How can the borehole three-dimensional displacement data help improving in situ stress estimation across a fault reactivated by fluid injections?

Maria Kakurina
Yves Guglielmi
Christophe Nussbaum
Benoît Valley

SCCER-SoE Annual conference

14 September, 2018

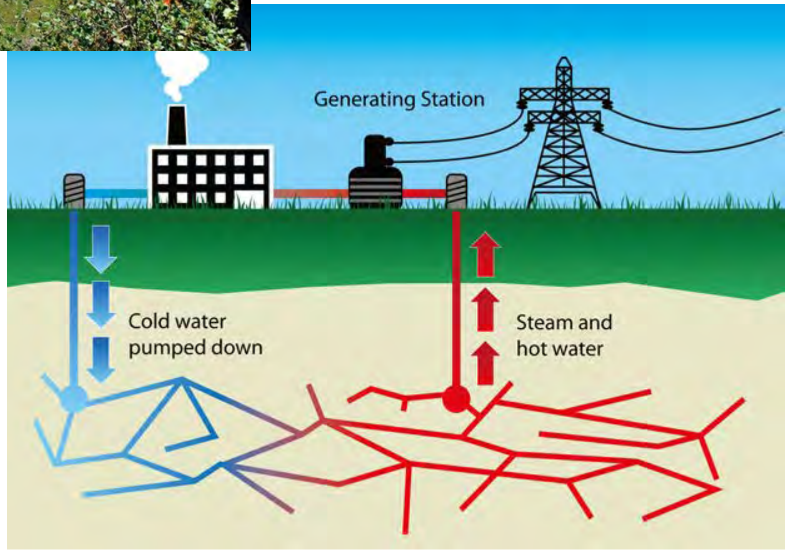
Why do we estimate in-situ stress?

Stress state drives FAILURE OF ROCK at many scales (from the largest earthquakes to the smallest micro-seismic events)

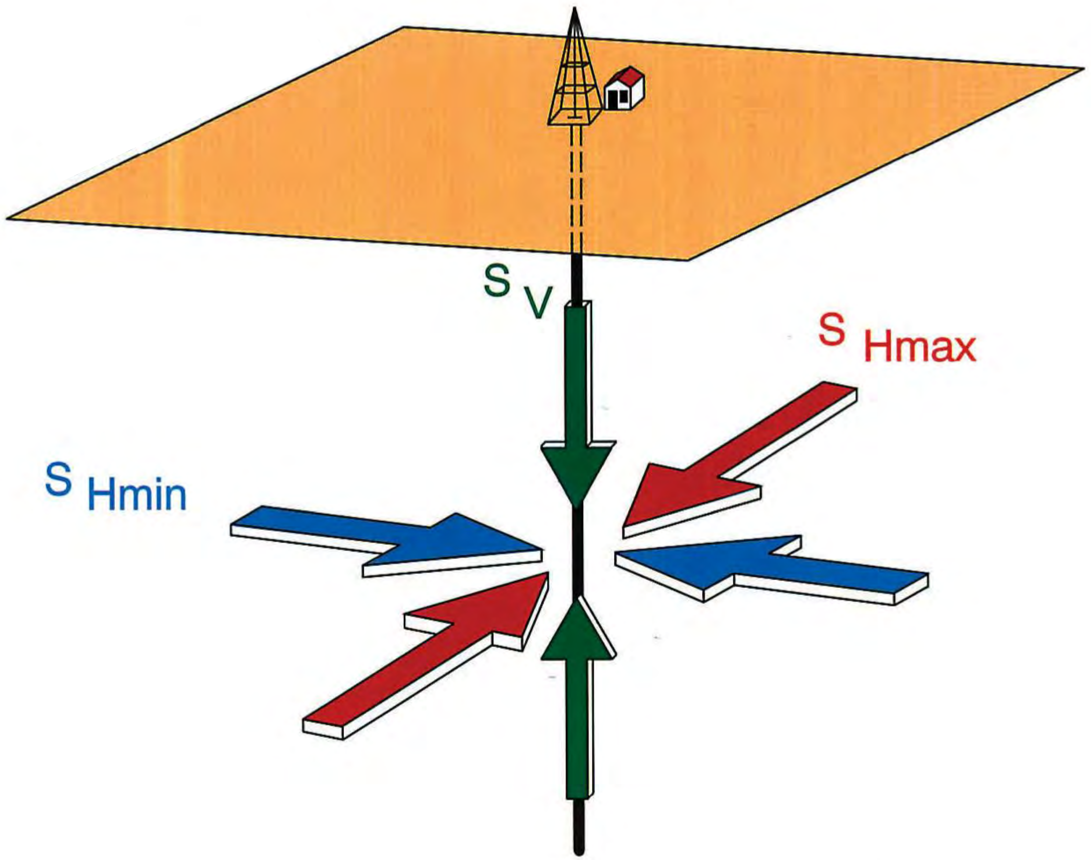
- STABILITY and SAFETY of underground facilities and boreholes

- Improve of engineering hydraulic stimulations for WATER or hydrocarbon RECOVERY

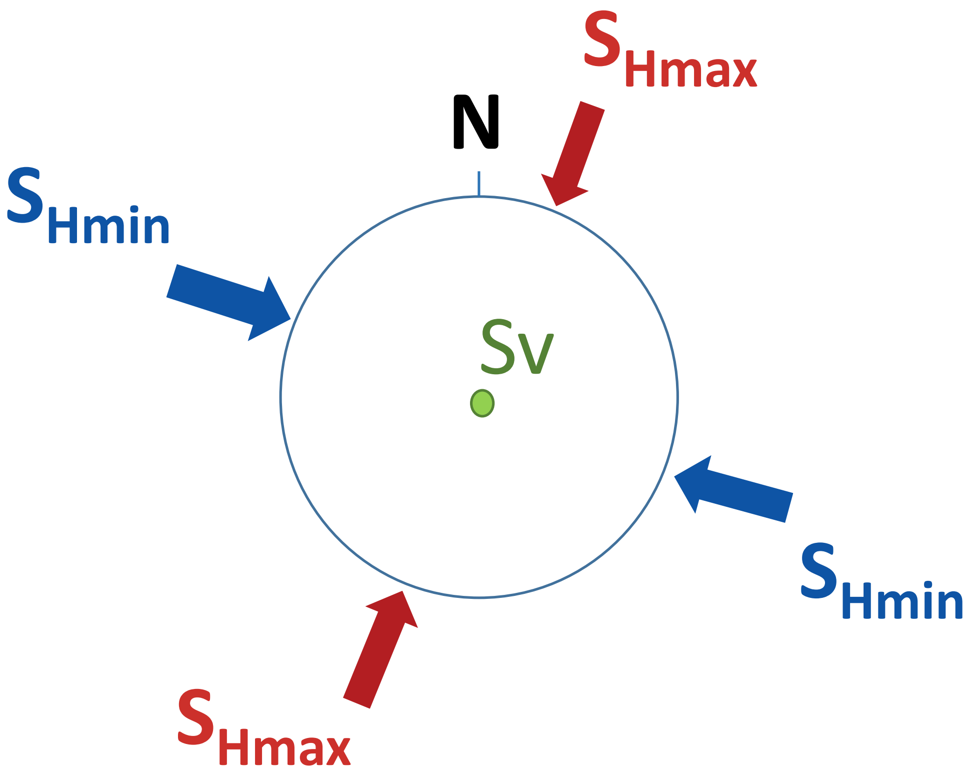
While limiting earthquake hazards



How do we represent in-situ stress?



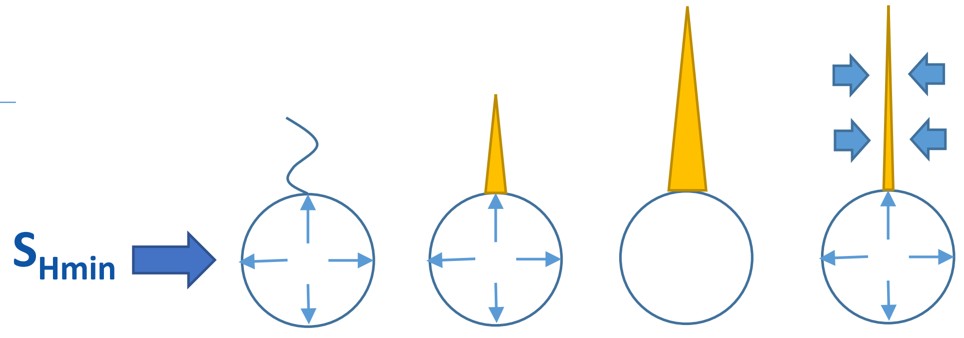
Horizontal View



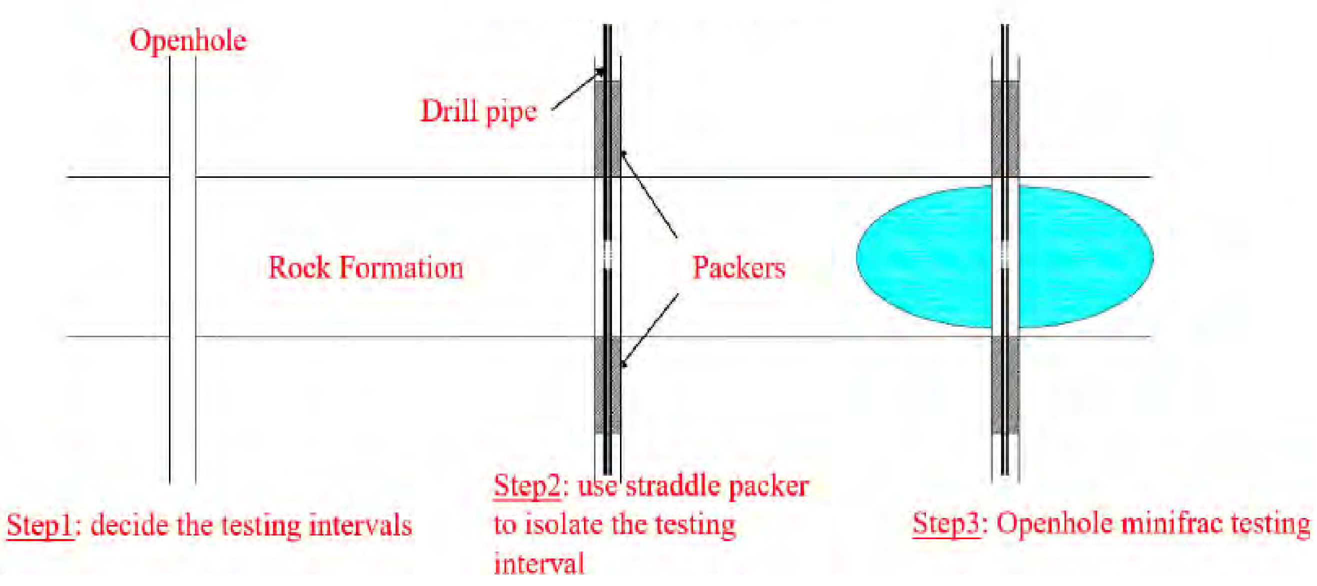
S_v (MPa)	S_{Hmax} (MPa)	S_{Hmin} (MPa)	S_{Hmax} (°)
6±0.4	5±0.5	3±1.0	N20±20

Current measuring methods

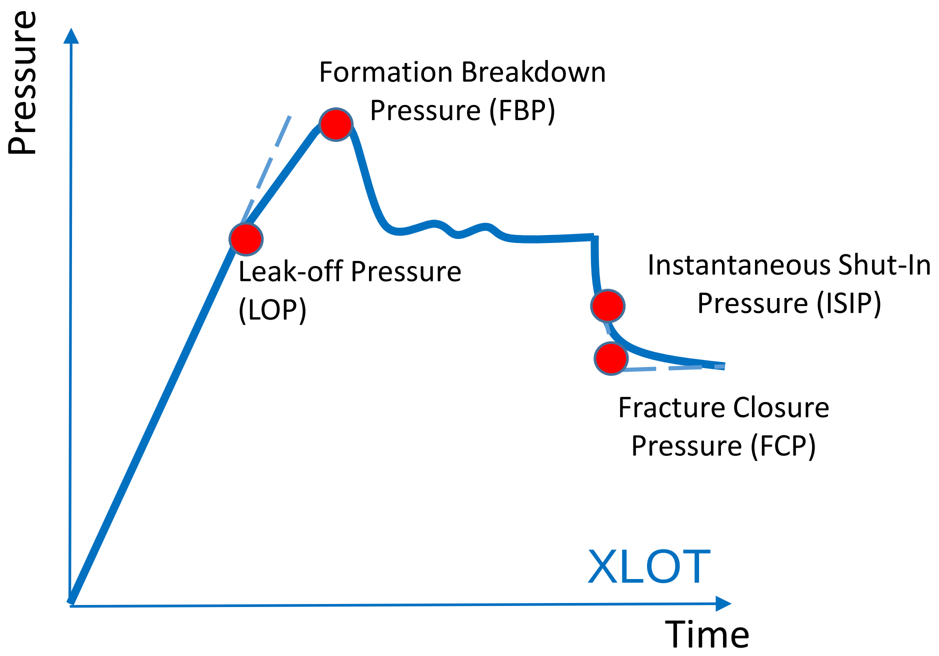
Traditional hydraulic fracturing tests
(HF, HTPF, LOT, XLOT)



Testing procedures



A schematic test curve



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

Current Measuring methods

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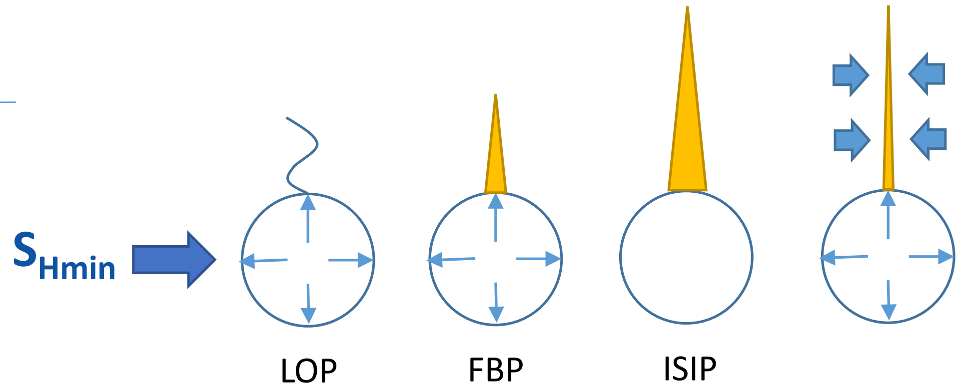

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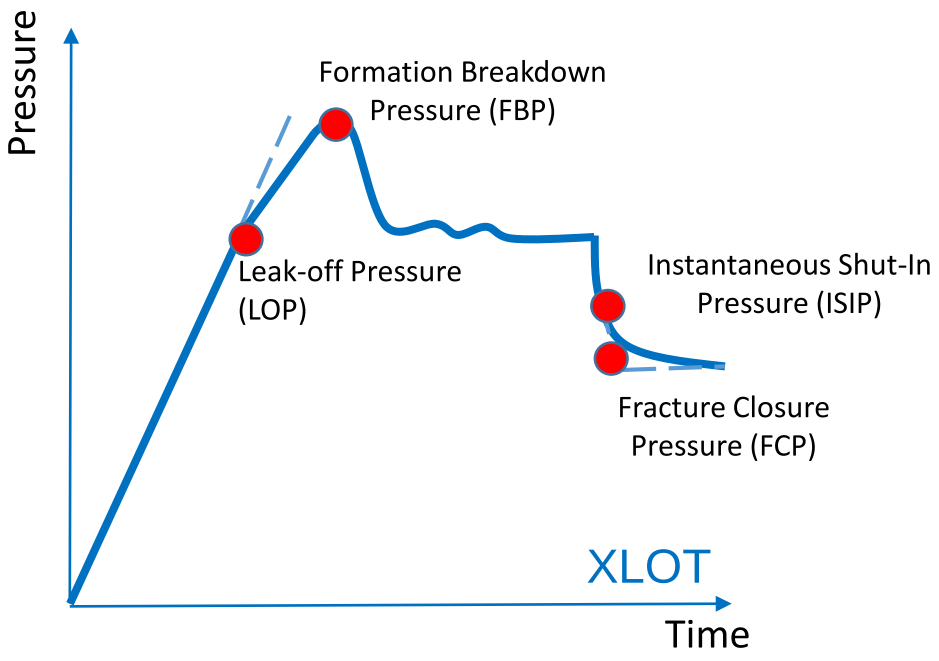


<u>Pressure + Flowrate</u>

Stress magnitude:

S_{Hmin} = the closure stress (when fracture closes itself)

S_v = overburden weight

S_{Hmax} = analytically

Stress orientation:

Borehole image analysis

A new method of measuring in-situ stress

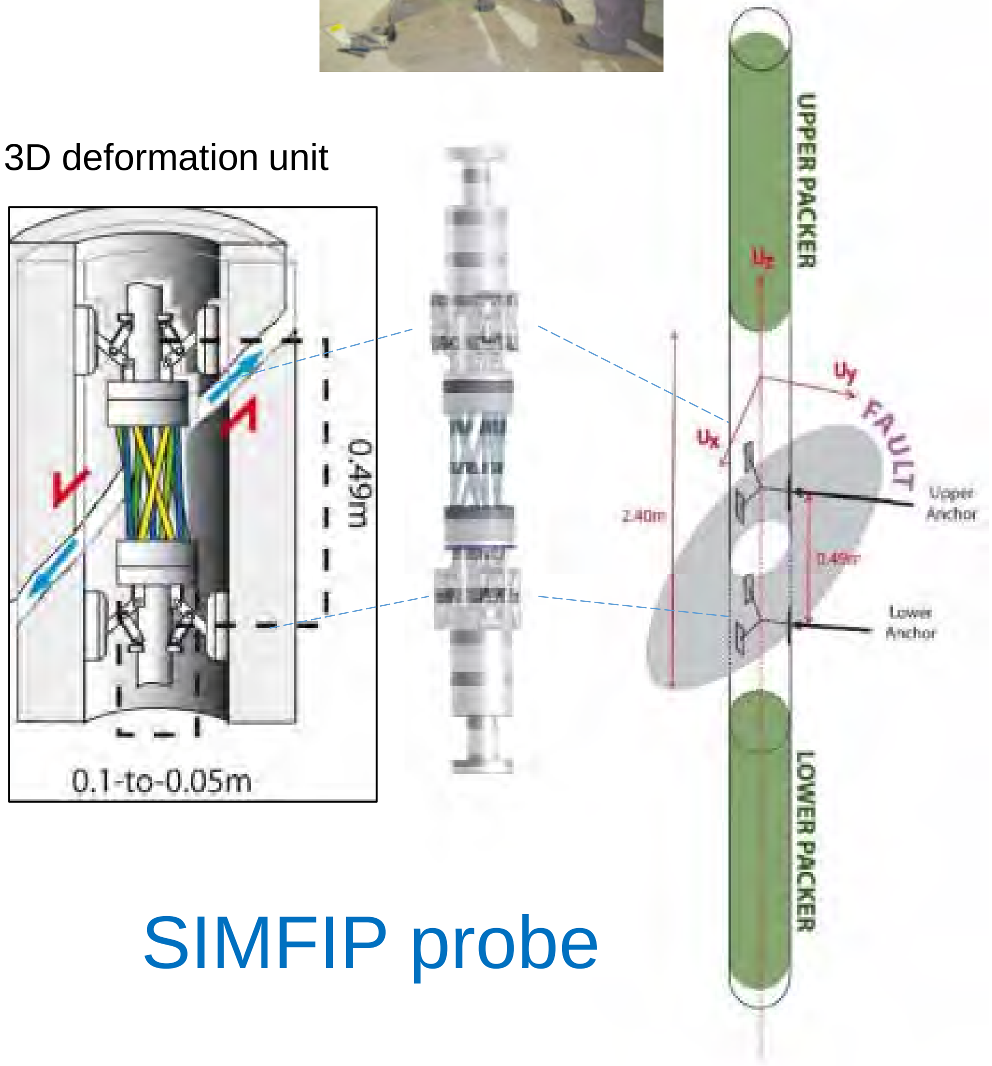
Step-Rate Injection method for Fracture In-Situ properties (SIMFIP)

Pressure + Flowrate

+ 3D diplacement data

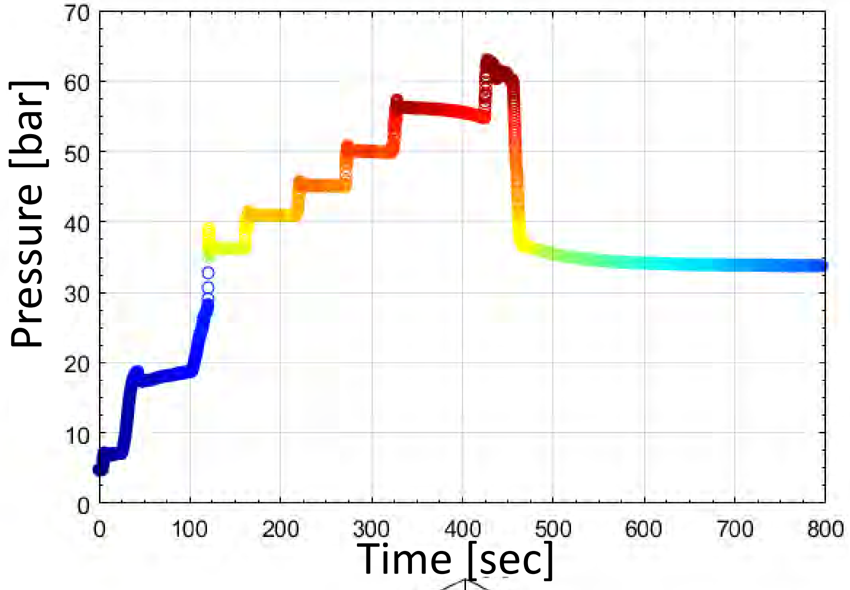
- One SIMFIP probe (for stress magnitude and orientation)
- Synchronous monitoring of pressure, flowrate, 3D-displacement and micro-seismicity
- Better identification of point locations on the test curve

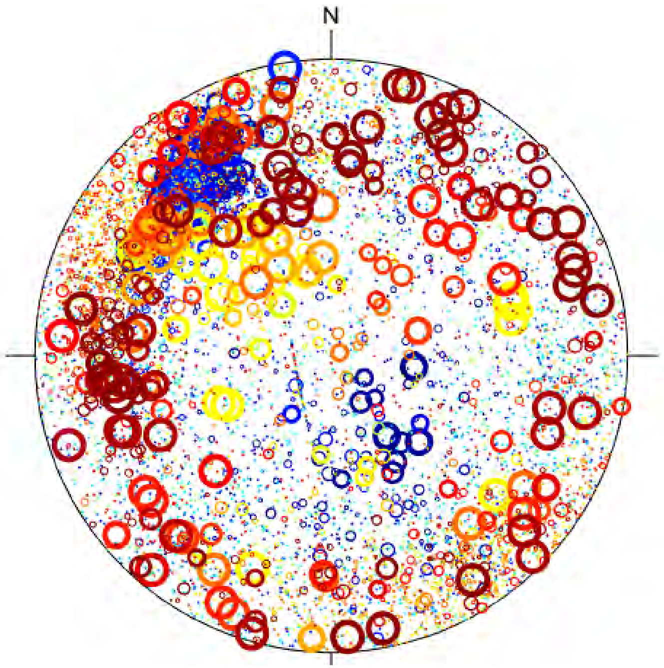
3D deformation unit



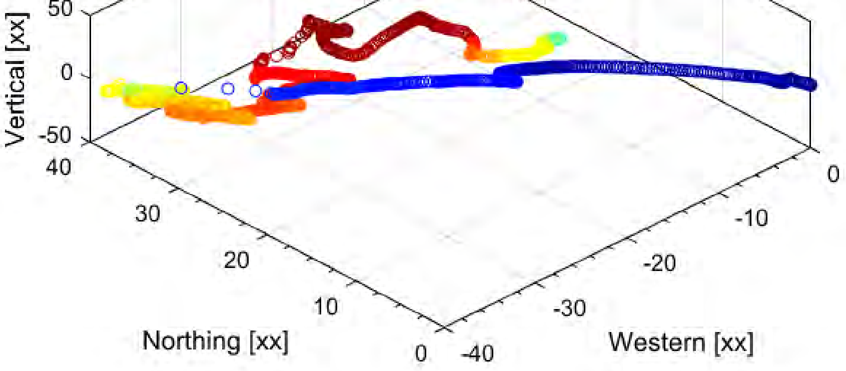
SIMFIP probe

Experimental data and objectives



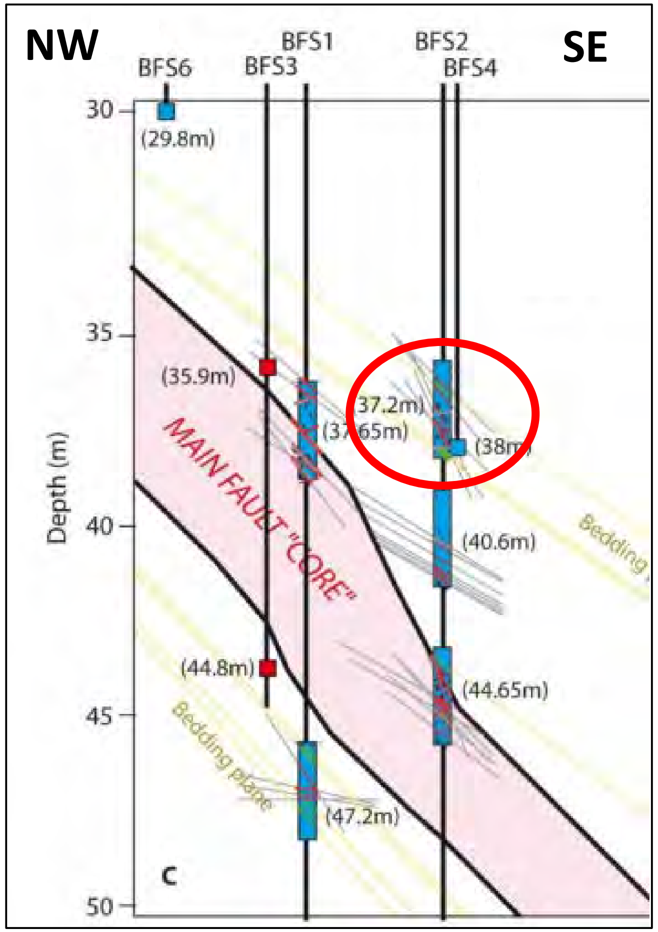


Complex 3d displacement

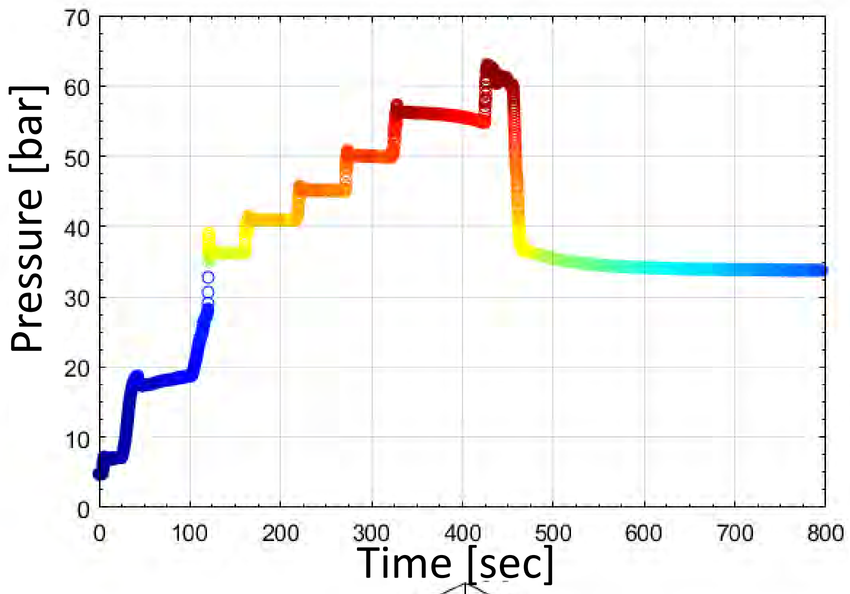


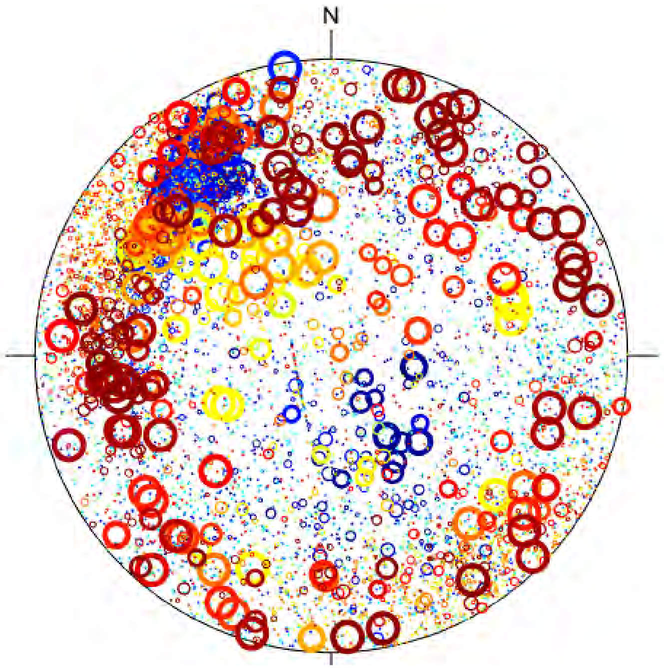
Challenge is to isolate the response of each element of the complex system:

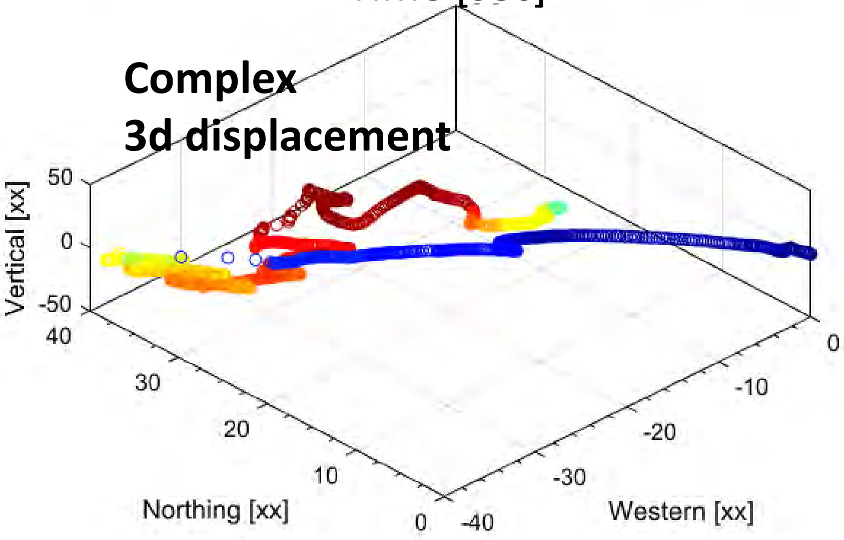
1) Probe + borehole
2) Stress concentration + background stress
3) Fracture geology



Experimental data and objectives







Challenge is to isolate the response of each element of the complex system:

1) Probe + borehole
2) **Stress concentration + background stress**
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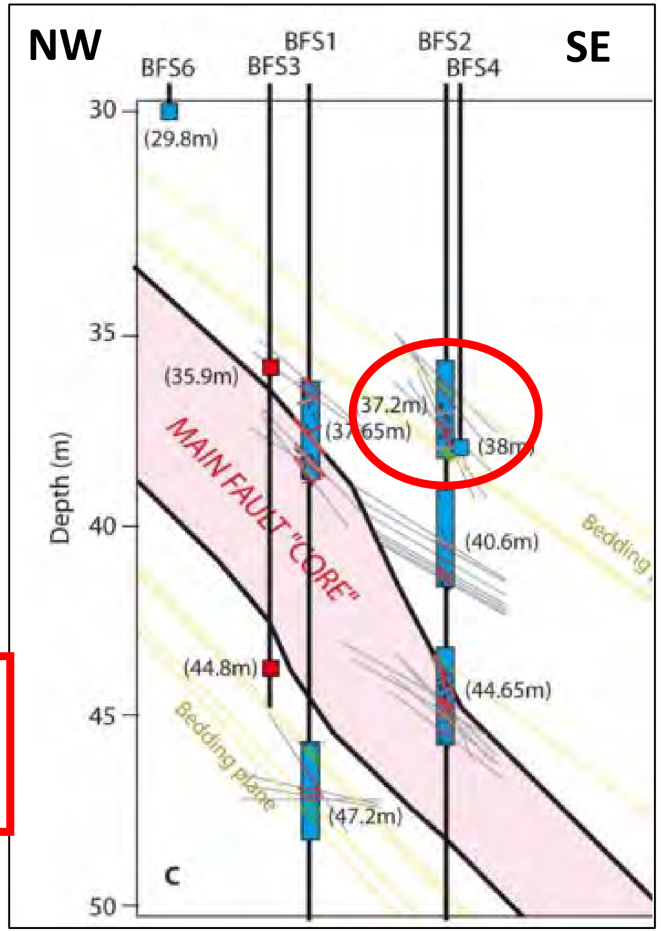
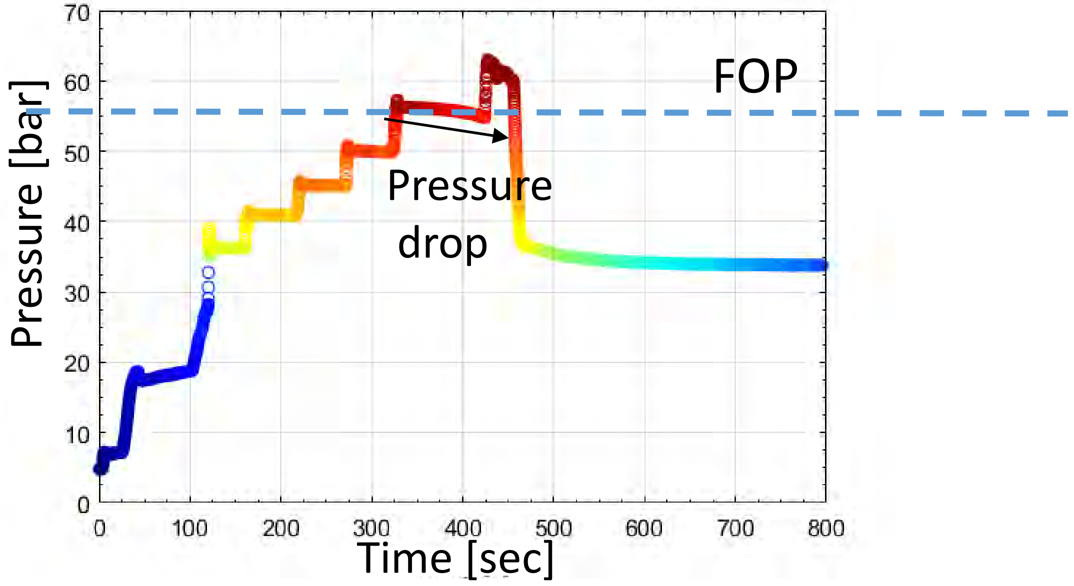
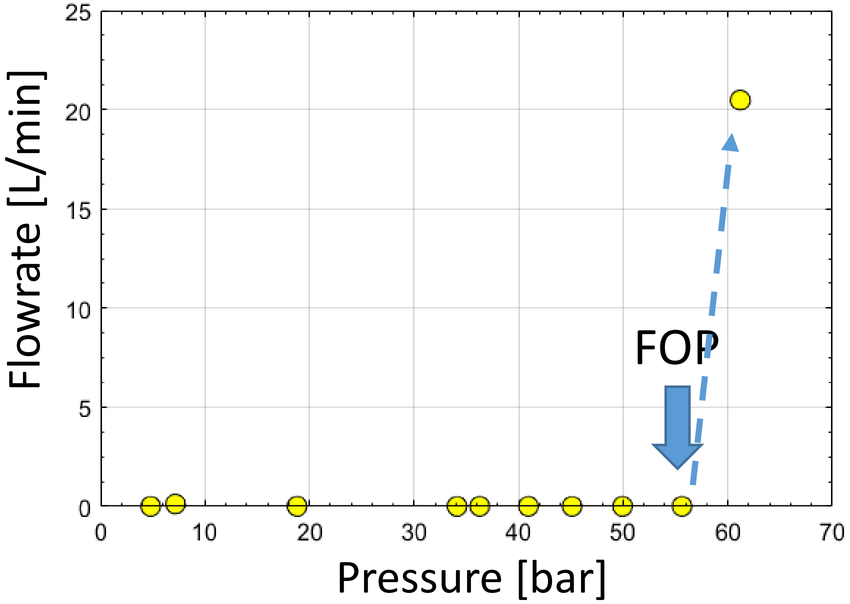
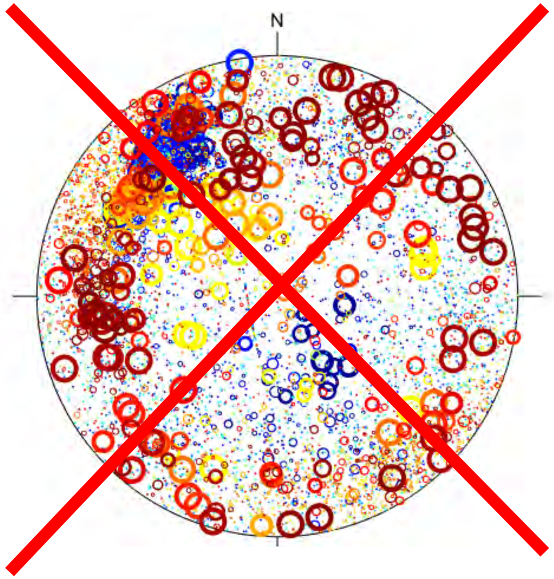


Fracture Opening Pressure at 55 bars





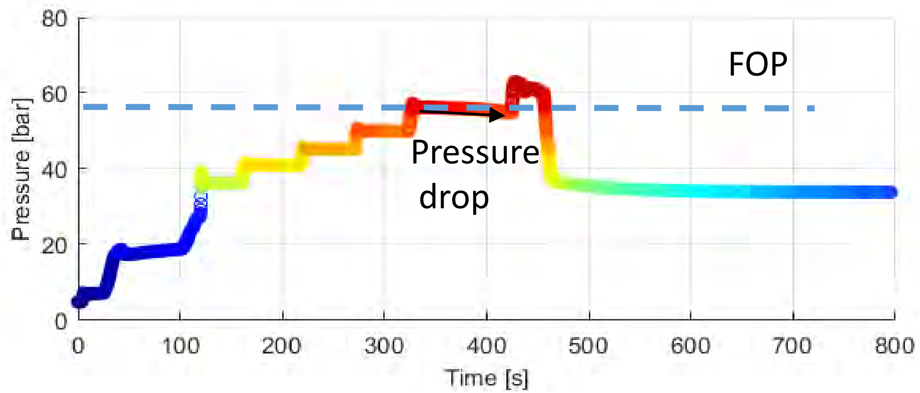


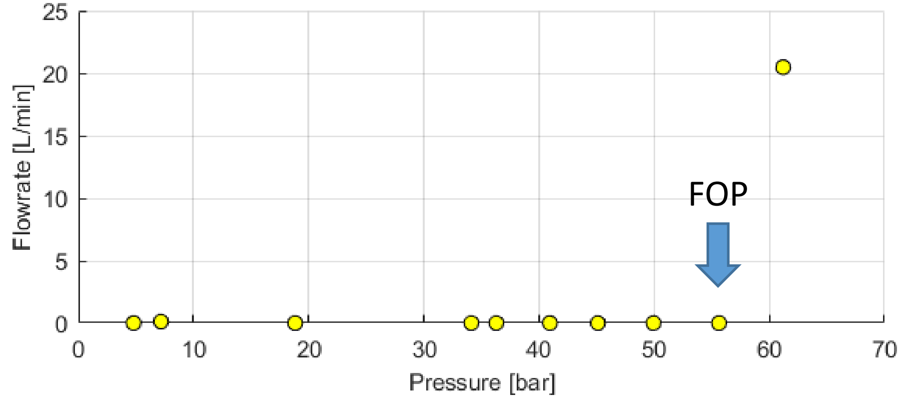
FOP - Fault Opening Pressure (55 bars)

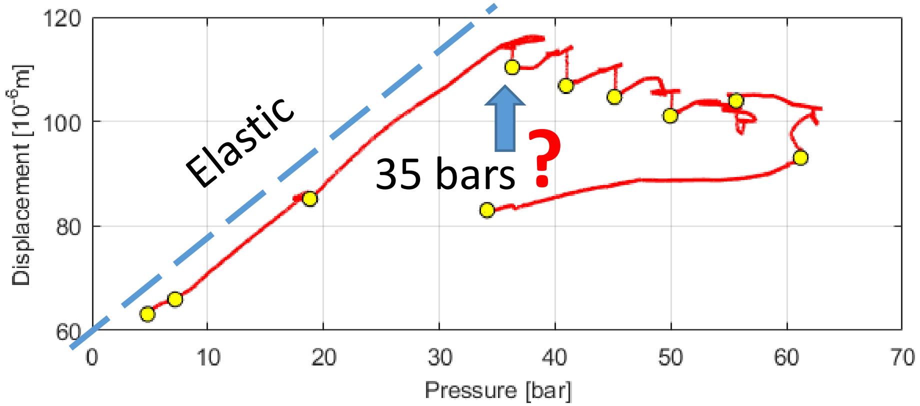
S_{Hmin} ?

In classic methods

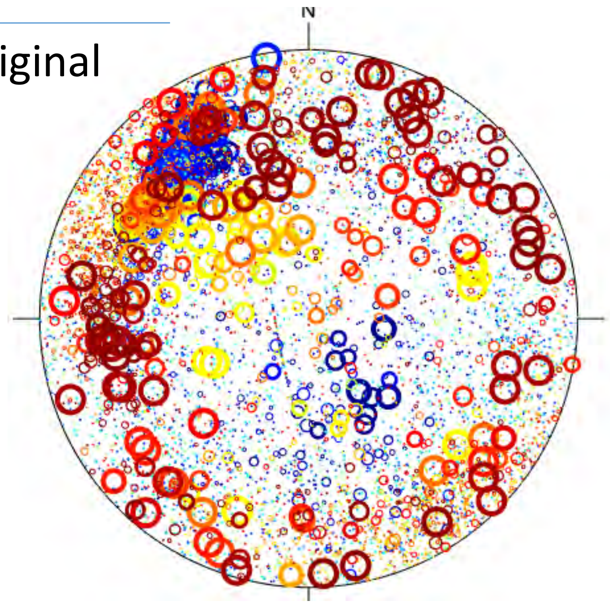
Results



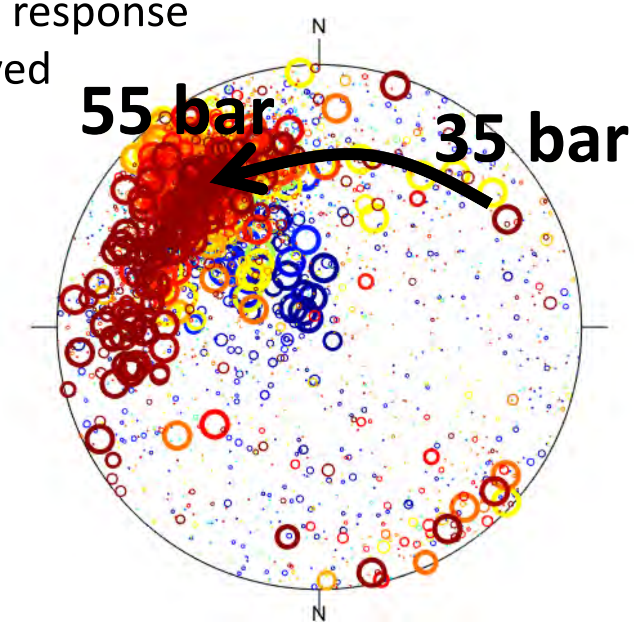




Original



Elastic response removed



1) Signal is more focused after removing the elastic response

2) Two critical values of pressure 35 and 55 bars

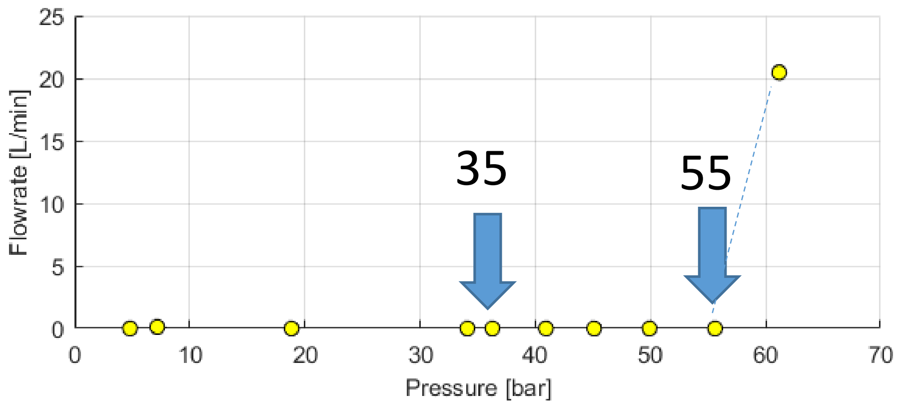
3) Between these two values the displacements directions migrate from N50 to N330

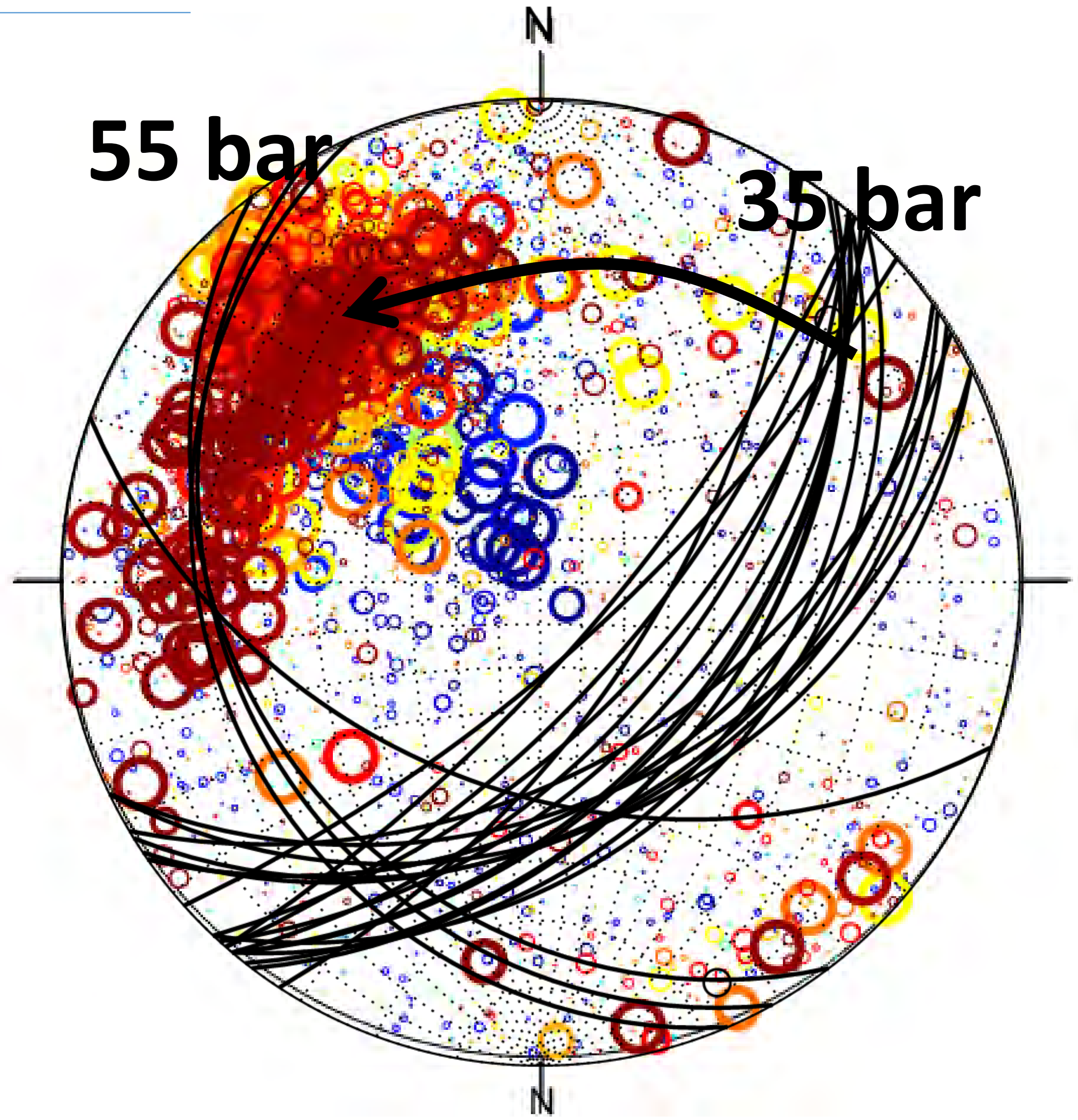
Results

Let's compare with the geology of the injected interval:

1) At 35 bar we activate the fault plane and it slips but flowrate does not increase

2) At 55 bar we activate the same fault plane in mode I that causes large increase in the flowrate





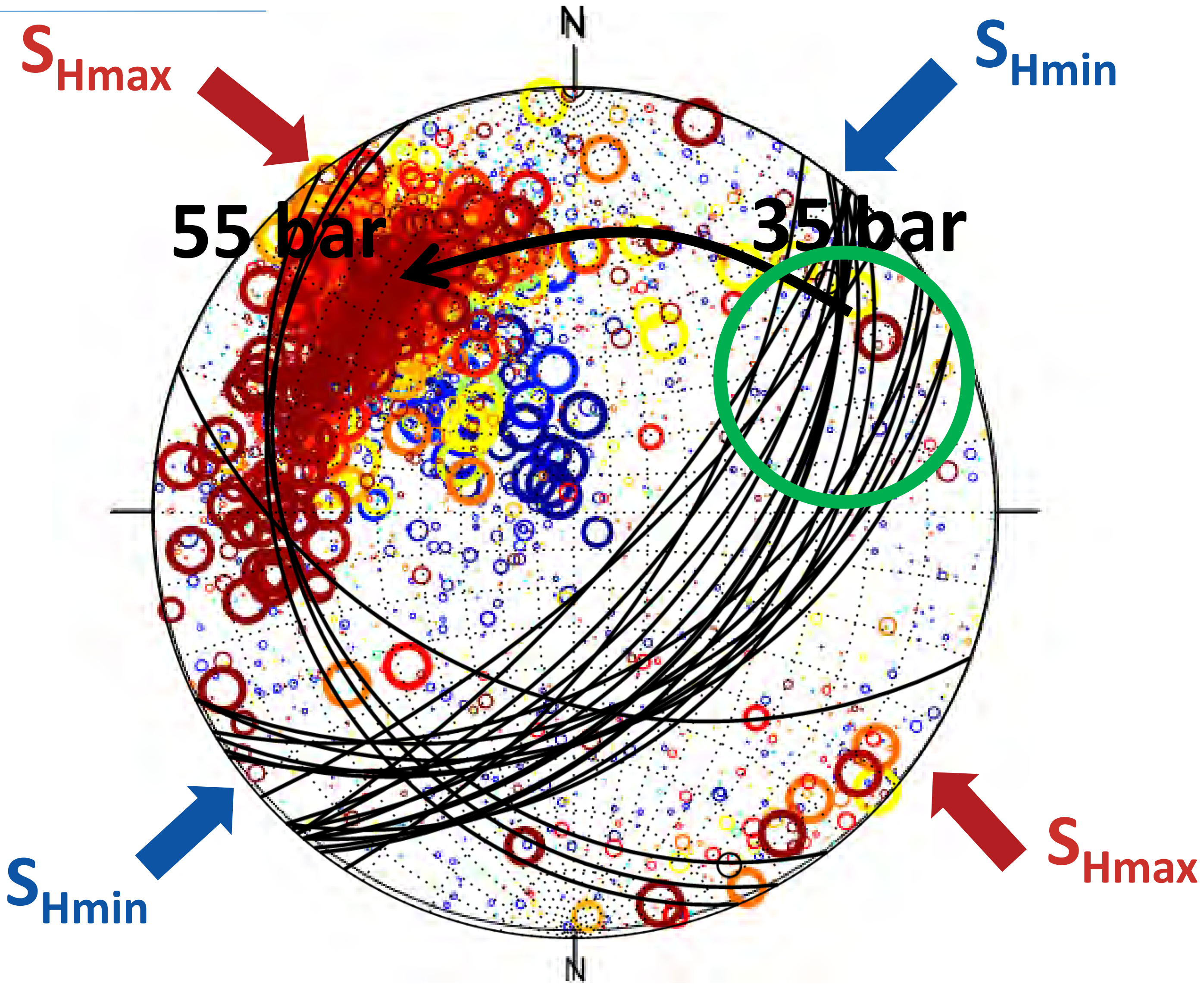
Results

Let's compare with the known stress tensor:

1) Shear slip is consistent with the known stress state (green circle)

3) At 55 bars – pressure exceeds fracture normal stress (Sn) and the fracture opens in mode I

S_v (bar)	S_{Hmax} (bar)	S_{Hmin} (bar)	S_{Hmax} (º)
54±4	52±8	43±5	N320±20



Guglielmi & Nussbaum (submitted abstract, 2018)

Conclusions

- 3D displacement data is very complex but show 2 activation pressures

- Displacement gives a physical meaning to these activation pressures and thus should allow for a refined estimation of the stress tensor

- FOP might not always be related to the minimum principal stress

- FOP appears to be more related to the failure mode.

Thank you for attention.

Questions?