RUHR-UNIVERSITÄT BOCHUM
Institute of Geology, Mineralogy and Geophysics

RESEARCH DEPARTEMENT
CLOSED CARBON CYCLE ECONOMY

Fraunhofer IEG

EGU General Assembly

IGAG
Istituto di Geologia Ambientale e Geoingegneria

RUB

Discrete fracture network analysis of Devonian carbonate rocks in Western Germany: Implications for deep geothermal energy, heat exploitation and anthropogenic fault reactivation

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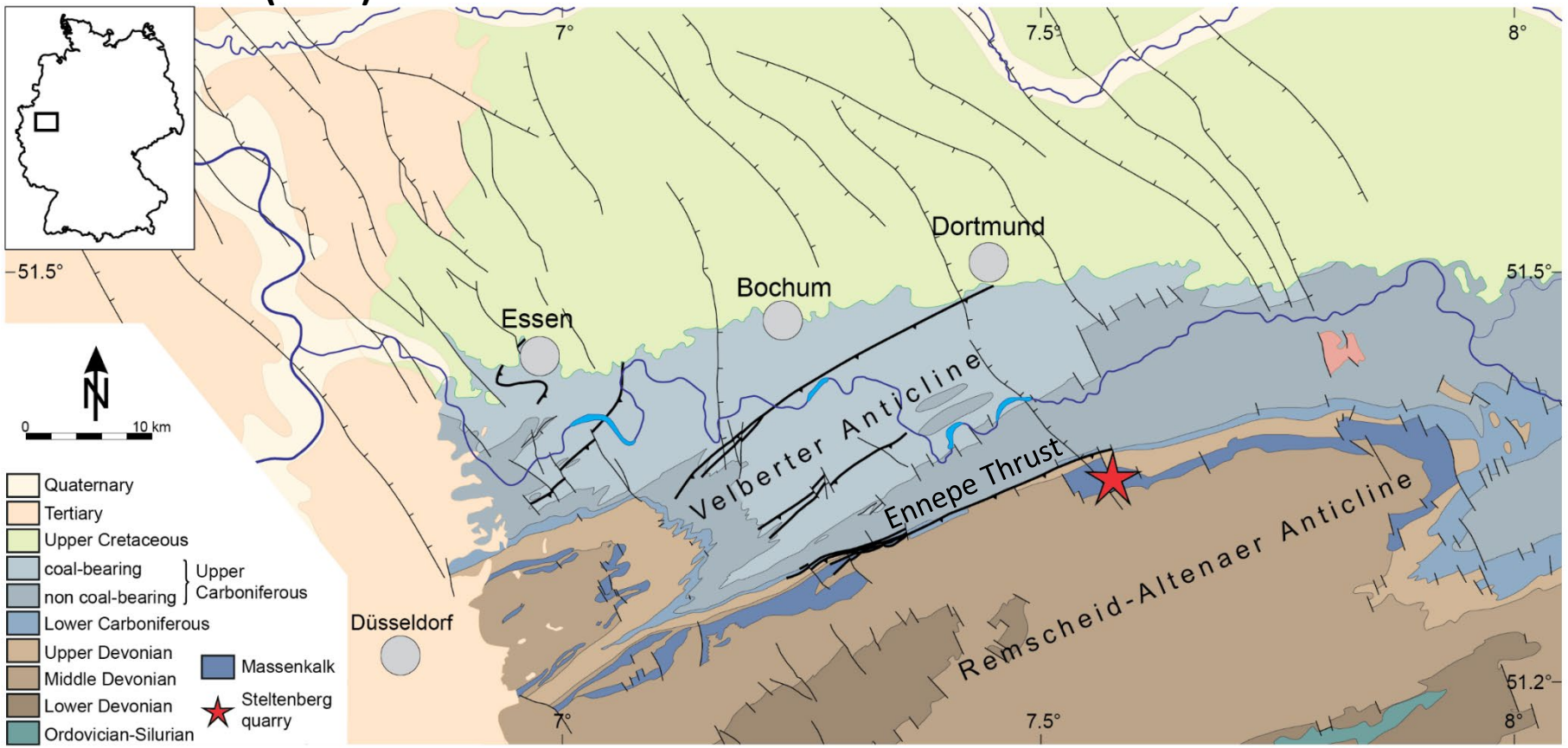
Introduction

Pedersen et al. (2022)



WSW – ENE Ennepe Thrust (Variscan)
NNW – SSE faults (post – Variscan)

Devonian carbonates (karstified? limestones and dolostones) potential reservoir for Deep Geothermal energy (DGE) exploitation

Fracture analysis (Field work + DFN modeling)

Thermo-hydro-mechanical (THM) model using permeability results from DFN

Fault and fracture stability analysis, and potential for fault reactivation

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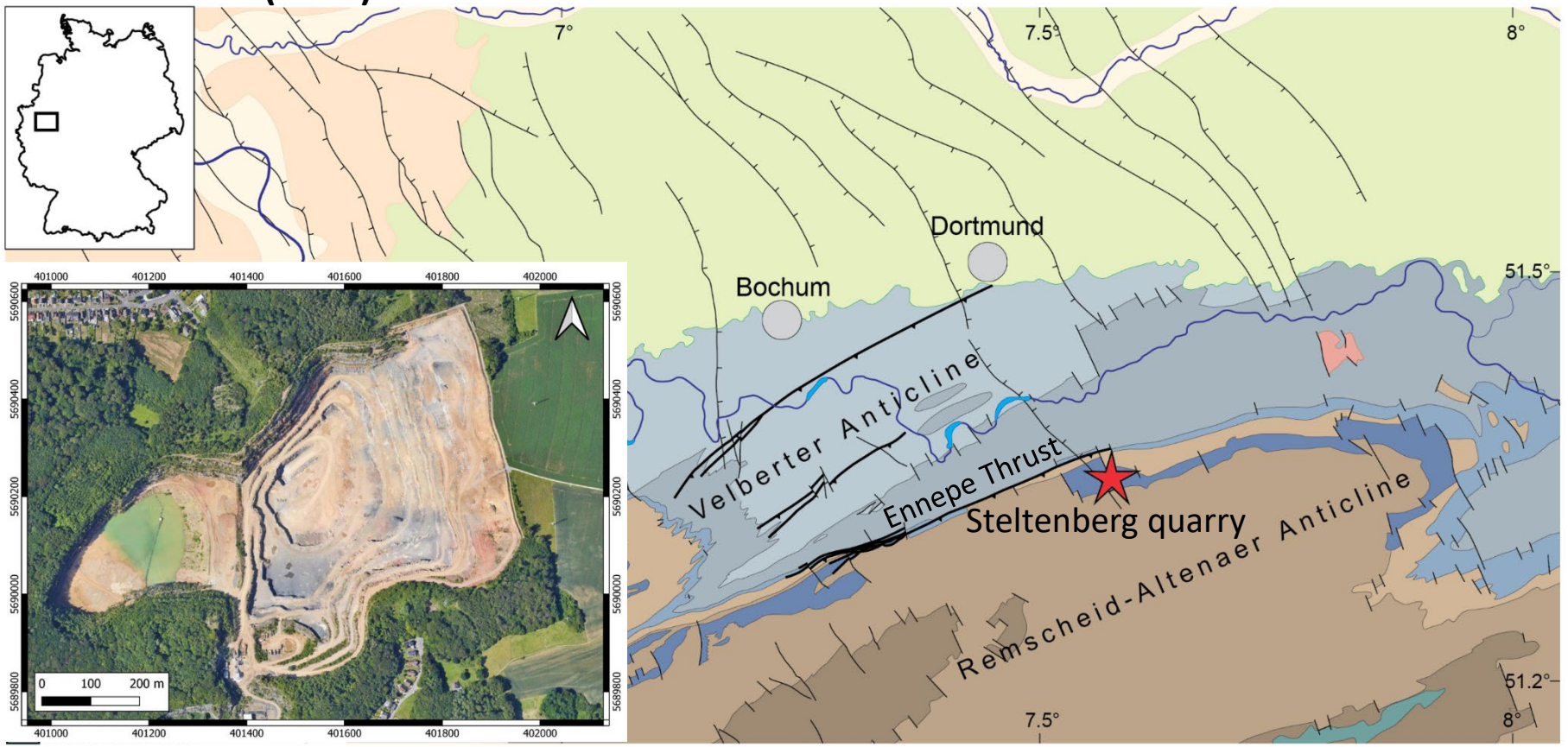

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Input data for DFN model

Meshed and Textured SfM 3D model from UAV images
(Agisoft Metashape)

N

View from East

Input data for DFN model

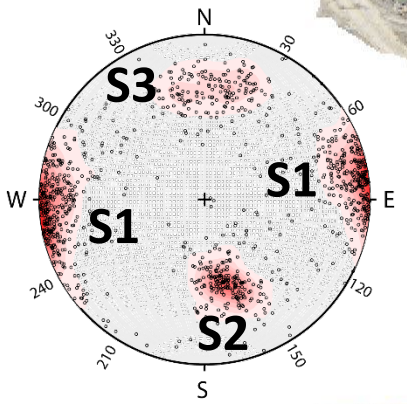
Meshed and Textured SfM 3D model from UAV images

(Agisoft Metashape)

Fracture and fault analysis

OpenPlot (Tavani et al., 2011)

N



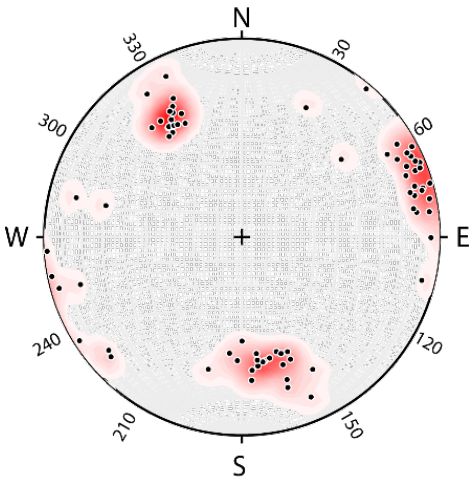
View from East

Input data for DFN model

Fracture and fault analysis from point clouds

(CloudCompare, Compass plugin)

NE **SW**



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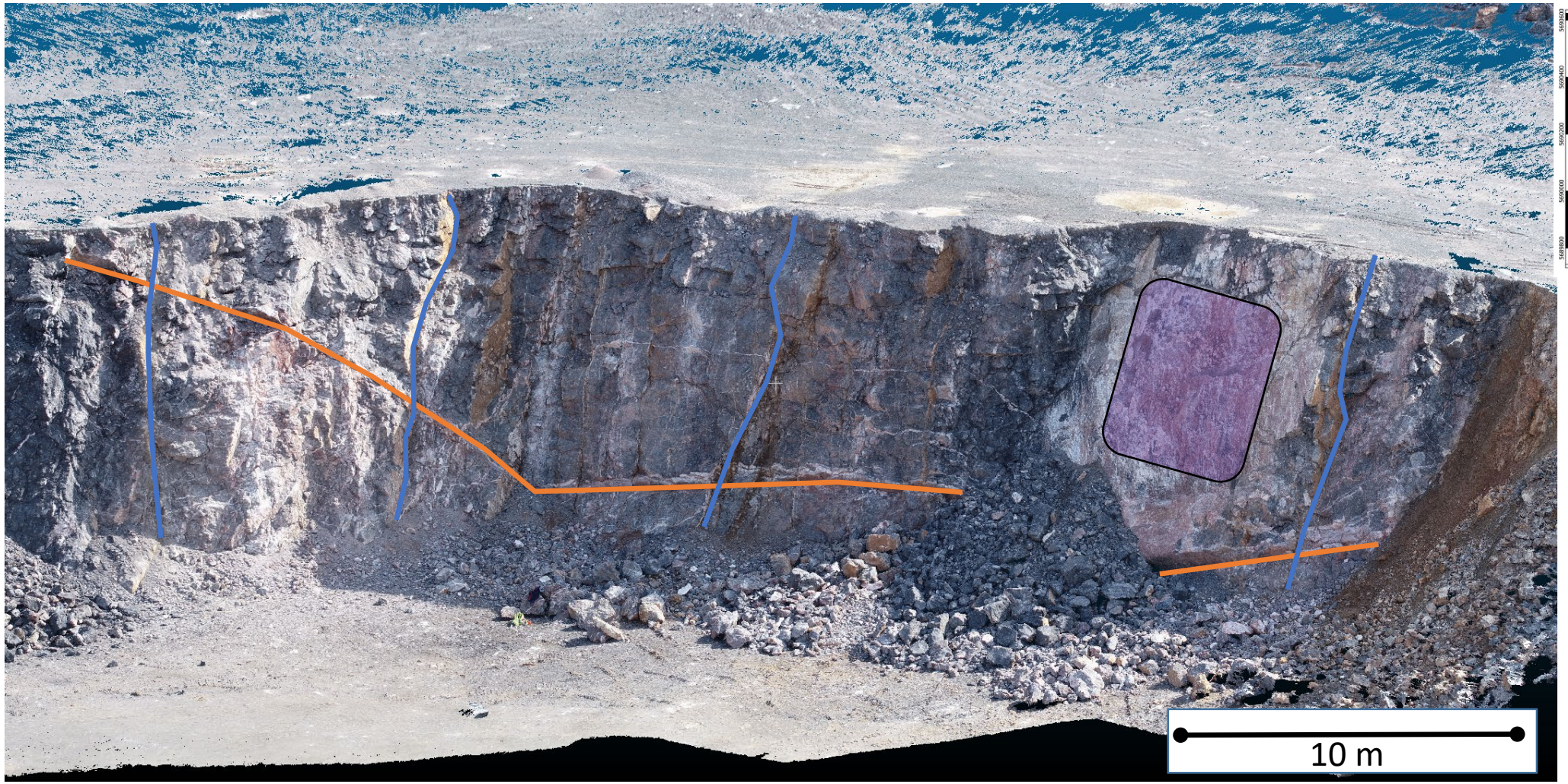

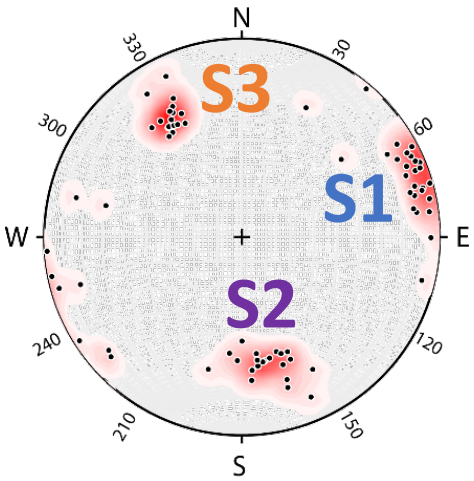

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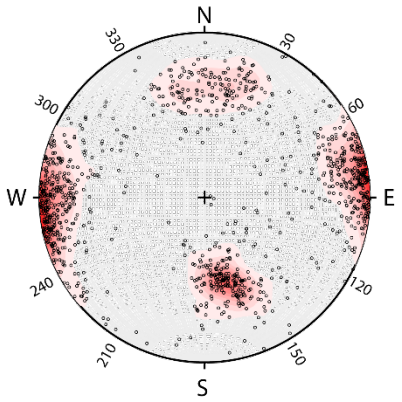
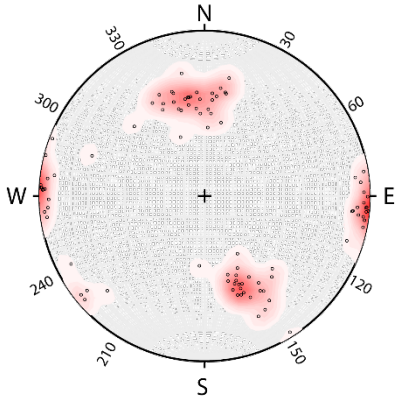
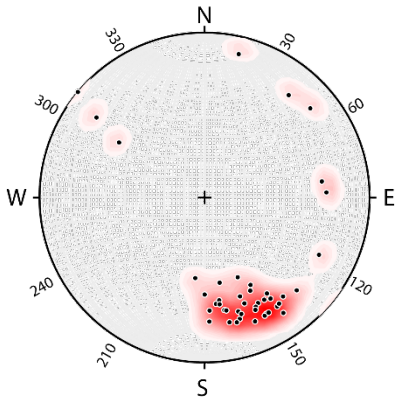
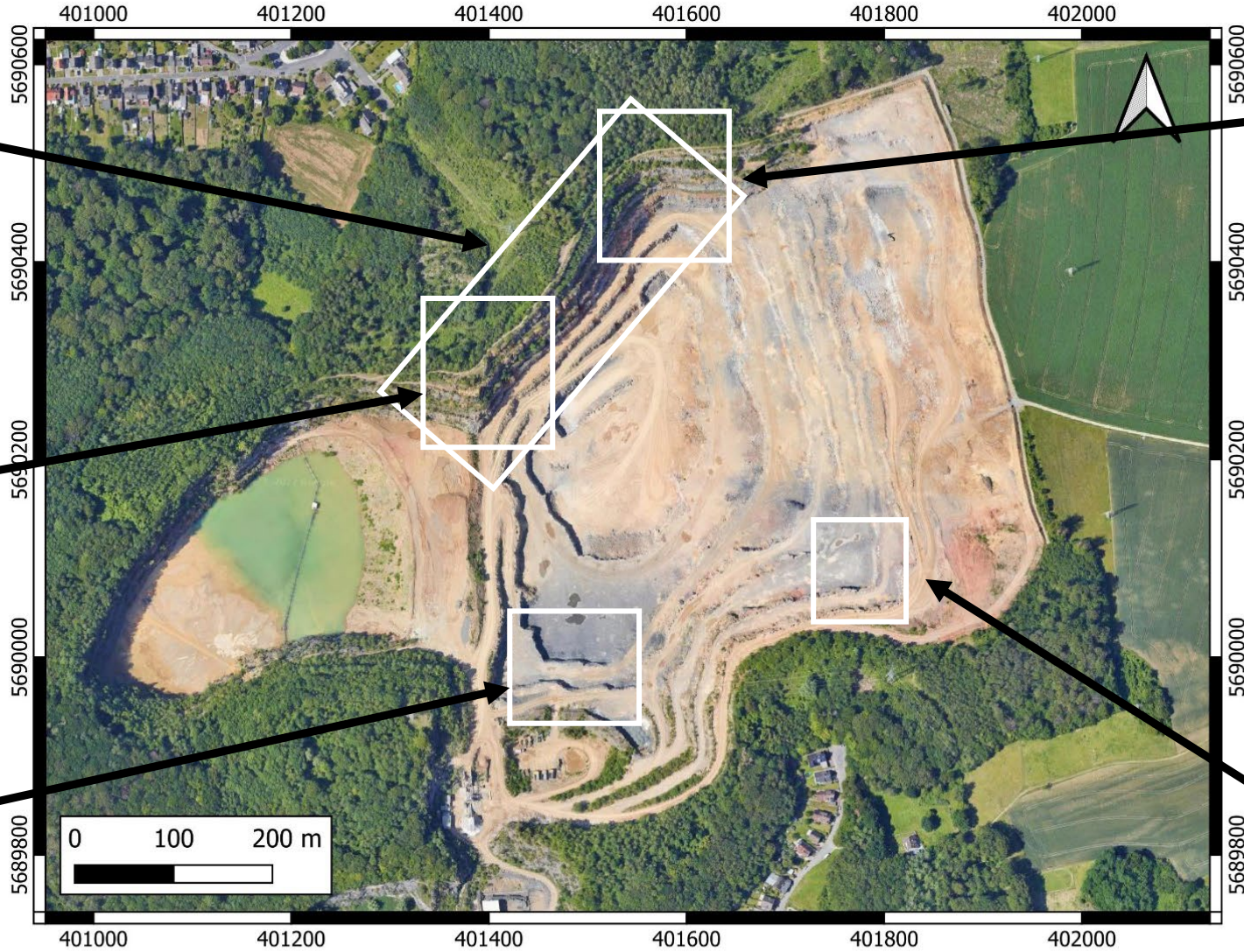
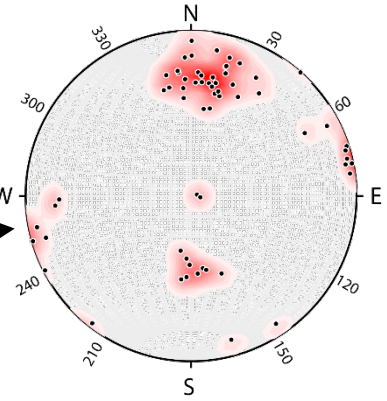






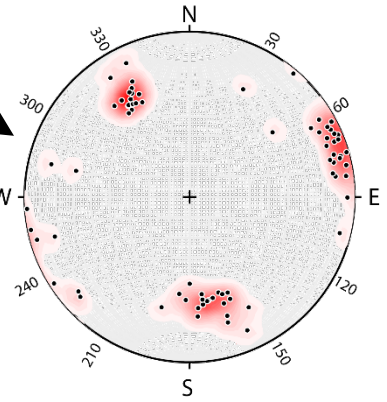




Set 1: ~ N-S striking

Set 2: ~ E-W striking, N-dipping (bedding parallel)

Set 3: ~ E-W striking, S-dipping



Input data for DFN model

SW

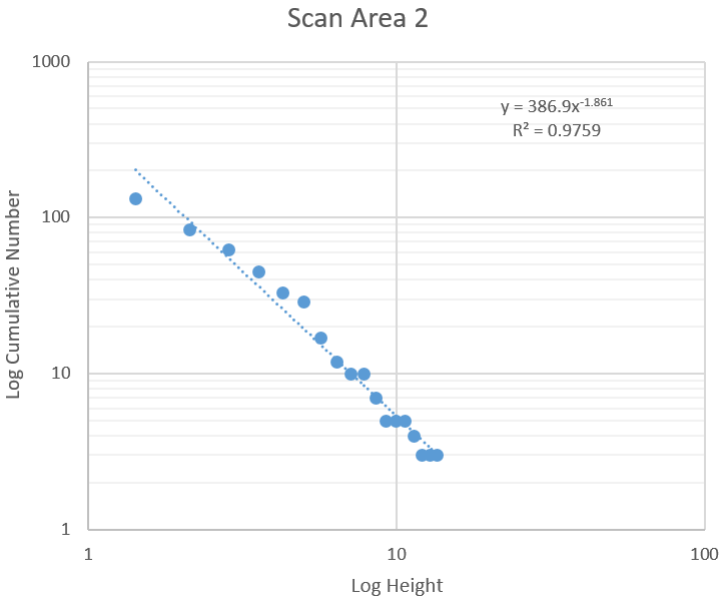
NE

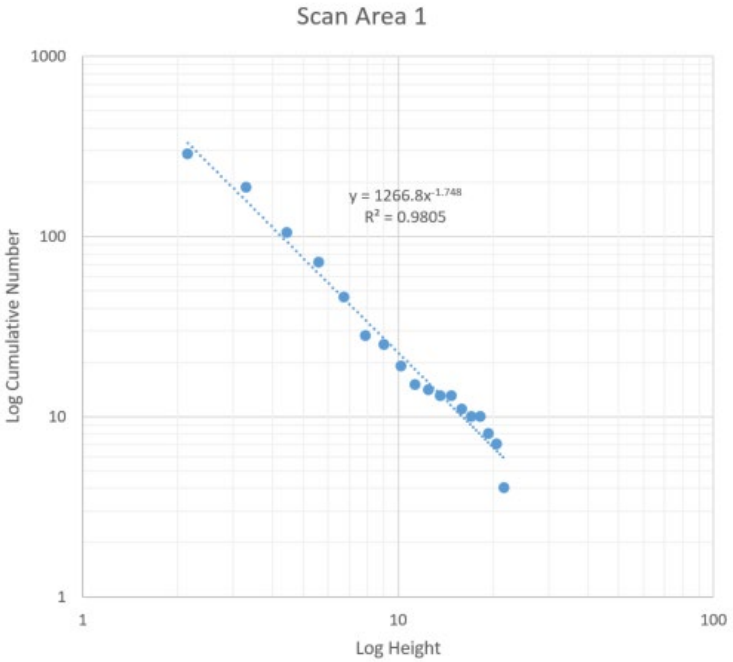
~ 80 m

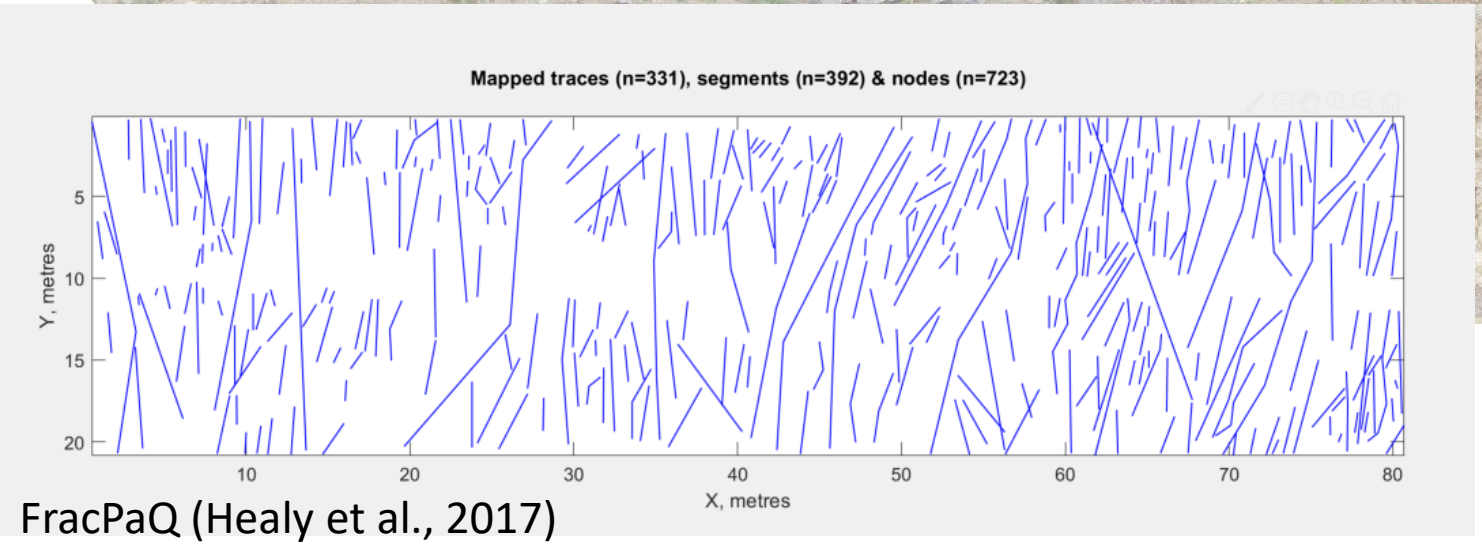
~ 20 m

Input data for DFN model

SW



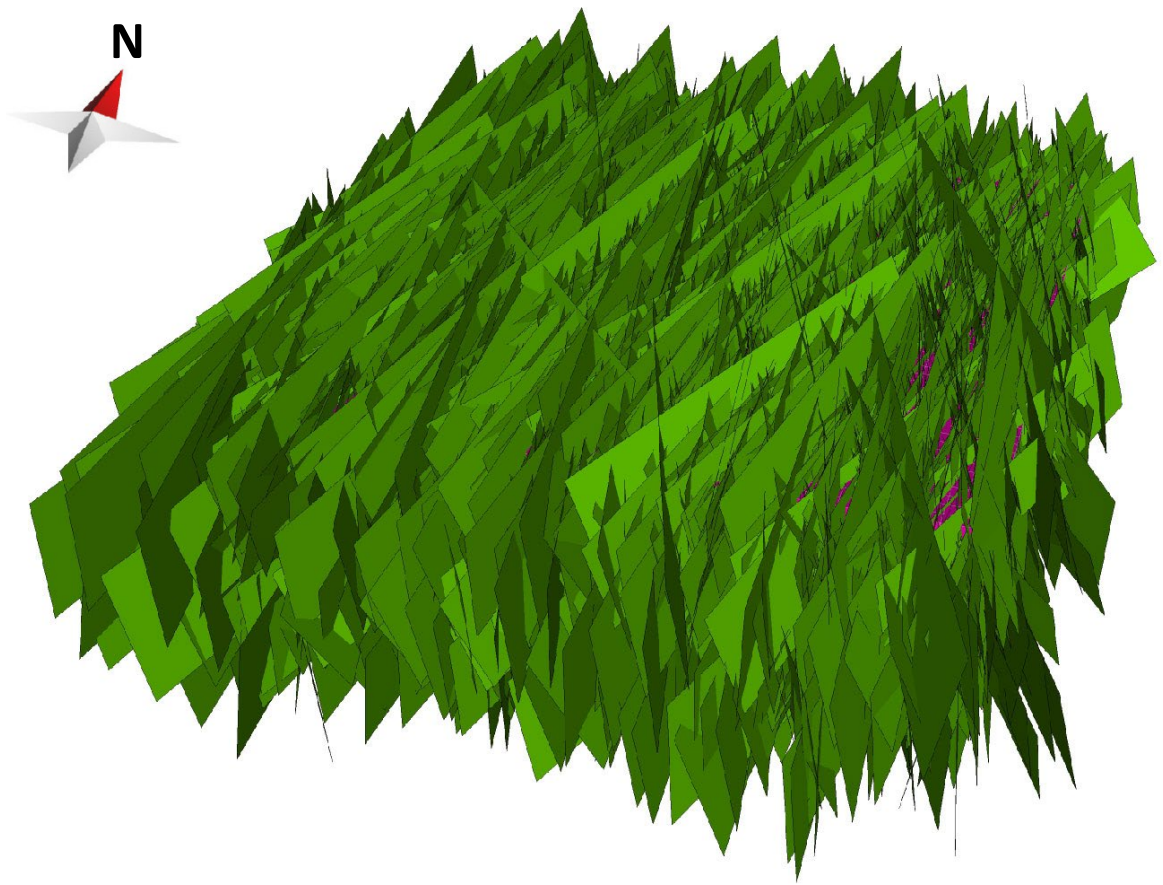




FracPaQ (Healy et al., 2017)

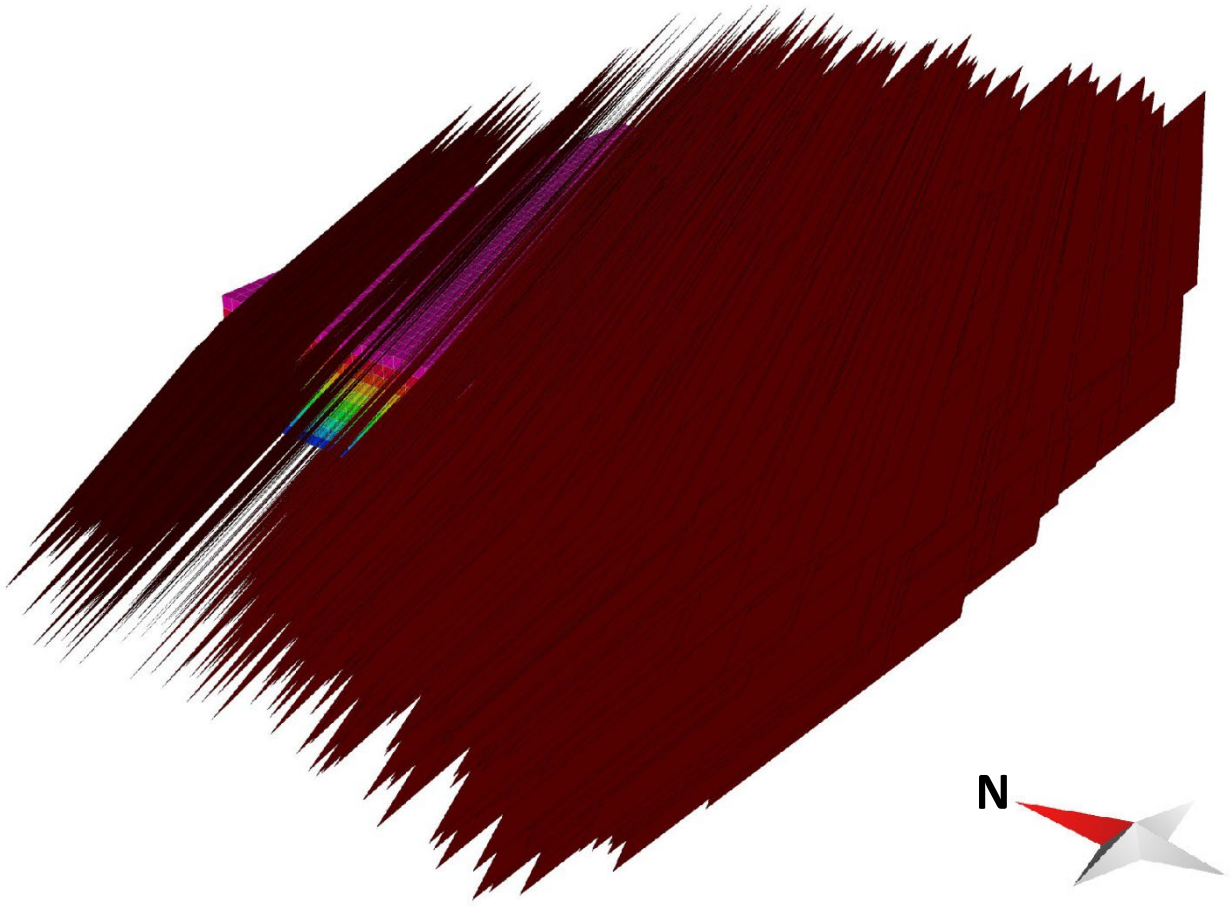
DFN model (500 x 500 x 100 m) (MOVE)

Set 1



Length = 5 – 400 m (1:5) Exp = 1.80
P32 = 2.62 N. fractures = ~100000
Dip = 80°; Dip Azimuth = 87°
K-Fischer = 28
Av. Aperture = 0.003-0.005 mm (length-proportional)

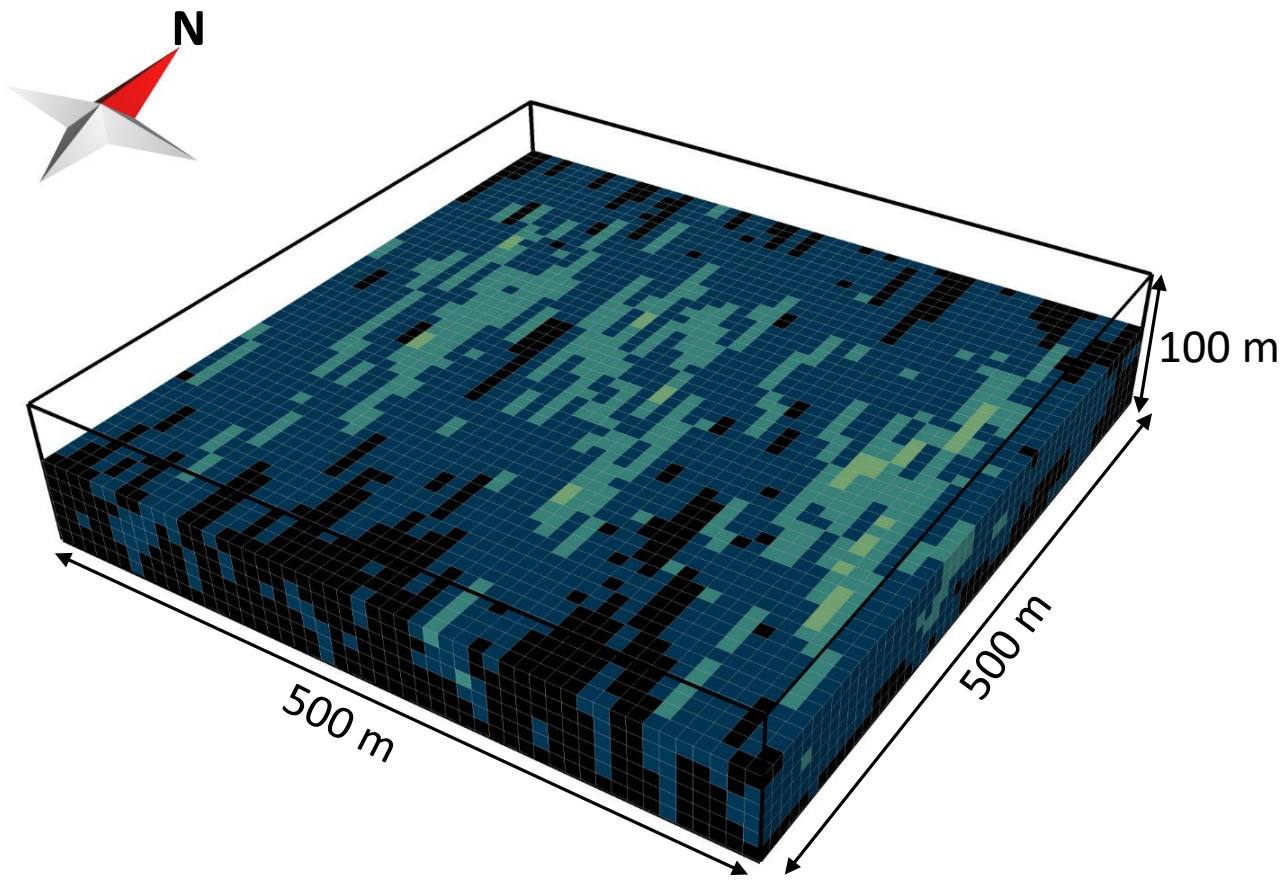
Set 2



Length = 500 m (1:2)
N. fractures = ~1000 (~ 70 cm spacing)
Dip = 50°; Dip Azimuth = 340°
Constant Aperture = 0.003-0.005 mm

DFN model (500 x 500 x 100 m) (MOVE)

Model 1 (Av. Aperture 0.005 mm)

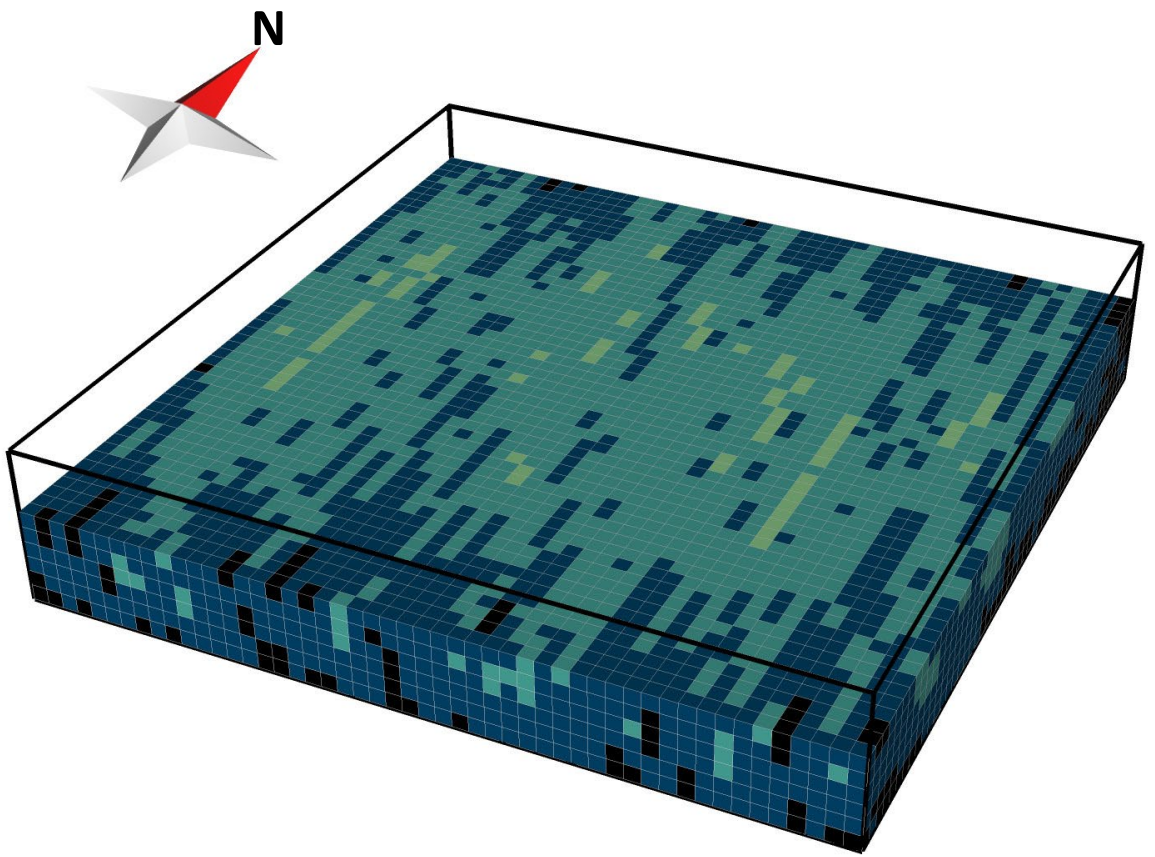


Permeability (m^2)

$5x10^{-16}$ $1x10^{-14}$ $2x10^{-14}$ $4x10^{-14}$

$Kxx = 1.3x10^{-15}$ $Kyy = 1.3x10^{-14}$ $Kzz = 1.2x10^{-14}$

Model 2 (Av. Aperture 0.003 mm)

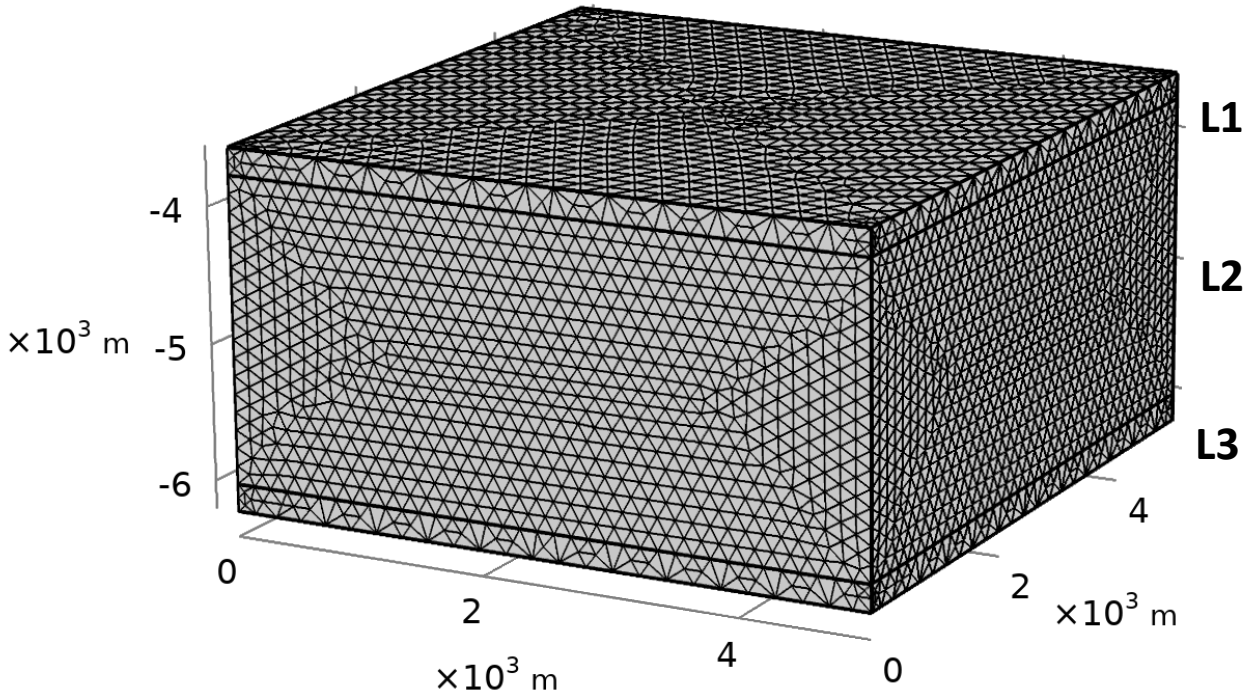


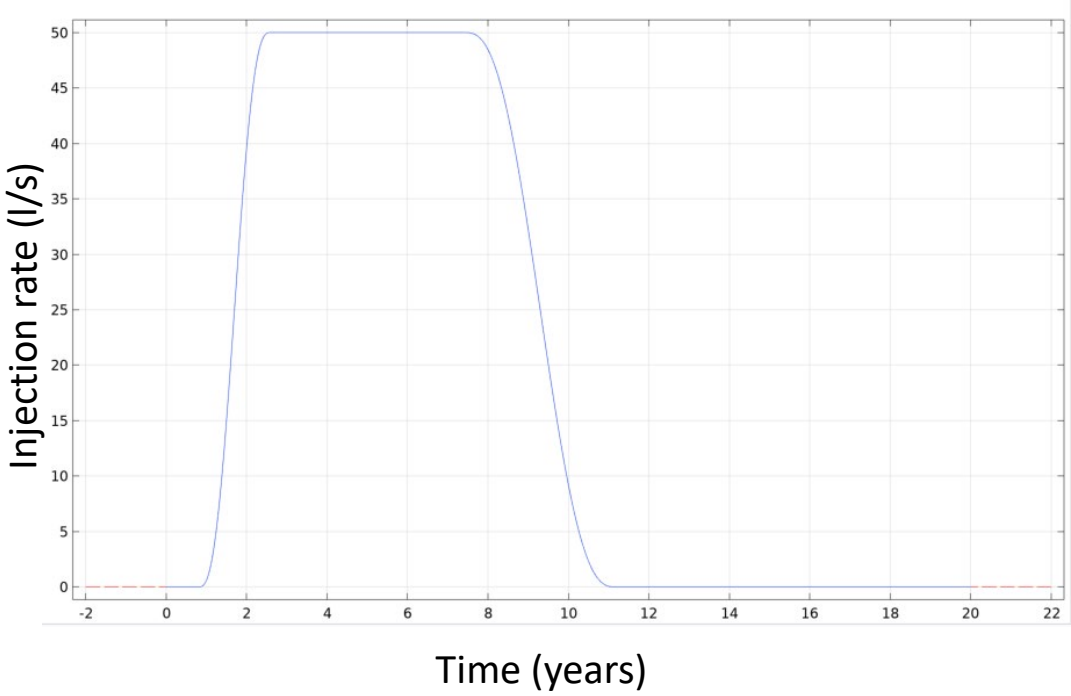
Permeability (m^2)

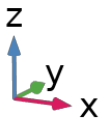
$5x10^{-17}$ $1x10^{-15}$ $3x10^{-15}$ $8.5x10^{-15}$

$Kxx = 3.1x10^{-16}$ $Kyy = 2.9x10^{-15}$ $Kzz = 2.8x10^{-15}$

Coupled thermo-hydro-mechanical (THM) model (Comsol)





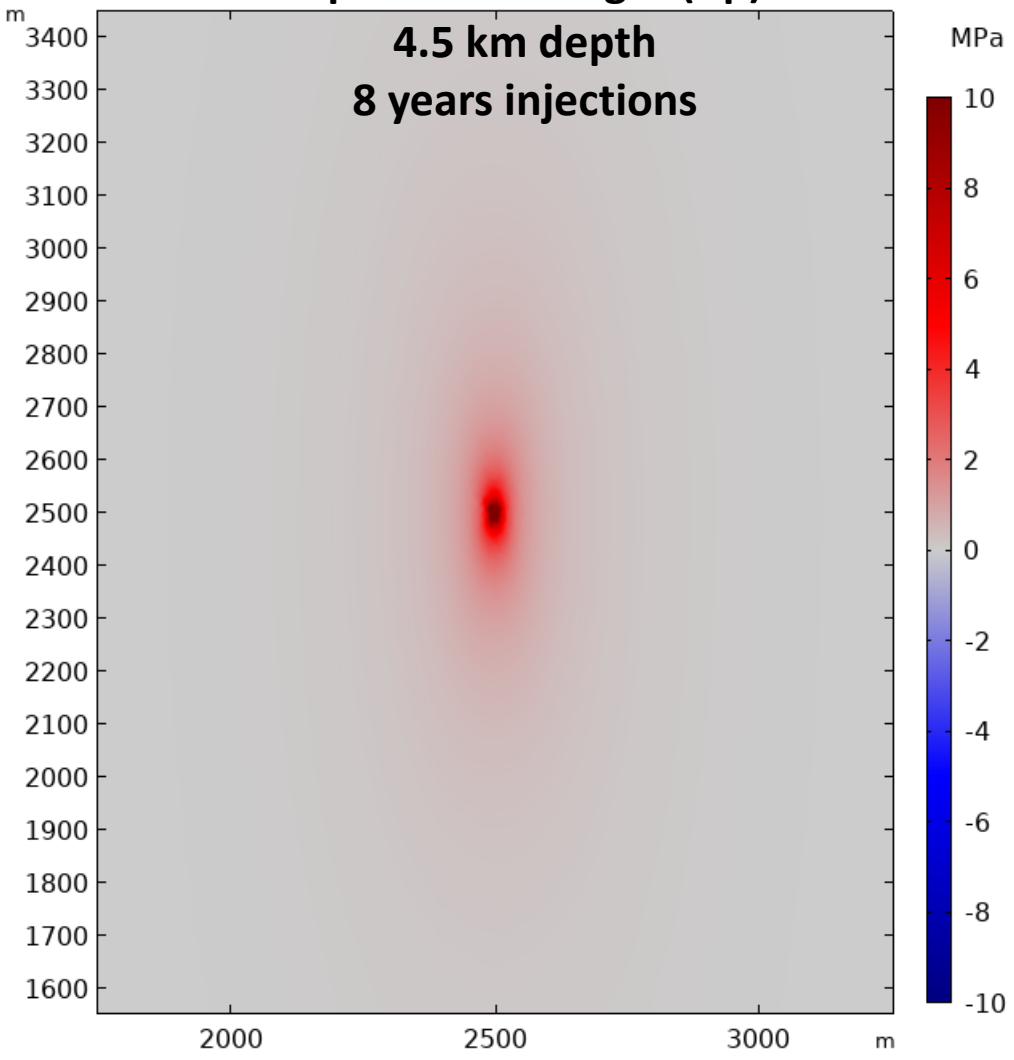


L1 (200 m) k = 1 x 10^{-18} m^2
L2 (2250 m)(Carbonates) k = Model 1 (DFN)
L3 (200 m) k = 1 x 10^{-18} m^2
Injection depth = 4.5 km

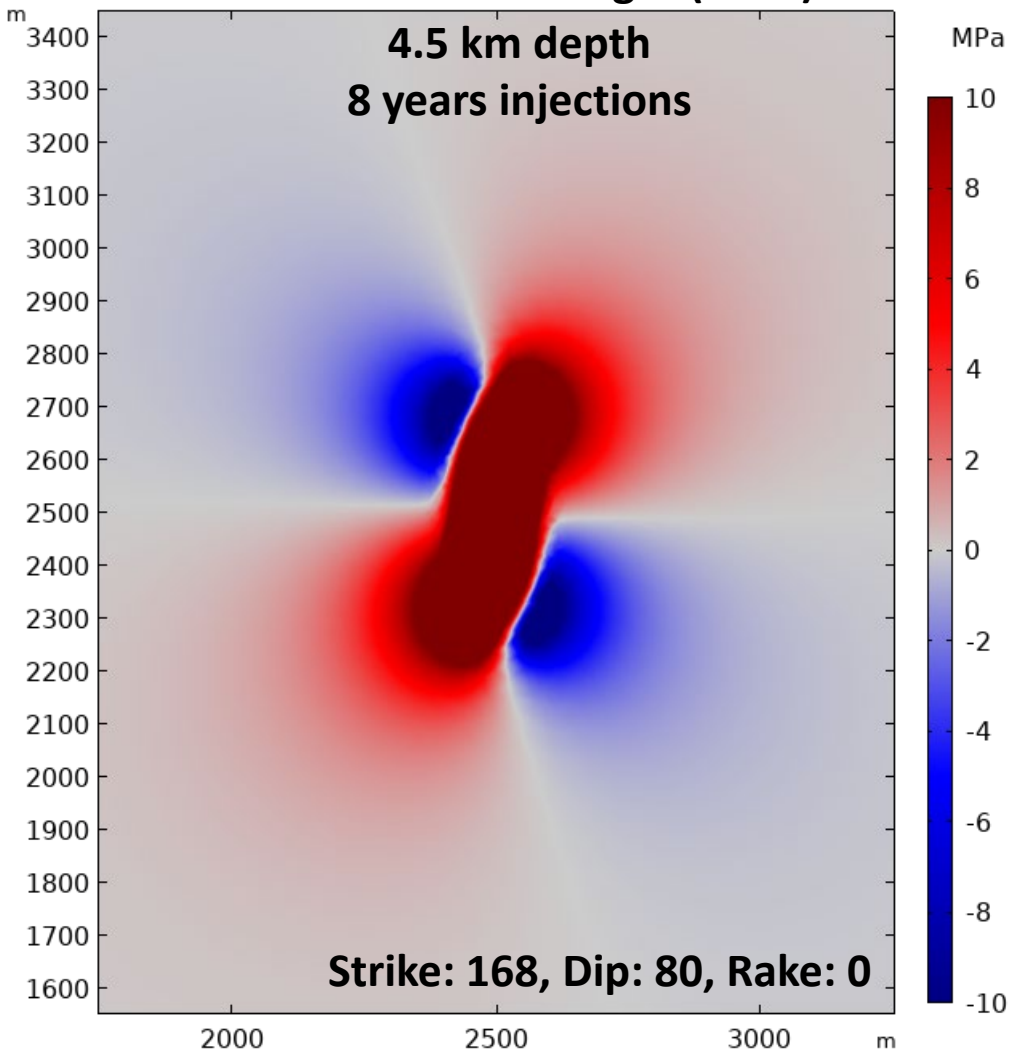
Geothermal gradient = 36 °C/km
Thermal conductivity = 2.59 W/(mK)
Heat capacity = 800 J/KgK
Coeff. thermal expansion = 7 x 10^{-6} 1/K

Coupled thermo-hydro-mechanical (THM) model (Comsol)

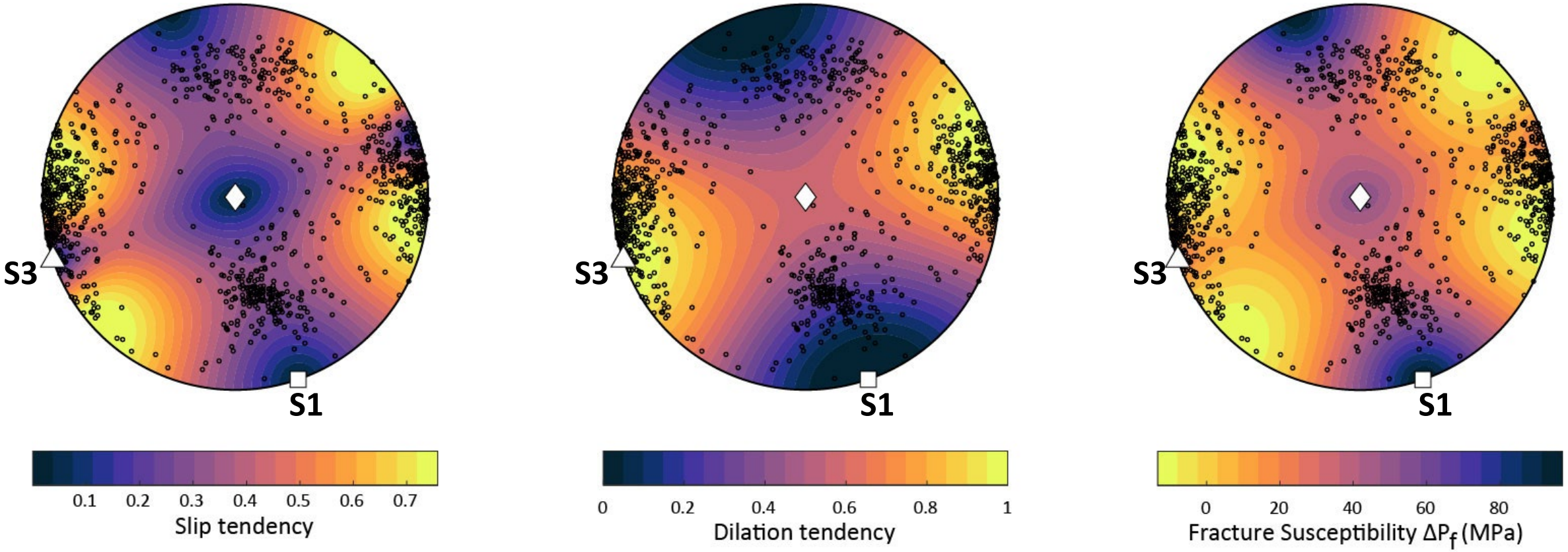
Pore pressure changes (Δp)



Coulomb stress changes (ΔCFS)



Fault stability

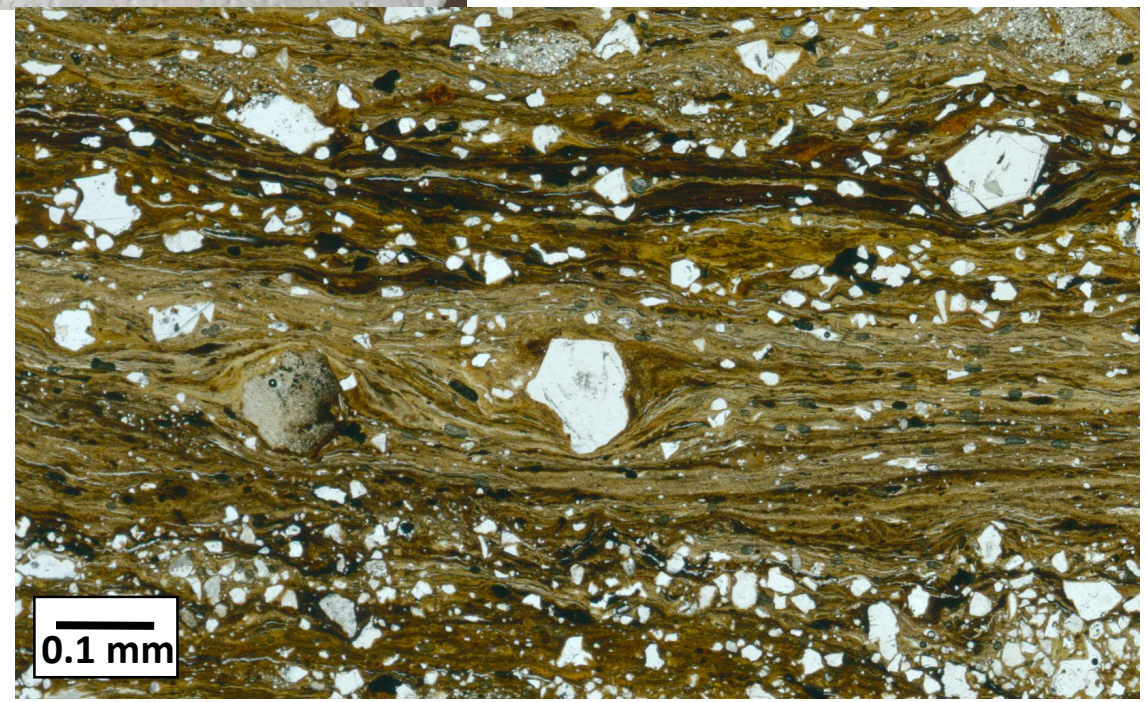


Data (Kruszewski et al., 2021)

Orientation	Magnitude	Depth	μ
S1 = SHMax = 161°	S1 = 33.6 MPa/km	4.5 Km	0.6
S2 = Sv	S2 = 23.1 MPa/km		
S3 = SHMin = 251°	S3 = 16.1 MPa/km		
	PP = 10.8 MPa/km		

Fault stability (friction)

Foliated and lithified clay material



Summary/Conclusions

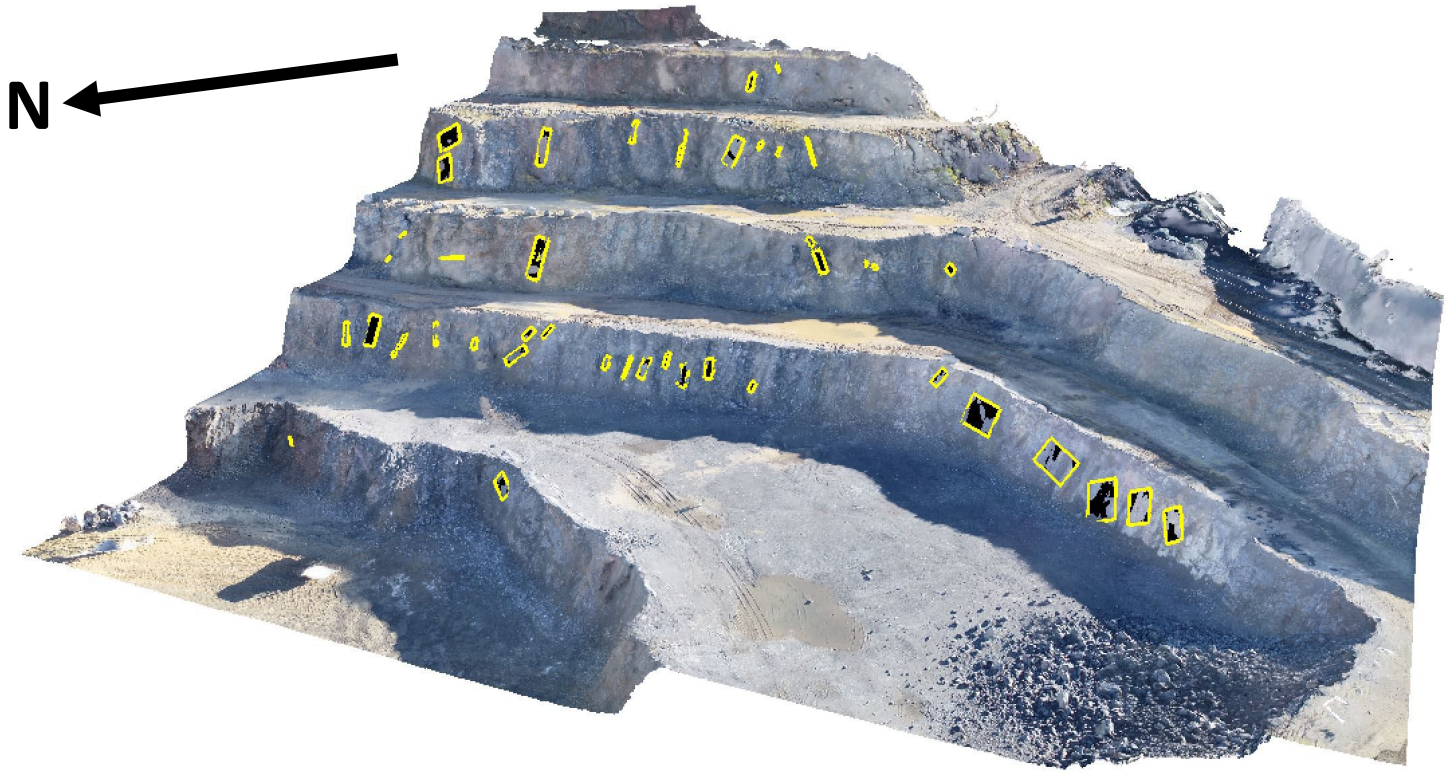
N-S-trending sub-vertical faults and fractures are main pathways for fluid flow in the Devonian carbonates.

Thermal stresses due to cold water injections can have a large impact on the magnitude and spatial extent of stress redistribution during, and after the injection period.

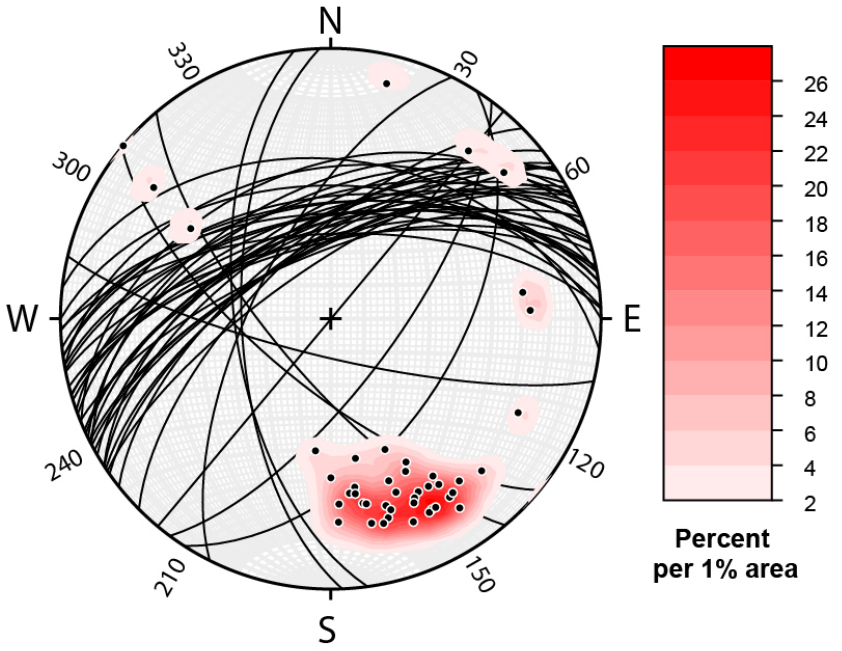
The Devonian carbonates in the Ruhr region could host faults optimally-oriented for reactivation.

Thanks for your attention!

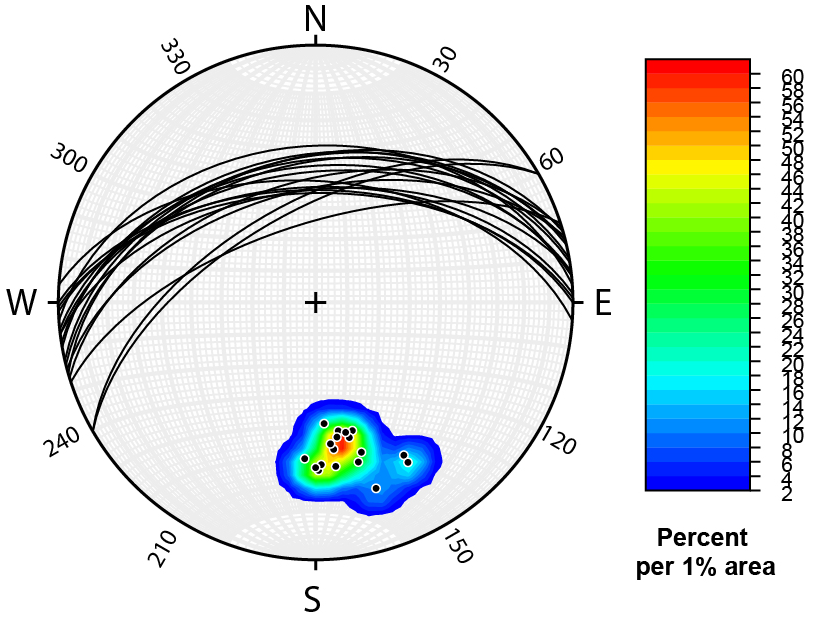
contact: alessandro.verdecchia@rub.de

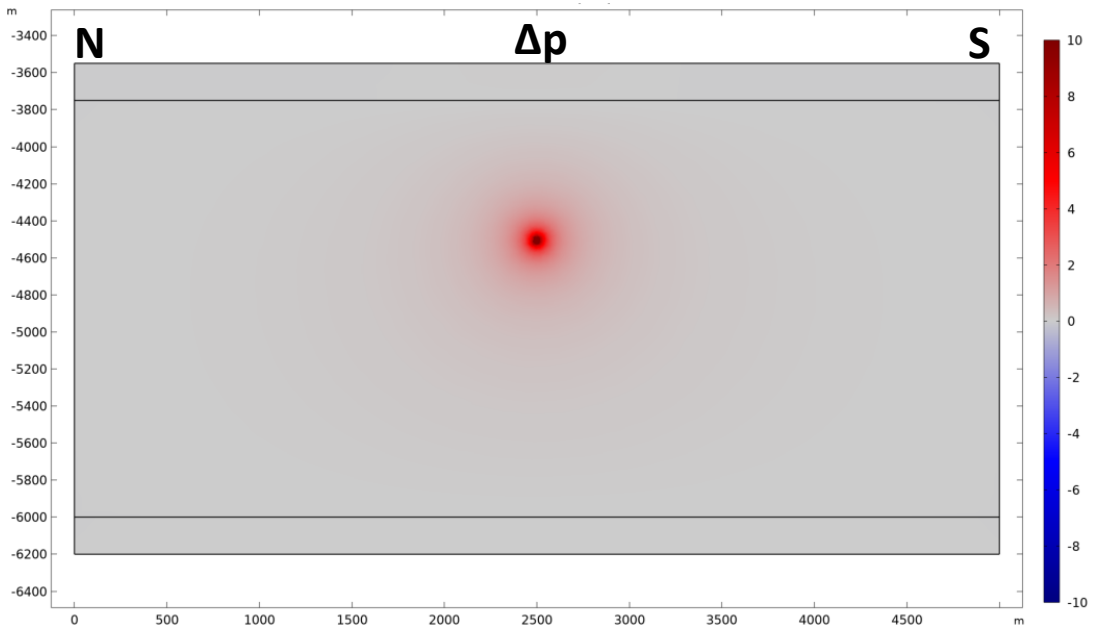


3D Model data



Field data

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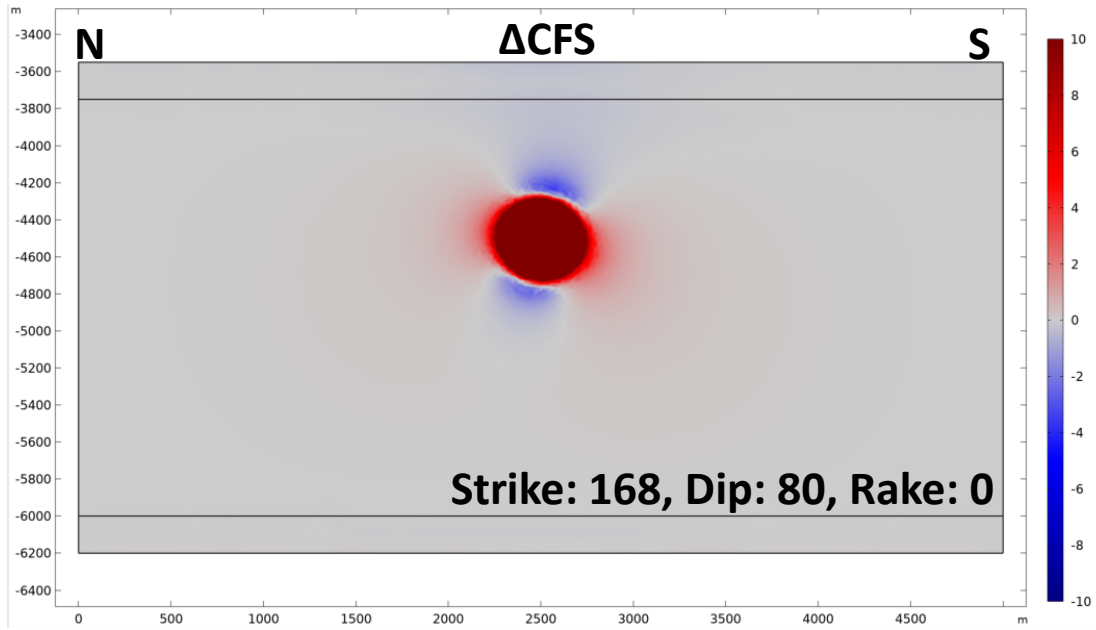
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Strike: 168, Dip: 80, Rake: 0
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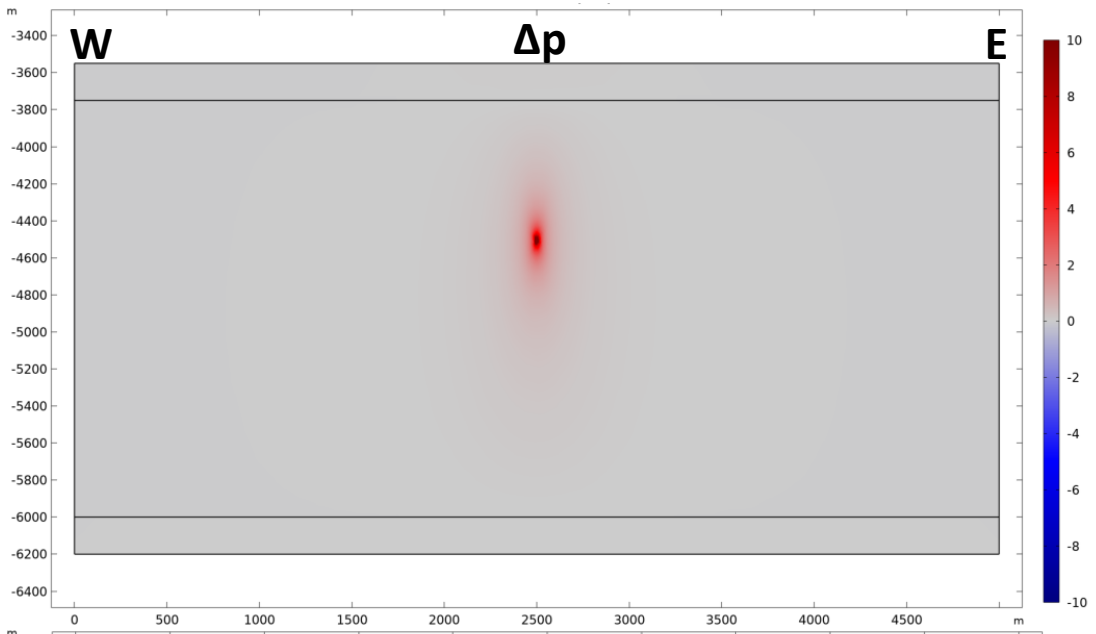
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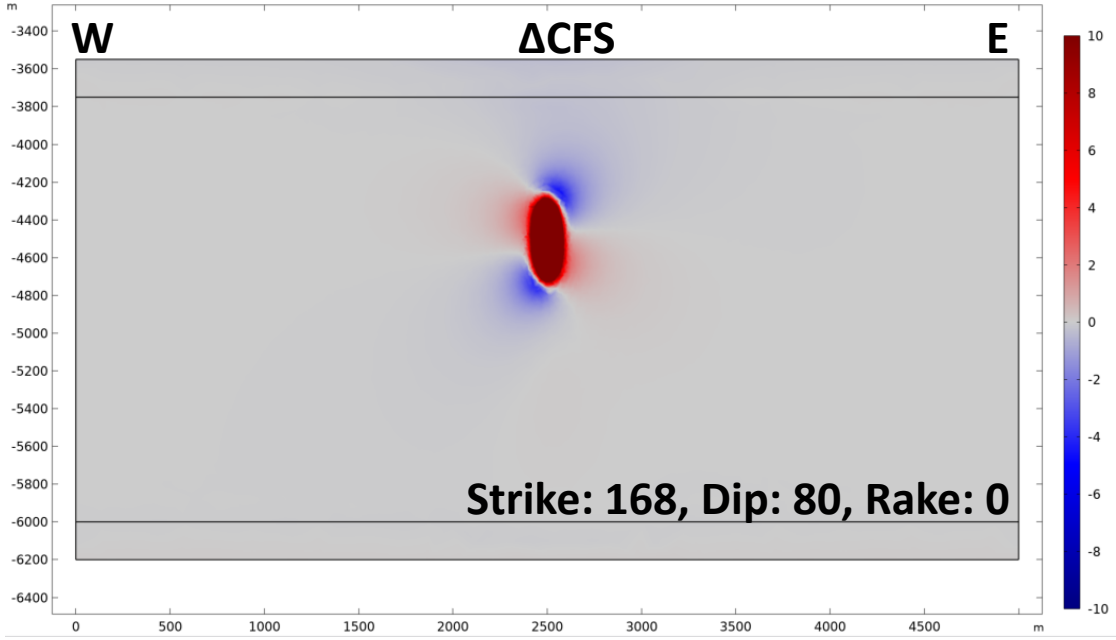
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