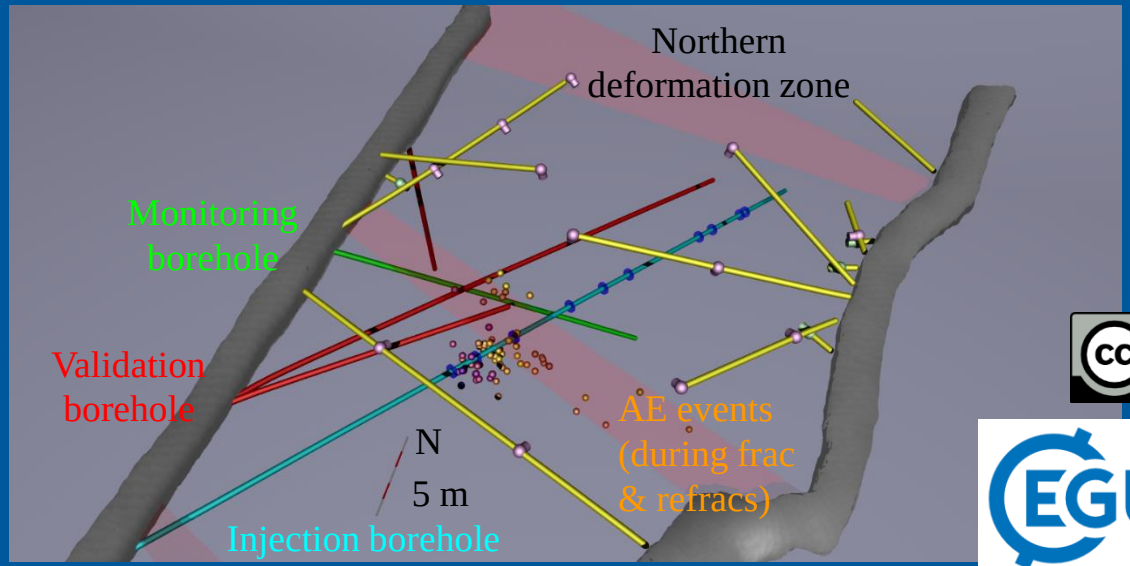
Characterising induced acoustic emission activity observed during a mine-scale hydraulic-fracturing experiment in anisotropic crystalline rock

C. Böse[1], G. Kwiatek[1,2], G. Dresen[1,3], and STIMTEC team

cboese@gfz-potsdam.de

1 Section 4.2 GFZ Potsdam, Germany; 2 Freie Universität Berlin, Germany; 3 Universität Potsdam, Germany



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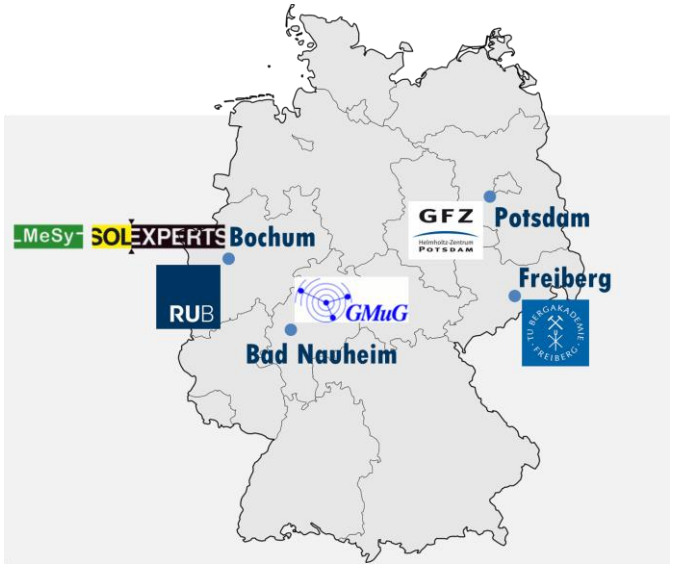
Outline

- Introduction STIMTEC experiment and Reiche Zeche URL
- Hydraulic Stimulation
- Seismic response to stimulation, hydraulic testing, and mini-fracs
  - Acoustic emission (AE) event locations
  - Focal mechanism (FM) solutions
- Summary & Conclusions

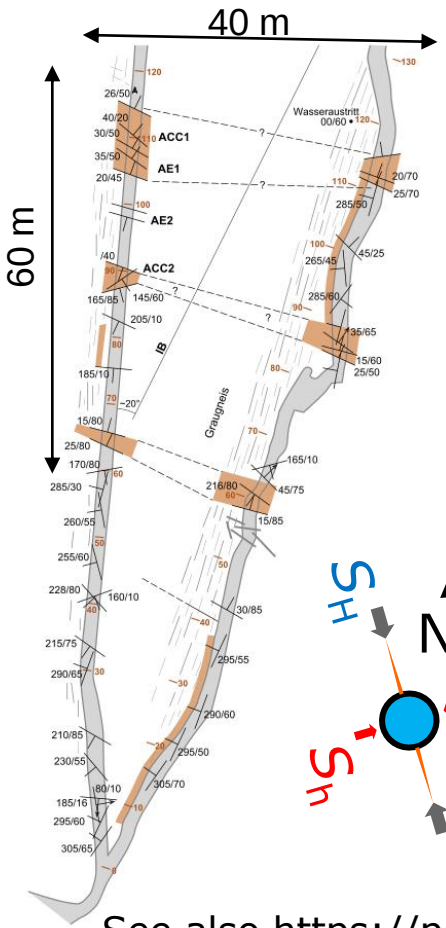
Introduction: STIMTEC experiment

STIMTEC hydraulic stimulation experiment at Reiche Zeche mine

- involves real-time monitoring technologies and 3-D numerical modelling
- **aims** to understand hydro-mechanical processes that occur during hydraulic stimulation, by associating and correctly identifying them through their seismic and hydraulic fingerprints
- comprised three phases that were **completed in December 2019**:
  - Pre-stimulation characterisation phase
  - Stimulation phase
  - Post-stimulation validation & characterisation phase
- a joint effort of an **inter-disciplinary team**



Reiche Zeche Underground Lab



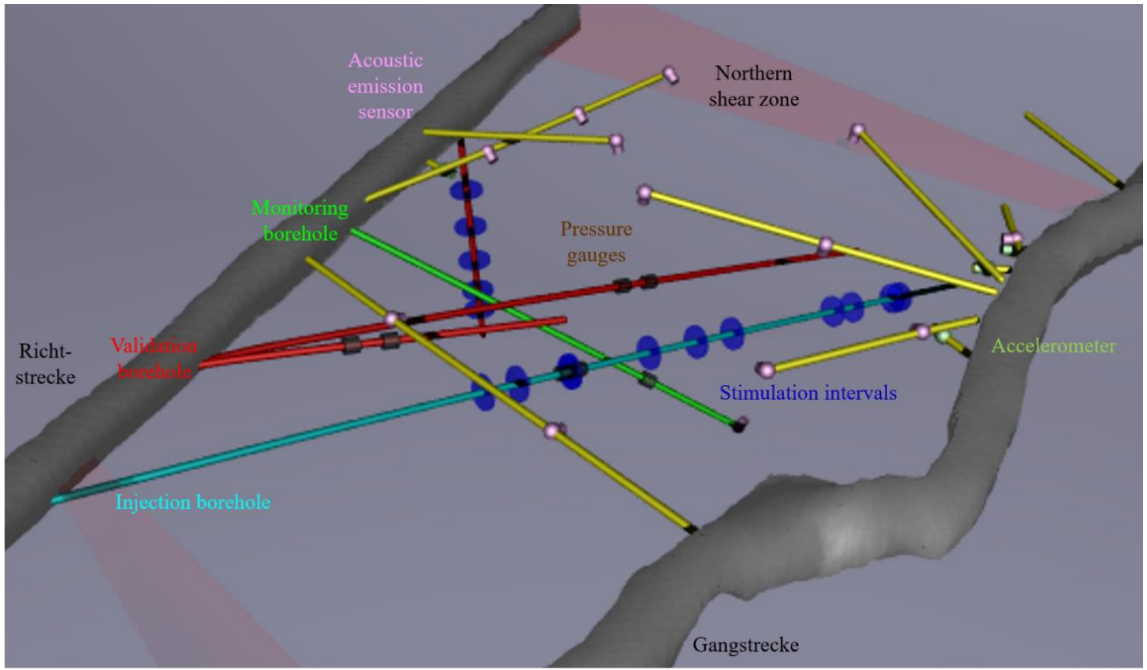
Freiberg
Eastern
Erzgebirge

~283 ASL
120-130 m depth

- Target volume ~60 x 30 x 20 m^3 of strongly foliated metamorphic Freiberg gneiss between two access tunnels
- comprises steeply dipping deformation zones
- foliation is sub-horizontal causing anisotropy

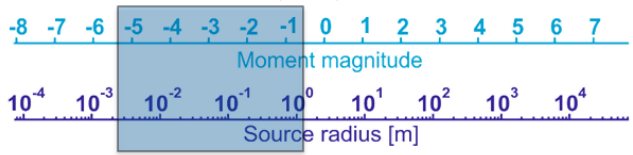
See also https://presentations.copernicus.org/EGU2020/EGU2020-14117_presentation.pdf

Instrumentation & Borehole Monitoring Network



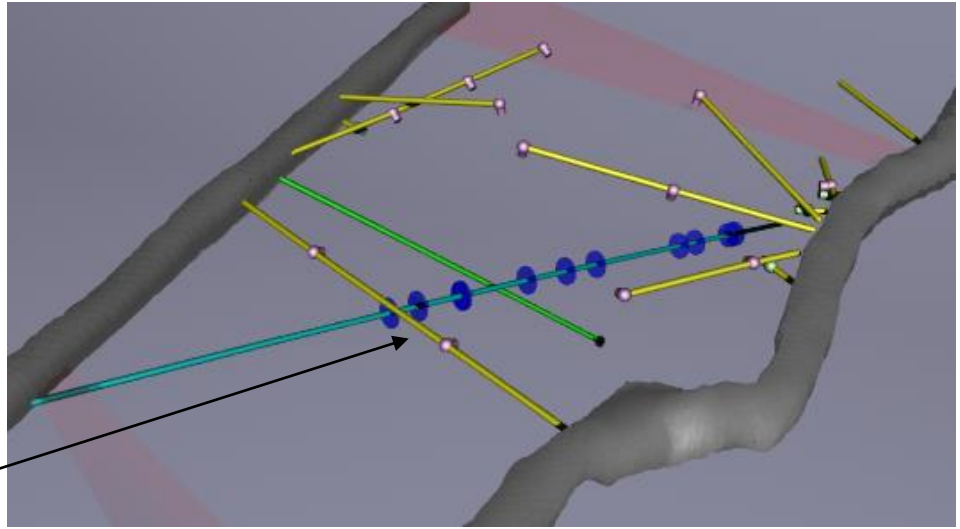
- 17 boreholes (Ø=76 mm)
- 12 AE sensors (1-100 kHz)
- 3 accelerometers (0.05-25 kHz)
- 1 broadband seismometer (0.01-100 Hz)
- 1 AE-type hydrophone (1-40 kHz)
- Up to 7 hydraulic pressure gauges

Target acoustic emissions (AE)



Hydraulic Stimulation (16-18 July 2018)

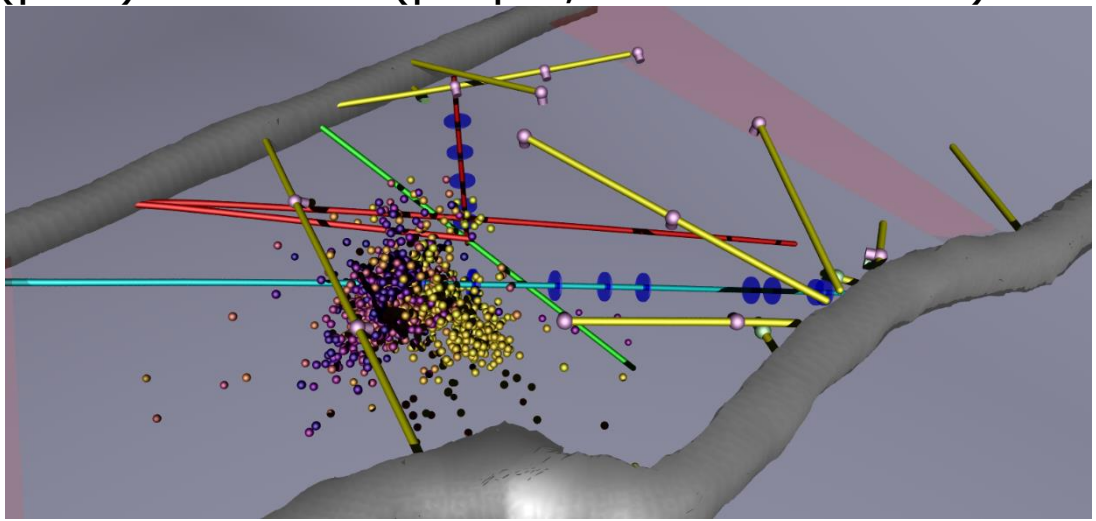
- 10 hydro-frac experiments were performed in a 63 m-long, 15° inclined injection borehole
- Real-time seismic monitoring revealed >11000 AE events in the three shallowest intervals (22.4; 24.6 and 28.1 m depth in the injection borehole)
- These were located using a transversely isotropic P-wave velocity model per station with station corrections

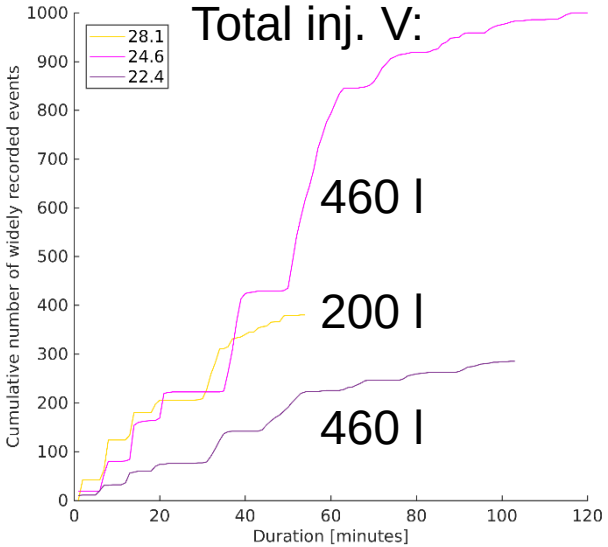


- The majority of events occurred during the periodic pumping tests, the seismic clouds extend ca. 5 m radially from the stimulated interval

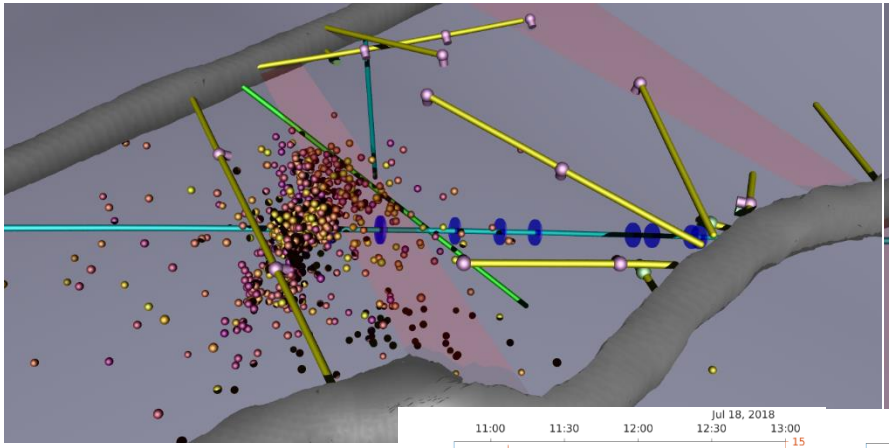
Spatio-temporal characteristics of shallow stimulation intervals (22.4-28.1)

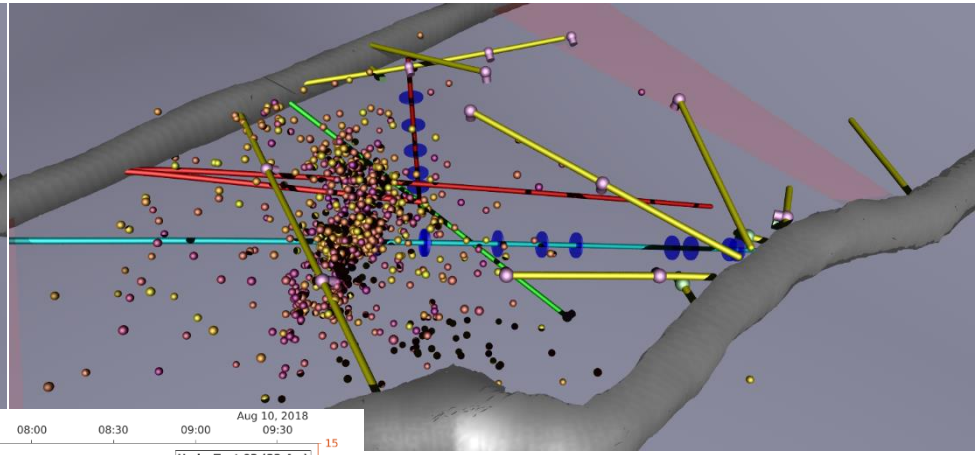
The AE events form two clusters, the one in yellow occurred first during the stimulation of interval 28.1, and is spatially more distinct than the other cluster comprising AE events from stimulation of intervals 24.6 (pink) and 22.4 (purple, last stimulation).



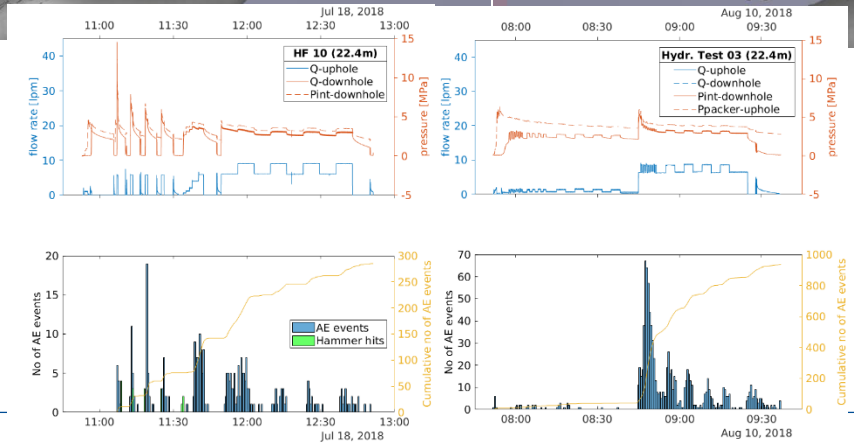


Stimulation and hydraulic testing of interval 22.4



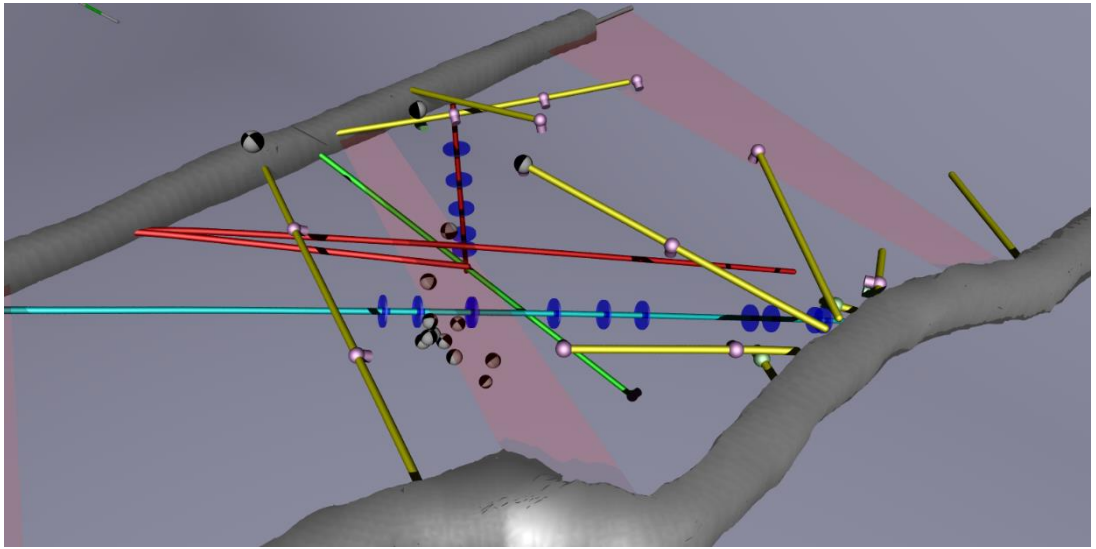


Events occurred whenever the fracture opening pressure was exceeded, with similar rate

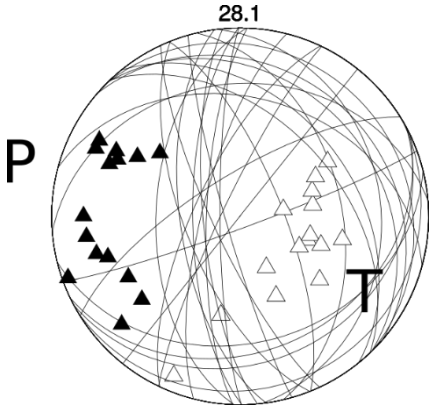


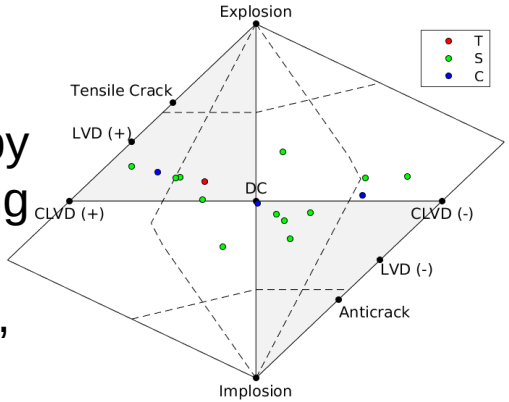
variations and locations during stimulation and hydraulic testing (1 month later) corresponding to small pressure rate changes.

Focal mechanisms (FMs) of frac and refracs from stimulation interval 28.1

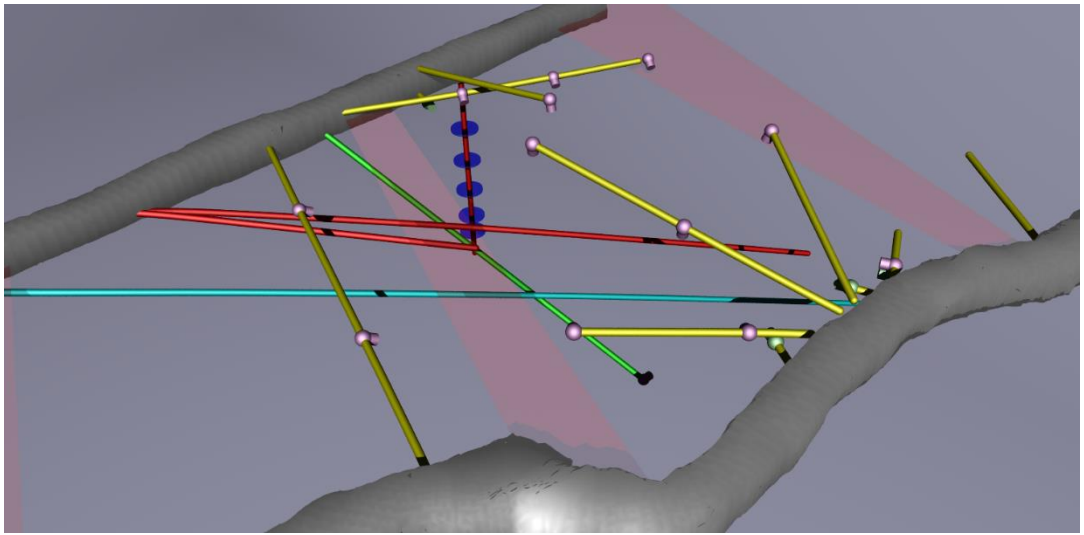


Systematic FMs with N-S to NW-SE trending nodal planes (that differ in orientation compared to the cluster elongation), dominated by shear faulting (green in Hudson plot, on right)





Stress measurements in vertical validation borehole (20/21 Aug 2019)

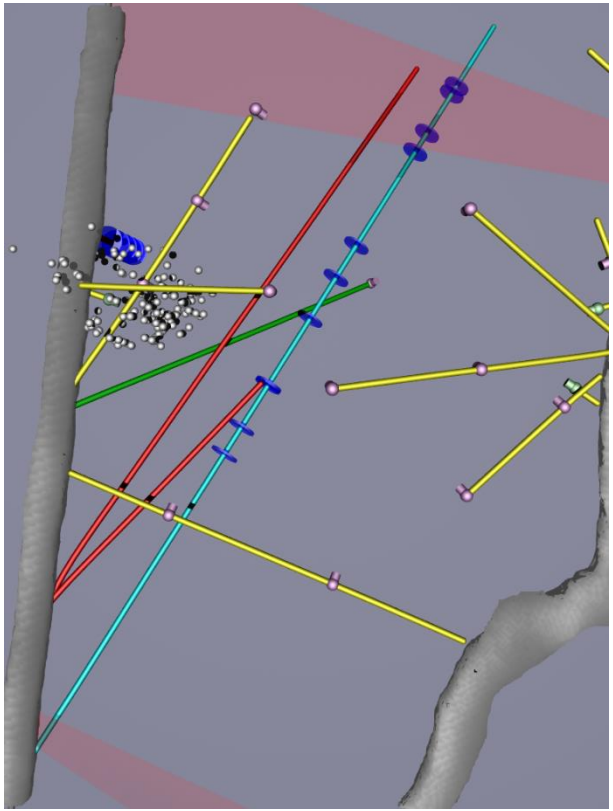


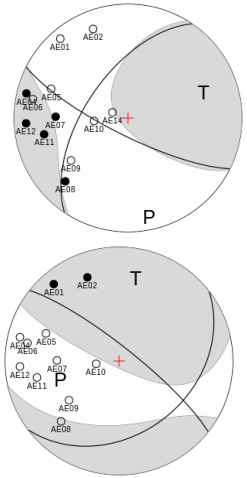
HF5	HF4	HF3	HF2	HF1
4.0 m	6.7 m	9.3 m	11.7 m	13.2 m
21/8	21/8	21/8	21/8	20/8
11:00-11:45	10:05-10:46	9:00- 9:45	8:10-8:40	13:10-14:00
22 l	19 l	21 l	18 l	33 l
11.07 MPa	14.95 MPa	7.95 MPa	14.73 MPa	7.46 MPa
303 AEs	188 AEs	52 AEs	56 AEs	9 AEs

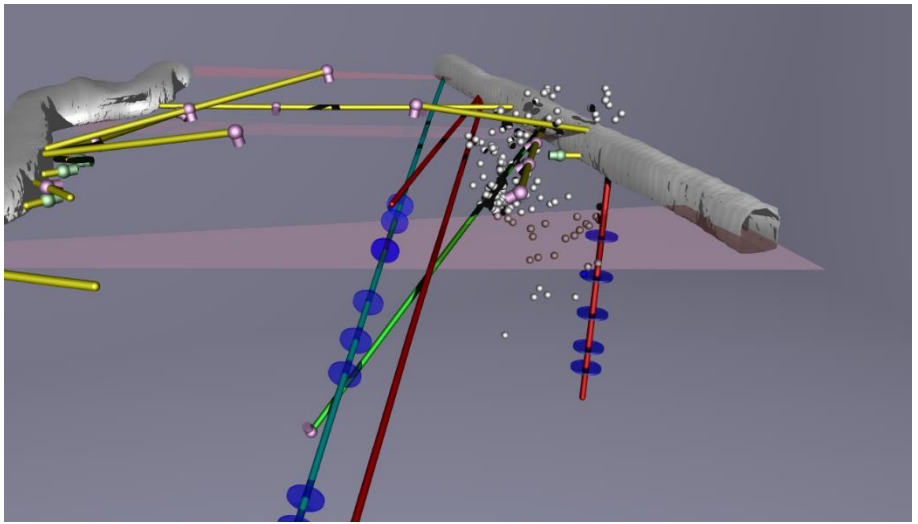
- 5 minifrac intervals
- Horizontal hydrofracs created in three intervals (4.0, 6.7 & 11.7 m depth)
- Breakdown pressures either high or low
- Seismic activity decreases with depth
- Different stress magnitudes than in injection borehole

Minifrac intervals (4.0-13.1 m)

AE event locations and representative focal mechanisms, showing NW-SE trending, steeply dipping nodal planes, consistent with the AE event cluster.







Summary & Conclusions

- In July 2018, a mine-scale hydraulic stimulation experiment with 10 stimulated intervals was conducted at the Reiche Zeche underground lab in Freiberg, Germany, in the anisotropic metamorphic gneiss formation.
- We derive moderate to strong elastic wave anisotropy (2–30%, average 12%) with fast and slow propagation parallel and perpendicular to the foliation of the host rock for the test volume using active seismic measurements and lab measurements.
- The seismic and hydraulic responses to the stimulation vary significantly along the length of the injection borehole. Most AE events were observed at the shallow injection intervals (22.4-28.1 m depth), and were associated with high breakdown pressures (11-13 MPa).
- AEs repeatably correlate with small pressure increases and decreases (but the response is independent of the pumping period applied)
- Focal mechanism solutions display a range of shear-dominated mechanisms, their variability is not the result of uncertainties, and the orientation of the nodal planes differ from the most prominent cluster elongation.
- The evaluation of the hydraulic testing and validation phases of the experiment is ongoing.

More Info: http://stimtec.rub.de/
Next ARMA newsletter 2020

STIMTEC team: B. Adero, F. Becker, F. Blümle, C. M. Boese, Y. Cheng, G. Dresen, T. Fischer, T. Frühwirt, C. Janssen, V. A. Jimenez Martinez, G. Klee, H. Konietzky, G. Kwiatek, K. Plenkers, S. Rehde, J. Renner, J. Starke, C. Wollin, T. Wonik

Thank you for your attention!

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