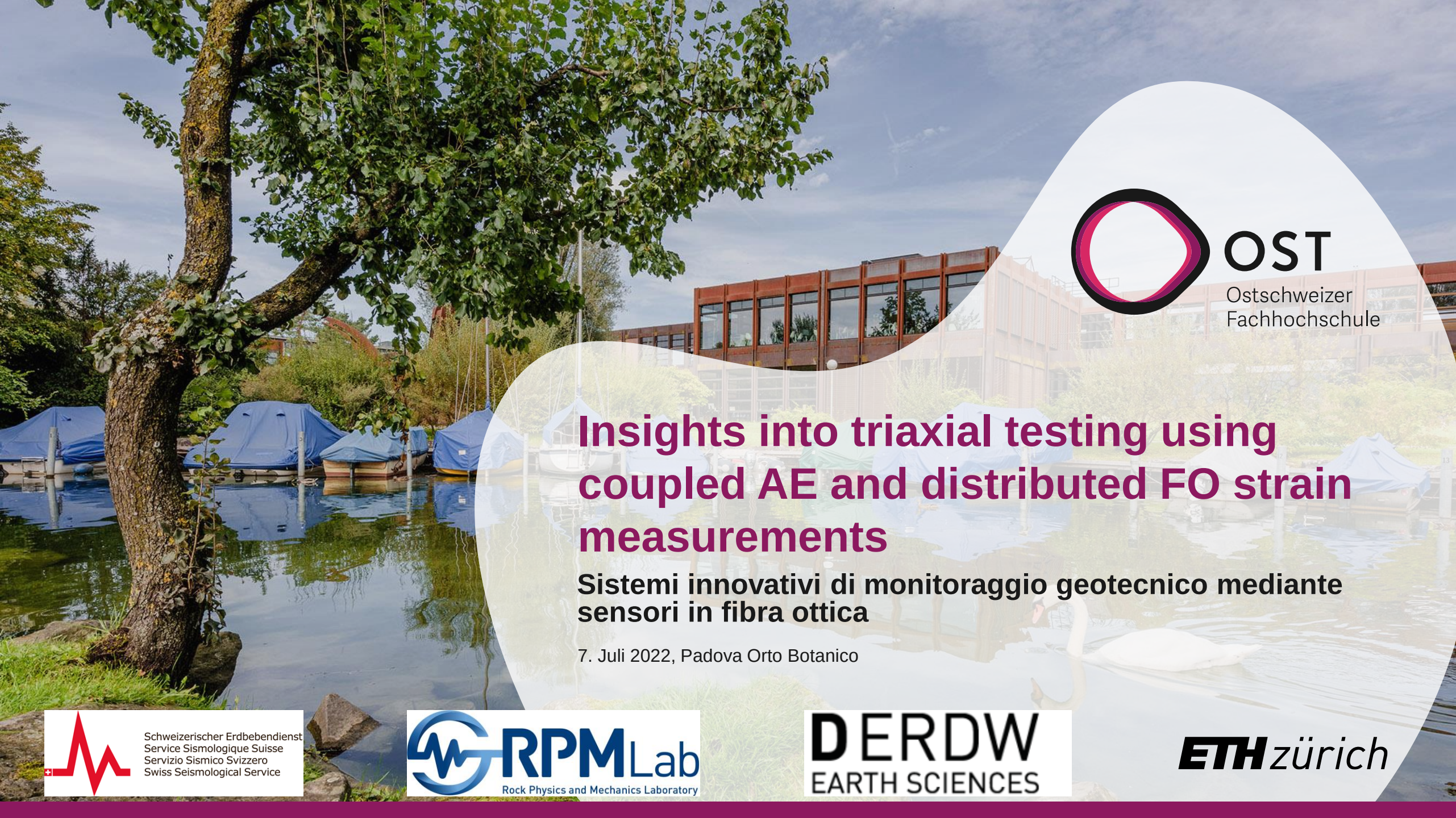


OST
Ostschweizer Fachhochschule

Insights into triaxial testing using coupled AE and distributed FO strain measurements

Sistemi innovativi di monitoraggio geotecnico mediante sensori in fibra ottica

7. Juli 2022, Padova Orto Botanico

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

RPMLab
Rock Physics and Mechanics Laboratory

DERDW
EARTH SCIENCES

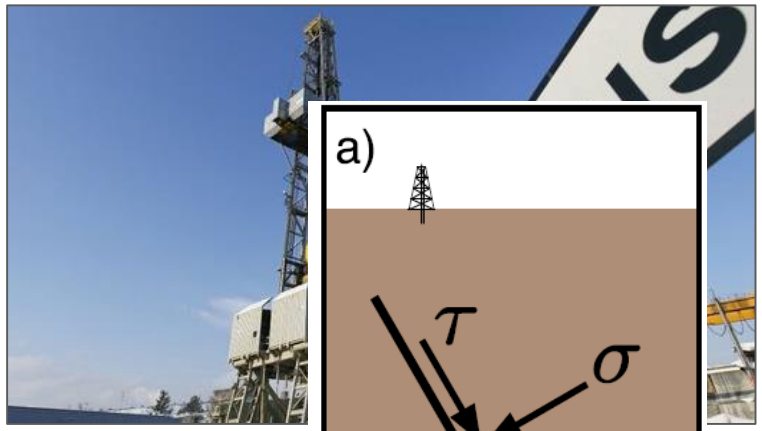
ETH zürich

Agenda

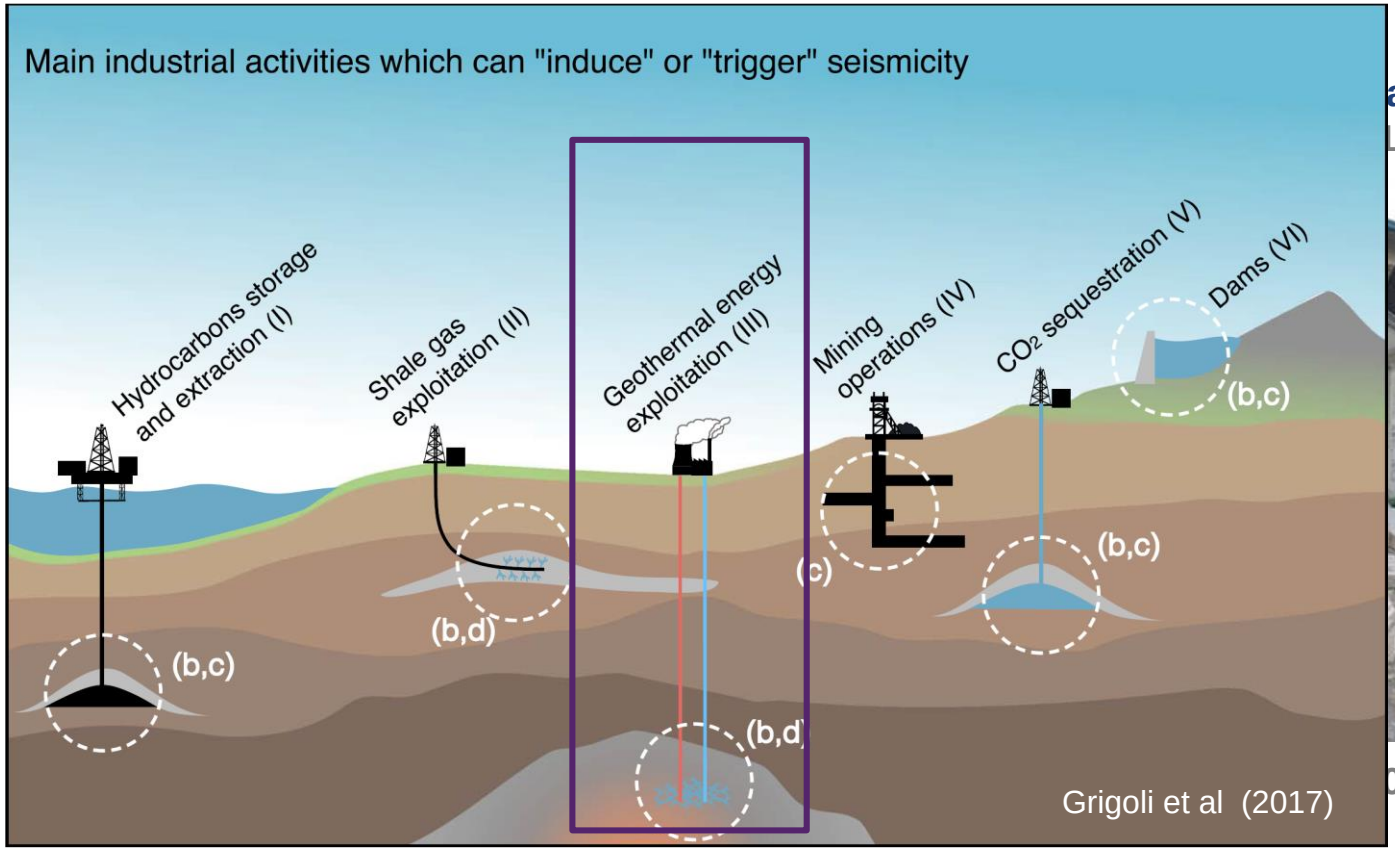
- **Motivation** – Understanding rock behaviour for deep geothermal wells (PHD)
- **Novel sensing methods** - Calibrated acoustic emission and distributed fiber-optic strain sensors.
- **Experimental methodology.**
- **Results:**
  - **High-resolution strain mapping**
  - **Acoustic emission prior to failure**
  - **X-ray computed tomography**
  - **Assessing variations in slow to rapid deformation**
- **Conclusions**

Motivation: Geo-energy activities and induced seismicity

- Industrial activities related to **geo-energy extraction** have been **valuable** to the high energy demands from society
- **Problem**: An **unpredictable** byproduct of operation are **induced earthquakes**
- **Induced seismicity poses risk** to society and **detract** from the **public acceptance** in certain countries



Basel
Sw



al" geothermal
19 Nature)

017,

Geoenergy research / new drilling technlogies

- AEGIS national project: Advanced GEothermal Systems to Improve the resilience of the energy supply of Switzerland
- Partners involved: ETH, PSI, SIKA, Swiss Geopower, Amberg Engineering, Basler & Hofmann
- Tasks at OST: Borehole stability and sediment transportation

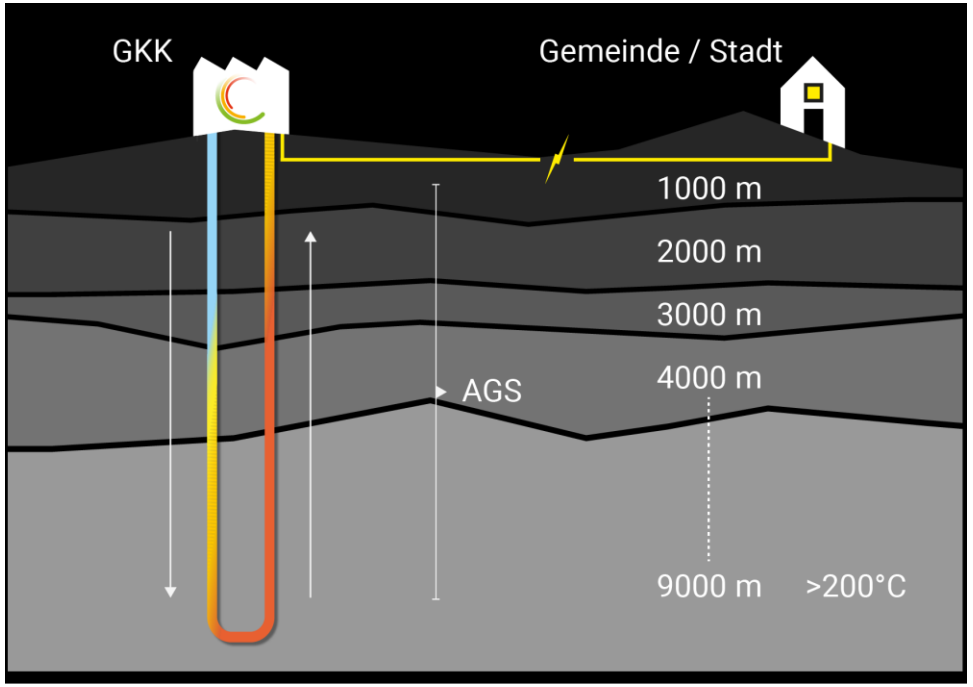


Illustration from Swissgeopower

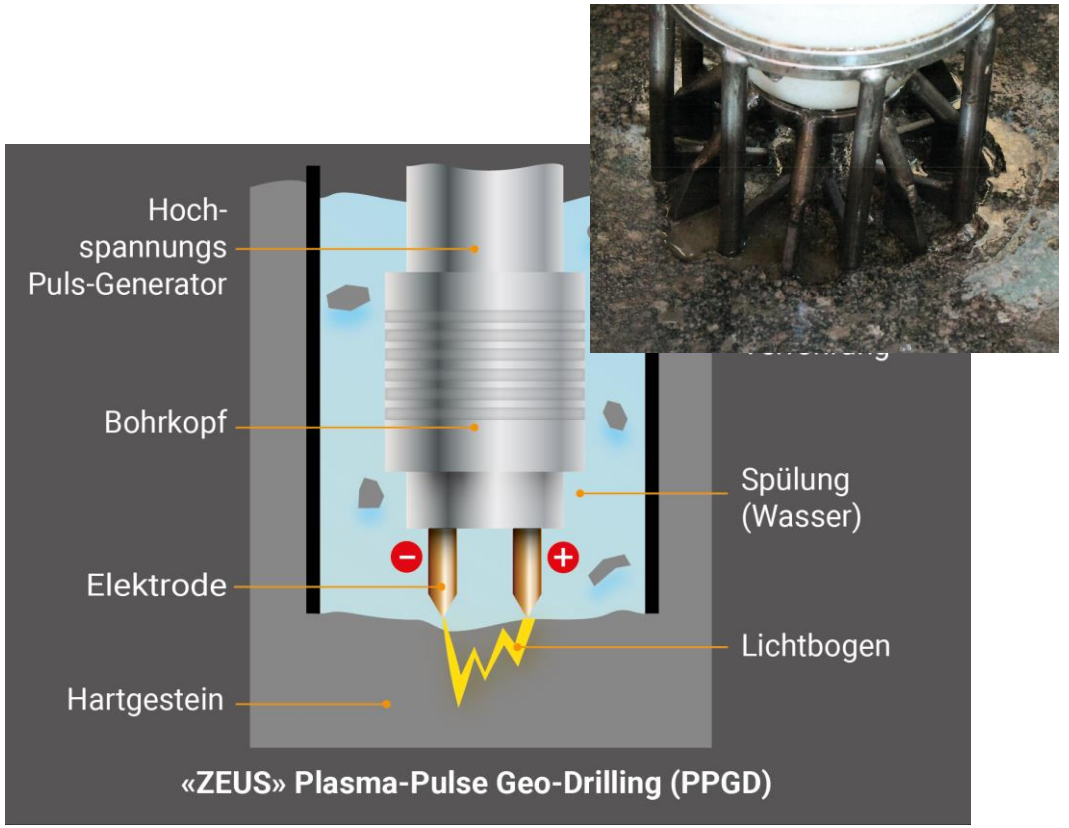
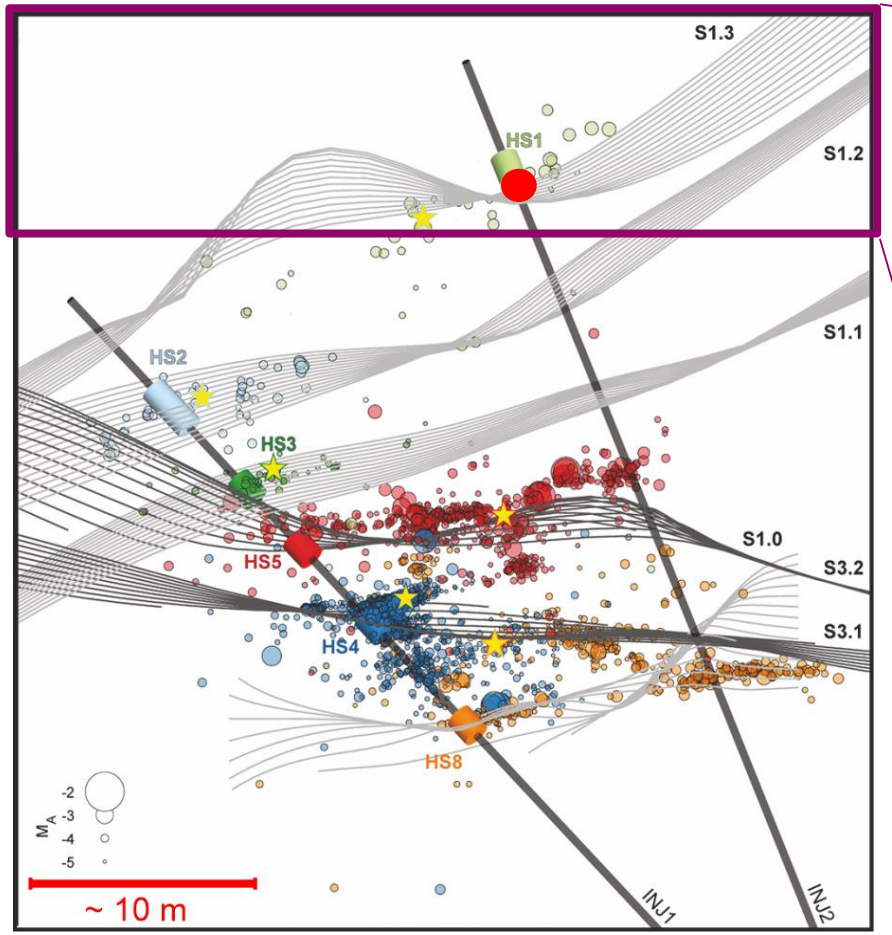


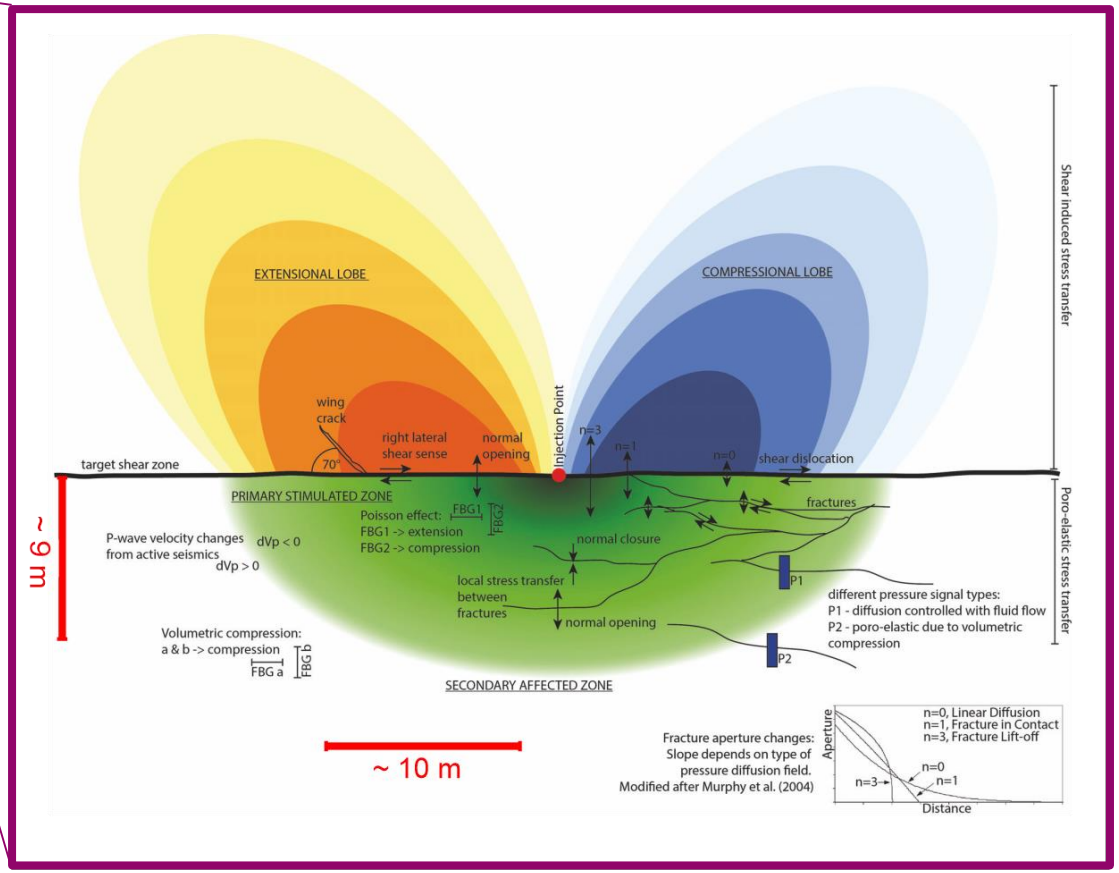
Illustration from Swissgeopower

Motivation: Geo-energy activities and induced seismicity

- High-density sensor arrays were deployed
- **Dynamic sensors** (AE sensors, accelerometers)
- **Quasi-static sensors** (Distributed strain sensing, pore pressure sensors)

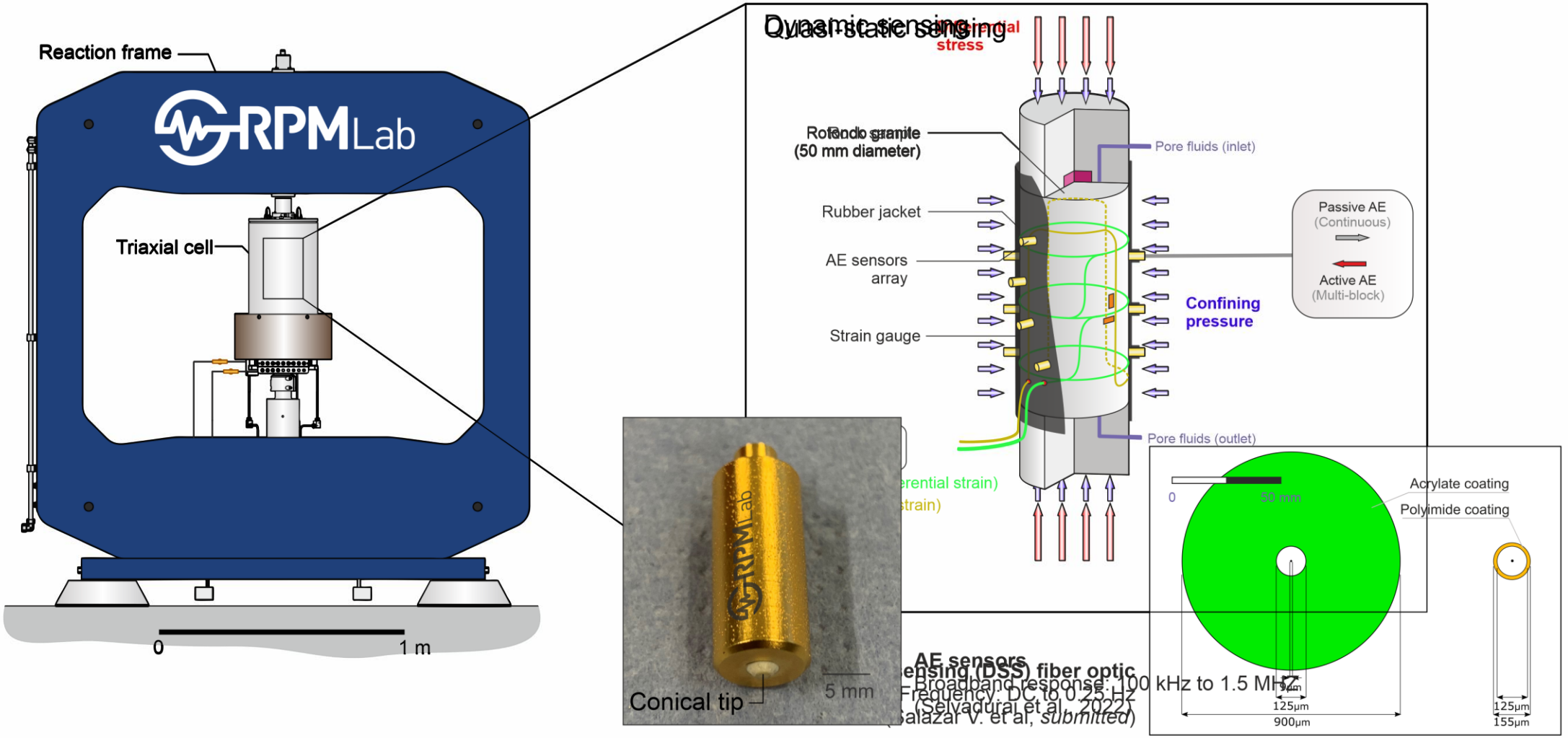


Acoustic emissions (AE)
Villiger et al. (2019, SE)



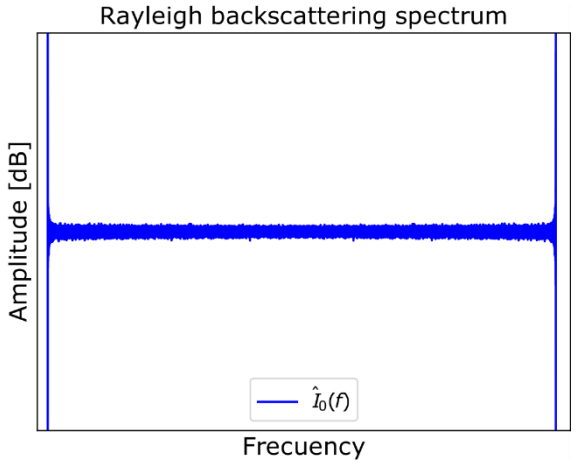
Hydro-mechanical response
Krietsch (2018, PhD)

Novel sensing methods



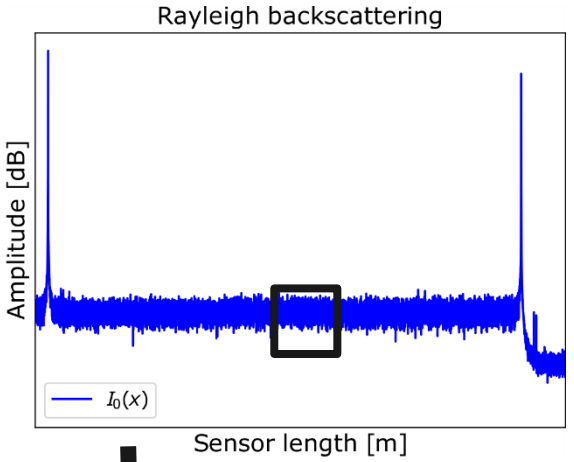
Concept

a) Back reflected light measured by the OBR (Frequency domain).

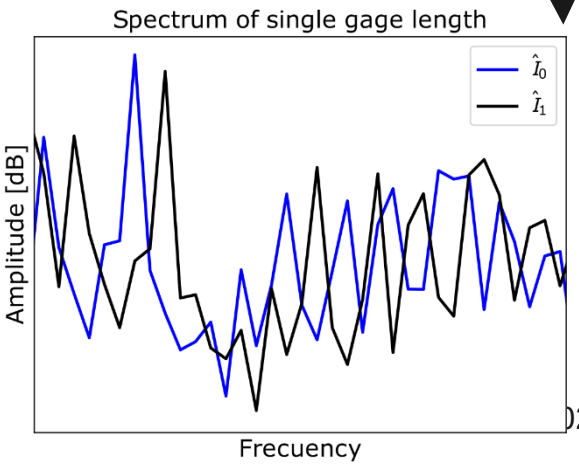


b) By an Inverse Fourier fast transform (Step 1.), the signal is projected in the time domain (distance using the refractive group index). .

1. IFFT

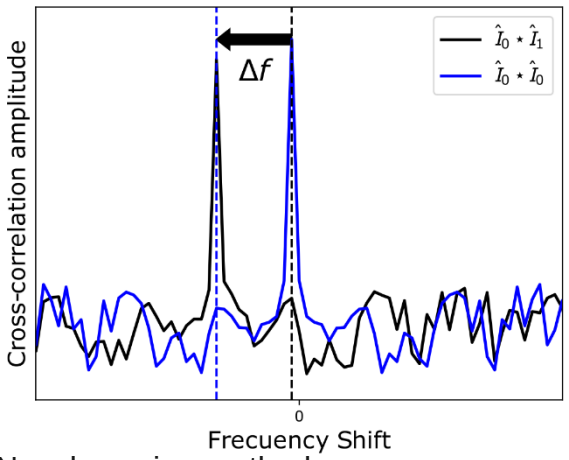


2. FFT



c) The user selects a "window" (gauge length), to which a Fast Fourier Transform (Step 2.) is applied to analyze the frequency content.

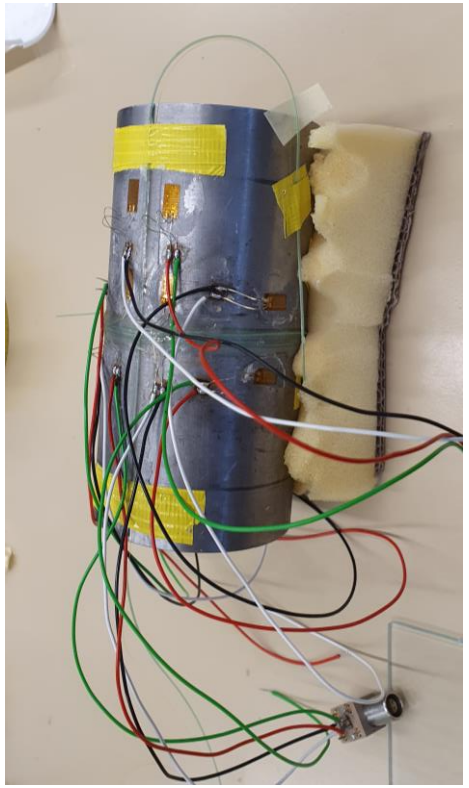
3. CC



d) For easier calculation a cross-correlation (Step 3.) is calculated between the two measurements analyzed.

Intro on methodology: The DFO Measurements

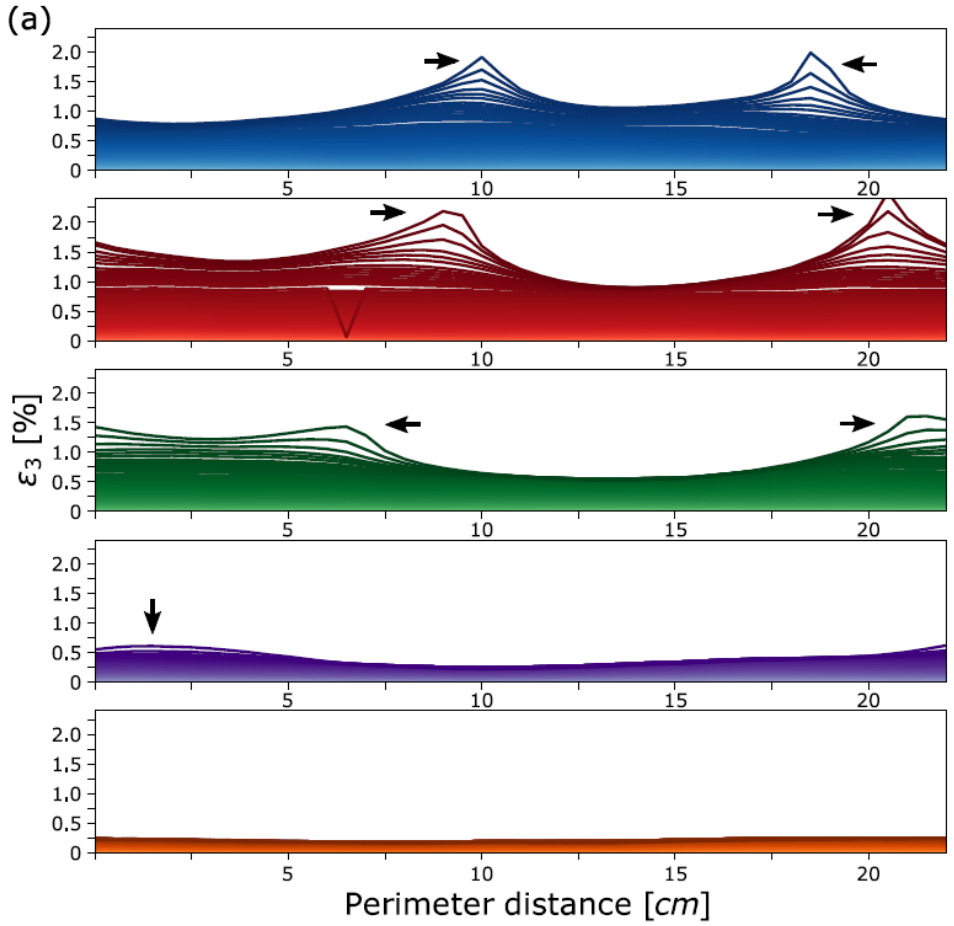
2 "Gauges" – LDVTs

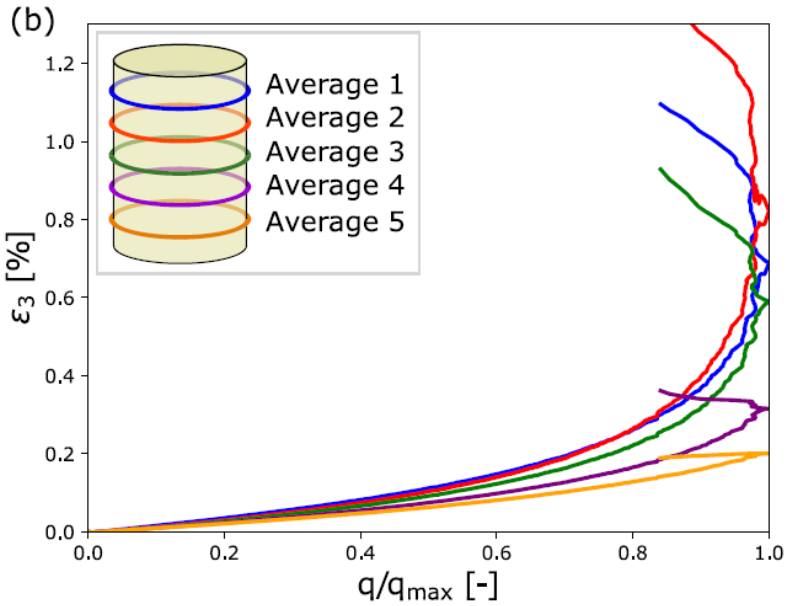


8 Gauges – 16 cables

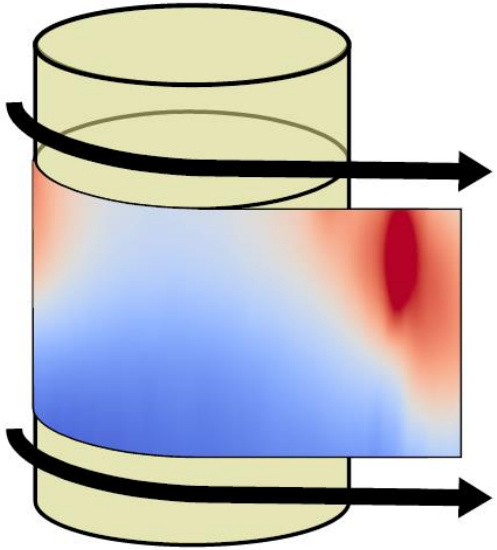
300 Gauges – 2 cables

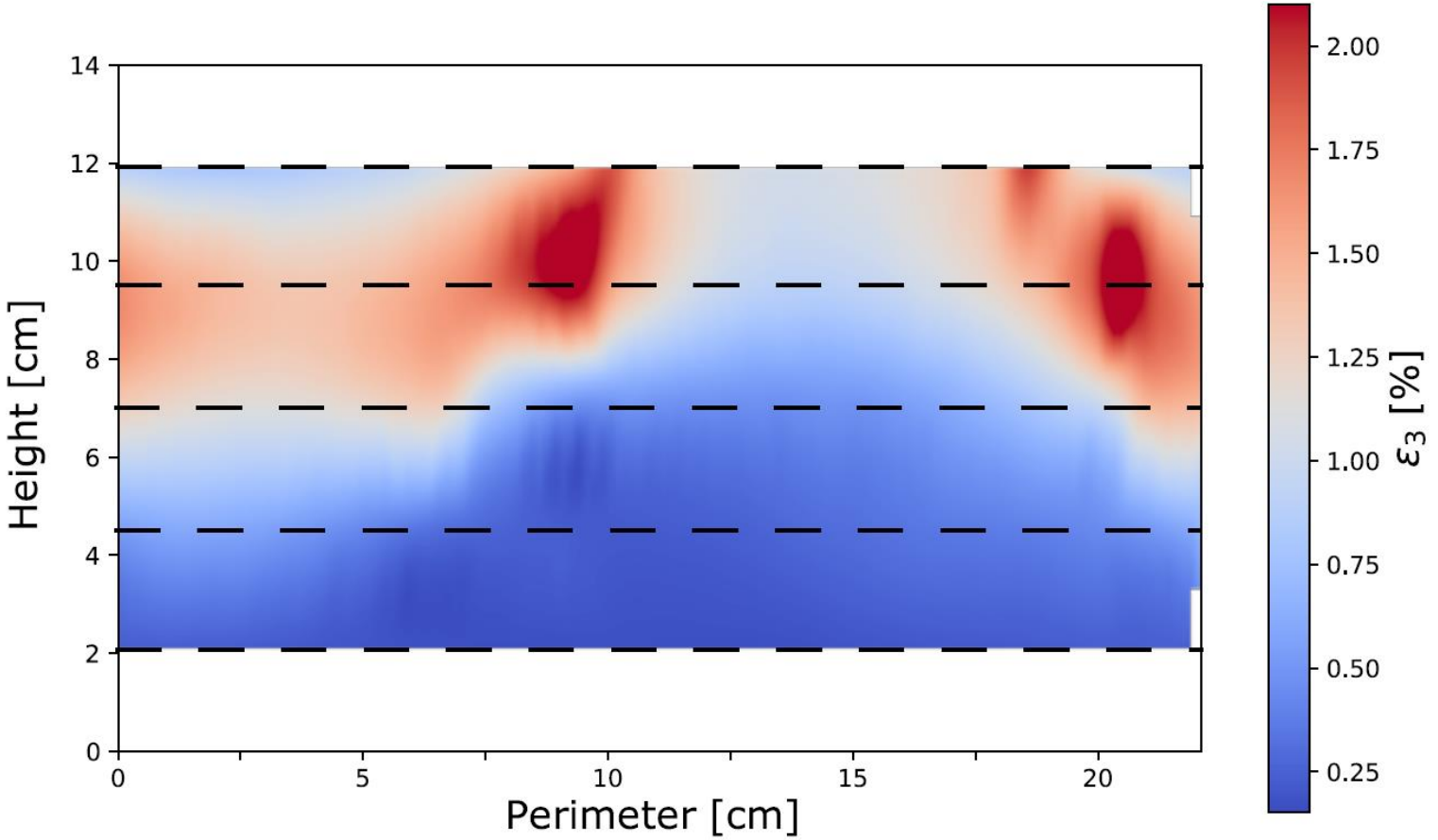
Intro on methodology: The DFO Measurements



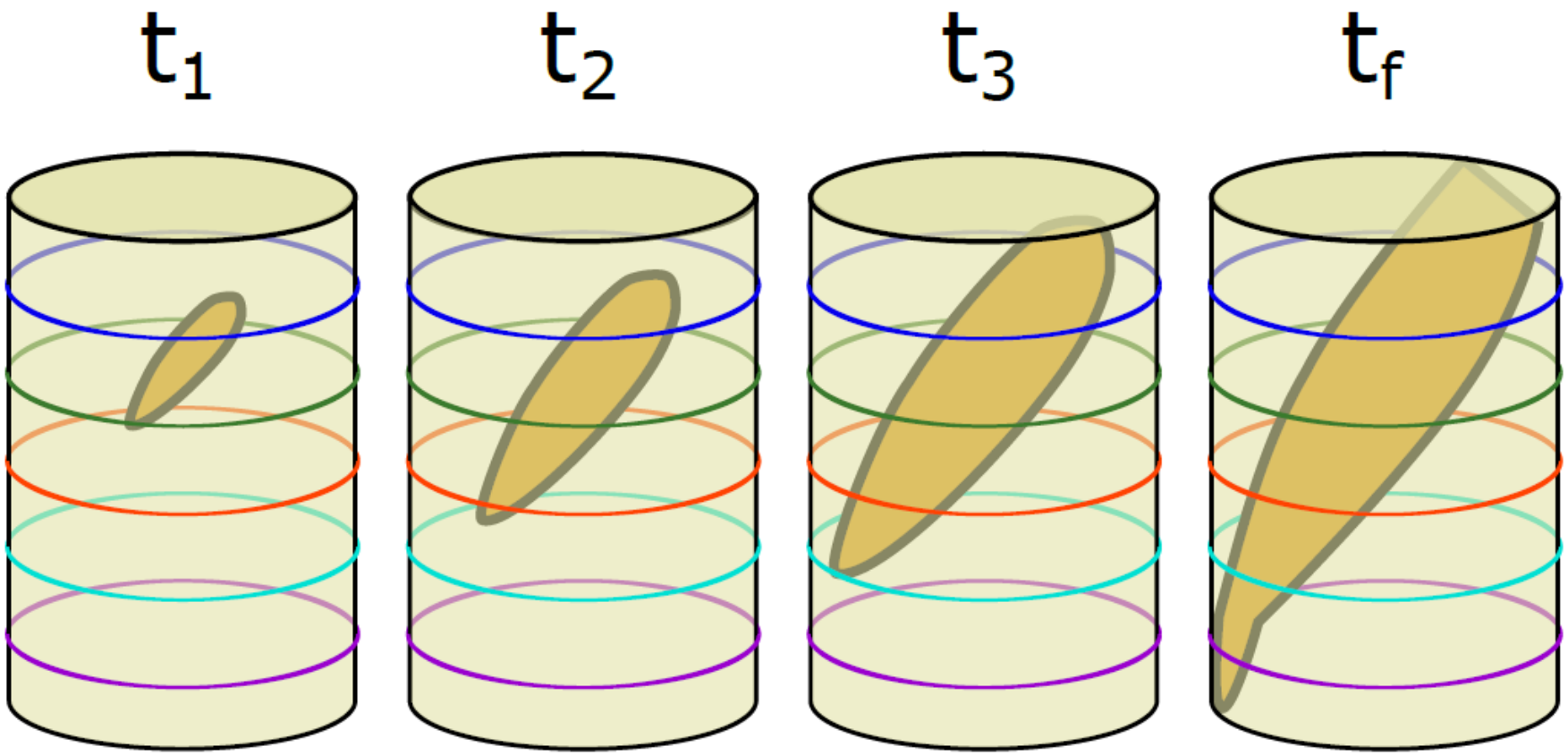


Intro on methodology: The information



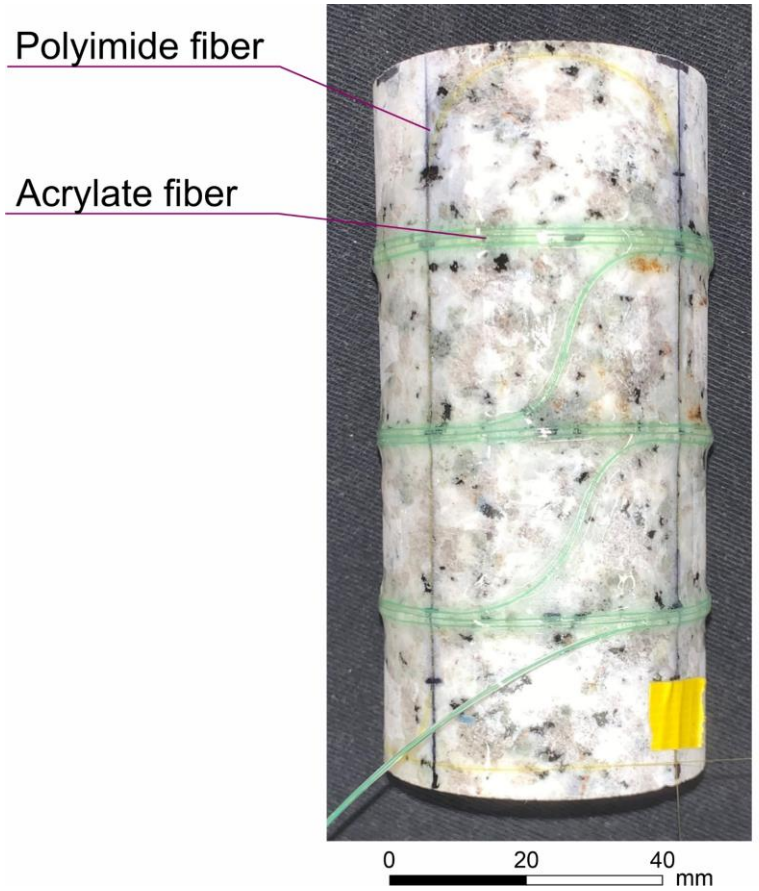


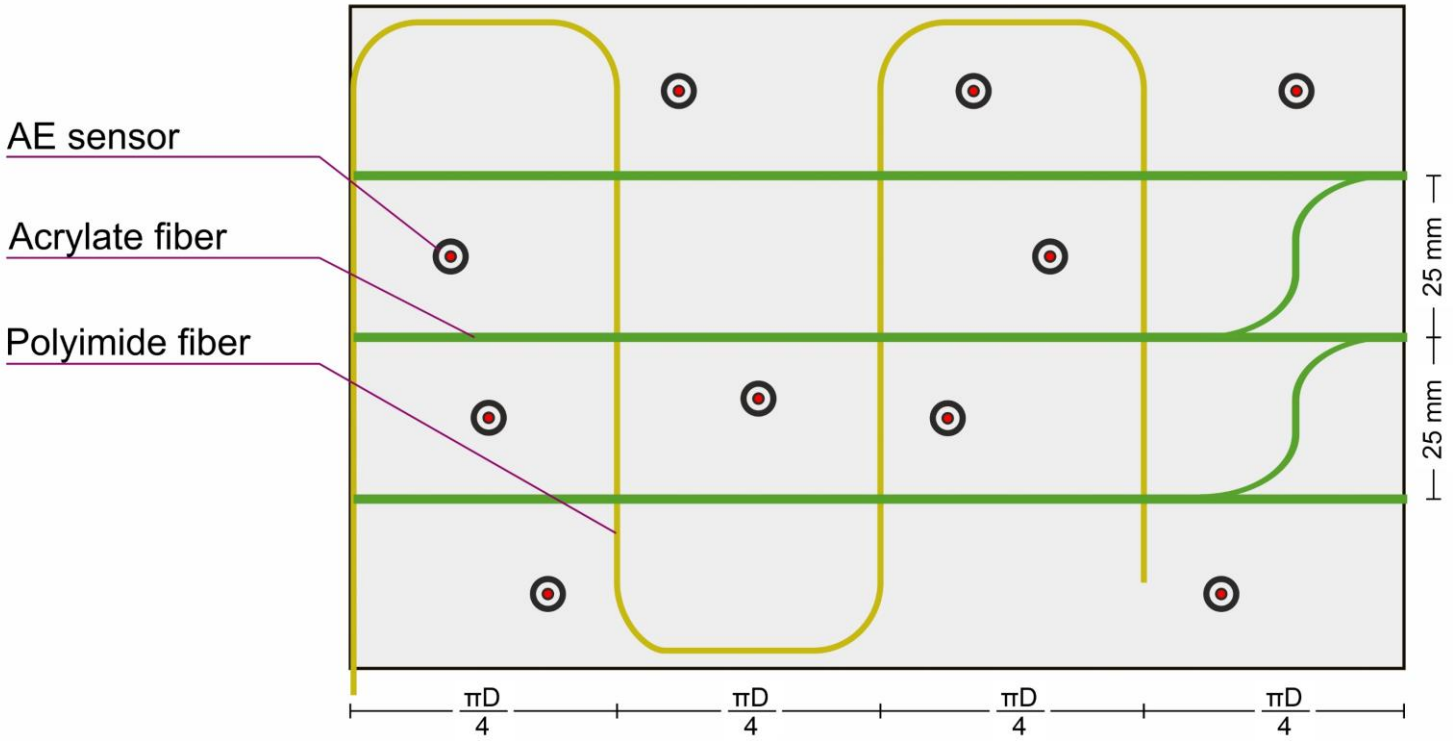
Intro on methodology: The Physics



Experimental methodology: Sensors

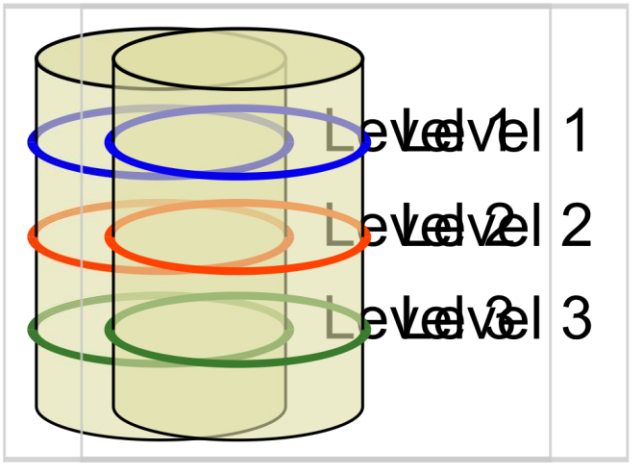
- Rotondo granite sample of 2'' in diameter and 4'' in length.
- Ten acoustic sensors were deployed
- Two types of optical fibers measured the circumferential and axial strain evolution.





Results: Distributed strain measurements (aseismic)

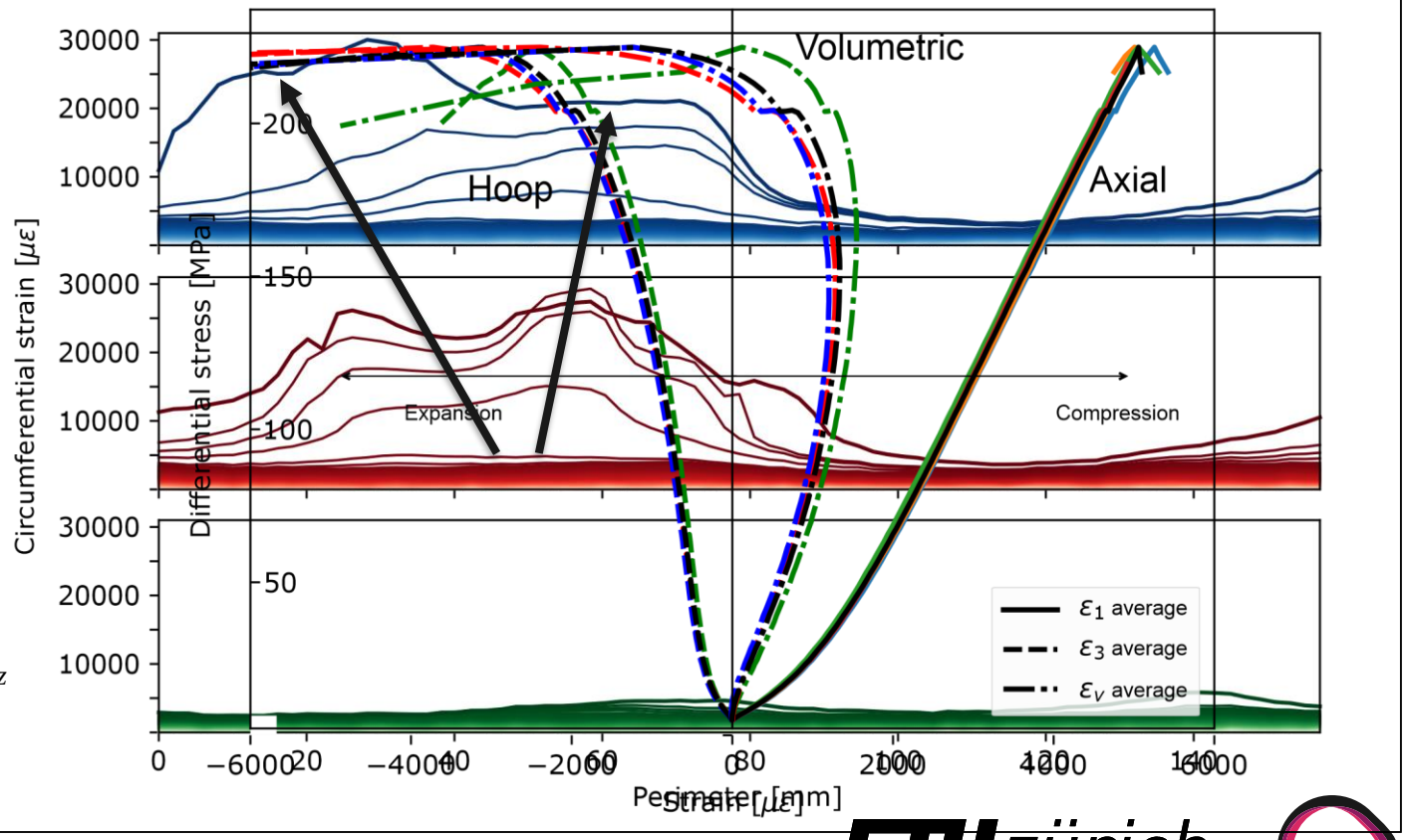
1. Sample compressed axially and expanded in the circumferential direction
2. At a certain point the volume expands (dilation of the shear fracture)
3. Spatio-temporal plot shows the fracture develop on the periphery at the later stages of failure



Volumetric strain:

$$\varepsilon_{vol} = \varepsilon_{rr} + \varepsilon_{\theta\theta} + \varepsilon_{zz} = 2\varepsilon_{\theta\theta} + \varepsilon_{zz}$$

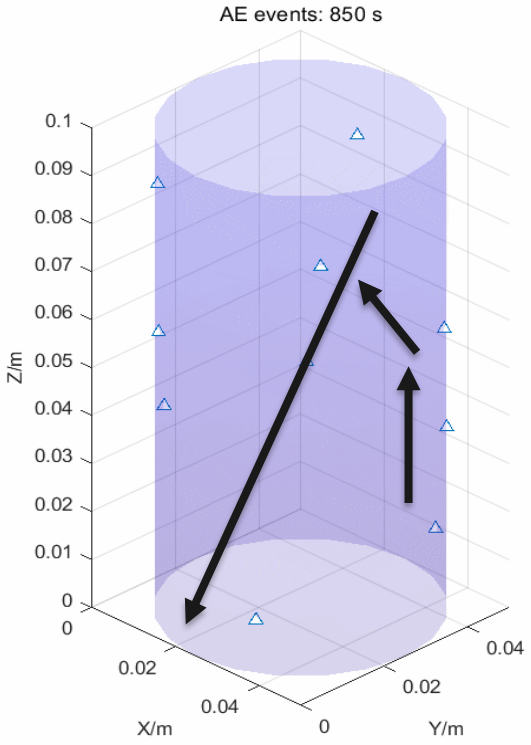
In the last ~40s strain concentrations were observed

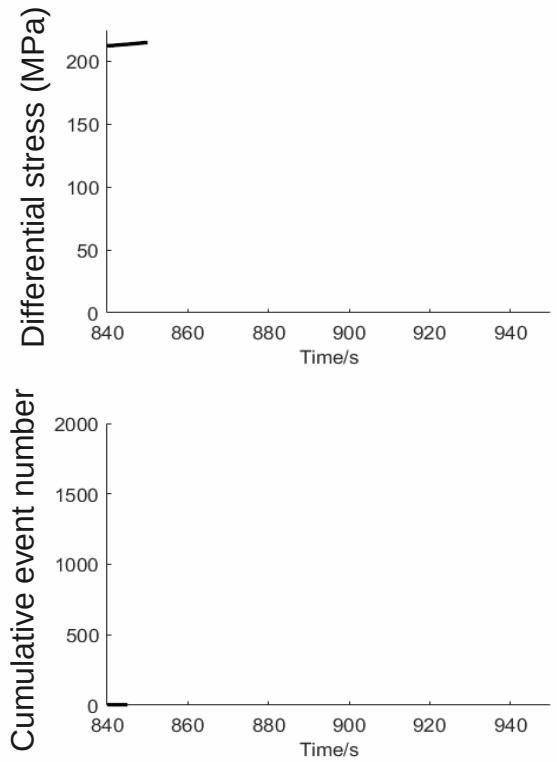


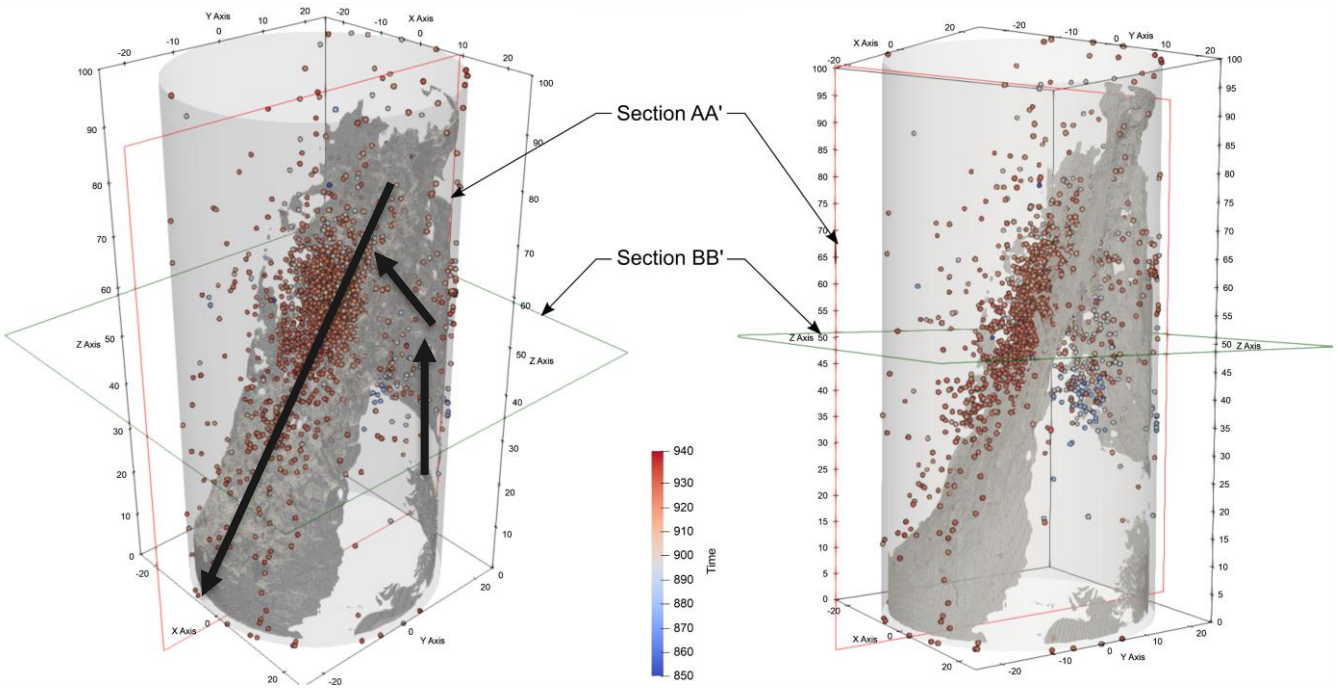
Results: Acoustic emissions prior to failure (seismic)

- Was investigated the fracturing using the X-ray CT scans from the sample post analysis
- HybridMT (Kwaitek et al., 2016) was used to solve for the moment tensor solution
- Clear evidence that a fracture was formed and the expression of AE events followed the fault plane geometry

Processed events: 1978



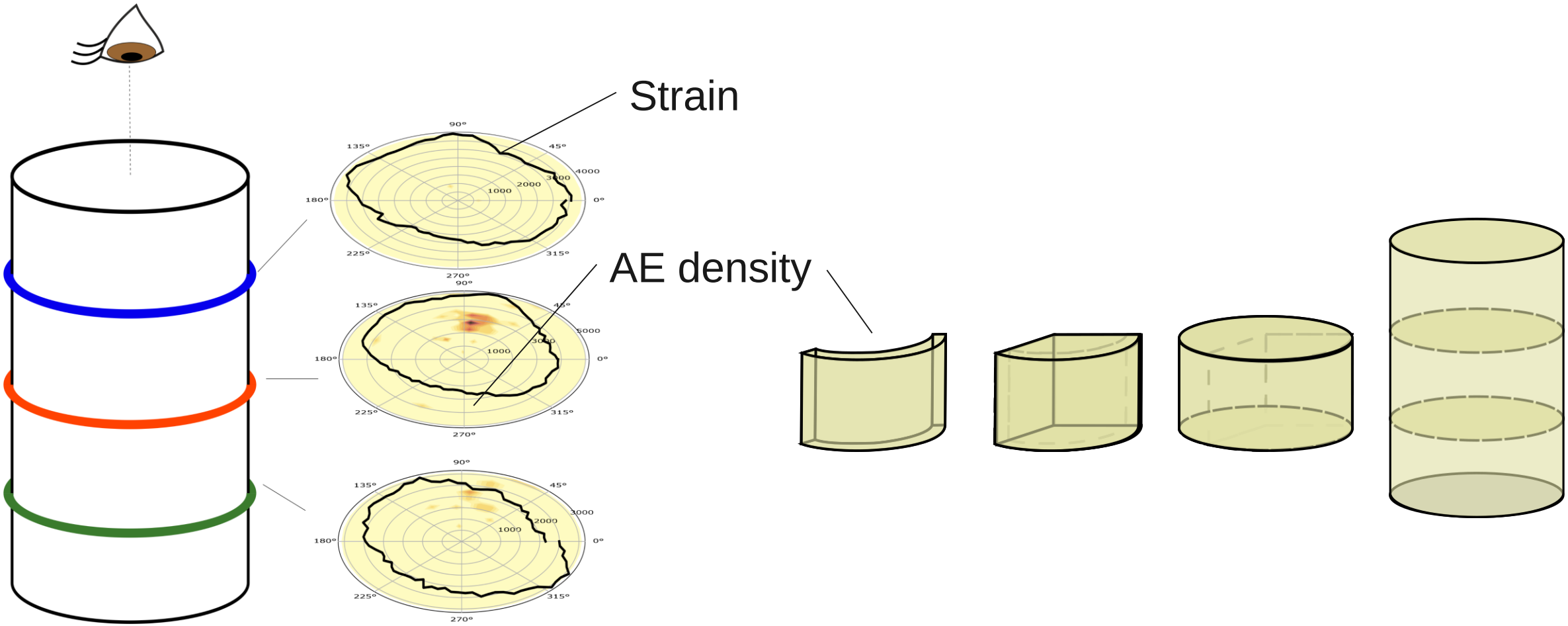




Niu (2021)

Results: Seismic and aseismic deformation

- Visualize the relationship between the localized seismicity and the larger slow circumferential strain accumulation

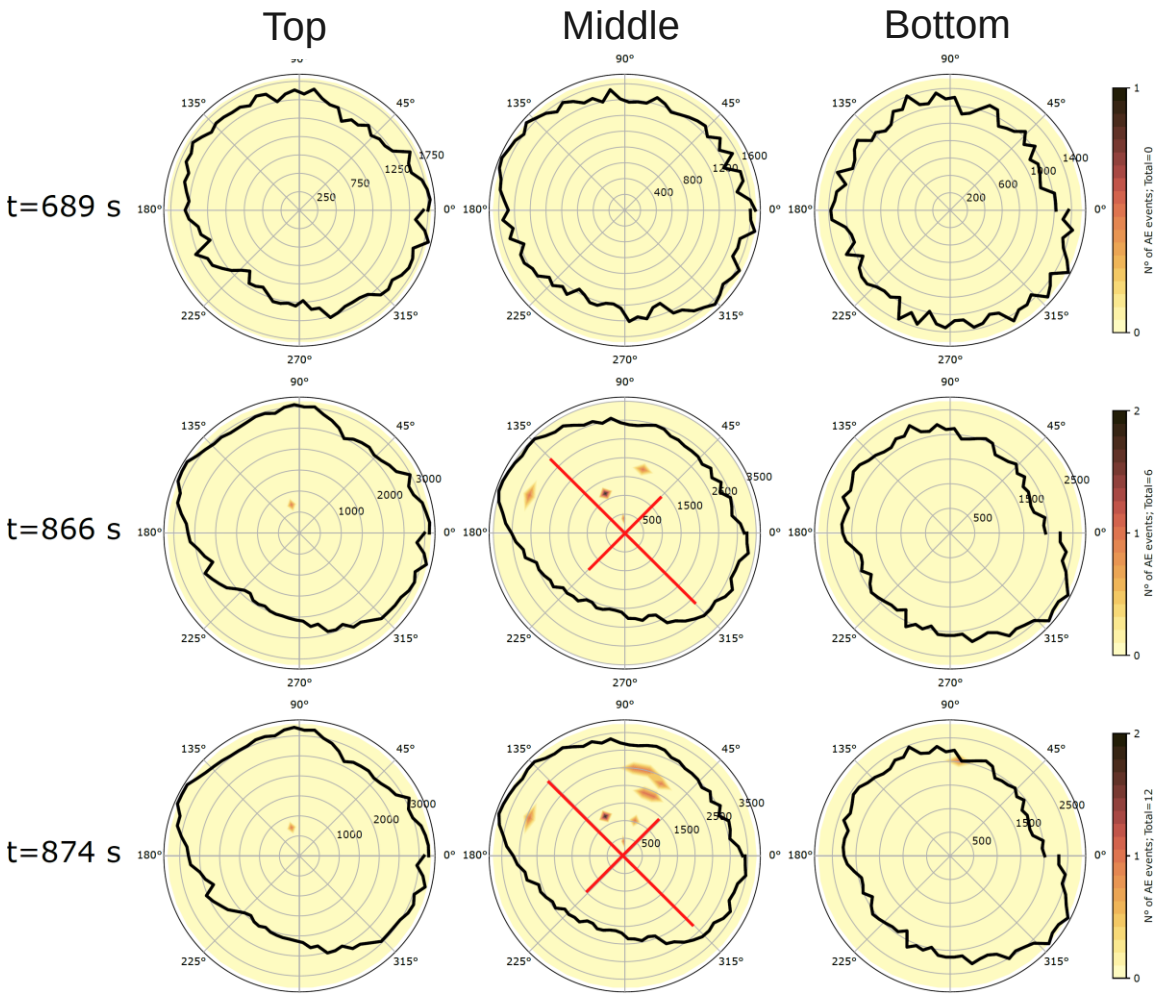


Results: Seismic and aseismic deformation

1. Circumferential strain is distributed relatively homogeneously at each height.

2. Strain begins to deviate to an elliptical distribution when the first AEs are recorded.

3. Magnitude of strain increases preferentially along major axis relative to the bottom.



Results: Seismic and aseismic deformation

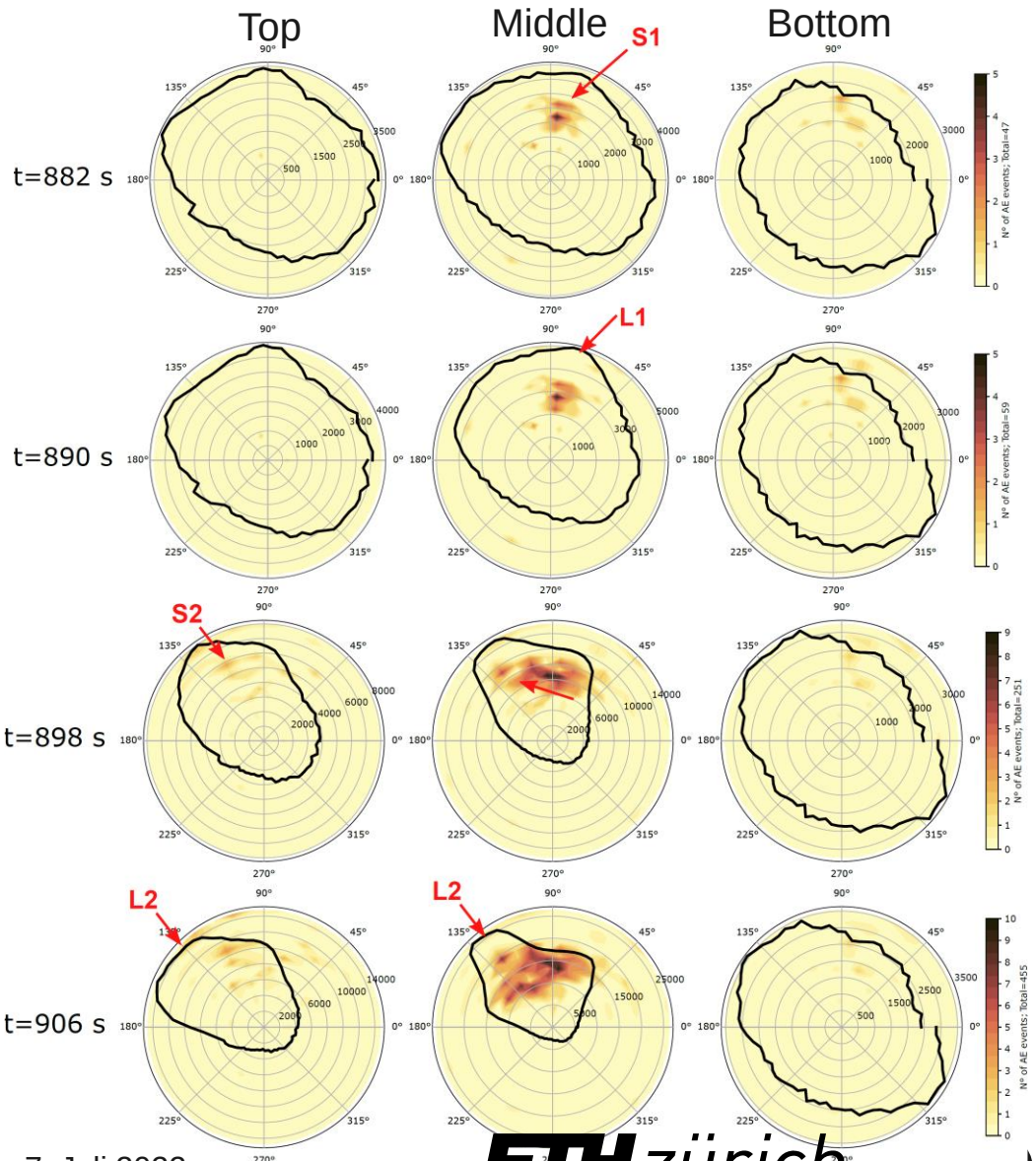
4. The first cluster of seismicity (S1) was observed in the middle of the sample

5. We observed a localization in the strain field (L1) that correlated to the region subjected to the seismicity cloud S1.

6. Seismicity cloud S2 propagated upwards

7. We observed a localization in the strain field (L2) in the upper section.

8. The strain concentration rotated to 135º



Results: Seismic and aseismic deformation

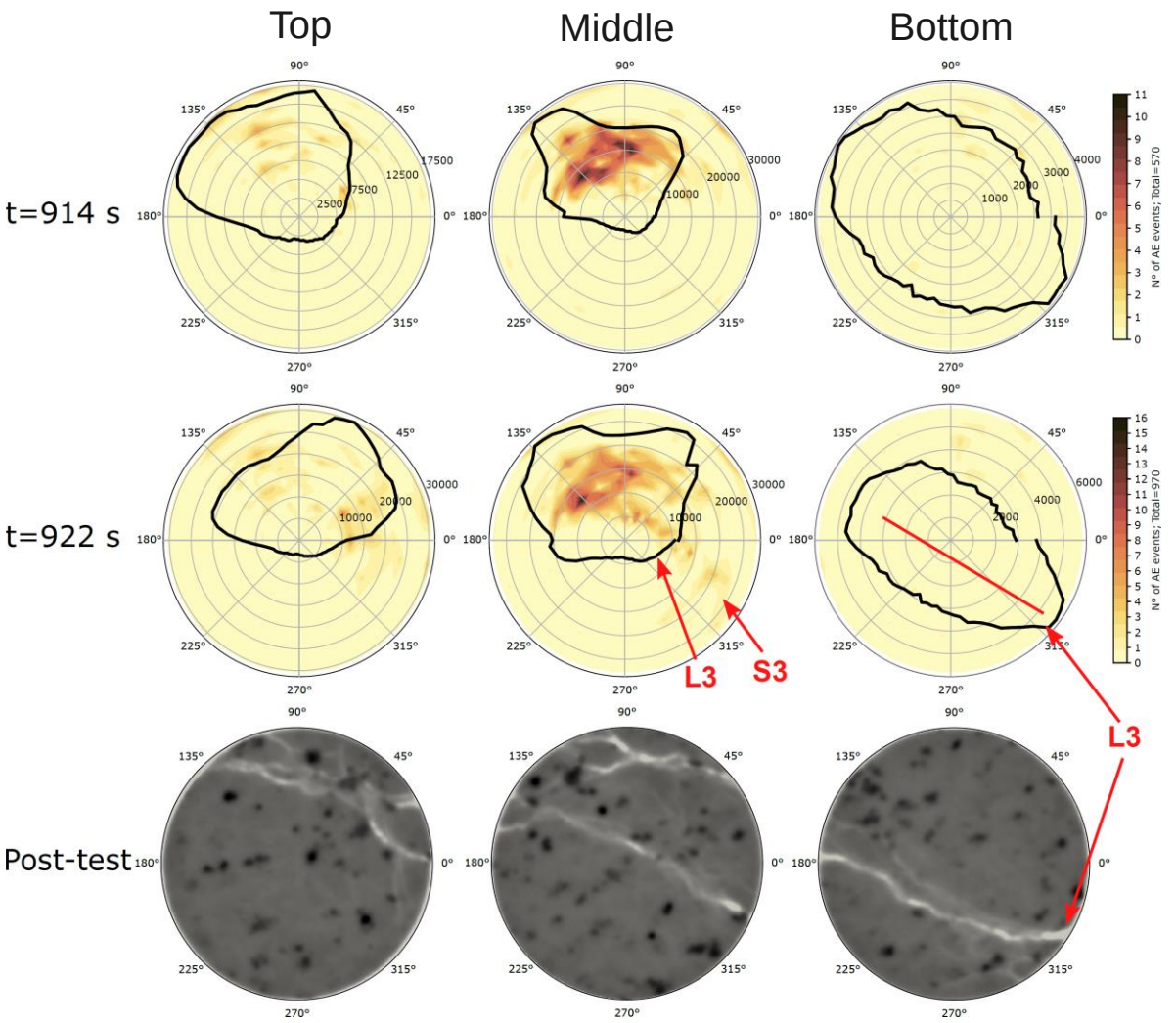
9. The strain concentration manifested itself in the top of the sample

10. Seismicity cloud S3 propagated from the top through the middle of the sample

11. Elliptical distribution in the bottom of the sample was most prominent in the last strain measurements

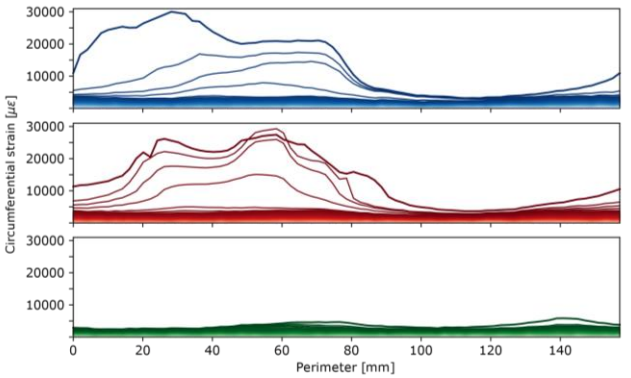
12. This strain is oriented with the crack that was measured in post-analysis using the XR-CT

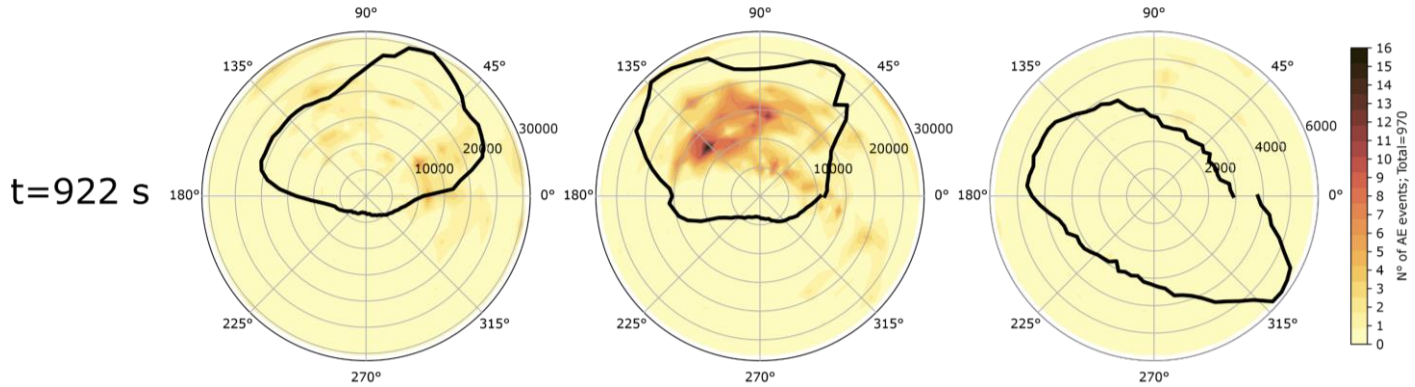
AE density is related to increase in the strain magnitude in both space and time

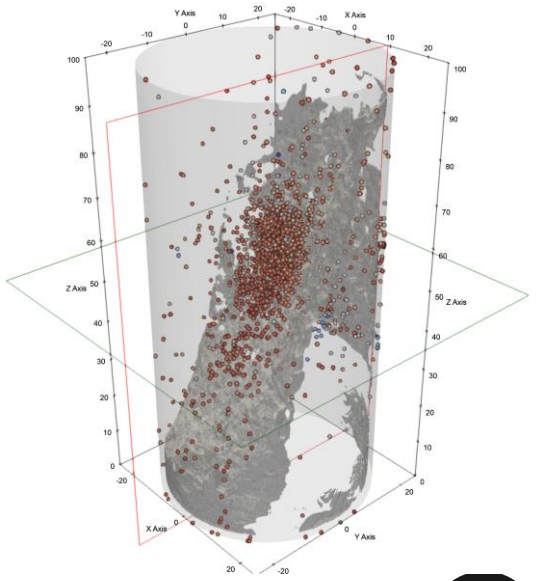


Conclusions

- Implemented **dynamic** and **quasi-static** measurements to study fracturing in granite
- Fiber-optics show **complex spatial distribution in strain** near failure due to shear fracture forming in the later stages.
- **Seismicity** and **XR-CT** (post-test) showed that a fracture was produced
- **Seismicity tracked** the progression of **slow deformation**
- **Seismic deformation** accounted for **[0.07 to 4]**$\times 10^{-2}$% of the total deformation.



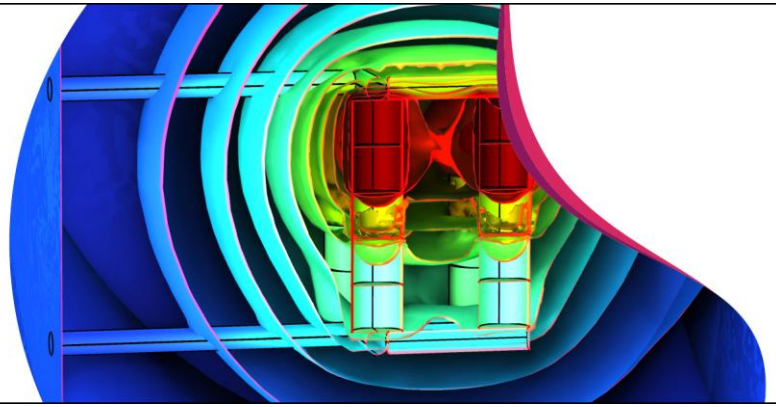




Thanks for your attention! Questions?

Authors:

- Antonio Salazar V.; C. Rabaiotti, OST
- P. A. Selvadurai; Z. Niu; P. Bianchi; C. Madonna; S. Wiemer ETH Zürich
- L.N. Germanovich, Clemson University



OST Geotechnik Fachtagung

Geotechnische Herausforderungen
bei der oberflächennahen und tiefen Geothermie

Fr, 25.11.2022, 9.00–17.00 Uhr, Campus Rapperswil

ibu.hsr.ch | www.geotechnik-fachtagung.com

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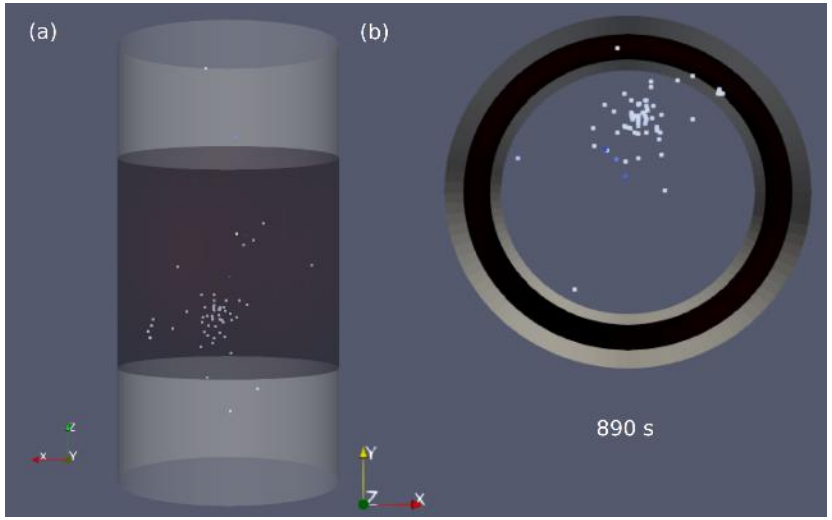
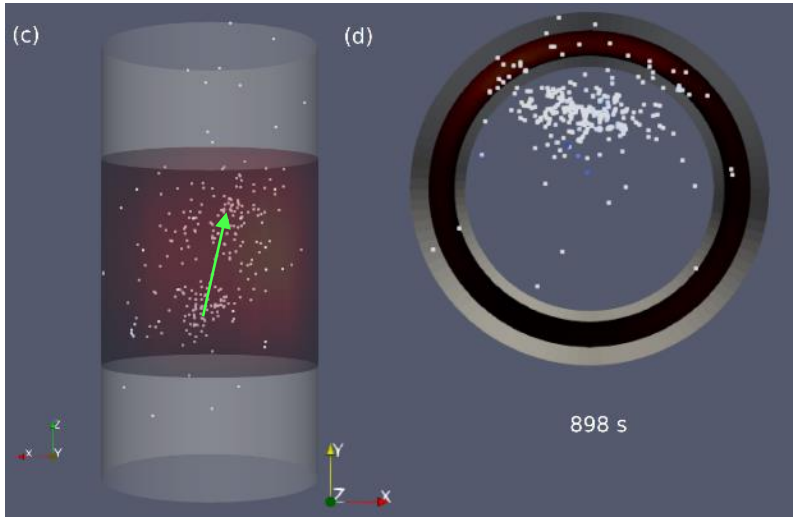
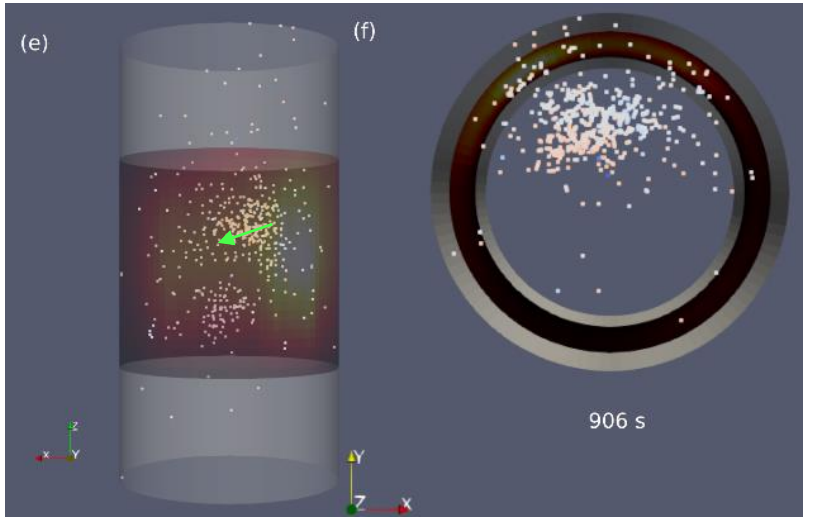
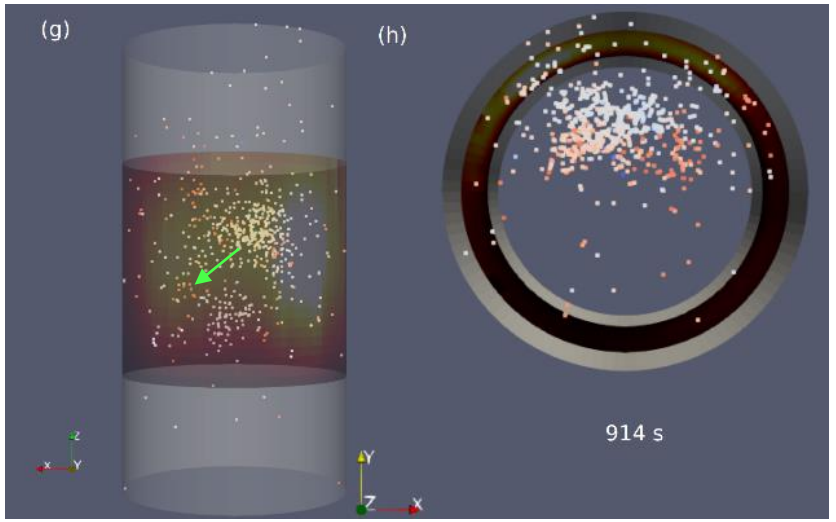
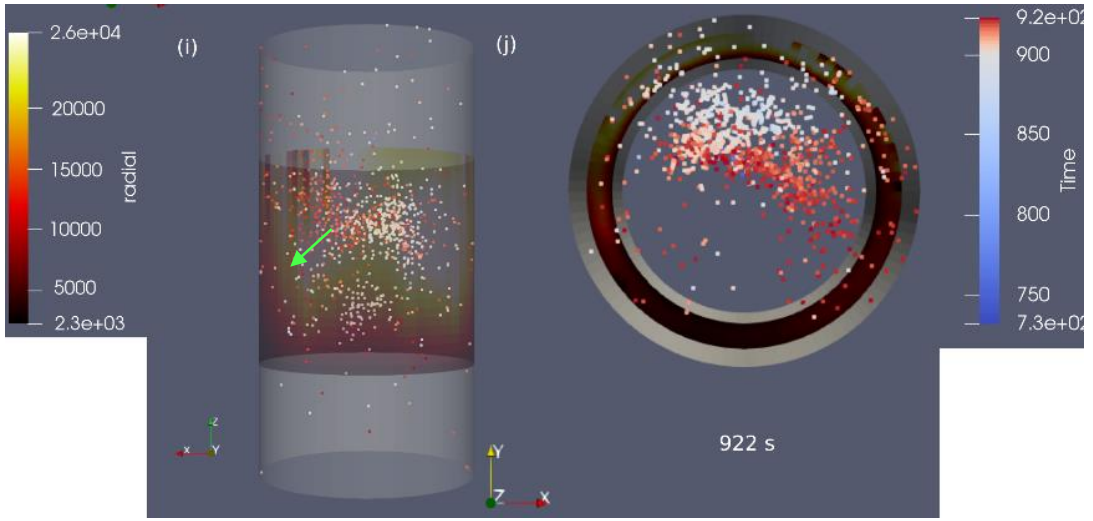
Strain heterogeneity and seismicity











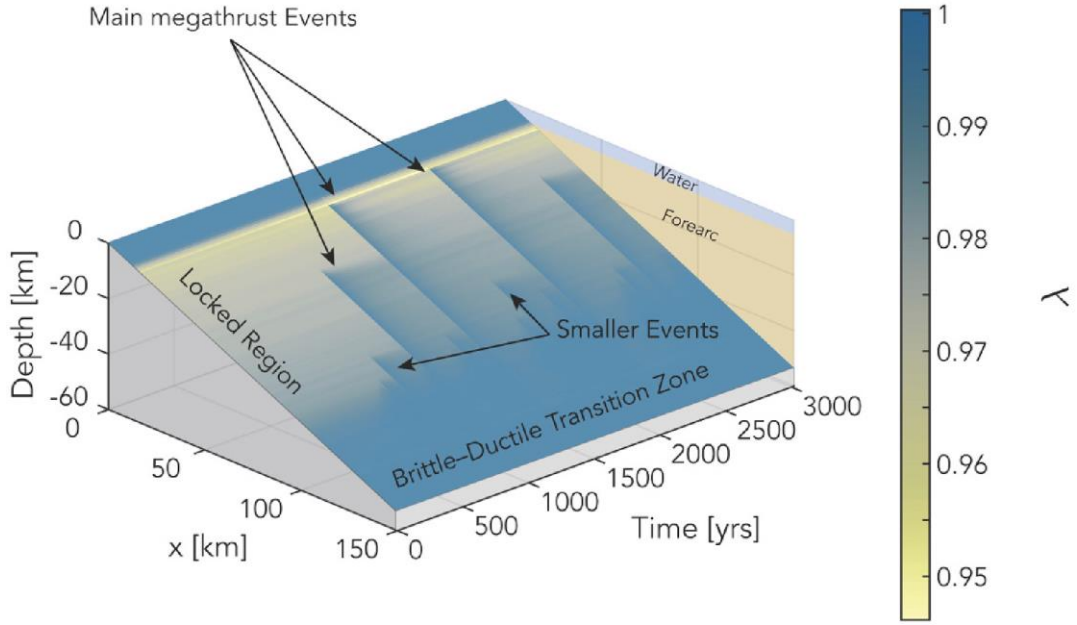
- **High strain** region expand in the **similar directions** as those of seismic events.

Numerical modelling outlook

Critical point behavior can be studied using AE techniques

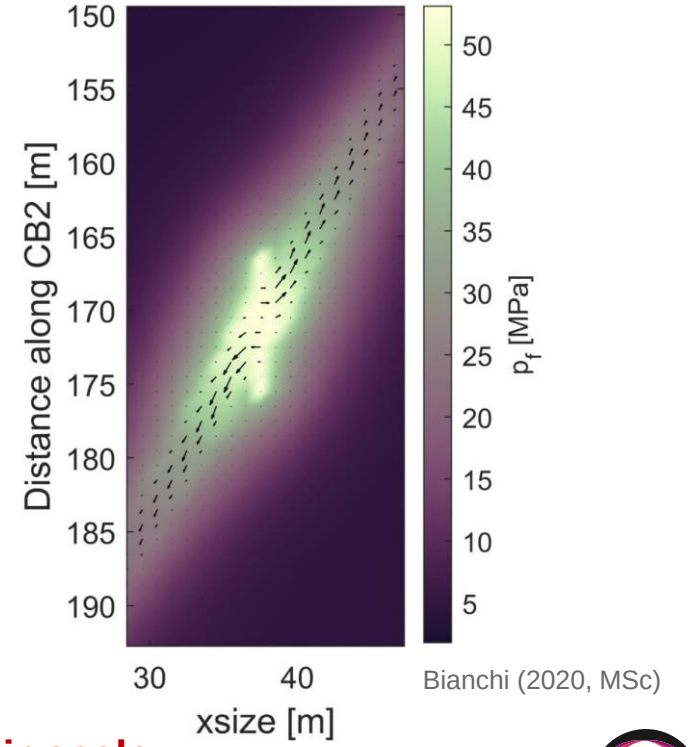
Can we use **continuum models** to study how the **system arrives at** this **critical point**?

- A **continuum-based** fully coupled **seismo-hydro-thermo-mechanical poro-visco-elasto-plastic** numerical modelling approach (Gerya, 2019)



Petrini et al. (2020, Tectono.)

→ **Subduction scale**



Bianchi (2020, MSc)

→ **EGS reservoir scale**