

Quantifying Fracture Heterogeneity in Different Domains of Folded Carbonate Rocks to Improve Fractured Reservoir Analog Fluid Flow Models

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Abstract

Fluid flow in carbonate reservoirs is largely controlled by multiscale fracture networks. Significant variations of fracture network porosity and permeability are caused by the 3D heterogeneity of the fracture network characteristics, such as intensity, orientation and size. Characterizing fracture network heterogeneity is therefore essential in order to understand and predict fluid flow in fractured reservoirs, but this cannot be accomplished using only 1D data from wells, which is usually the only type of data available from the subsurface.

To extend the 1D data to 3D data we commonly analyze the regional deformation, as different types of fold mechanisms produce different deformation styles and subsequent fracture patterns. 2D outcrop studies of fractures are often used to quantify these multi-scale relations between fracturing and large-scale structures.

We build a geometric model, then make a mechanical analysis, followed by populating the fracture domains with outcrop-derived information. We use a novel approach called Digifract, which allows us to collect large amounts of 2D fracture data from outcrops, including fracture size, orientation and spacing measurements. Using this method we accurately quantify the links between multi-scale deformations, from fractures to regional tectonics.

We applied the Digifract method in the outermost foothills of the Southern Tunisian Atlas, analysing fractures in different domains of four external folds with simple geometries and deformation histories. The lithology of the outcropping cores of all anticlines consists of the same fractured carbonates. The dimensions of the folds are on the same scale as reservoir analogs and form analogs for reservoirs in the Ghadames/Illizi basin, covering parts of Algeria, Tunisia and Libya.

We relate differences in fracture characteristics to different localities (e.g., far or close to fold axes) and different folding stages in order to derive general rules that can be applied to subsurface fold analogs.

Selected References

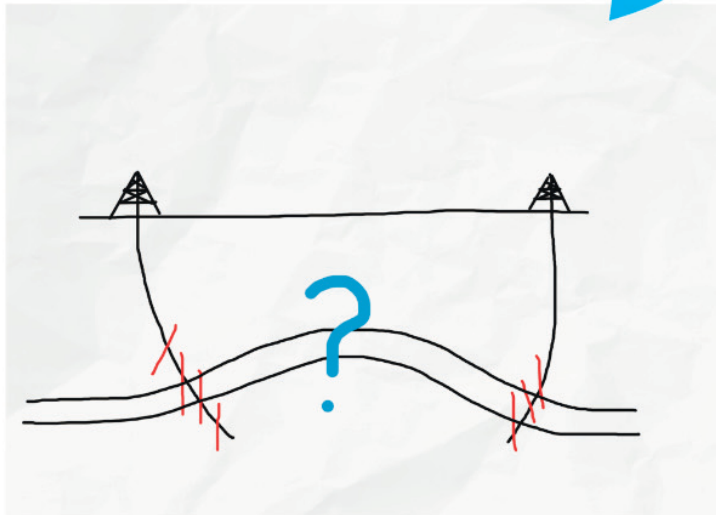
Hardebol, N.J., and G. Bertotti, 2013, DigiFract; a software and data model implementation for flexible acquisition and processing of fracture data from outcrops: *Computers & Geosciences*, v. 54, p. 326-336.

Rigane, A., and C. Gourmelen, 2011, Inverted intracontinental basin and vertical tectonics; the Saharan atlas in Tunisia: *Journal of African Earth Sciences*, v. 61/2, p. 109-128.

Riley, P., C. Gordon, J.A. Simo, B. Tikoff, and M. Soussi, 2011, Structure of the Alima and associated anticlines in the foreland basin of the southern Atlas Mountains, Tunisia: *Lithosphere*, v. 3/1, p. 76-91.

Quantifying fracture heterogeneity in different domains of folded carbonate rocks to improve fractured reservoir analog fluid flow models

From surface analog to subsurface predictions



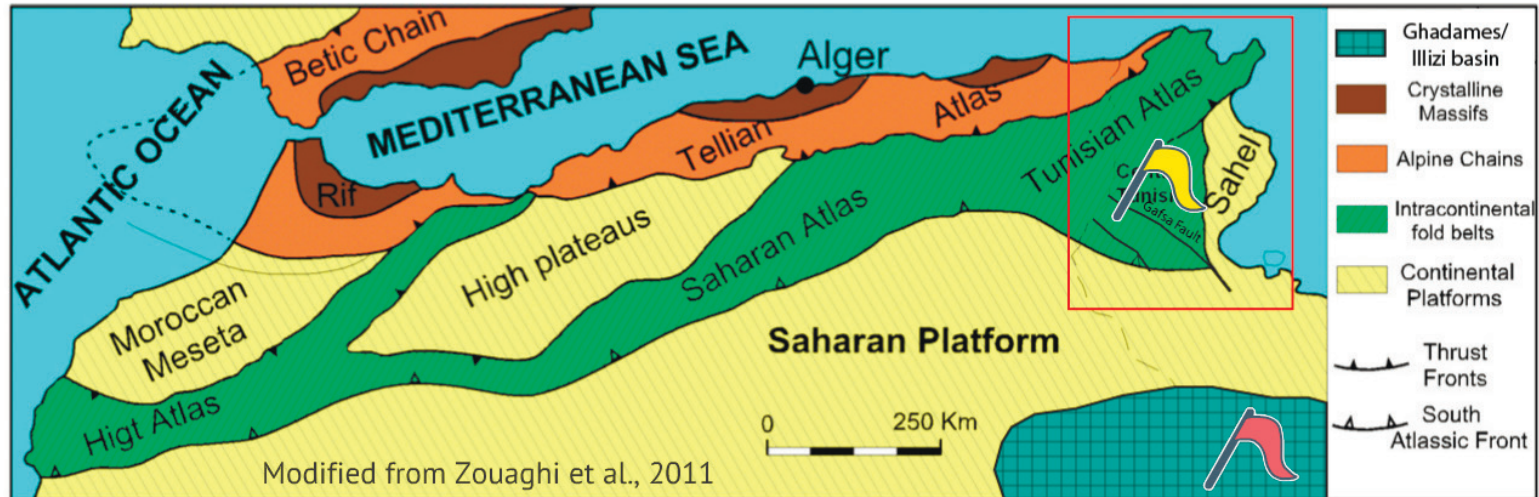
Outcrops providing key understanding of fracture geometry and spacing, which lacks from well data

AAPG Barcelona, April 9th, 2013

K. Bisdom*, G. Bertotti, B.D.M. Gauthier, N.J. Hardebol

Geological setting

of the outcropping analog and subsurface basin



Surface analog fieldwork area

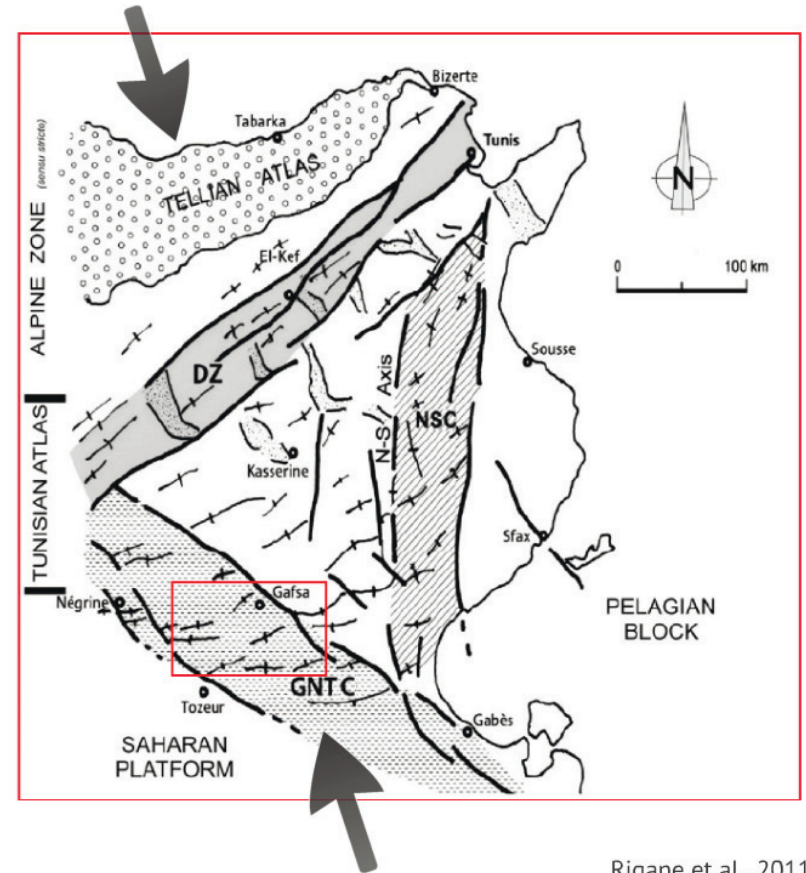
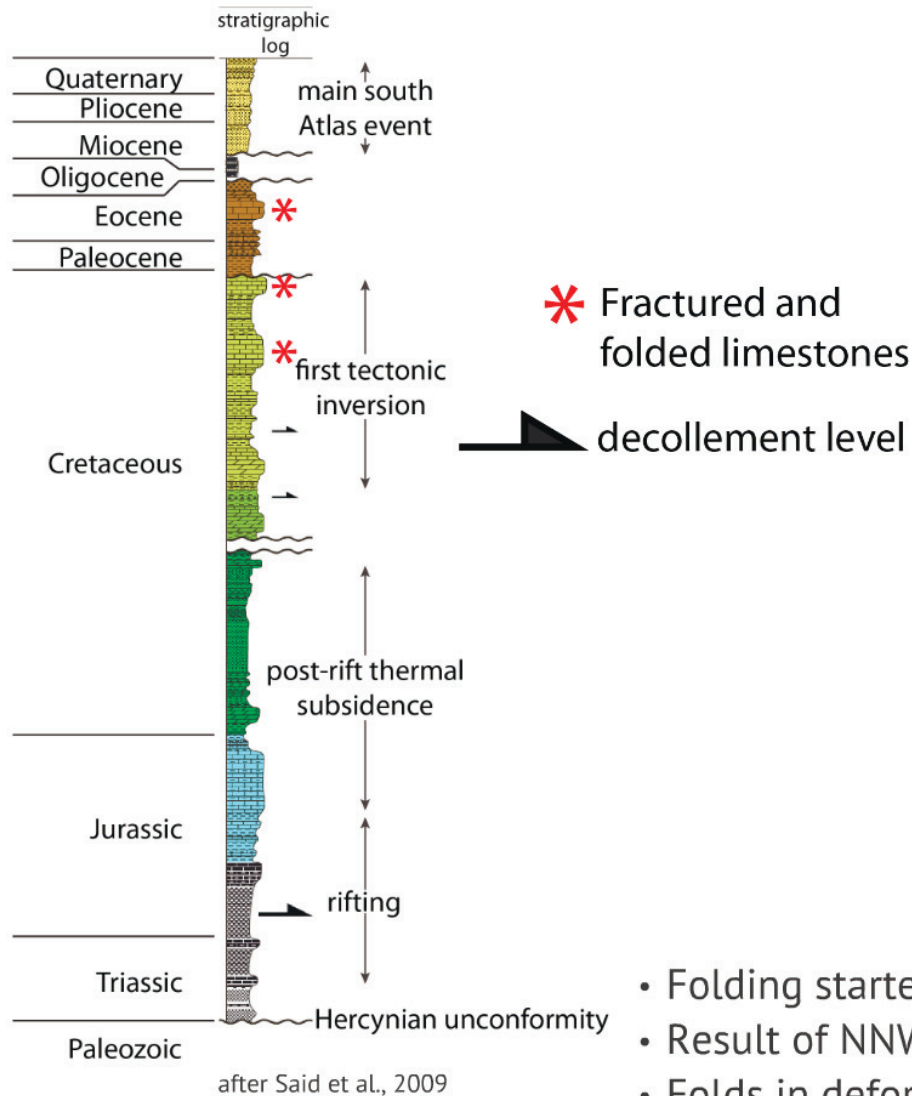


Subsurface fractured reservoirs

Links between the surface and subsurface:

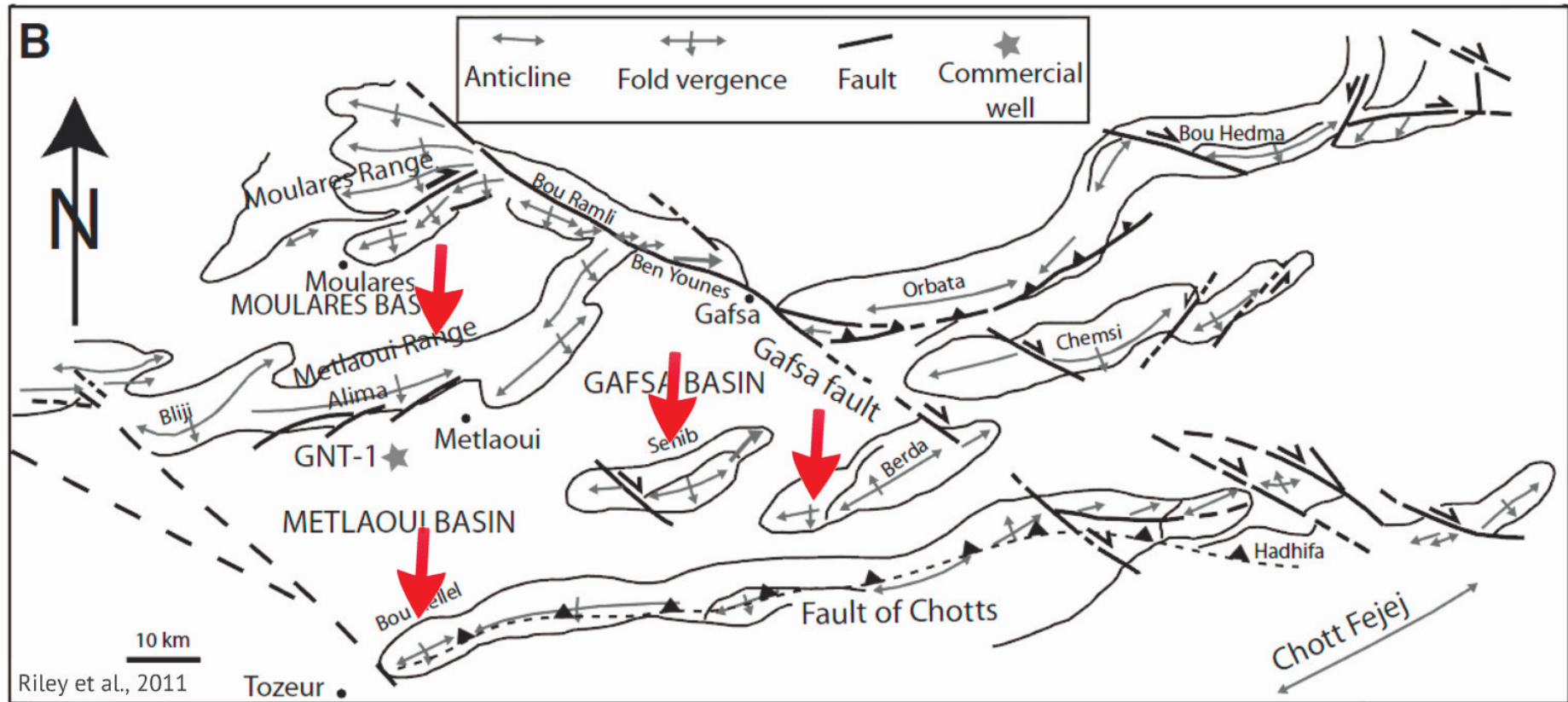
- Fault-propagation fold structures
- Fractured limestones

Tectonic setting



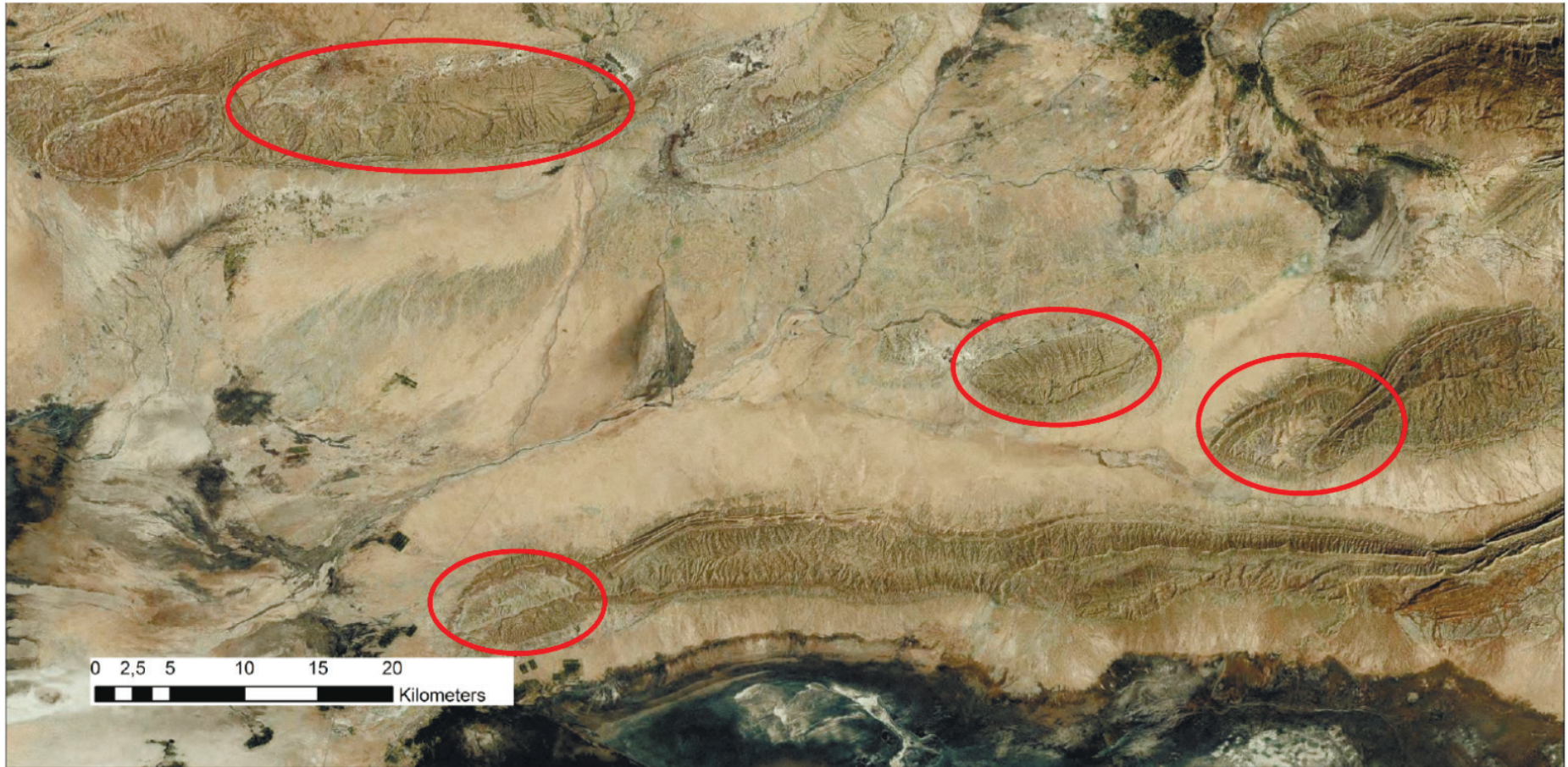
- Folding started in Miocene
- Result of NNW-SSE shortening
- Folds in deformation zone between two major strike-slip faults
- 3 fractured limestone formations are studied in 4 structures

Fieldwork structures



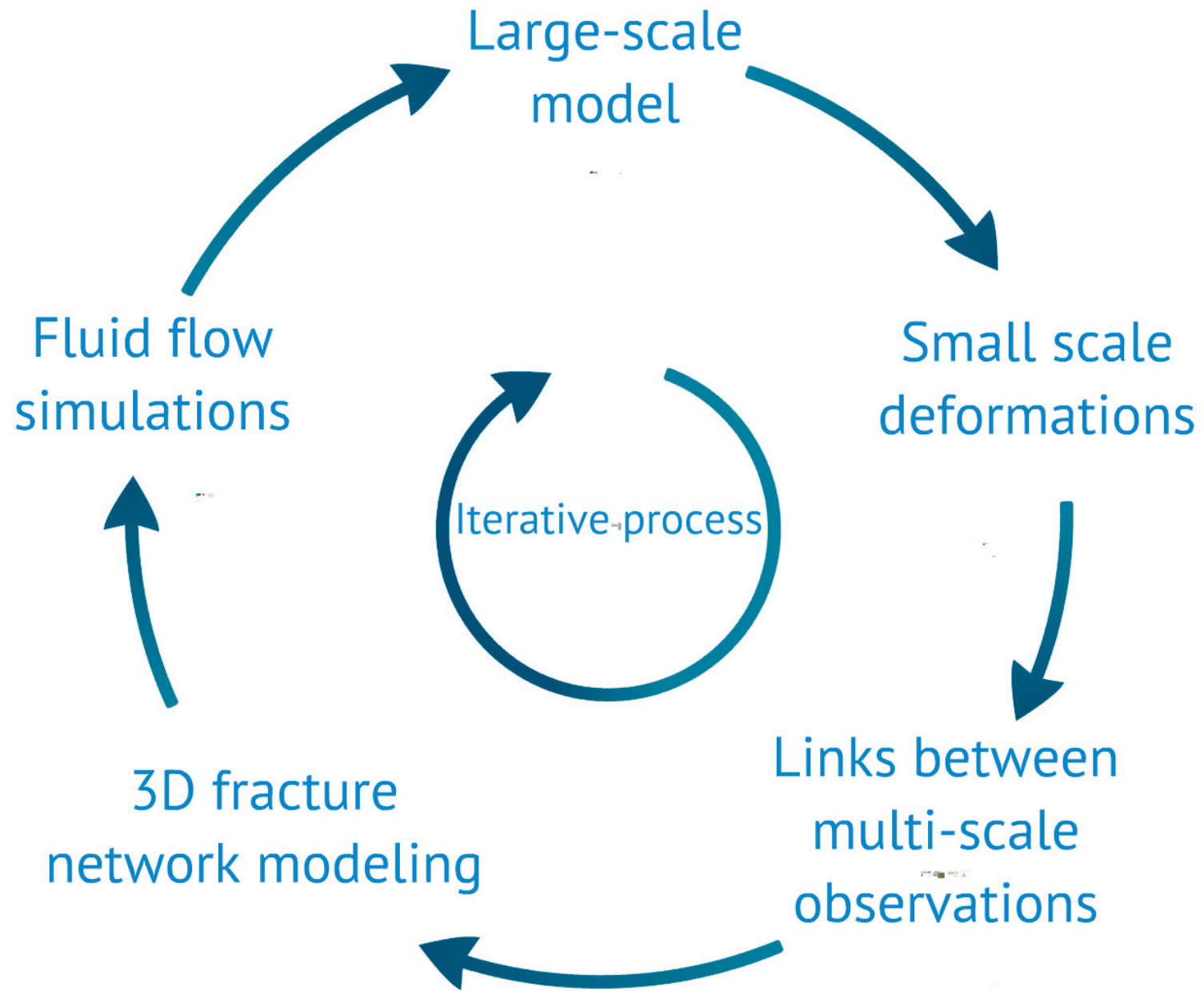
4 structures with:

- 'Simple' deformation history
- reservoir-scale dimensions



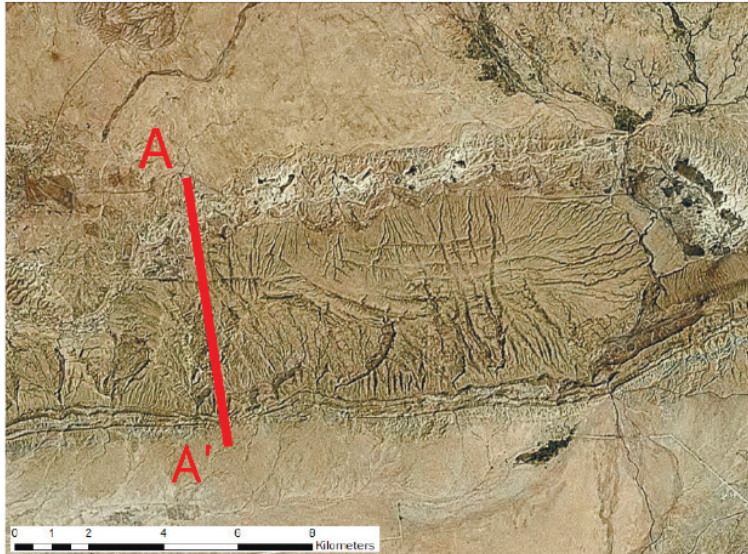
Structures have:

- Well-defined 3D geometries
- Comparable dimensions
- Excellent exposure

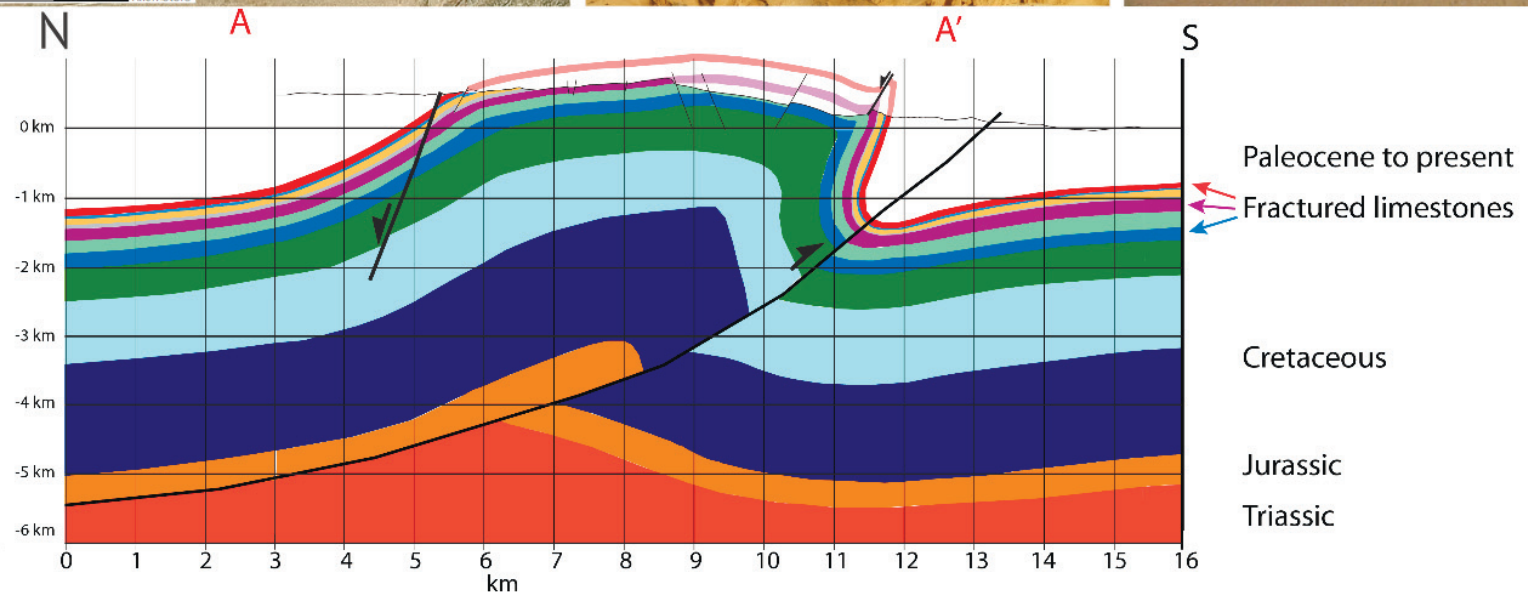


Large-scale modeling of structures

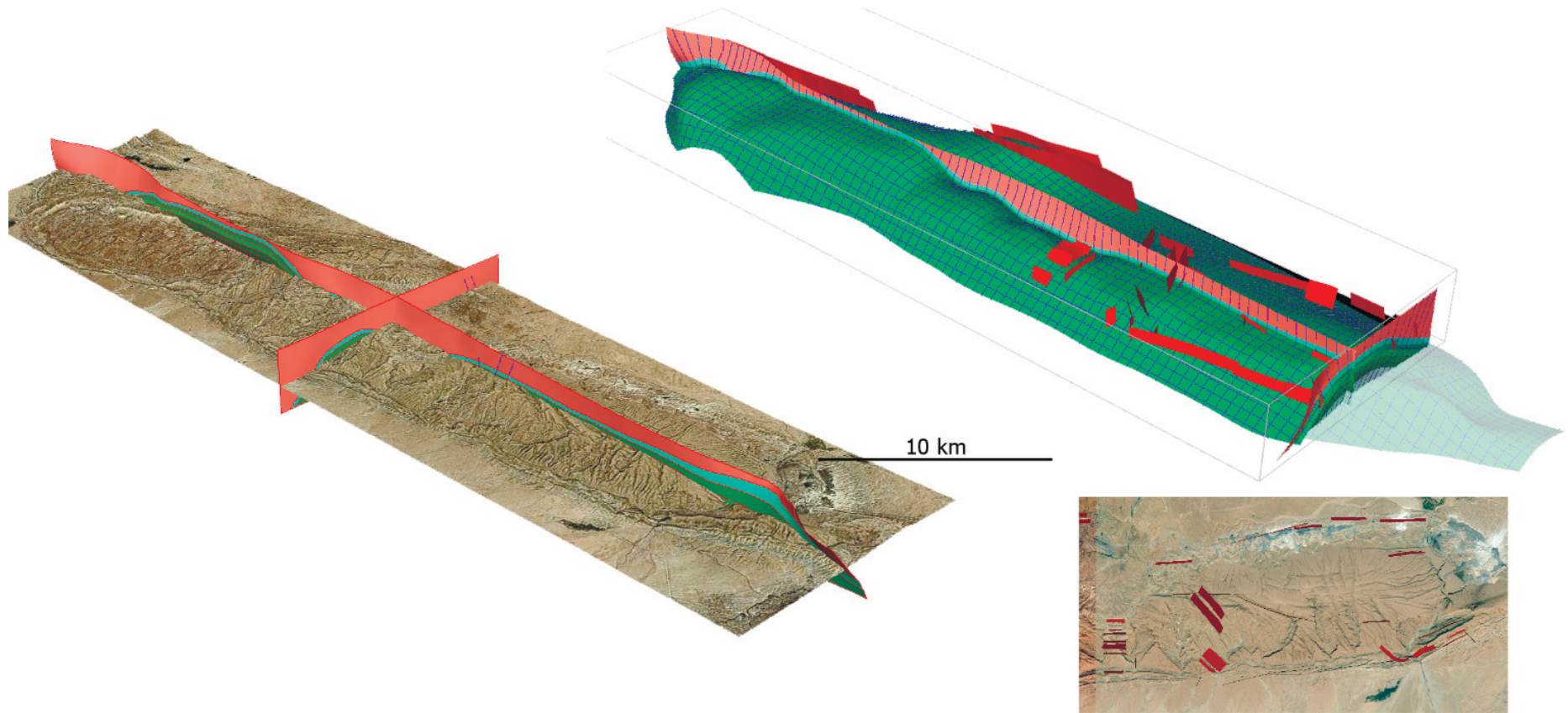
Example: Fault-propagation fold



- 3D surface modeling and 2D subsurface modeling



3D modeling of large-scale geometry



Based on:

- Satellite imagery (boundaries, faults)
- Literature cross-sections (seismic)
- Digital Elevation map (dips)
- Fieldwork data (dips, cross-sections)

Including:

- Fold geometry (surface and subsurface down to -1800m)
- Seismic-scale faults

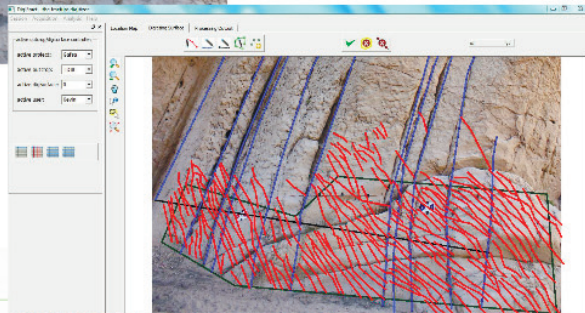
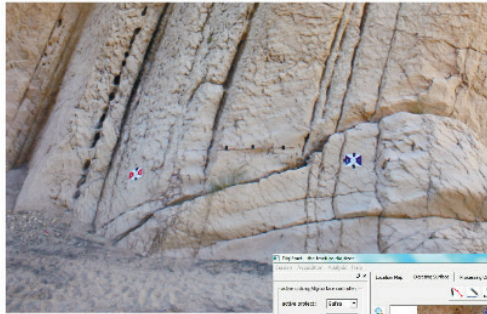
Capturing small-scale deformations

Using the Digifract digitizing tool

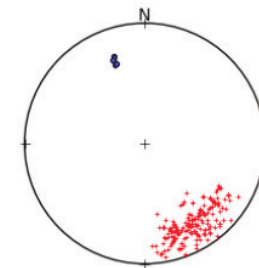
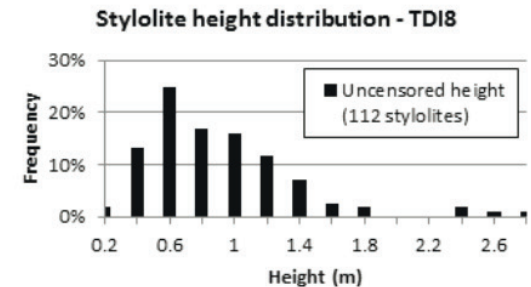
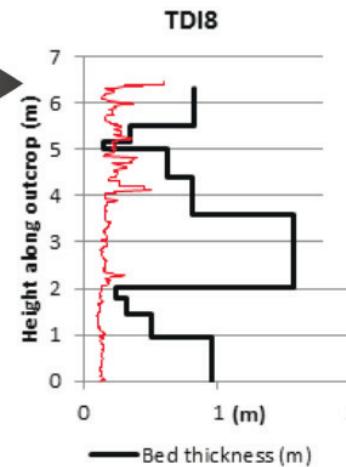
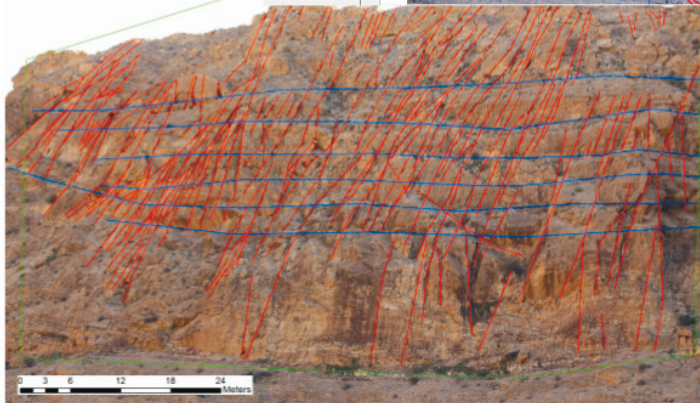
Acquisition



Processing



ENE



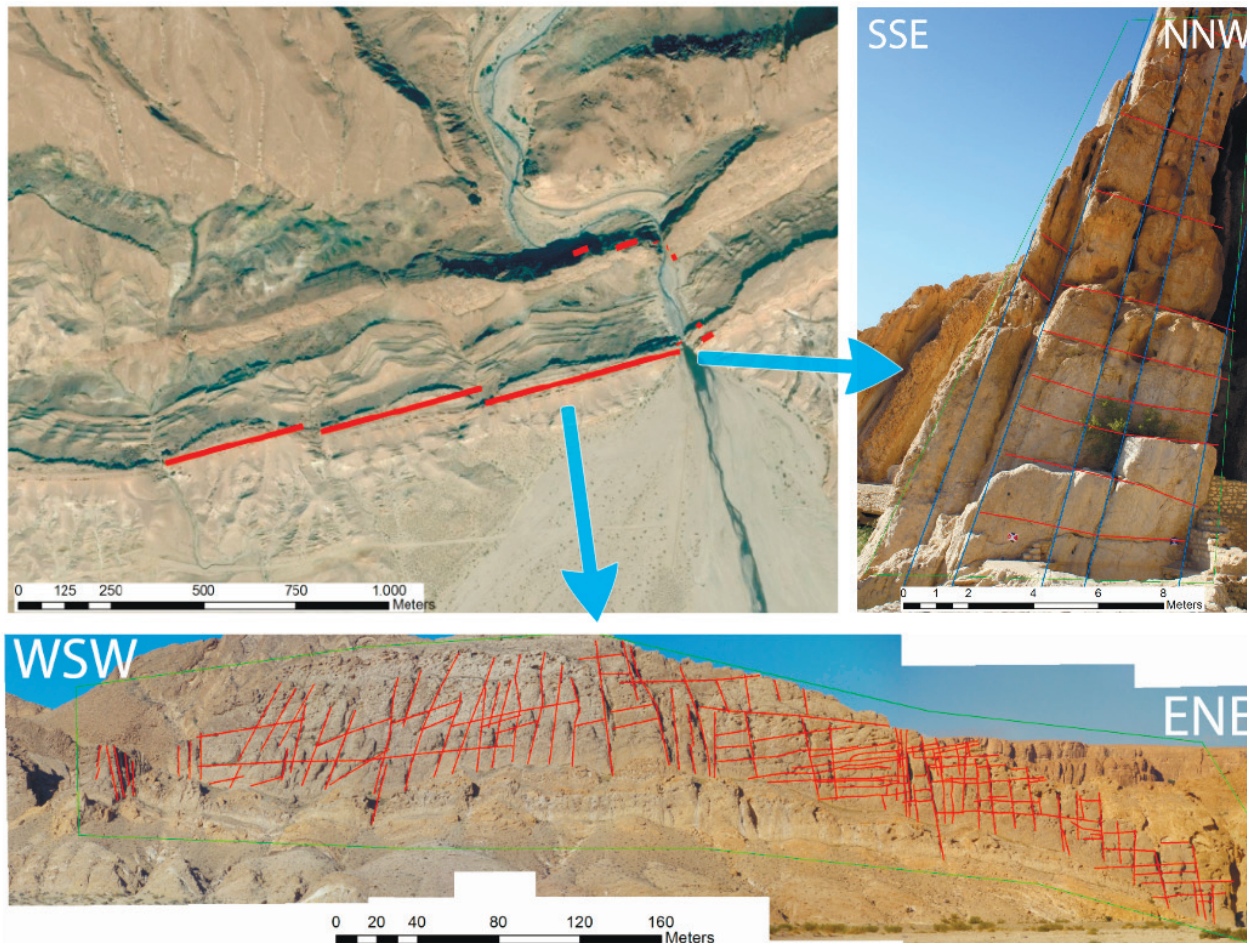
Open-source tool - developed at VU Amsterdam and TU Delft

Hardebol and Bertotti (2012)

A unique 2.5D fracture and bedding dataset

Data gathered in 2-week fieldwork:

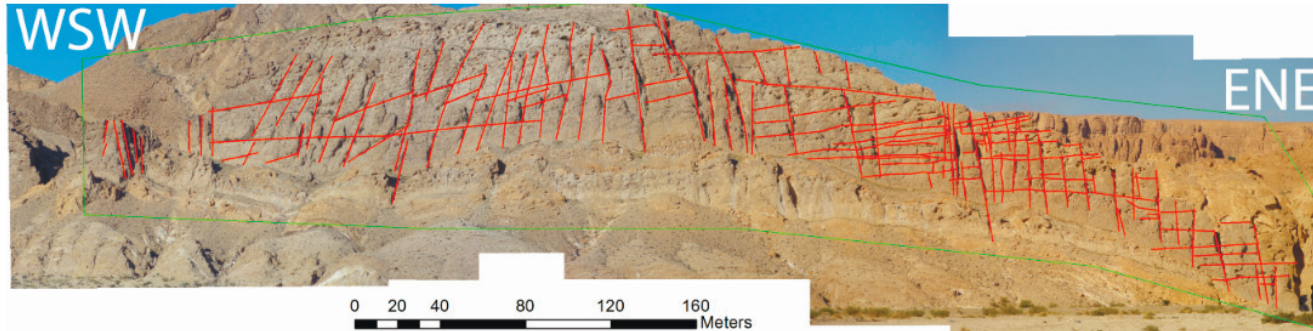
- 2100 fractures, veins and stylolites in 25 outcrops from 4 structures
- covering different structural domains
- cm-scale to km-scale fracture scales
- bedding measurements



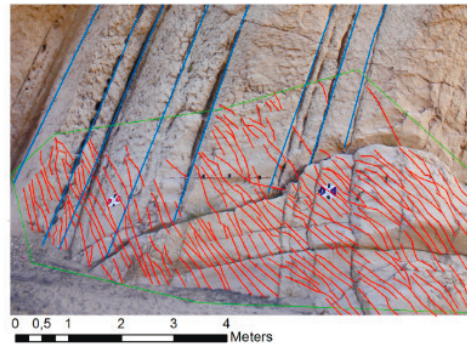
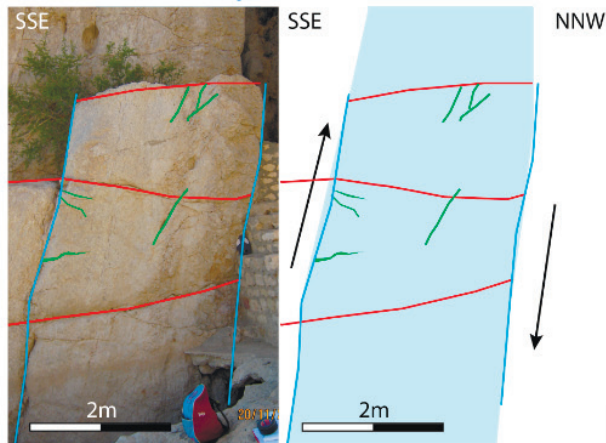
Fractures related to different mechanical processes

Layer Parallel Shortening, Flexural slip and fiber stresses

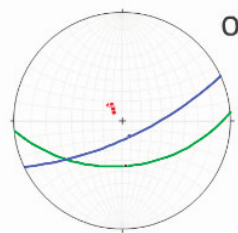
Layer Parallel Shortening



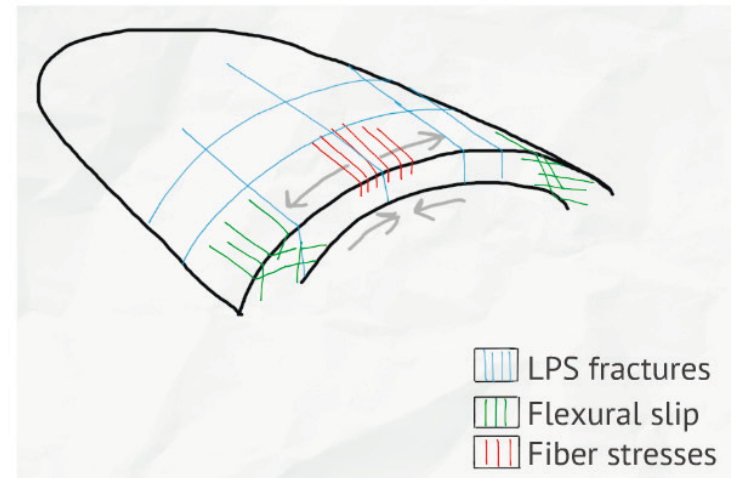
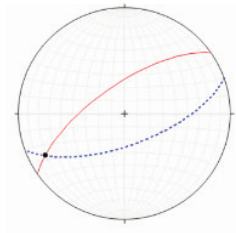
Flexural slip



oblique to bedding stylolites



oblique-to-bedding veins



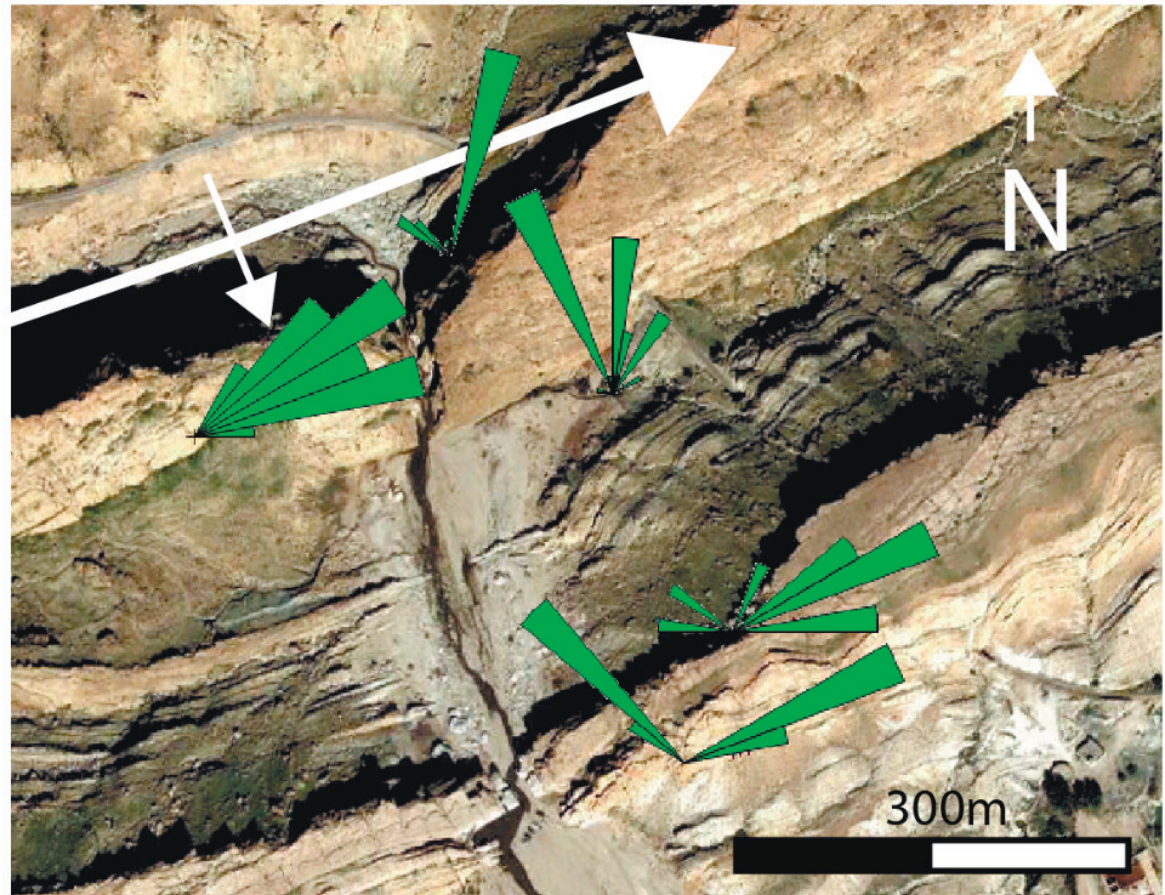
Fractures related to flexural slip

Formed during folding

- Low-angle fractures in the flank of anticline
- Striking mostly parallel to fold axis
- Small size (<1 m) and small spacing

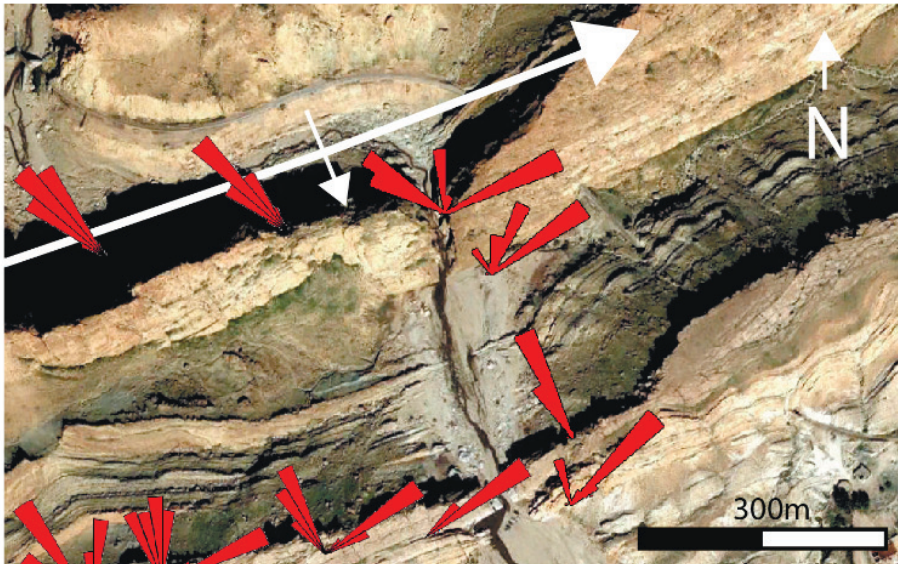
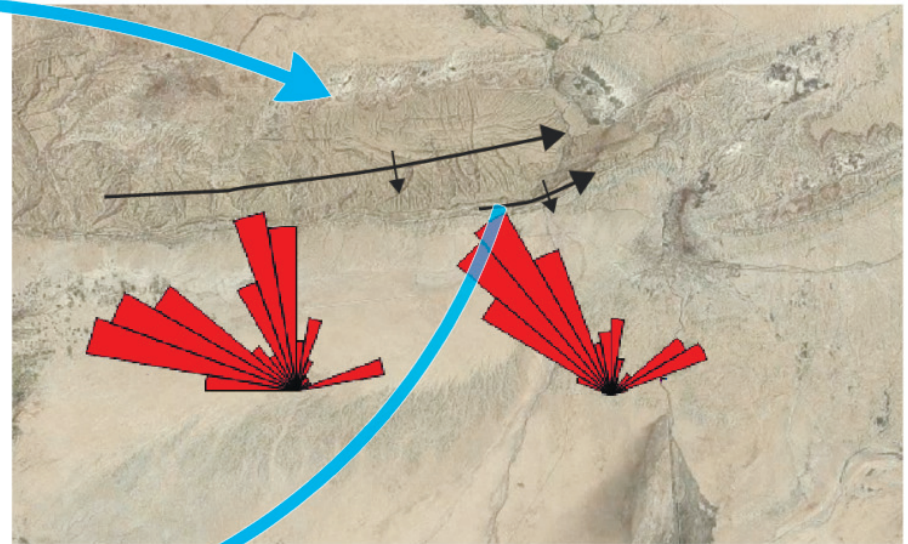
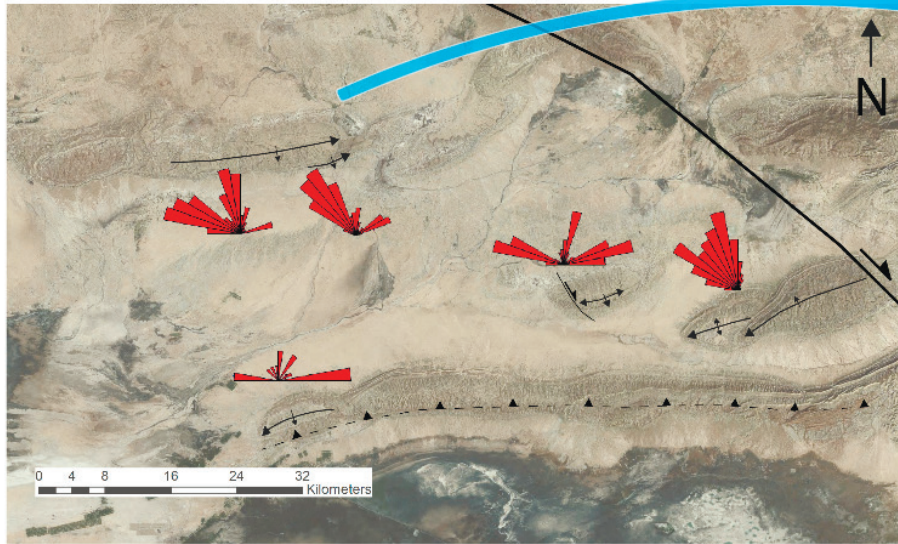


All fractures combined



Fractures related to Layer Parallel Shortening

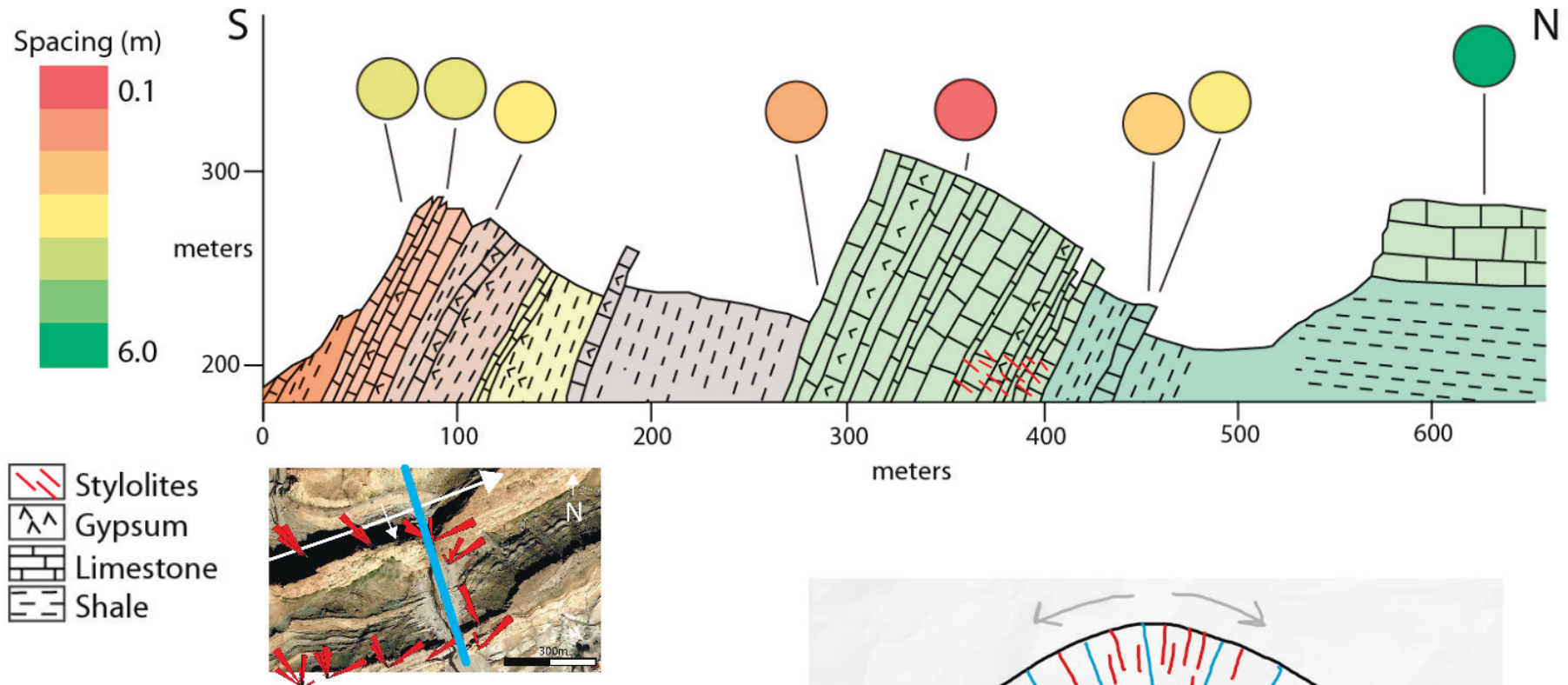
Formed before folding



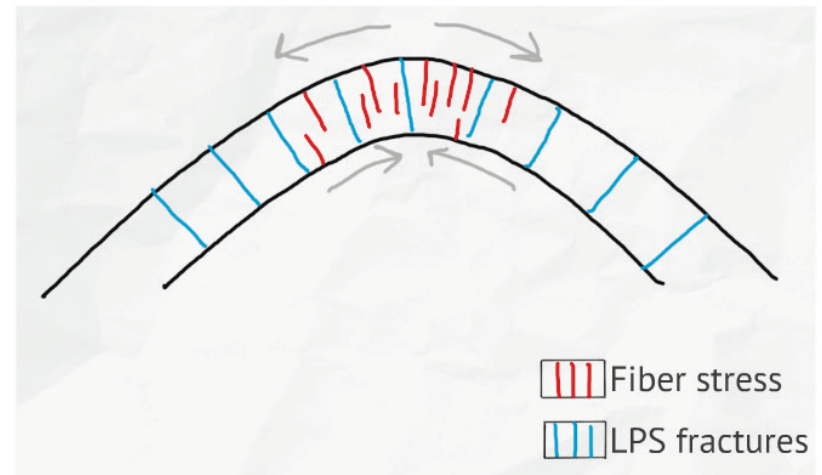
- Fractures sub-vertical to bedding
- 2 orthogonal sets per structure
- Large non-stratabound fractures

Trends in fracture density

Related to Fiber stress fractures formed during folding



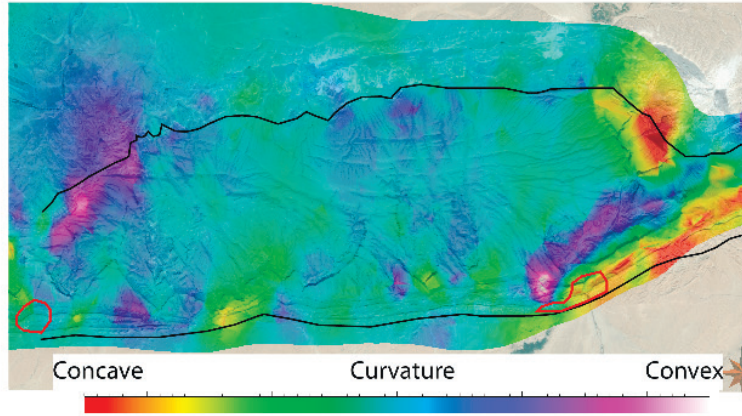
- Increase in fracture density of sub-vertical fractures towards core of anticline
- Part of these fractures are parallel to the fold axis -> fiber stress related



Identifying homogeneous domains

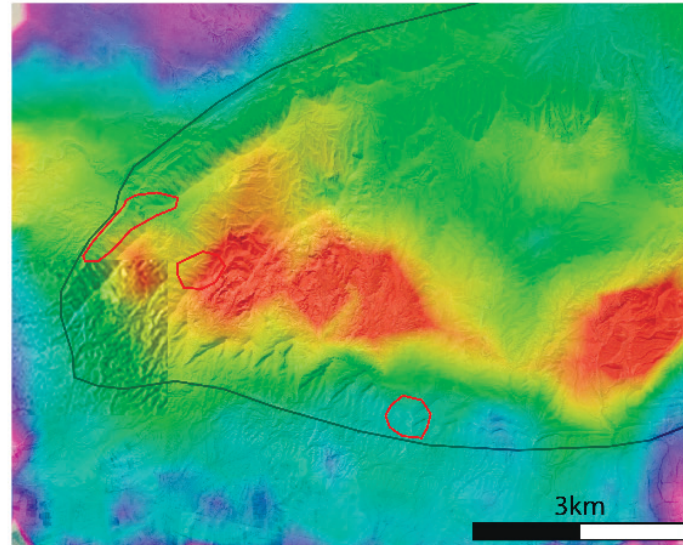
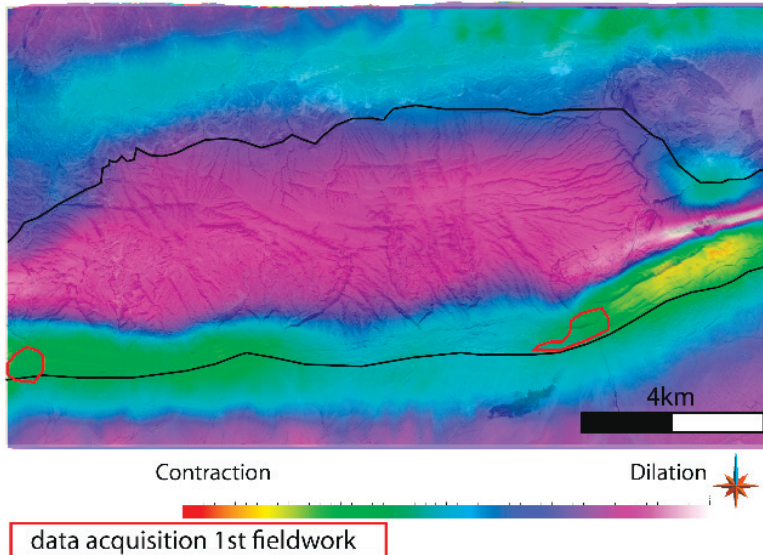
For extrapolation of outcrop data to anticline fracture networks

Curvature map

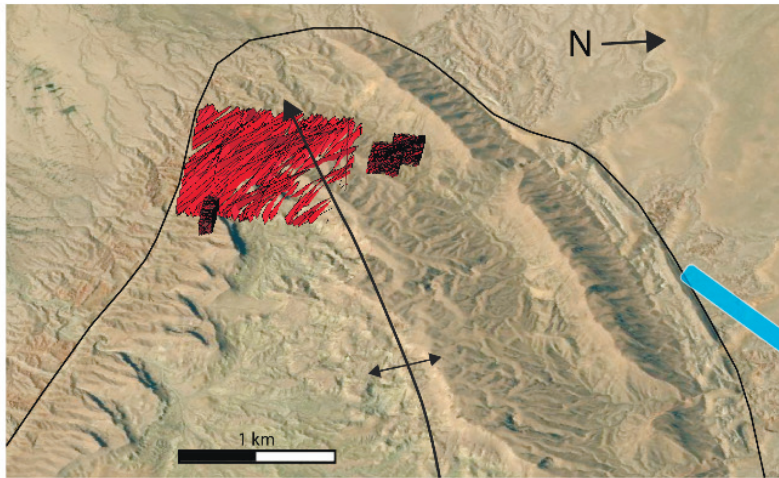


- We test different geometric, kinematic and mechanical drivers
- e.g. curvature (objective but no direct proxy for strain)
- mechanical (provides strain but depends on choice of fold mechanism)

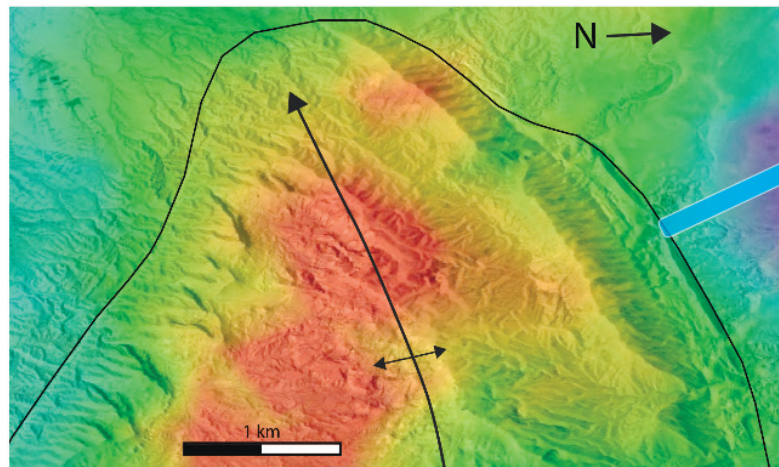
Mechanical (2D and 3D)



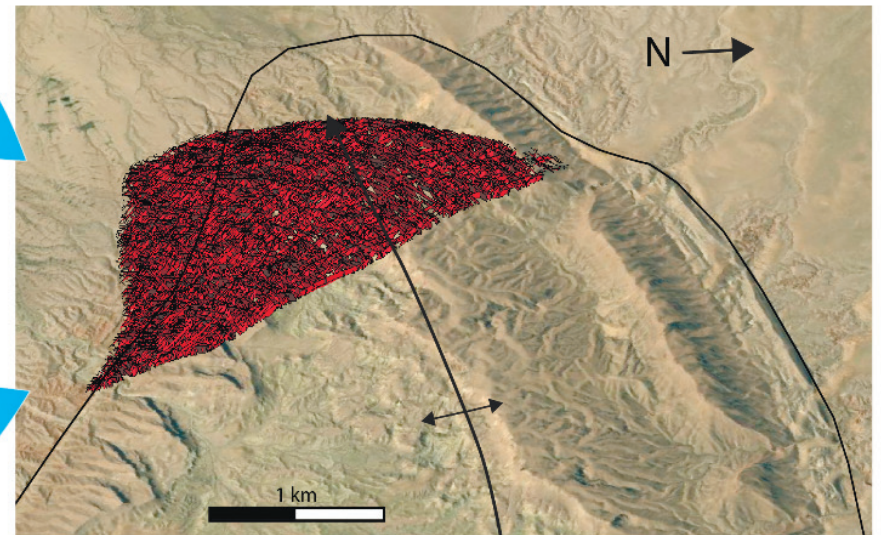
Populating domains with 3D fracture networks



3D Discrete Fracture Networks
conditioned to outcrops



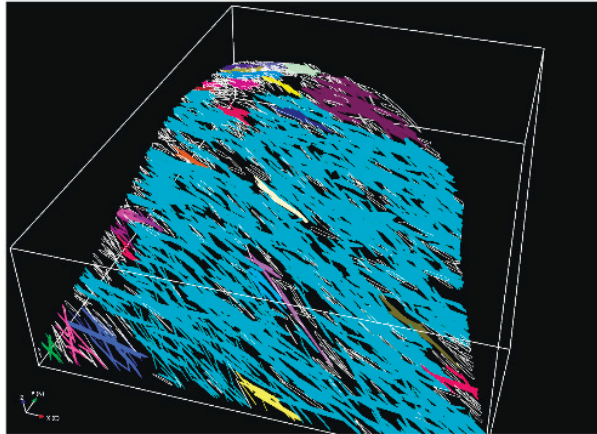
Dilation as a proxy for 3D
fracture density



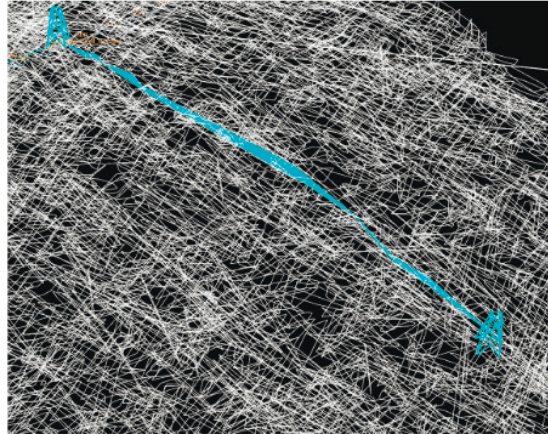
Extrapolating small-scale DFNs
using different large-scale drivers

Fast and effective fluid flow quantification

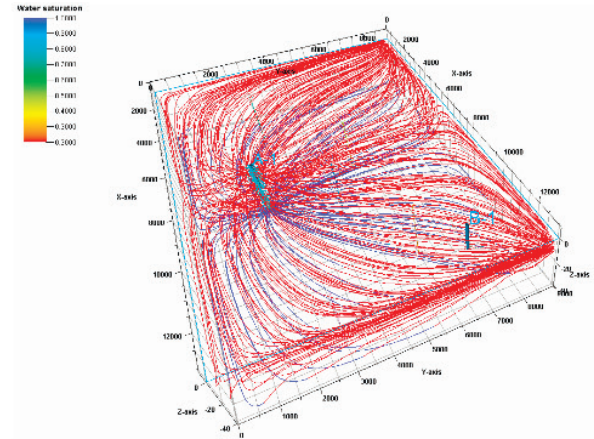
Rapid calculations to quantify uncertainties and their effect on fluid flow



Fracture clustering



Pathway / percolation analysis



Streamlines

Sensitivity analysis to quantify the influence of different parameters on fluid flow:

- Fracture size, orientation, spacing
- Depth of fracturing

Large amount of simulations using quick methods:

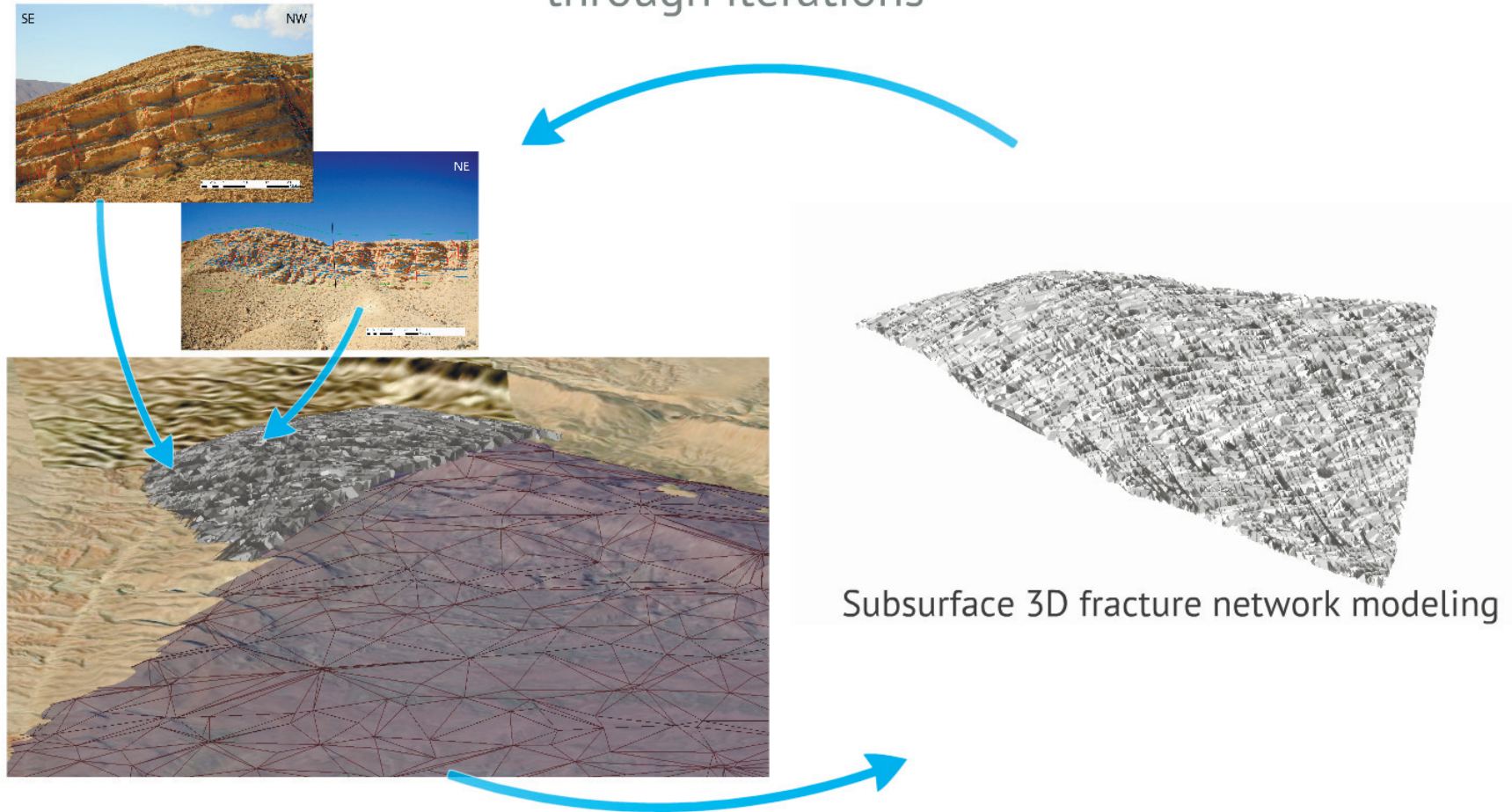
- Cluster analysis
- Pathway analysis
- Streamlines

Full upscaling and fracture-matrix fluid flow modeling

Using novel upscaling and fluid flow simulation techniques

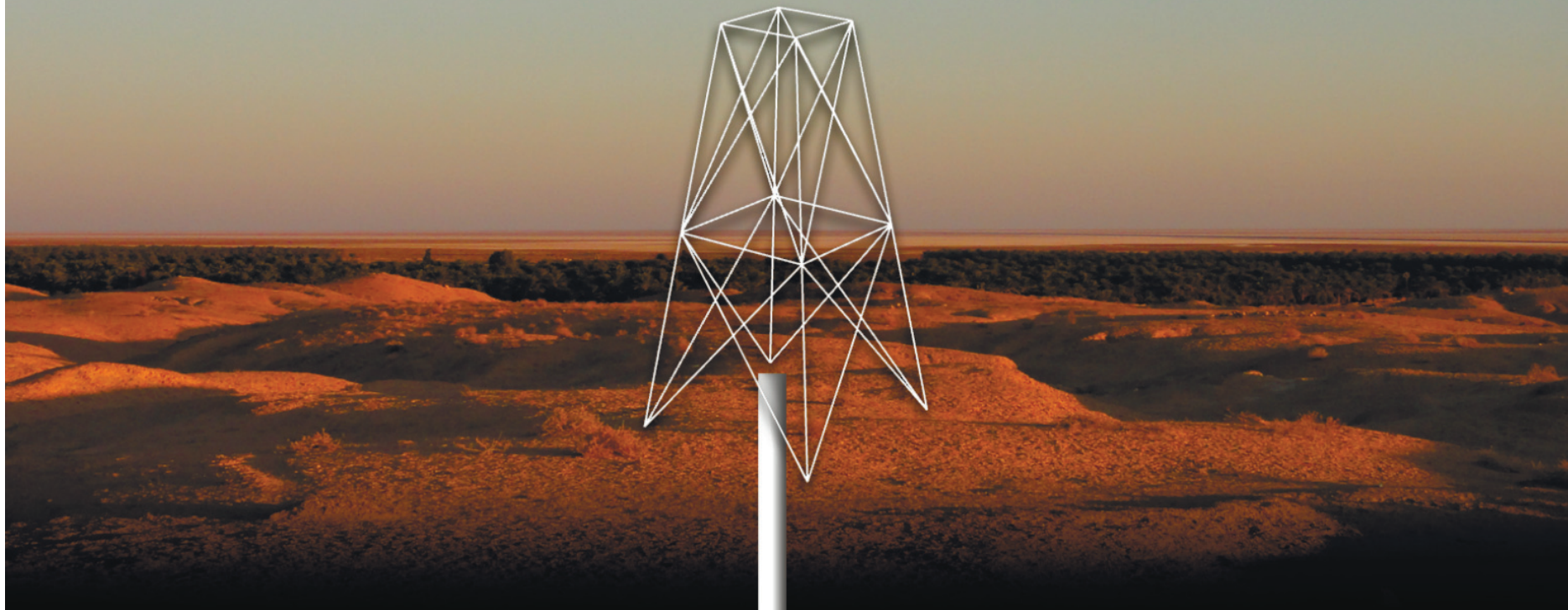
1. Build an accurate and detailed fracture-matrix fluid flow model using complex (unstructured) DFN grids
2. Compare the accuracy of quick connectivity estimations to the complete fluid flow simulations

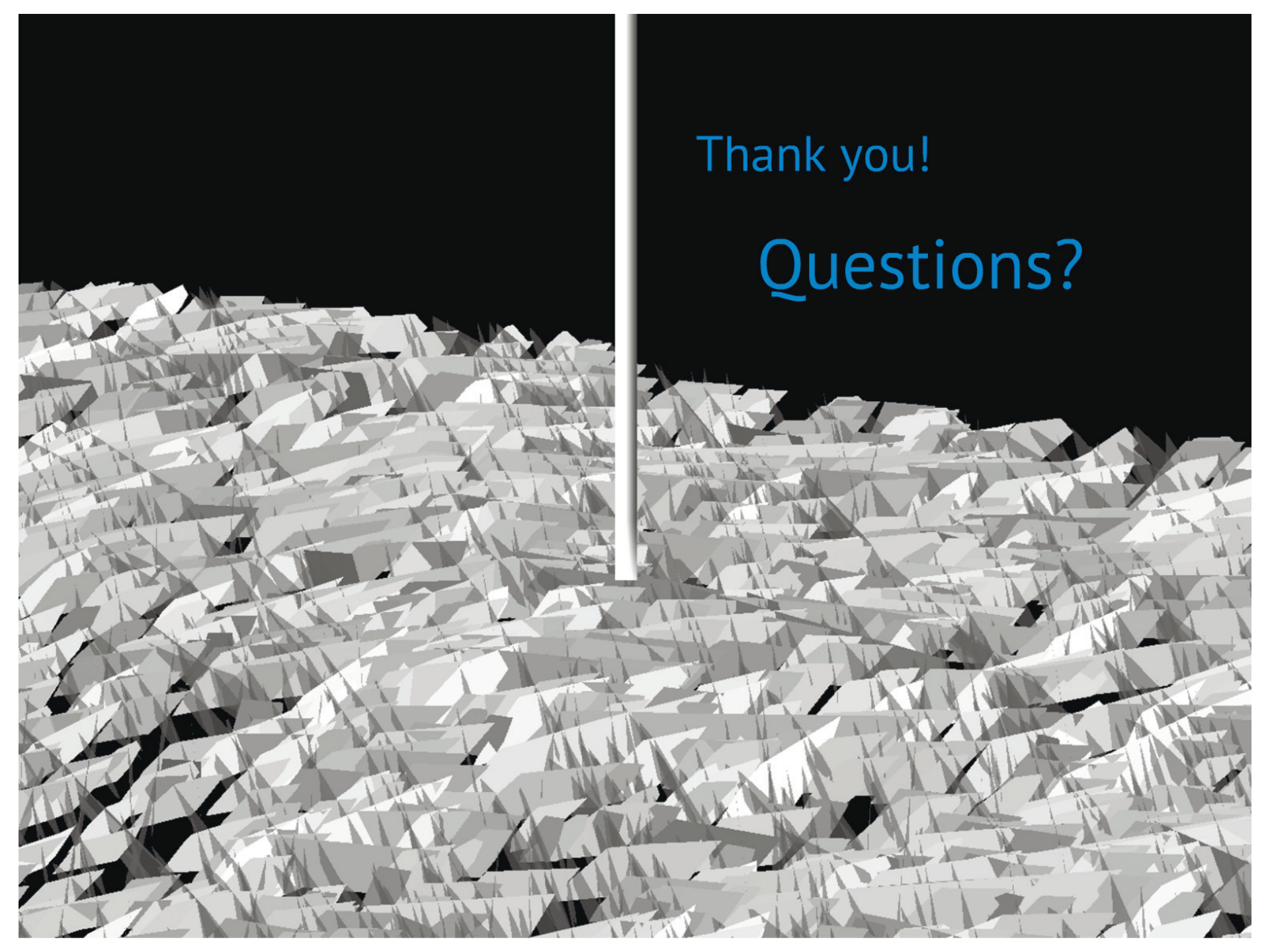
From surface analog to subsurface predictions through iterations



1. Predict fracture network behavior in different anticline domains
2. Quantify the most uncertain domains
3. Go back to the field to fill in the model gaps
4. Improve the predictions

Apply to the subsurface analog



The background of the slide is a grayscale, low-poly landscape. It consists of a dense field of triangular polygons of varying heights and orientations, creating a textured, mountainous terrain. A single, solid white vertical line runs from the top edge to the bottom edge of the slide, positioned slightly to the left of the center. The sky area above the terrain is a solid black.

Thank you!

Questions?