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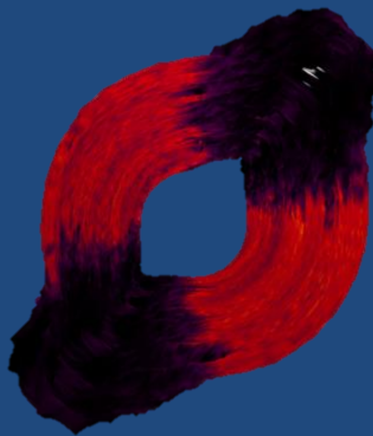
Workflow for managing deep deviated geothermal well stability



Asmae Dahrabou, Benoît Valley – CHYN, University of Neuchâtel
Florentin Ladner, Peter Meier, Frédéric Guinot - Geo-Energie Suisse, AG

UNIVERSITÉ DE NEUCHÂTEL

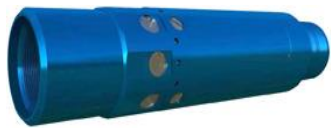
GEO ENERGIE SUISSE

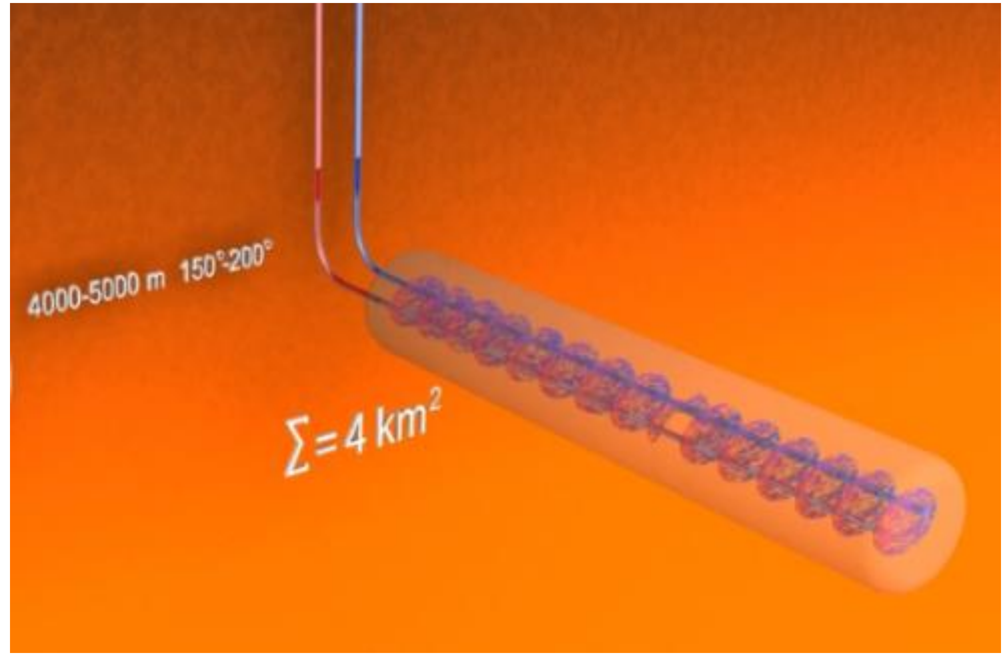
OUTLINE

- **Project context & objectives**
- **Workflow development approach**
- **Conclusions**
- **On-going work & Next steps**

Project context & objectives

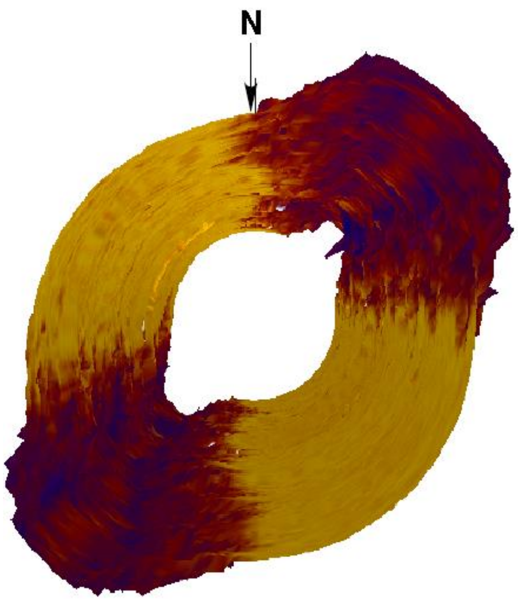
MULTI STAGE STIMULATION CONCEPT FOR EGS

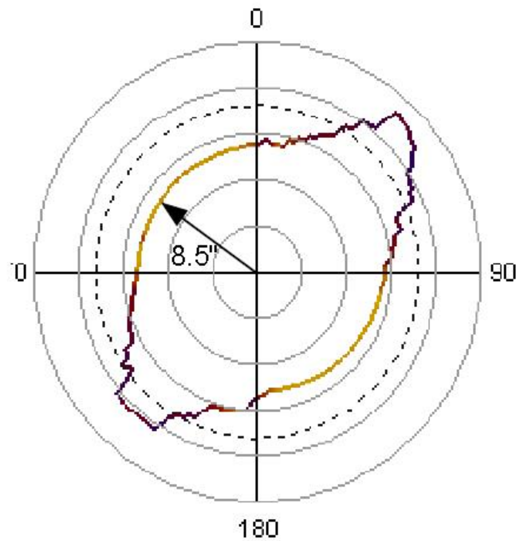


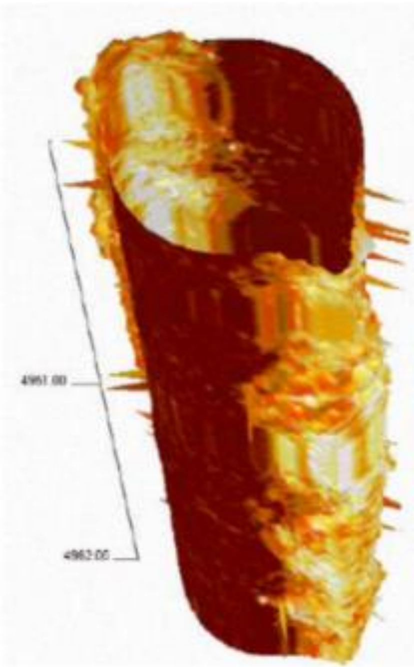


- Deviated well trajectory
- Zonal isolation using swellable packers for up to 30 smaller, sequential and focussed stimulations along the well

BREAKOUTS IN GEOTHERMAL WELL BASEL-1



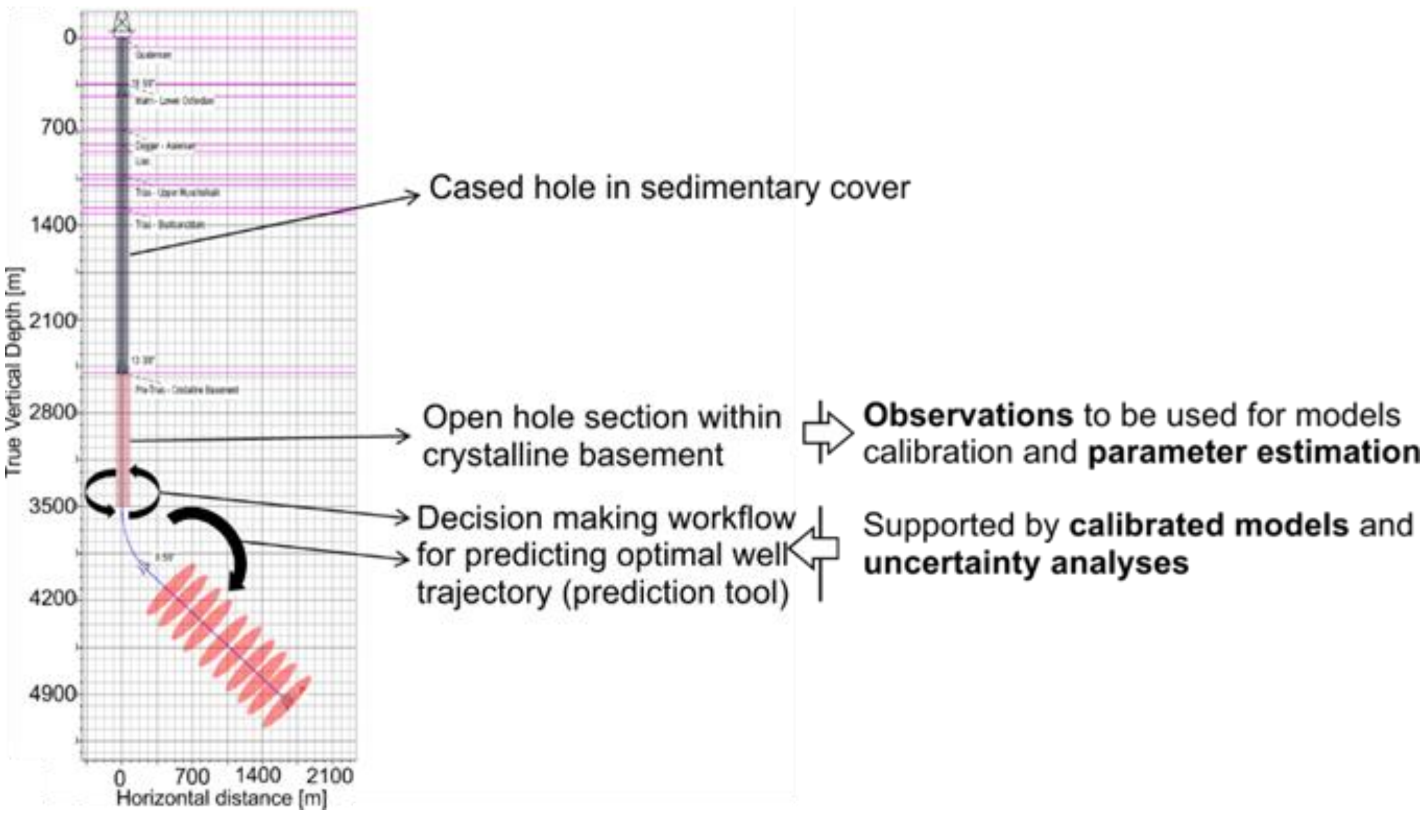




- Deep wells in crystalline basement are affected by drilling induced borehole failures (in-situ stress acting on the borehole)
- **highly irregular hole shapes complicating a proper installation of any completion system**
- **Low drilling performance**

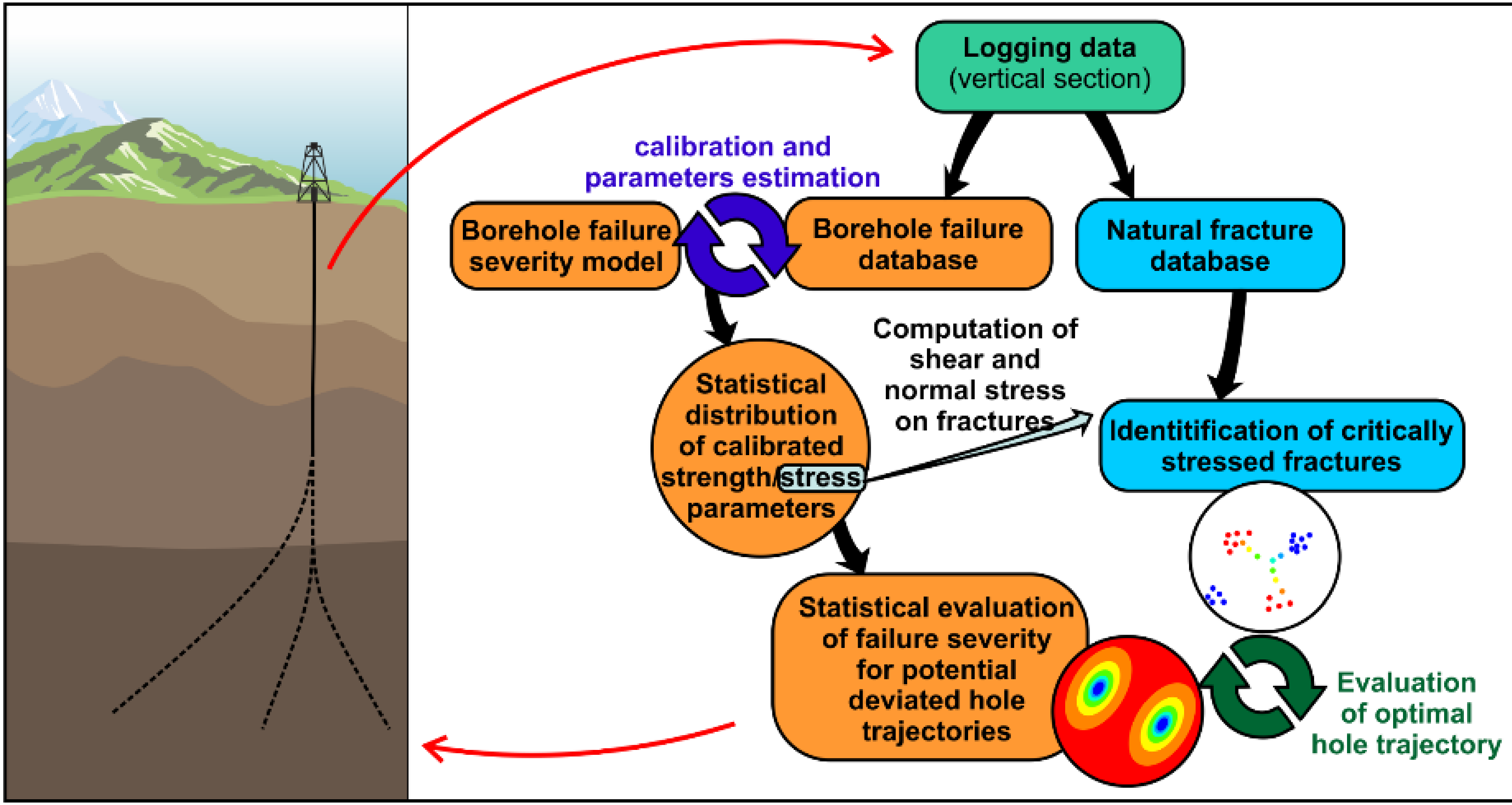
DEEP GEOTHERMAL WELL OPTIMIZATION (DG-WOW)

- Development of a workflow and a set of supporting software tools to define the optimal borehole direction for:
  - Maximize the probability of **intersection with potential feed zones**
  - **Maximize borehole stability** in order to apply the multi stage stimulation concept



WORKLFOW DEVELOPMENT APPROACH

INITIAL WORKFLOW DESIGN



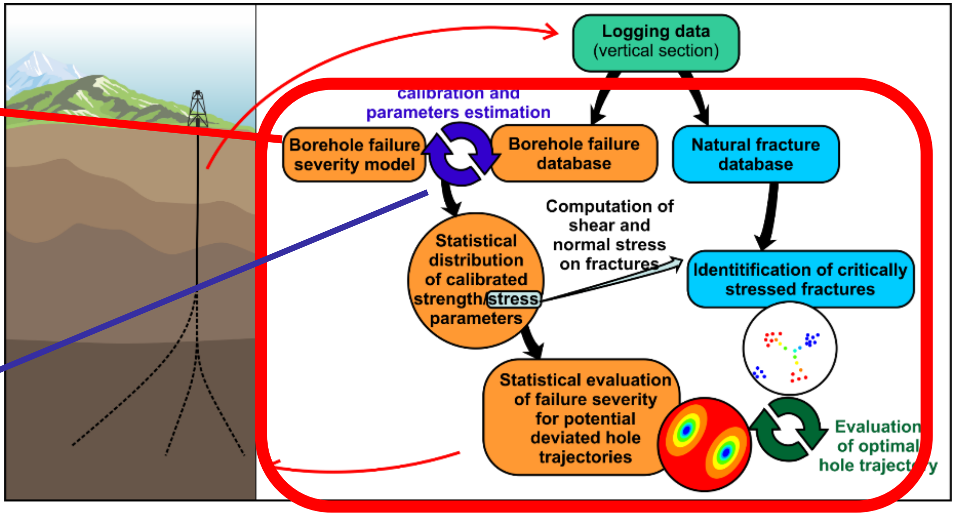
MAIN CHALLENGES

Challenges that have been conditioning the development of the workflow:

1) The workflow must be executed in a short period of time in order to minimize rig down-time costs

This part of the workflow must be executed in 1 day or less

2) The calibration step is central to the workflow and is basically not a well constrained problem (stress and strength are unknown)

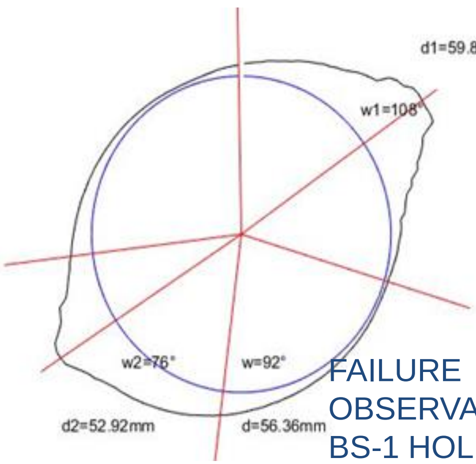


CONSEQUENCES:

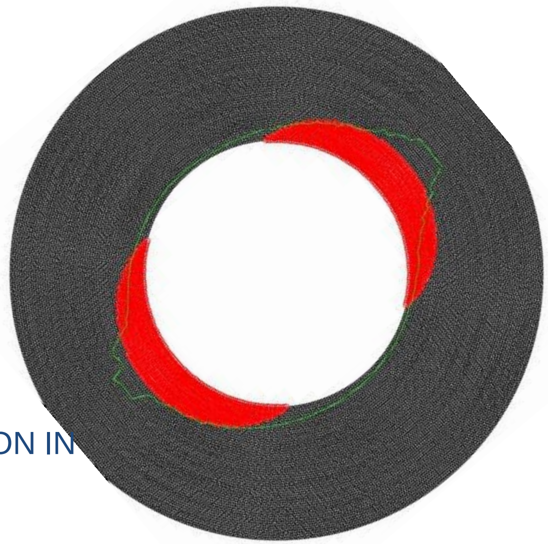
- ✓ A workflow based on simple analytical solution and simplified failure criterion was developed
- ✓ The sensitivity of the workflow to key parameters changes was tested
- ✓ The workflow was calibrated on existing data sets

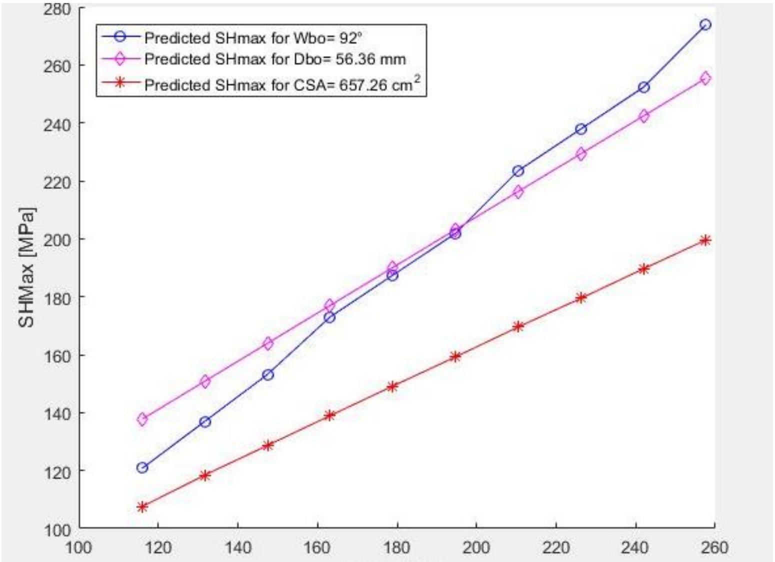
FAILURE CRITERIA SELECTION

Standard Mohr-Coulomb criteria is not appropriate to model breakout formation in crystalline rocks:



FAILURE OBSERVATION IN BS-1 HOLE





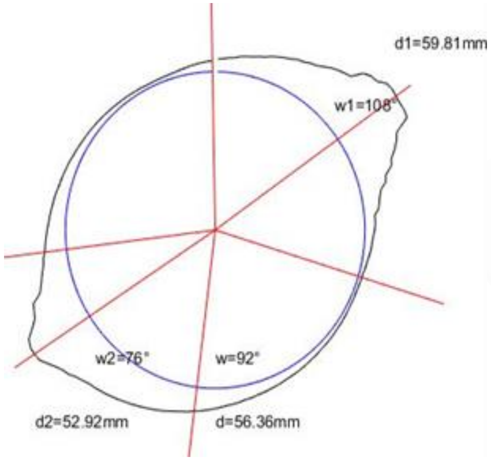
UCS [MPa]

- Not possible to capture all failure observation simultaneously
- Tends to overestimate Cross Sectional Area (CSA) which is an important parameter for the sealing of swellable packers

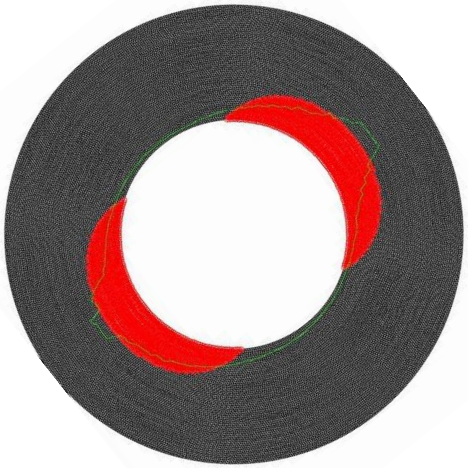
FAILURE CRITERION SELECTION

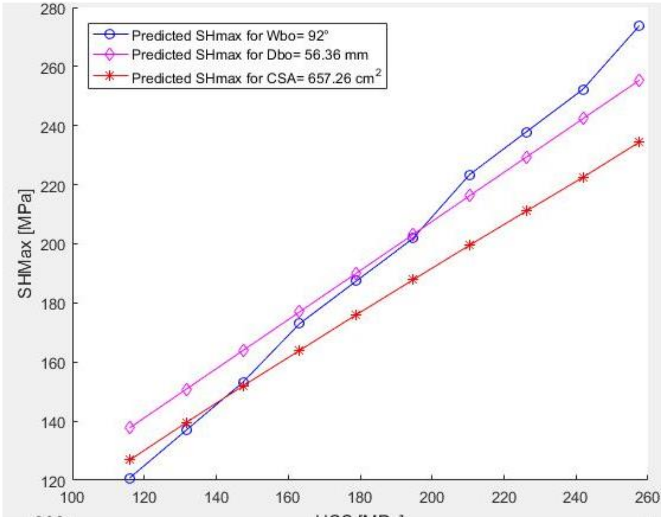
In order to meet the workflow requirements, we decided to **use a purely cohesive criteria:**

- **Reduce the number of parameters** which simplify the calibration approach
- Generates **more consistent calibration** across observed failure
- **Consistent with literature** (breakout formation is a cohesion weakening/ friction strengthening process in crystalline rocks)



FAILURE OBSERVATION IN BS-1 HOLE

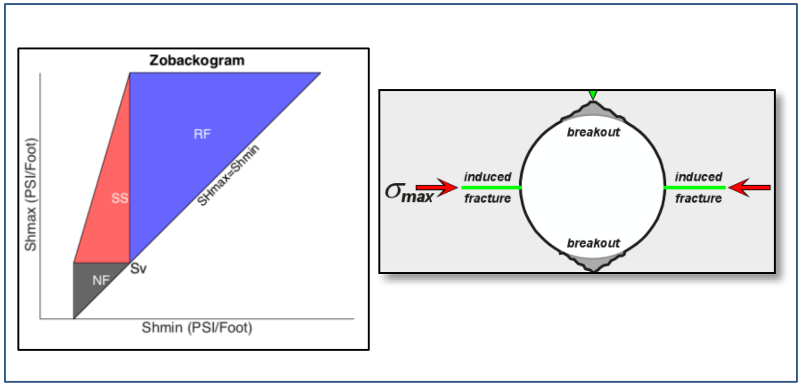




UCS [MPa]

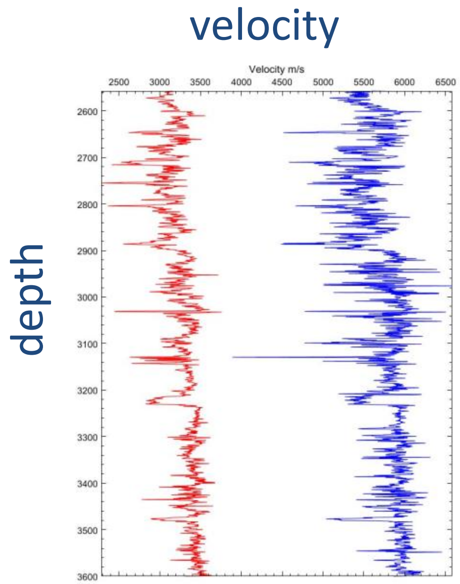
STRENGTH / STRESS CALIBRATION PROCESS

For the strength / stress calibration process we used a pragmatic approach that includes information from independent data set:



A. Limit the stress state to reasonable range based on strength limit of the earth crust and observation of tensile failure in the well

B. We use information from sonic log in order to get an independent proxy for strength

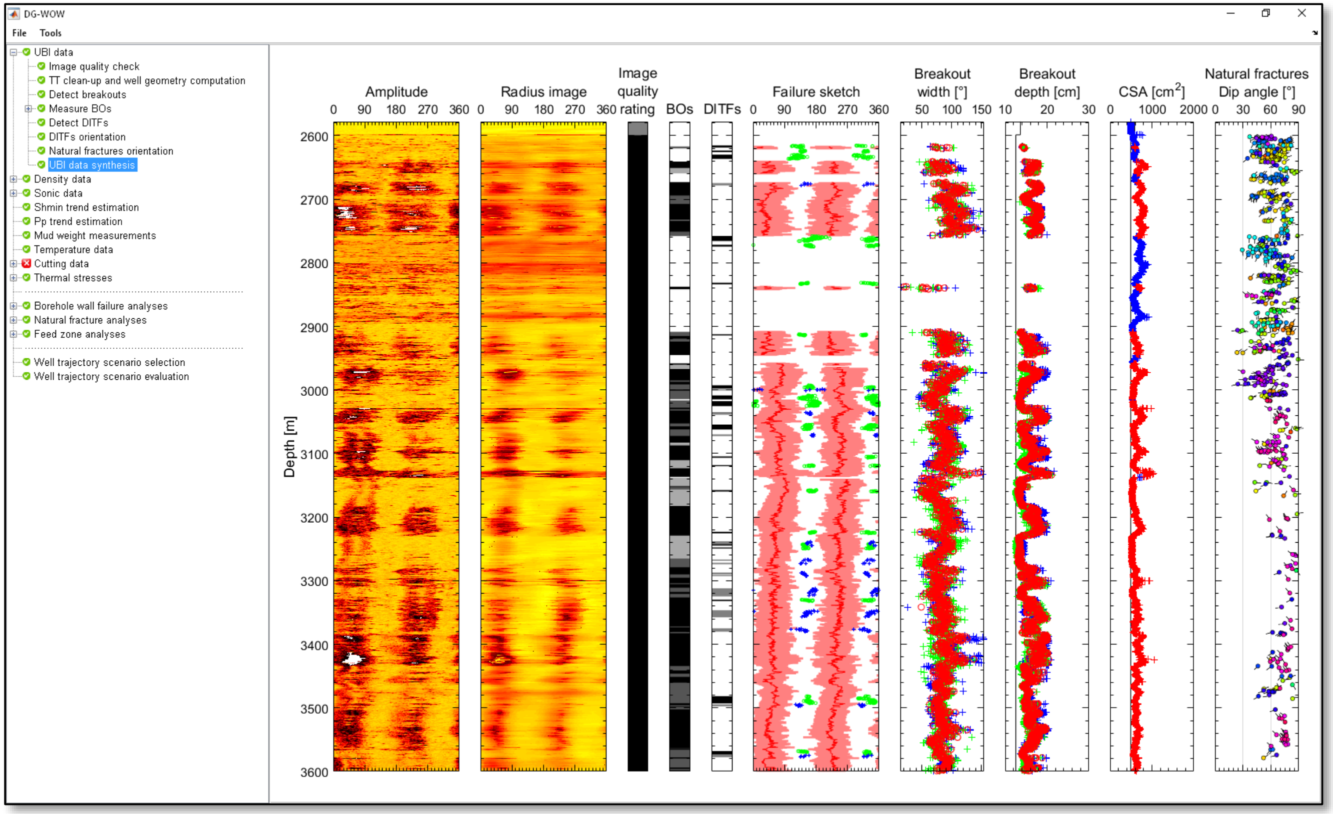


C. We calibrate our model in two steps (1) we derive a realistic estimate of strength and (2) we evaluate the in-situ stress state

WORKFLOW IMPLEMENTATION

WORKFLOW IMPLEMENTATION

- The technical solution developed has been implemented in a complete software solution that streamlines the execution of the workflow.



Screenshot of the software solution

THE COMPLETE WORKFLOW

- UBI data
- Density data
- Sonic data
- Shmin trend estimation
- Pp trend estimation
- Mud weight measurements
- Temperature data
- Cutting data
- Thermal stresses

Data assimilation

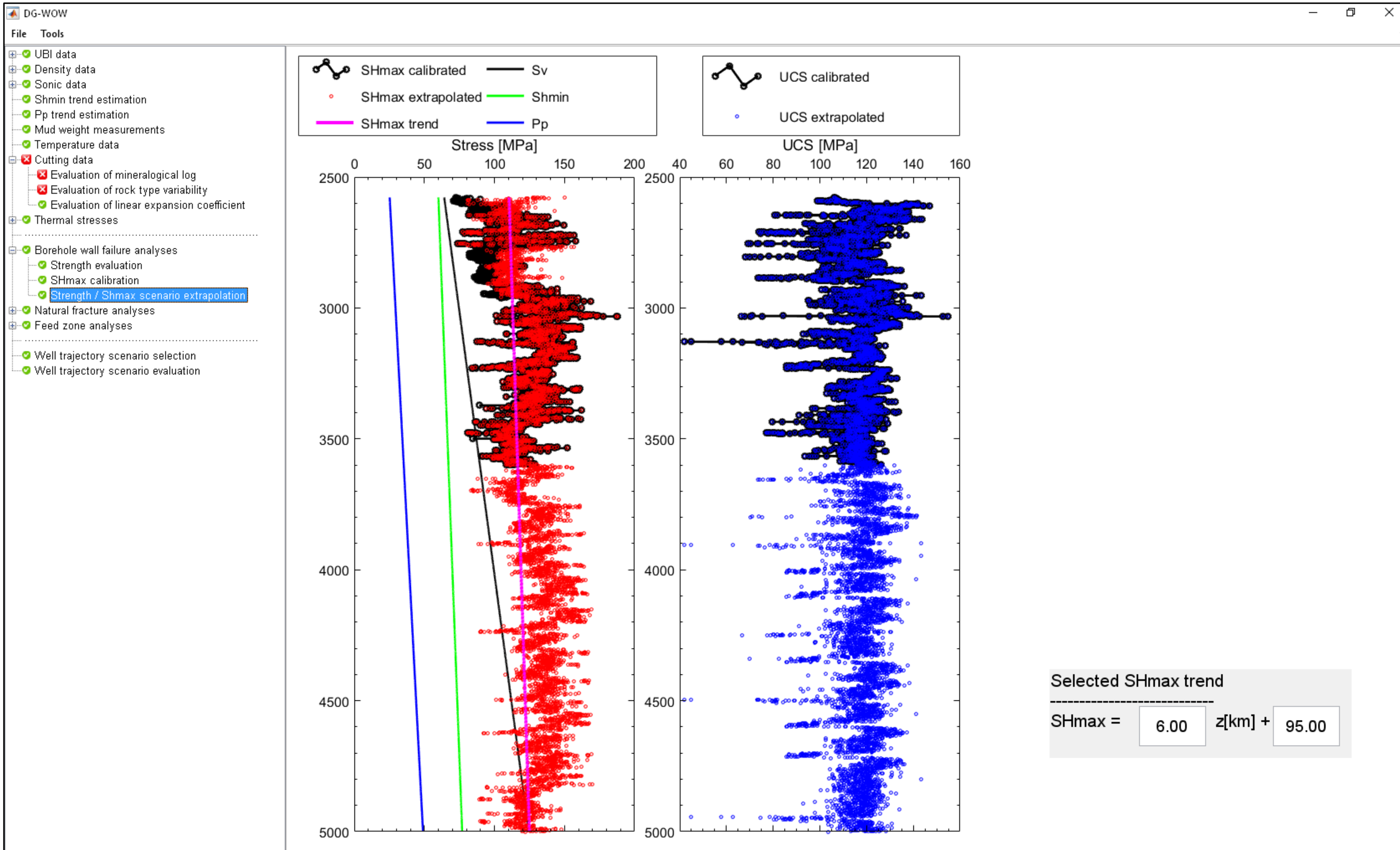
- Borehole wall failure analyses
- Natural fracture analyses
- Feed zone analyses

Data analysis and model calibration

- Well trajectory scenario selection
- Well trajectory scenario evaluation

Well trajectories evaluation and failure prediction

STRENGTH CALIBRATION



SUMMARY OF KEY MESSAGES FOR CALIBRATION PROCEDURE

1) **Focus on what matters most**
    - UCS and S_{Hmax} (maximum horizontal principal stress) are the parameters the most influential on failure computation.

2) **Use simple but consistent failure modeling approach**
    - In combination with an elastic solution for the computation of the stress concentration around the borehole, a purely cohesive criteria provides the most consistent prediction across failure indicators.

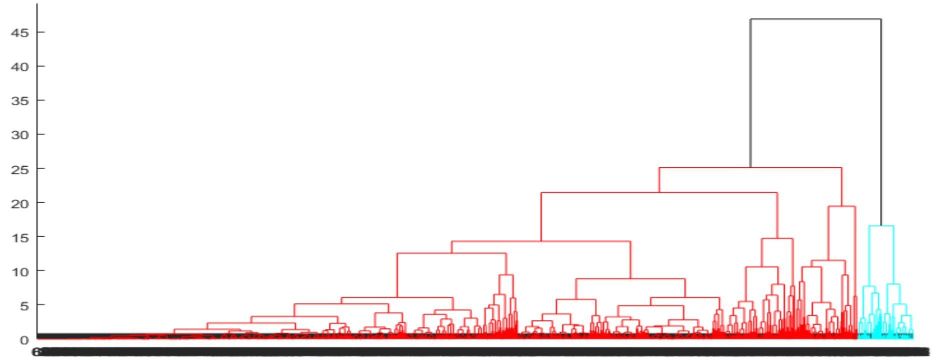
3) **Use independent data (sonic and density) as a proxy for strength in a two step calibration process**
    - In a first step, realistic parameters ranges are computed based on admissible stress limits.
    - In a second step, the strength is approximated using strength proxy and the strength/stress couple is calibrated.

PERSECTIVES AND NEXT STEPS

ONGOING WORK & NEXT STEPS

- Further develop the calibration approach adding some additional important parameters like well stability control with drilling mud

- Bring in some more systematic approach in selecting scenario based on identification of key drilling scenario using cluster analysis



- Further test and develop the simple failure model used so far against more advanced modeling approach

- Further test and troubleshot the workflow on existing deep geothermal drilling dataset (Soultz,…)

- Apply the workflow to new deep geothermal drilling site (Haute-Sorne or other opportunities)

THANK YOU FOR YOUR ATTENTION

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