A Method for Estimating the Permeability of Reservoirs during Hydro-fracturing Stimulations.

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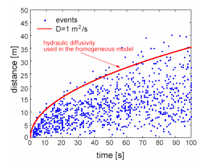
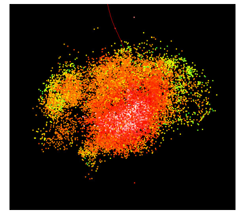
Purposes

Hydro-fracturing stimulation is a classical method to achieve better flow rate in hard geothermal rock reservoirs. The stimulation is performed by maintaining a high fluid pressure (several MPa) into pilot boreholes. The pore pressure increases gradually from the injection source to the surrounding rocks, implying local changes in the stress field that induces shears and/or opening of sealed micro fractures or faults, and, when the differential pressure is greater than the rock cohesion, leads to normal faulting.

This approach has been applied to the Soultz-s-Forêts, France HDR geothermal reservoir for depths ranging from 3500 to 5000m. It provides a detailed map of the permeability and of its variations before and after stimulation with a resolution of tenths of meters over an extension of several hundred meters around the injection source.



Reservoir 5000m



Each of these events induces small magnitude micro-seismic events which can be recorded from the surface by tri-axial geophones located deep in observation boreholes.

This induced micro-seismicity provides indirect information on the reservoir permeability.

A new methodology is proposed to characterize the geothermal reservoir potentialities by estimating its 3D anisotropic heterogeneous diffusivity and its time evolution during the stimulation.

Estimating Permeability from Micro Seismicity

$$\int_a^r \frac{ds}{D(s,t)} = \sqrt{4\pi \int_0^t \frac{d\tau}{D(r,\tau)}}$$

Temporal average

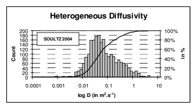
r is the distance between the source and a microseism recorded at time t

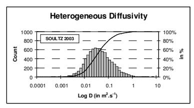
<u>If D remains constant in space and time :</u>

$$r = \sqrt{4\pi D t}$$

(Shapiro, 1997)

Diffusivity at 5000m





Estimating hydraulic diffusivity and permeability

$$\mathbf{D} = \begin{pmatrix} 13 & 0 & 0 \\ 0 & 10 & 0 \\ 0 & 0 & 3 \end{pmatrix} \times 10^{-2}\ \mathrm{m^2/s}$$

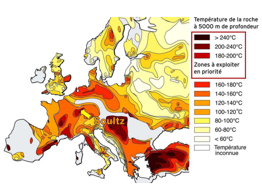
$$\mathbf{K} = \begin{pmatrix} 16 & 0 & 0 \\ 0 & 12 & 0 \\ 0 & 0 & 3.6 \end{pmatrix} \times 10^{-17}\ \mathrm{m^2}$$

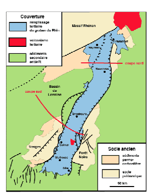
Discussion

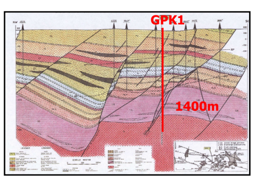
- D & K in reservoir 5000m have same order of magnitudes than at 3800m
- Slight Rotation of Principal Axis (Anisotropy)
- Higher permeability between GPK2 and GPK3
- Smaller permeability between GPK4 and GPK2 along a plane, but similar values around GPK4

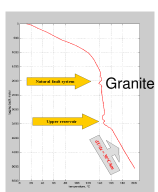
HDR Project At Soultz-s-Forêts

Heat Surface Flow Map in Europe

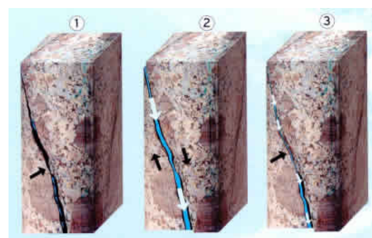


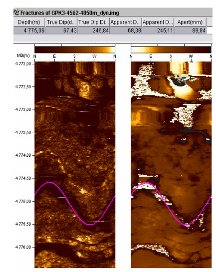






Fracture Opening during Hydrofracturation





UBI Images

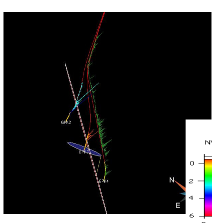
Methodology

Main active fractures zones were identified on three available wells by interpreting and processing the boreholes UBI images. Orientation and opening of each fracture were evaluated using the GMI software, and integrated into a comprehensive 3D model using the gOcad geomodeler.

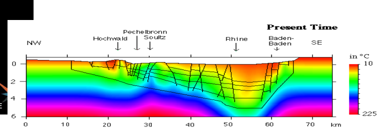
The 3D fracture network seems to be coherent with a strike slip model related to the formation of the Soultz horst. The relationship between the induced miro-seismicity and the identified fracture zones are then discussed in terms of hydraulic potentialities

Shearing Model

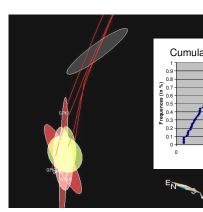
Wells Connection

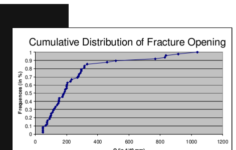


Displacements are compatible with a shearing link to the uplift of the horst. Fractures at depth (5000m) result from this regional deformation model.



Fault Identification





Major fractures are connected to wells GPK1, GPK2 and GPK3, not to GPK4 explaining the good connectivity between GPK2 and GPK3 at depth and the bad connectivity of GPK4.

Conclusions

Careful study of the fracture network shows:
- good connection between wells GPK1, GPK2 and GPK3.
- bad connection of wells GPK4 to the surrounding fracture network

Two groups of sub-vertical fractures can be identified based on opening and orientation criterions: large open N170 fractures in agreement with the regional stress field and conjugates. This pattern corresponds to the uplift of the Soultz-s-Forets horst and indicates a shearing with about 100m in displacement.

Future Works

- Need experiments for calibrating the new micro-seismic methodology (Pumping tests)
- Further work for interpreting microseismicity induced by several injection sources
- Accounting for uncertainties
- Continue to calibrate this approach onto real case tests such as reservoirs and natural analogues
- Better integration of fractures in reservoir modeling

References

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