How to optimize drilling strategies and reservoir management: lessons learned from the Soultz EGS project?

Leiden, The Netherlands
7-9 November 2007

Risk Analysis for Development of Geothermal Energy

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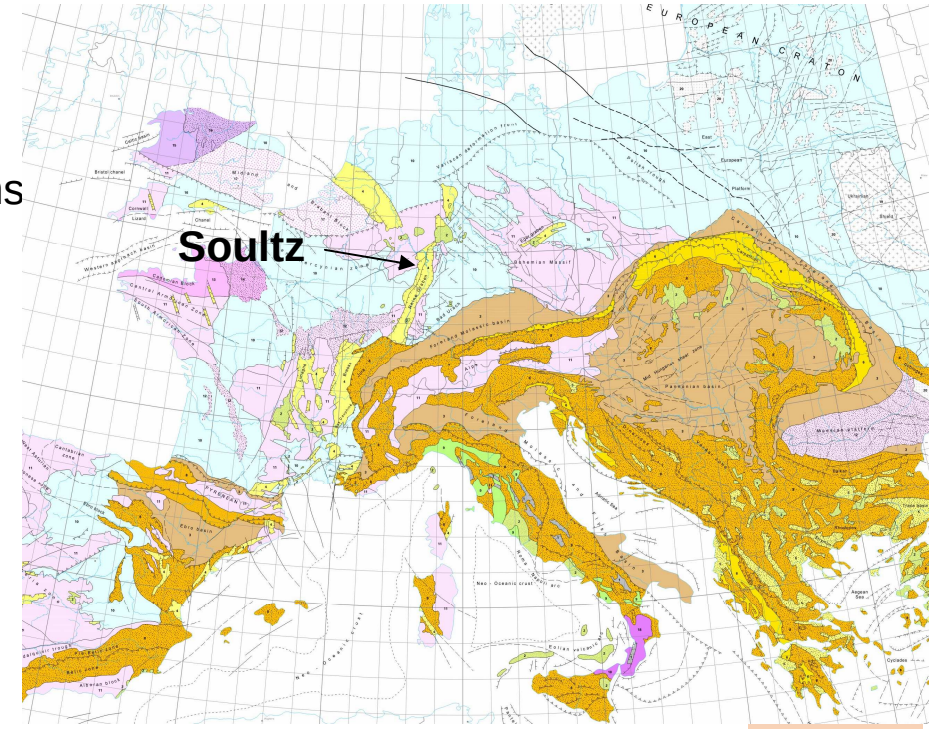
Exploration: Challenges

> **How Exploration can contribute to a better Exploitation of the geothermal reservoir**

> **Unconventional Geothermal Reservoirs**
  - No trace on surface (fumaroles, hot soil, thermal springs, altered zone)

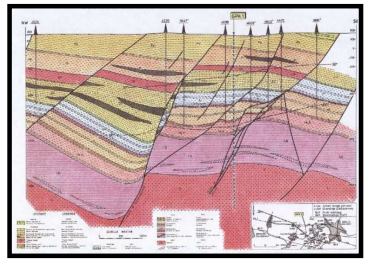
> **EGS**
  - Enhanced Geothermal Systems
  - Engineered Geothermal Systems



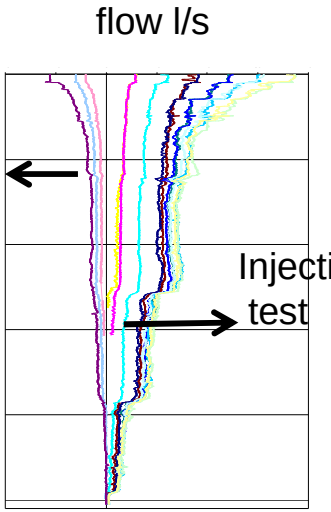
3D organisation of the faults and the flow channels

Best practices for exploration EGS fractured reservoirs

- **Based on Soultz experience: high quality datasets but partial vision (borehole wall)**
- **Fractured zones controlled the flow**
- **Low natural permeability associated with fracture zone (brines, 100g/L)**
- **Hydrothermal alteration related to (paleo)fluid circulations are related to natural permeability**



Soultz horst



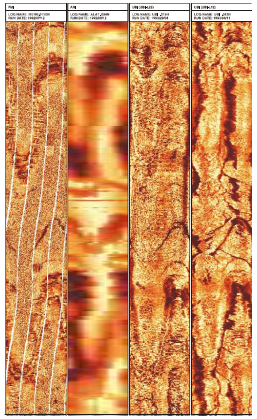
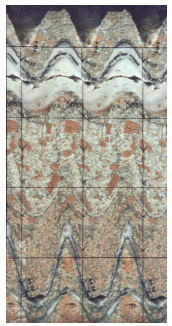
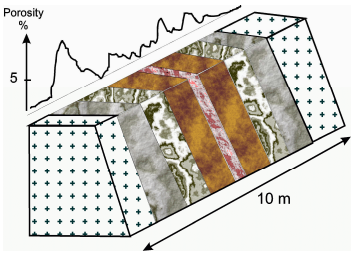


Image logs GPK1



EPS1 Core 2555 m



Conceptual model

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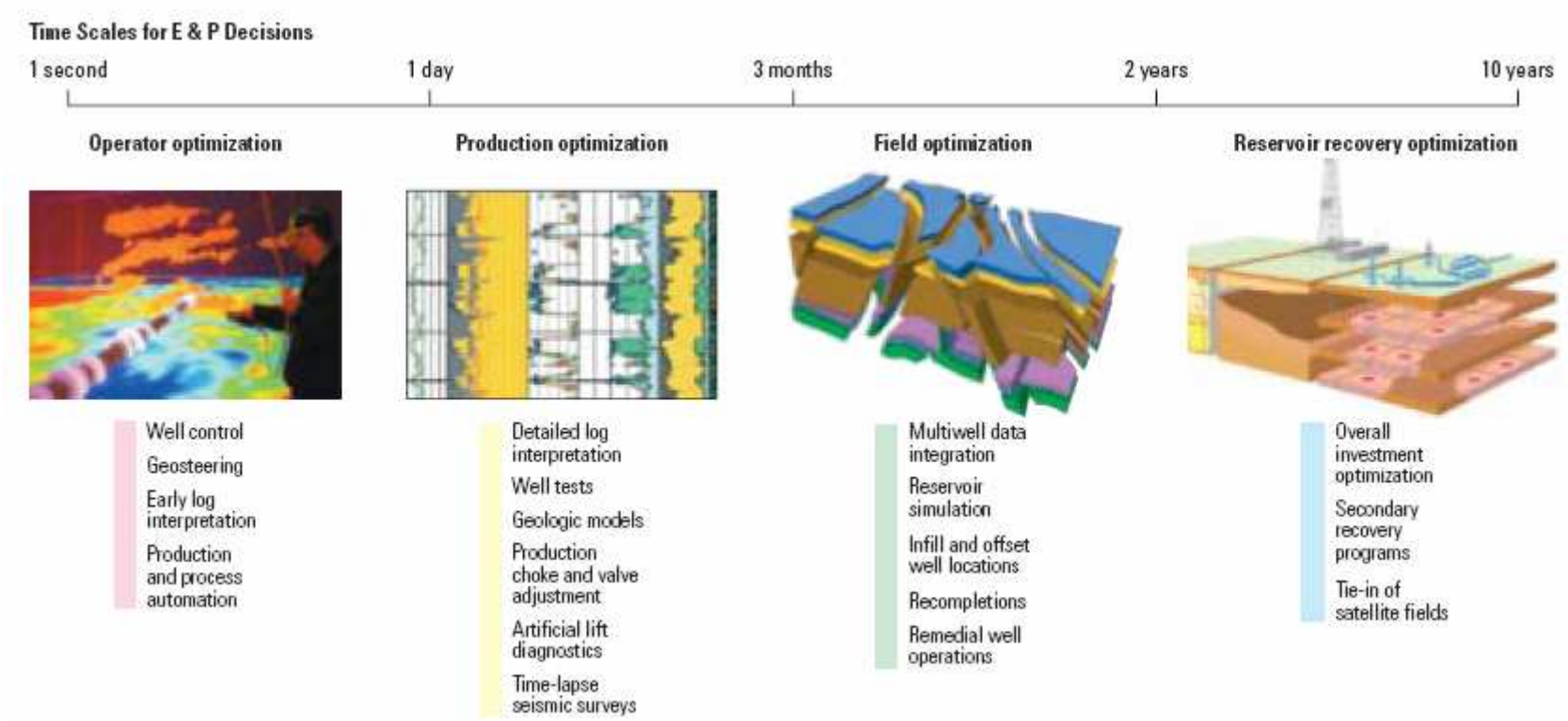
Best practices in oil industry from exploration to exploitation



2D/3D seismics **well data** **multiwell - oil field** **Reservoir exploitation**

From Oil field review, 2005/2006

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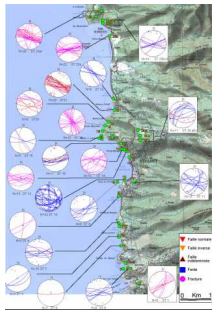
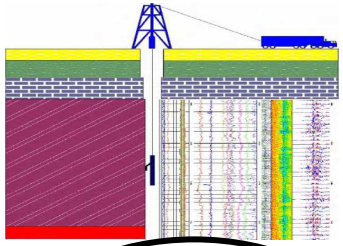
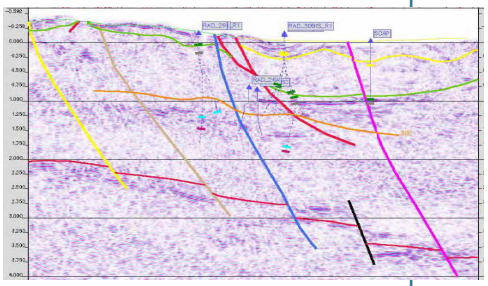
Best practices for EGS reconnaissance at concessionnal scale







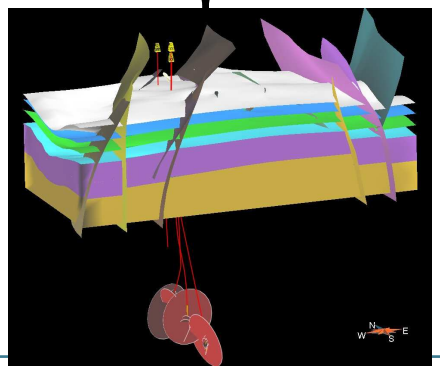
Local field mapping
-Fractures/faults geometry
-Geological interfaces
-Volcanoes
-Rock dating
-Thermal spring location
-Fumaroles

Local outcrop analysis
-Fractures/faults
-Rock petrography
-Mineralogy
-Hydrothermal alteration

Well analysis
-Cuttings/cores
-Fractures/faults vs depth
-Rock Petrography
-Hydrothermal alteration
-Petrophysics (porosity)
-Geophysical logging
-Borehole image logs
-Vertical Seismic Profile

2D/3D geophysics
-Seismic
-Gravi-mag methods
-EM, MT Methods
-Other methods

3D conceptual model



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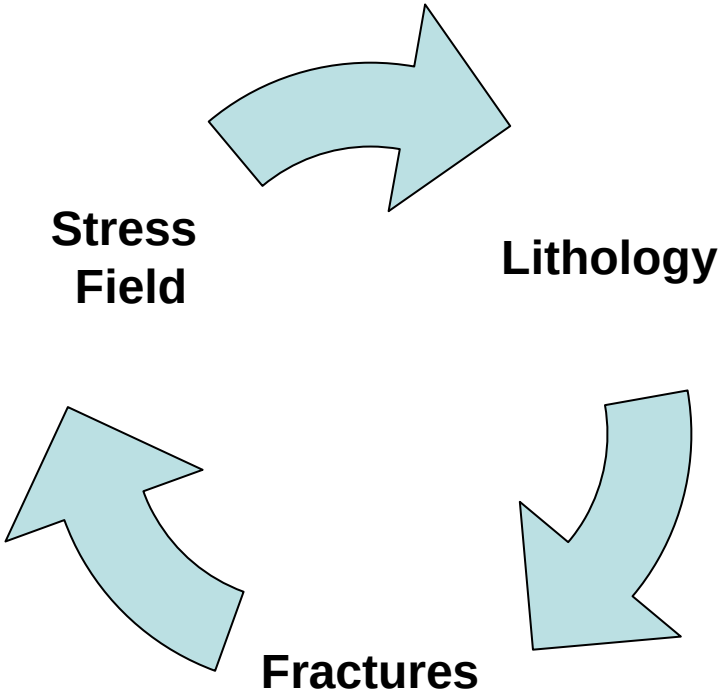
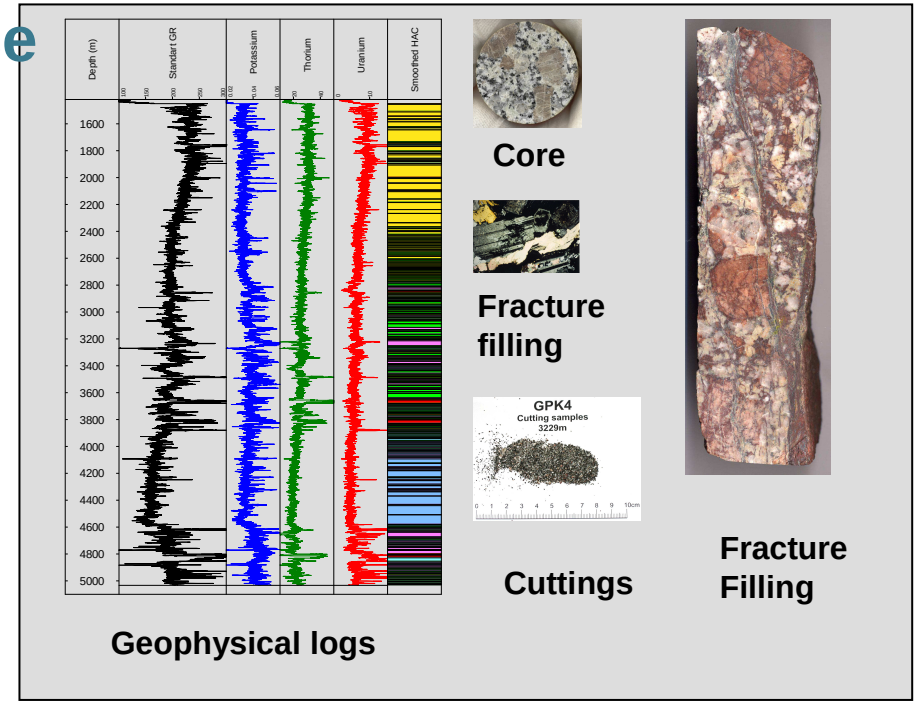
Geology and EGS: Coupled C - THM processes

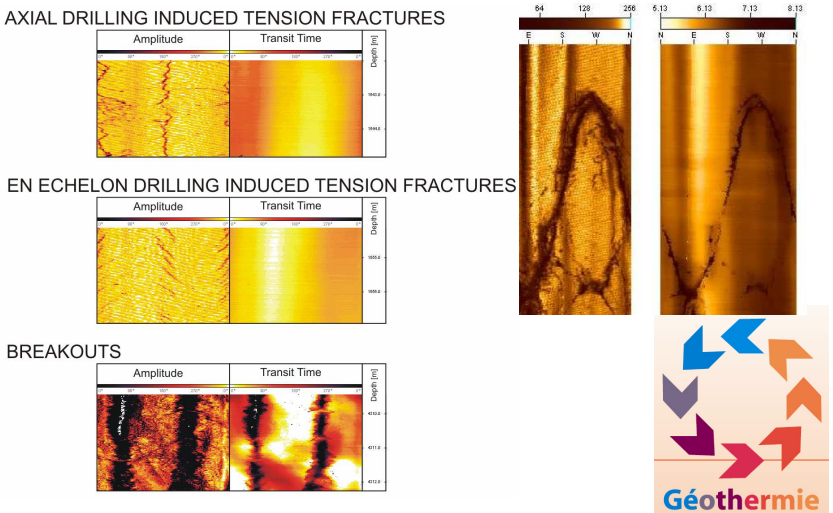
CHEMICAL	THERMAL	HYDRAULIC	MECHANICAL
Mineralogical rock-matrix composition Hydrothermal Alteration Fracture filling	Lithology (U, Th, K) Rock-matrix composition Thermal properties	Matrix K, Φ Fracture K, Φ Fracture network	Lithology, Alteration (drilling) Fracture Properties In situ Stress
Chemical stimulation Scaling, Tracing W-R interaction	Thermal stimulation	Hydraulic stimulation	Drilling Hydraulic stimulation

Rock composition, Fracture, Stress

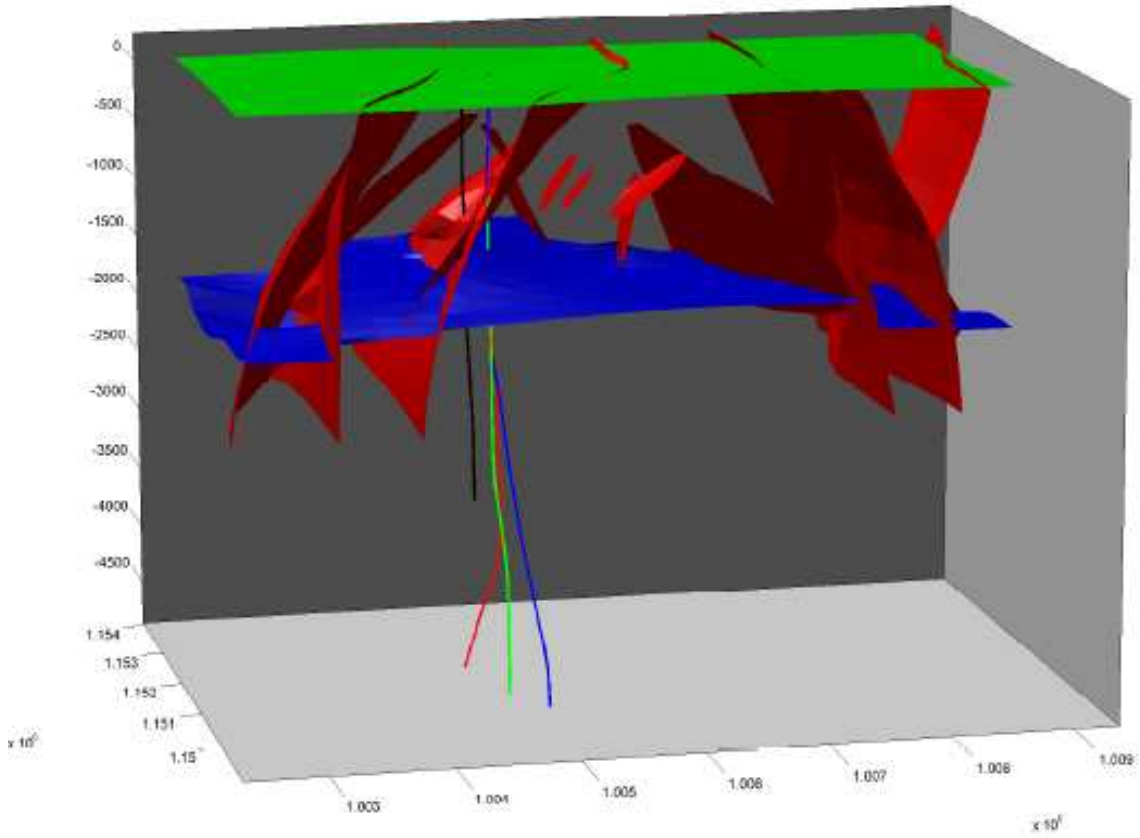
EGS drilling reconnaissance







Fault network at Soultz derived from 2D seismics



Sediments

Granite

Large-scale faults versus local-scale faults
Relationship between basement faults and sediments faults
Need for imaging deep fractured crystalline rocks

3D model from Renard & Courrioux, 1994; Valley, 2007

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Fault network at well scale

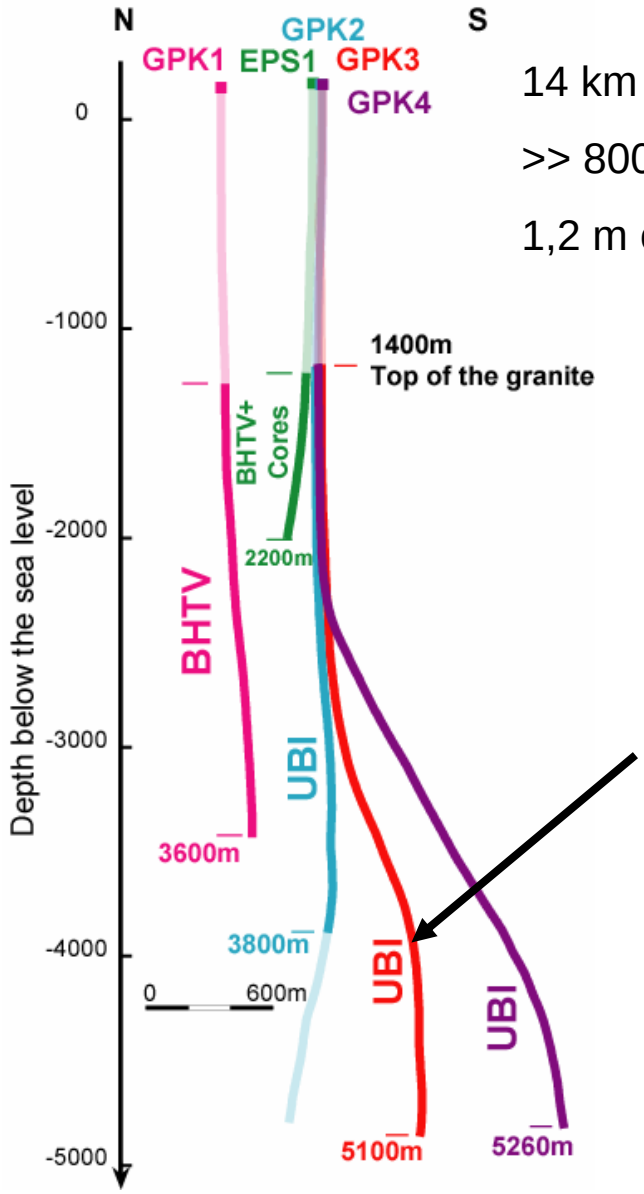
FMS, FMI, ARI

BHTV, UBI

Cores

Cuttings

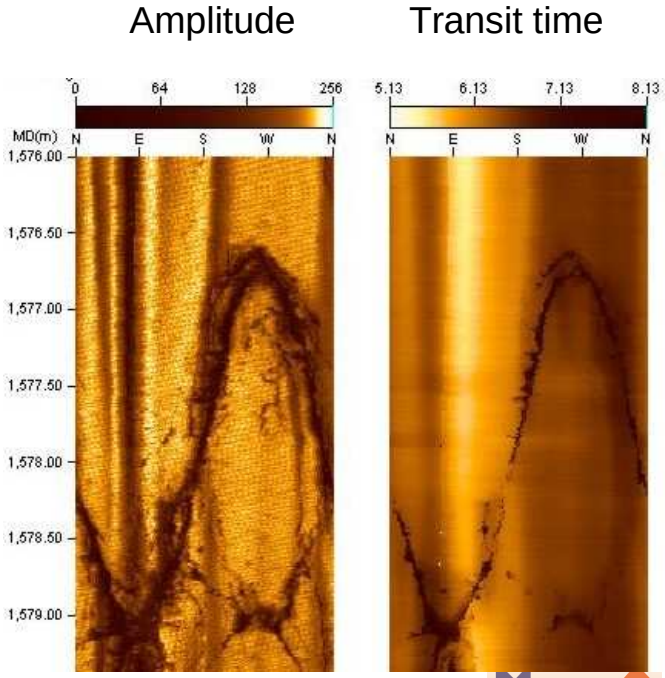
Geophysical logs



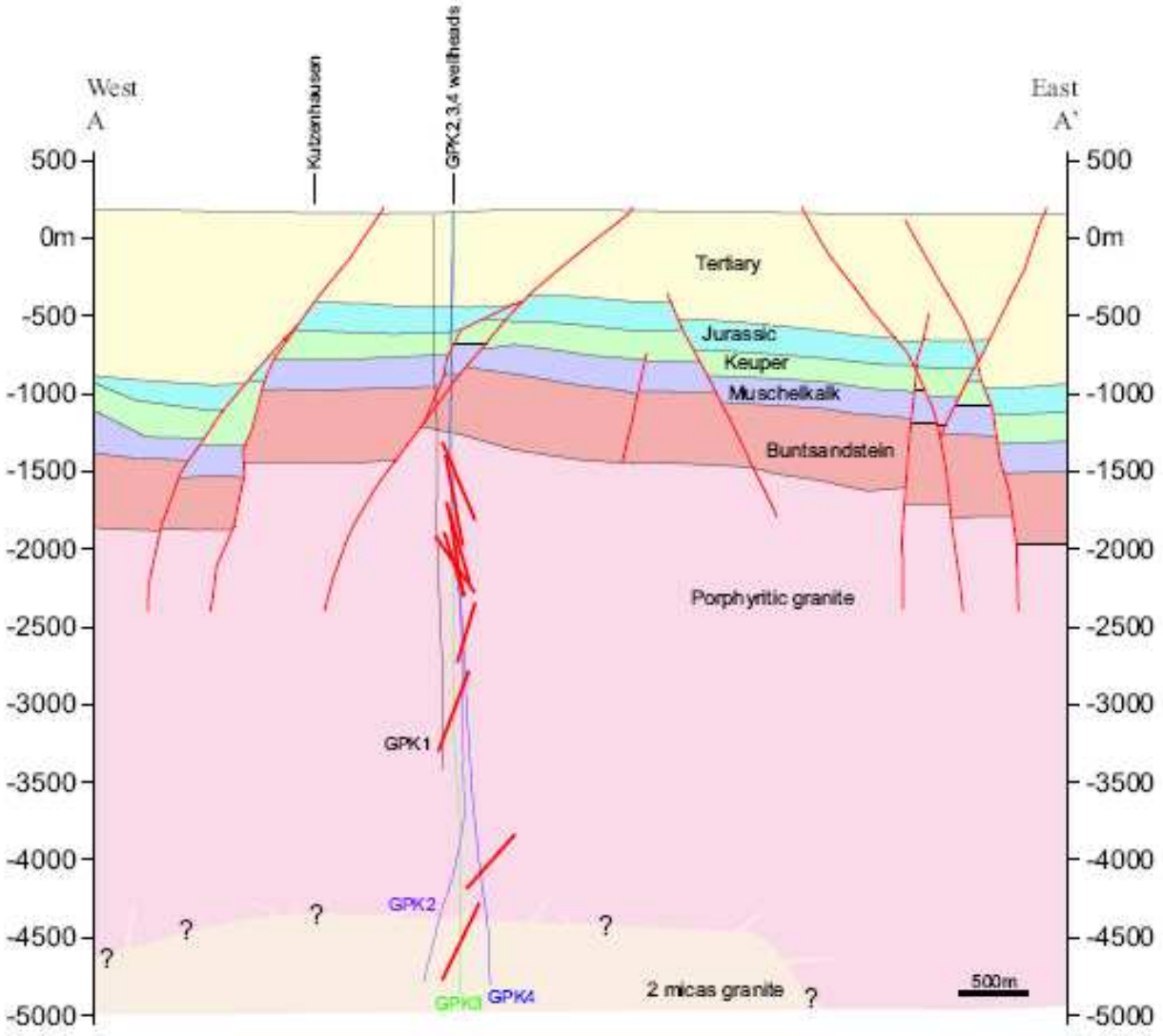
14 km length of borehole image logs

>> 800 m length of cores in the upper reservoir

1,2 m of core in the lower reservoir

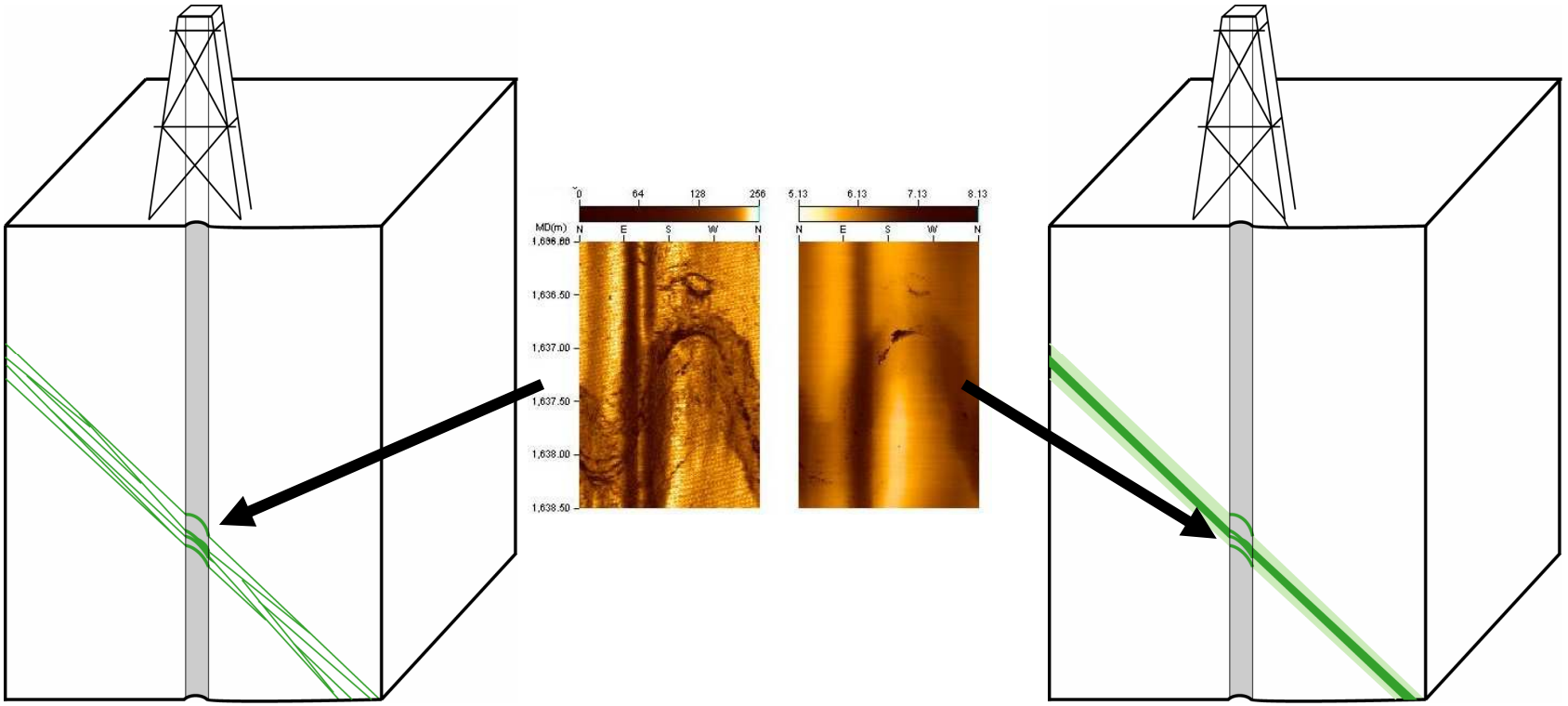


Fracture zones along the well bore

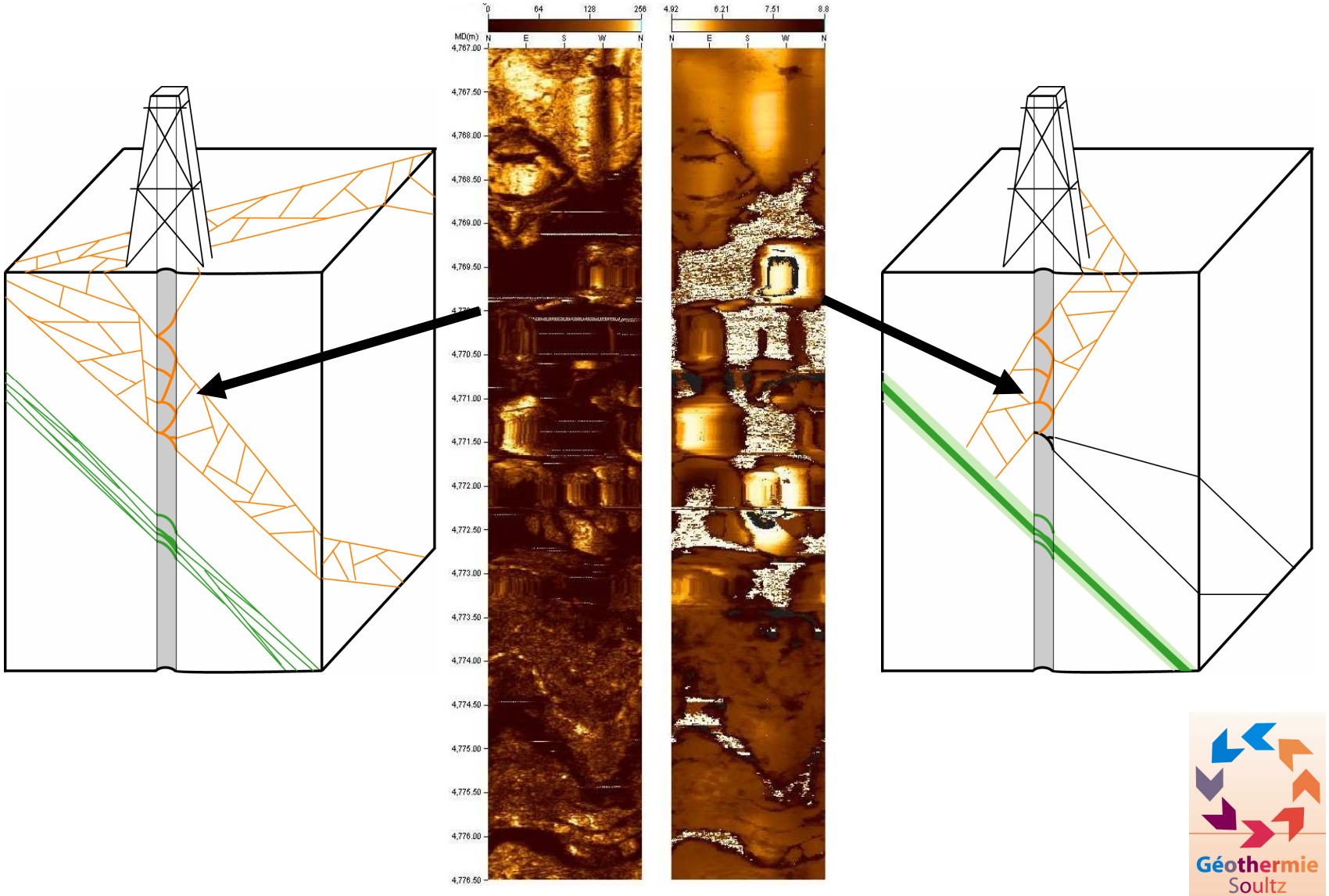


From Valley, 2007

How to get the 3D fracture network from well only



Fracture network: from 1D to 3D



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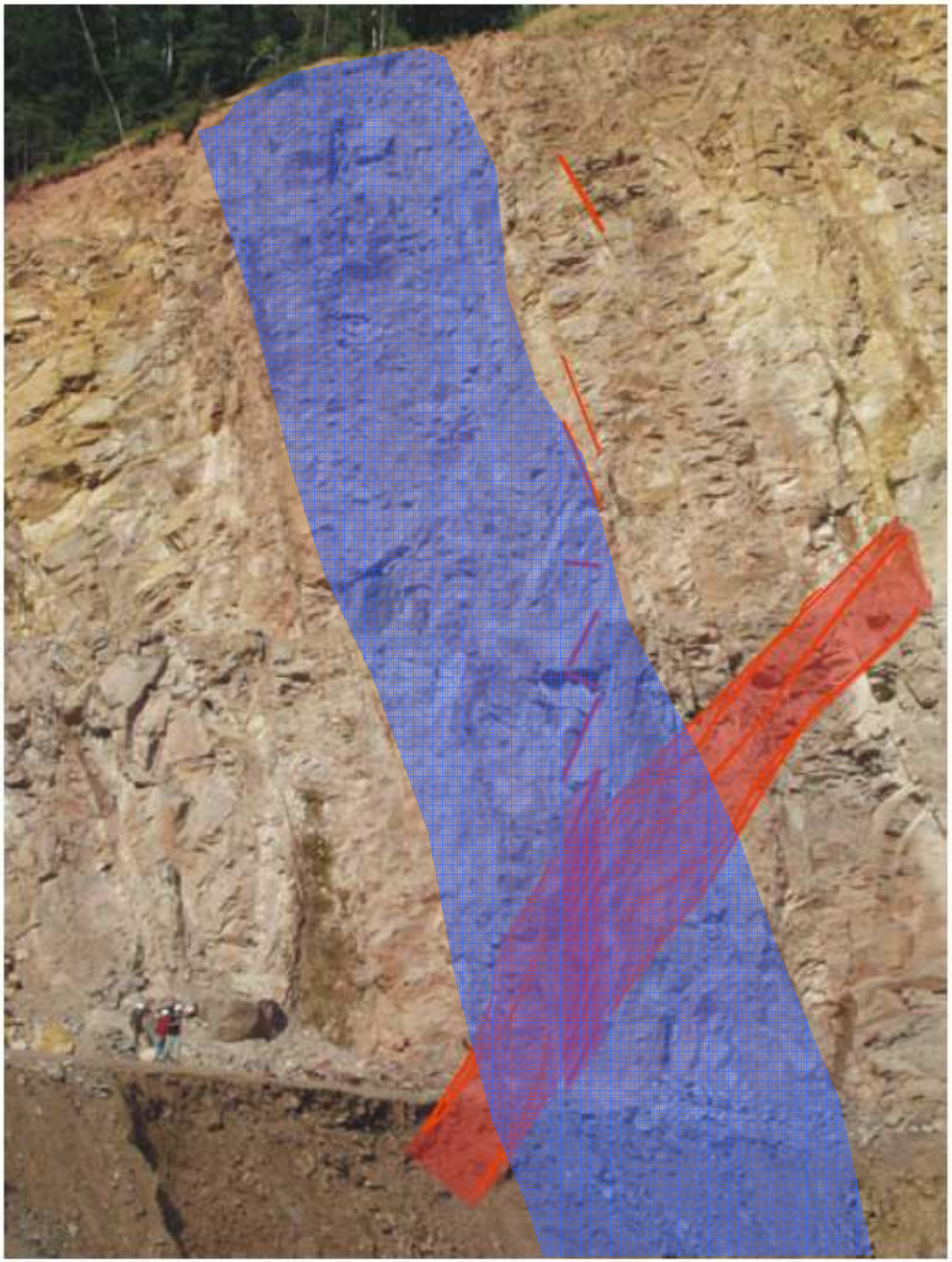
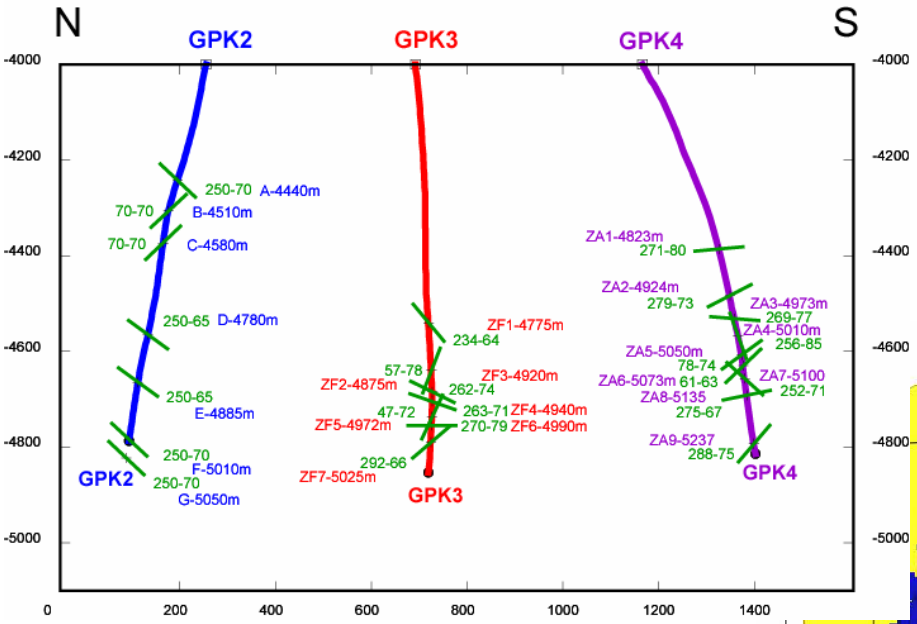
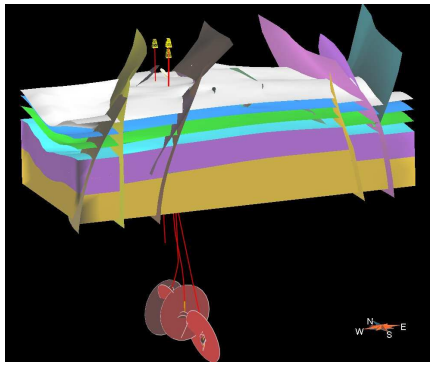
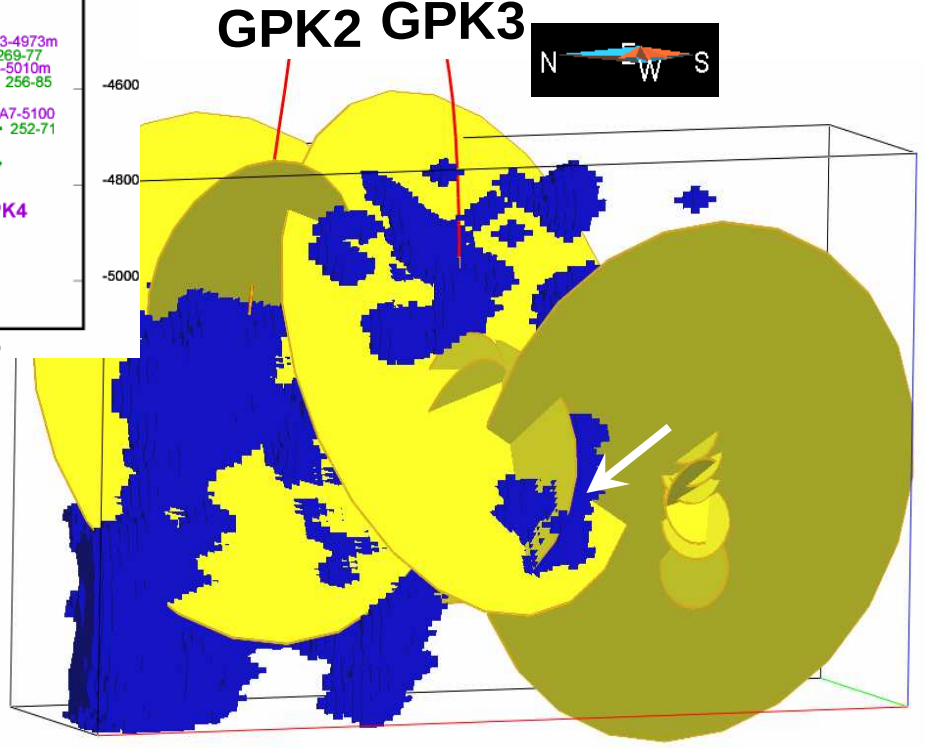


3D modelling procedure



BRGM, 2006





Sausse et al., 2007

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AE reflection method

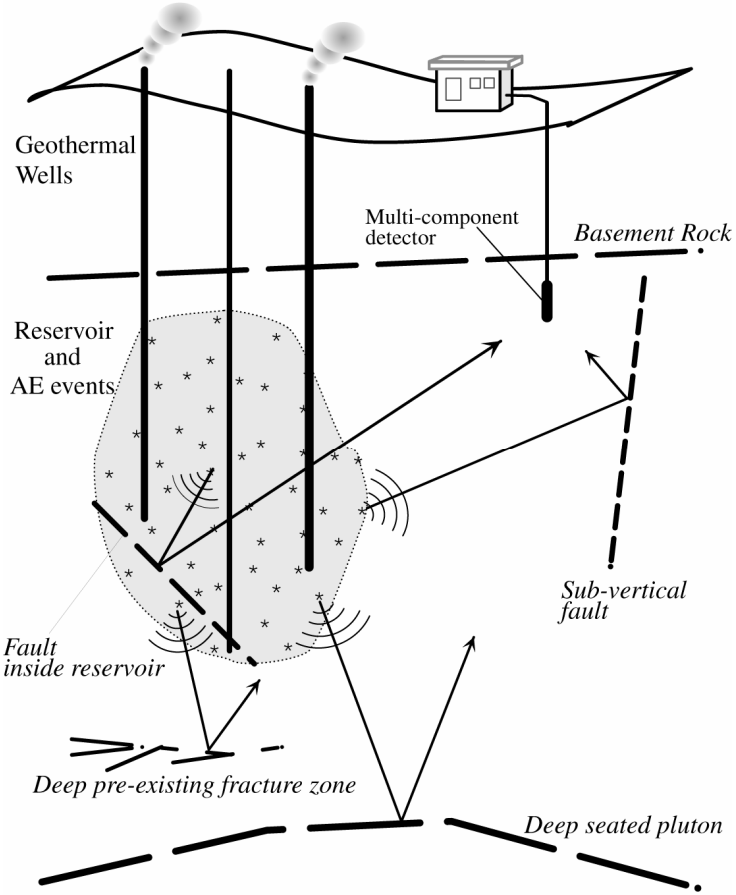
Basic concept

Using AE/MS waveform as a wavesource
3D imaging like a reflection survey

Advantages

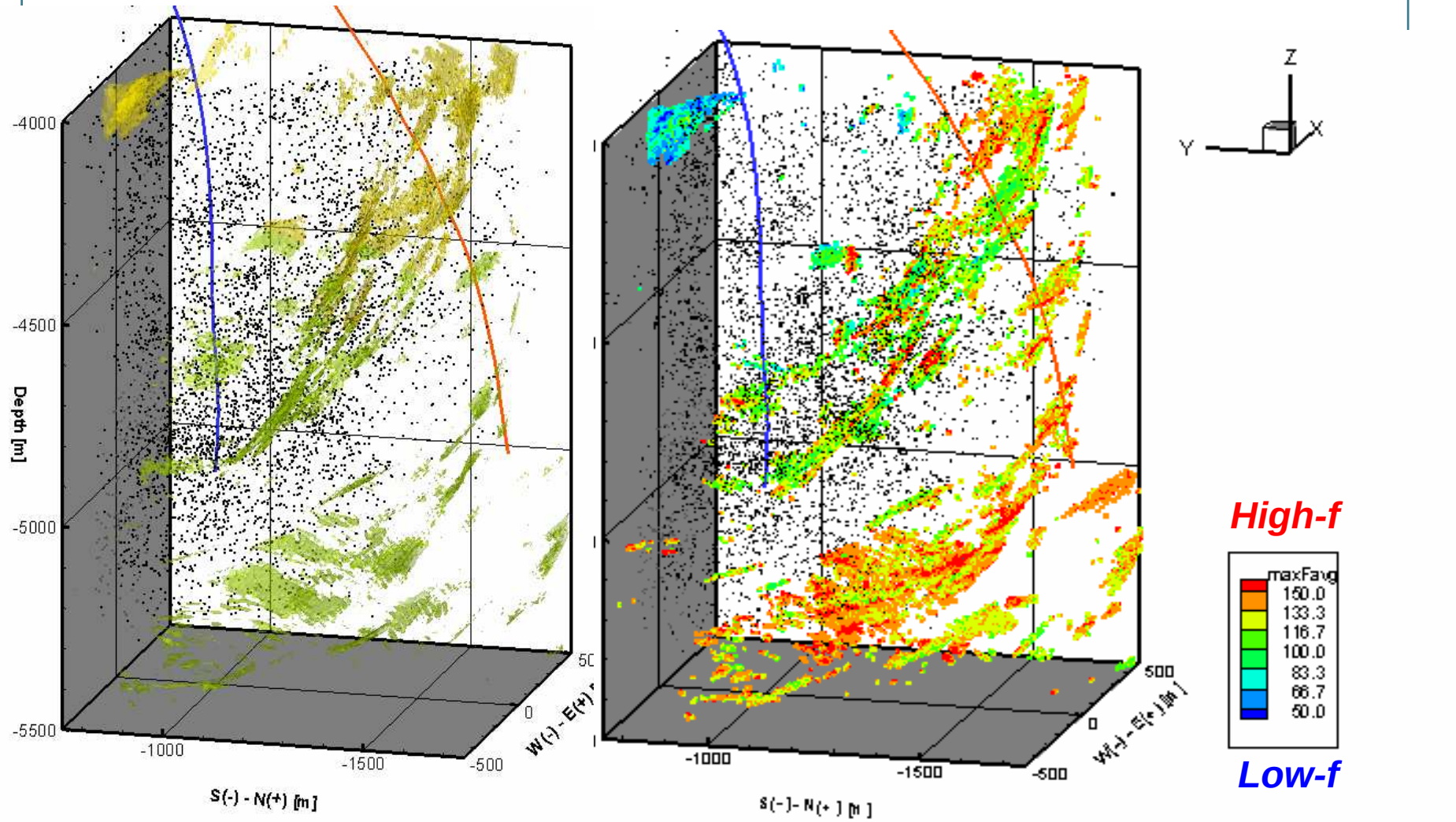
High energy, robustness,
Resistant to surface condition,
Simple & easy, low costs

- Available for inside basement rock or highly attenuated media in geothermal fields
- Detection of sub-vertical structures
- Sensitivity to fractured zone (S-wave)

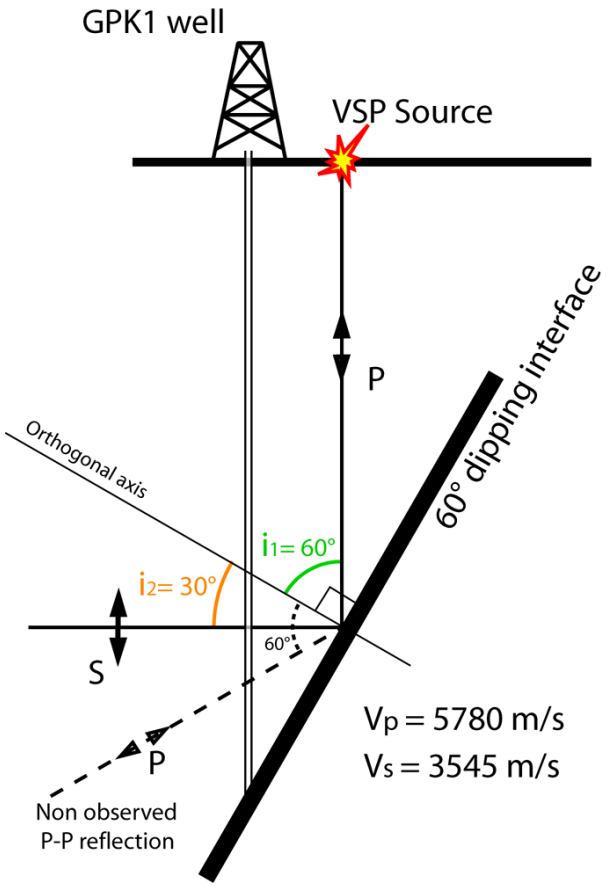


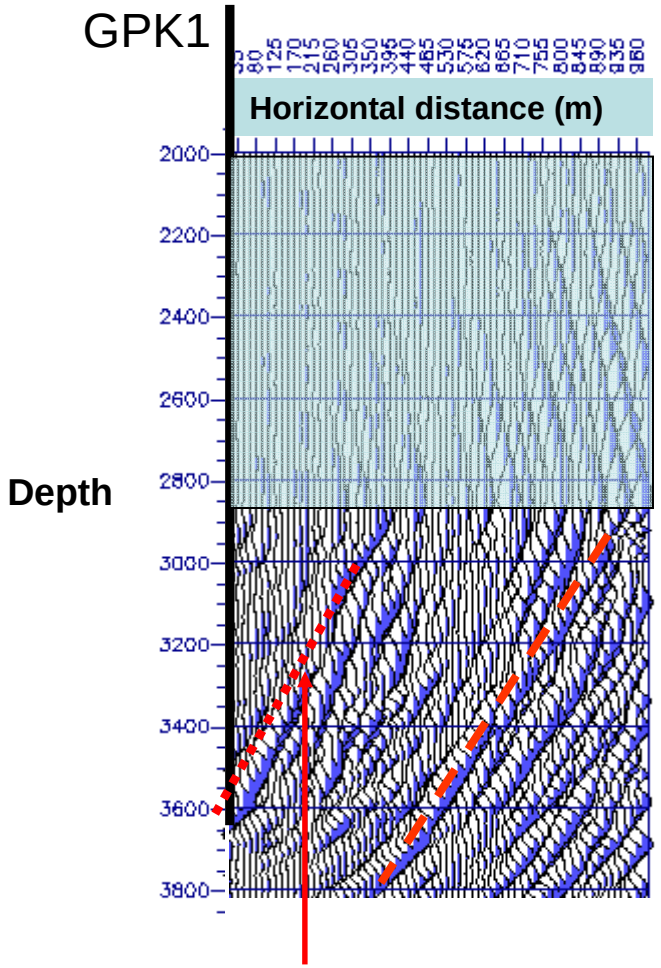
from Soma

GPK3-GPK4: AE and structures (from Soma et al., 2004)



Vertical Seismic Profile (VSP): better characterisation of fracture zone network?





Permeable fracture (dip 60°)

Observed in the well

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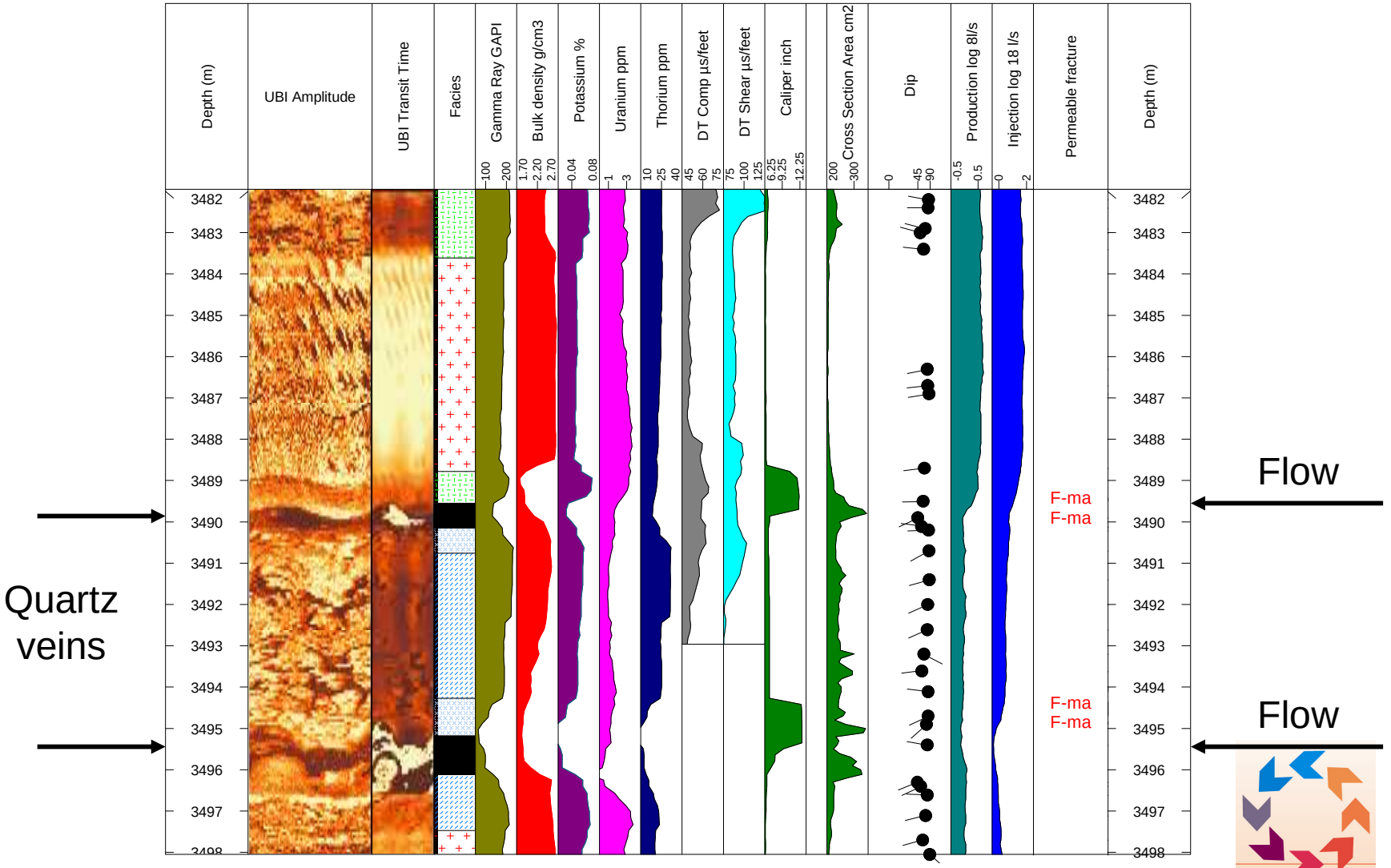
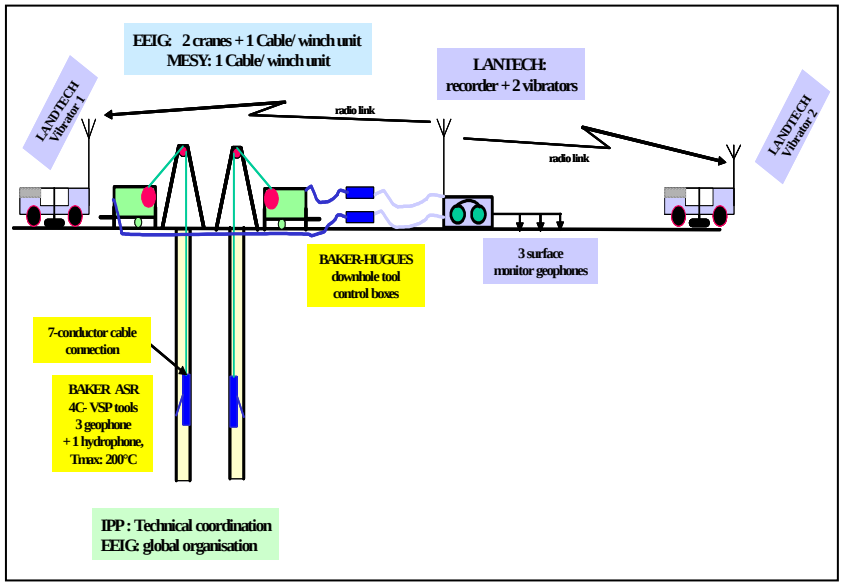
Characterization of permeable fracture zone in drillhole



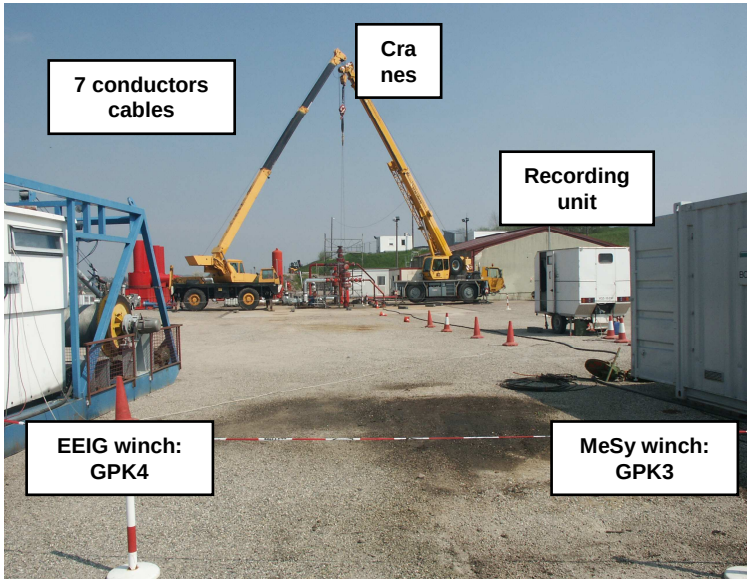
Soultz, GPK1 3500 m, Natural brine outflow

VSP Survey: April 2007

Vibrator Truck



IFP, EEIG, EOST, MeSy,
Baker Hughes, Landtech, VSFusion



VSP preliminary results in GPK4

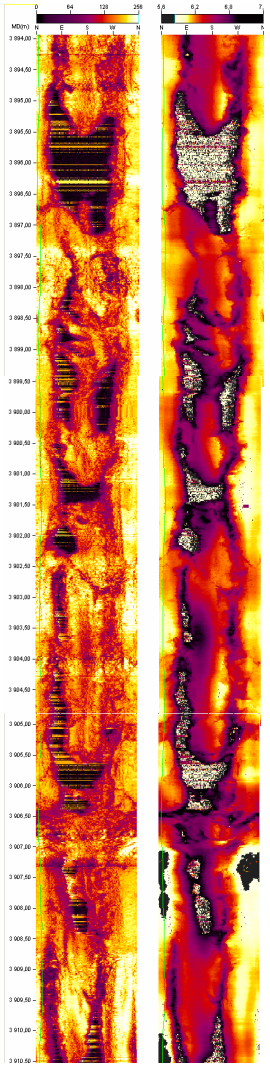
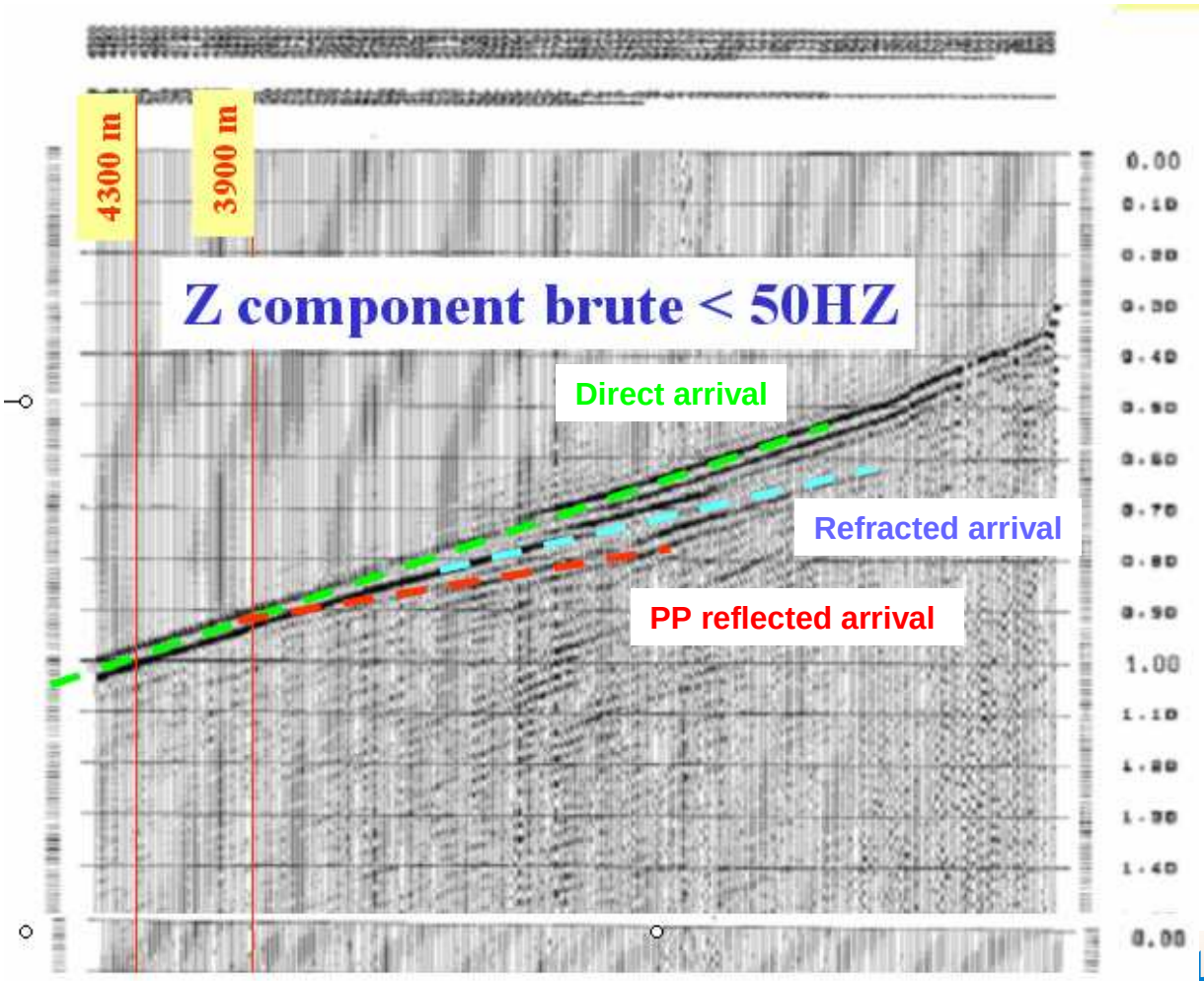


Image log at 3900 m



3900 m depth: complex damaged zone
4380 m depth: permeable fracture zone

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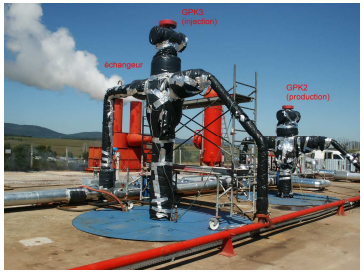
Conclusion



- **Exploration: hierarchy between faults**
- **Regional scale**
  - compilation at regional scale (seismics, old wells)
  - Integration by producing conceptual model
- **Local scale**
  - 3D/2D seismics (25 km²)
  - Drill an exploration well
  - Geophysical logging, borehole image, core, cuttings,…
- **VSP survey**
  - Top basement fault map
  - Locate major faults in the basement
- **Target new wells**
  - Optimize well trajectories (inclined/deviated wells)
  - Secure well design and thus future exploitation

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