Aquifer analogue study to determine the effects of fracture networks regarding the deposition of CO_2

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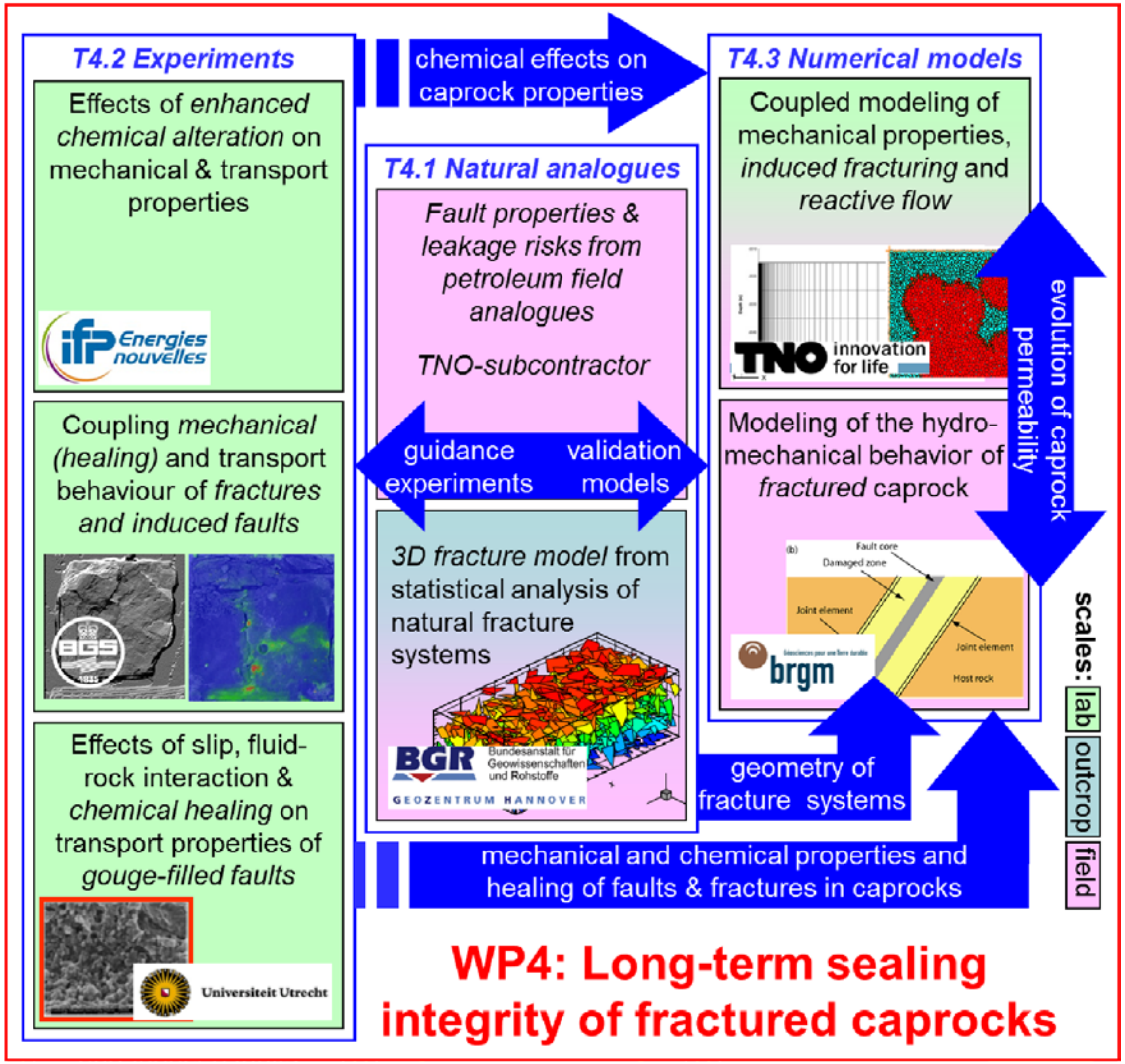
www.ultimateco2.eu

Task 4.1: Evidence for the impact of faults and fractures on CO_2 migration from natural analogue studies



source BRGM

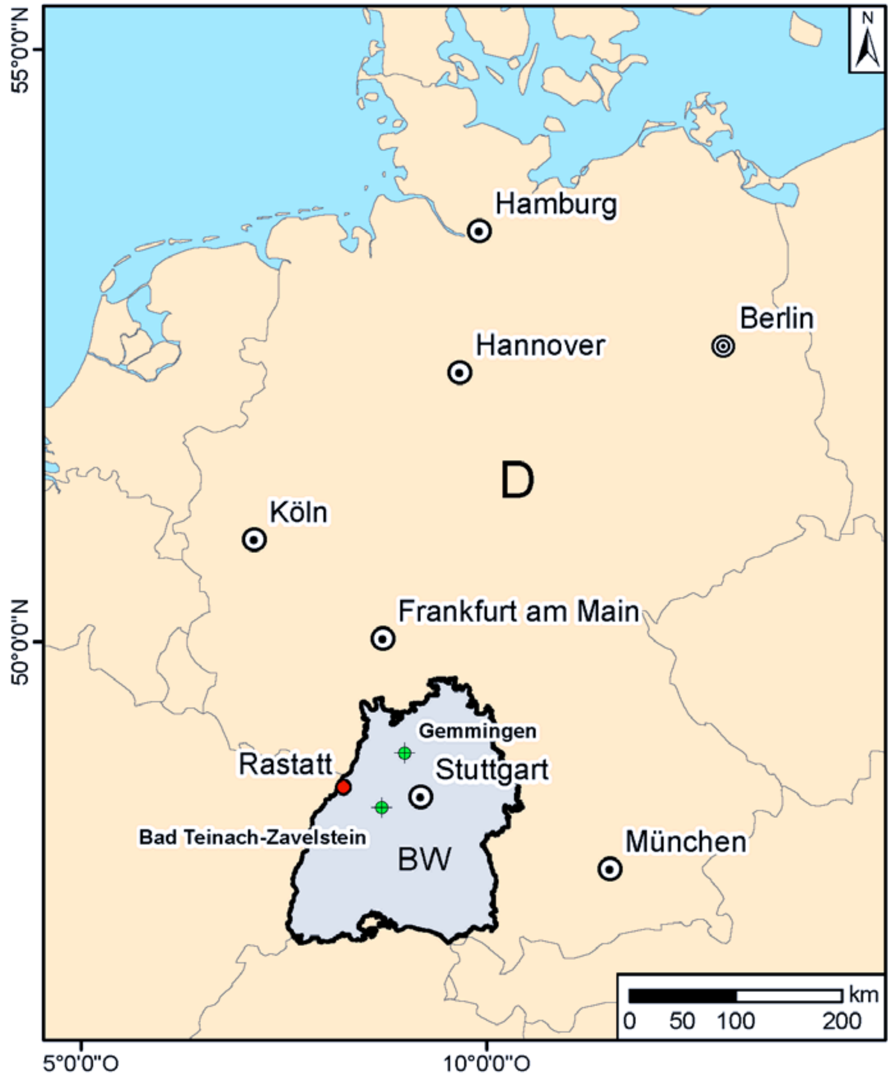
Natural Analogue Studies

- **Idea:** Study effects of ascending CO_2 (and trace gases) on the mineralogical and geochemical rock composition in the near-field of fractured outcrop walls

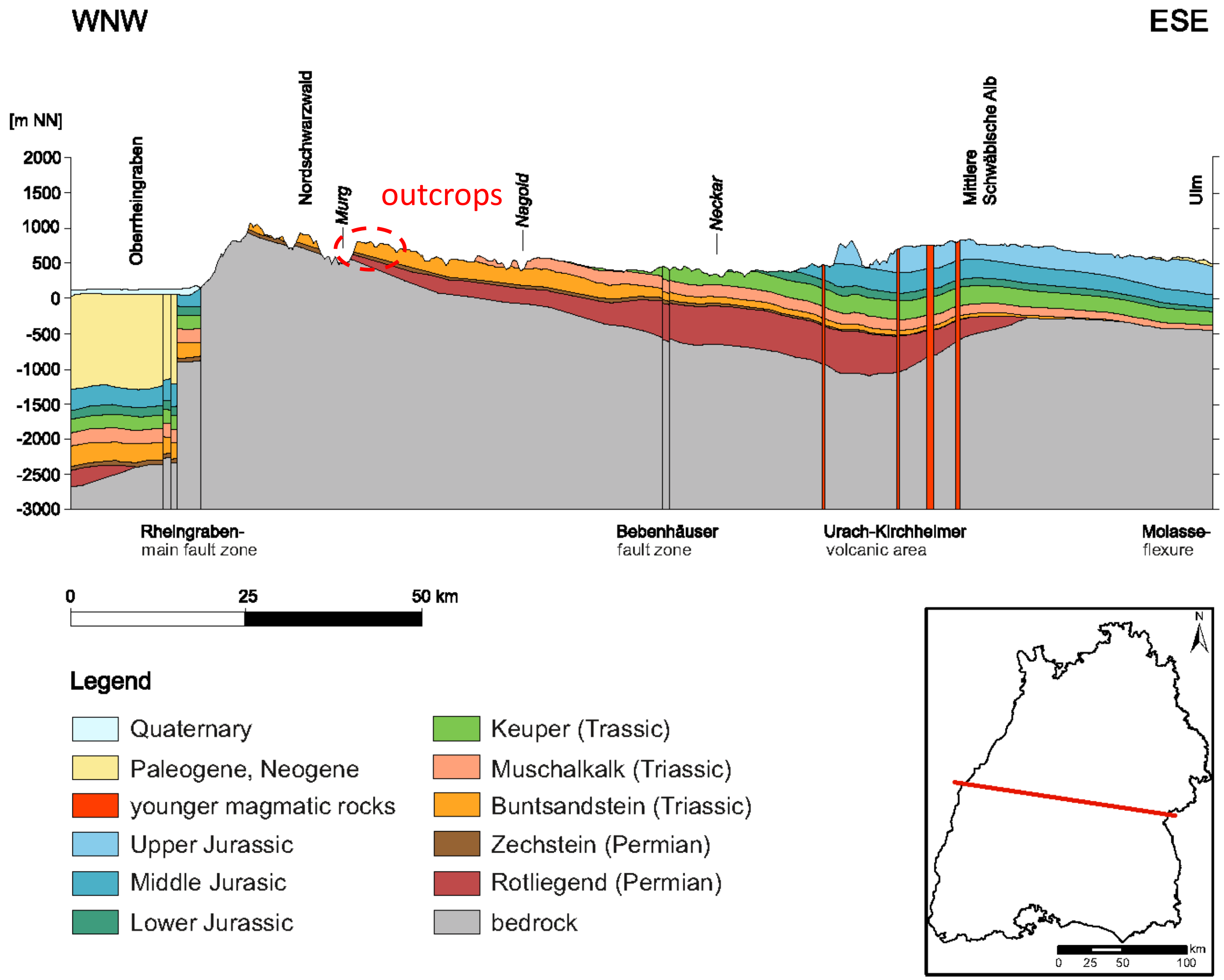
- **Step I: Analysis of core material**
  Samples taken from two research drillings in Baden-Württemberg from Triassic Vogesensandstein-Fm. (sV) to Permian Tigersandstein-Fm. (zT)

- **Step II: Field measurements**
  Geo-statistical data analysis of fracture patterns and the physical properties of rock material

Natural Analogue Sites in Baden-Württemberg

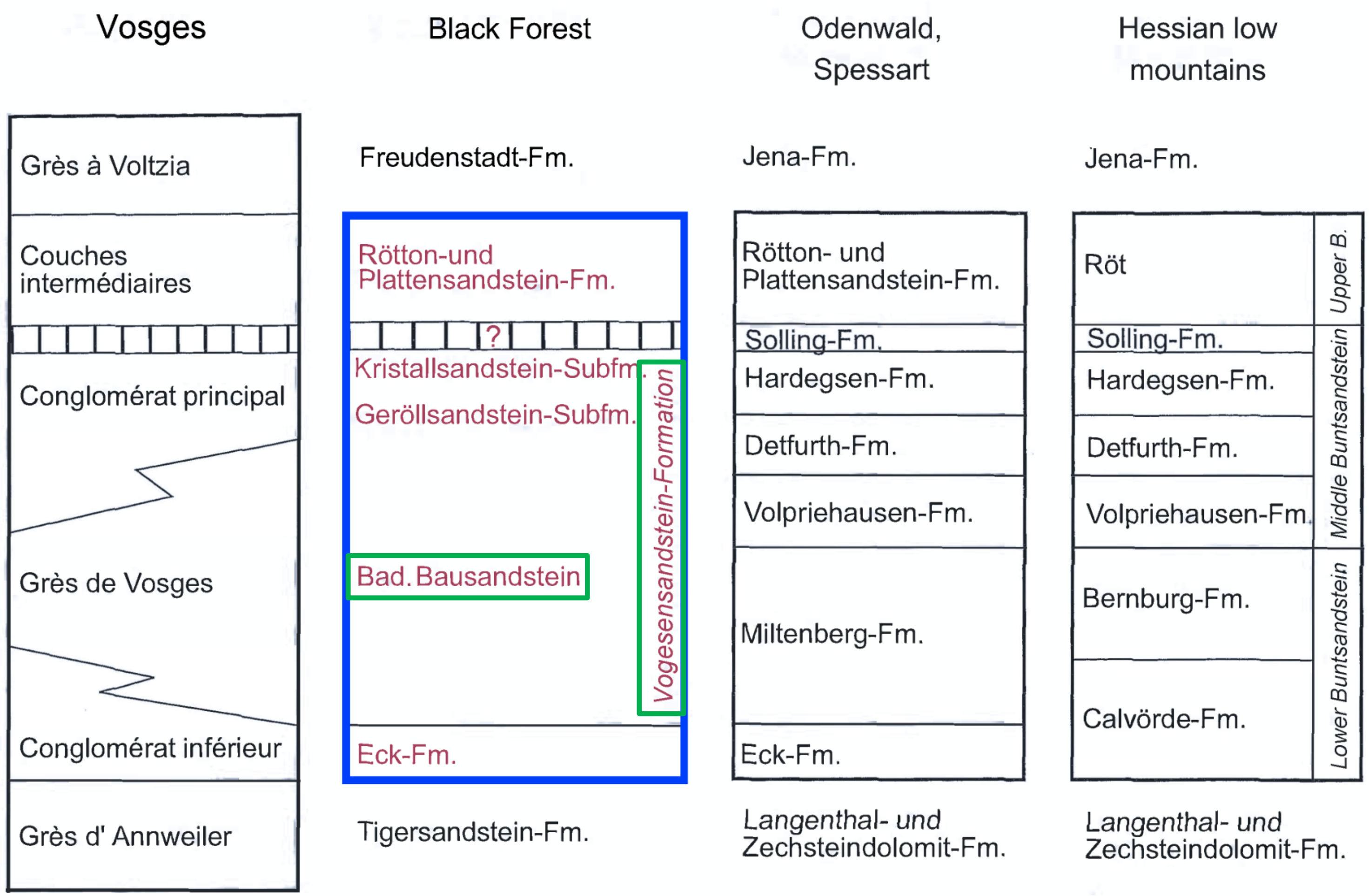


Geological Setting



(modified after Rupf & Nitsch 2008)

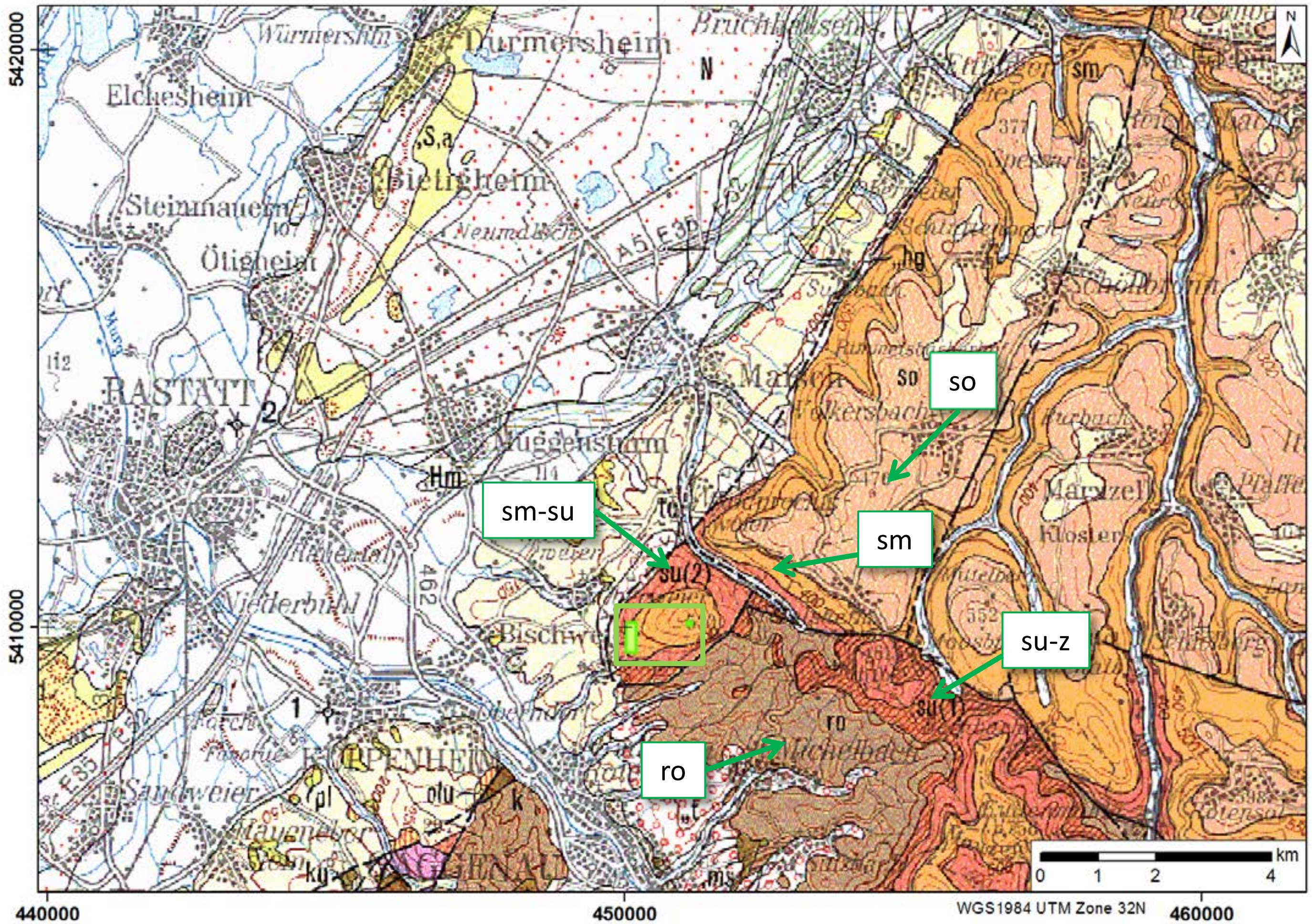
Geological Setting



- Correlation of Buntsandstein formations from France and Germany

(modified after Geyer & Gwinner 2011)

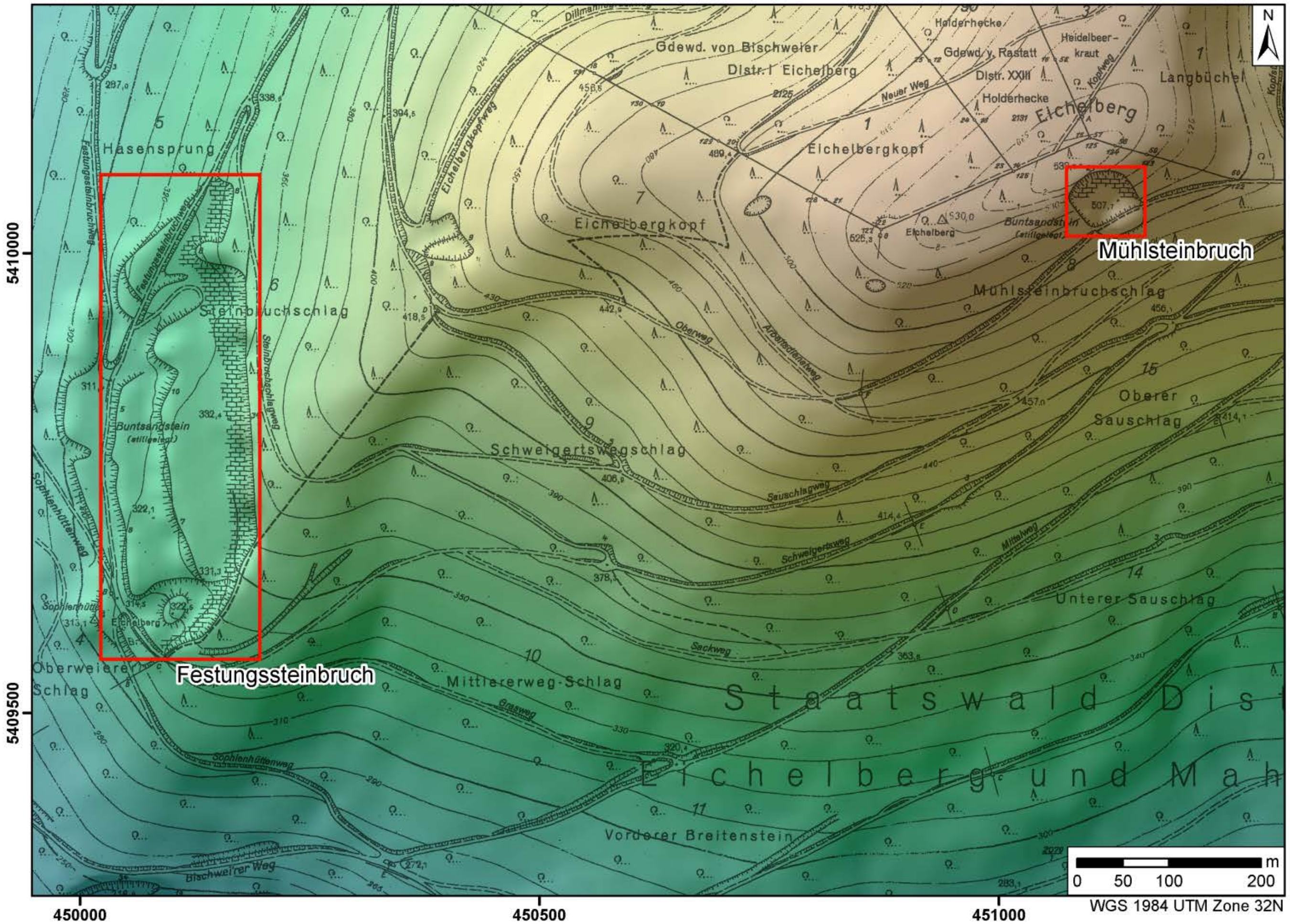
Geological Setting



- Geological map (GÜK200) of the northern Black Forest with study area

(modified after BGR 1986)

Outcrop sites



- Topographical map (DTK5) of the Eichelberg with DEM10 data

(source BKG, LGL)

ULTimate CO2 BGR

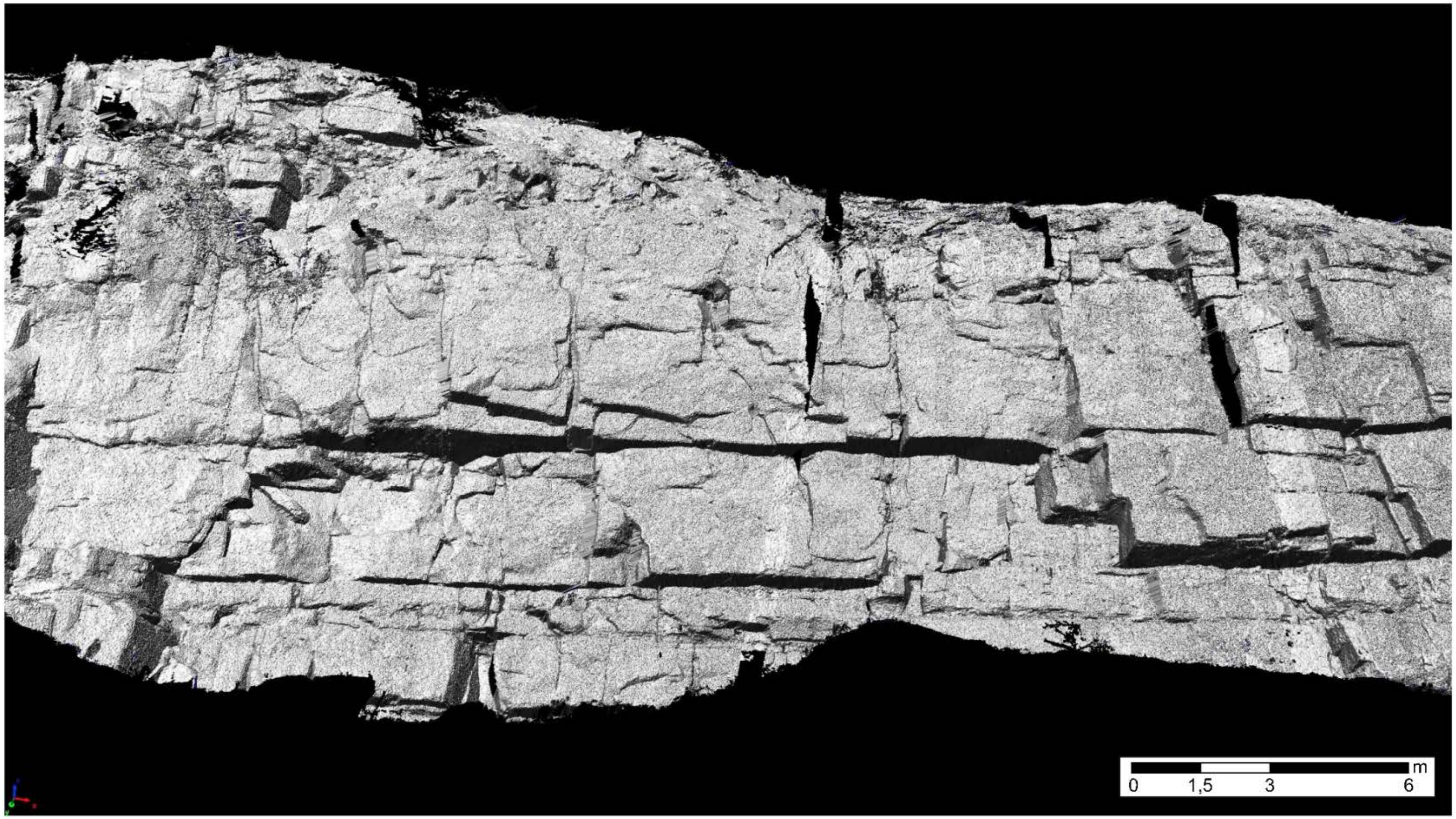
Outcrop sites

- Festungssteinbruch (massive sandstone layering, intercalated mudstone)

Data collection I

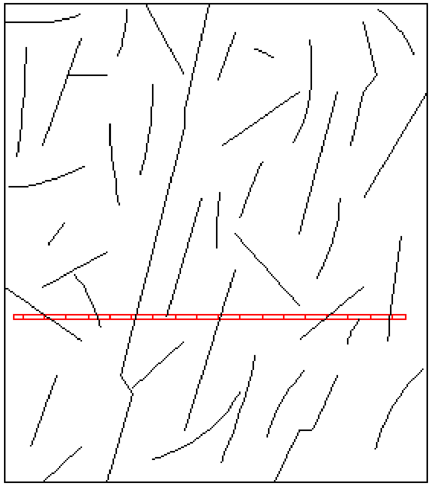
- Terrestrial Laser Scanning system in field operation

Data collection I

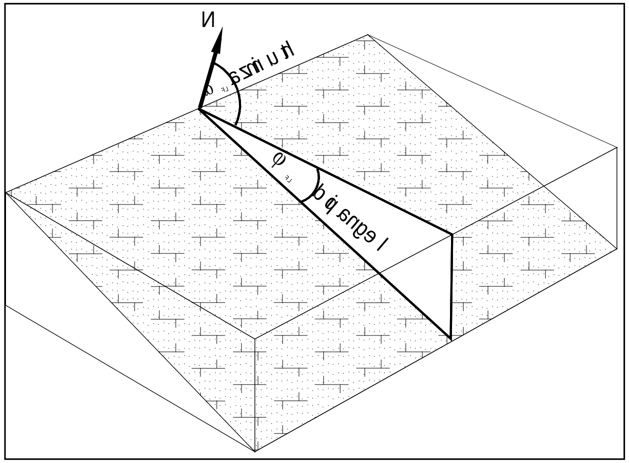


- Section from calculated 3D surface model (point cloud: density depending on distance to the scanned object, acquiring 2500 points/s)

Data collection II



scanline technique

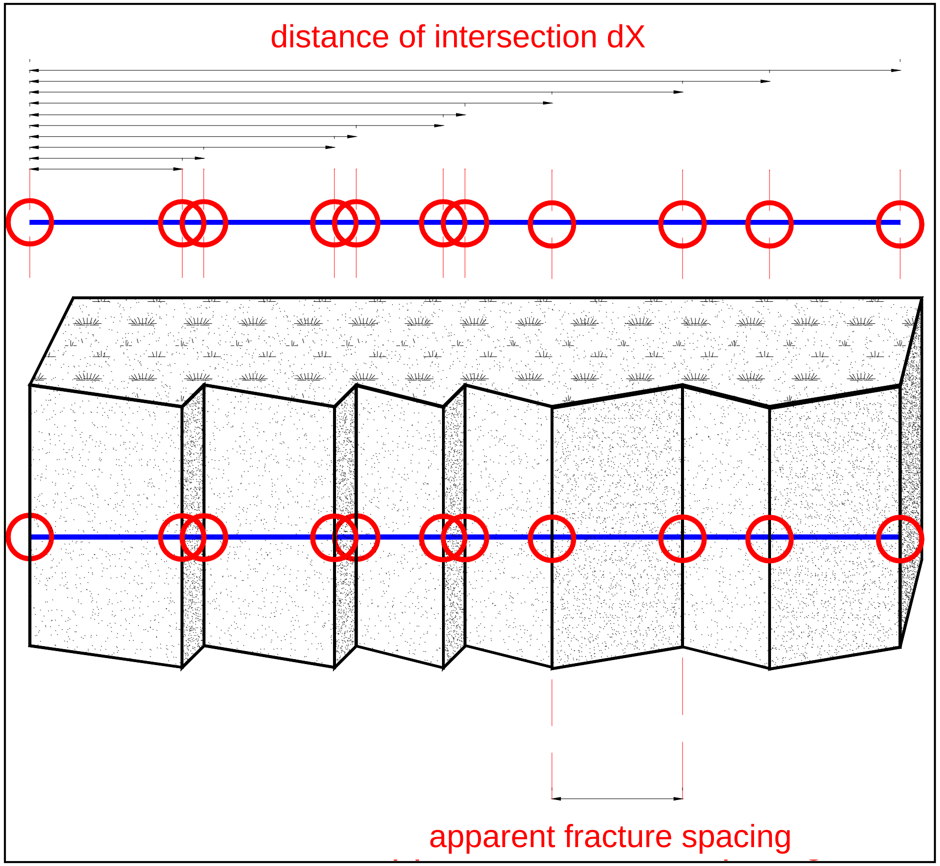


(HIMMELSBACH 2007)

- Raw data are collected as dip direction (azimuth) and dip angle (also for the fixed tape measure) with a geological compass

- Transformation in normal vector data for further evaluation

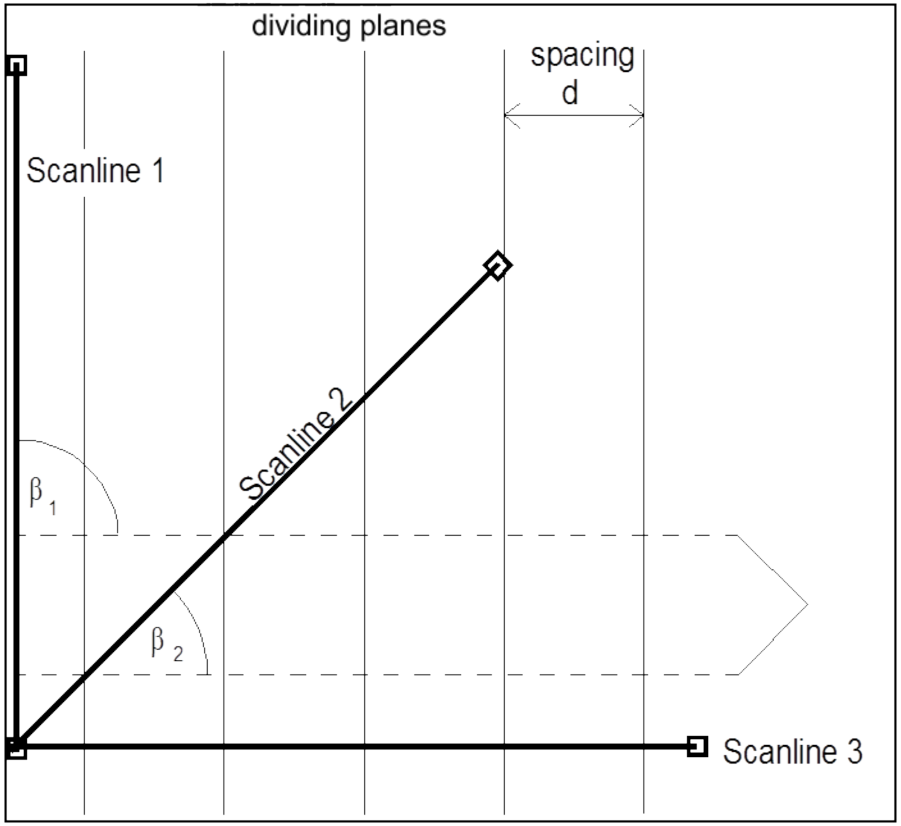
Data collection II



(HIMMELSBACH 2007)

- Scanline procedure is objective
- All the dividing planes along the profile are measured
- Oversampling occuring while measuring parallel lines is intended
- But it incorporates systematic error sources
- Error can be minimized by arranging the scanlines in different spacial directions almost perpendicular to one another

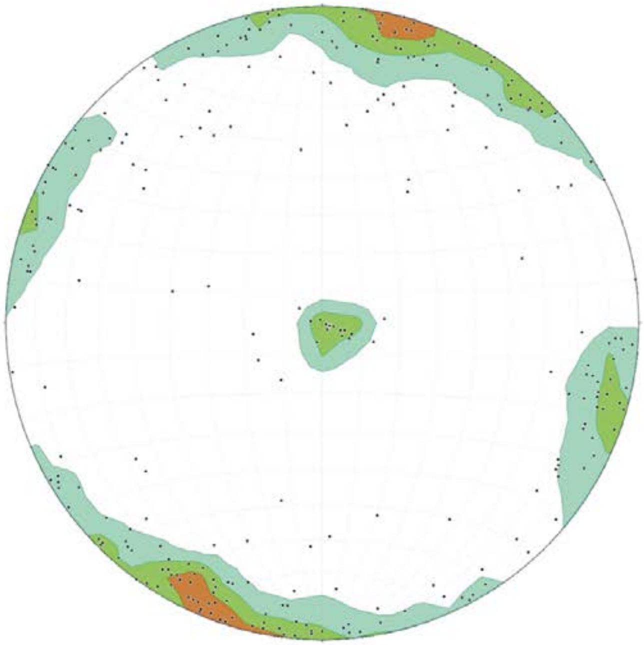
Statistics

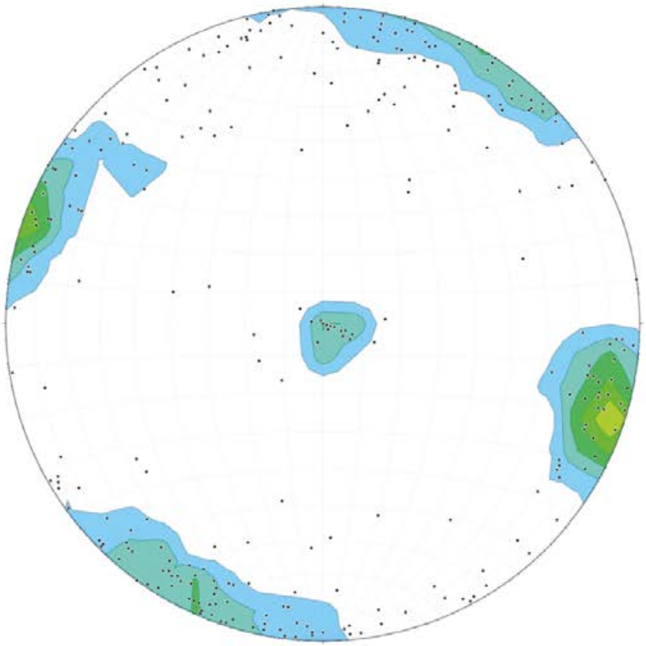


(HIMMELSBACH 2007)

- Geometrical error of the „blind zone“
- Fractures that are oriented approximately parallel to the outcrop wall are statistically underrepresented
- The amount of recorded fractures along a scanline is dependent on its orientation to the dividing planes

Statistics (vectorial data)

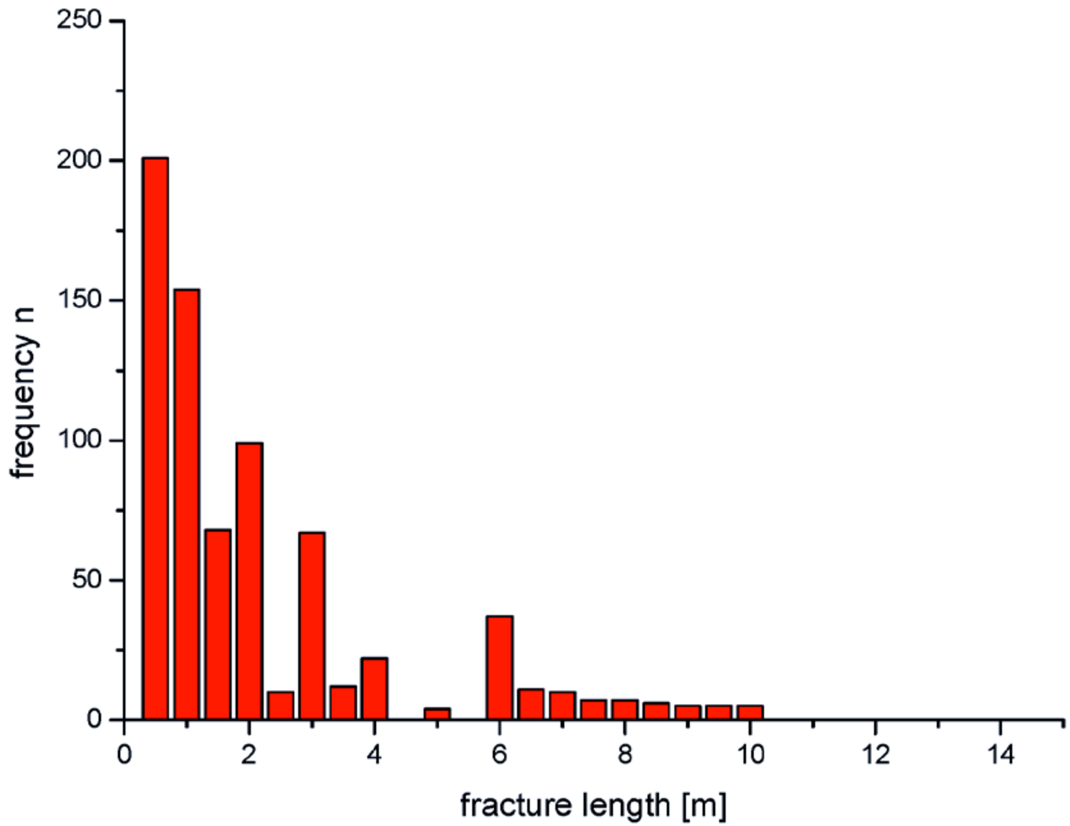




- Before weighting
- After weighting

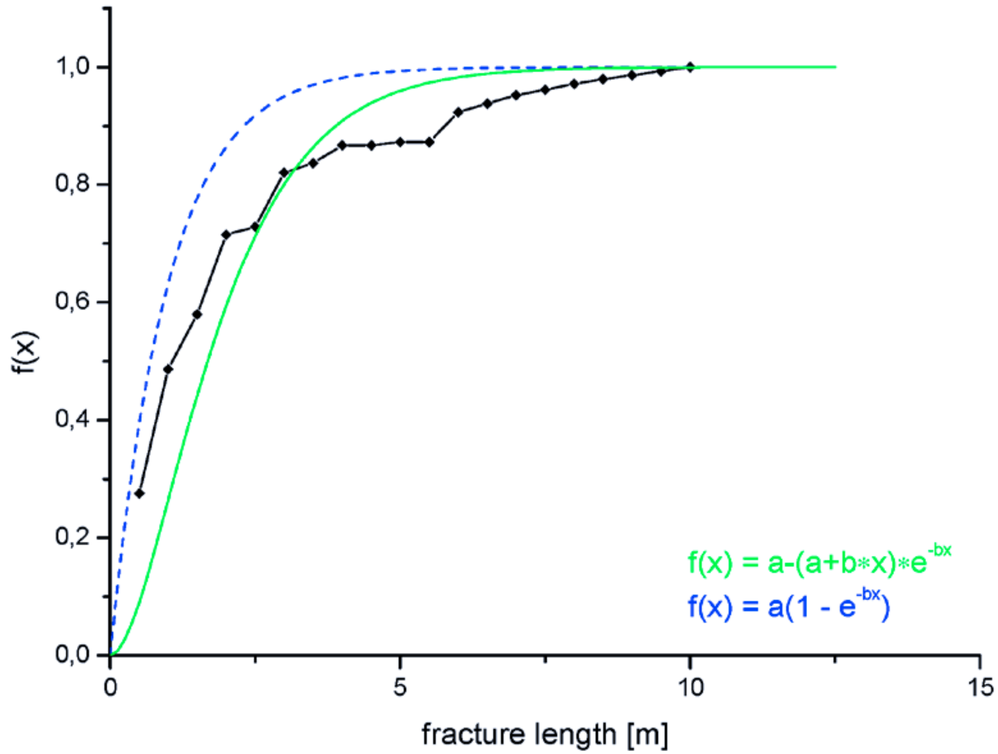
- Cluster centers caracterized by Fisher distributions with a critical angle of selection can be defined
- Calculation of spherical degree of opening ω and k-factor as input data for GOCAD modelling

Statistics (scalar data)



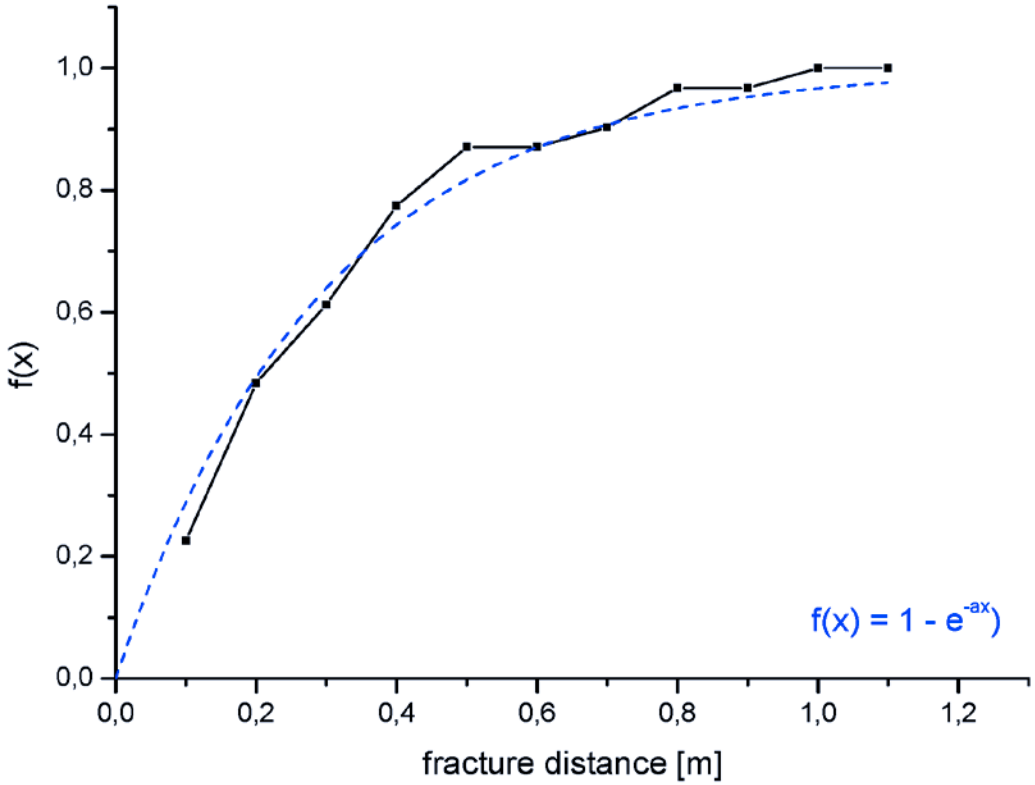
- Frequency distribution of fracture lengths
- Choosen class width 0,5 m

Statistics (scalar data)



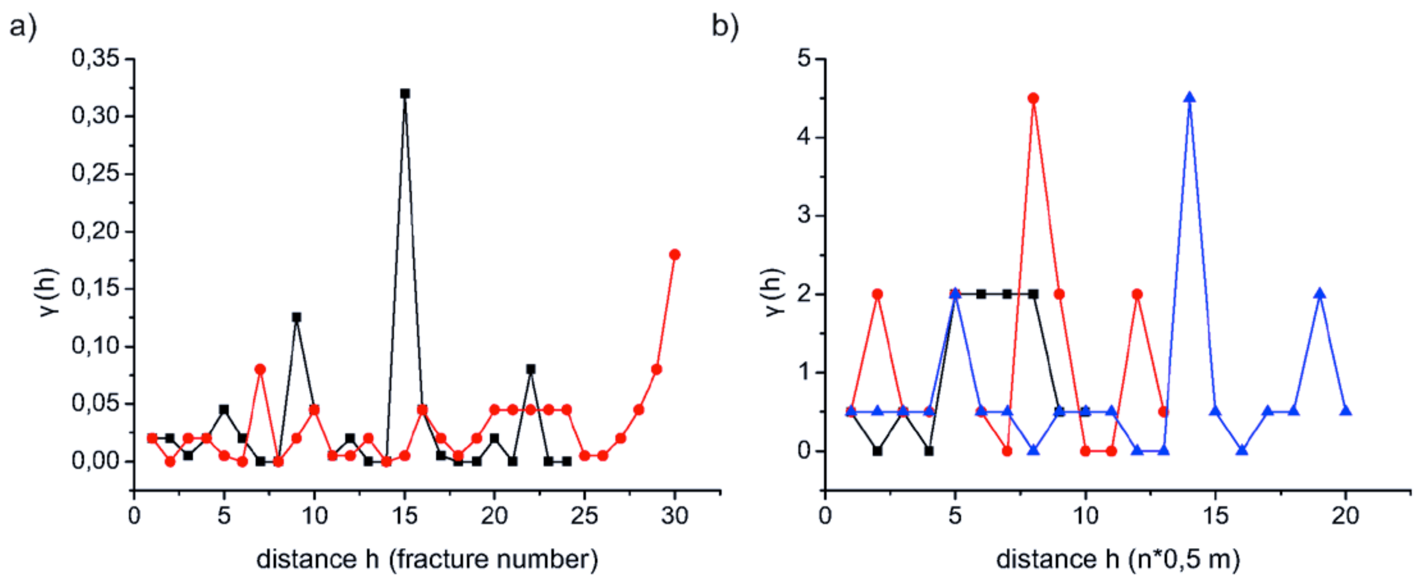
- Empirical fracture length distribution (all data, black line)
- Functions for Erlang-2 (green curve, best fit for scanline measurements) and expected exponential distribution for the whole outcrop (dashed blue curve)
- Length overestimation by scanline measurements visible

Statistics (scalar data)



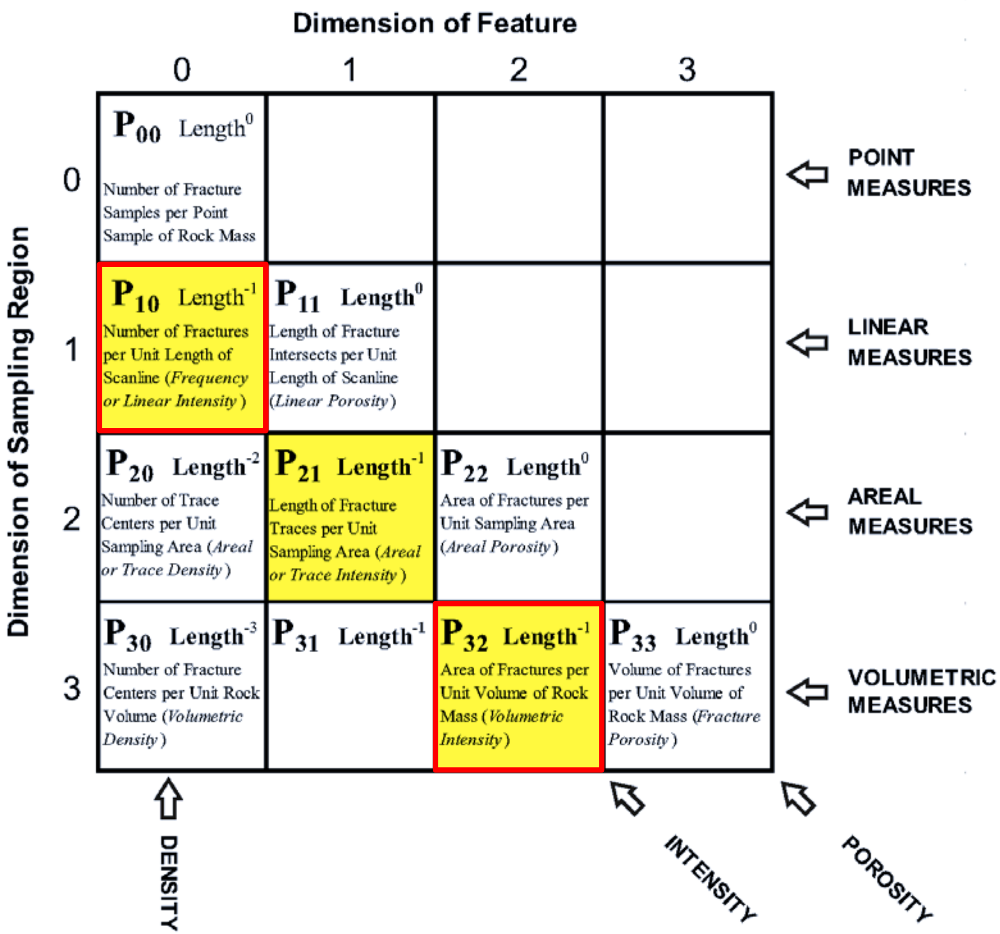
- Fracture distance distribution for a single scanline (black line)
- As spacial random distribution a negative exponential distribution can be closely adapted (a=3,4/dashed blue curve)

Statistics (scalar data)



- Variograms of fracture distance (a) and density (b) show no spacial correlation for the examnied areas
- But in outcrop scale a spacial correlation cannot be ruled out completely

Statistics (fracture abundance)



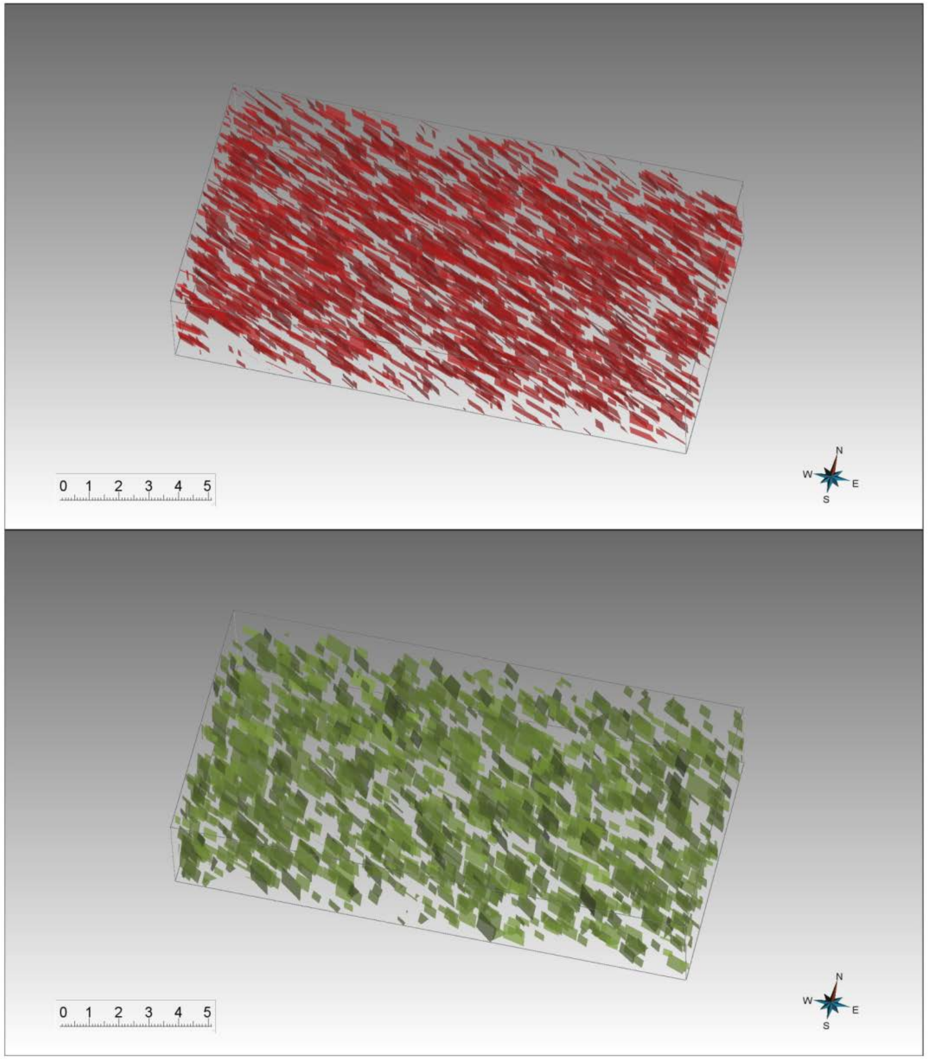
- Intensity P_{10} can easily be derived from scanline measurements
- Intensity P_{32} can be calculated from P_{10} and conversion factor (input data for FracMV™)

(Dershowitz & Herda 2012)

Modelling (input data GOCAD)

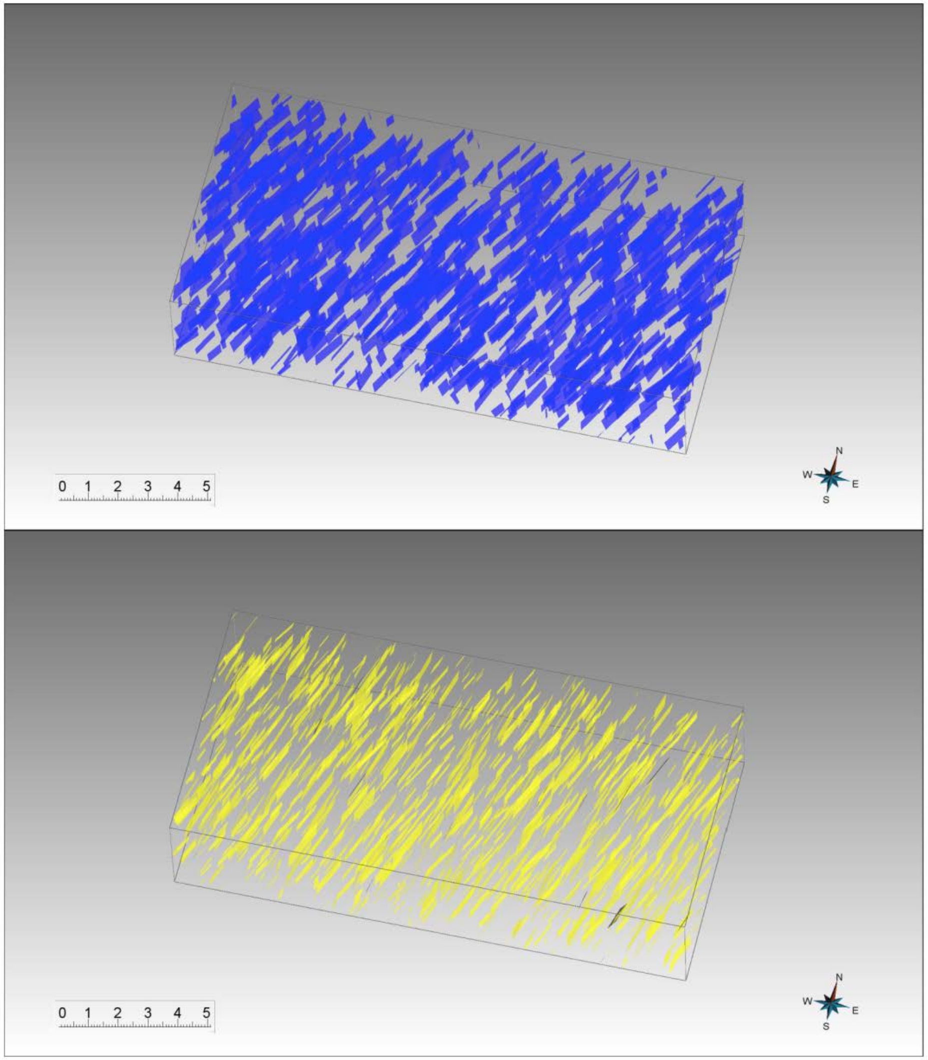
- SGrid object (3D grid which can be cut and deformed to fit a structural surface model)
- Fracture intensity (P_{32}: fracture area per cubic meter)
- Fracture length (minimum/maximum, power law distribution, exponent)
- Fracture orientation (dip direction, dip angle, Fisher distribution with k-parameter representing fracture concentration)
- Fracture aspect ratio (height:length, default 1:2, horizontal layering)
- Fracture aperture (proportional to length, proportional to square root of length or constant)

Modelling (results and evaluation)



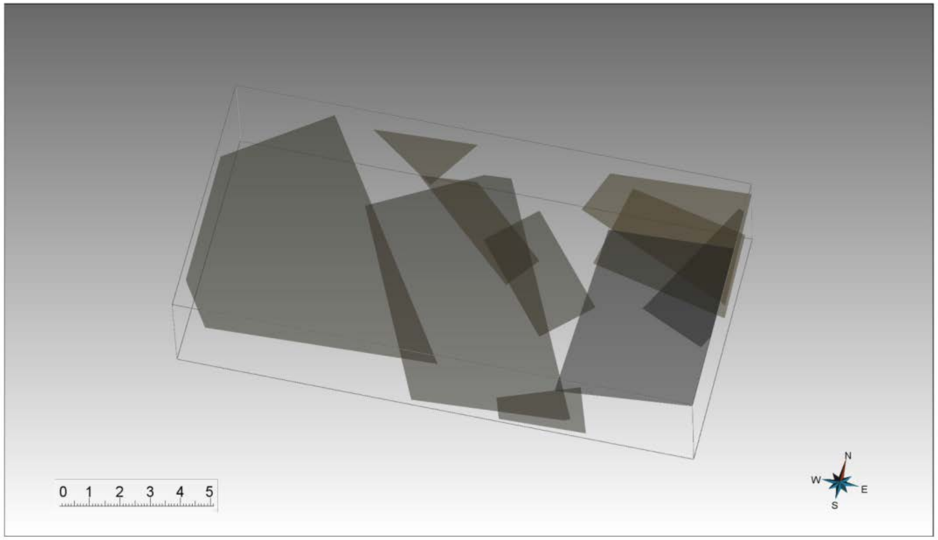
- Cluster 2 (red) and 4 (green) similar strike direction but different dip direction

Modelling (results and evaluation)



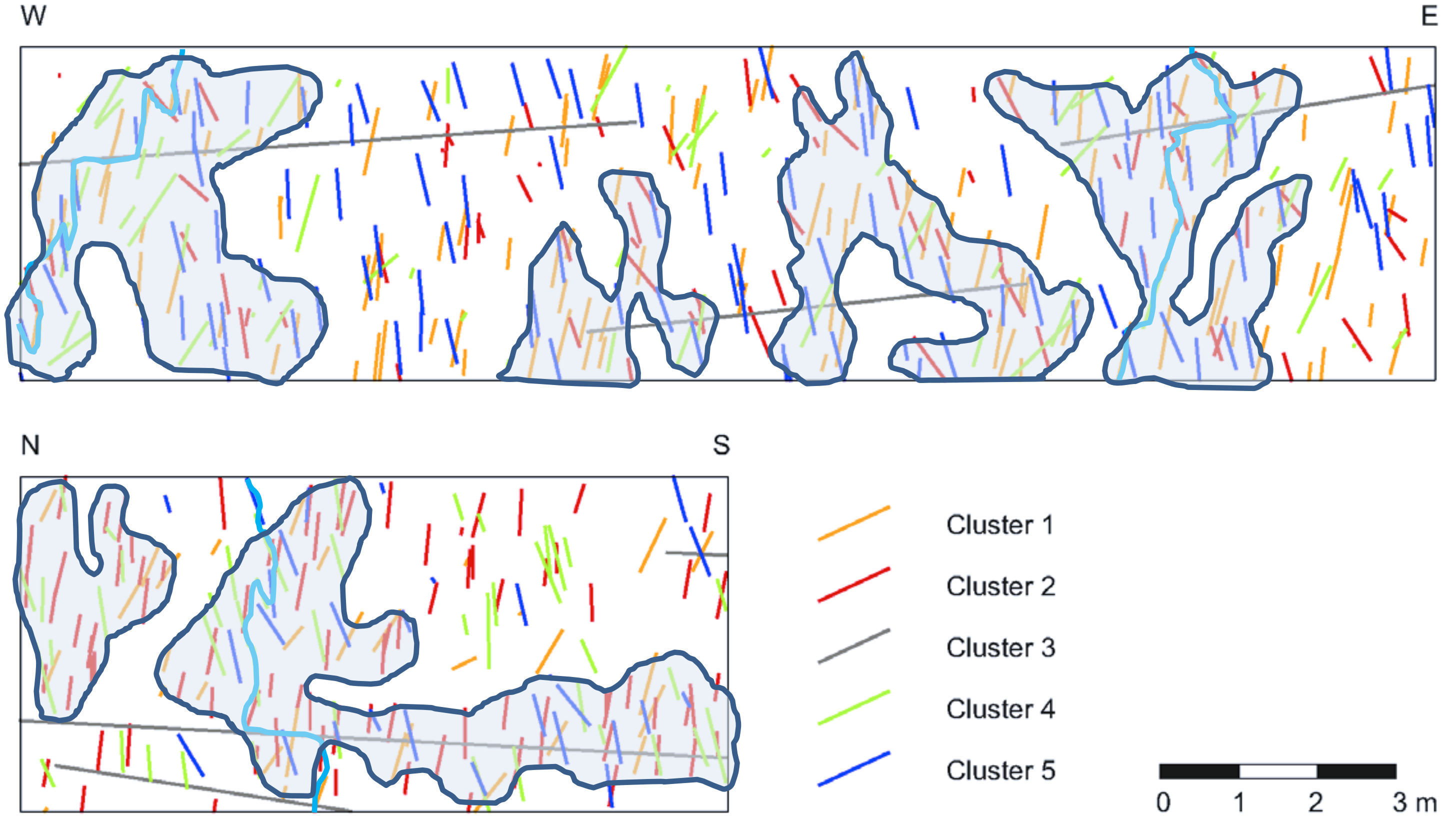
- Cluster 1 (yellow) and 5 (blue) similar strike direction but different dip direction

Modelling (results and evaluation)



- Cluster 3 representing subhorizontal bedding planes

Modelling (results and evaluation)



- Cross sections in mutually perpendicular directions
- Possible percolation paths for an assumed vertical hydraulic gradient
- Areas of high fracture connectivity (Percolation threshold reached?)

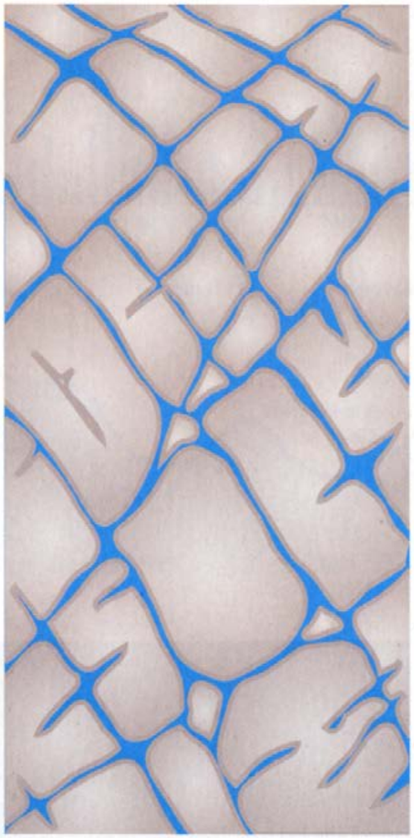
Summary and Outlook

- For the stochastic creation of a 3D fracture model as basis for numerical flow and transport calculations it is necessary to collect as many data as possible of the rock complex of interest.
- Therefore a combination of methods like TLS and compass measurements is a good option.
- Measurements of fracture orientation, length and offset supply relative exact results.
- The raw data have to be evaluated and corrected statistically in order to reveal the genuine distributional patterns.
- If possible, anisotropy as a possible source of error should be ruled out.

Summary and Outlook

- Averaging and restriction to cluster centres cause loss of information
- Decisive for the migration of fluids along fractures is if the fracture density is sufficient to create a linked fracture network which reaches the so called percolation threshold.
- The 3D model shall be utilized to characterize the transport properties of fractured rocks by determining values for porosity and permeability.
- Detailed information about distribution patterns of fracture filling, roughness and aperture are task of further investigations and therefore could only be first approximations.

Permeability of fractured rock aquifers



Derived from Hagen-Poiseuille "Cubic Law"

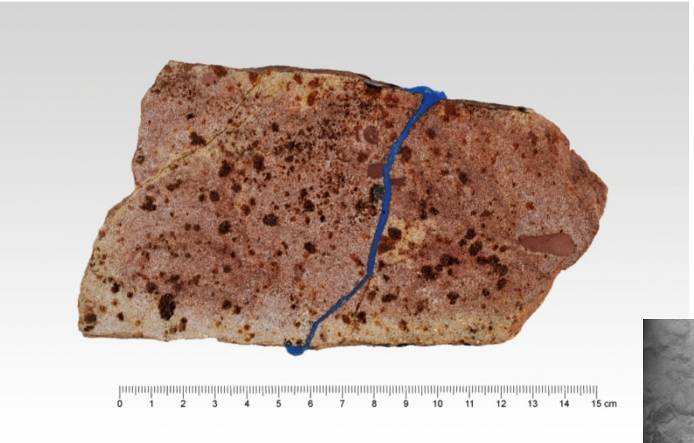
$$K = N \cdot \frac{\rho \cdot g}{\eta} \cdot \frac{b^3}{12 \cdot f}$$

cubic !!!

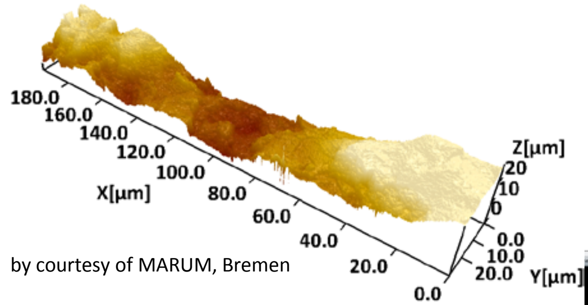
N = number of parallel fractures
b = width of fracture (aperture)
f = surface roughness of fractures
ρ = density of water
η = kinematic viskosity of water
g = gravity constant

(source: Snow 1969)

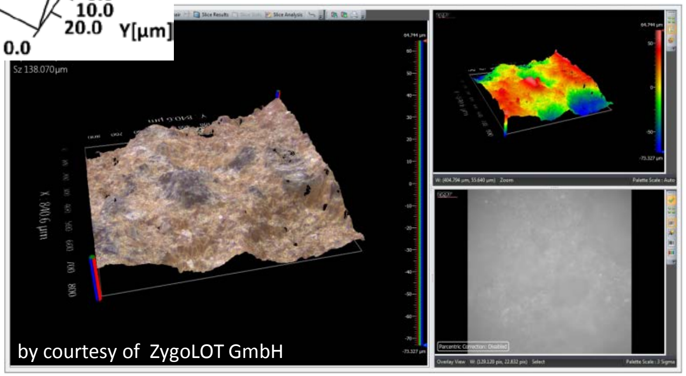
Summary and Outlook

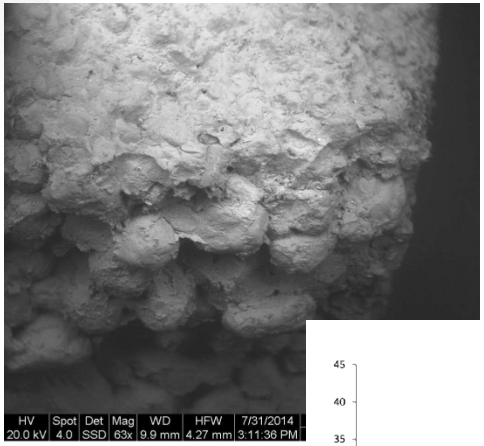


XRD/XRR

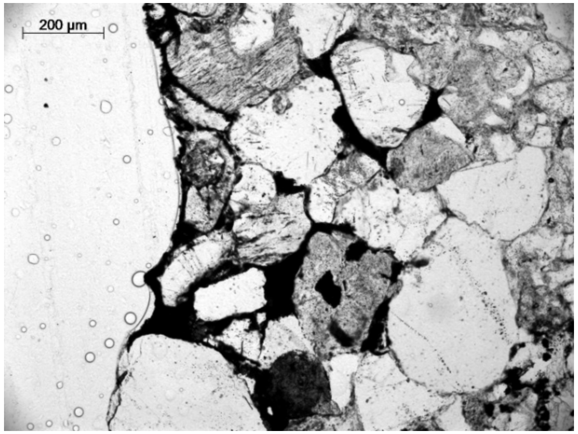


surface scans

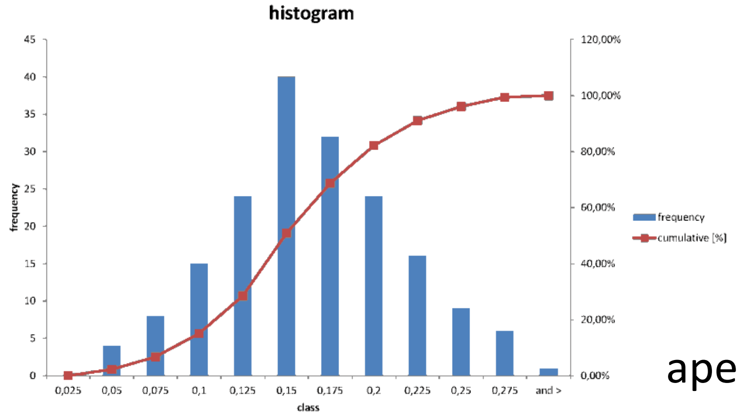




SEM/EDX

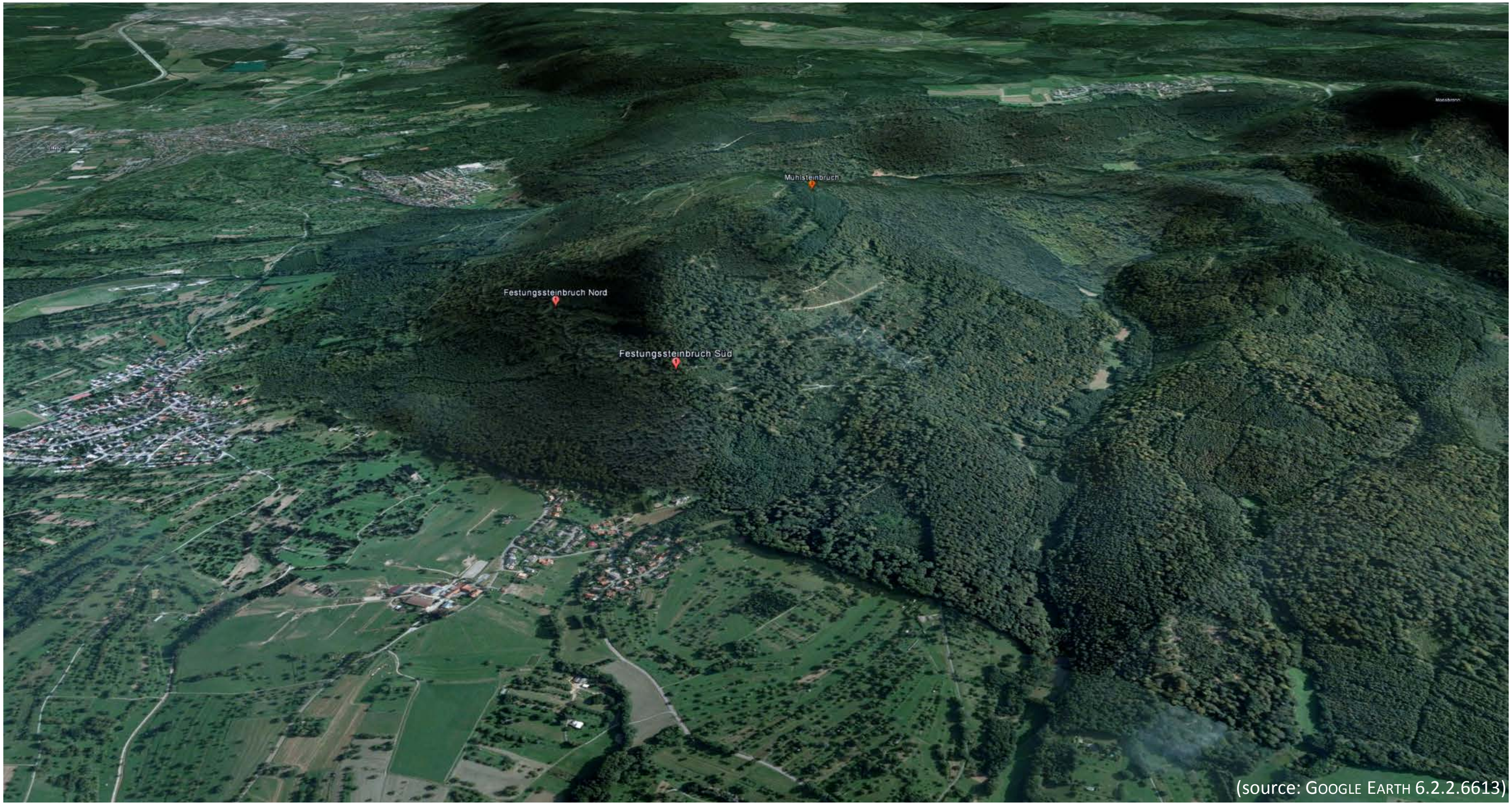


thin sections



aperture

Thank you for your attention!



(source: Google Earth 6.2.2.6613)

www.bgr.bund.de/EN/Themen/Wasser/Projekte/laufend/F+E/Ultimate/Ultimate_projektbeschr_en.html?nn=1546392

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