[PS]3-D Fracture Patterns in Outcropping Reservoir-Scale Anticline: New Acquisition Methods and Results from the Tata Anticline (Central Morocco)*

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Abstract

Natural fractures are common in anticlines and control physical properties of tight sandstones or carbonate reservoirs (e.g. Miocene Asmari reservoirs, Iran). General knowledge and commercial software packages often assume that fractures are caused by fiber stresses associated with folding and, consequently, that fractures are parallel to the fold axis and their intensity controlled by fold curvature. In the vertical dimension, it is thought that fracture spacing is directly proportional to the thickness of sedimentary layers. These models are unsatisfactory as they neglect 1) the difference in fracture patterns generated by different folding processes, 2) the importance of regional stress fields, and 3) the 3D organization of fractures. Outcrop analogs have been used to provide answers to these issues but the resulting data sets are incomplete.

As an outcropping analog we use the Tata anticline (Morocco). The Tata anticline is exposed for an across-strike width of >400m and a length >1km. The folded succession is 30m thick and composed of Devonian sandstones with bed thicknesses from 0.2 to 2m. The dip of the flanks is <10degrees. To overcome known shortcomings of conventional data acquisition methods and acquire full fracture data on the Tata anticline we have made developed new techniques. To analyze fractures on the back of the anticline we use a Helium balloon. The efficient recording of fracture data on vertical outcrops was done with DigiFract, an innovative implementation within an existing GIS that offers custom fracture acquisition procedures. Fractures in the Tata anticline are organized in three sets. A first set includes fractures parallel to the fold axis. They have spacing distances in the order of 0.2-0.3m and are typically longer than the outcrop (>1km). In vertical outcrops, fractures of the first set cross the entire stratigraphy which, therefore, behaves as a single mechanical unit. Smaller fractures are observed in the outer and inner parts of the anticline. The 2nd set is composed of joints perpendicular to the fold axis. They show spacing of 1-2m. Fractures of set 2 are generally

longer than the outcrop. The 3rd set is composed of closely spaced fractures generally <1m long bounded by fractures parallel to the fold axis. The orientation of the fractures is oblique to the fold axis. The difference between the characteristics of the fracture sets has implications for drilling strategies in fractured anticlinal reservoirs.

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support by Statoil

1. Acquisition and processing tools

data acquisition

pavements

Challenge and boundary conditions

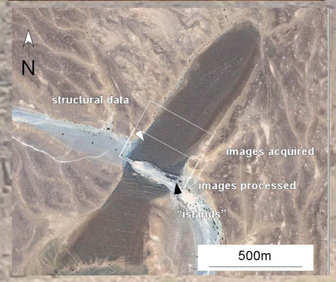
- efficiently acquire full fracture data from large pavements with high detail
- tools should be low-tech enough, to be used in remote areas with little chance of failure

The tool. Kuky: a hand-held blimp with a camera steered by a remote control

As the blimp does not carry any positioning device, its precise position is unknown. Stitching and rectification of the acquired images is dependent on a grid set on the ground and visible in the images

Results

Kuky performed greatly and a surface of 2500m^2 in two flights during two days (+ 1 day for gridding).



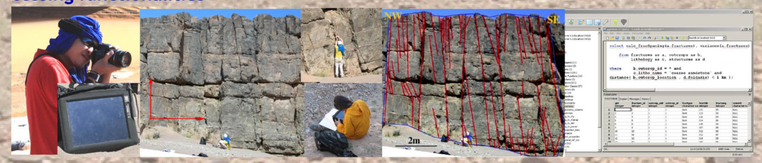
vertical outcrops

Challenge and boundary conditions

- efficiently acquire full description of fractures inclusive of their dimensions, relative position and attributes such as direction and infill.
- Acquisition should be objective, i.e., with no assumption on the potential existence of layers with homogeneous behaviour
- Data acquisition and storage must allow processing and result-reporting in the field in order to allow for immediate quality check

The tool: DigiFract

A tool developed at VU-TUD and based on the full use of GIS capabilities and processing functionalities



outcrop image is loaded in a GIS application running on a Tablet PC. Reference points provide an internal scale

Fractures are traced on the screen and their position and geometry stored as individual digital objects. Attributes such as direction and infill are recorded by a 2nd operator and associated to each digital fracture

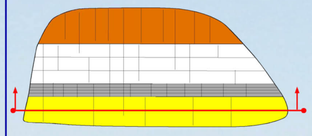
Bedding with sedimentology description are stored in the same data file

Performance and strategy

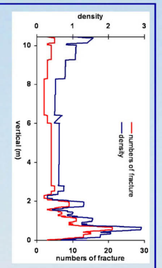
We acquire 50-70 fractures per outcrop in 2-3 hours. Two to three outcrops per day can be achieved having spare batteries

Outcrops are chosen to cover the area and the different sedimentological and structural domains.

data processing



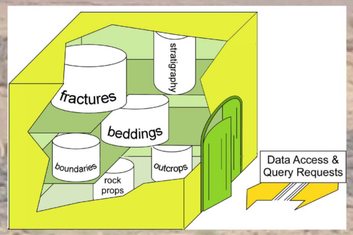
A digital cursor line scans the outcrop, measures the outcrop width and defines the intersections with fractures reporting fracture density (inclusive of SD etc) changes across the outcrop. (Groups of) layers with homogeneous densities define the fracture stratigraphy



Density analysis and, therefore, the definition of homogeneous intervals, can be performed for sub-sets with different properties such as orientation and height

Fracture and sedimentological (bed thickness, facies etc) data from all outcrops are stored in single Data Base System

Querying the Data Base, factors controlling fracture distribution and geometry (in vertical and horizontal dimensions) are established. Typical candidates are, for instance, bed thickness, sedimentary facies.



past- and future case studies

In the Tanqua-Karoo basin (South Africa) we investigate differences in fracture patterns affecting the different components of multistacked deep water turbidte fan system

In the Dolomites (Italy) we analyze fracture patterns across the different domains of atoll-like carbonate platforms characterized by sedimentological domain with differing mechanical properties

In Cambrian continental to transitional sands (Jordan) we investigate the anatomy of large-scale fracture corridors and the fine distribution of fractures in the intervening blocks

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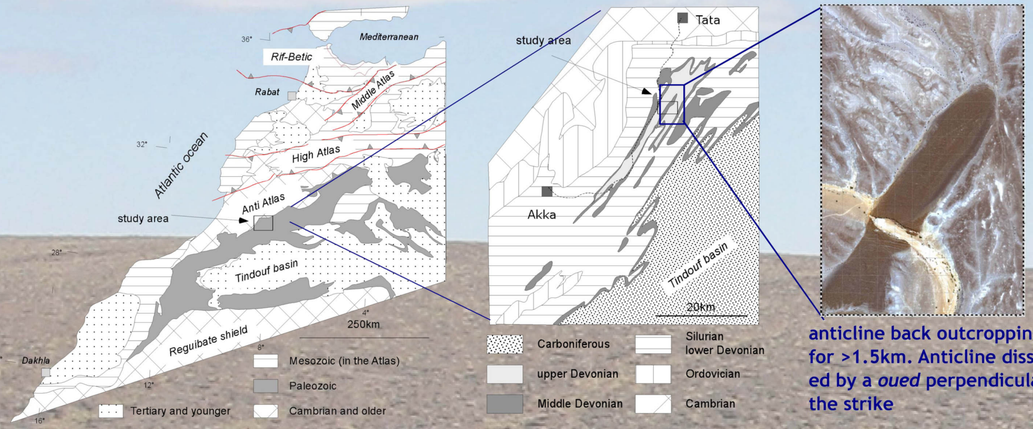
2. Geology and fracture systems

Geology of the Tata anticline

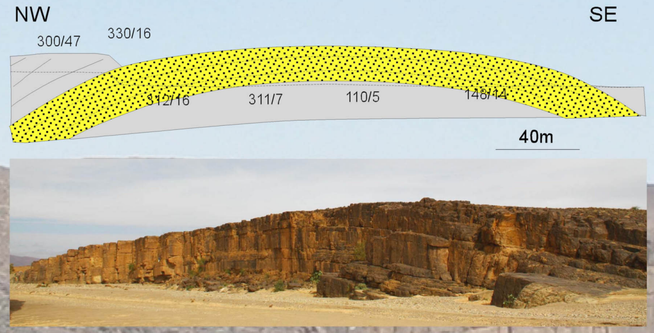
Located at the transition between the Anti Atlas and the Tindouf basins



anticline back outcropping for >1.5km. Anticline dissected by a *oued* perpendicular to the strike

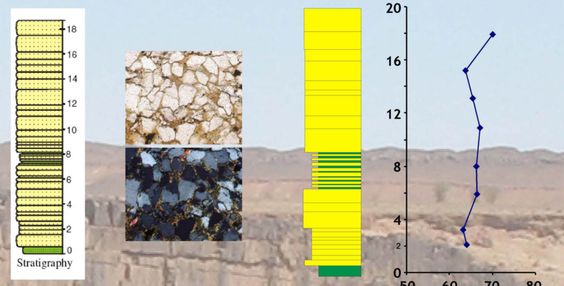
geometry

- 20m thick succession in shales
- curvature of $10^{-3}m^{-1}$
- length of horizontal section ~400m
- fold axis directed N40



stratigraphy

- 20m thick multilayer of quartz-rich sands
- ca. 40 layers 0.1-1.5 m thick
- little porosity preserved following pressure-solution and cementation



data base

pavement

- a surface of 400m*500m covered by 50 images during two several hours long flights
- images from the S half (better outcrop quality) rectified, stitched and interpreted
- >6000 fractures traced in two windows (work in progress)

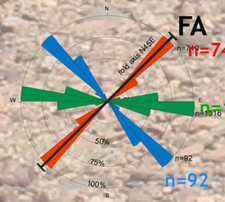
The pavement and fractures traced in window 1

vertical outcrops

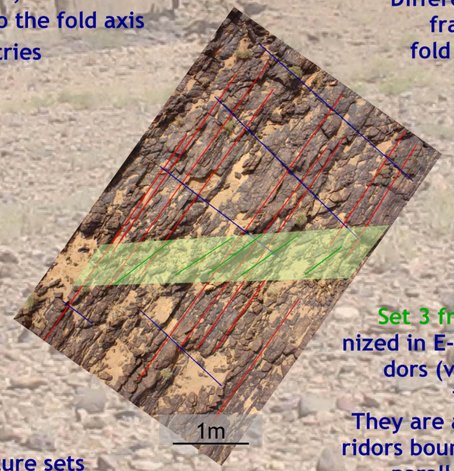
- 11 structural stations acquired on the N flank of the *oued* traversing the anticline covering the entire stratigraphy
- structural stations in different orientations to capture the different fracture sets
- structural stations in sub-vertical layers to the W of the Tata anticline to explore relations between spacing and bedding dip
- >600 fractures measured and interpreted

fracture patterns

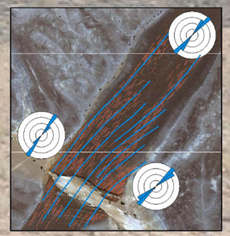
- the Tata anticline is highly fractured
- fractures are organized in three sets, perpendicular, parallel and oblique to the fold axis
- fracture sets have different geometries



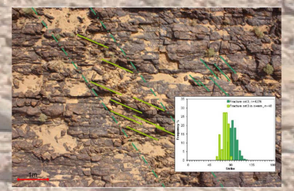
The three fracture sets of the Tata anticline



Differently from other sets, fractures parallel to the fold axis change direction in map view



Set 3 fractures are organized in E-W trending corridors (visible on satellite images) oblique... They are also found in corridors bounded by fractures parallel to the fold axis



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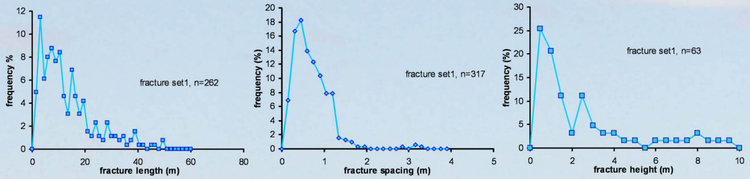
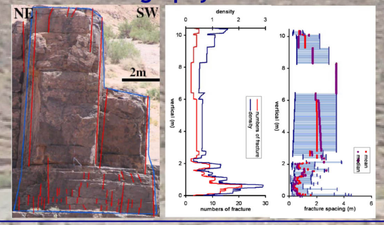
3. Quantifying fracture patterns and controlling factors

fracture characteristics

set 1: fractures perpendicular to the fold axis

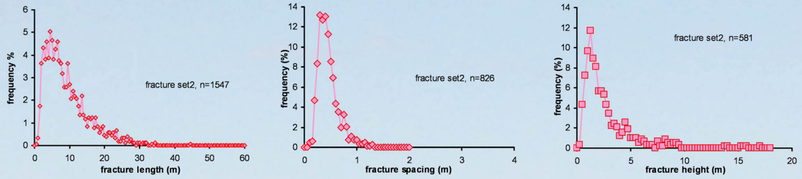


- Fractures are <50m long, i.e., they do not cross the entire outcropping anticline
- Spacing distances cluster around 1m but outliers are common up to 3-4m
- Fractures <10-15m high and there are no fractures cutting the entire stratigraphy

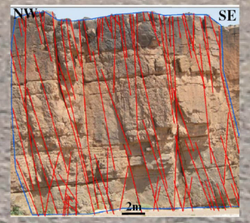


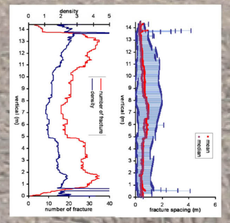
- Fracture densities are highest in the upper and lower boundary of the multilayer and lowest in its central part

set 2: fractures parallel to the fold axis



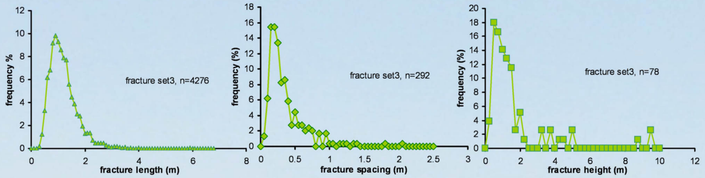
- Most fractures are <30m long and are therefore substantially shorter than the outcrop length
- Spacing distances show a strong cluster around 0.5m
- Fractures are <10-15m high and typically around few meters. No fracture cuts the entire stratigraphy





- Fracture densities are highest in the upper and lower boundary of the multilayer and lowest in its central part

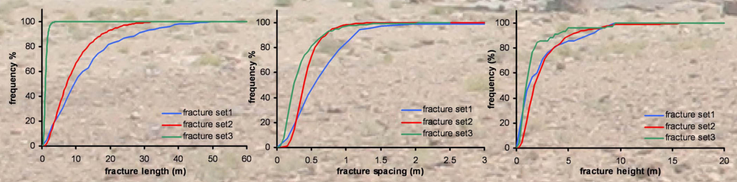
set 3: fractures oblique to the fold axis



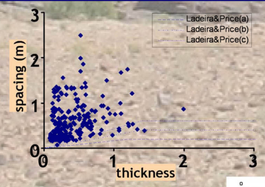
- Most fractures are <3m and generally 1-2m
- Spacing distances show a strong cluster around 0.2-0.3m
- Fractures are generally <2.5m high

Insufficient information is available on the vertical distribution of set 3 fractures

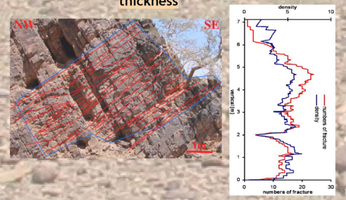
comparative analysis and controlling factors



- Set 3 fractures are the shortest ones observed in the Tata anticline. Sets parallel and perpendicular to the fold axis are substantially longer. None of these fractures traverses the entire outcrop
- Spacing distances show less variability but those of the set perpendicular to the fold axis are significantly larger
- Fractures parallel and perpendicular to the fold axis have similar heights, always shorter than the thickness of the stratigraphy



- Homogeneous lithology
- Beds exert little to know control on fracture spacing



steep dipping layers have higher fracture densities

we are investigating areal density changes on the pavement of the Tata anticline

implications and conclusions

- The tools we have developed for the acquisition and processing of distributed fractures are very efficient and flexible
- We have acquired a rich data set providing one of the few 2.5D description of fracture patterns affecting a reservoir-like anticline
- Fractures are organized in 3 sets, perpendicular, parallel and oblique to the fold axis
- fractures of sets 1 & 2 are 10s meters long, i.e. shorter than the outcrop
- fractures are less high than the stratigraphy.
- Their density is highest at the top and bottom of the multilayer. Single layers are mechanically “invisible”
- Realistic geometries can replace “sugar cubes” in fluid flow modelling efforts