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

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Risk Analysis for Development of Geothermal Energy

Cuenot N., Genter A., Naville Ch.
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
Best practices in oil industry from exploration to exploitation

From Oil field review, 2005/2006
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**
- Mineralogical rock-matrix composition
- Hydrothermal Alteration
- Fracture filling
- Chemical stimulation
- Scaling, Tracing
- W-R interaction

**THERMAL**
- Lithology (U, Th, K)
- Rock-matrix composition
- Thermal properties
- Thermal stimulation

**HYDRAULIC**
- Matrix K, Φ
- Fracture K, Φ
- Fracture network
- Hydraulic stimulation

**MECHANICAL**
- Lithology, Alteration (drilling)
- Fracture Properties
- In situ Stress
- Drilling Hydraulic stimulation

Rock composition, Fracture, Stress
EGS drilling reconnaissance

Stress Field

Lithology

Fractures

Geophysical logs

Core
Fracture filling
Cuttings
Fracture Filling
Fault network at Soultz derived from 2D seismics

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*
Fault network at well scale

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

FMS, FMI, ARI
BHTV, UBI
Cores
Cuttings
Geophysical logs
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
3D modelling procedure

BRGM, 2006

Sausse et al., 2007
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?

GPK1 well

VSP Source

60° dipping interface

P

Orthogonal axis

\( i_1 = 60° \)

\( i_2 = 30° \)

Non observed P-P reflection

\( V_p = 5780 \text{ m/s} \)

\( V_s = 3545 \text{ m/s} \)

Permeable fracture (dip 60°)

Observed in the well

Horizontal distance (m)

Depth

GPK1
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

Z component brute < 50HZ

Direct arrival
Refraction arrival
PP reflected arrival
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