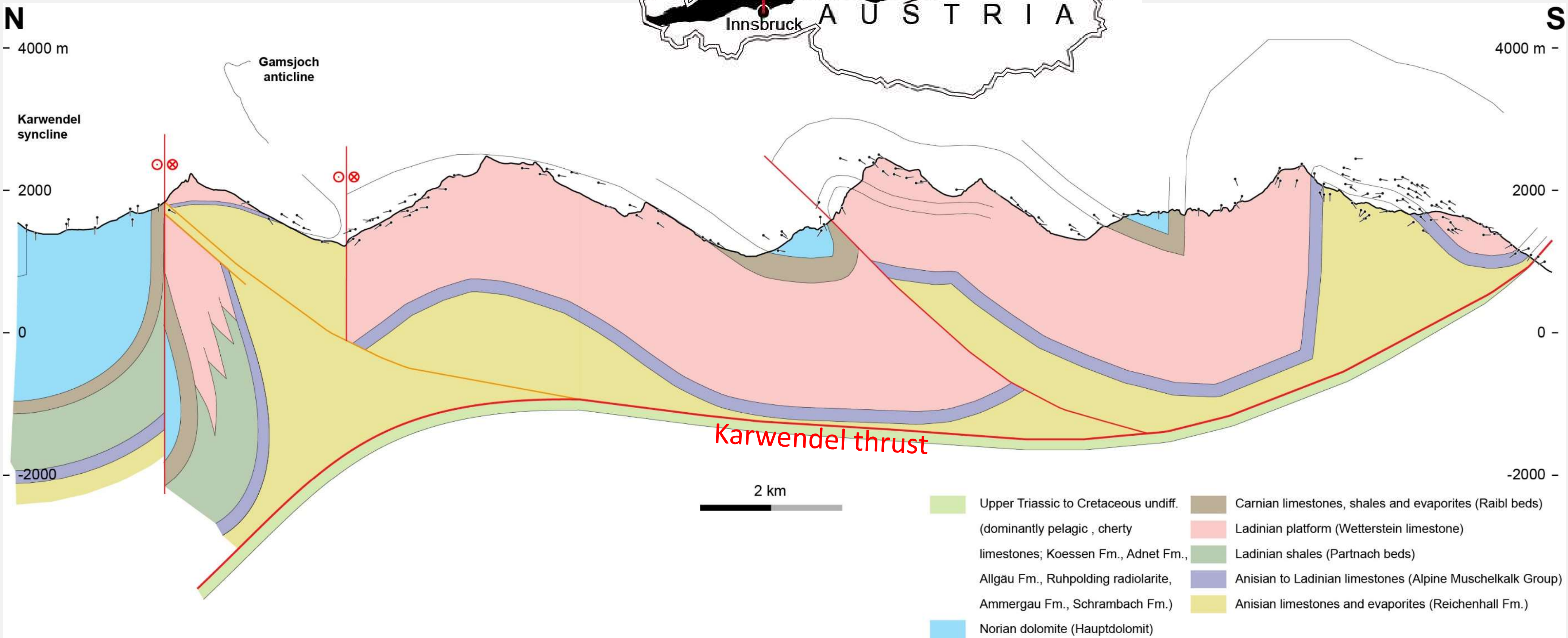




Fig. 1: (a) location of cross section in the Northern Calcareous Alps (b) Large scale buckle folds in the Brandjoch section across the Karwendel mountains.

# Study design

In a finite element numeric simulation in Abaqus, folding of the NCA is tested under varying boundary conditions to understand field observations.


**Fig. 2: Simple 3-layer model for the numeric simulation based on the stratigraphic knowledge of the NCA.**

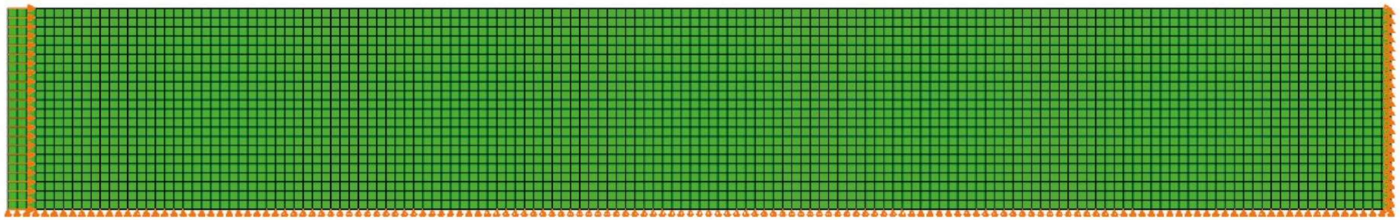


**Fig. 3: Undeformed finite element model realised in Abaqus. Orange arrows indicate the boundary conditions.**

# Numeric model is based on the deformation history of the NCA

For the NCA it is known that as a consequence of initial stacking at the end of the Early Cretaceous, the thrust sheets were uplifted and eroded (e.g., Wagreich and Faupl, 1994) down to the Ladinian platform carbonates in the study area (Krois and Stingl, 1994; Ortner, 2003), removing roughly half of the sediment column. Syntectonic sediments on top of the thrust sheets transgress in the Late Cretaceous and record folding into the Paleogene, and 20% of the folding postdates preserved syntectonic deposits, as documented in the Muttekopf Gosau outcrop (Ortner, 2001, 2016; Ortner et al., 2016).

We expected that the **erosion after the initial stacking and the sedimentation of syntectonic sediments** is controlling for the structural evolution of buckle folds in the study area. Erosion, sedimentation and material parameters were tested during the numeric simulation (Figs. 4 and 5).

# Numeric modelling – Modelling Erosion

a.) Overburden: 800m; Stiff layer: 3000 m;
Total thickness: 4400m
Deviatoric stress distribution after 22% of shortening.

b.) Stiff layer: 1600m; Total thickness: 2200m
Deviatoric stress distribution after 16.8% of shortening.

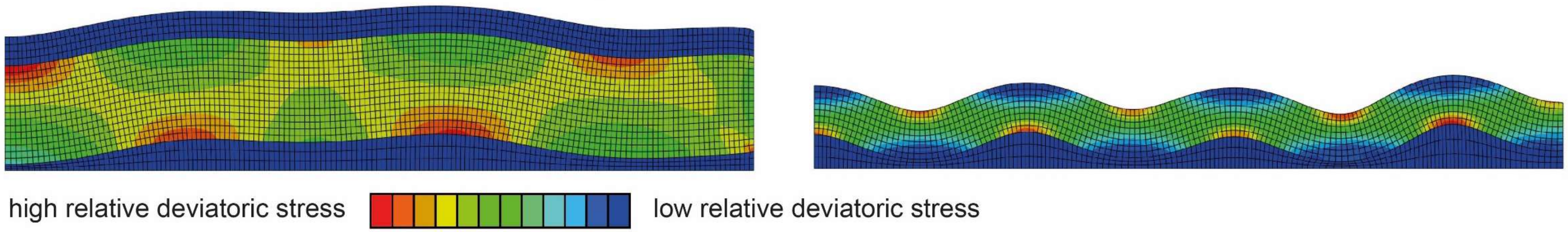



Fig. 4: Results of the erosion modelling. a.) Model a. shows the maximal thickness before erosion b.) Model b. shows the minimum of thickness after the erosion.
The material model is linear elasticity. Coloration represents the relative deviatoric stress distribution. The base layer is constant (600 m) while the incompetent layer on top and the middle stiff layer is eroded. Following material characteristics were assumed: Layer 1 (bottom): E-Module 2 000 000 kN/m$^2$, Poisson ratio 0.25; Layer 2 (middle): E-Module 80 000 000 kN/m$^2$, Poisson ratio 0.2 ;Layer 3 (top) : E-Module 10 000 000 kN/m$^2$; Poisson ratio 0.25.

# Numeric modelling – Modelling Sedimentation

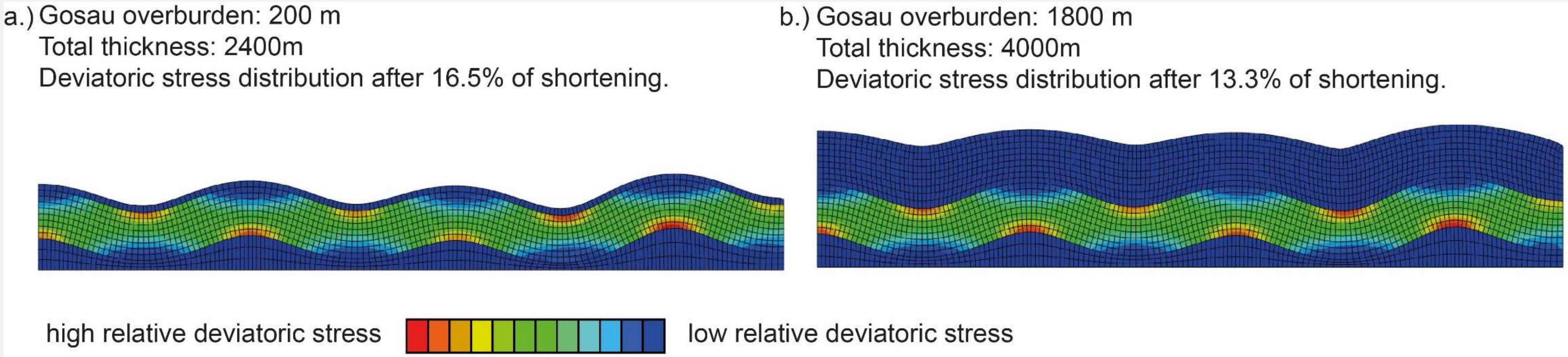



Fig. 5: Results from modelling with changing overburden. a.) Model a. shows a minimum of overburden b.) Model b. shows the maximum of overburden
The model is linear elasticity. Coloration represents the relative deviatoric stress distribution. The competent intermediate unit and the basal incompetent unit have constant thickness (600 m) in the models, while the top incompetent unit ("Gosau overburden") increases in thickness. Material characteristics: Layer 1 (bottom): E-Module 2 000 000 kN/m$^2$, Poisson ratio 0.25; Layer 2 (middle): E-Module 80 000 000 kN/m$^2$, Poisson ratio 0.2; Layer 3 (top) : E-Module 10 000 000 kN/m$^2$; Poisson ratio 0.25.

# Results – What did we learn from modelling?

- The modelling showed that the thickness of the stiff layer and the competence contrast between the layers is a control on the development of buckle folds.
- Additionally, a very weak décollement horizon is necessary to allow folding.
- Testing the influence of erosion showed that the sediment thickness of the stiff layer controls the initial wavelength of the folds. The produced limb lengths of the folds fit field observations.
- We assume that folds developed after the initial stacking in the late Early Cretaceous and after a decrease in lithostatic pressure due to Upper Cretaceous erosion.
- This research gives a new perspective on the interpretation of structures in the NCA but also indicates the need for geometric-rheologic models for the construction of cross sections in fold-and thrust belts.

## References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