Seismological characterization of a Hot Dry Rock geothermal system in the Gonghe basin, China

Bressan Sofia [2,3], Verdon James [1], Zhang Hao [4], Brovelli Alessandro [3], Fuggi Antonio [4] , Cassiani Giorgio [2]

DIPARTIMENTO DI GEOSCIENZE

PARTNERS

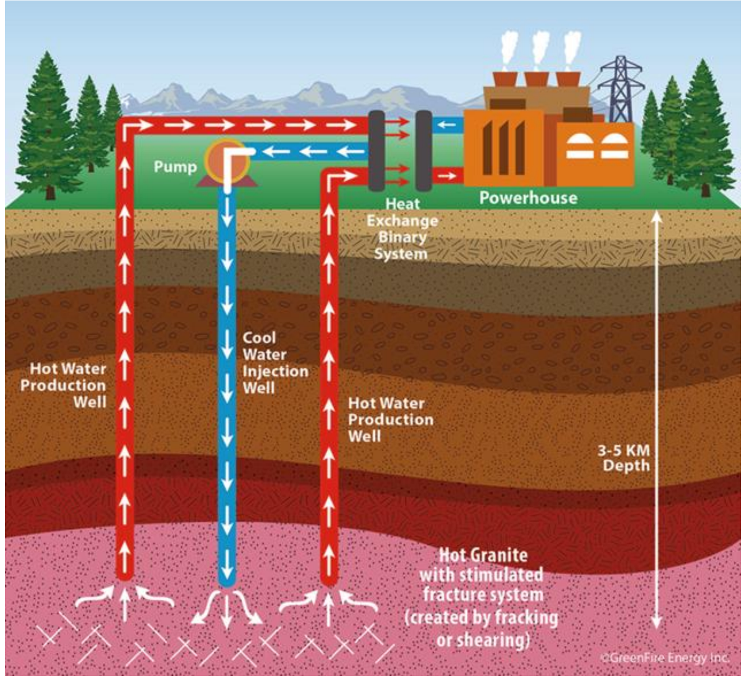
1 2 3 4

18 Sep 2025

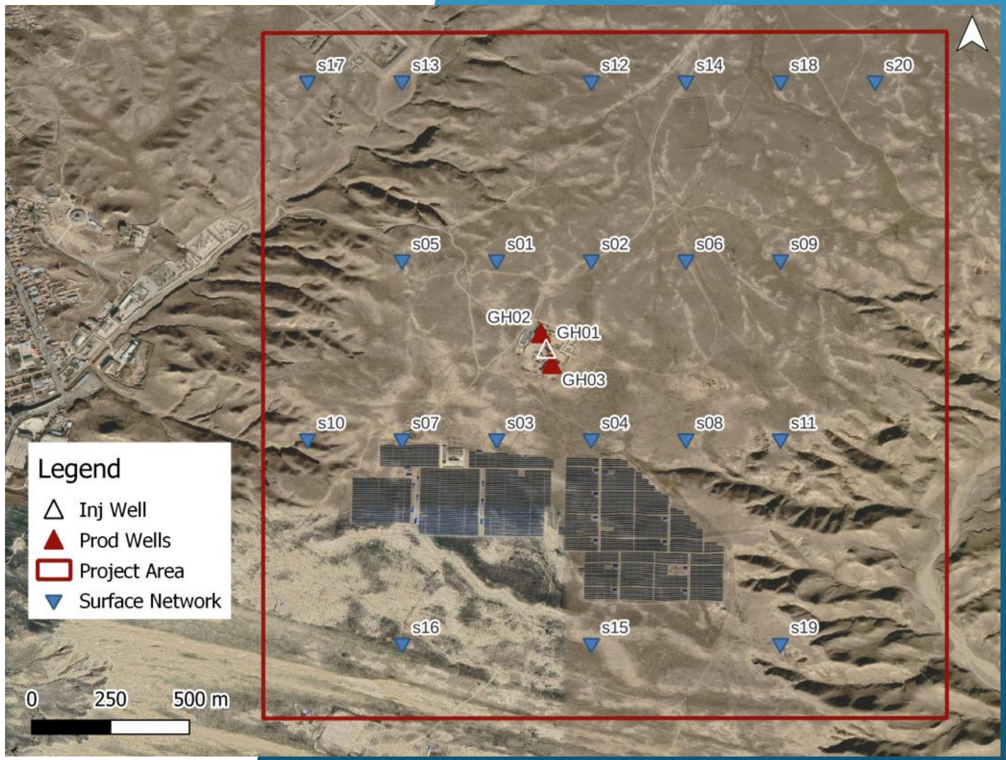
Gonghe Project

China
NE Quinghai region
into the Tibetan Plateau

First well: 2017
First Injection: 2019
Operational period:
2019 – still in operation

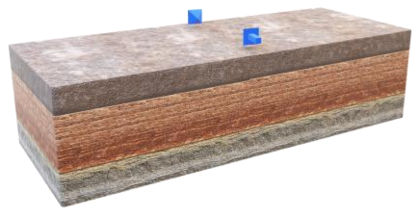


Hot Dry Rock (HDR): A particular type of EGS that exploits **hot** but **impermeable rock** formations with **no natural fluids.** In these cases, water is injected under high pressure to stimulate fractures.



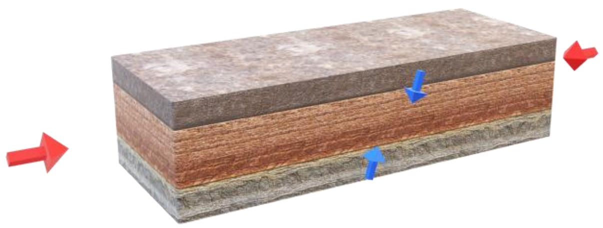
Geological Setting

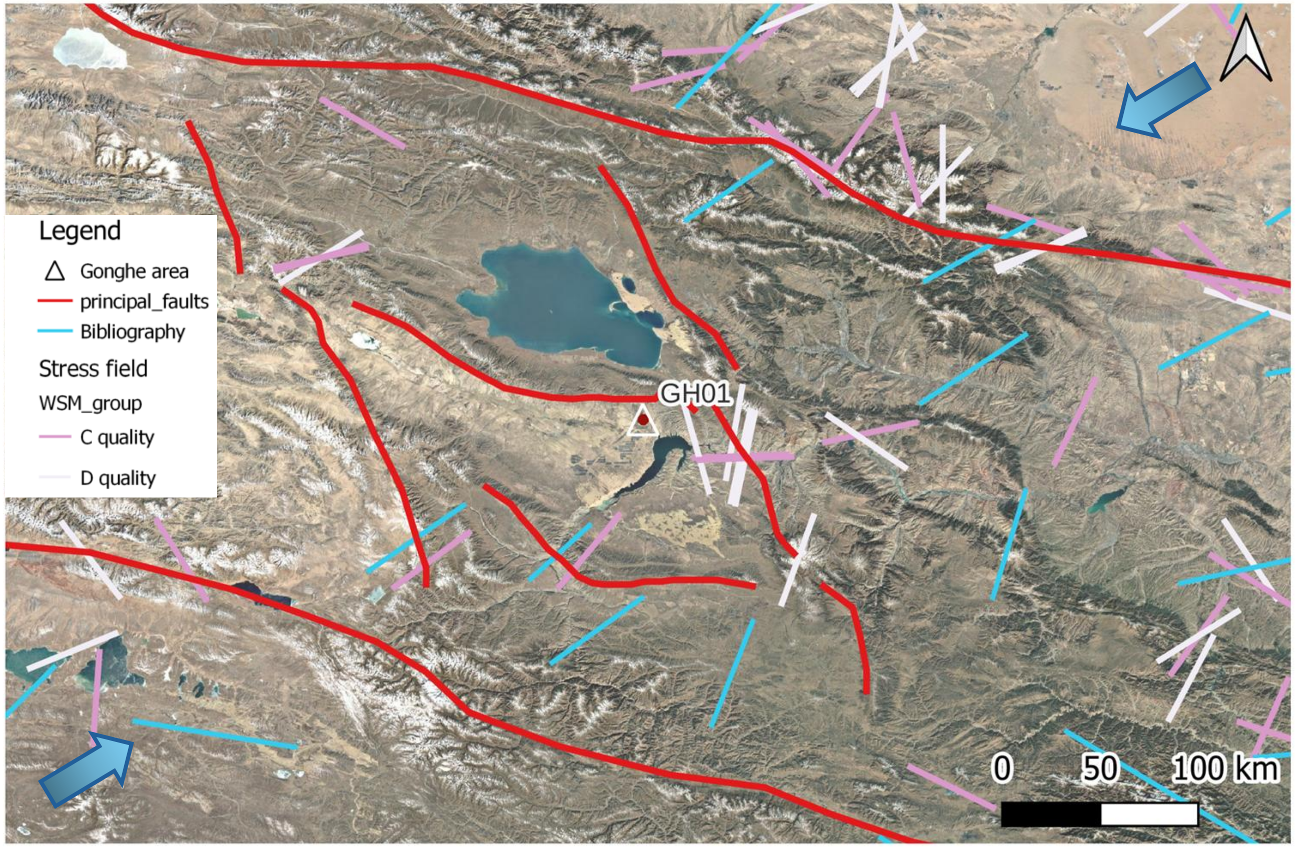
- 2 principal **left-lateral strike-slip faults**: clockwise transrotational regime



- 2 NNW-SSE **dextral strike-slip faults**: anticlockwise block rotation

- 2 **thrust faults**: the associated movement is like a large-scale anticline





Maximum horizontal stress NE-SW
Shmax NE55/56°

Micro Seismicity

DATABASE

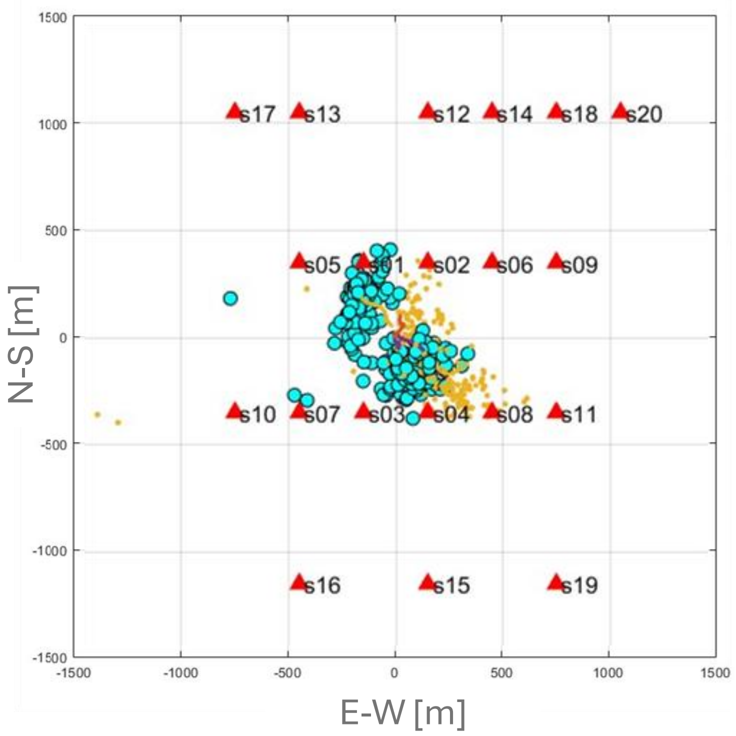
- **2615** seismic events **automatically localized**, recorded between July 2021 and October 2021
- **204 selected** events with M_L ranging from 0,7 to 3,3

Manual localization revealed **location discrepancies**, indicating the need of **reprocessing the localization**

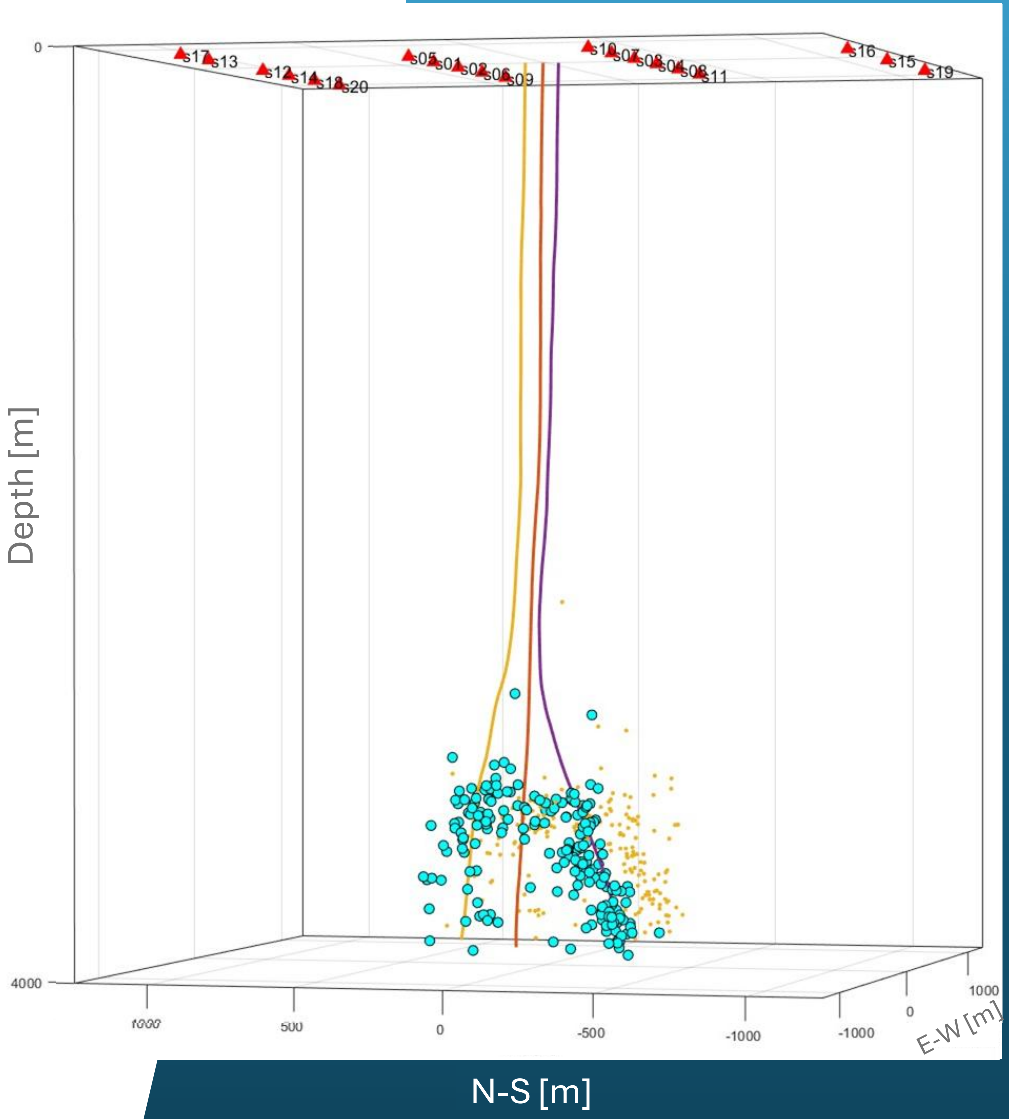
- **204** events **relocated with Double Difference** method

Double Difference is a relocation algorithm that **minimizes travel-time differences** whitin clusters

PLAN VIEW



3D VIEW

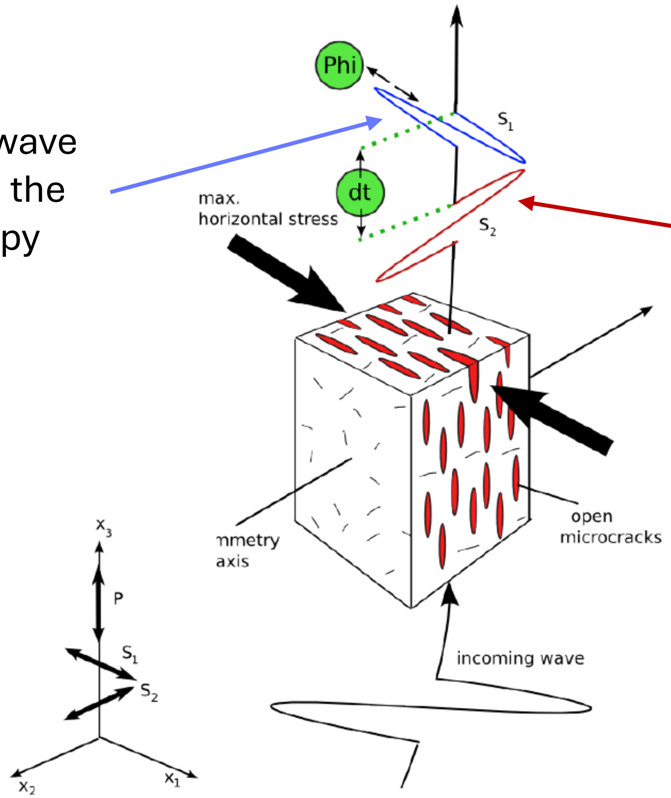


Shear Wave Splitting

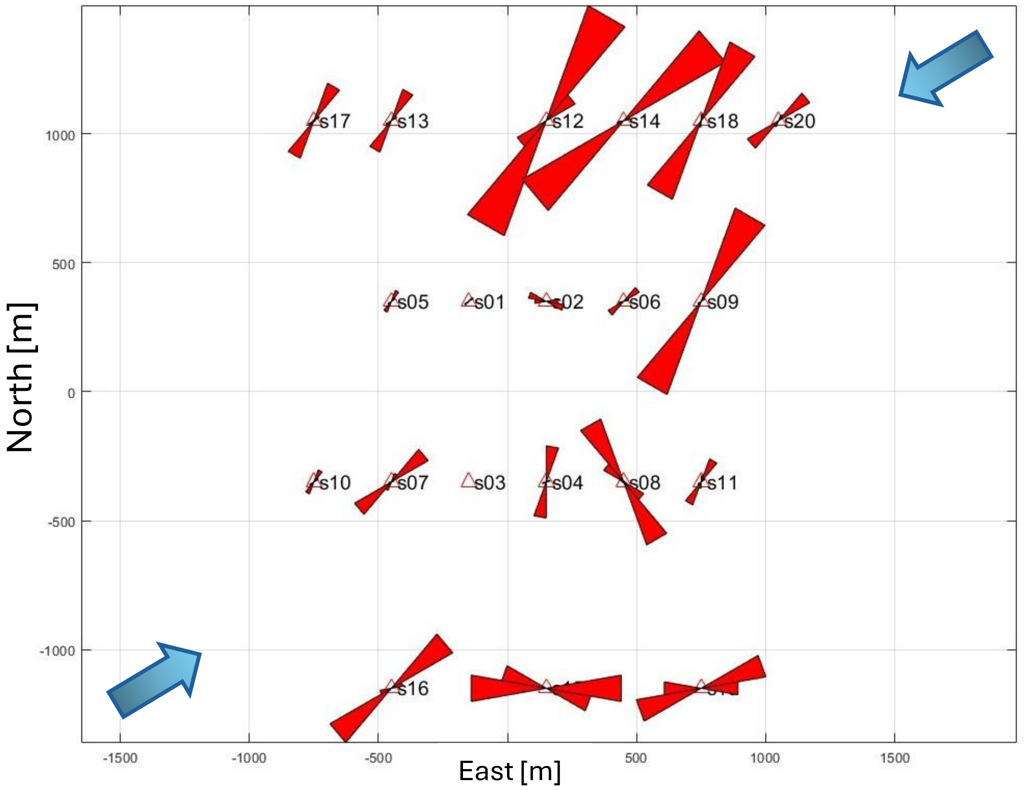
Shear Wave Splitting is a method used to investigate **anisotropy**, particularly in **fractured materials**

SWS occurs when an S-wave encounters an anisotropic medium, causing it to **split into two** orthogonal components that propagate at different velocities depending on the material properties

S1 faster: wave parallel to the anisotropy



S2 slowest: wave perpendicular to the anisotropy



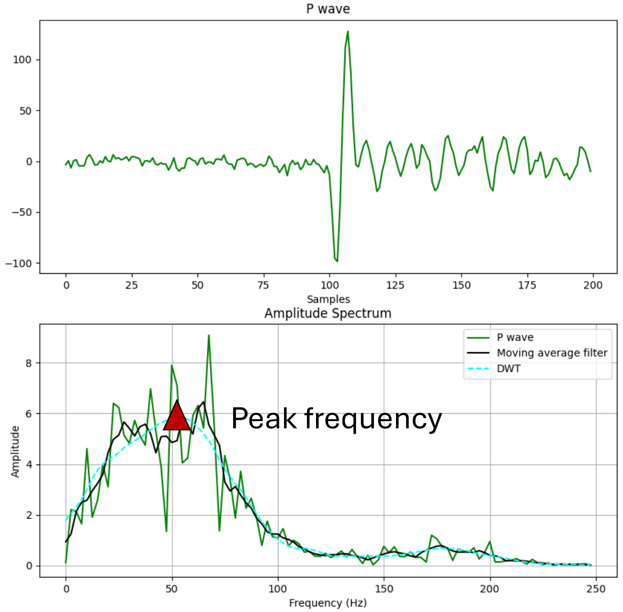
The fractures show a **marked NE–SW elongation** (N22°), consistent with the regional stress regime (N55°)

Cluster Analysis

WAVEFORM ANALYSIS

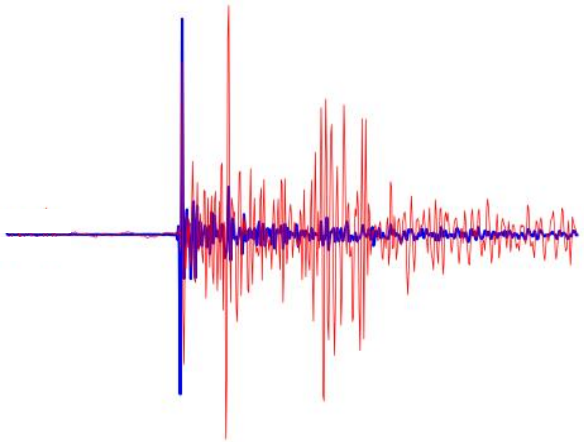
- Seismic signal analysis was performed to extract amplitude and **frequency values** from P and S waves separately
- The peak frequency value is used to define the **time window length** for cross-correlation

$$window\ lenght = \frac{3}{f_{peak}}\ [s]$$

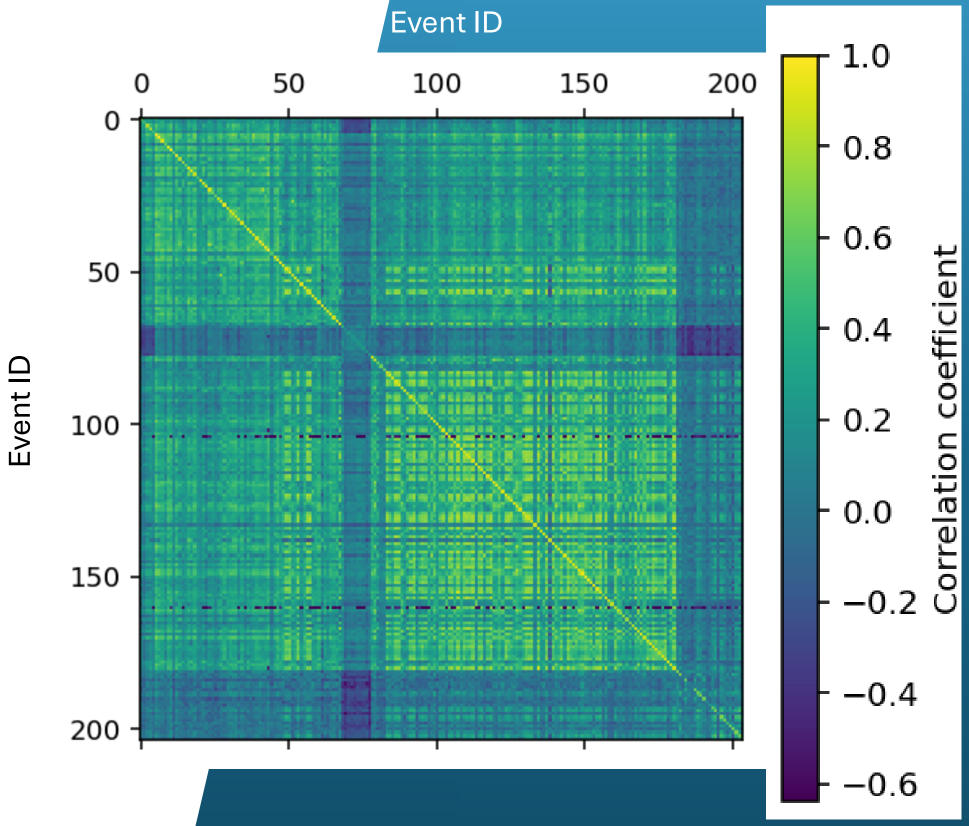


CROSS-CORRELATION ANALYSIS

- Technique used to quantify the **similarity** between two seismic waveforms and improve the localization of the event
- The resulting cross correlation matrix provides a **measure of waveform coherence**



Highest similarity

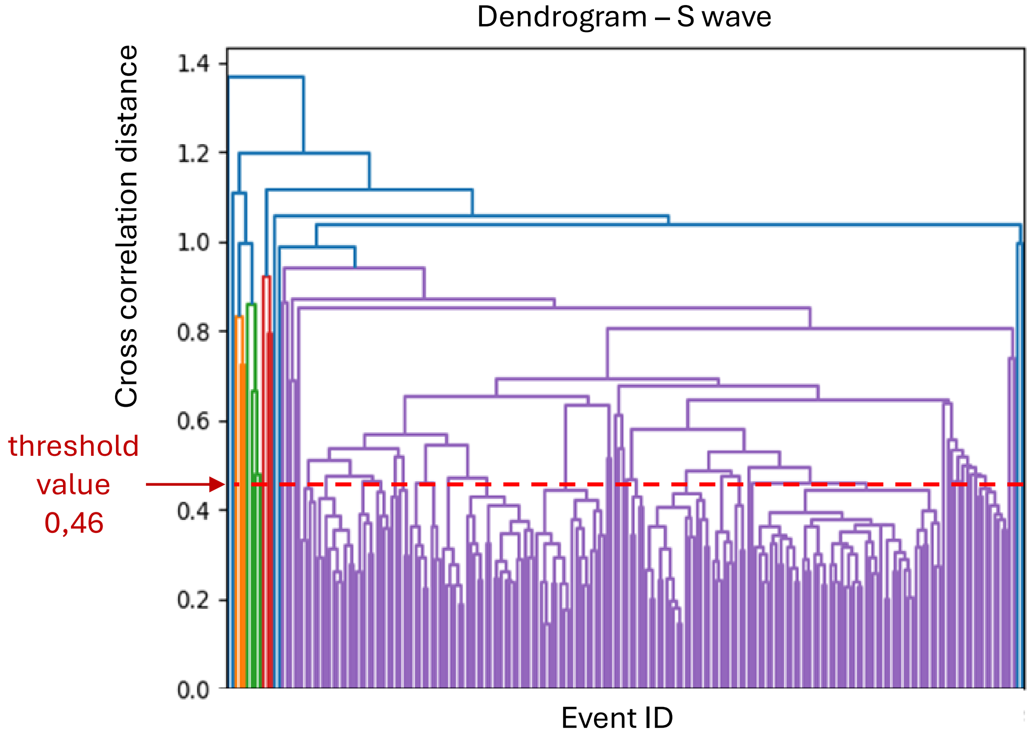


Slighlest similarity

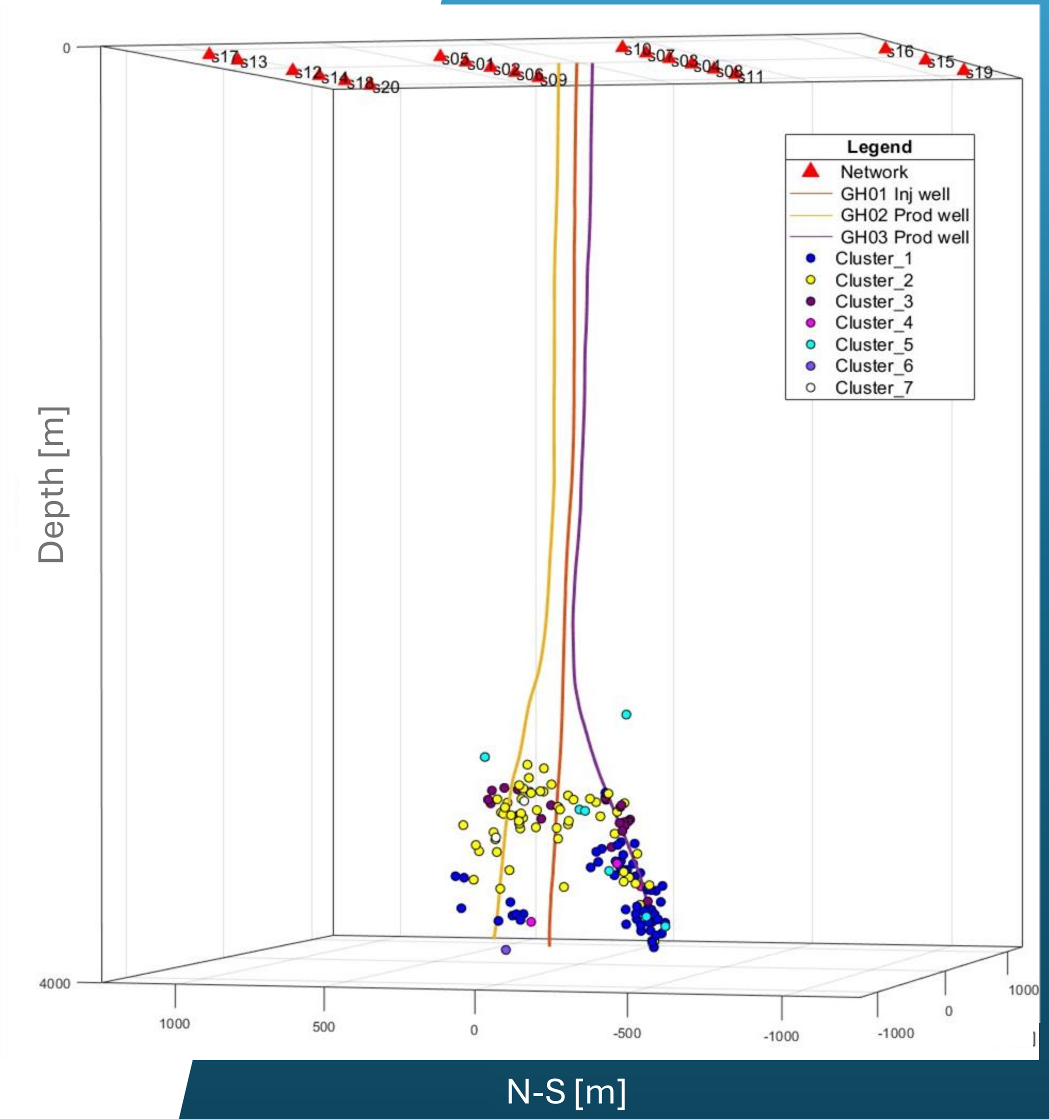
Cluster Analysis

HIERARCHICAL CLUSTERING

- Cluster analysis for both P and S separately: threshold value set on dendrogram coming from cross correlation
- Cluster definition:
  - Minimum cluster size: 3 events
  - Waveform coherence and spatial proximity
  - Final cluster: intersection of P and S clustering results
- Results: **204 micro seismic events divided into 7 clusters**



3D VIEW

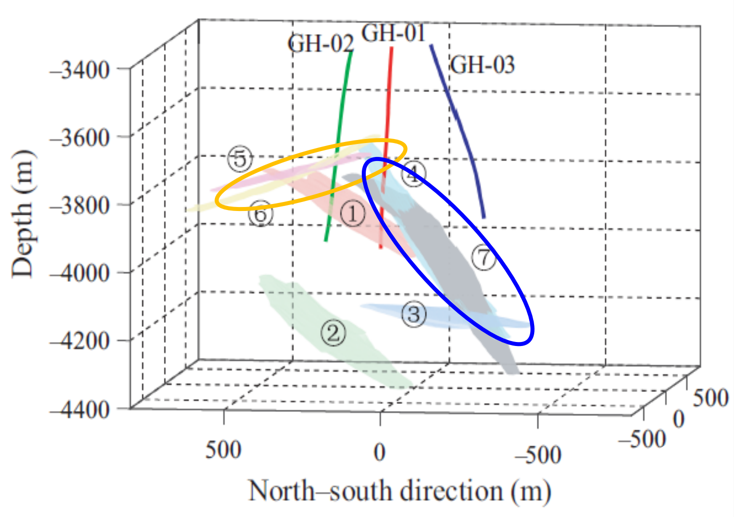


Cluster Analysis

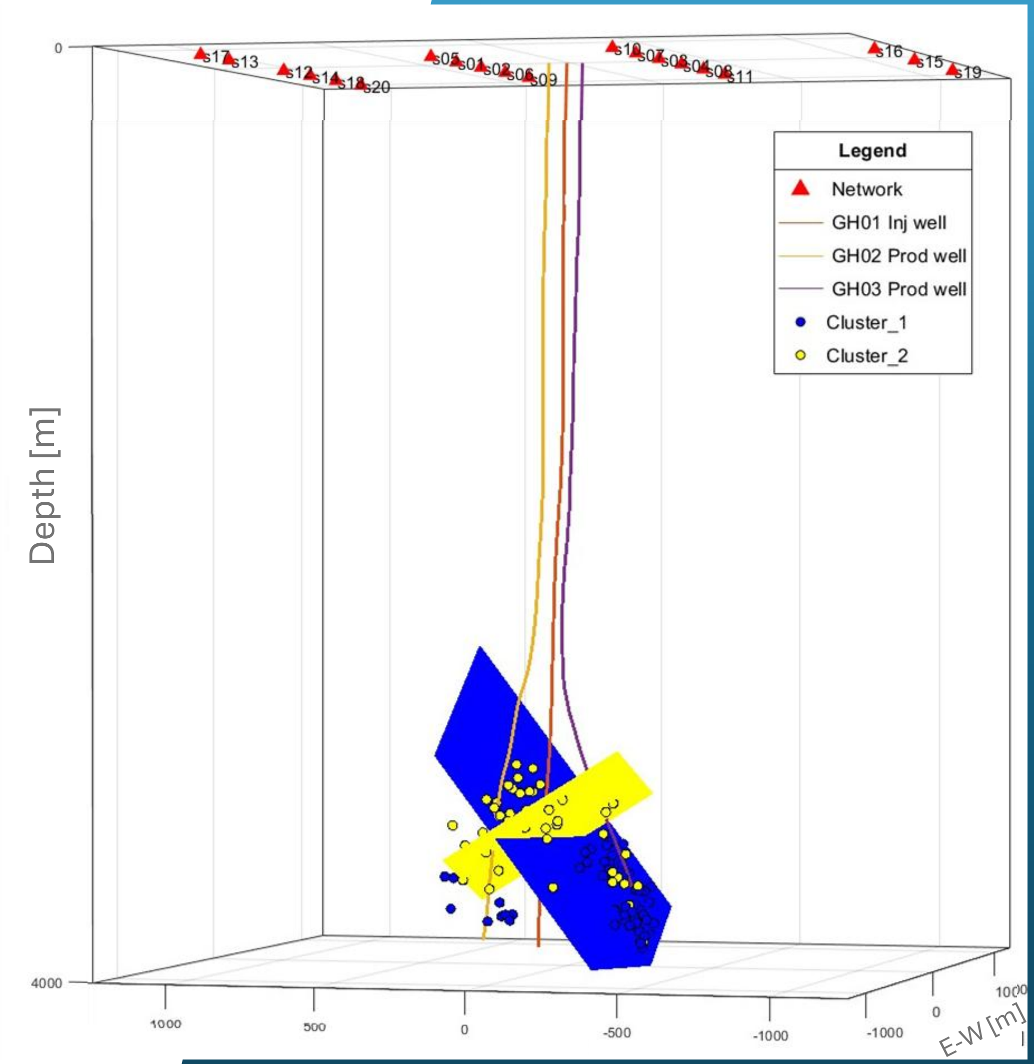
1. We selected the 2 main seismicity clusters

The spatial distribution of the events suggests **alignment with two dominant seismogenic structures** consistent with those identified in literature

Yin et al (2024)



3D VIEW



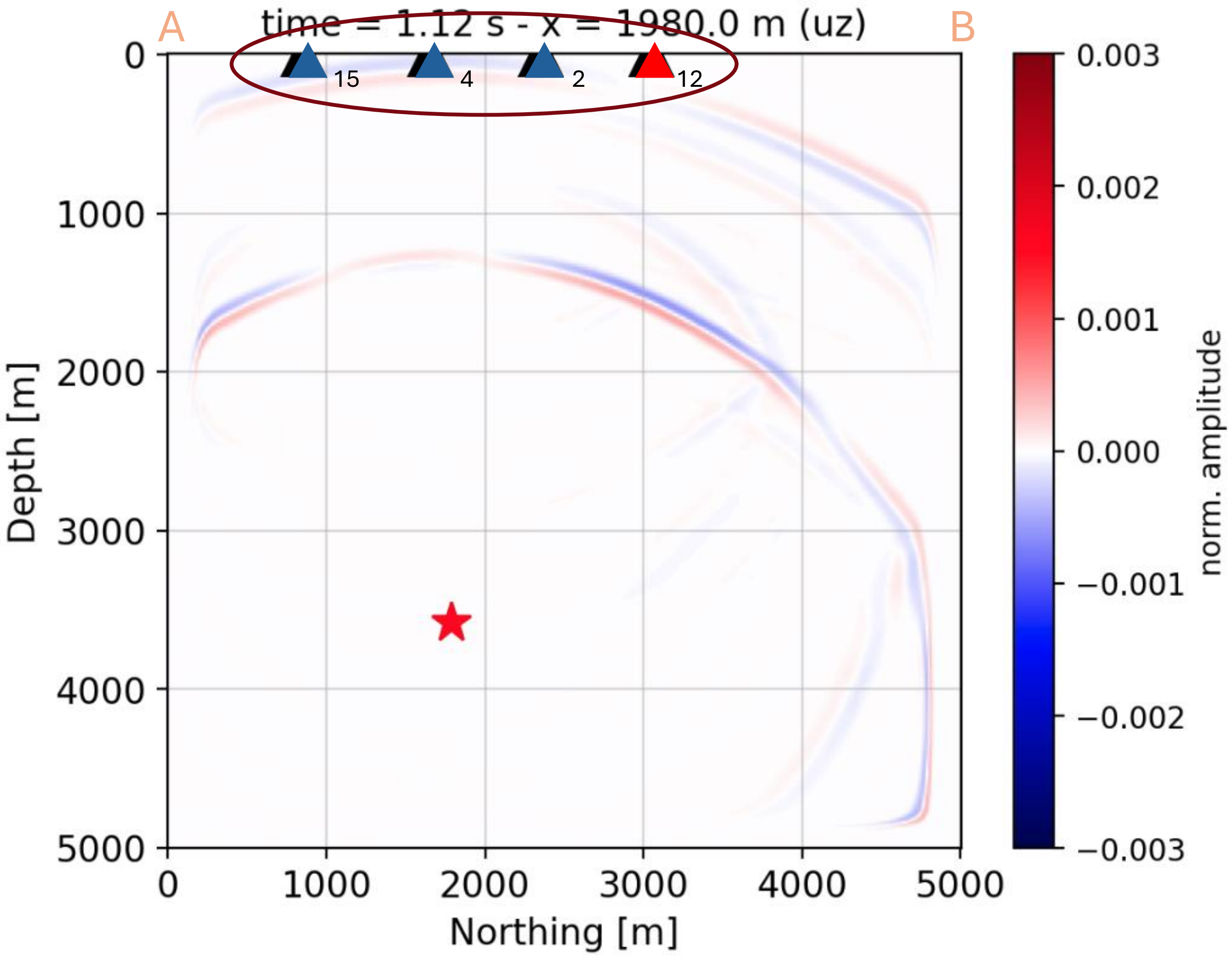
N-S [m]

2. We applied a Principal Component Analysis (PCA) to the approximate **fault plane surfaces** to the two clouds

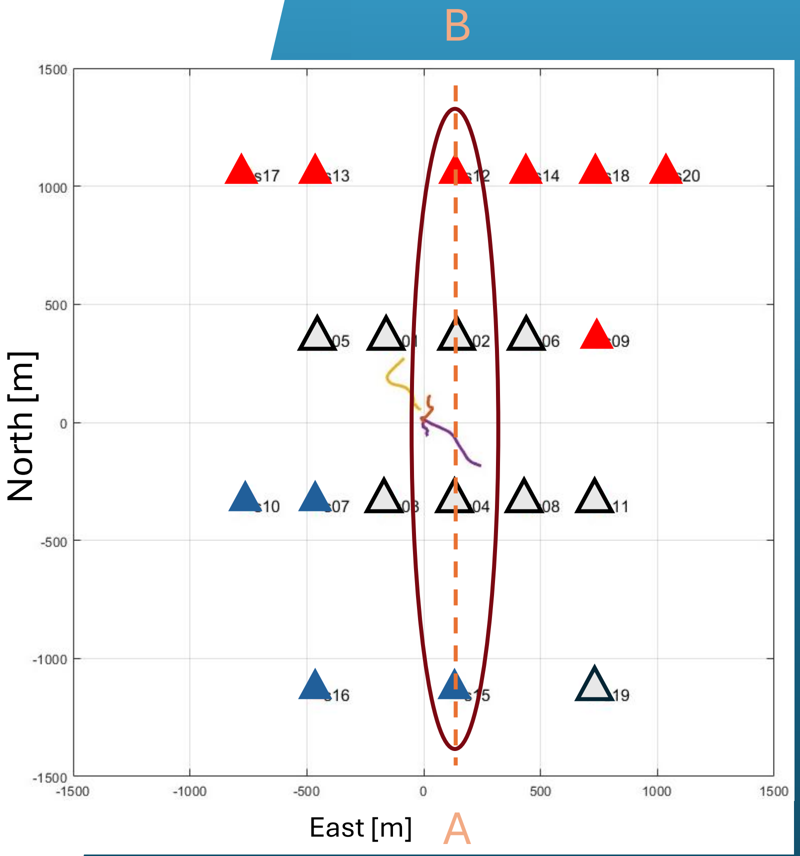
3. Comparison of the fault plane parameters (Strike – Dip – Rake) using Seismic Waves 4th order (**SW4) software for 3D seismic propagation modeling**

Full waveform analysis

SW4 SIMULATION



REAL OBSERVED POLARITIES



Preliminary results

- The event **locations** showed large **discrepancies**, most likely due to the **small aperture of the array**, which limited localization accuracy.
- **Shear Wave Splitting:** Small array aperture highlights local fracture orientations rather than larger-scale trends (apparent rotation in the south).
- **SW4** simulations limited by network resolution: surface sensors show **identical polarities on the surface**, reducing ability to reproduce wave propagation patterns.

<u>Original network design is non optimal for microseismic monitoring of a target area at about 3-4km depth.</u>

- Increase aperture and azimuthal coverage to improve mechanism resolution and depth control.
- The number of sensors could remain unchanged, but they should be redistributed