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

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Search and Discovery Article #41177 (2013)
Posted August 19, 2013

*Adapted from oral presentation given at AAPG 2013 European Regional Conference & Exhibition, Barcelona, Spain, April 8-10, 2013.

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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

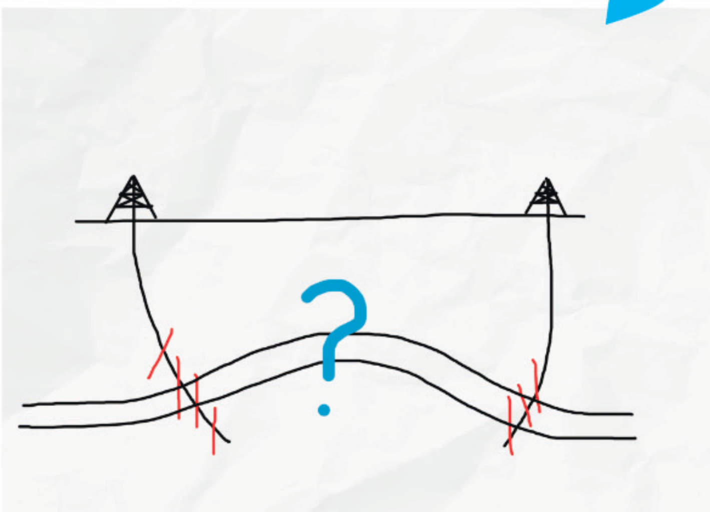
Hardebol, N.J., and G. Bertotti, 2013, DigiFract; a software and data model implementation for flexible acquisition and processing of fracture data from outcrops: Computers & Geosciences, v. 54, p. 326-336.

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

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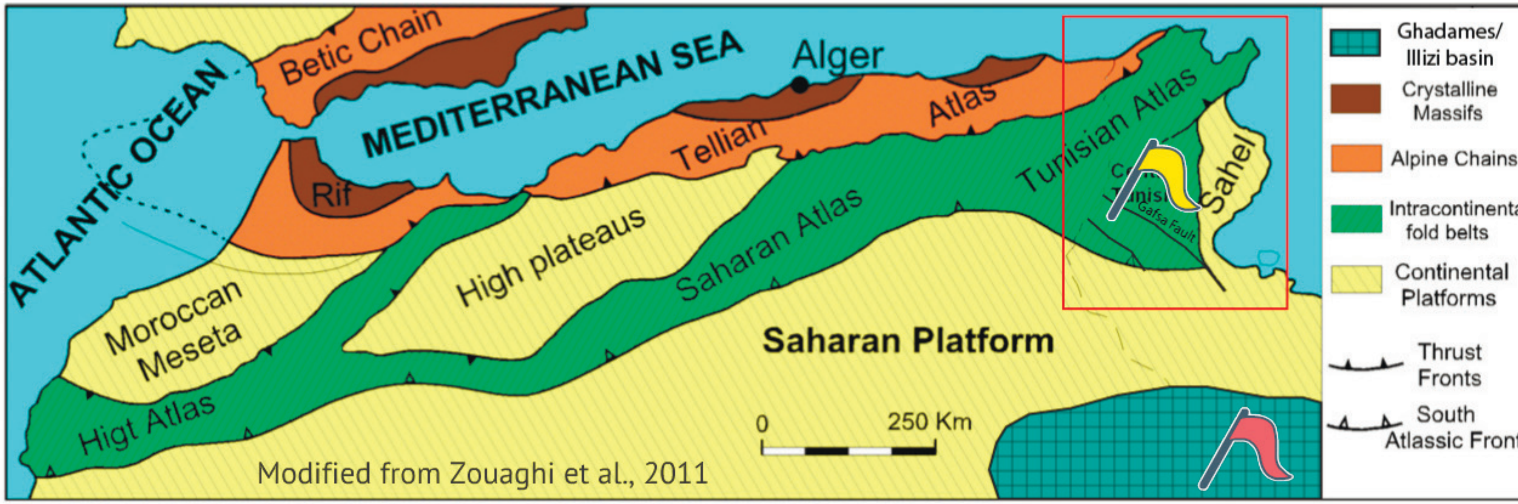
Geological setting

of the outcropping analog and subsurface basin



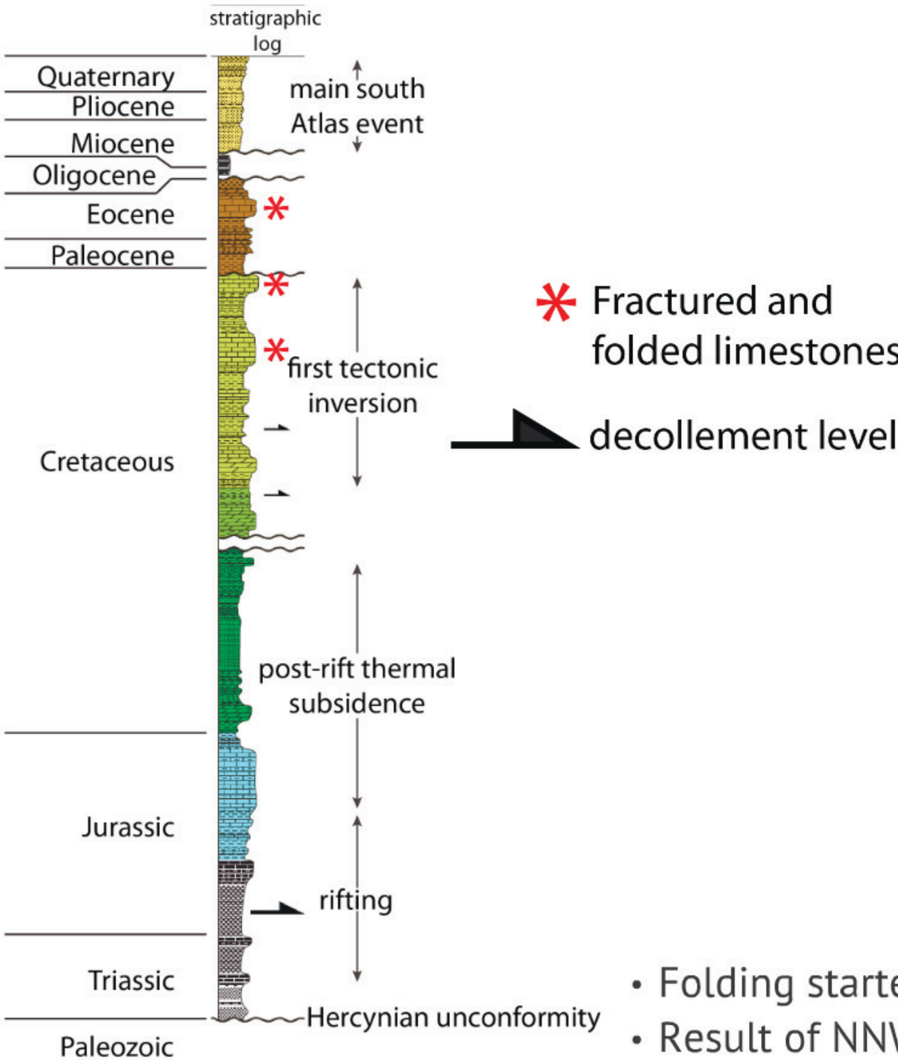
Surface analog fieldwork area

Subsurface fractured reservoirs

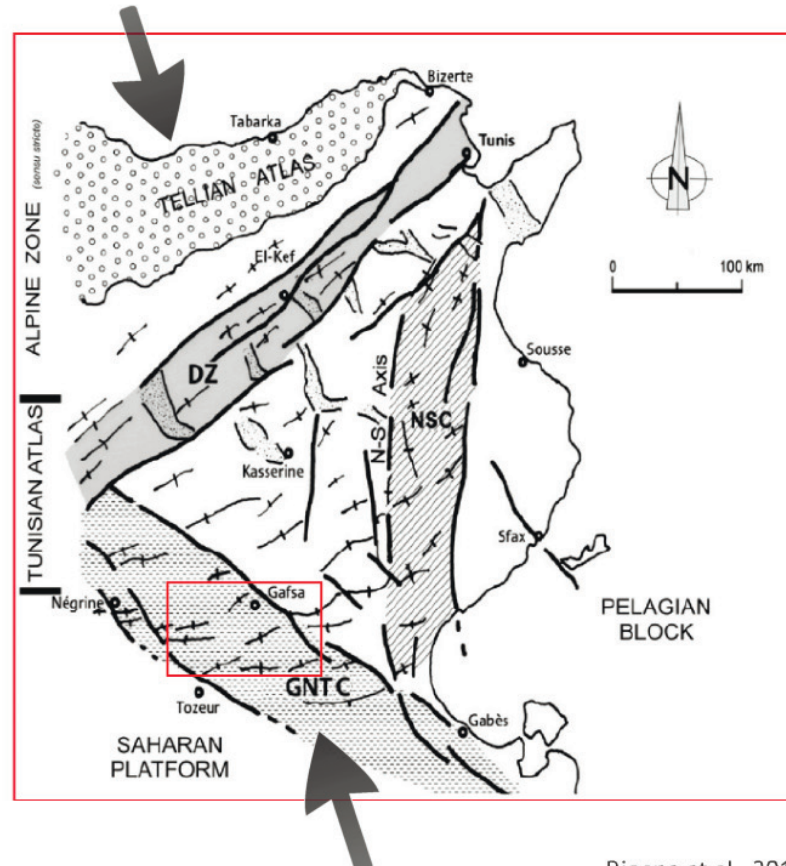
Links between the surface and subsurface:

- Fault-propagation fold structures
- Fractured limestones

Tectonic setting



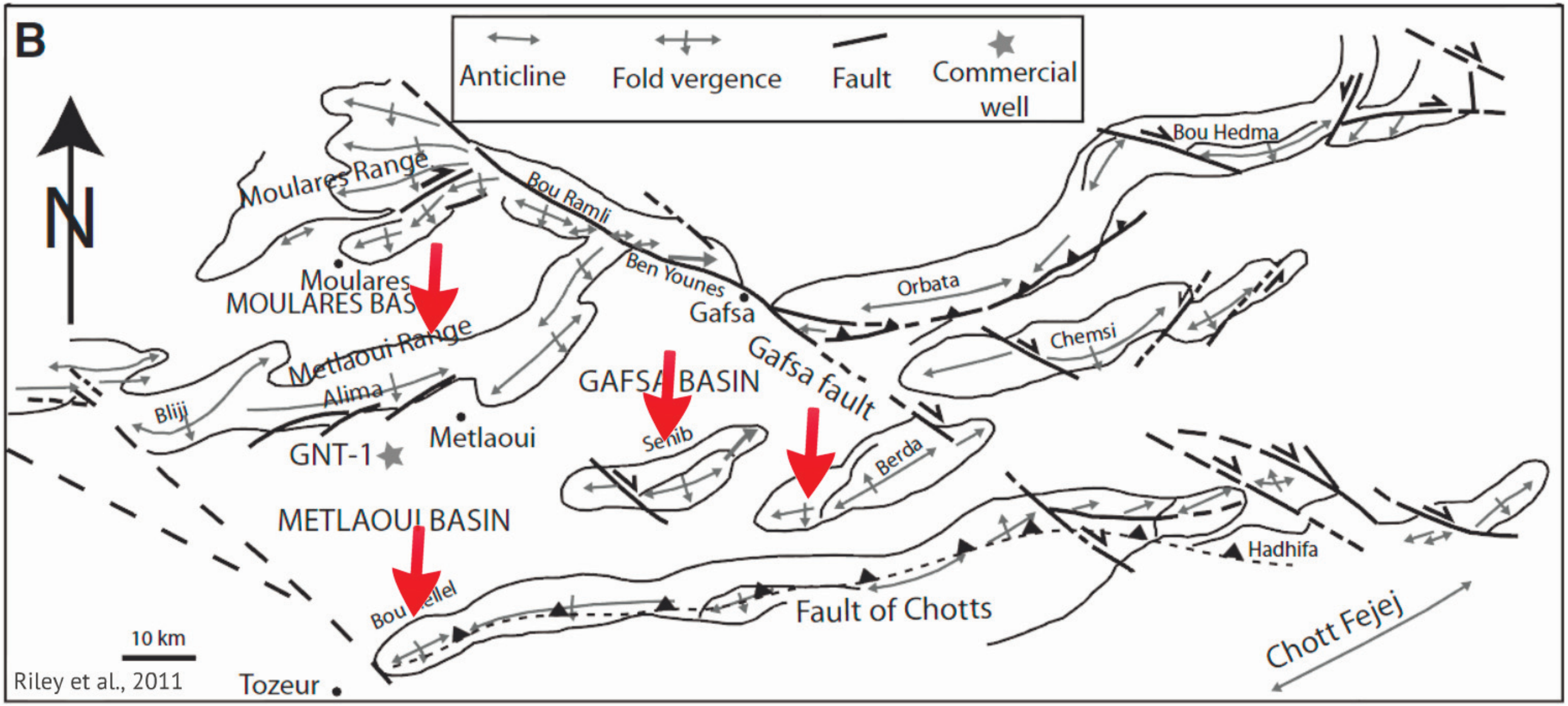
after Said et al., 2009



Rigane et al., 2011

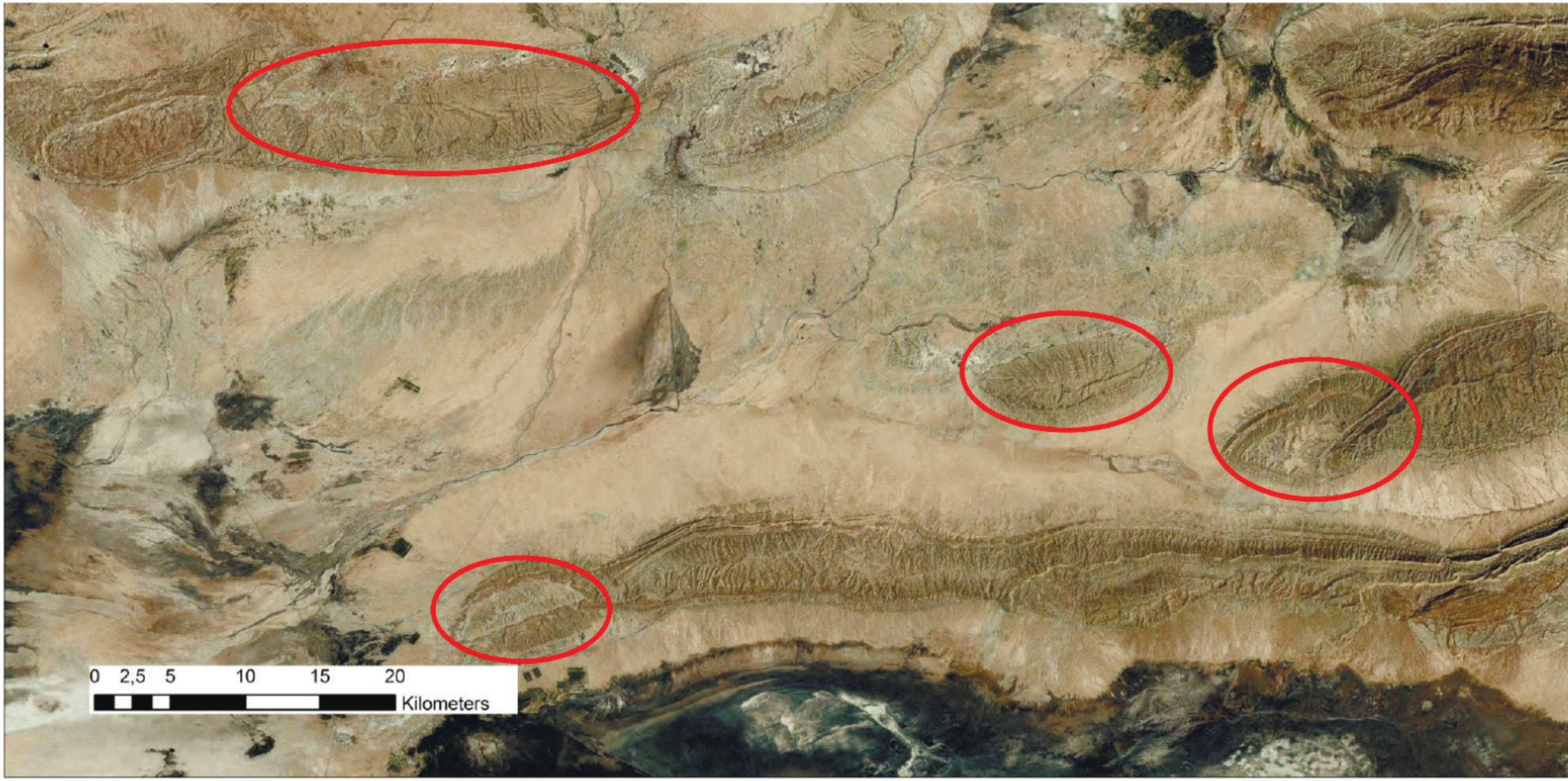
- Folding started in Miocene
- Result of NNW-SSE shortening
- Folds in deformation zone between two major strike-slip faults
- 3 fractured limestone formations are studied in 4 structures

Fieldwork structures



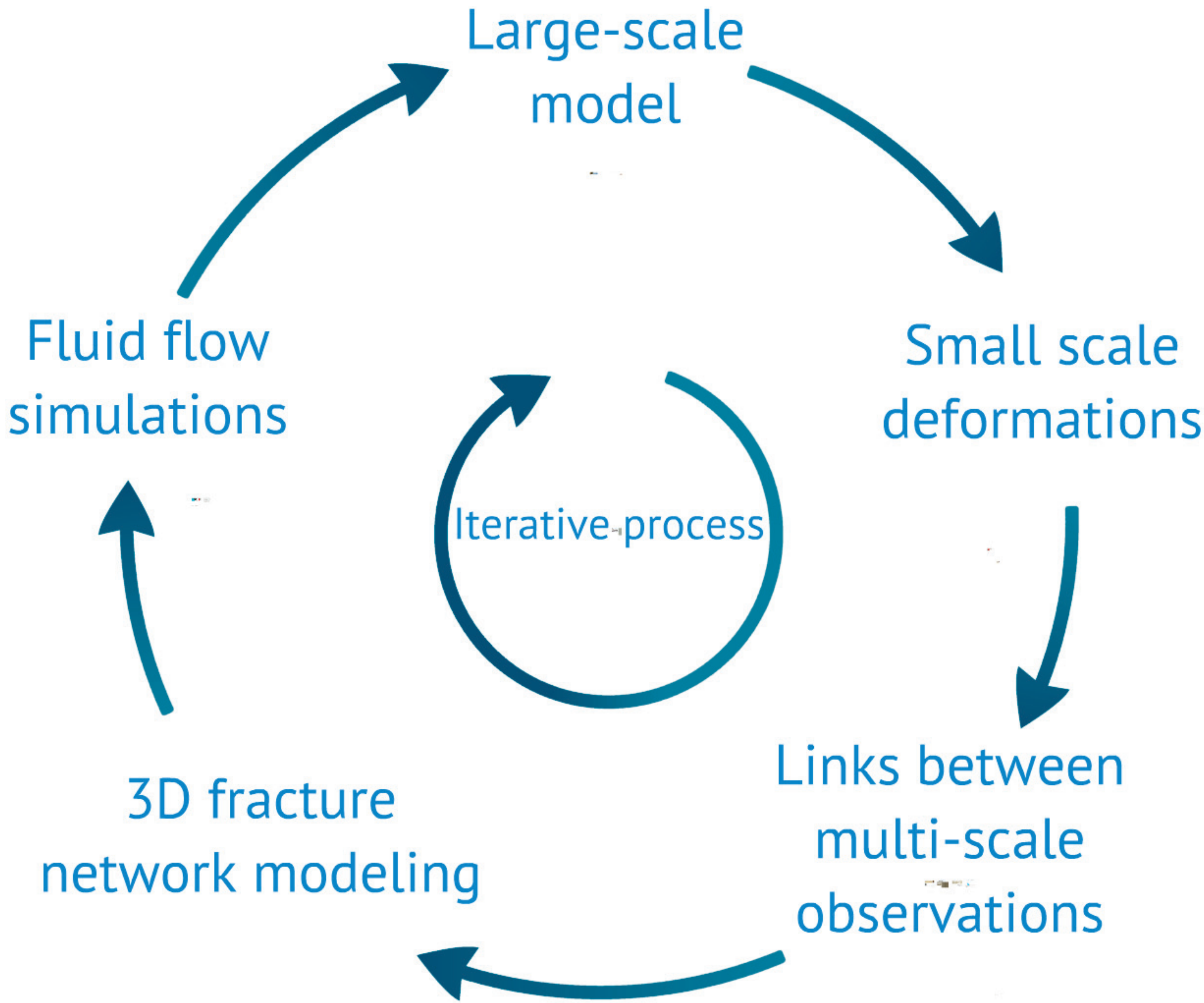
4 structures with:

- 'Simple' deformation history
- reservoir-scale dimensions



Structures have:

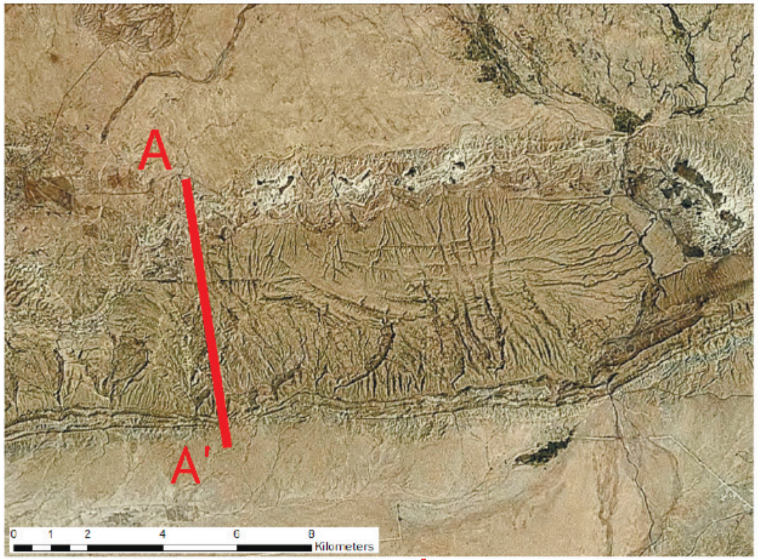
- Well-defined 3D geometries
- Comparable dimensions
- Excellent exposure

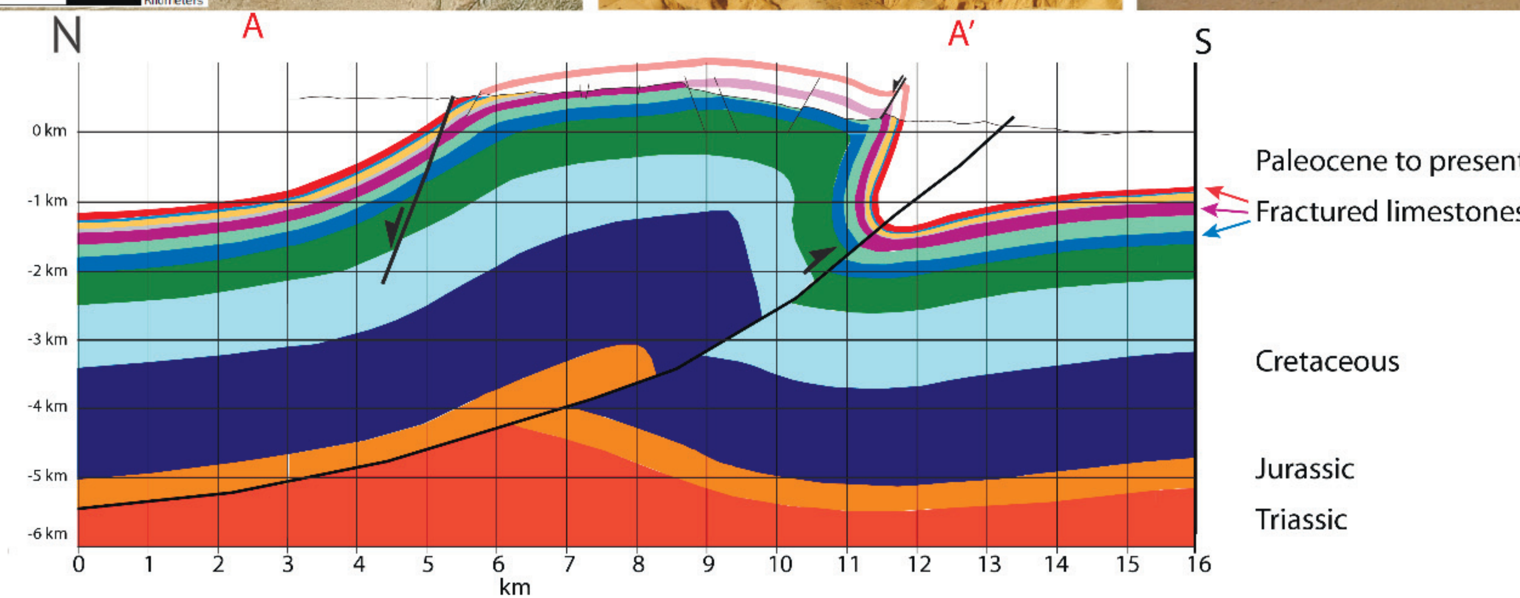

Large-scale model
Small scale deformations
Links between multi-scale observations
3D fracture network modeling
Fluid flow simulations
Iterative process

Large-scale modeling of structures

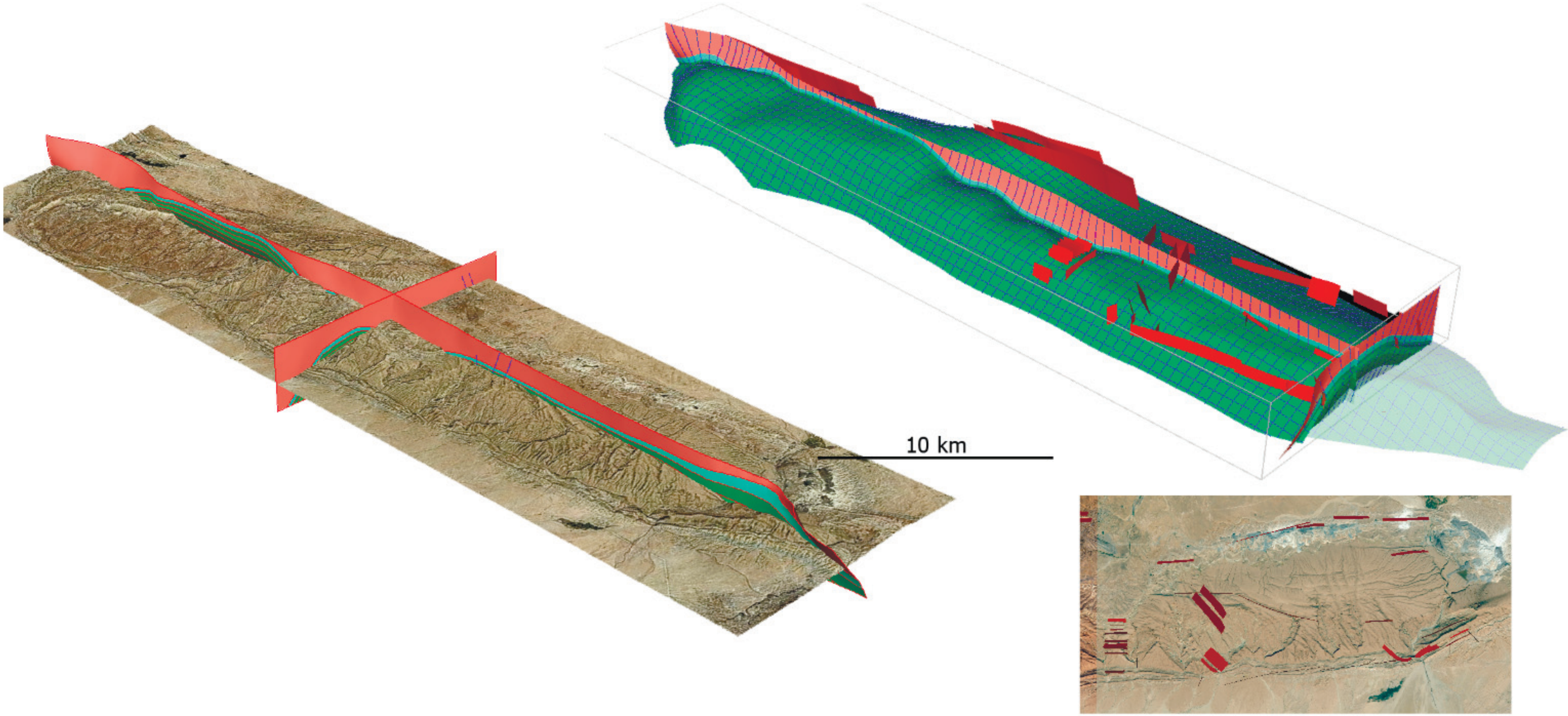
Example: Fault-propagation fold

- 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:

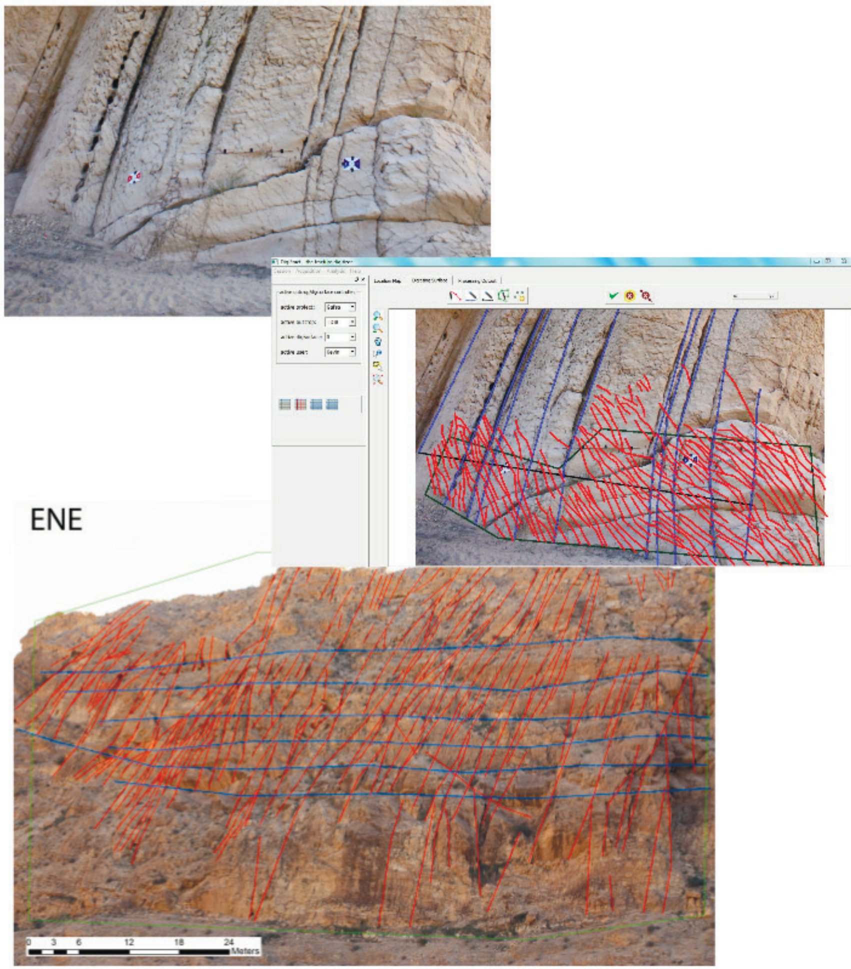
- Fold geometry (surface and subsurface down to -1800m)
- Seismic-scale faults

Capturing small-scale deformations

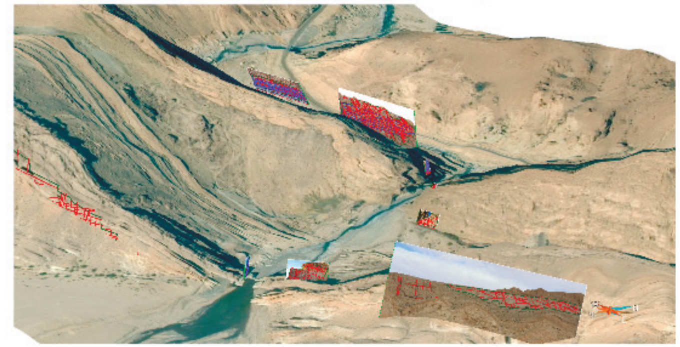
Using the Digifract digitizing tool

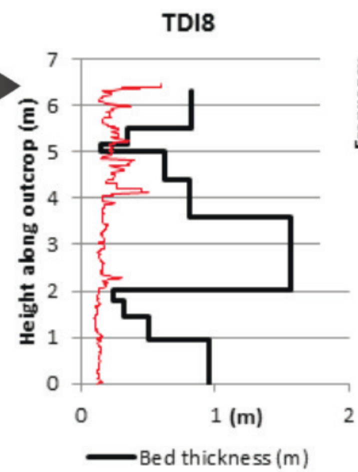
Digifract

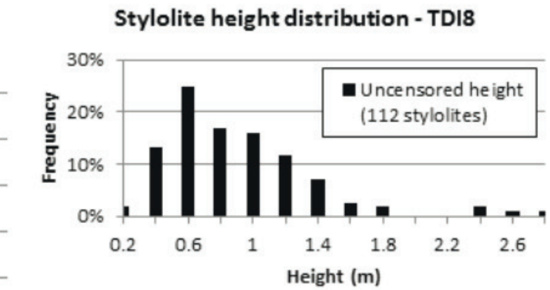
Acquisition

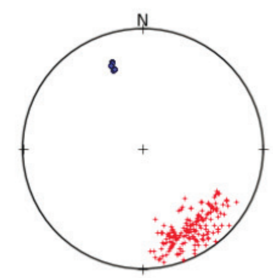


Processing









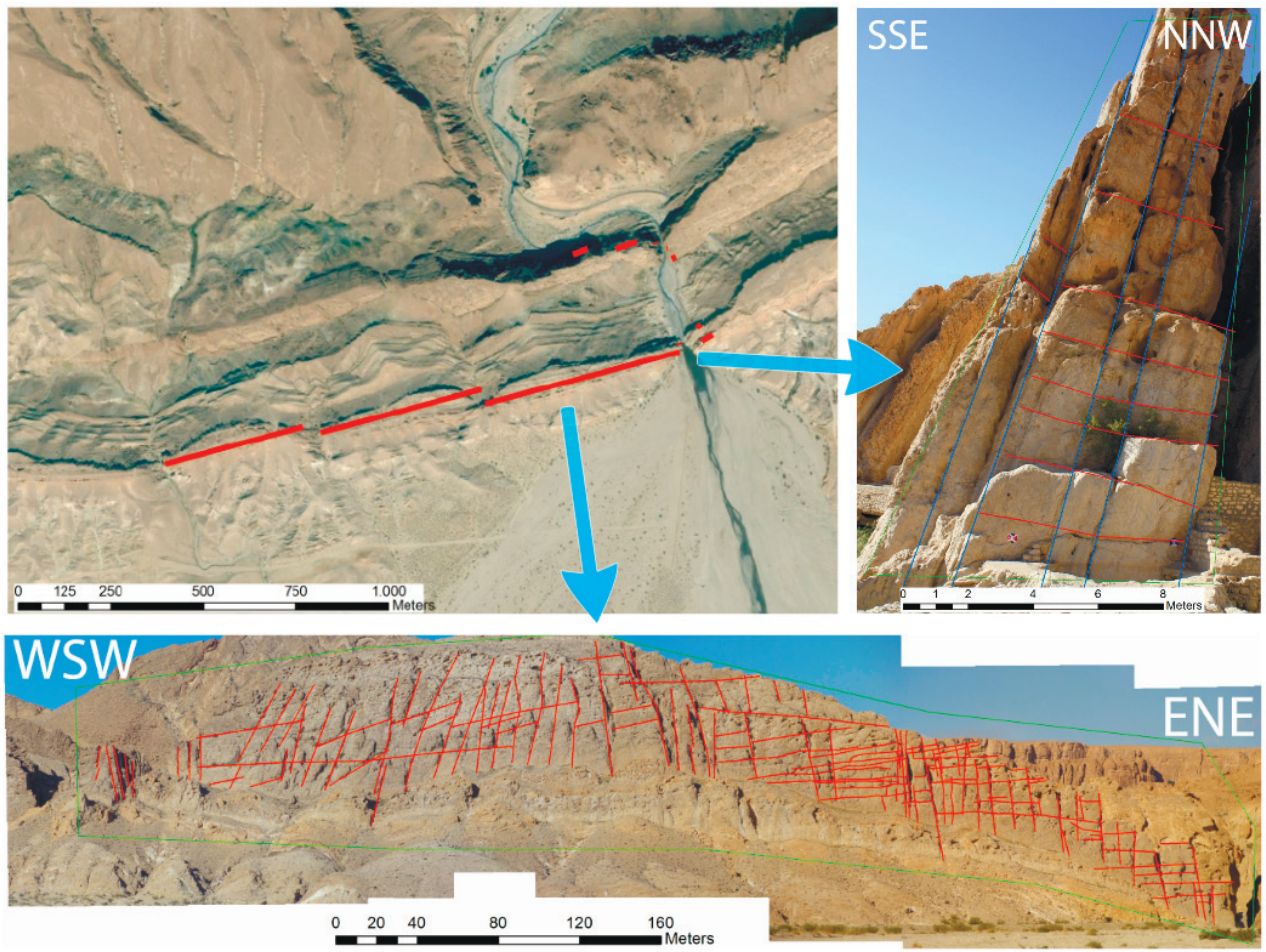
Open-source tool - developed at VU Amsterdam and TU Delft

Hardebol and Bertotti (2012)

A unique 2.5D fracture and bedding dataset

Data gathered in 2-week fieldwork:

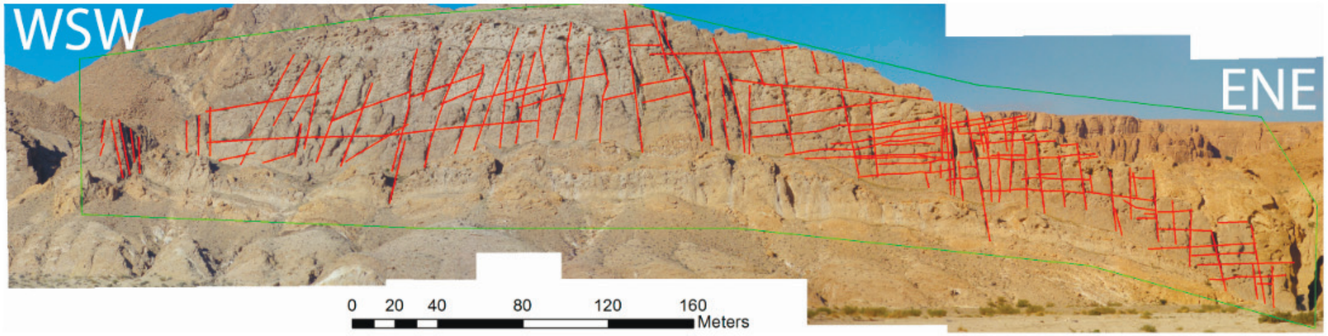
- 2100 fractures, veins and stylolites in 25 outcrops from 4 structures
- covering different structural domains
- cm-scale to km-scale fracture scales
- bedding measurements



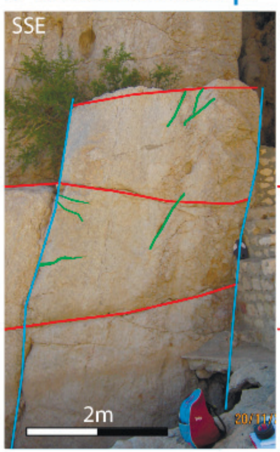
Fractures related to different mechanical processes

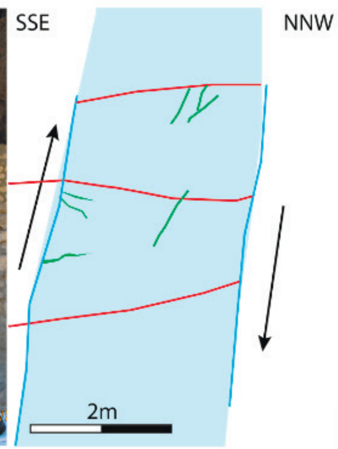
Layer Parallel Shortening, Flexural slip and fiber stresses

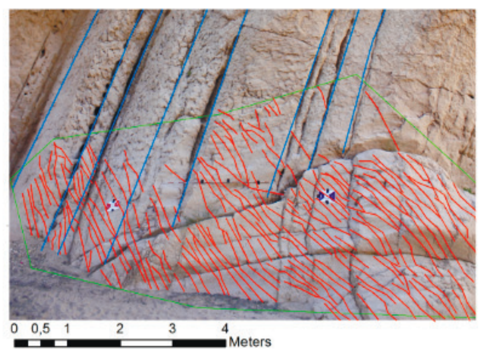
Layer Parallel Shortening



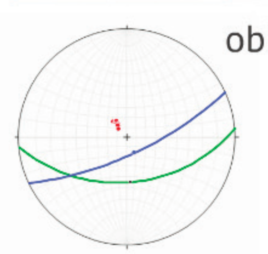
Flexural slip



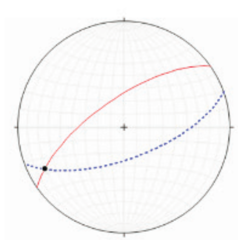


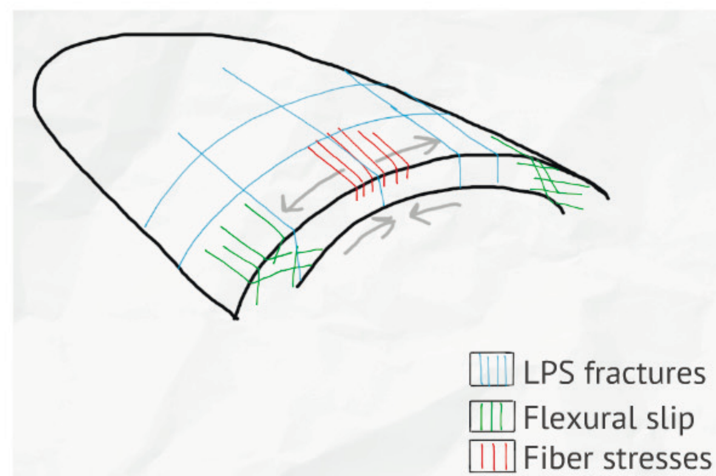


oblique to bedding stylolites



oblique-to-bedding veins



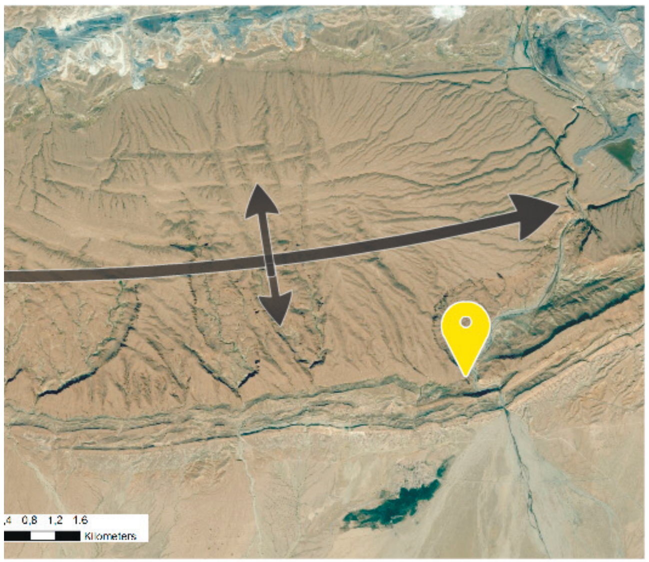


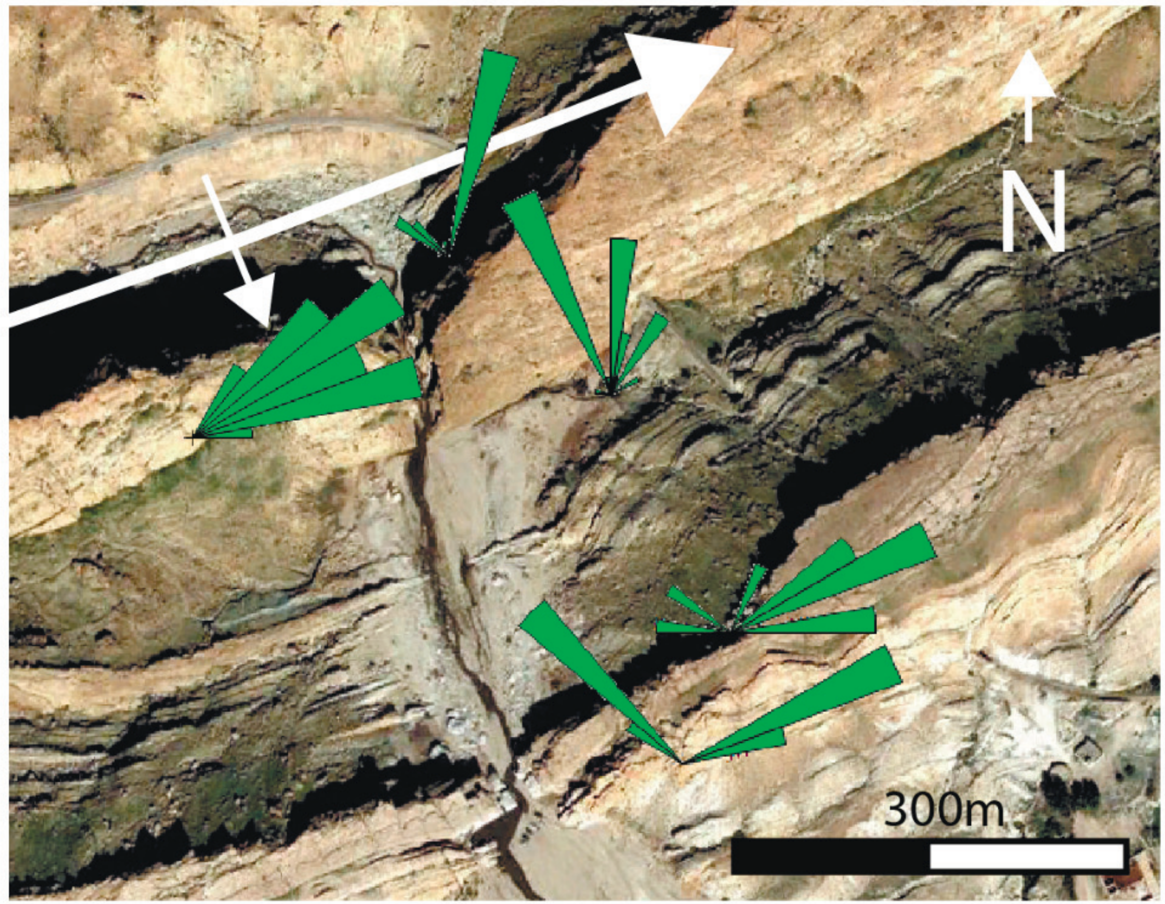
Fractures related to flexural slip

Formed during folding

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

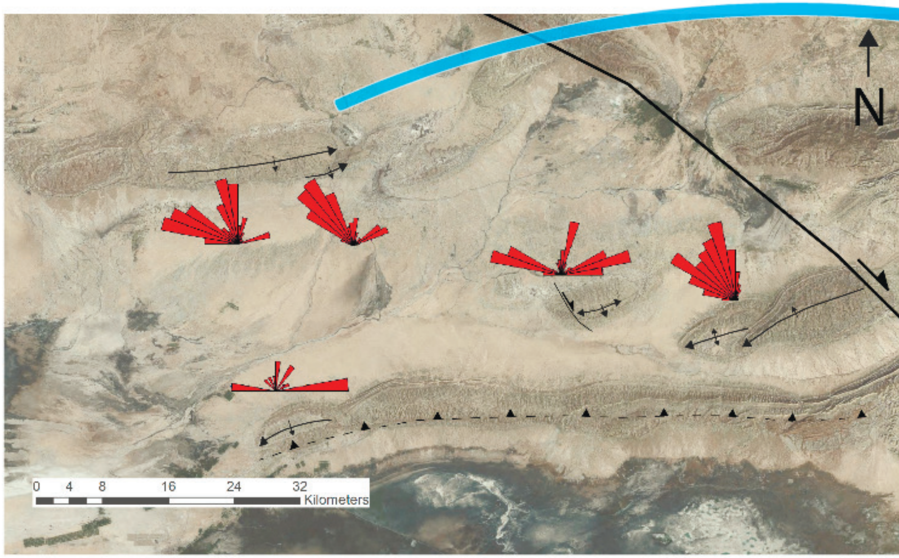
All fractures combined

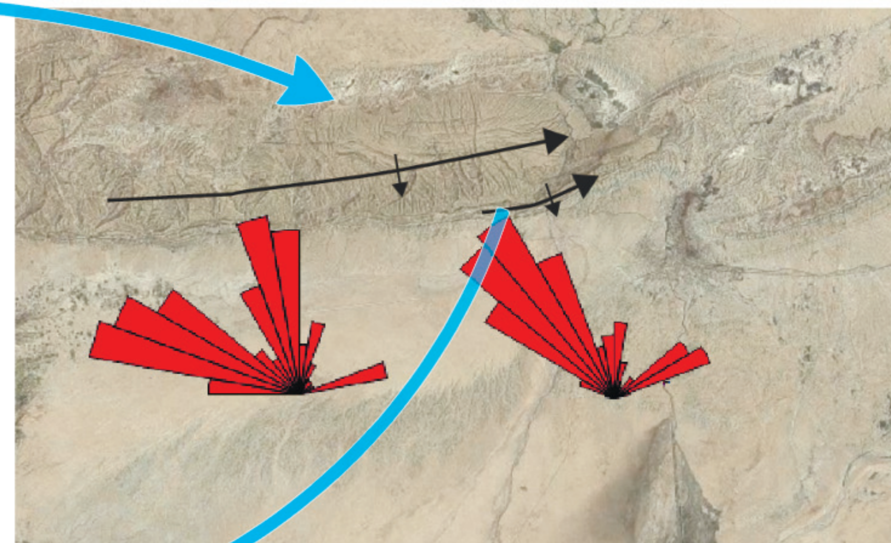


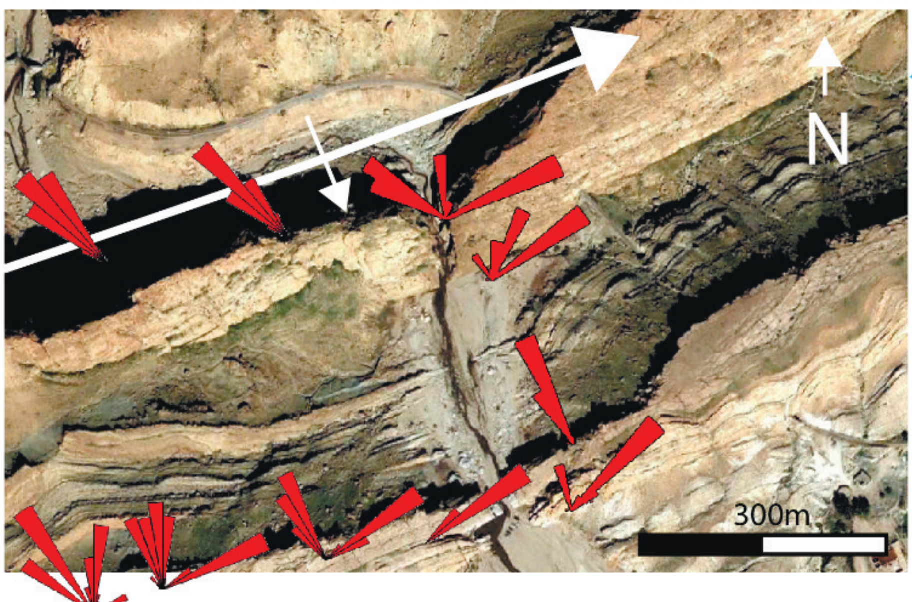


Fractures related to Layer Parallel Shortening

Formed before folding



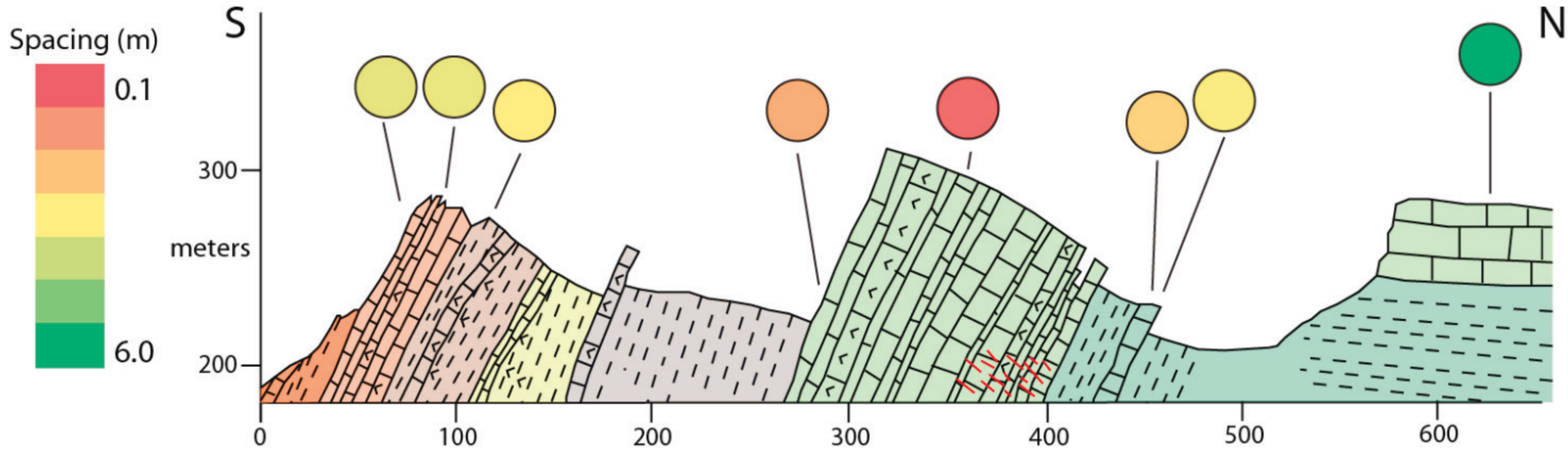


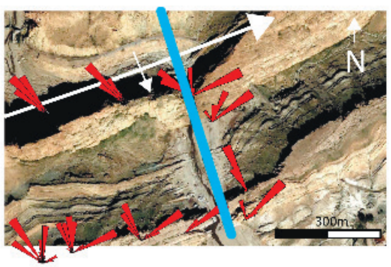


- Fractures sub-vertical to bedding
- 2 orthogonal sets per structure
- Large non-stratabound fractures

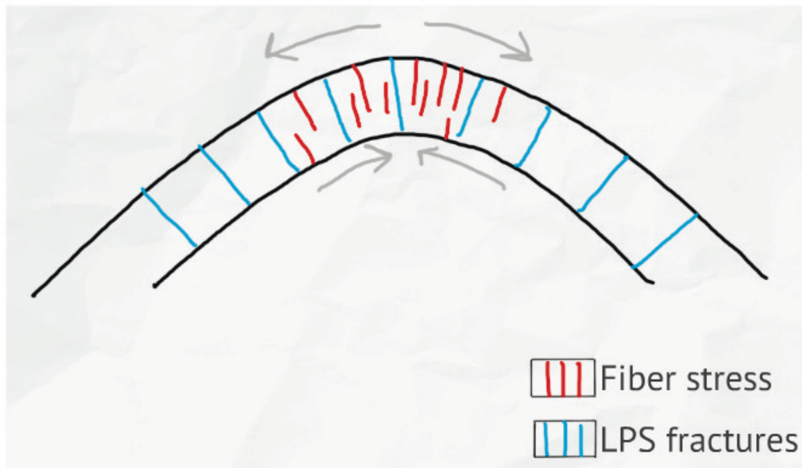
Trends in fracture density

Related to Fiber stress fractures formed during folding





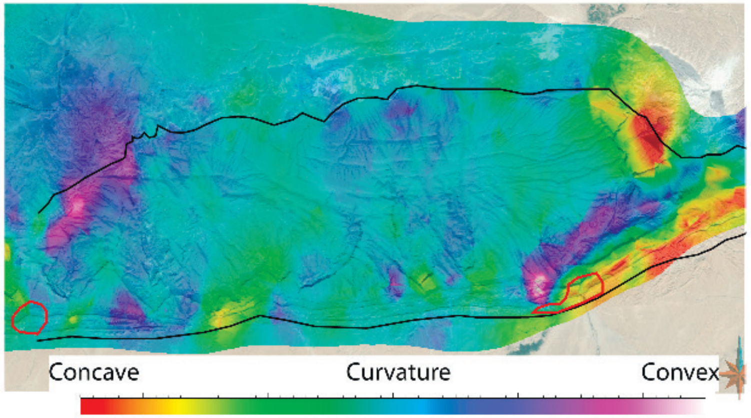
- Increase in fracture density of sub-vertical fractures towards core of anticline
- Part of these fractures are parallel to the fold axis -> fiber stress related



Identifying homogeneous domains

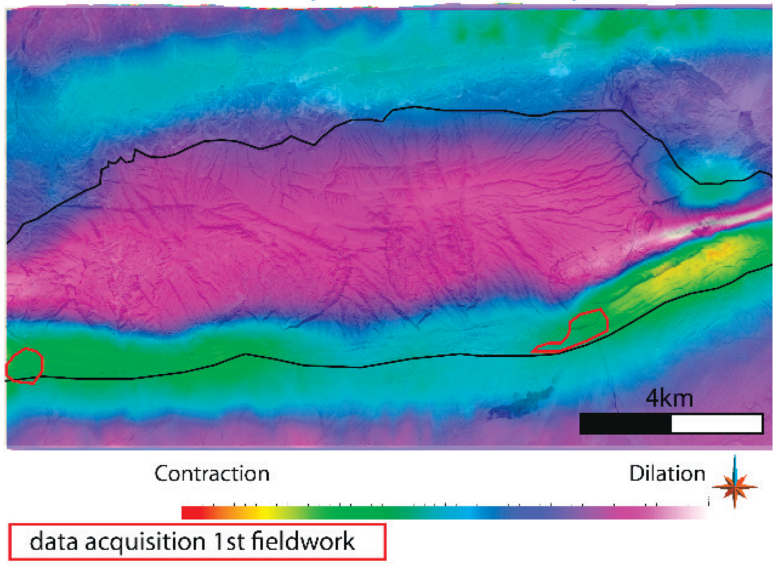
For extrapolation of outcrop data to anticline fracture networks

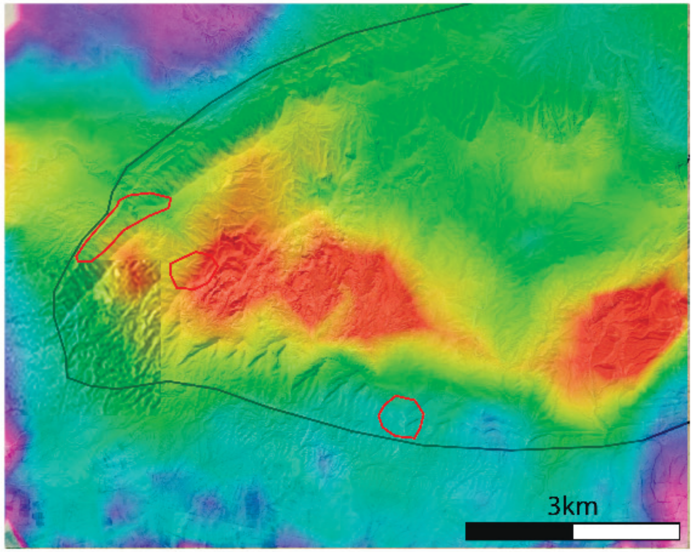
Curvature map



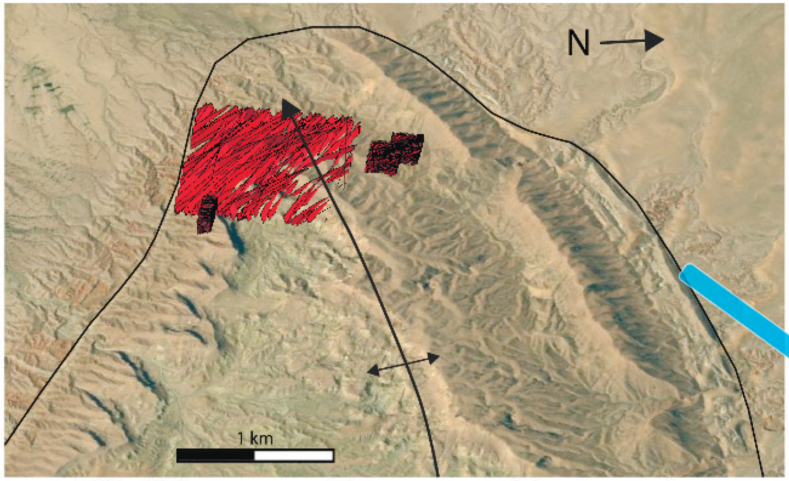
- We test different geometric, kinematic and mechanical drivers
- e.g. curvature (objective but no direct proxy for strain)
- mechanical (provides strain but depends on choice of fold mechanism)

Mechanical (2D and 3D)

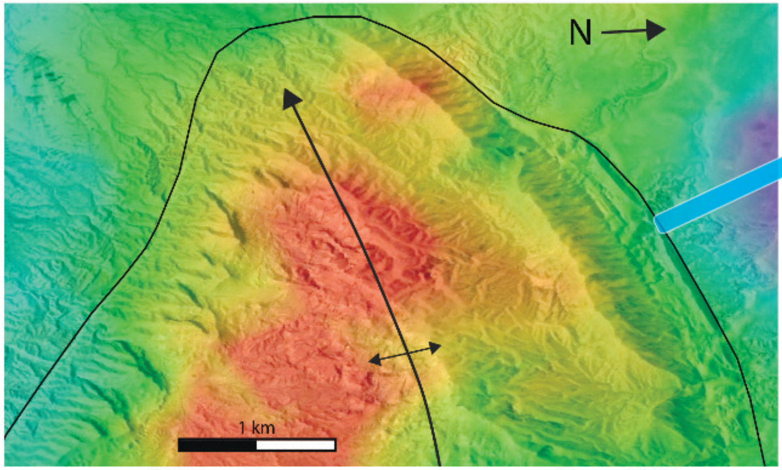




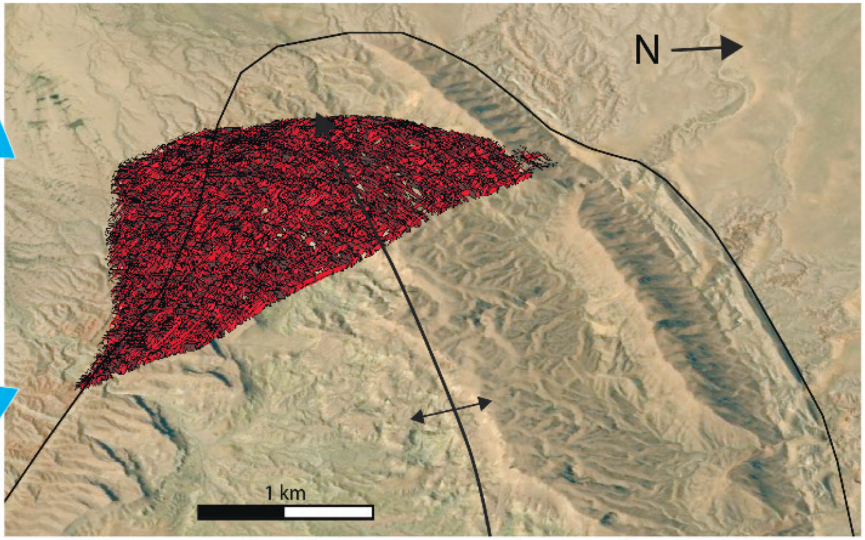
Populating domains with 3D fracture networks



3D Discrete Fracture Networks conditioned to outcrops



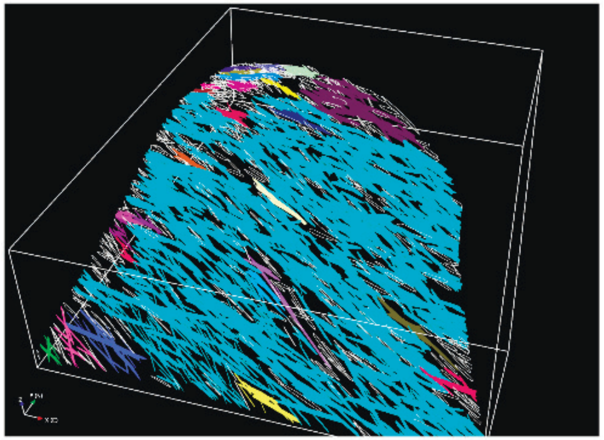
Dilation as a proxy for 3D fracture density



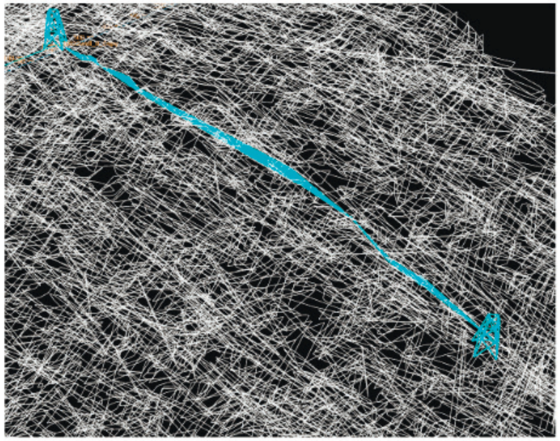
Extrapolating small-scale DFNs using different large-scale drivers

Fast and effective fluid flow quantification

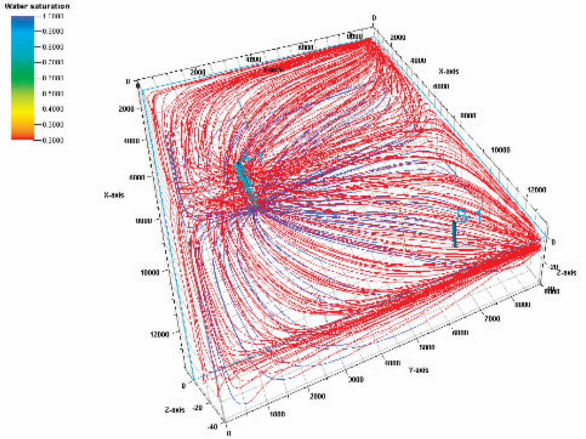
Rapid calculations to quantify uncertainties and their effect on fluid flow



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

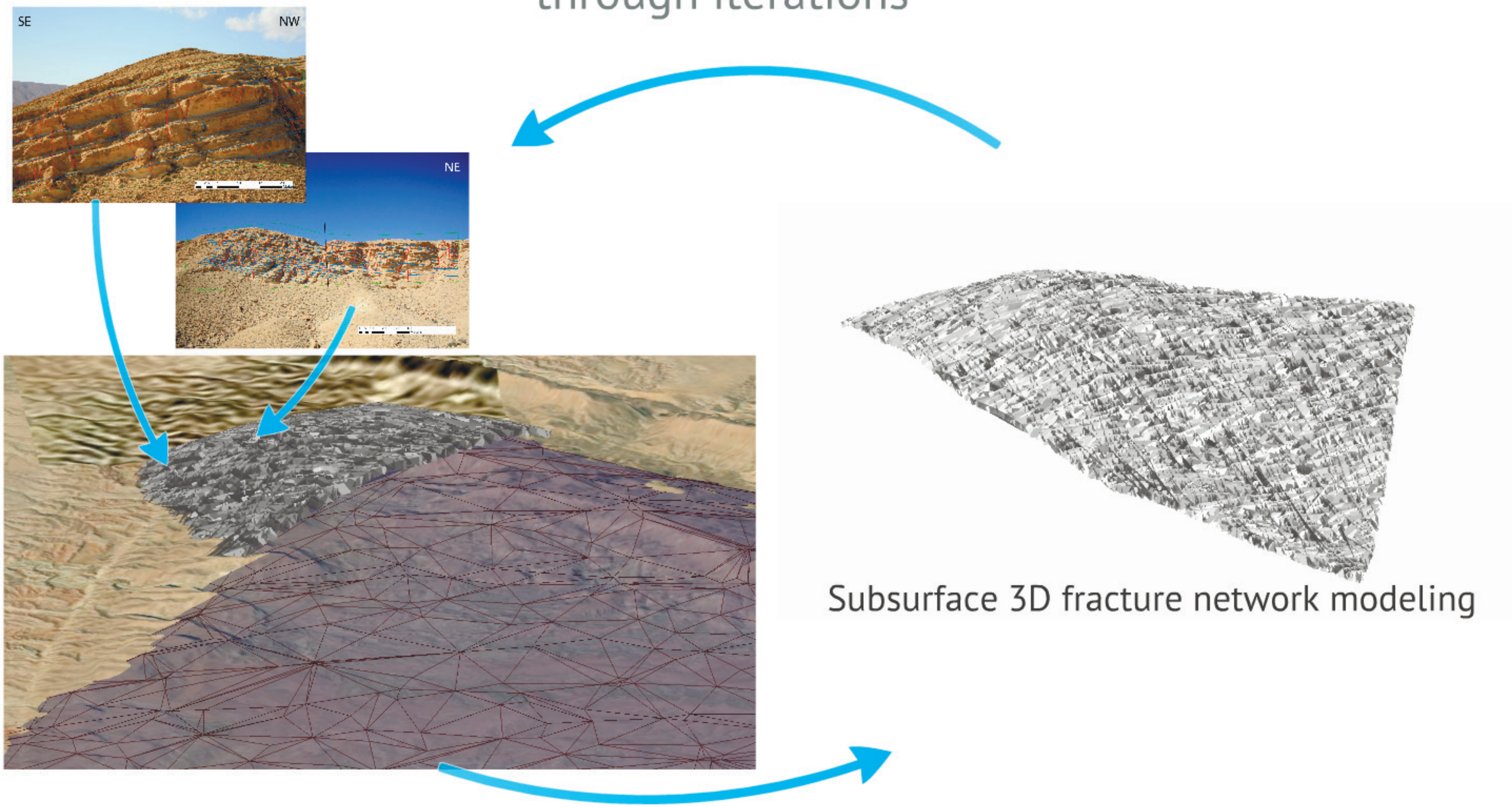
Using novel upscaling and fluid flow simulation techniques

1. Build an accurate and detailed fracture-matrix fluid flow model using complex (unstructured) DFN grids

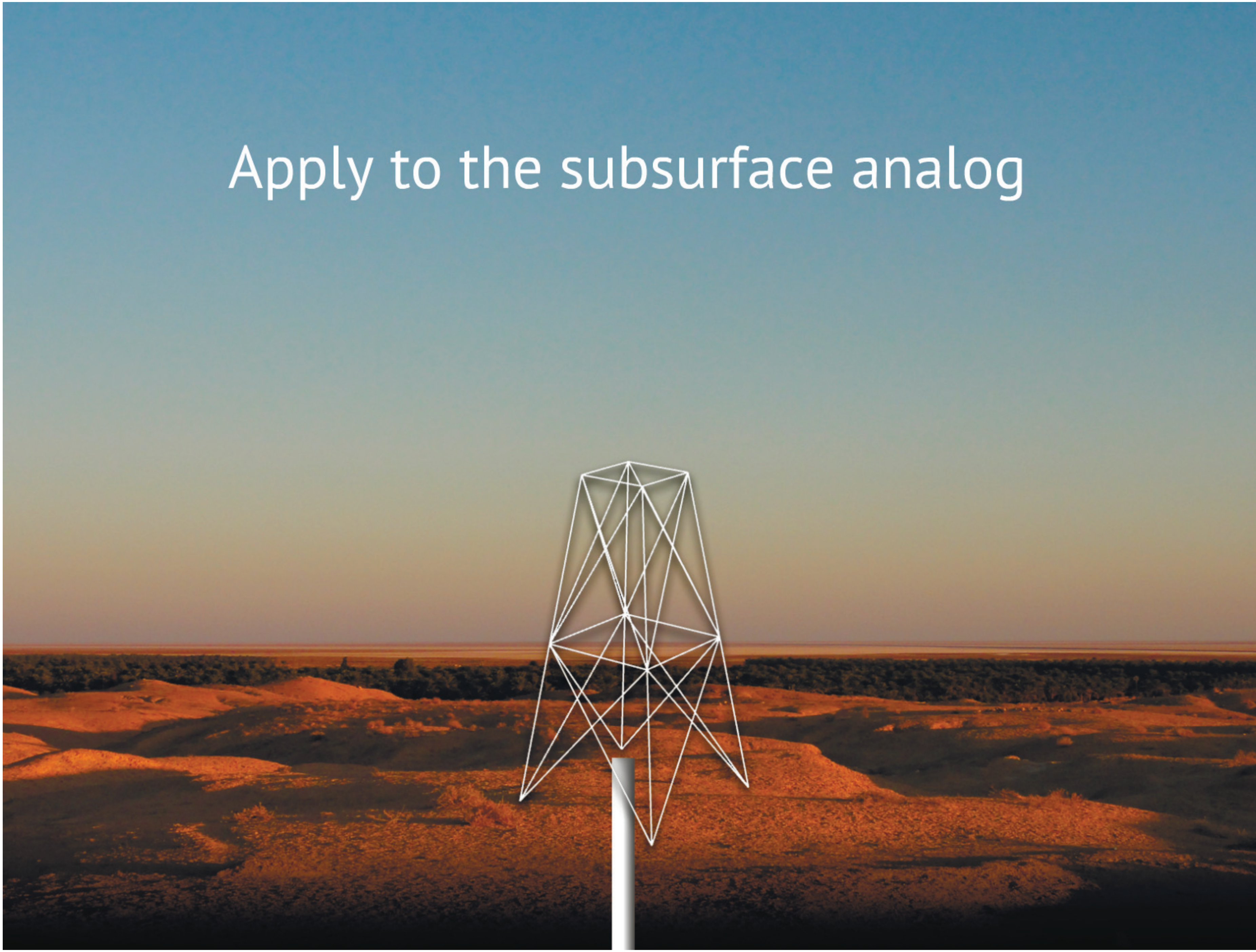
2. Compare the accuracy of quick connectivity estimations to the complete fluid flow simulations

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


Thank you!
Questions?