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FAULT INSTABILITY DETECTION USING FIBER OPTIC BASED MONITORING AT THE GARPENBERG ORE MINE, SWEDEN – FIMOPTIC PROJECT

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FIMOPTIC project 2022-2025

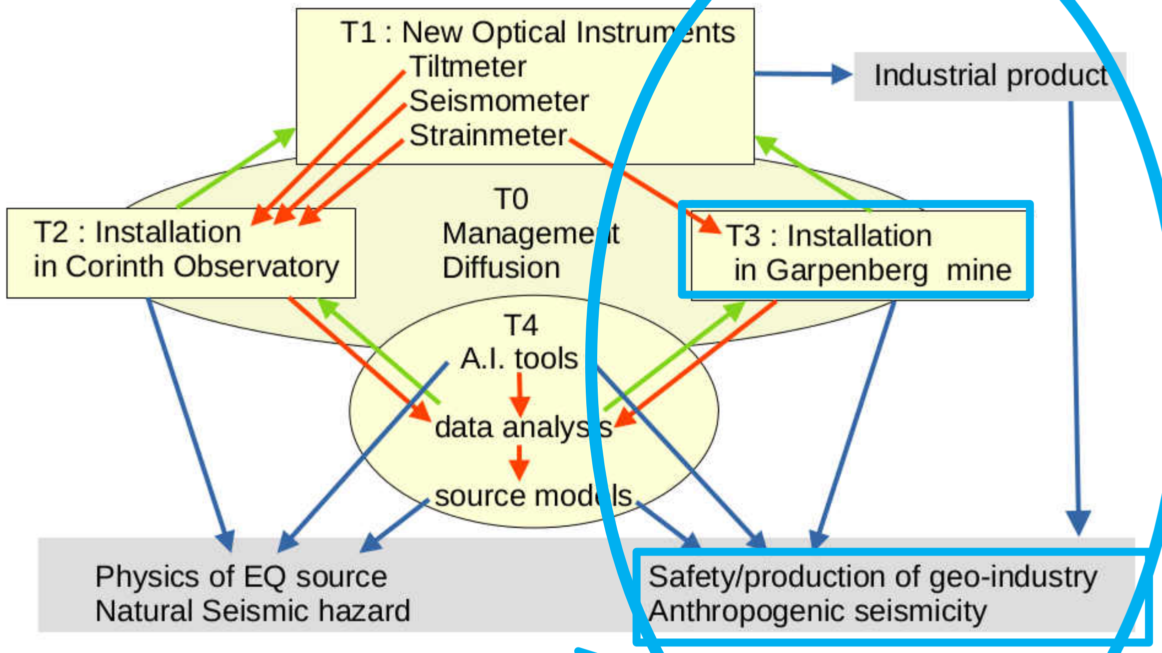
FIMOPTIC Fault Instabilities Monitored by innovative OPTICal instruments

Funding: French agency of research

Partner:

Strategical partner:

Project structure:



Objectives:

Develop and demonstrate the potential of new, high resolution, innovative optical instruments, for:

1) Improving the detection, monitoring, and characterization of ***slow, transient mechanical processes*** involved in the ***preparation phase of earthquakes ruptures***

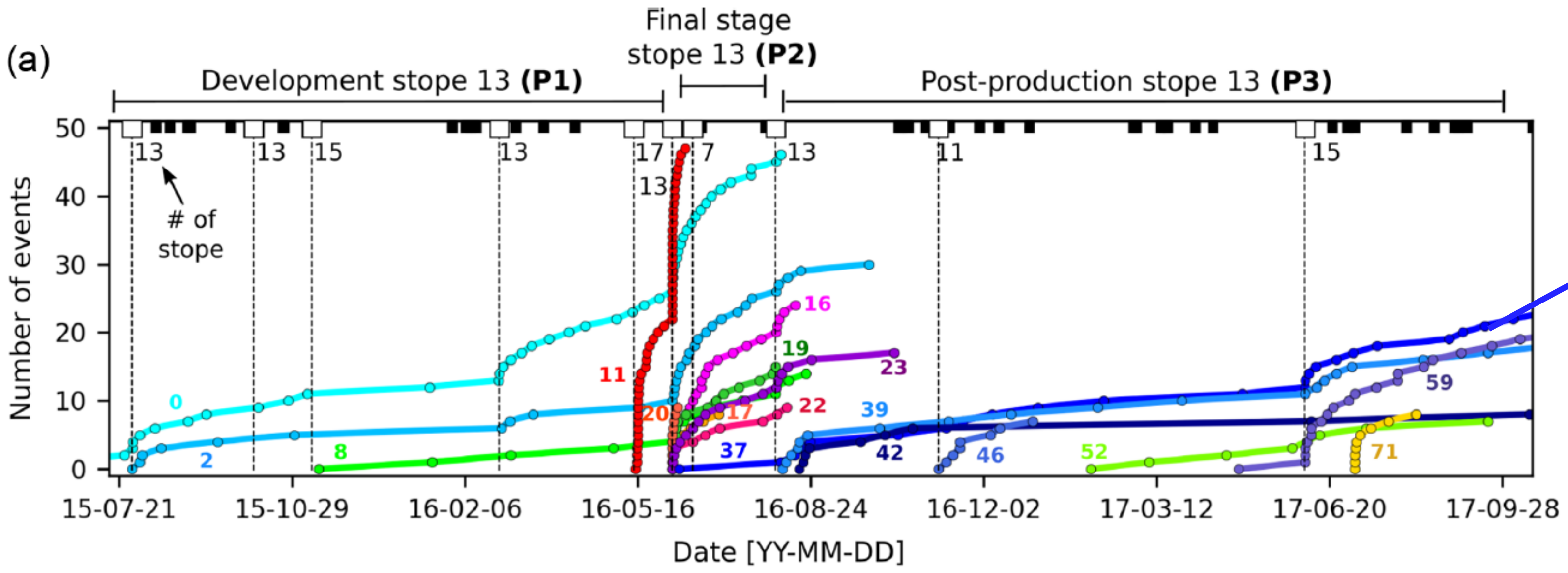
2) Evaluating its potential to mitigate ***anthropogenic seismic hazard*** (underground mining)

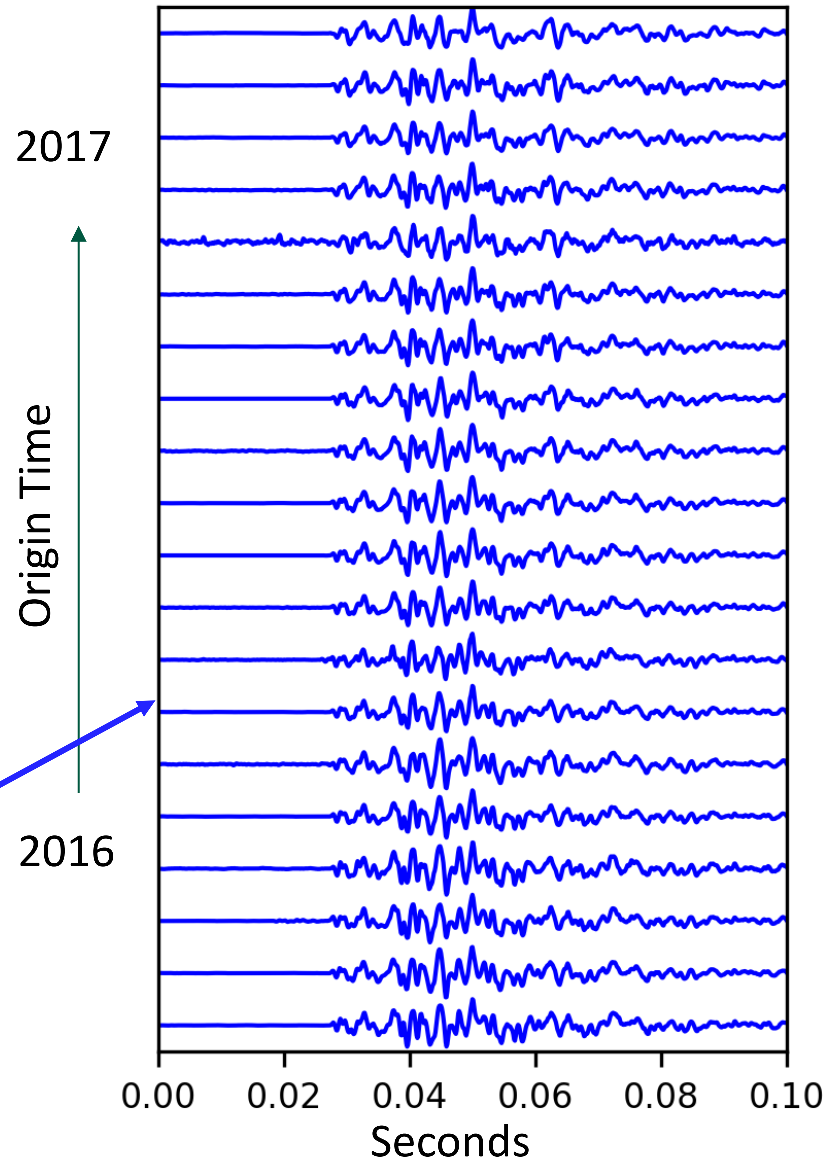
Why Garpenberg ?

Example of high coherency in wave forms

1) Observation of persisting, highly similar wave forms (multiplet families) induced from blasing

⇒ we «know» where and when seismicity will likely occur which allows for monitoring of the full seismic cycle





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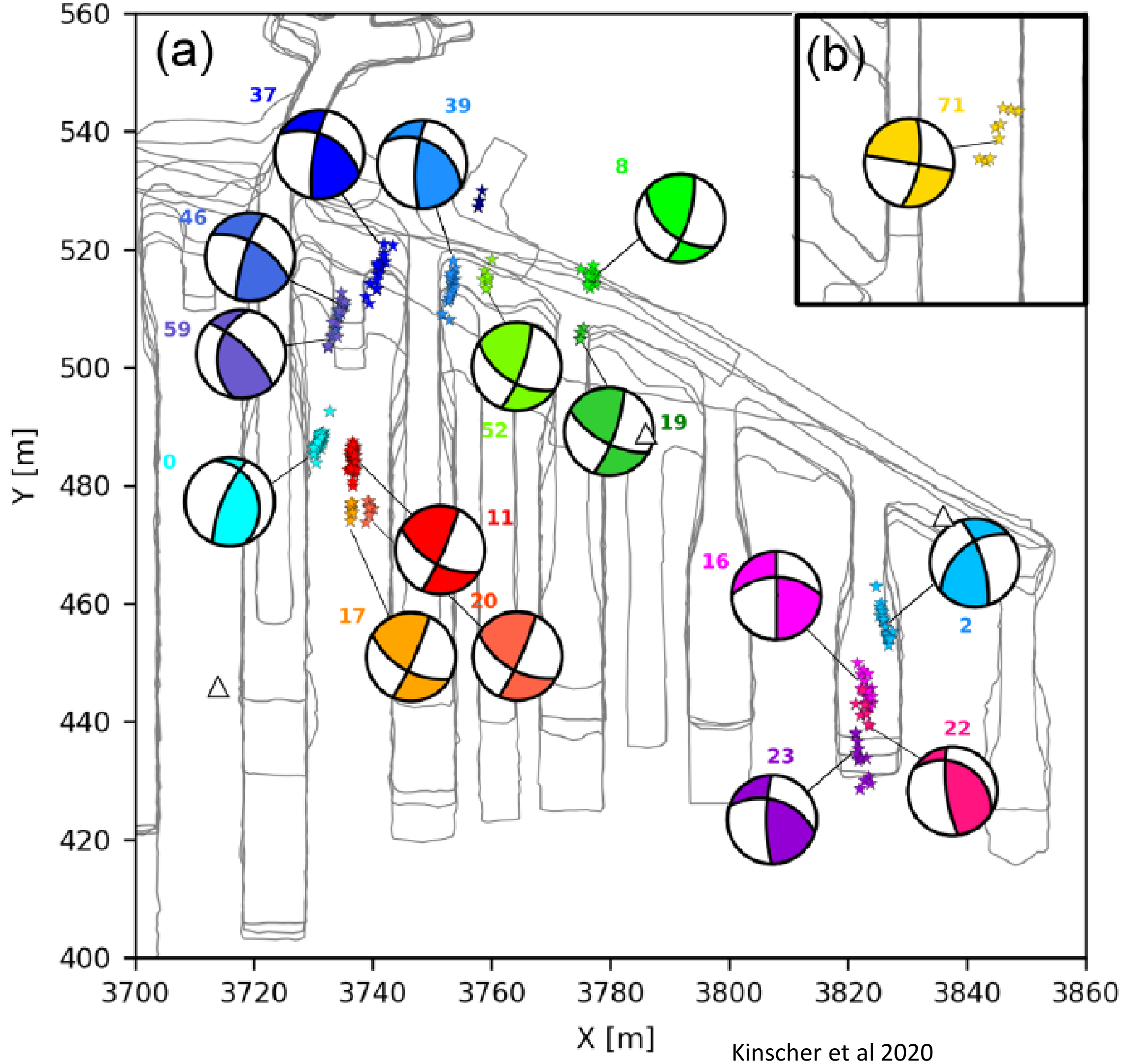
2) Seismicity occurs on fault-like structures

⇒ Faulting phenomena (even though forced/accelerated from excavation) is comparable to tectonic faults…

Multiplet families
Source mechanisms and relocation



Kinscher et al 2020

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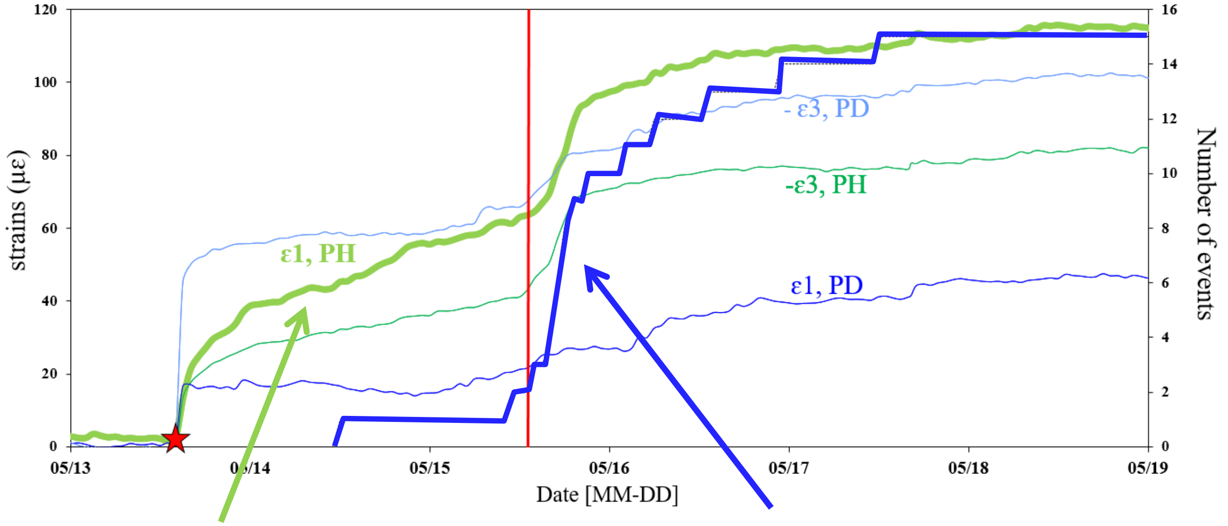
3) Evidence for presence of aseismic creep and potential link to seismic triggering

⇒ Slow transient mechanics and seismic-aseismic coupling processes involved in faulting dynamics

Post-blast creep sequence example

Post-blast creep vs multiplet transient



adjacent strain cell

recurrence rate

Lhoumaud 2023

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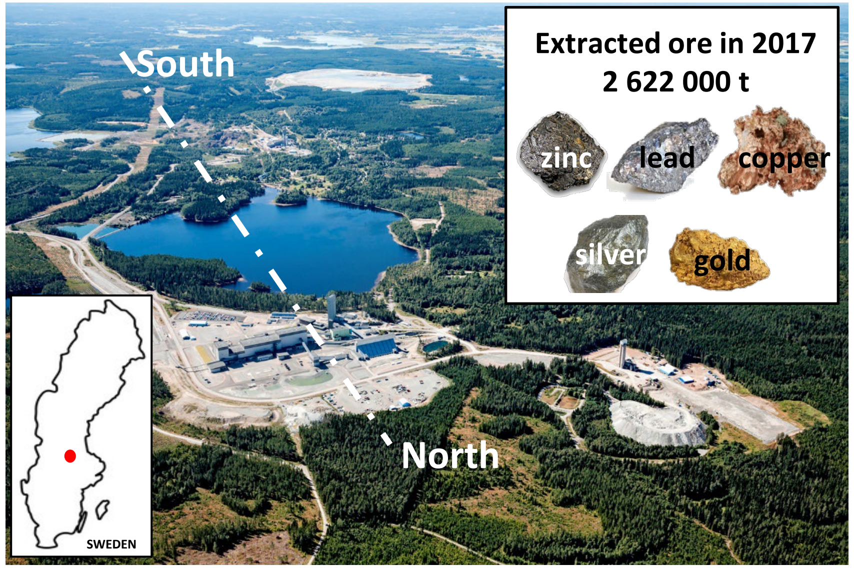
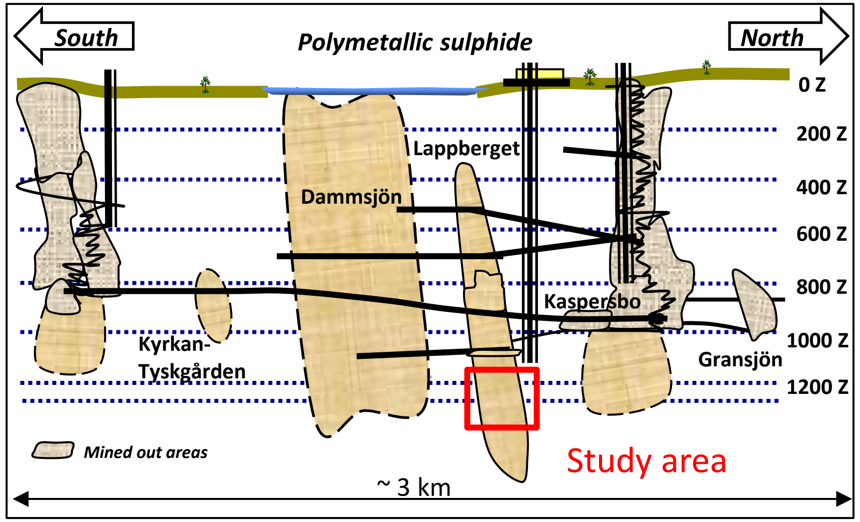
Garpenberg mine: Study site

Areal view of Garpenberg mine



Vertical profile of Garpenberg mine



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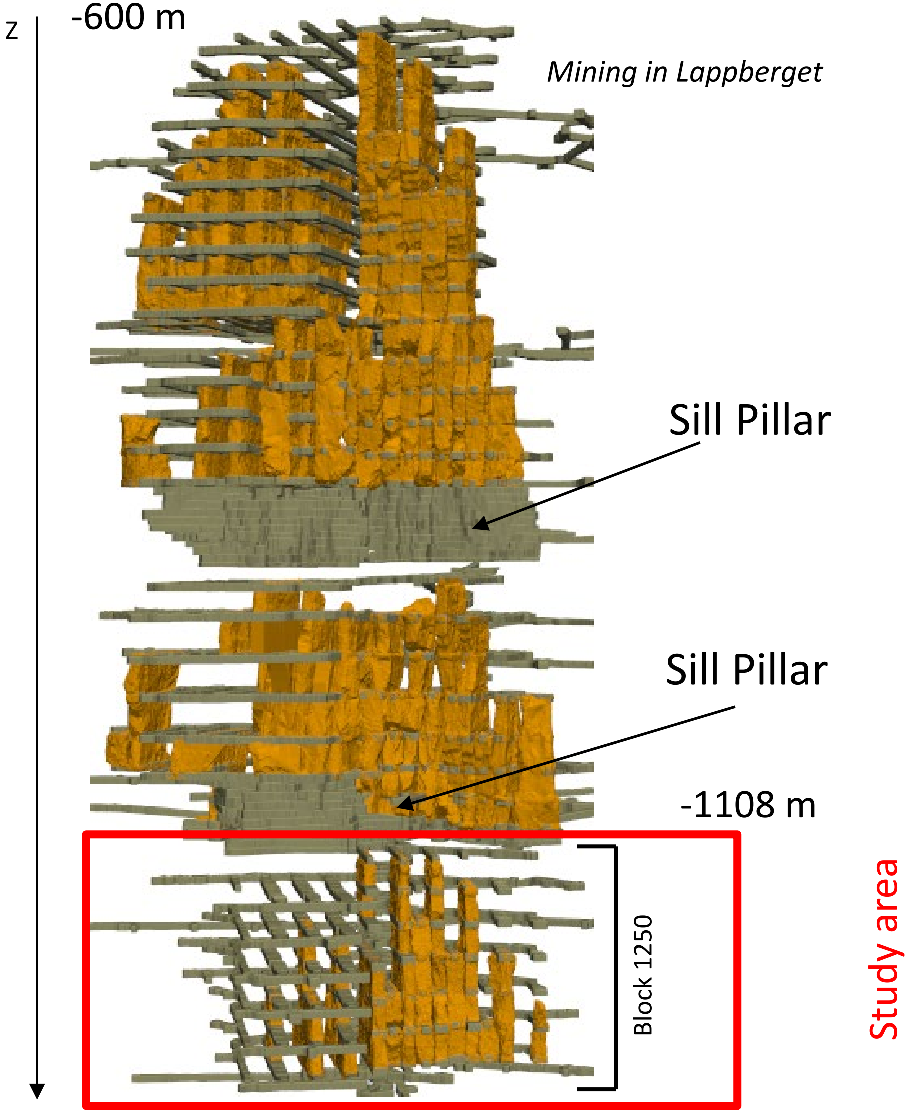
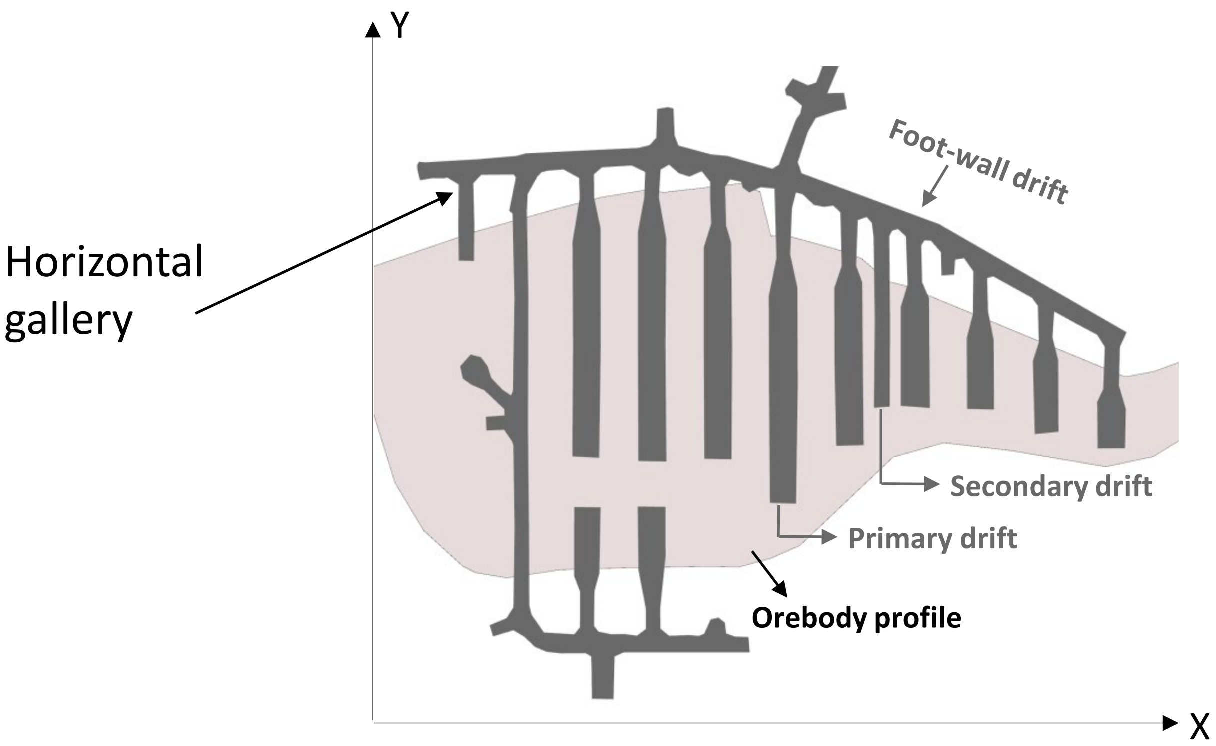
BOLIDEN



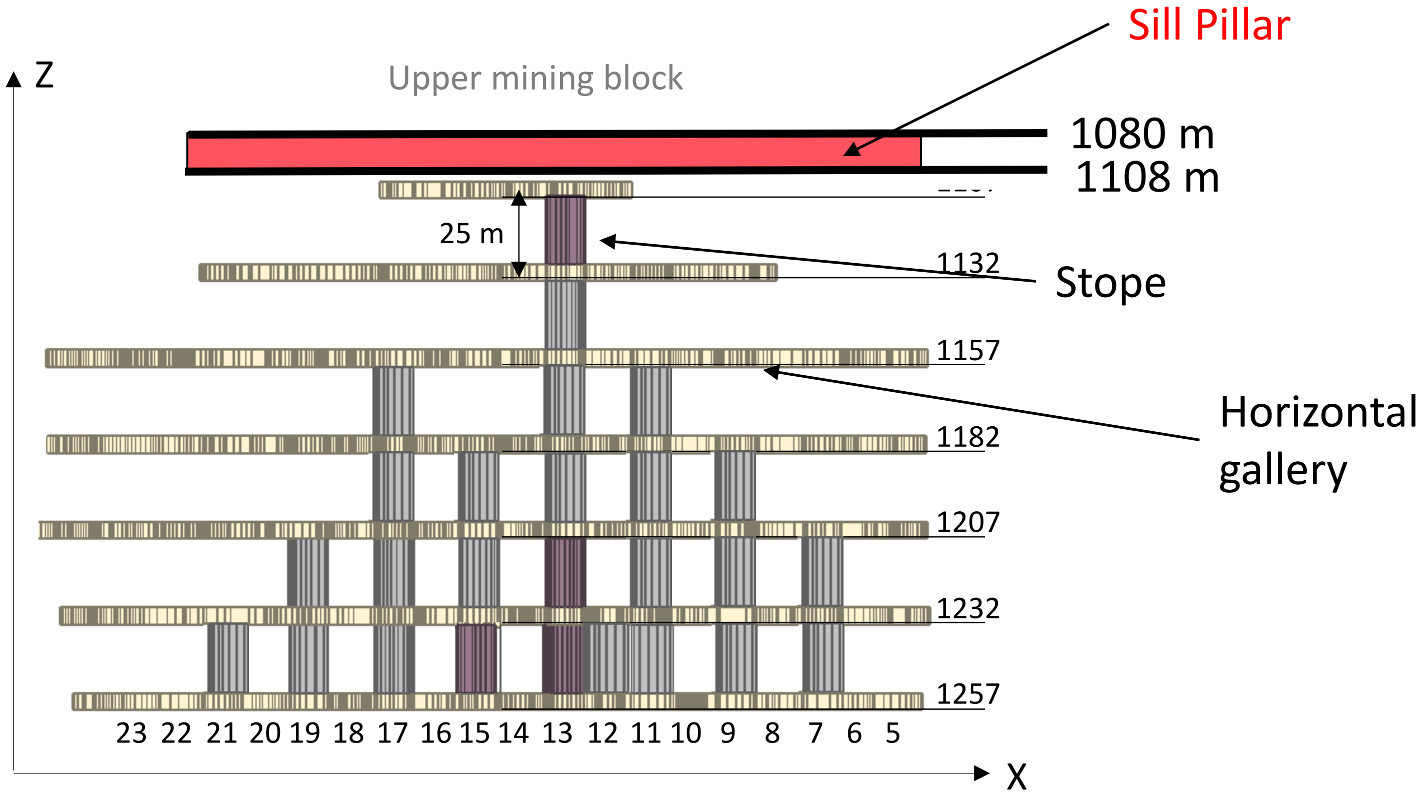
Study site: Sill Pillar Block 1250

Sublevel Stoping with backfilling

Horizontal section



Vertical section



De Santis 2019

… Persistent multiplet families in the Sill-Pillar since 2017 …

FIMOPTIC Project structure/strategy

Phase1: locate and characterize repeater sources

Phase 2 : local in-situ monitoring on target repeater

Commercial fiber optic technologies:

DAS (Distributed Acoustic Sensing)

- Sensitivity: nano strain rate (>10 Hz)
- Sampling: 5 kHz

DTSS (Distributed Temperature Strain Sensing)
Brillouin diffusion based interrogator (BOTDR)

- Sensitivity: > 10 micro strain
- Min sampling: 1 min

⇒ *Monitor strain and seismicity of the compete seismic cycle*

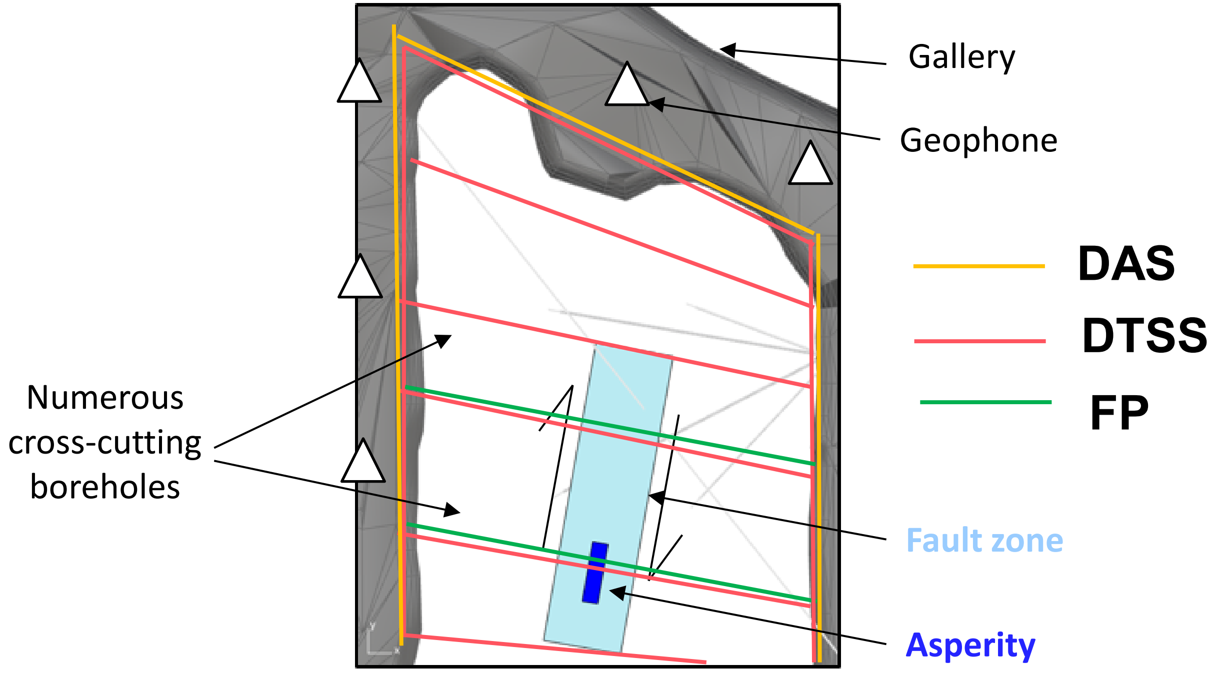
Innovative fiber optic technologies:

FP: (Fabry-Perot interferometry)
Optical strain meter developed by ESEO and IPGP

- Sensitivity: 0.1-1 nanostrain (<10 Hz)

⇒ *Potential detection of (slow mechanic) rupture nucleation and loading phase of asperity*

Possible design of optical fiber based repeater in-situ monitoring along galleries and boreholes



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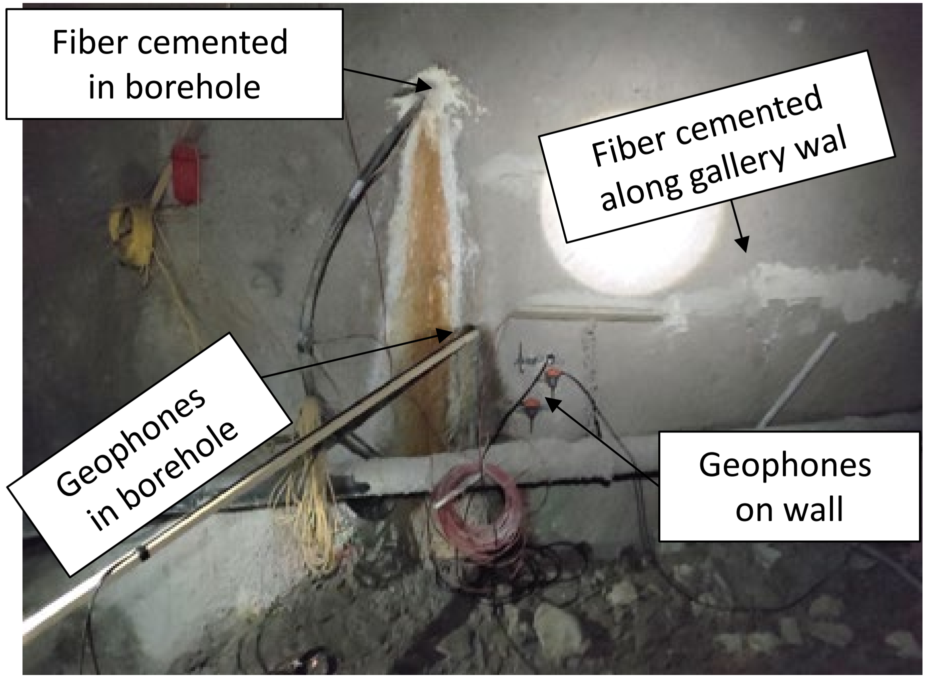
Challenges during monitoring set up

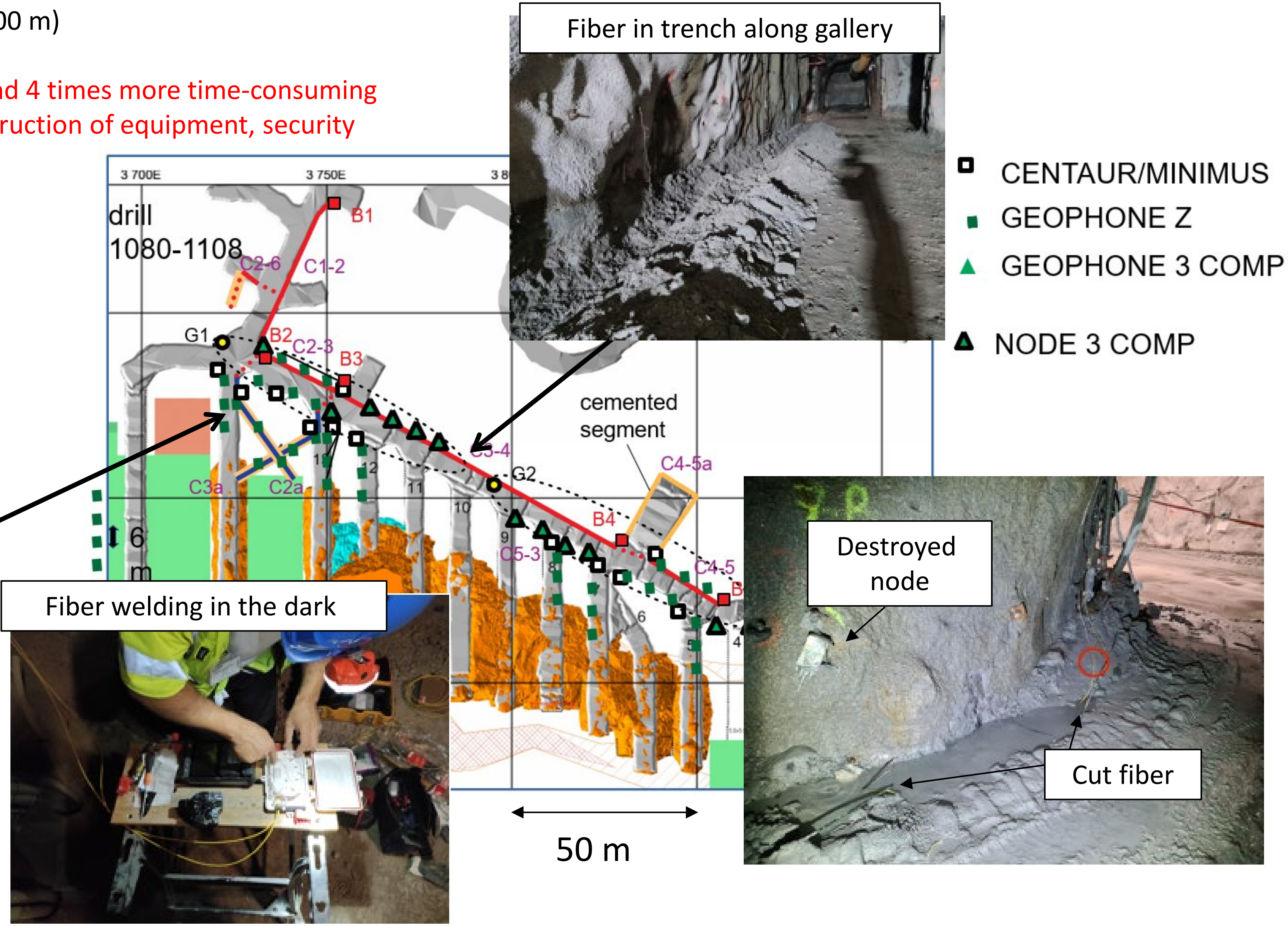
Initial ambitious plan of extensive installation in Sill-Pillar:

- Using DAS and ~ 60 geophones and nodes along two galleries (> 200 m)

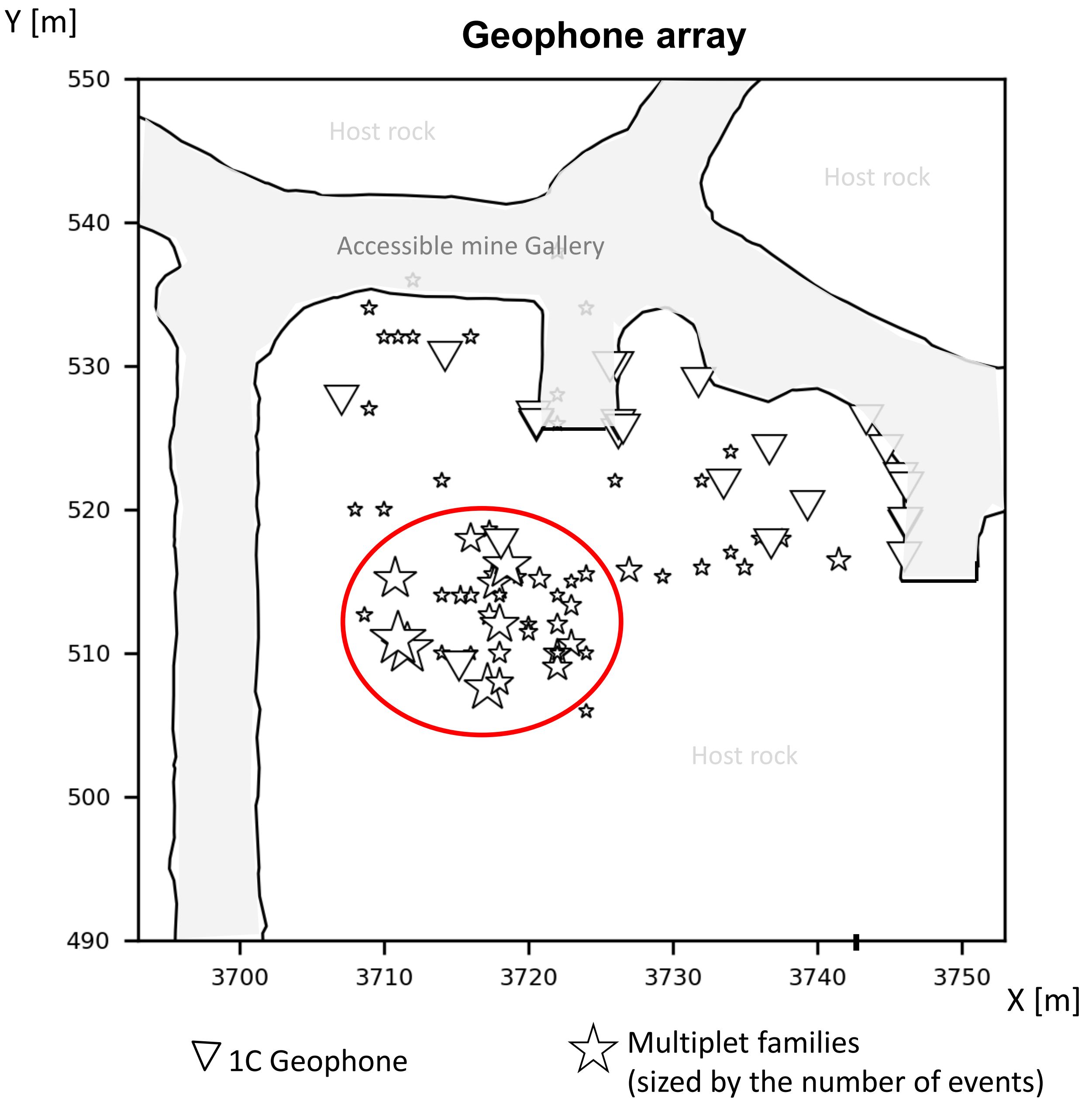
=> Intervention in active mining environment is challenging and around 4 times more time-consuming compared to standard field missions (changes in production plan, destruction of equipment, security measurements etc.)

Fiber in boreholes and gallery walls





Seismic monitoring



- Focus on area associated with long-term repeater occurrences (2016-2022)
- Installation (May – Sep 23) of > 20 geophones and nodes
- Identification of zone of major multiplet activity

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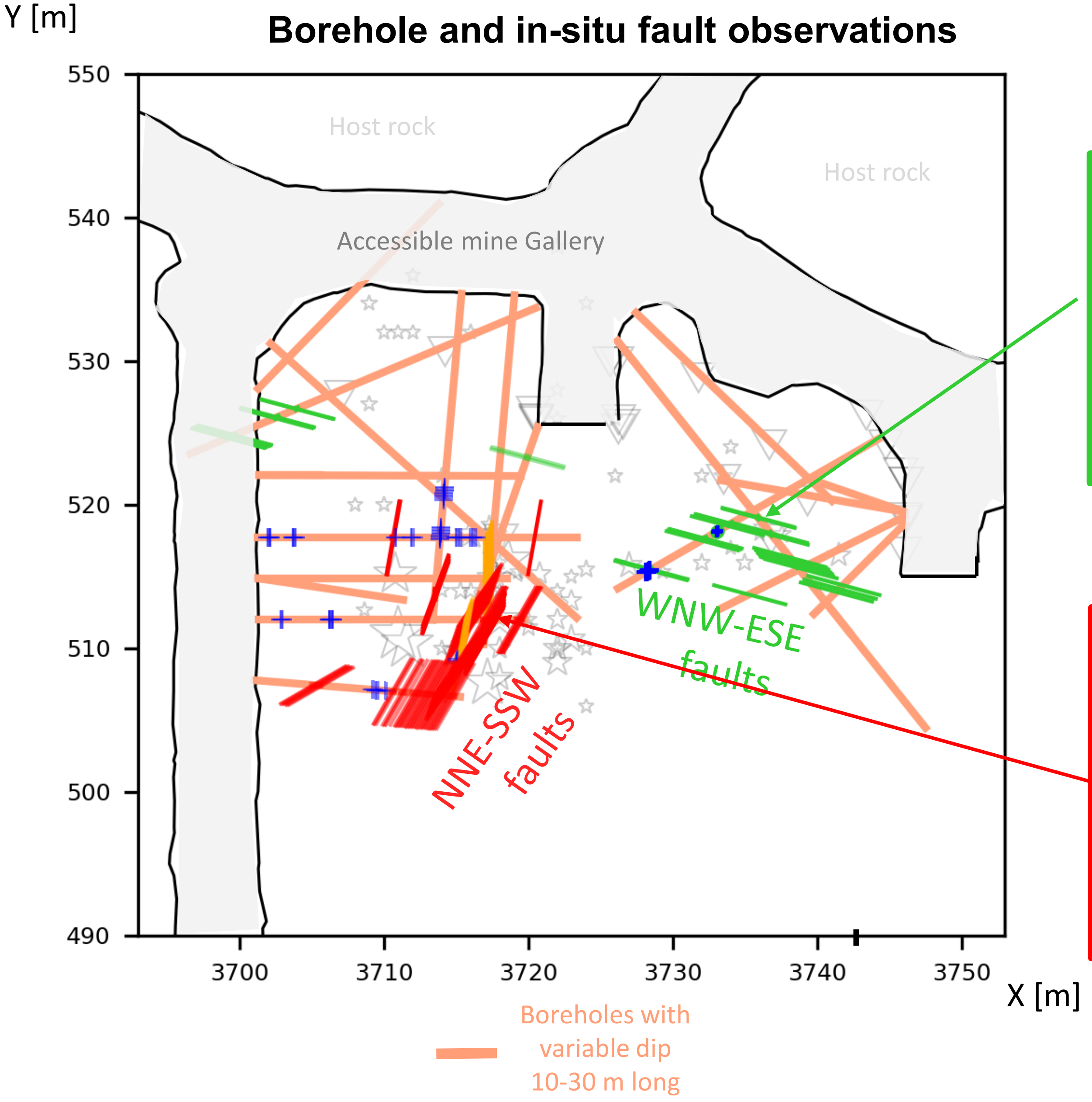
In-situ borehole observations



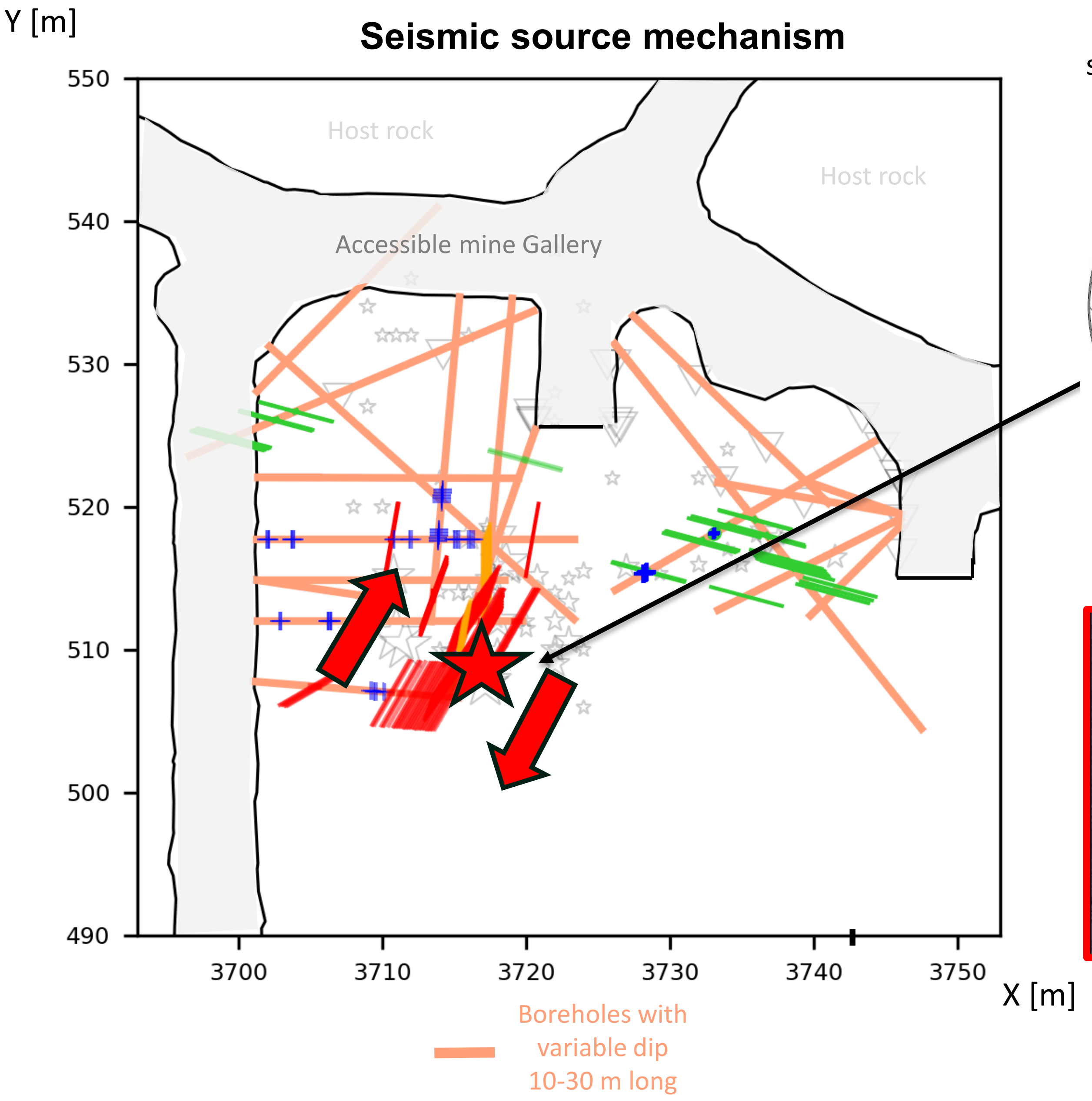
Borehole camera images

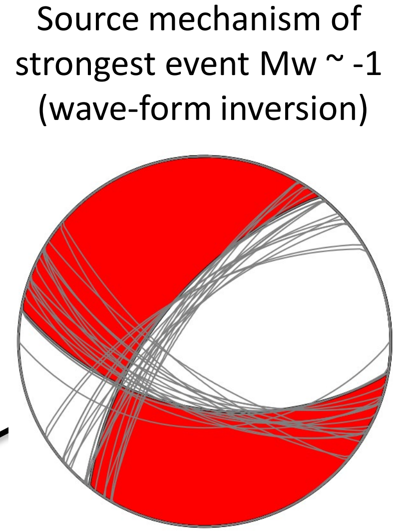
WNW-ESE strikings fauls

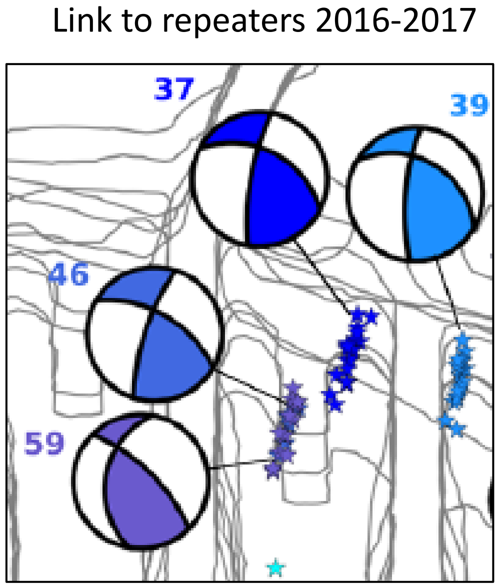
NNE-SSW stiking faults

- 2 main groups of “open” fault structures
- NNE-SSW Faults dominant in most active multiplet zone

Seismic source mechanism







NNE-SSW Fault

- 2 main groups of "open" fault structures
- NNE-SSW Faults dominant in most active multiplet zone
- Fault trend consistent with source mechanisms of multiplets and long-term repeaters

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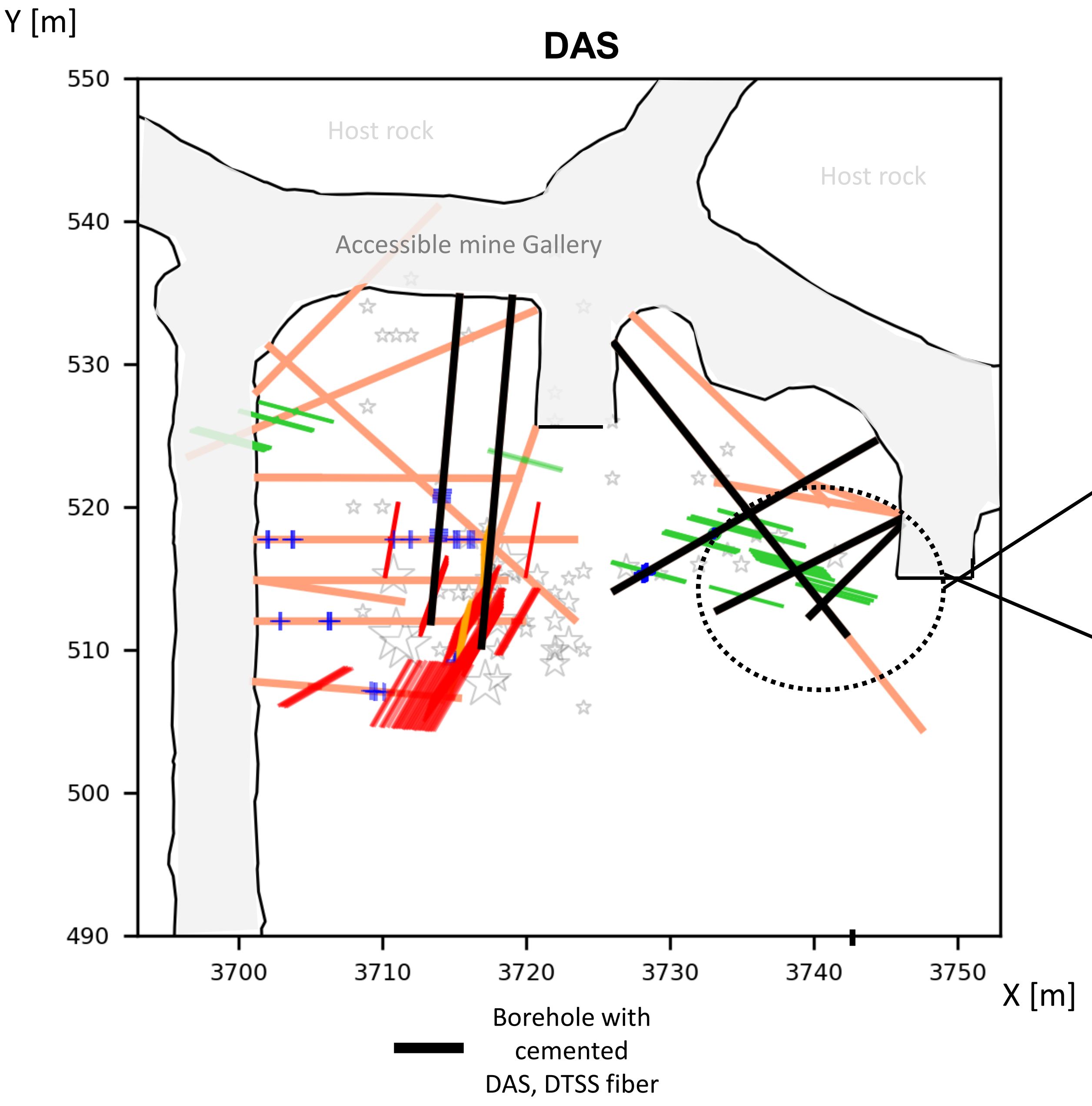
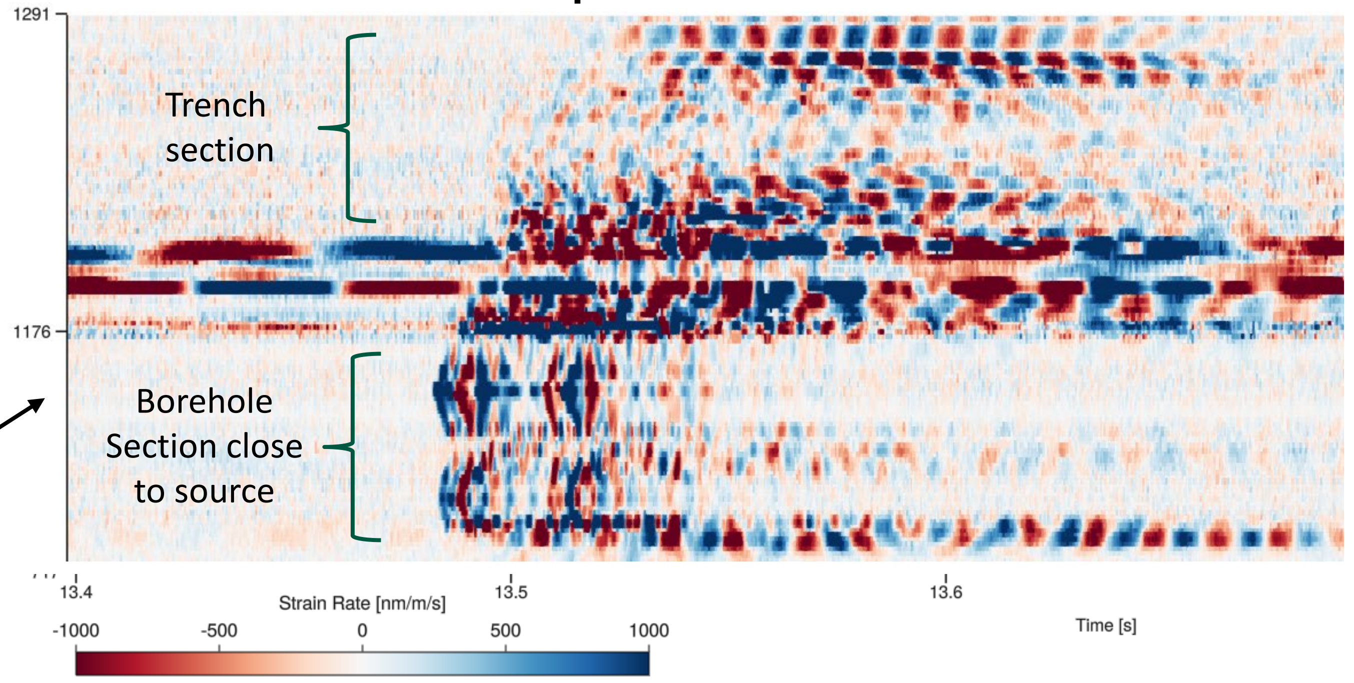
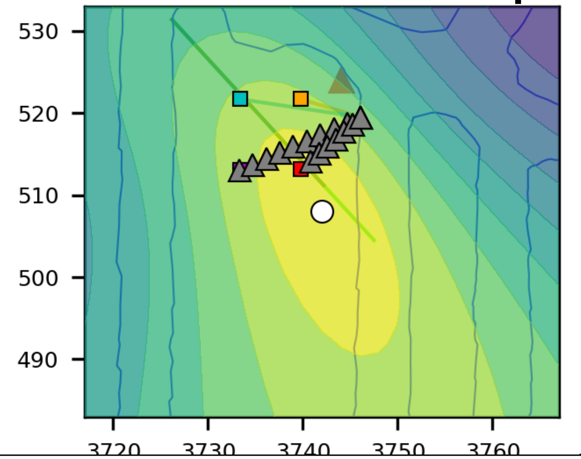
Seismic source characterization using DAS



Example seismic event on DAS



Event Location example



- Best quality in cemented boreholes
- DAS useful for location of stronger events and study on wavefield radiation and propagation

- Shortcomings/challenges:
⇒ 10-100 less sensitive compared to geophone
⇒ Data volume (3 Gb/min) (5kHz sampling rate)

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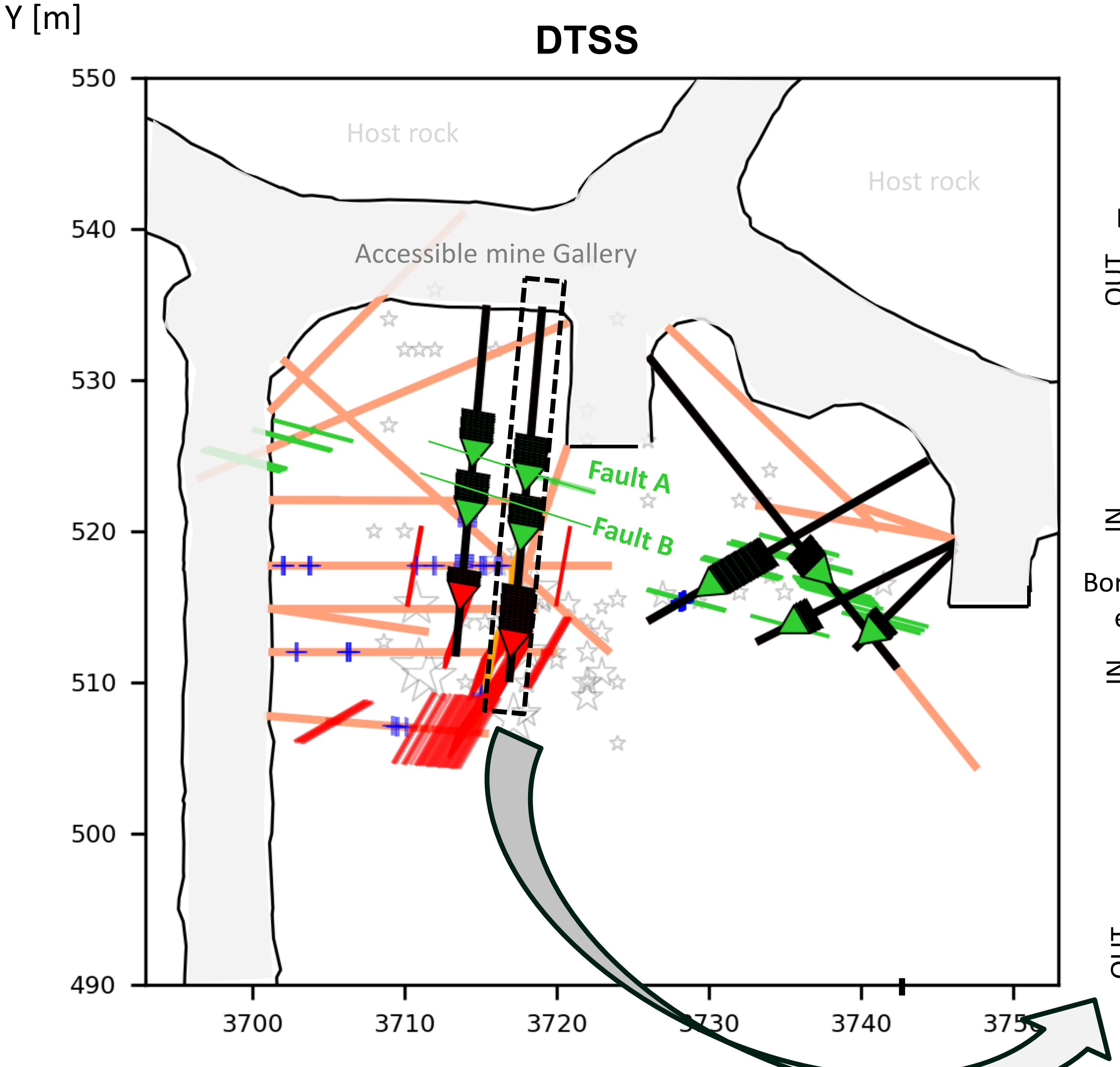
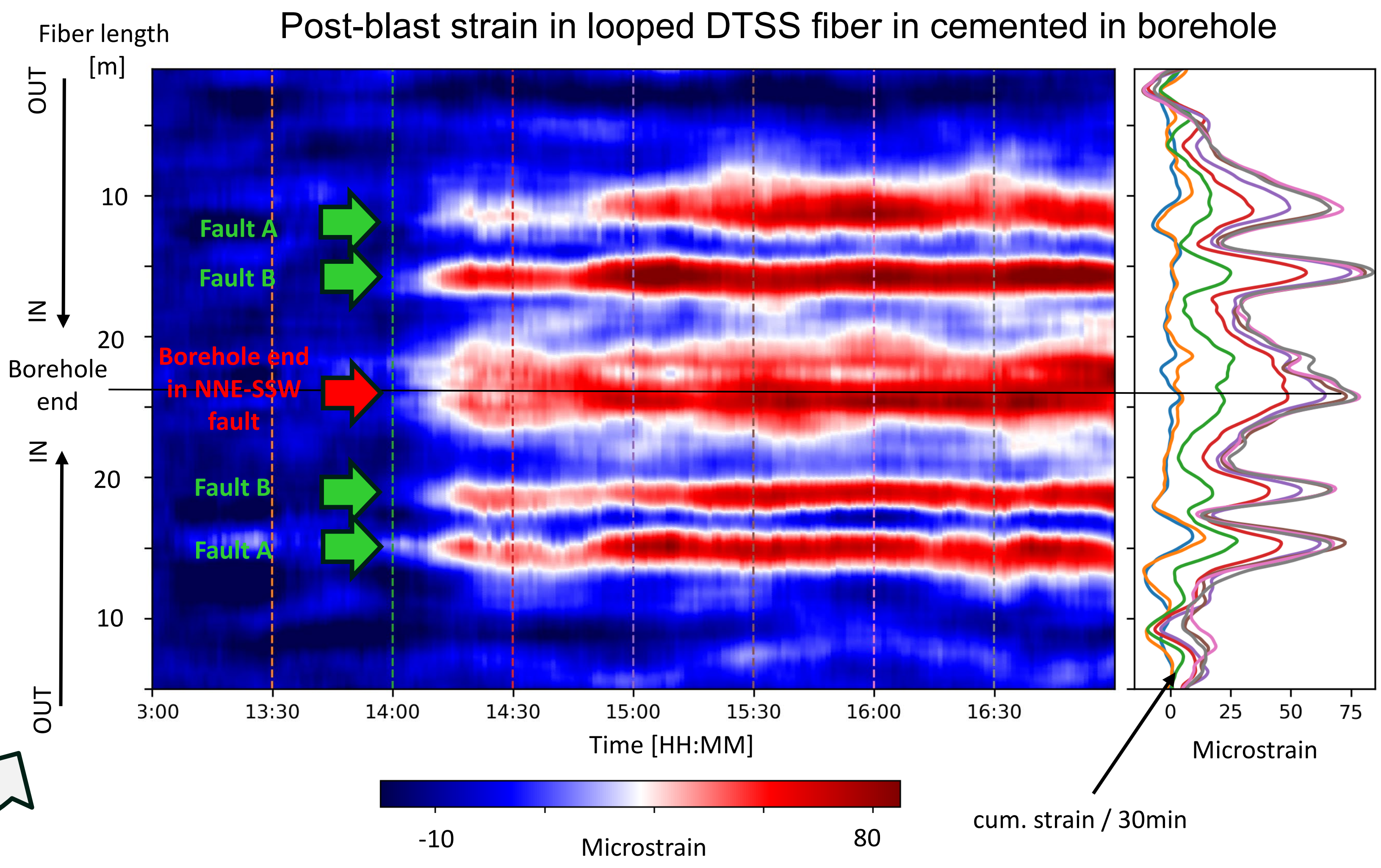
Phase 1: locate and characterize repeaters

Fault (creep) detection using DTSS



▽ Extensional (pos.) strain in DTSS

- Detection of 2-3 m thicks fault zones



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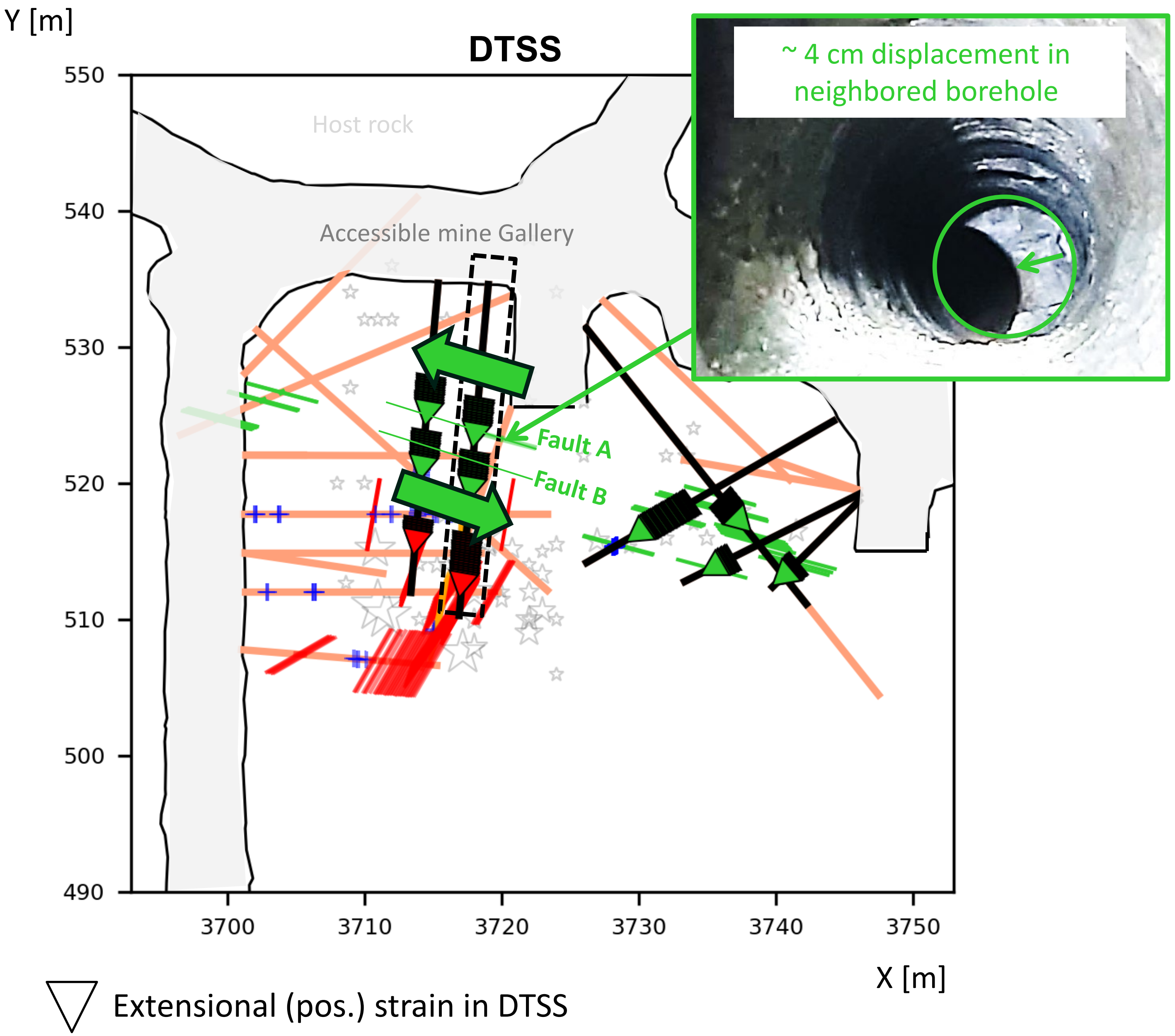
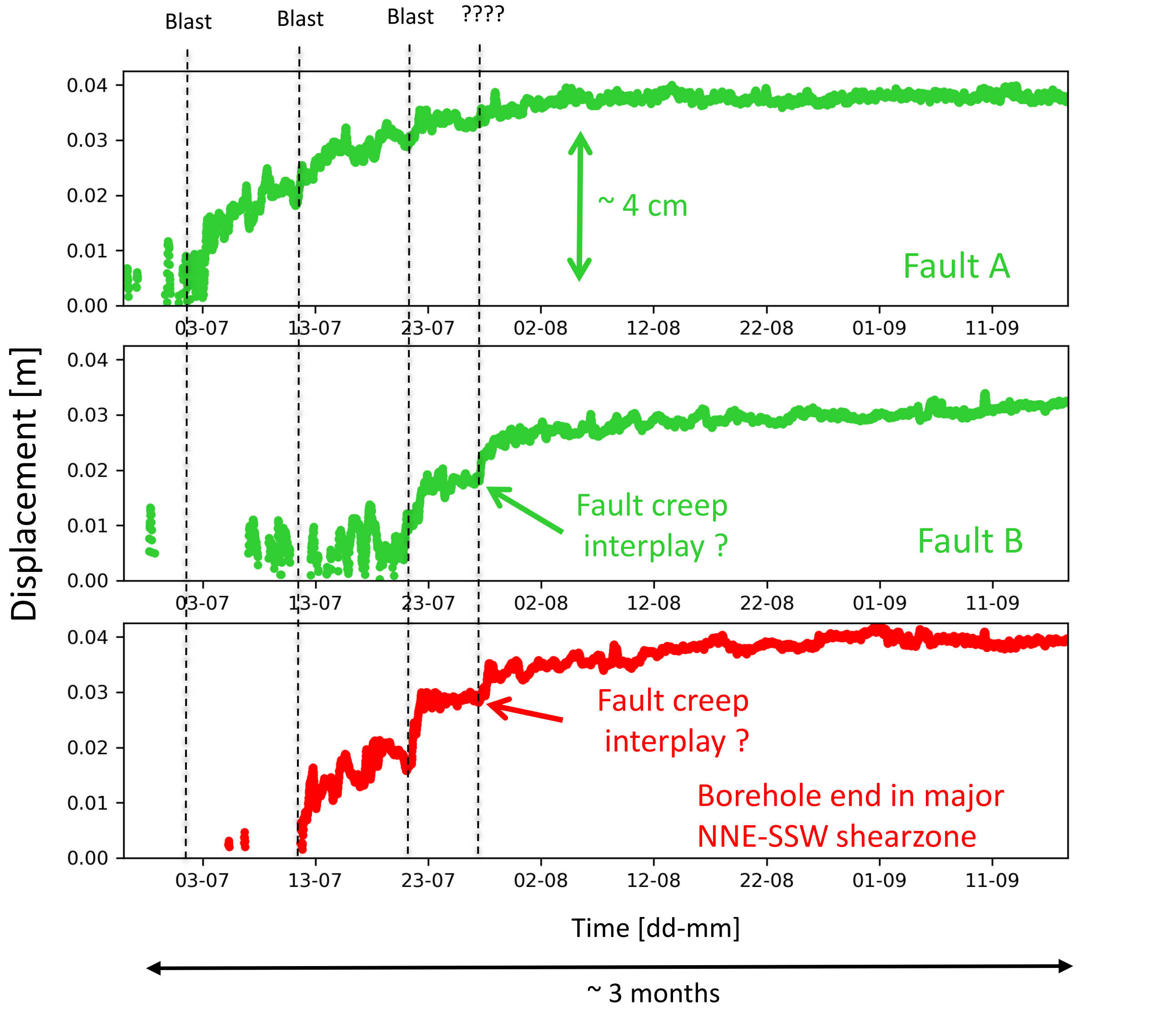
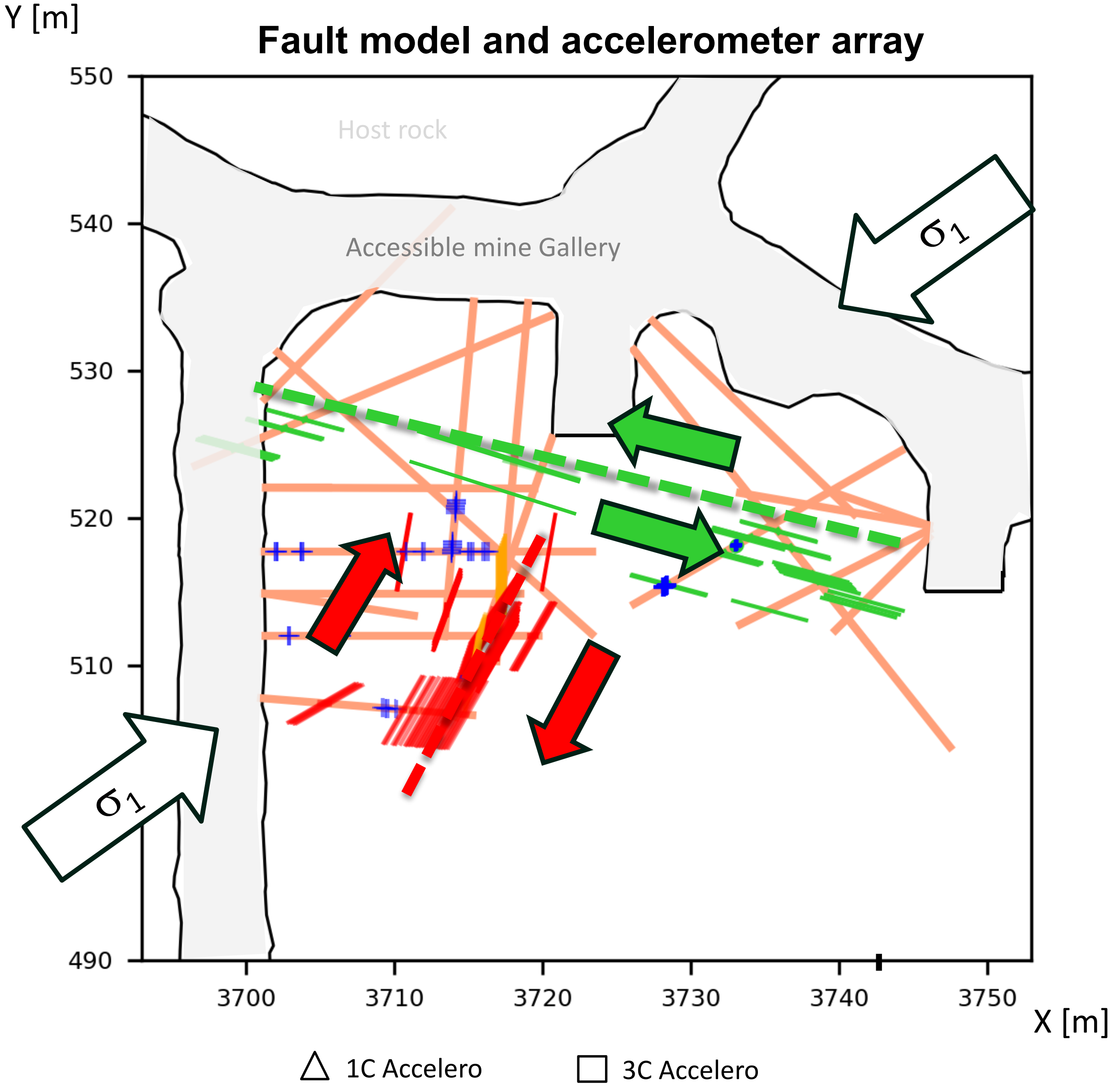
Evidence for different long-term creep behaviors



Displacement deduced from strain integration over shear zones
(assumptions on fault angle, shear zone width and fiber bending)



Fault model and repeater origin



Hypothetic fault/repeater model

- Post-blast stress redistribution widely accommodated by means of creep along (preexisting) fault structures opened subparallel to the main galleries

- Repeaters/multiplet represent parts in fault zones associated with higher friction loaded from fault creep

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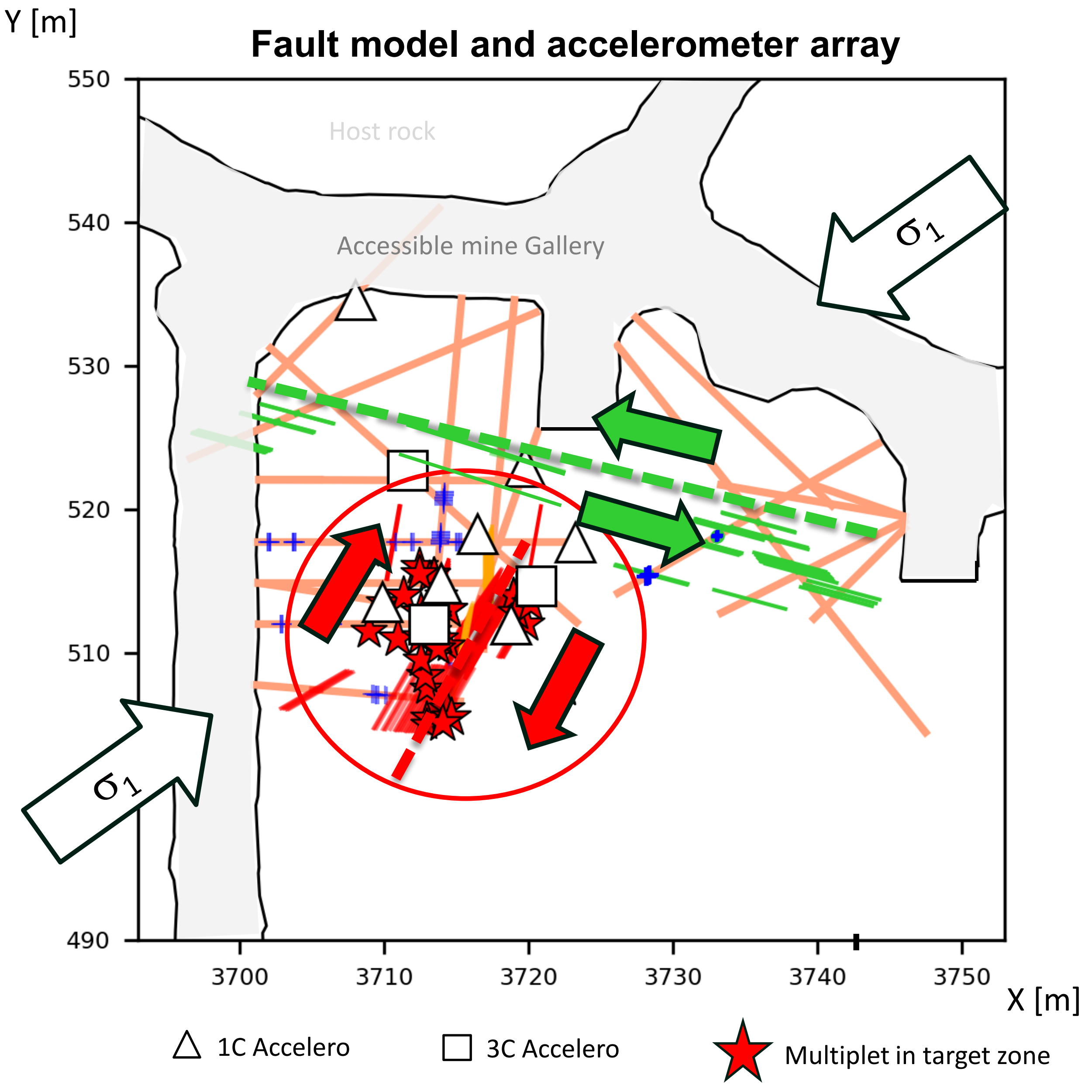

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Current investigations:

- Focus on NNE-SSW fault
- Set up of very local accelerometer network to locate precisely (< 1 m) seismic asperities

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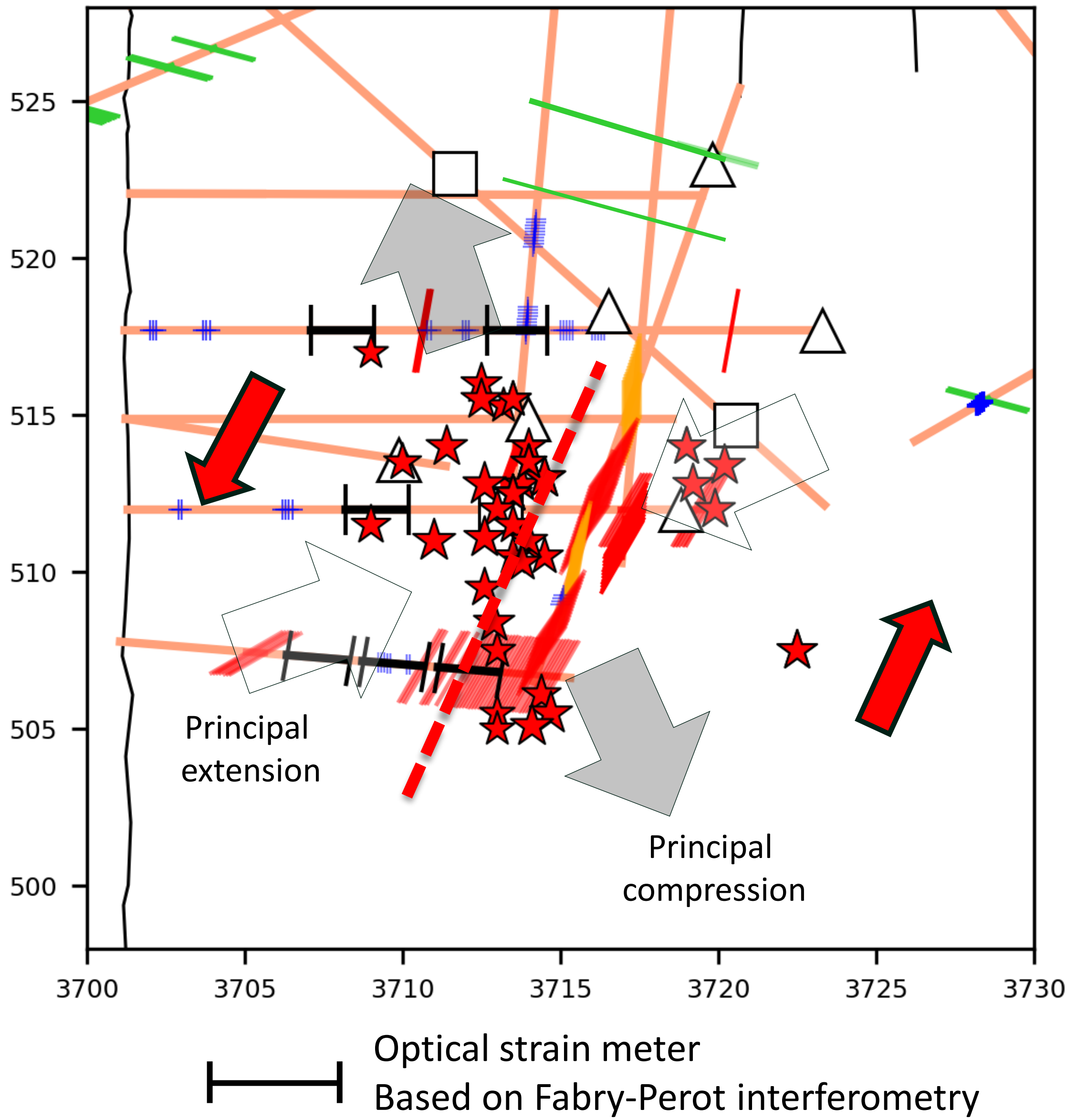
Co and inter-seismic slip detection



Current investigations:

- Focus on NNE-SSW fault
- Set up of very local accelerometer network to locate precisely (< 1 m) seismic asperities
- FP strainmeters placed next to seismic asperities and at the expected principal strain axis during inter-and co-seismic fault slip

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Conclusions

- Repeaters/multiplets are related to aseismic-seismic coupling processes in fault zones

- Fault creep is important mechanism for post-blast stress redistribution

- DTSS highly valuable tool for fault detection and creep monitoring

- DAS is promising for studies on wave radiation and propagation but remains challenging when using high sampling rates (data volume)

- Inter- and co-seismic strain monitoring under investigation

Merci

Particular thanks to