SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

UNIVERSITÉ DE NEUCHÂTEL

EXPLORATION AND CHARACTERISATION FOR DEEP GEOTHERMAL PROJECTS

What questions do the geothermal operators ask me about the development of their project ?

Do I have better answers now than I did 6 years ago when the SCCER-SoE started?

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Centre for Hydrogeology and Geothermics - CHYN
University of Neuchâtel

2 November 2020

Heatstore project
Reza Sohrabi

WHAT QUESTIONS DO THE GEOTHERMAL OPERATORS ASK ME ABOUT THE DEVELOPMENT OF THEIR PROJECT ?

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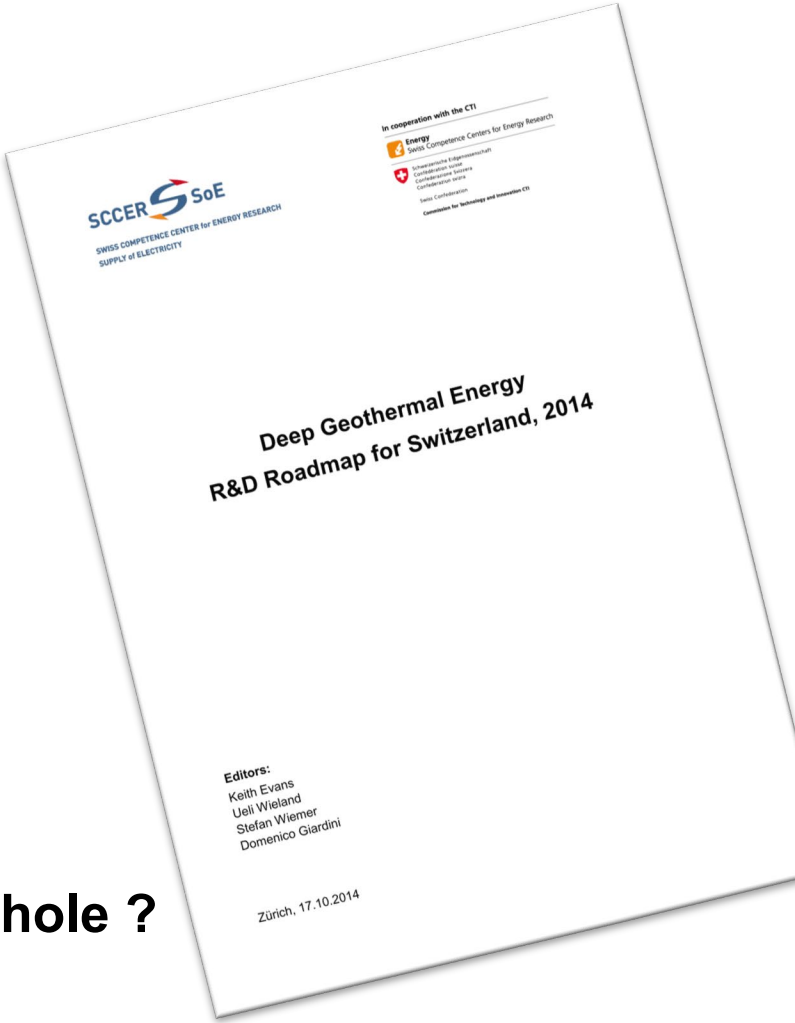


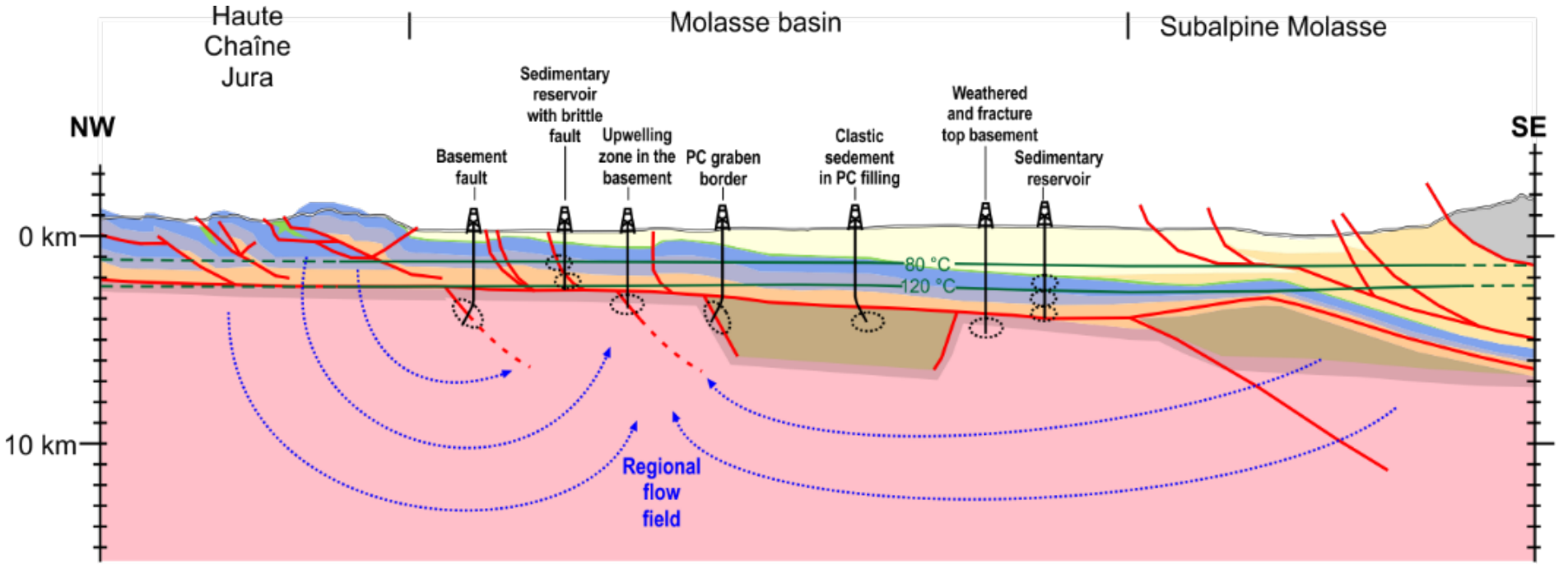
1. **Where shall I drill my boreholes ?**
2. **What is the best way of drilling my borehole ?**
3. **What shall I measure in my boreholes ?**
4. **What volume of rock will I influence when I develop my reservoir ?**

Conceptual targets

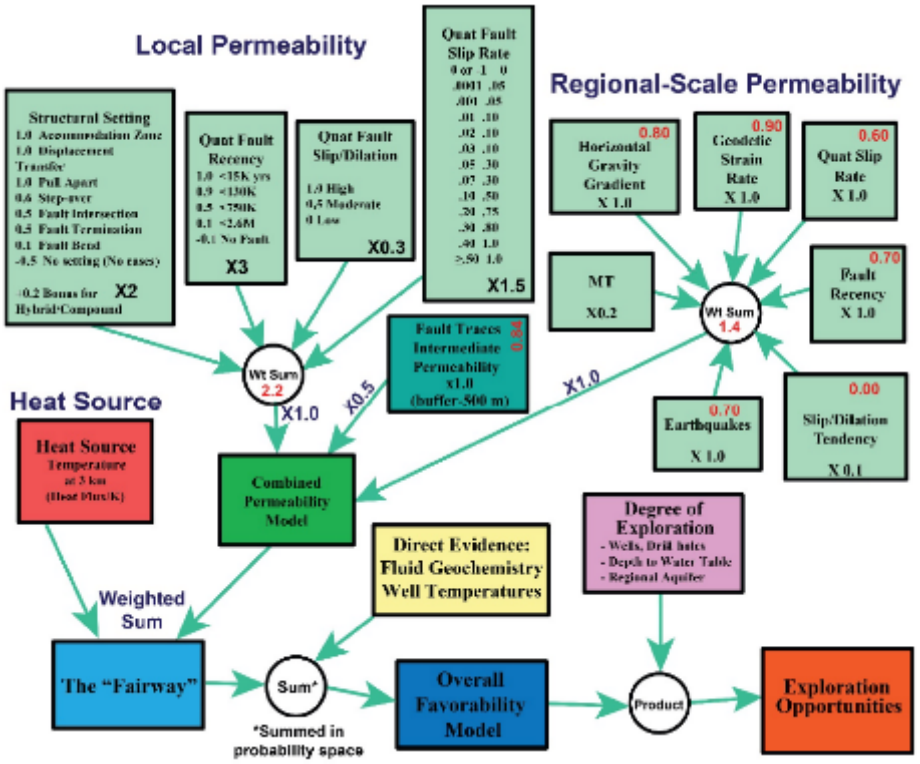
1) Temperature : sufficient for the planned application

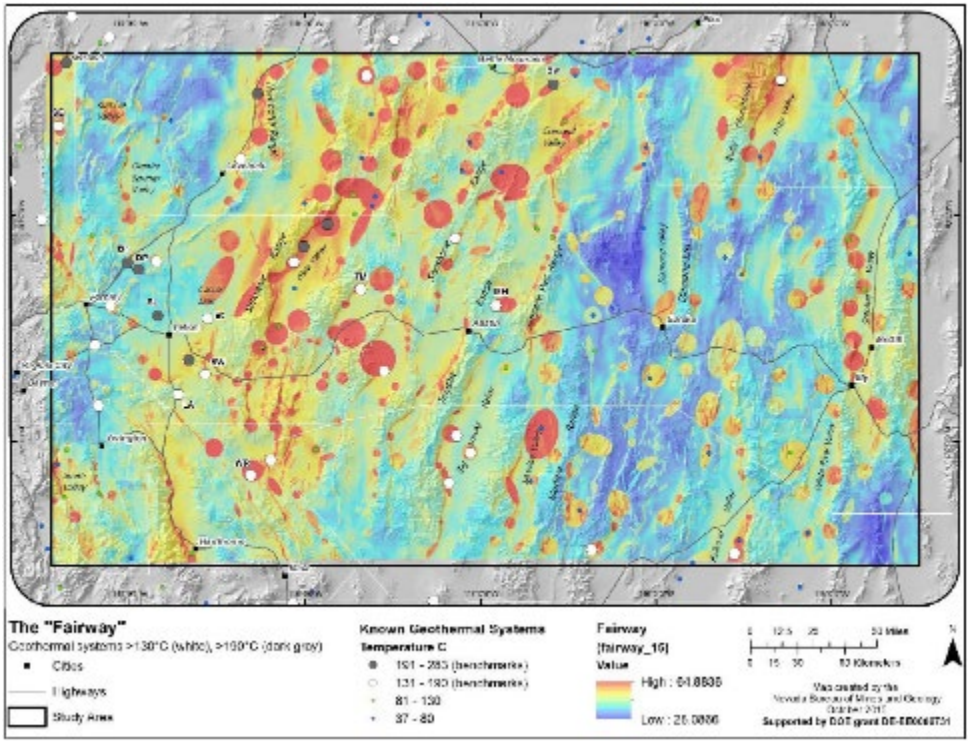
2) Water flow and permeability
   - Primary permeability/porosity
   - Secondary permeability/porosity (fractures, karst)
   - Hydrogeological boundary conditions

3) Stress state and faults slip tendency



1 PLAY-FAIRWAYS ANALYSES APPROACH

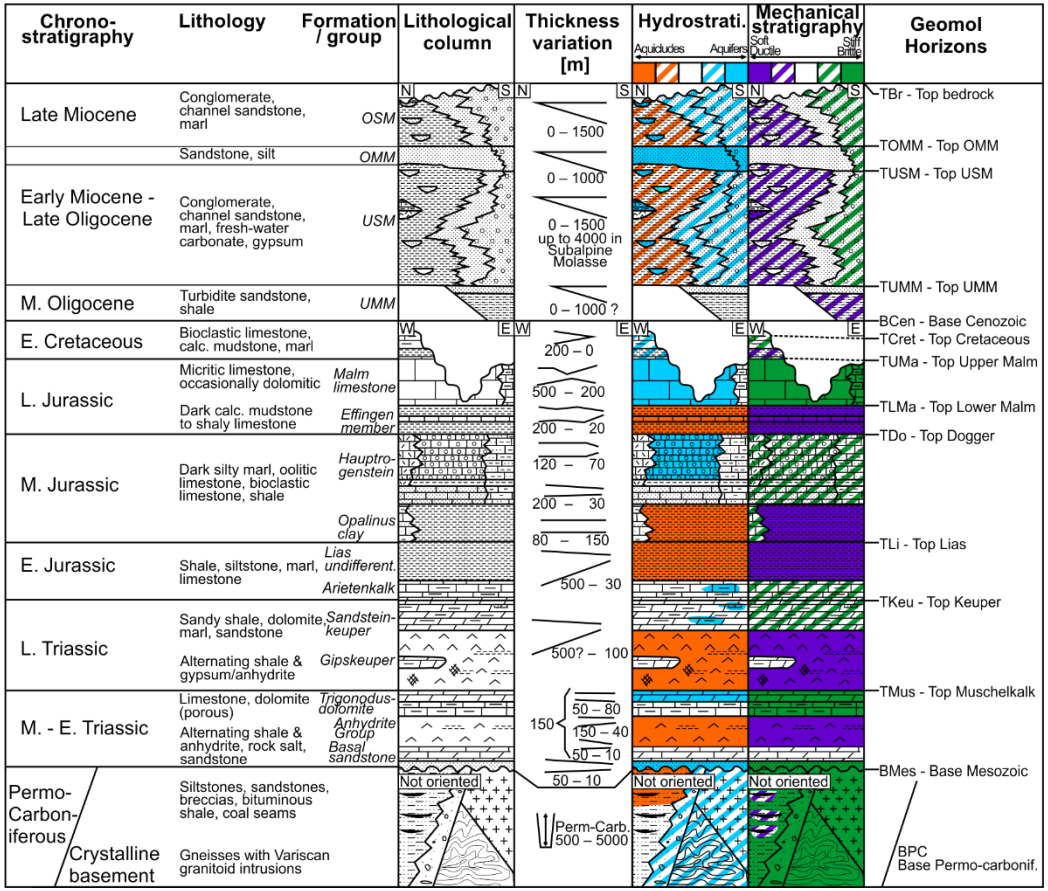




(Faulds et al., 2018)

DATA AVAILABLE TO IDENTIFY TARGETS

- **Hydrostratigraphy (Chevalier et al. 2010)**
- **Mechanical stratigraphy (Hergert et al., 2015)**
- **Geomol horizon model (swisstopo)**
- Geomol fault model (swisstopo)
- Geomol temperature model (swisstopo)
- Heat flow map (swisstopo)
- Spring and thermal spring locations (Hydr. Atlas of CH, Sonney and Vuataz; 2008)
- Evaluation of regional flow pattern
- Stress field estimation with a Swiss-scale finite element stress simulation
- Earthquake catalog of Switzerland (download from SED website)



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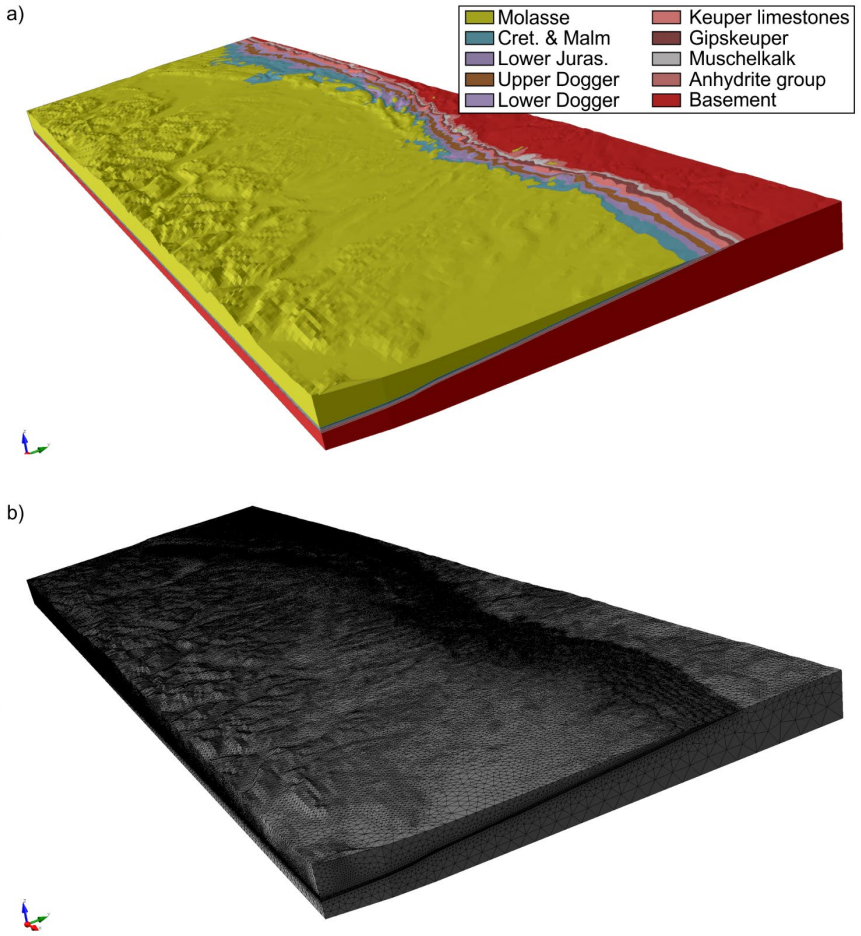
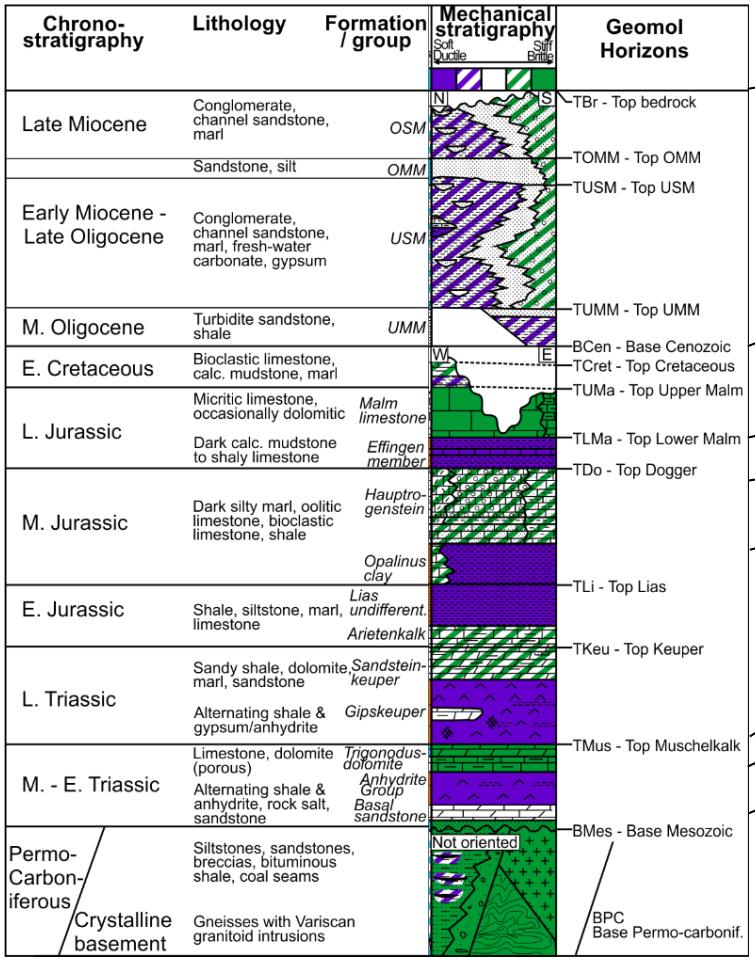
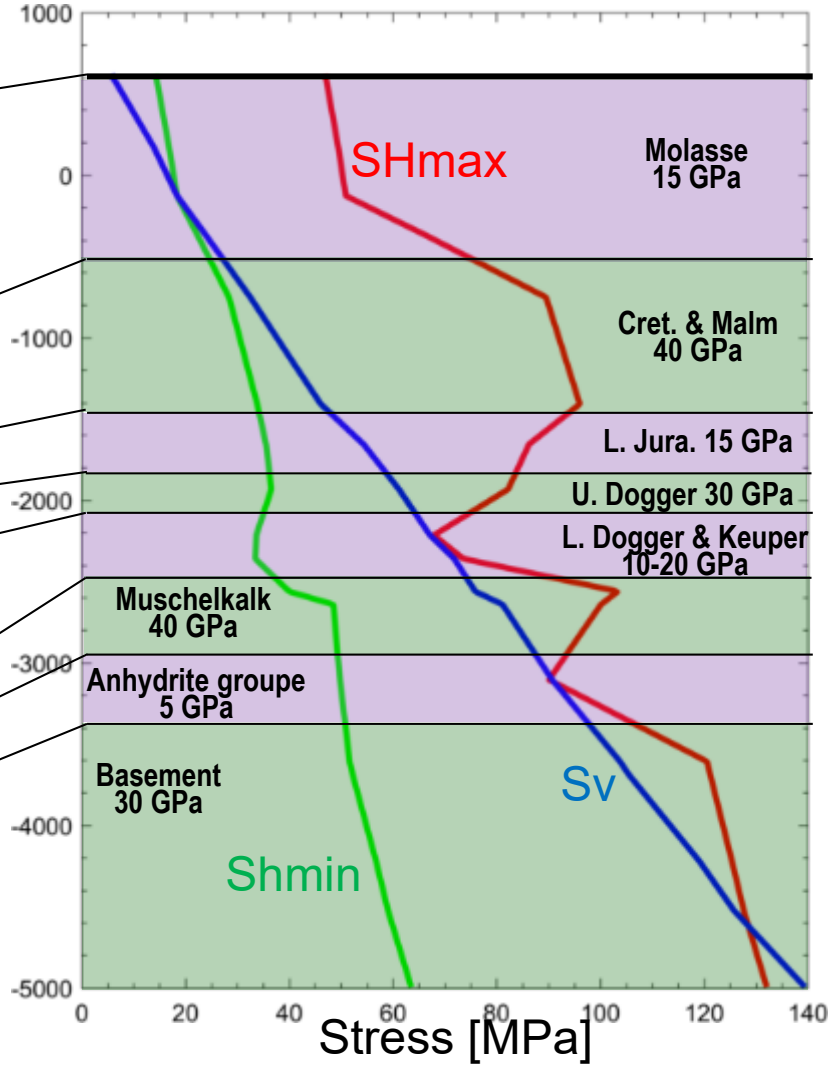


Working assumptions:

As a first order approximation stress is controlled by **gravity** and **stiffness contrast** under tectonic loading

EXAMPLE OF STRESS PROFILE





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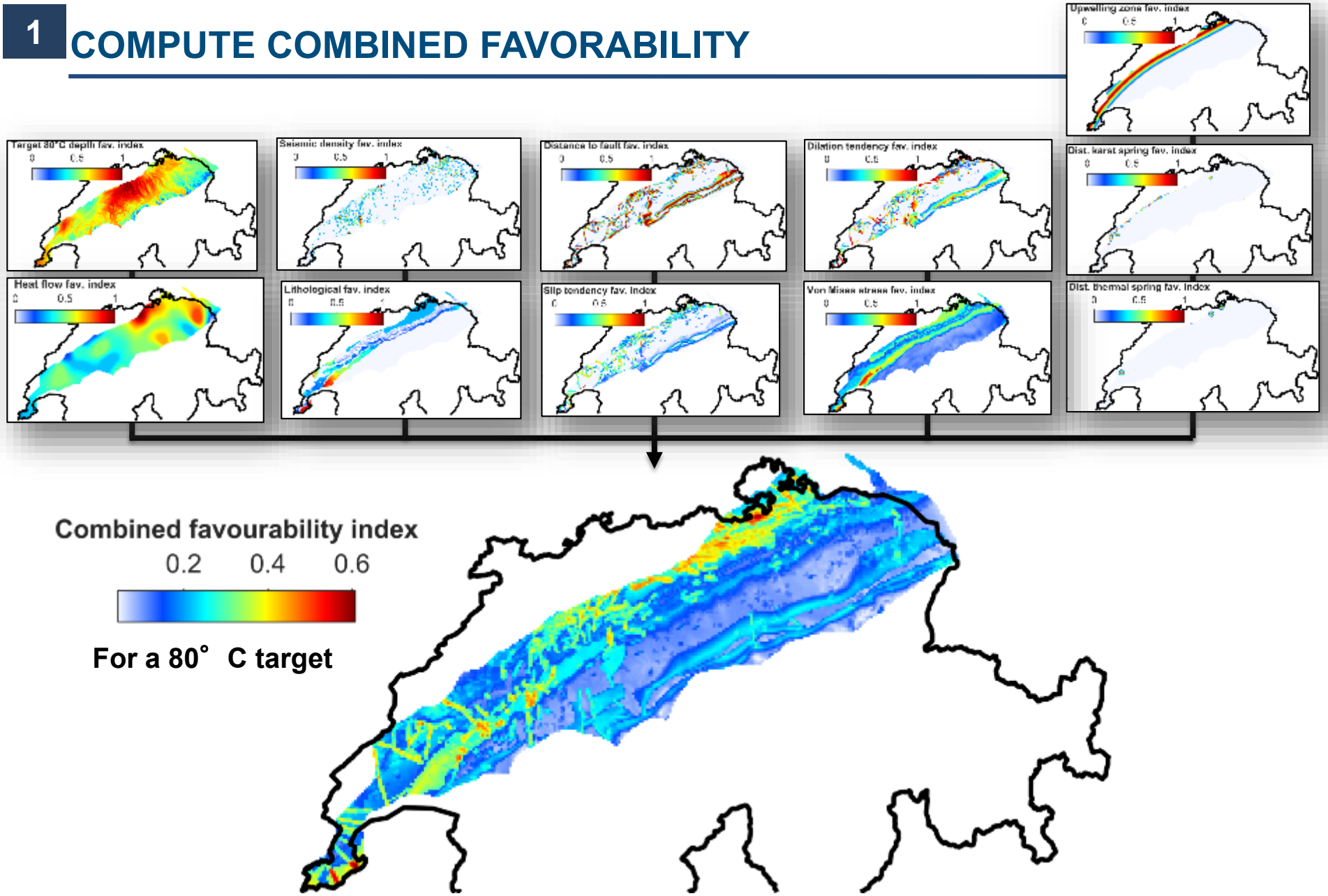
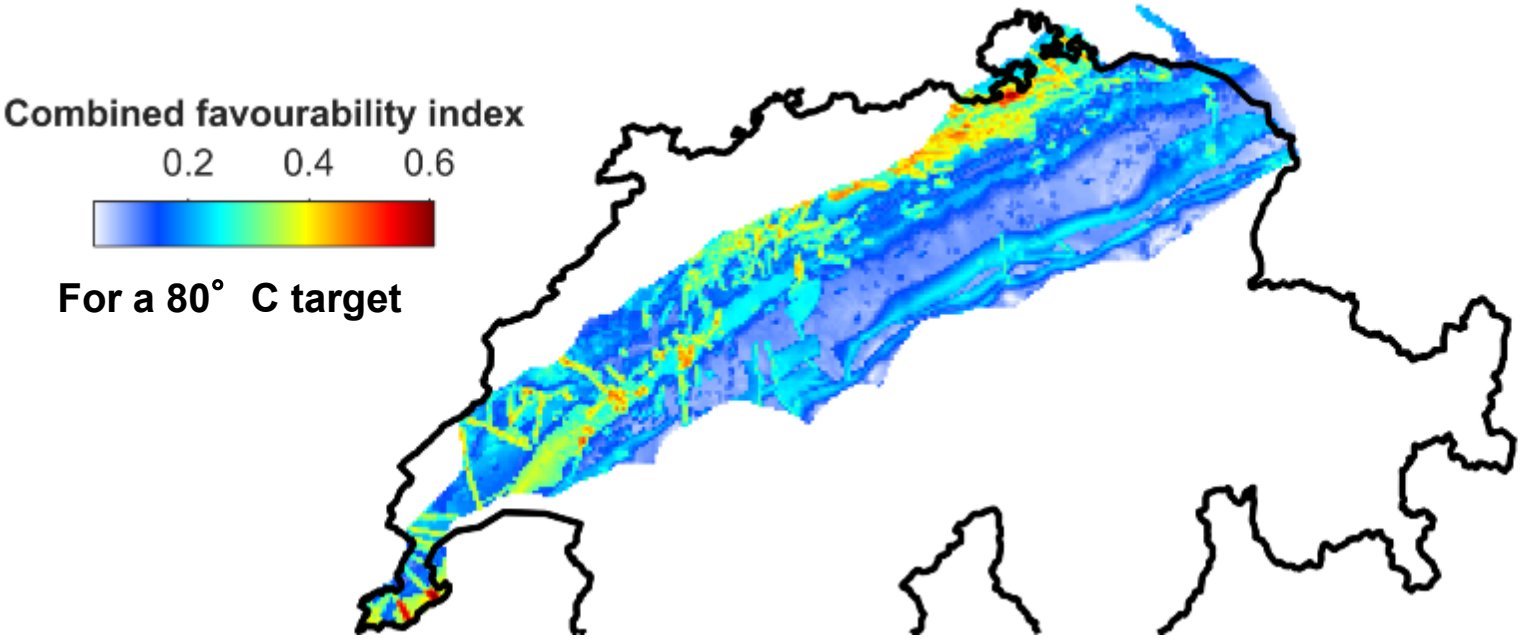
1 COMPUTE COMBINED FAVORABILITY



1 WHERE SHALL I DRILL MY BOREHOLES ?

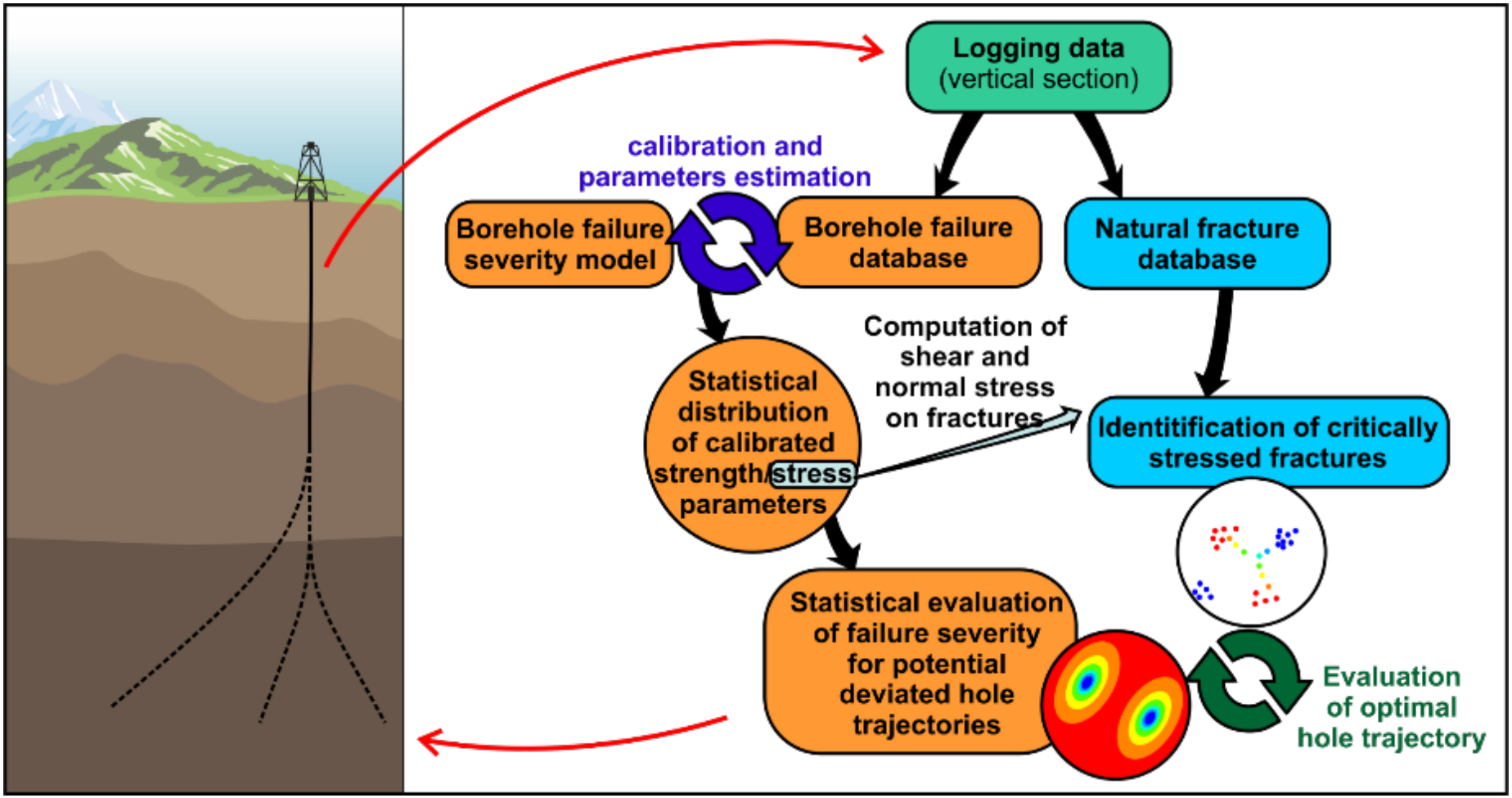
- Contrast in favorability index
- Uncalibrated criteria combination and weighting scheme

  → Need to calibrate against deep borehole productivity index
- Rely completely on the quality and homogeneity of the underlying datasets
- At a scale that is too large for geothermal site selection



2 WHAT IS THE BEST WAY OF DRILLING MY BOREHOLE ?

DGWOW : Deep Geothermal Well Optimisation Workflow



UNIVERSITÉ DE NEUCHÂTEL

Asmae Dahrabou
Benoît Valley

GEO ENERGIE SUISSE

Andres Alcolea
Peter Meier

2 DEEP GEOTHERMAL WELL OPTIMISATION WORKFLOW

Data preparation

Input data	Data processing	Input for calibration
Acoustic televiewer data	Acoustic data processing	**Observations**
Well trajectory	Wellbore failure assessment	breakout width
Temperature data	Natural fracture determination	breakout extent
Pressure data	Vertical stress profile assessment	breakout orientation
Material properties estimates	Pressure and cooling assessment	DITFs occurrence and corresponding wellbore minimum stress
		Independant data
		Sv, Pp, cooling, wellbore pressure, well trajectory, tensile strength elastic parameters

Models calibration

1st order models	2nd order models
9 model parameters	**7 variability parameters to calibrate**
SHmax : $a_{SHmax}\mathrm{tvd} + b_{SHmax}$	ϵ_{SHmax}
Shmin : $a_{Shmin}\mathrm{tvd} + b_{Shmin}$	ϵ_{Shmin}
Shmax orient. : α	ϵ_{α}
Cohesion : c	ϵ_{c}
Friction : ψ	ϵ_{ψ}
Shen's extent model : A_{Shen} , B_{Shen}	$\epsilon_{A_{Shen}}$
	$\epsilon_{B_{Shen}}$
Starting points	**Starting points**
Random but respecting crust stability constraints	Selected calibrated 1st order models
Optimisation parameters	**Optimisation parameters**
PEST optimisation parameters	PEST optimisation parameters
1st order calibrated models	**2nd order calibrated models**

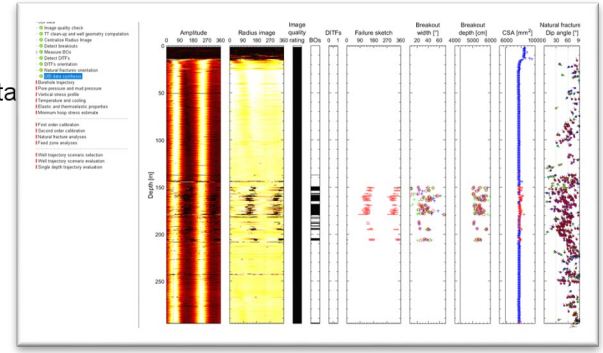
Failure prediction

Extrapolated 1st order models + 2nd order variability models from multiple-point statistics

Stochastic rockmass models + Well trajectory scenario

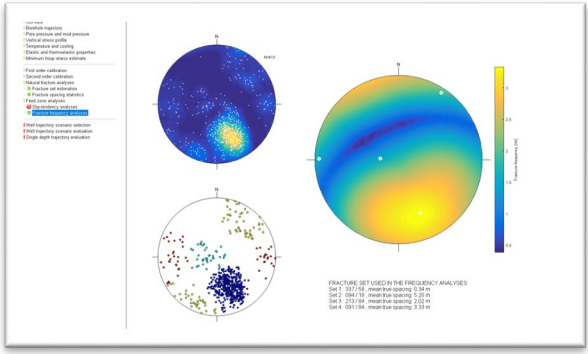
Failure intensity prediction and evaluation

- Project Information
- UBI data
  - Image quality check
  - TT clean-up and well geometry computa
  - Centralise Radius Image
  - Detect breakouts
  - Measure BOs
    - Ellipse section fit
    - BOs Orientation
    - Failure width
    - Failure depth
    - CSA
  - Detect DITFs
  - DITFs orientation
  - Natural fractures orientation
  - UBI data synthesis
- Borehole trajectory
- Pore pressure and mud pressure
- Vertical stress profile
- Temperature and cooling
- Elastic and thermoelastic properties
- Minimum hoop stress estimate



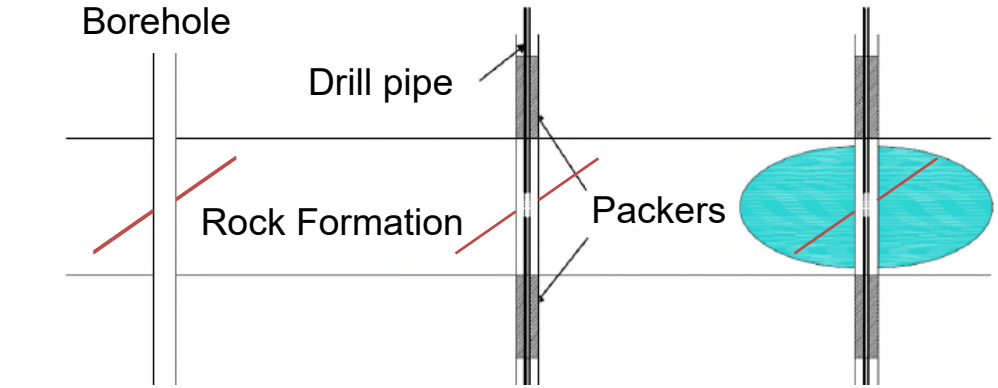
- First order calibration
  - Zone and data definition
  - Starting point and calibrations
  - 1st calibrated profiles
  - 1st calibrated histograms
  - 1st calibrated objective function
  - 1st order calibration sorting
- Second order calibration
  - Second order calibration evaluation
- Natural fracture analyses
  - Fracture set estimation
  - Fracture spacing statistics
- Feed zone analyses
  - Slip-tendency analyses
  - Fracture frequency analyses

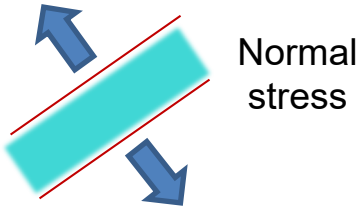
- Well trajectory scenario selection
- Well trajectory scenario evaluation
- Single depth trajectory evaluation



3 WHAT SHALL I MEASURE IN MY BOREHOLES ?

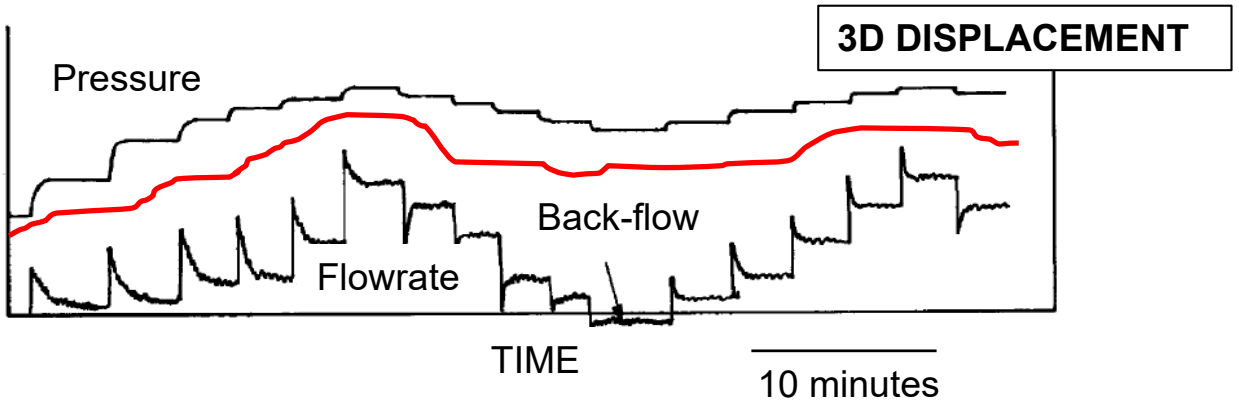
… many things, but one of the key parameter is the in-situ stress state !





http://apetrol.com/mini-frac-test-services/

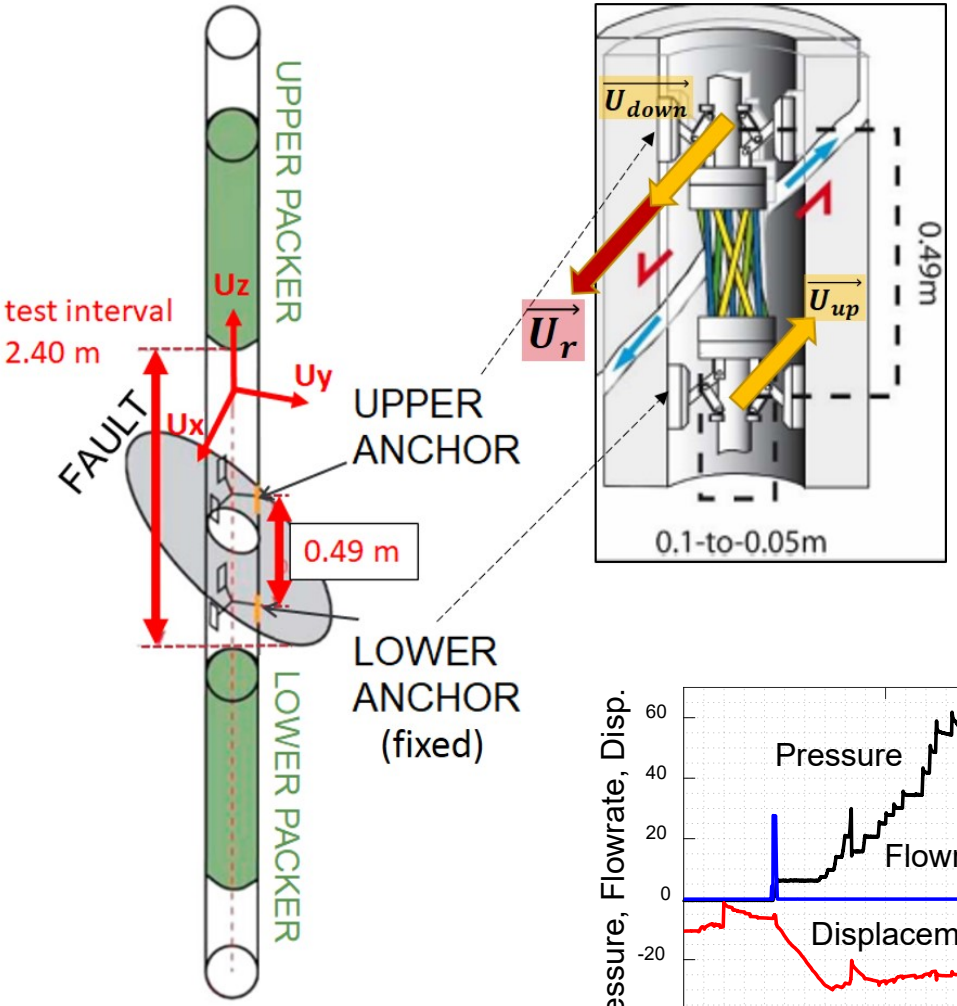
- 6 measurements of **normal** stress to estimate complete stress tensor

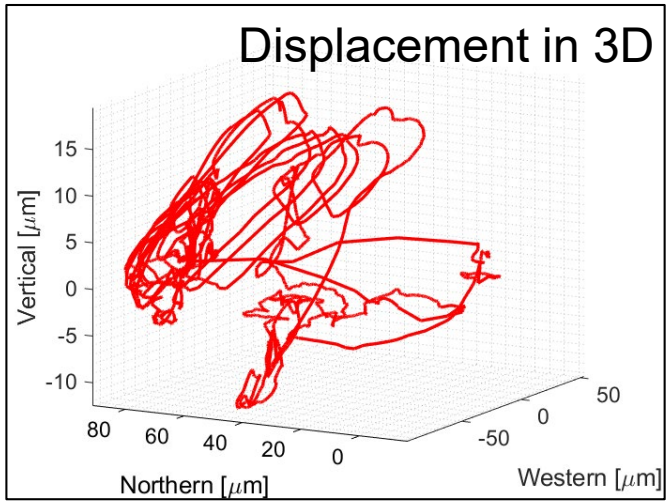


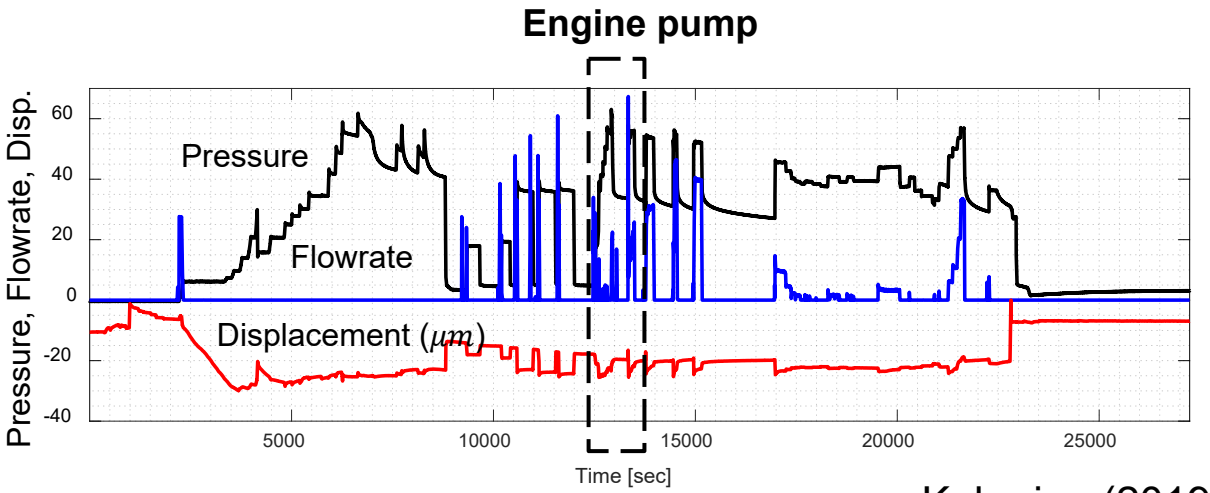
Kakurina (2019)

Haimson and Cornet, 2003

3 HYDRAULIC TEST ON PRE-EXISTING FRACTURE WITH SIMFIP







Guglielmi et al (2015). *ISRM Suggested Methods* p. 179–186)

Kakurina (2019)

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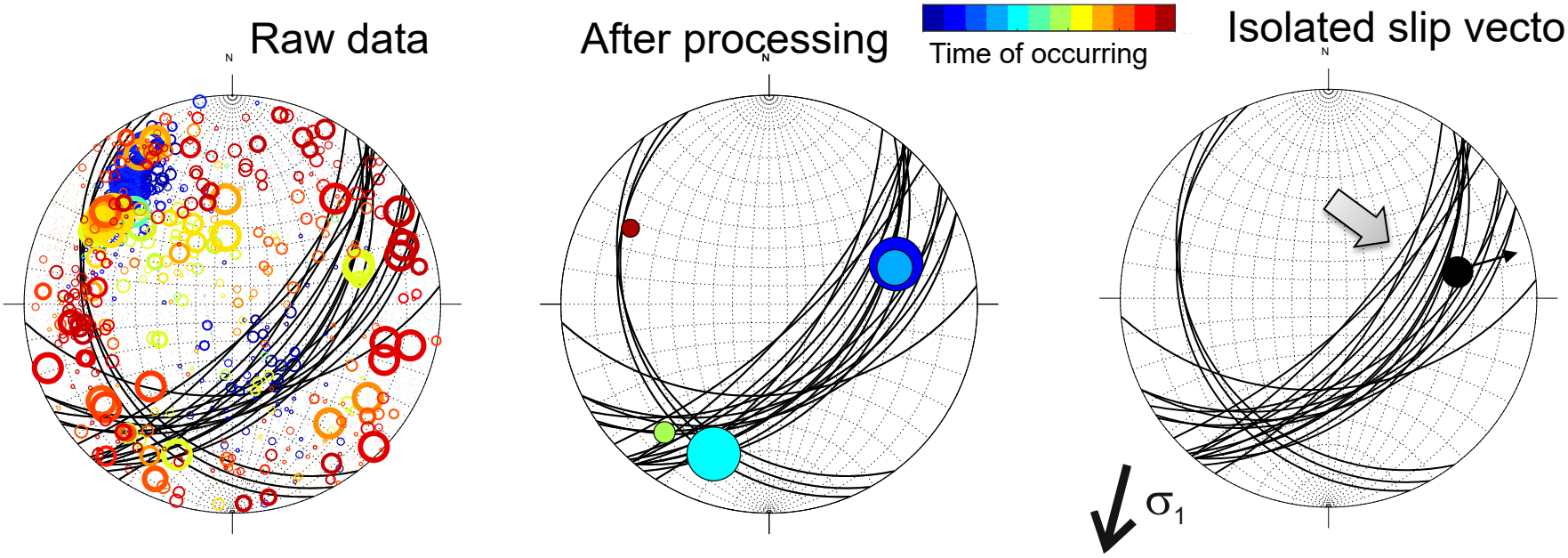
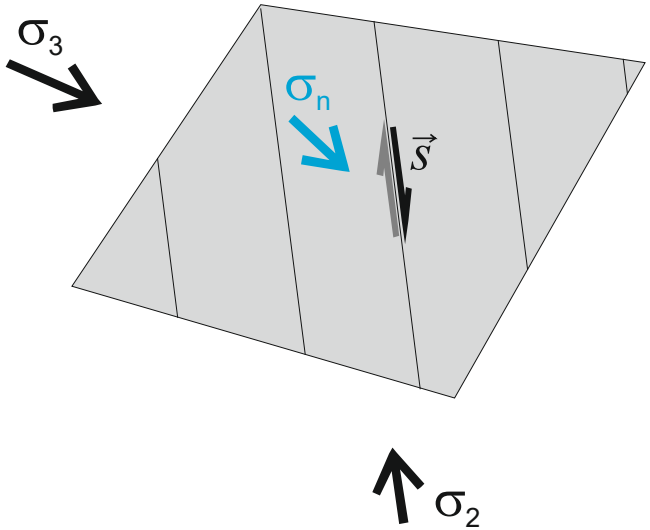


Data extracted:

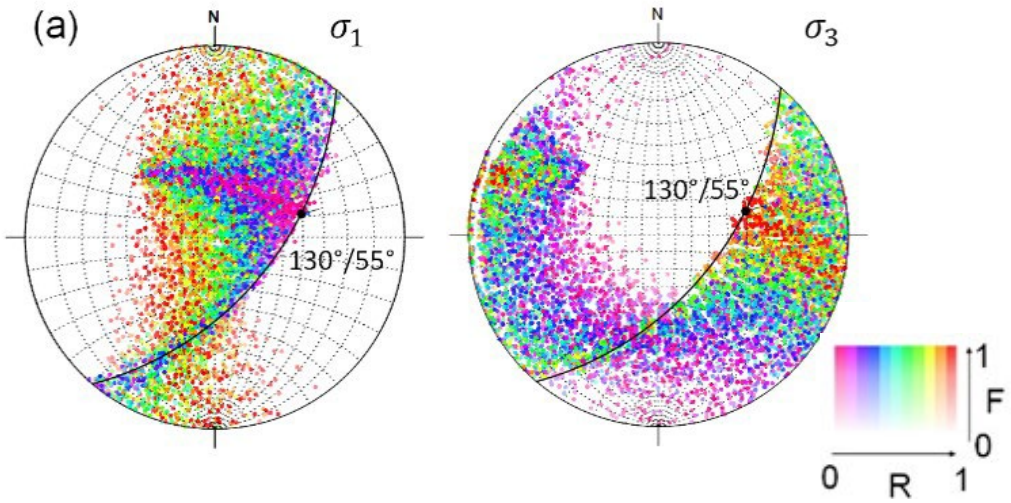
- Slip vector
- Potential slip planes (fractures)
- Fracture normal stress
- (Vertical stress component)

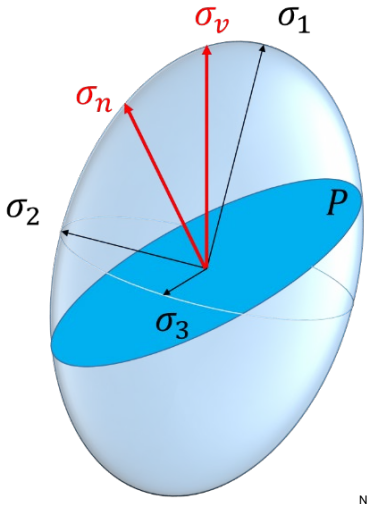
→ Find stress tensor honouring all these observation



Kakurina (2019)

GRID SEARCH ON STRESS ORIENTATION AND RATIO TO MATCH SLIP ORIENTATION

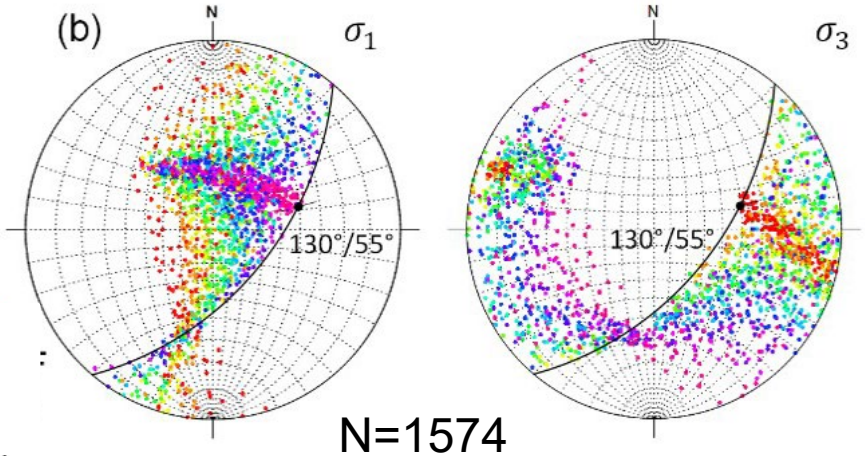




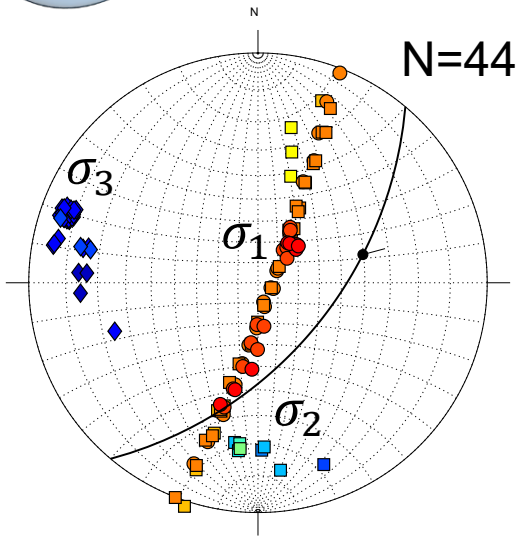
σ_n : stress normal to the fracture estimated from pressure record during injection

σ_v : estimated from overburden

Misfit angle between measured and predicted slip < 5°



N=1574



Kakurina (2019)

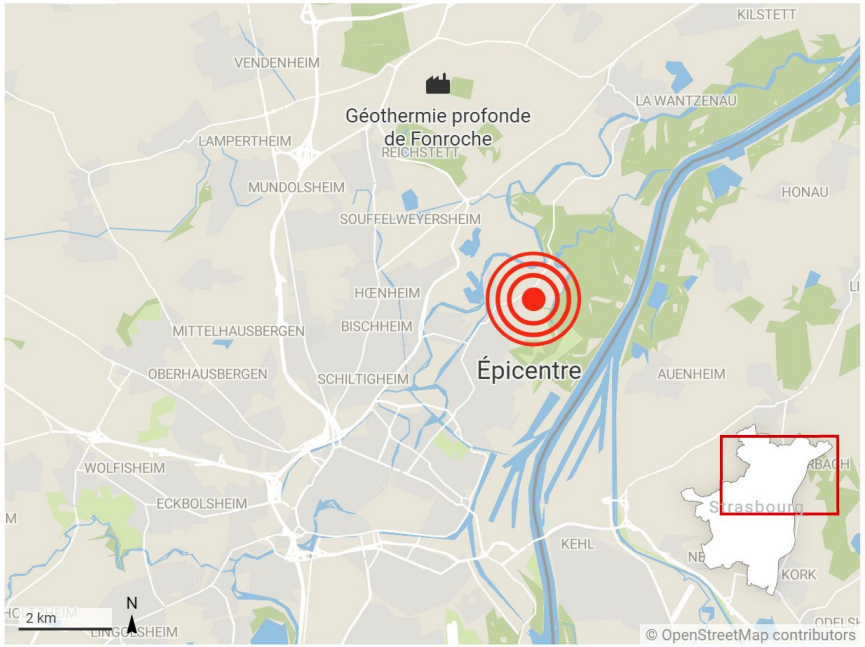
Full stress tensor estimate from a single injection test

Opportunity for stress profiling

WHAT VOLUME OF ROCK WILL I INFLUENCE WHEN I DEVELOP MY RESERVOIR ?

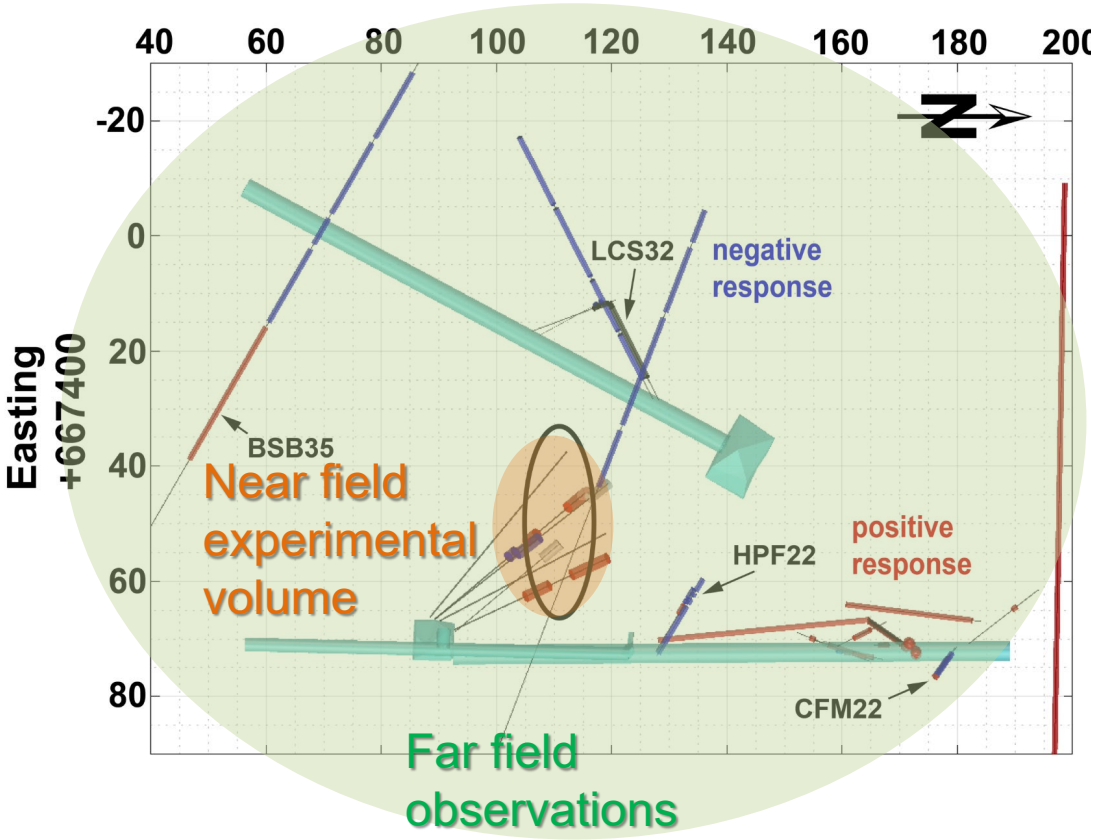
Un séisme secoue Strasbourg, Fonroche dément en être à l'origine

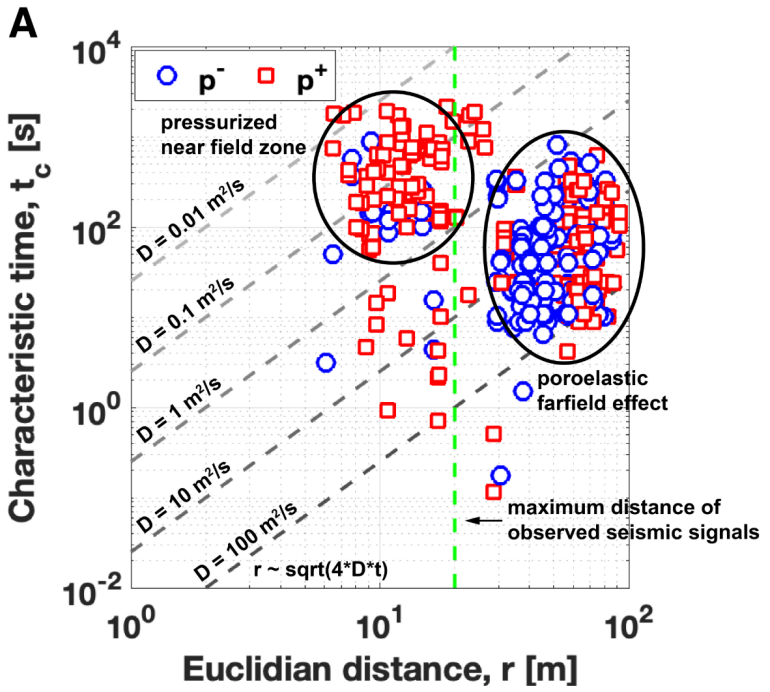
Une secousse d'une magnitude de 3,3 a été ressentie à Strasbourg, mardi 12 novembre à 14h38. Son épicentre se situe au nord de Strasbourg. Peu de dégâts signalés. Évoqué comme cause possible, le site de géothermie de Fonroche à Vendenheim dément.

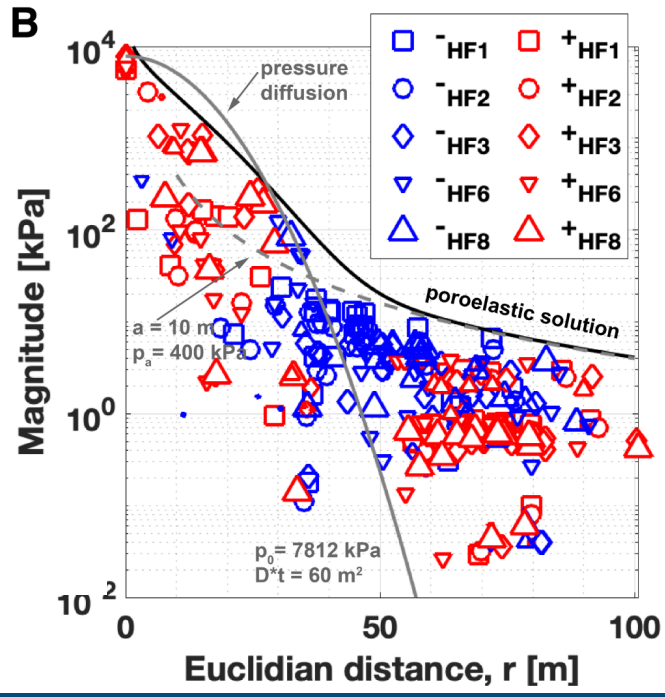


- Unity of time
- Unity of space
- Unity of action

4 FAR FIELD EFFECTS

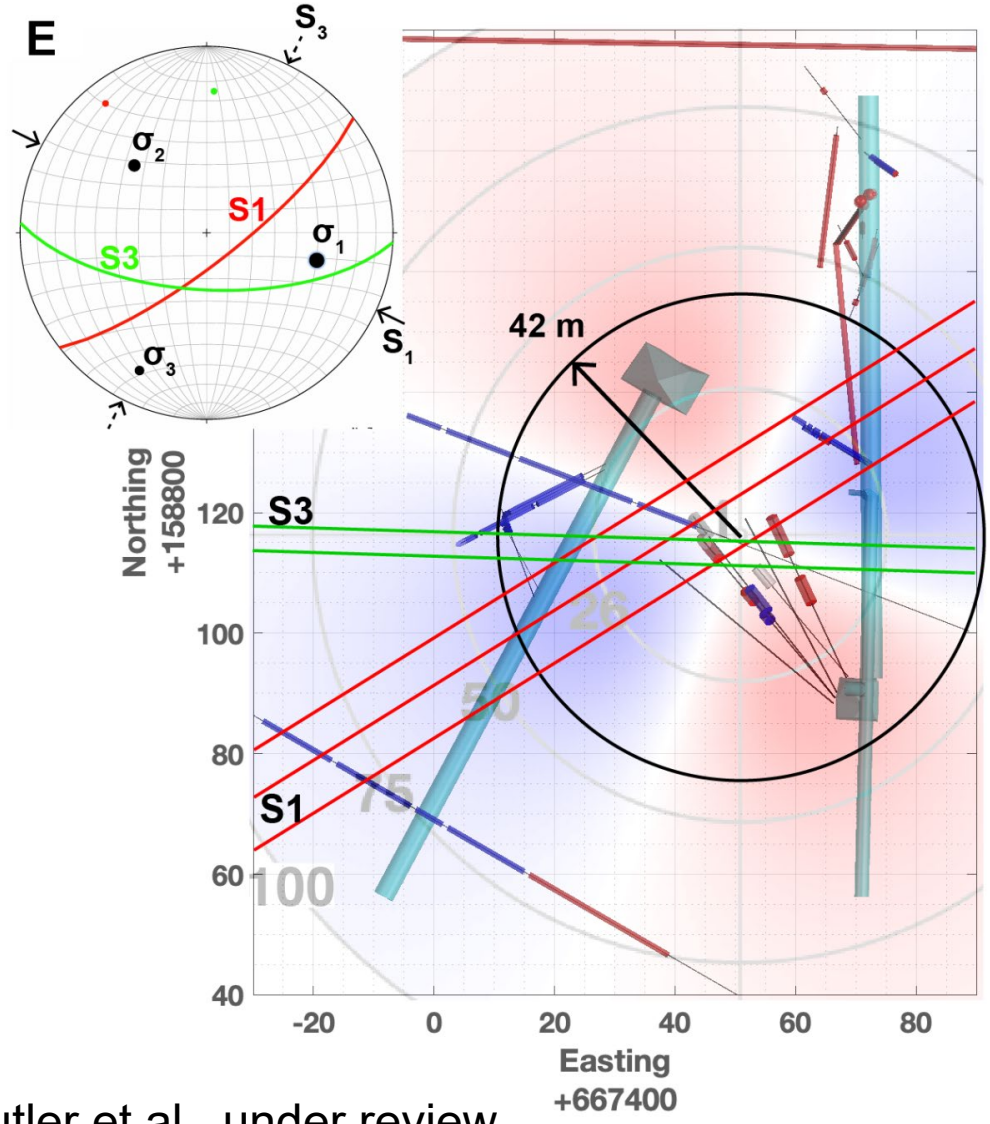


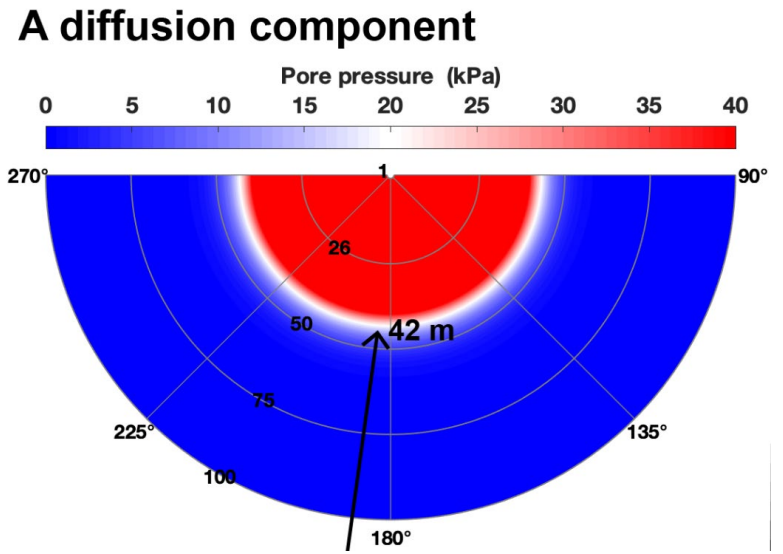


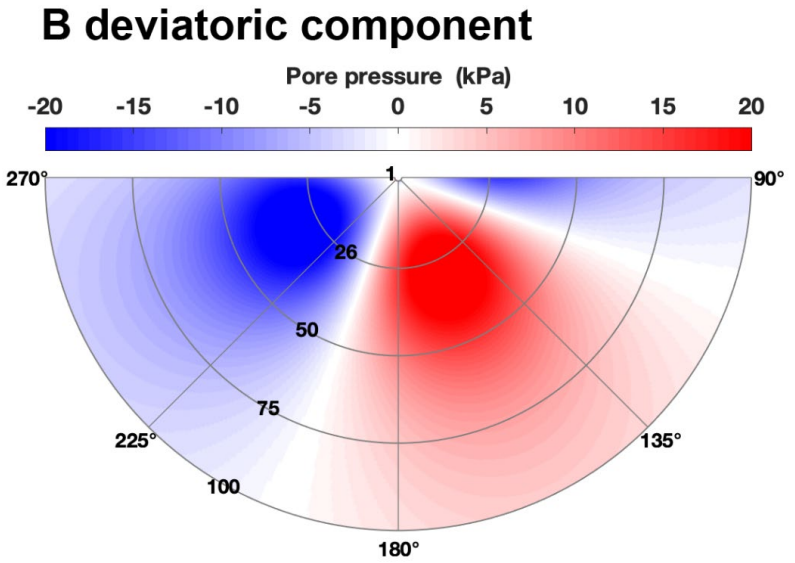


Dutler et al., under review

4 DOMINANT RESERVOIR DEFORMATION MECHANISMS REFLECTED IN THE FAR FIELD RESPONS







Dutler et al., under review

THANKS FOR YOUR ATTENTION

Team-work, the key for advancing geothermal in Switzerland

Let's keep working together !

Hydraulic testing at the Concise test site

DUG-Lab team at the Grimsel test site