

# Monitoring and development of deep geothermal energy sites

Matchmaking: Industry meets academia – building consortia for relevant R&D-projects  
26th January 2023

Volker Oye, NOR SAR

[Volker@norsar.no](mailto:Volker@norsar.no)



# NORSAR activities within geothermal energy

## Projects:

**Paralana, South Australia:** Generating an Enhanced Geothermal System

- real-time characterization of fracture creation
- event locations, seismic imaging and modelling

**Basel, Switzerland:** precise relocation of micro-earthquakes during hydraulic fracturing

- determination of type of cracks (opening or shearing)
- risk analysis for post-injection seismicity

**Reykjanes, Iceland:** discrimination between natural and induced seismicity

**Hengill, Iceland:** exploration of new prospects for deep geothermal energy generation  
Geothermica project DEEPEN

# EGS at Paralana, Australia

Geothermics 52 (2014) 6-21  
doi: 10.1016/j.geothermics.2014.06.005

## Analysis of induced seismicity in geothermal reservoirs – An overview

Arno Zang<sup>a,\*</sup>, Volker Oye<sup>b</sup>, Philippe Jousset<sup>c</sup>, Nicholas Deichmann<sup>d</sup>, Roland Gritto<sup>e</sup>,  
Art McGarr<sup>f</sup>, Ernest Majer<sup>g</sup>, David Bruhn<sup>e</sup>

<sup>a</sup> German Research Center for Geosciences (GFZ), Section 2.6 Seismic Hazard and Stress Field, Telegrafenberg, 14473 Potsdam, Germany

<sup>b</sup> NORSAR, P.O. Box 53, N-2027 Kjeller, Norway

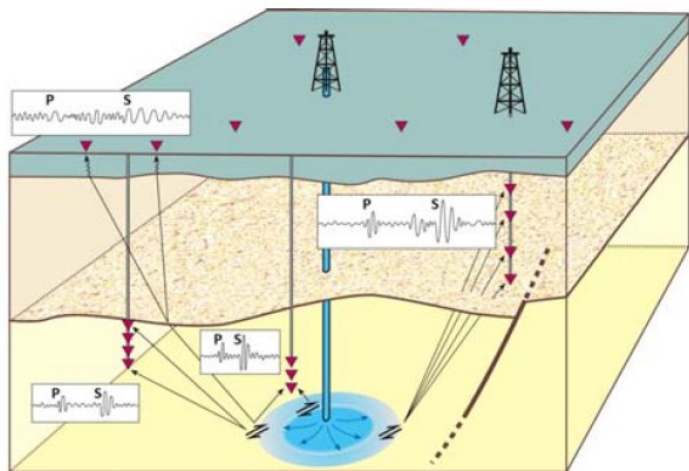
<sup>c</sup> GFZ, International Center for Geothermal Research, 14473 Potsdam, Germany

<sup>d</sup> Swiss Seismological Service, ETH Zürich, Sonneggstrasse 5, CH-8092 Zürich, Switzerland

<sup>e</sup> Array Information Technology, 2020 Cedar Street, Berkeley, CA 94709, USA

<sup>f</sup> U.S. Geological Survey, Menlo Park, CA 94025, USA

<sup>g</sup> Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA



ELSEVIER

Geothermics

Volume 52, October 2014, Pages 120-131

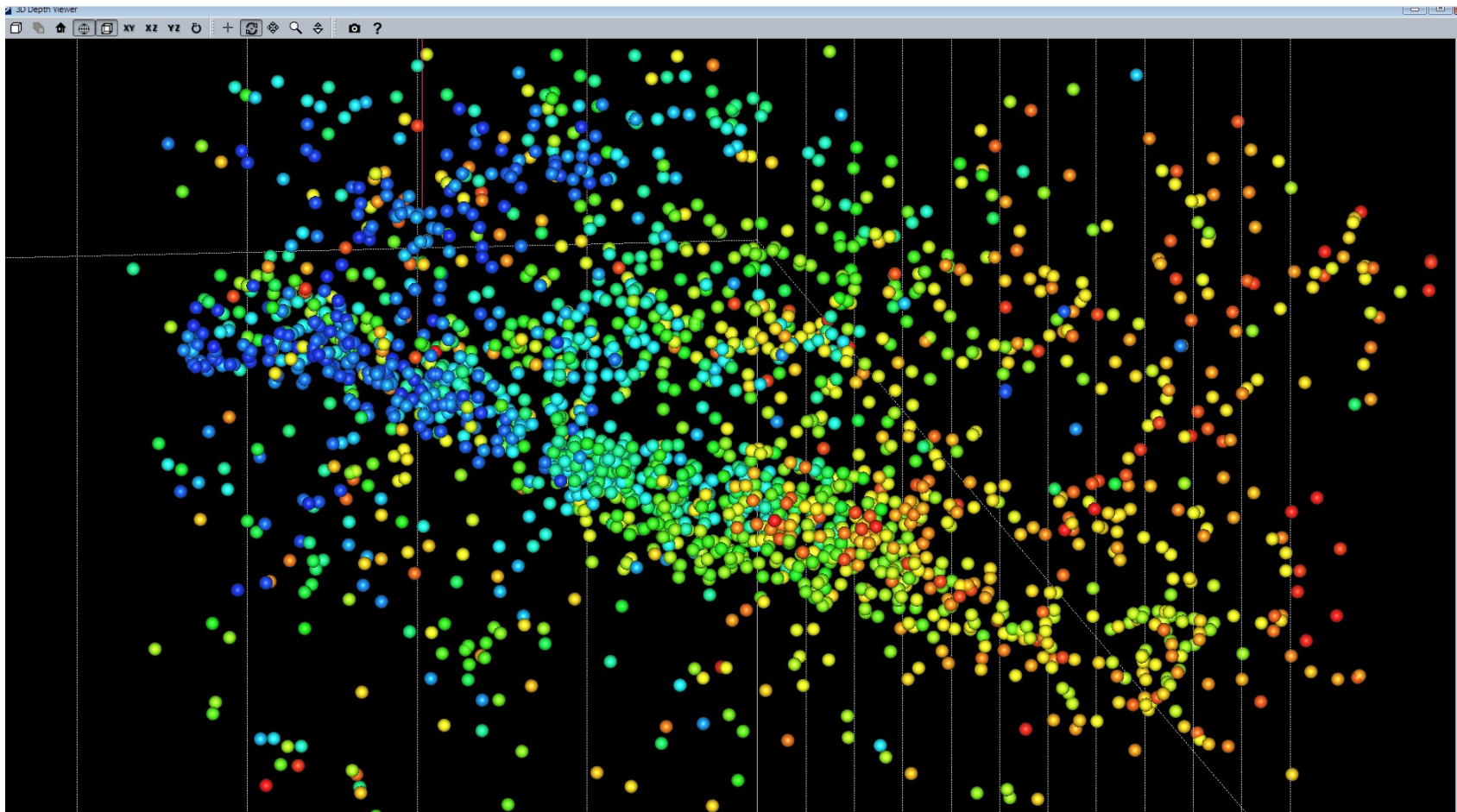


## Monitoring of induced seismicity during the first geothermal reservoir stimulation at Paralana, Australia

J. Albaric<sup>a</sup>, V. Oye<sup>a</sup>, N. Langet<sup>b</sup>, M. Hasting<sup>c,1</sup>, I. Lecomte<sup>a</sup>, K. Iranpour<sup>a</sup>, M. Messeiller<sup>d</sup>, P. Reid<sup>d</sup>

Show more

**NORSAR**





# Geothermal power around Hengill volcano, Iceland

- The Hengill area is an important energy source for Reykjavík and surrounding area, both for electricity and district space heating.
- Two production fields are located in the area: Nesjavellir and Hellisheiði.
- The Iceland Deep Drilling Project (IDDP) is a long-term program to improve the economics of geothermal energy by producing supercritical hydrous fluids from drillable depths.
- The hottest well experienced so far, is well NJ-11 at Nesjavellir,  $\sim 380^{\circ}\text{C}$ .

NJ-11,  $\sim 380^{\circ}\text{C}$  at  
2265m depth

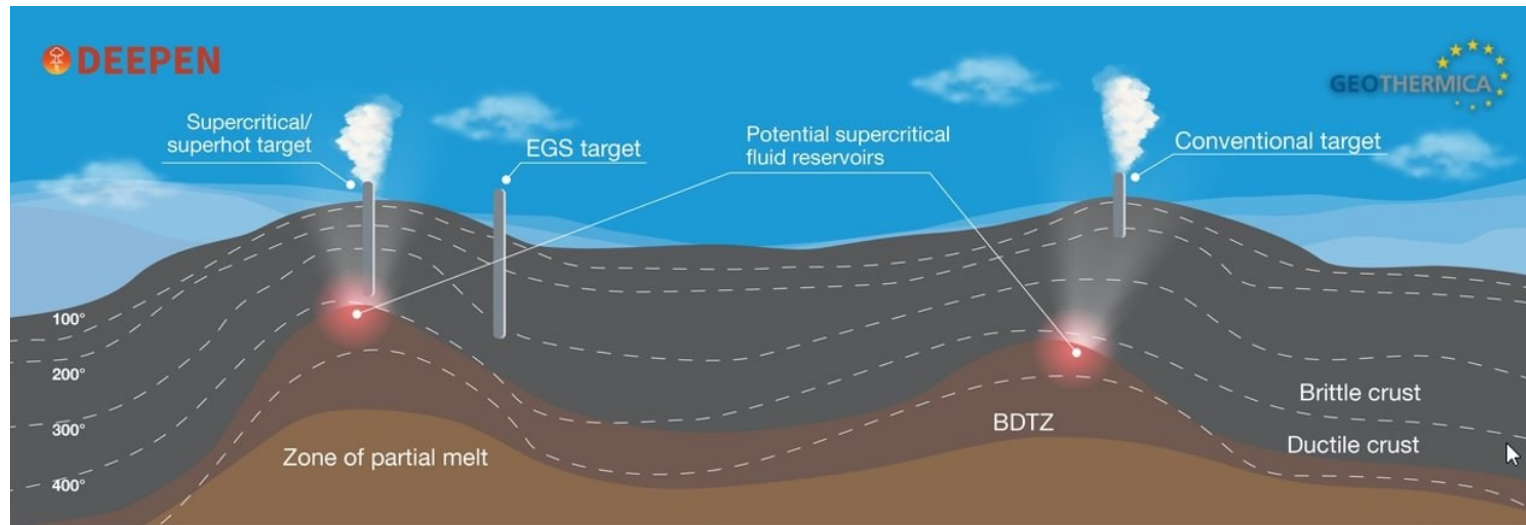


Nesjavellir power plant

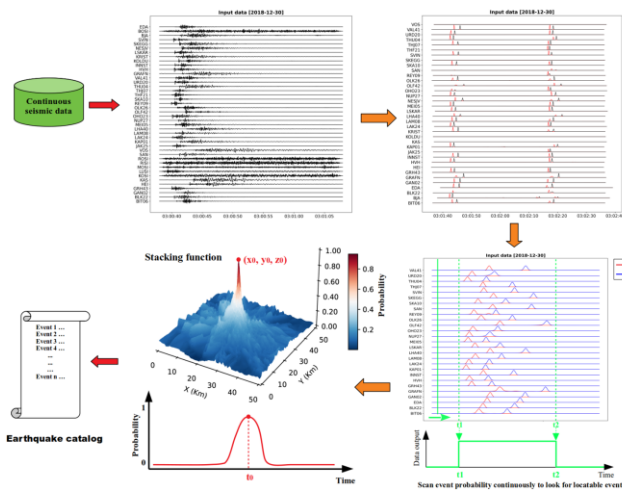


# DEEPEN: DERisking Exploration for geothermal Plays in magmatic ENvironments

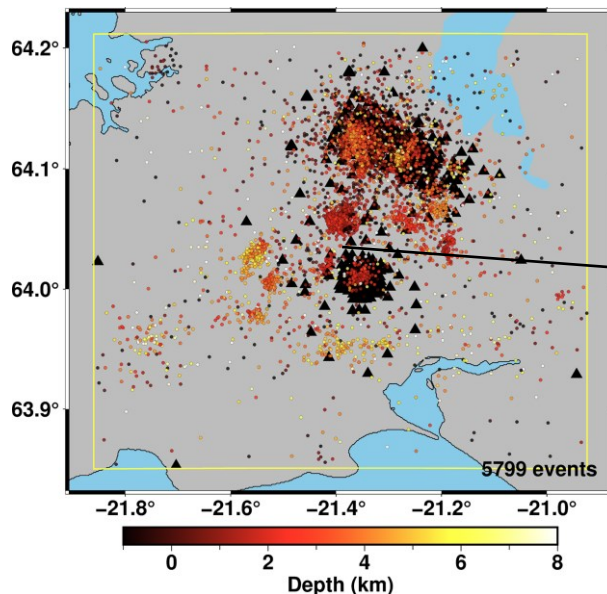
- The DEEPEN project contributes to reducing the upstream risk of geothermal energy development through increasing the probability of success when drilling in magmatic systems.



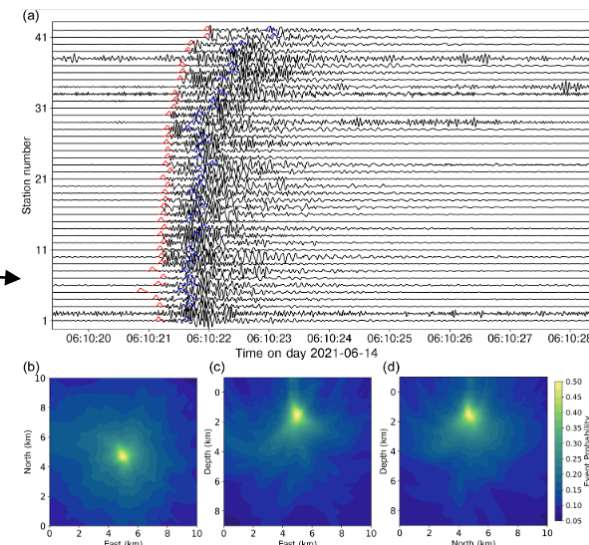
# Monitoring seismicity using nodal array



seismic detection and location workflow



Preliminary catalog (Shi et al., in prep)



Event detection and migration location of one event

- fully automated: MALMI (ML + waveform migration);
- use all available stations: broadband + nodal;
- preliminary catalog: ~5800 events;
- several event clusters: induced events + tectonic events;
- a large event cluster in the northern part;

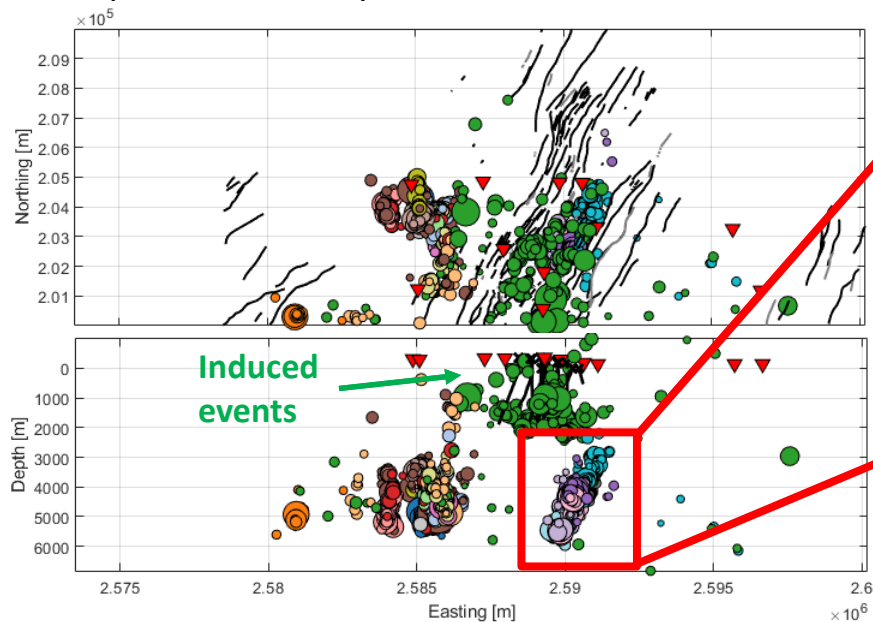
## Plans to do next:

- further quality control of the automated catalog;
- magnitude estimation;
- double difference relocation to improve precision;



# Event clustering

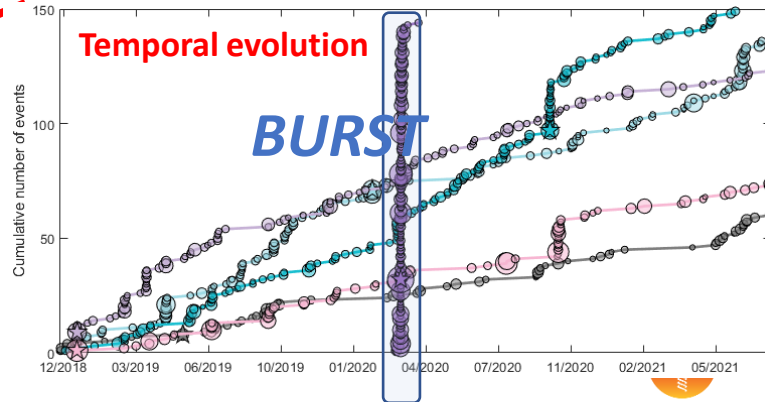
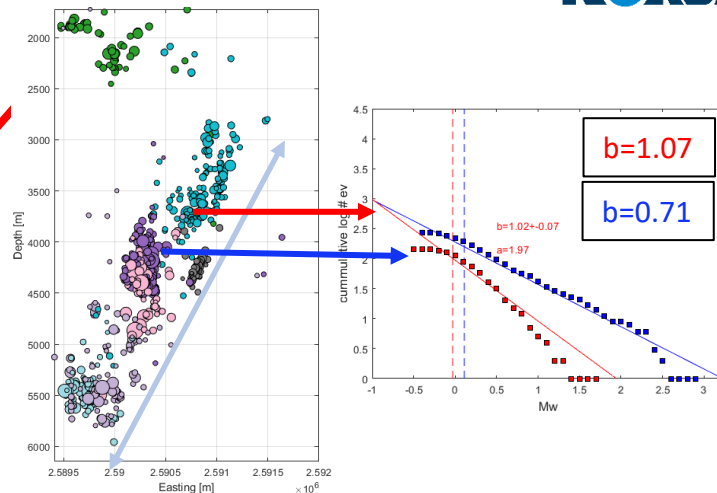
Clusters can separate events with different characteristics and help to delineate planar structures



## Observations:

- Good separation in terms of location.
- Green shallow cluster might be induced events
- No mapped faults to the West

## 7 "clusters" in the East

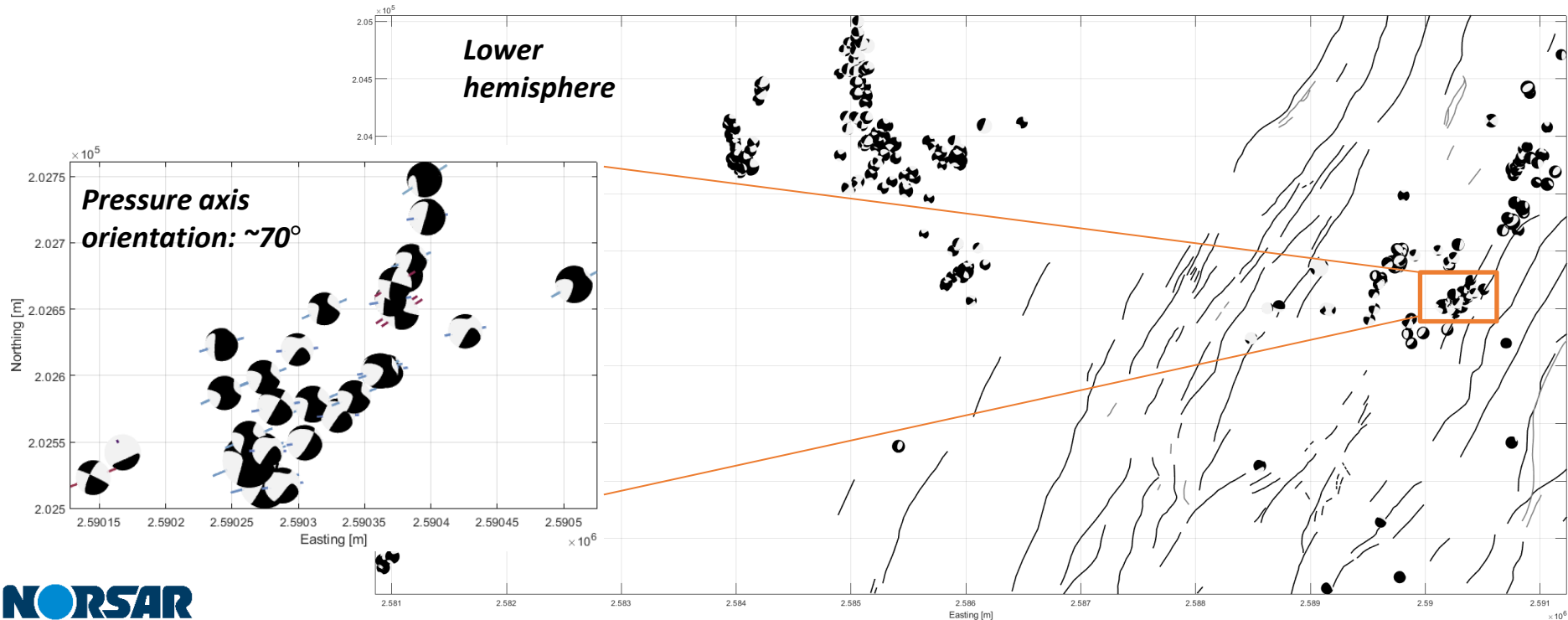




# Focal mechanisms

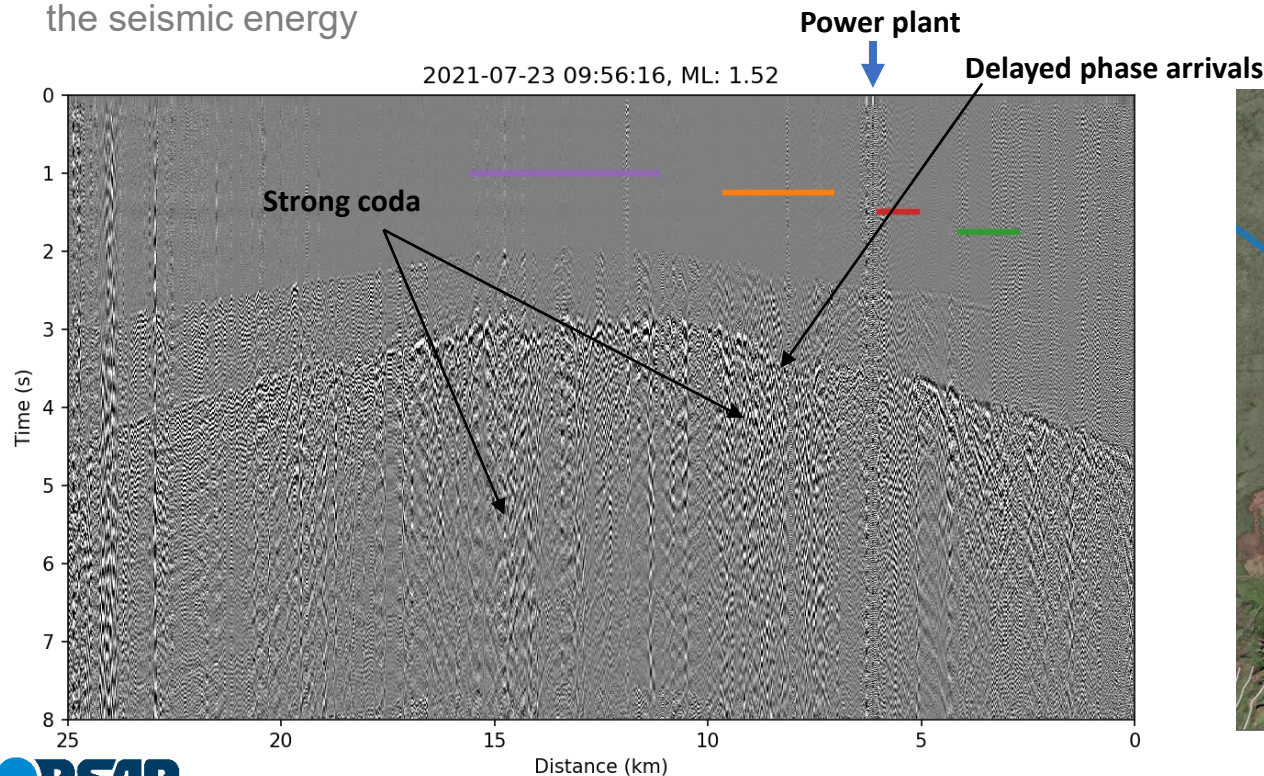
Provide information on the processes that generated the events by characterising the rupture / fault.  
Similar waveforms  $\Leftrightarrow$  similar mechanisms.

$\rightarrow$  A total of **259** focal mechanisms have been computed so far.



# Fault characterization using DAS

- Study the features we observe in the DAS data and correlate with mapped geological features
- Fibre segments with long tailed coda may indicate fibres crossing faults where low velocity layers trap the seismic energy



# Summary

- Location of seismicity is vital to map the creation and extent of any Enhanced Geothermal System
- Characterization of seismicity will allow to describe differences in performance within geothermal reservoir, and assist in risk and safety management
- Seismicity and fibre-imaging assists in prospecting and exploration of new geothermal regions (i.e., identifying depth and path of fluid-filled fault systems)

The background of the slide features a dark blue gradient with a pattern of concentric, overlapping ripples in the upper left quadrant, resembling water droplets on a surface.

# Thank you for your attention

Volker Oye, NORSAR

[Volker@norsar.no](mailto:Volker@norsar.no)

