A Methodology for the Hydro-mechanical Characterisation of EGS reservoirs

Session:
Reservoir characterisation during stimulation

Content:

1. Principal task in EGS development
2. A methodology: HEX-S code
3. Example: Coso geothermal field, USA
4. Example: Europ. EGS project Soultz, France

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ENGINE Workshop3: Stimulation of reservoir and induced microseismicity
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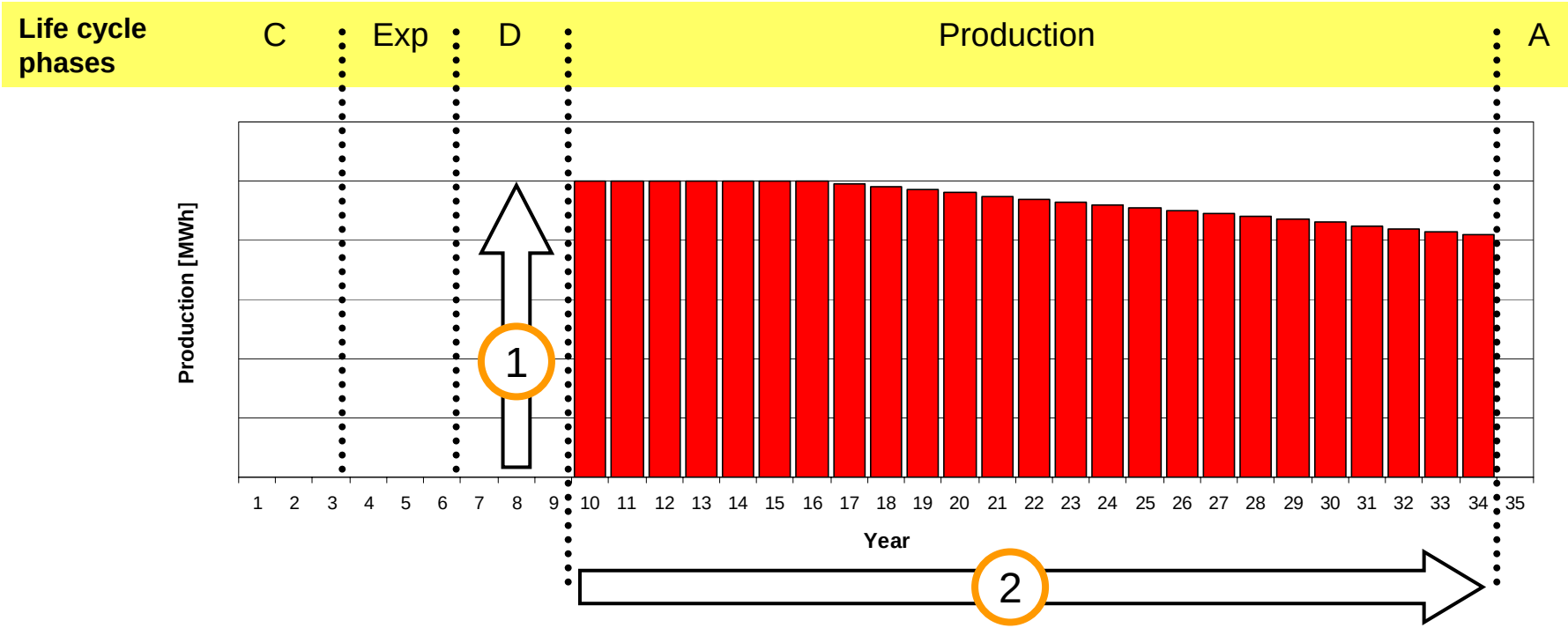
Principal task in EGS development



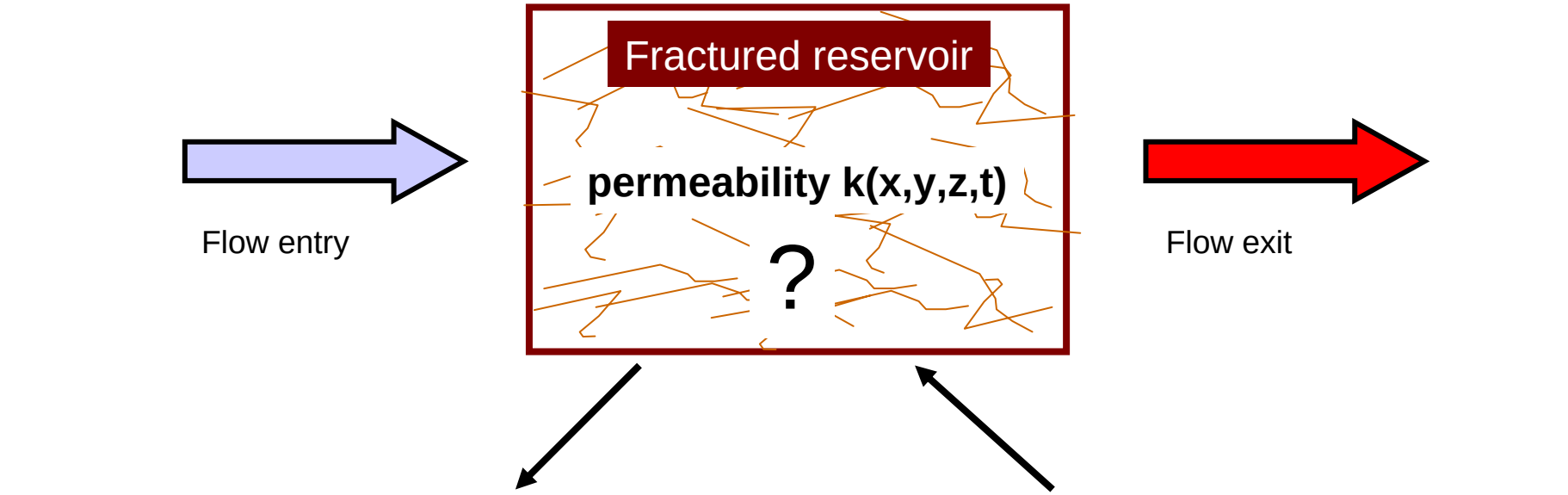
Principal Tasks:
1. Maximise production
2. Guarantee production

⇨ **Reservoir parameters of production ?**

Principal task in EGS development

Production

Q [l/s] = Function of permeability k(x,y,z,t) → Reservoir impedance
T [°C] = Function of permeability k(x,y,z,t) → Heat exchange surfaces



Characterising the reservoir
= Identifying k(x,y,z,t)

Tests/measurements/data analysis

Strong interrelation of knowledge

Conditioning the reservoir
= Creating/modifying k(x,y,z,t)

Stimulation

Data for characterising an EGS reservoir

Phase	Borehole scale	Reservoir scale
Before drilling		Regional/local geological model Geophysical survey data
After drilling	Cuttings (**z**) UBI/ARI... logs (**z**) Temp logs (**z**,t) Stress field (**z**)	
After hydraulic tests 1. well	Flow log (**z**,t) Pressure (z,**t**)	
After stimulation 1. well	Pressure (z,**t**)	Microseismic locations (**x,y,z,t**)
2. well		
3. well		

Identifying k(x,y,z,t)

Predict k(x,y,z,t) for a stimulation scenario

Hydro-mechan. Physics

Principal concept of HEX-S

1. Hydraulic structure model

Identification of hydraulic structures from existing data sets

↓

Mapping of the **deterministic** structures to a FE-grid

↓

Mapping of **stochastic** structures to the FE-grid = k(x,y,z,t=0)

→

2. Hydromech. calc. of k(x,y,z,t)

timestep t_i

Injection flow (t) foreseen

↓

Pressure development in the reservoir (FE-grid)

↓

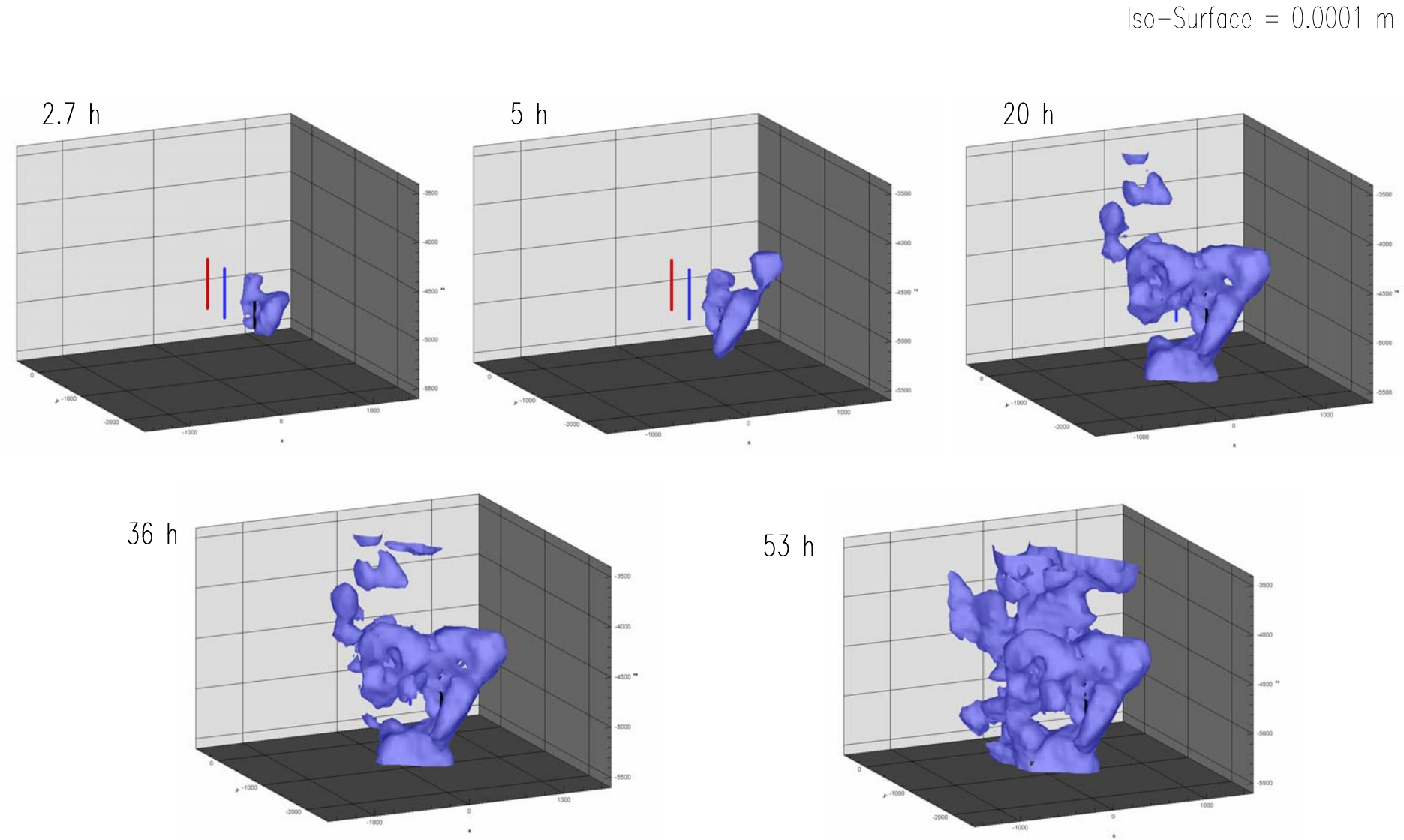
Shearing and opening of fractures

↓

Adaptation of $k(x,y,z,t_i)$ in FE-grid

A methodology: HEX-S code

Example: Stimulation GPK4, development of fracture apertures



Implementation of hydraulic structures

Representation:

Circular fracture zones
subdivided into circular slip patches

Mechanics of fracture aperture a:

- by compliance →

$$a = \frac{a_0}{1 + 9 \cdot \sigma_{n,eff} / \sigma_{n,ref}}$$

- by shearing →

$$\Delta\tau = \tau - \sigma_{n,eff} \cdot \tan\left(\Phi_{basic} + \Phi_{dil}\right)$$

$$U = \Delta\tau / K_s \; ; \quad a_S = U \cdot \tan\left(\Phi_{dil}\right)$$

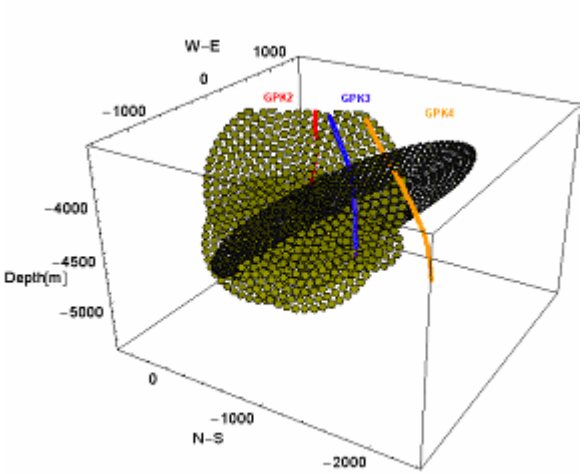
- by jacking : $\sigma_{n,eff} < 0$

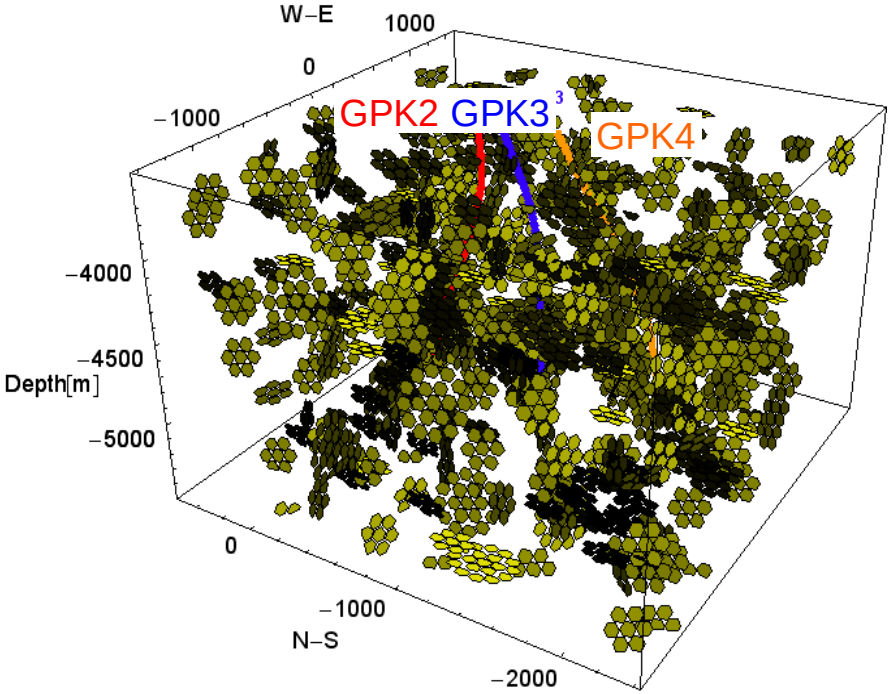
A methodology: HEX-S code

Representation of hydraulic structures

Example: European EGS project Soultz-sous-Forêts, France

Deterministic fracture zones + Stochastic fracture zones





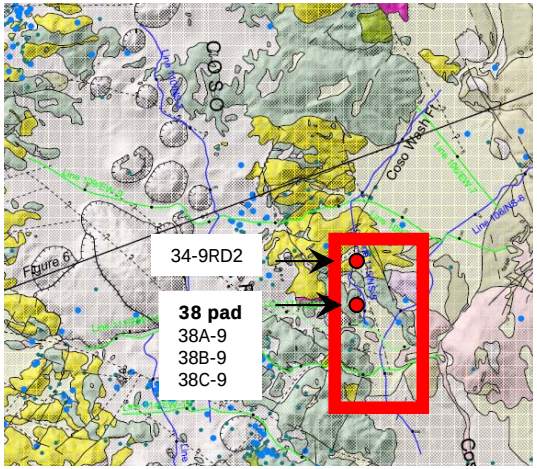
data used

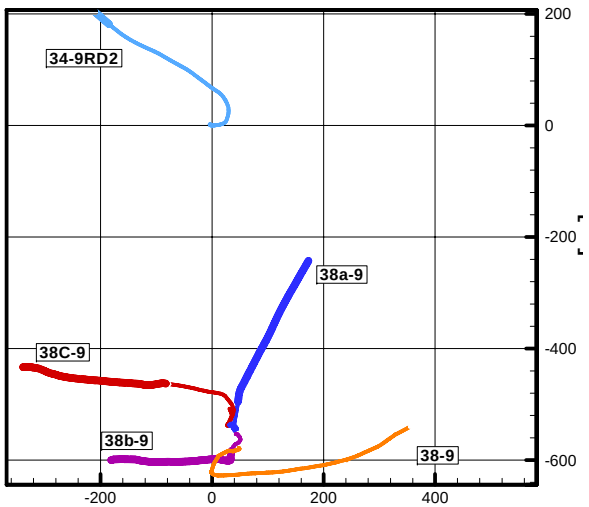
"known" data:
- borehole logs (UBI, T, flow,...)
- structures from microseismicity
- others

→ statistical interpretation of "known" data: stat. distribution of structure parameters

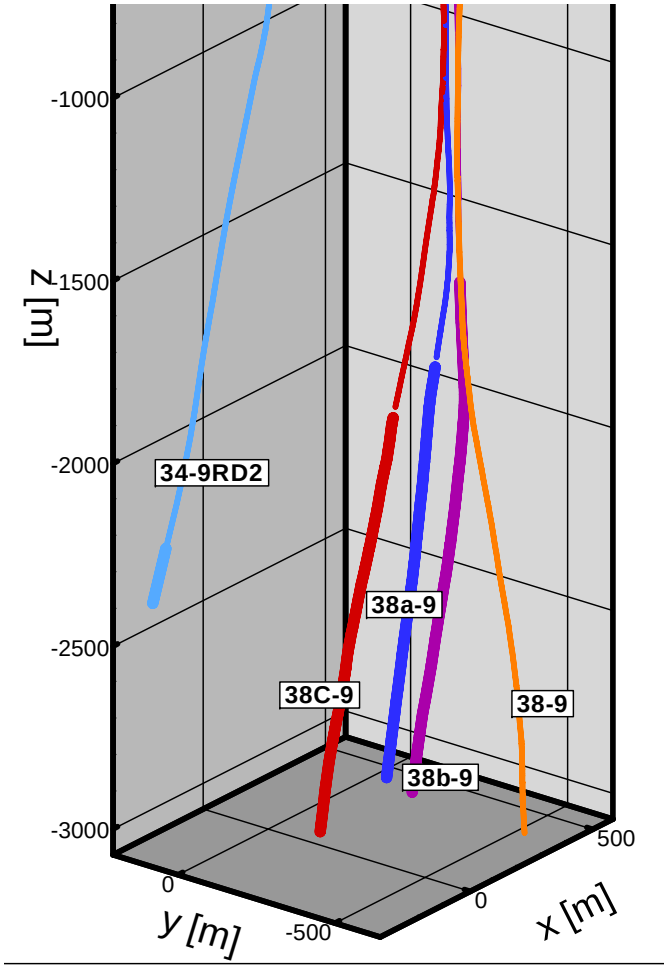
Example: Coso geothermal field, USA

Representation of hydraulic structures





38A-9
38B-9
38C-9
34-9RD2



Representation of hydraulic structures

Network of hydraulically active fracture zones	• Dip, Azi of dip, depth • Shear friction angle (31°) • Shear dilation angle (3°) • 90% reference closure stress (30e6 Pa) • Fracture zone density [2e-3 m^{-1}] • Fracture zone radii (500 m) • Slip patches radii (40 m)
Rock parameters	• E-modulus (6e10 Pa) • Poissons ratio (0.25)
Stress field (linear function with depth)	• shmin (z) • SHmax (z) • Sv (z) • Azi of SHmax (11°)
Initial hydraulics	• P (z) • Initial permeability: 5e-16 m^2 (defines the initial apertures)

Representation of hydraulic structures

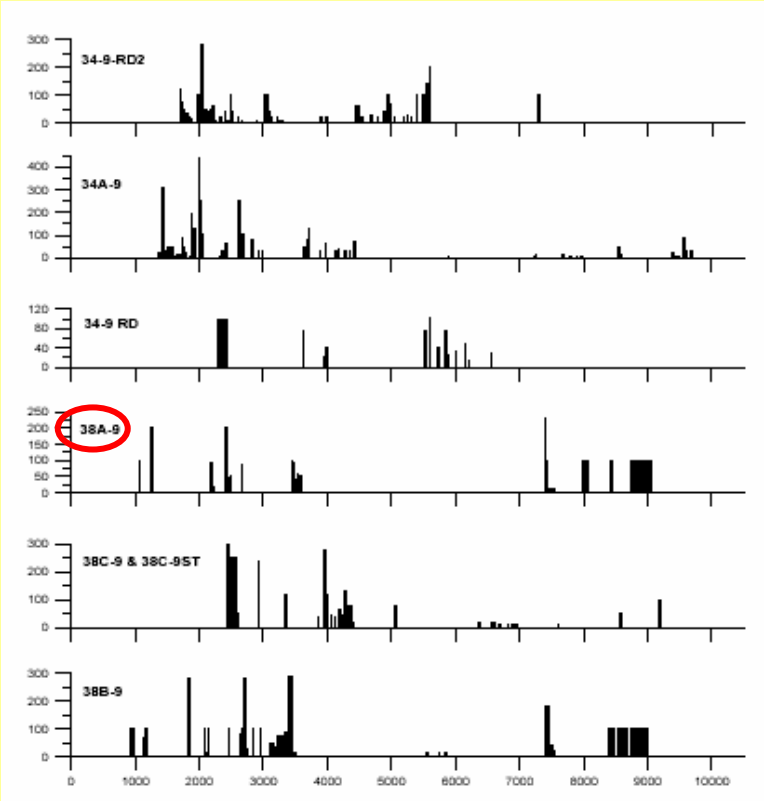
Task	Method
1. Identification of the hydraulic activity	1. Extracting the depth range of zones of lost circulation 2. Extracting depth range of signals (significant deviations in gradient) in temperature logs 3. Others ?
2. Identification of the orientation	1. Extracting dip + azidip from FMS-logs for the depth range of each identified FZ under task 1 2. Determination of the set of orientations with the highest occurrences

Example: Coso geothermal field, USA

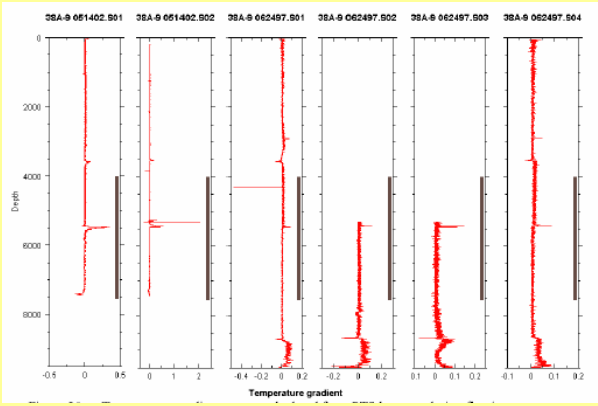
Representation of hydraulic structures

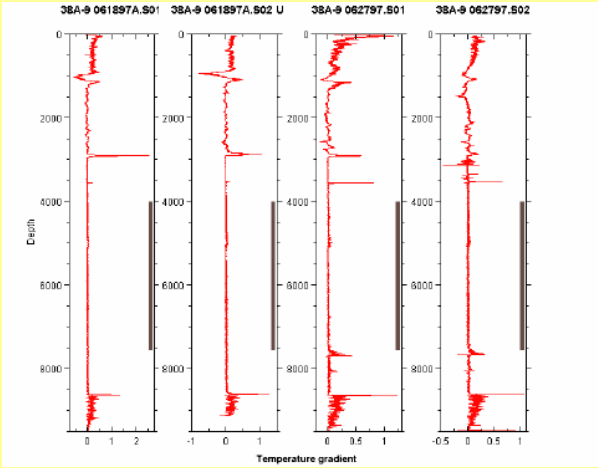
1. Identification of the hydraulic activity, Pad 38A

Lost circulation zones



Temperature gradient





Example: Coso geothermal field, USA

Representation of hydraulic structures

2. Identification of the orientations

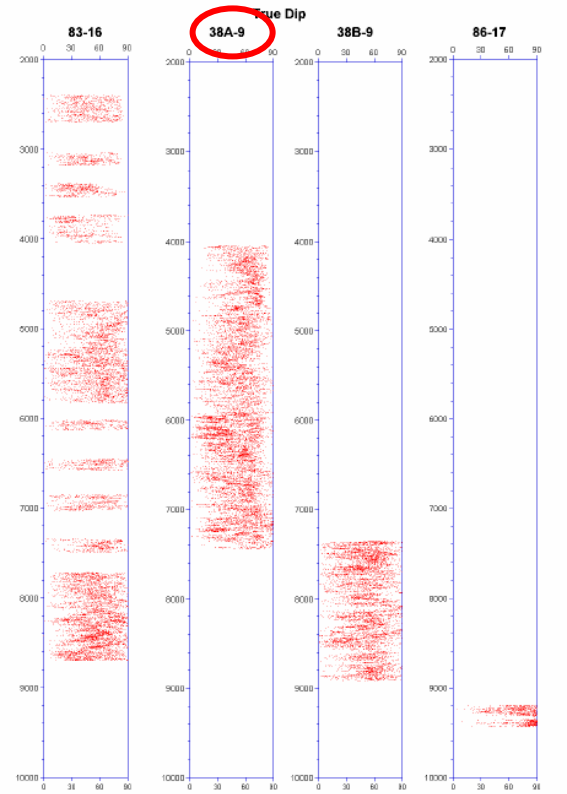


Figure A26. True fracture dip versus true vertical depth (feet TVD) for the Coso study wells.

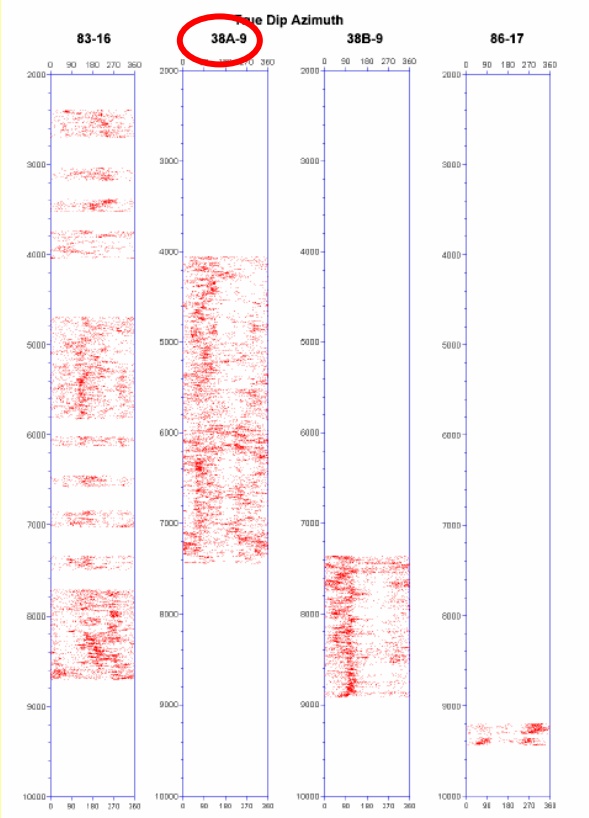
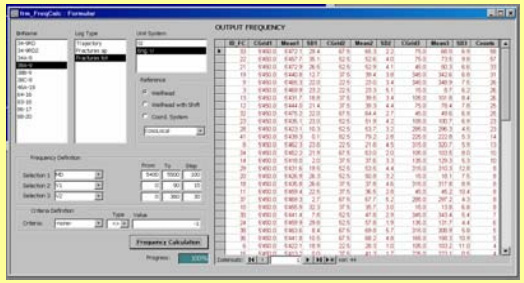


Figure A27. True fracture dip azimuth versus true vertical depth (feet TVD) for the Coso study wells.

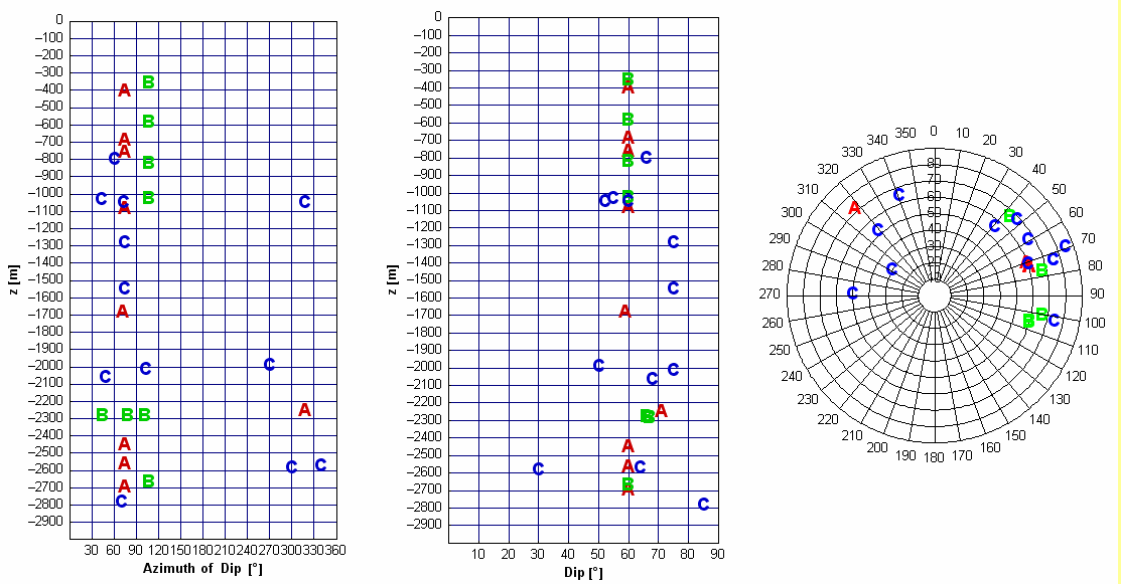
Example: Coso geothermal field, USA

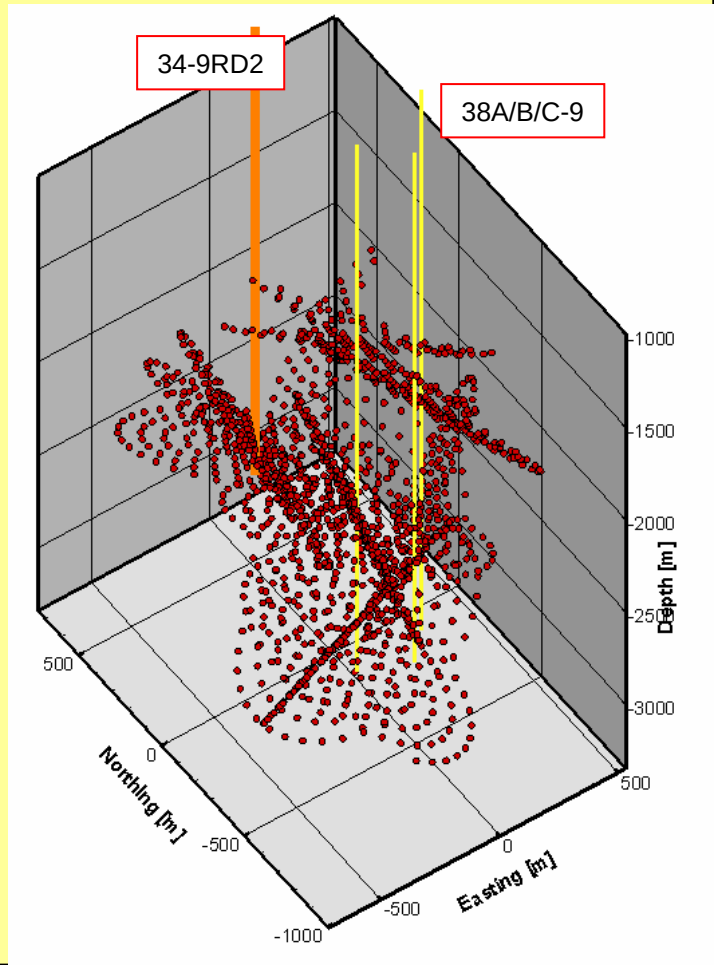
Representation of hydraulic structures

Deterministic hydraulic structures



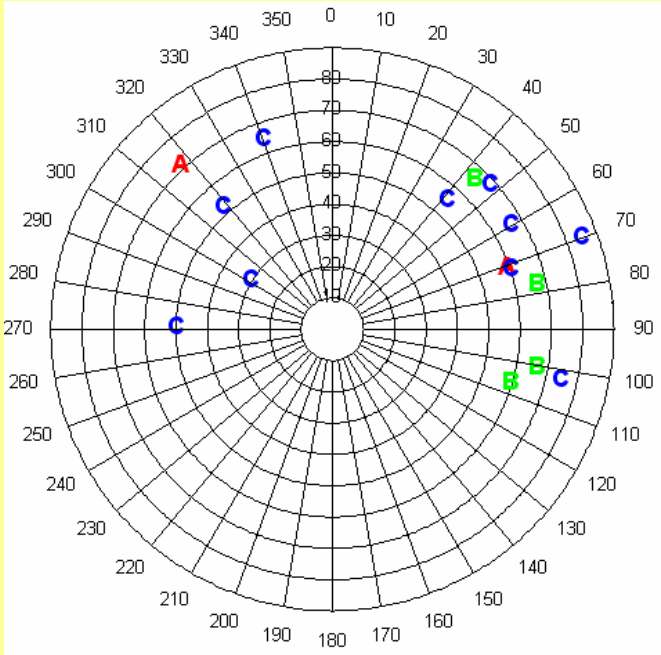
Orientations + depths of **deterministic** FZ for HEX-S model



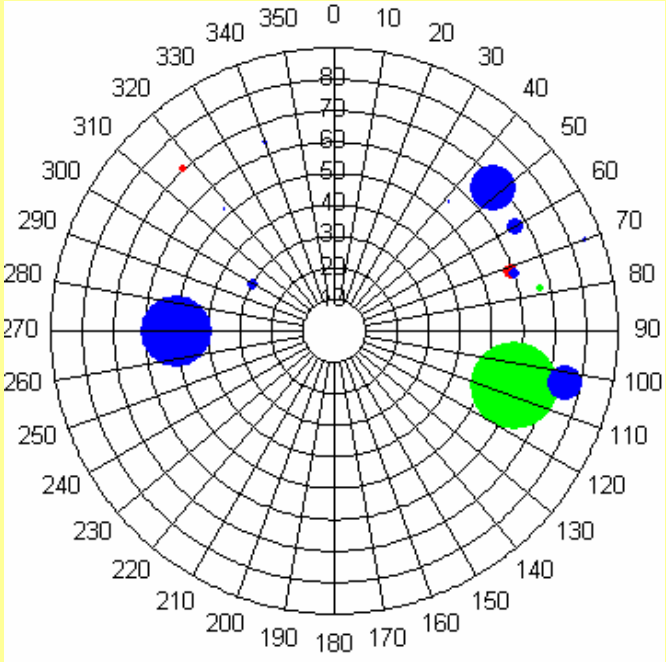


Representation of hydraulic structures

Stochastic hydraulic structures



Orientation of all fractures with an assumed hydraulic relevance, with the sign of the corresponding BH

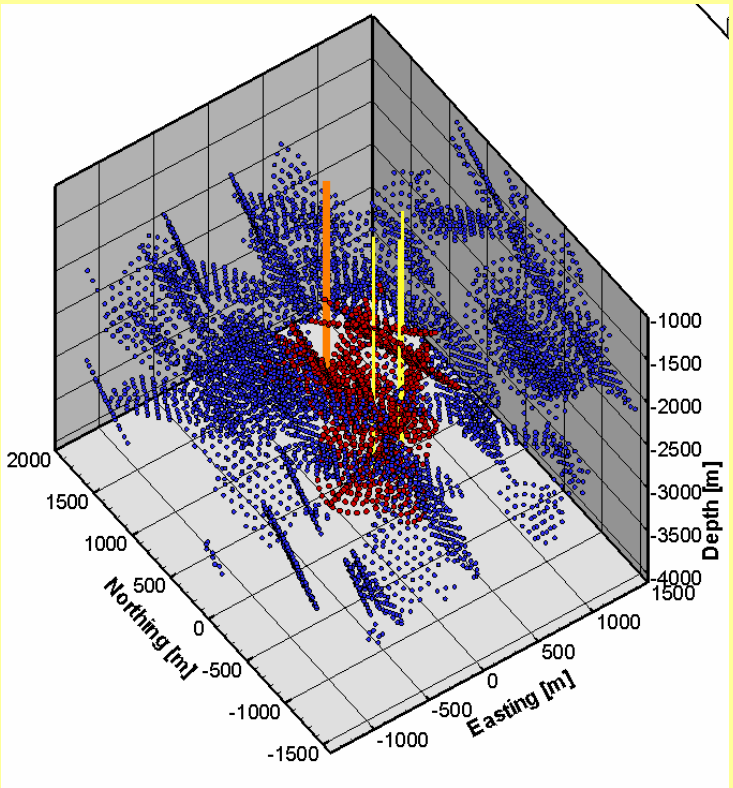


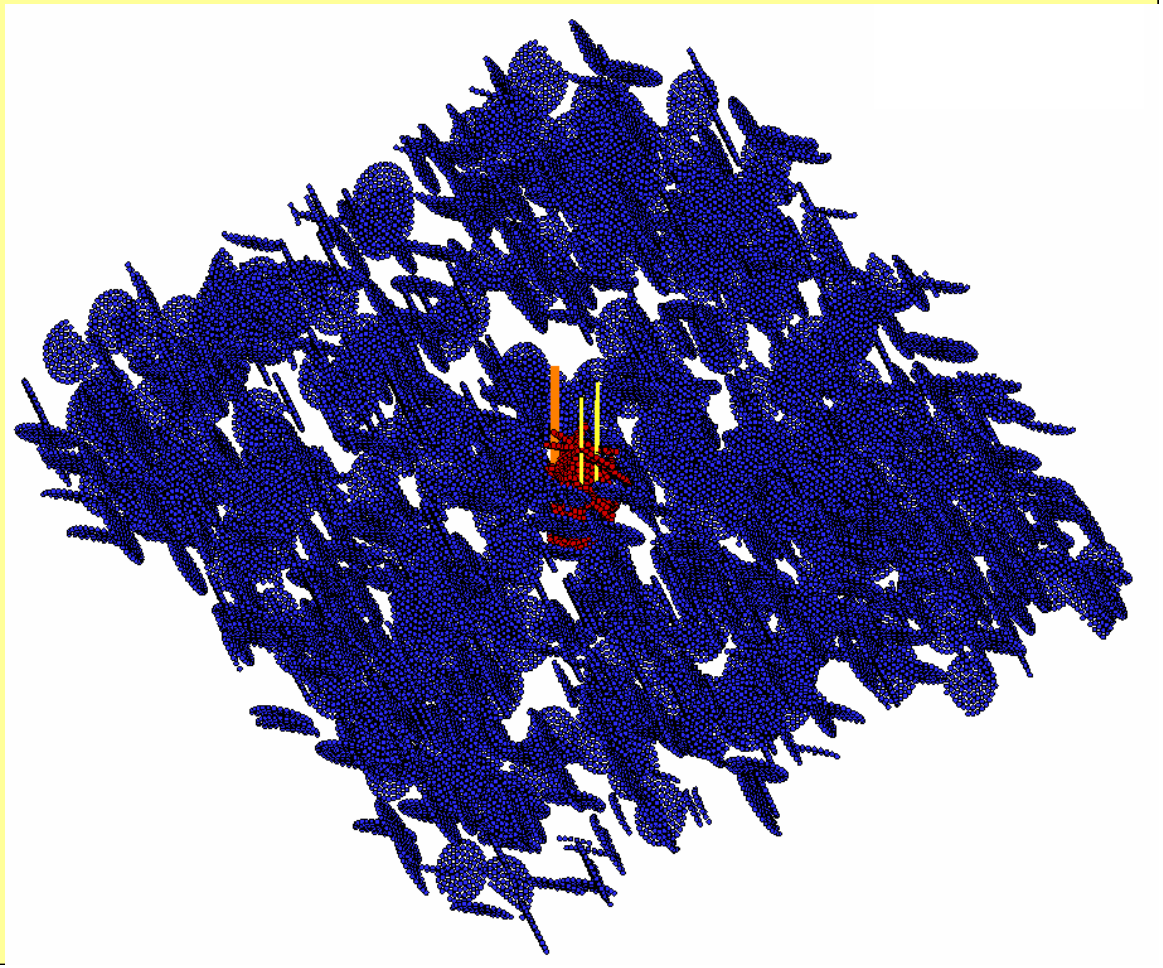
Orientations + frequency of all hydraulic active fractures from pad 38

Representation of hydraulic structures

Stochastic hydraulic structures

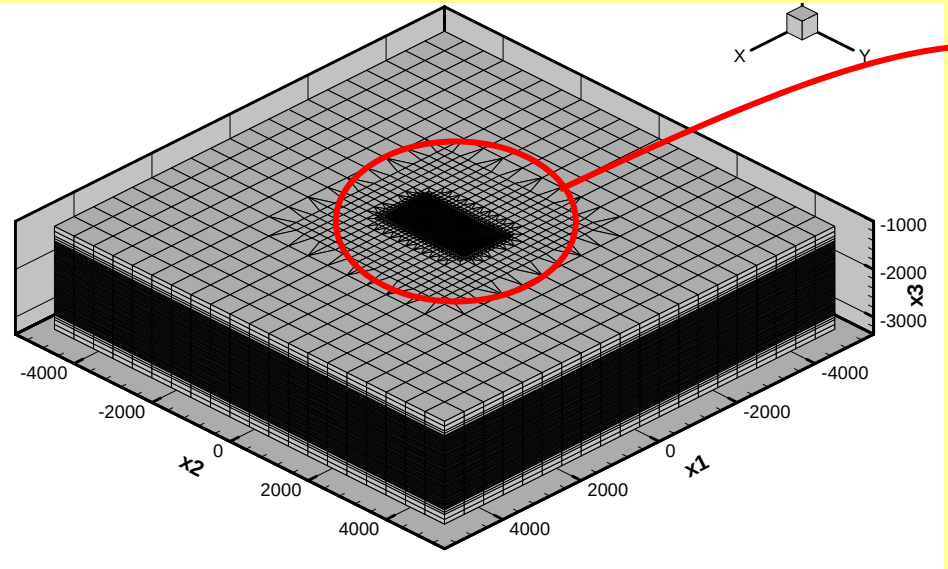
red: deterministic structures
blue: stochastic structures





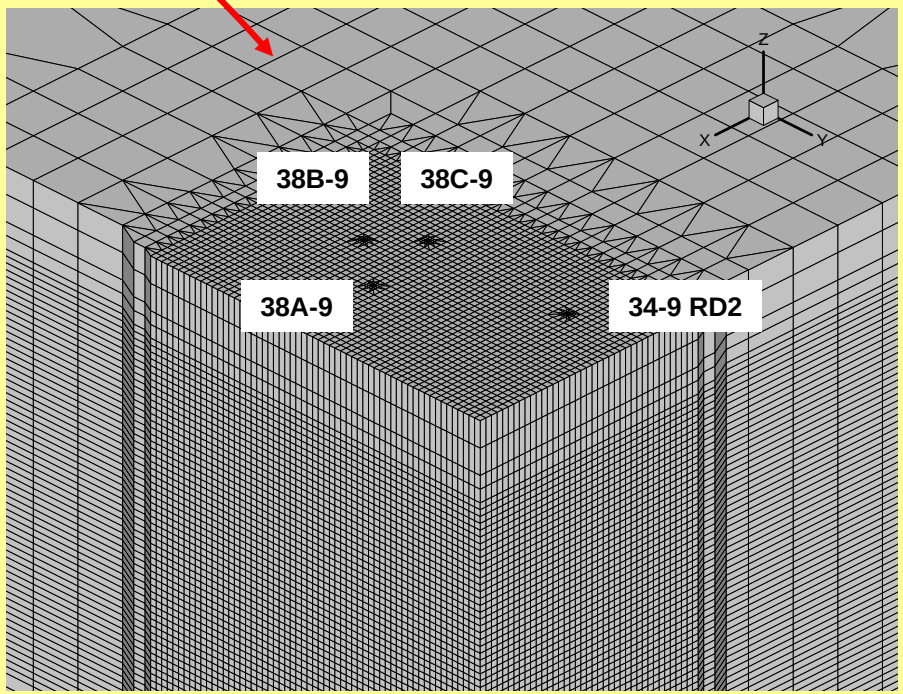
Transient hydro-mechanical calculation

FE-grid for transient hydraulic calc.



Each element has a permeability corresponding to the apertures of the intersecting fractures

$\Rightarrow$ **$k(x,y,z,t_i)$**



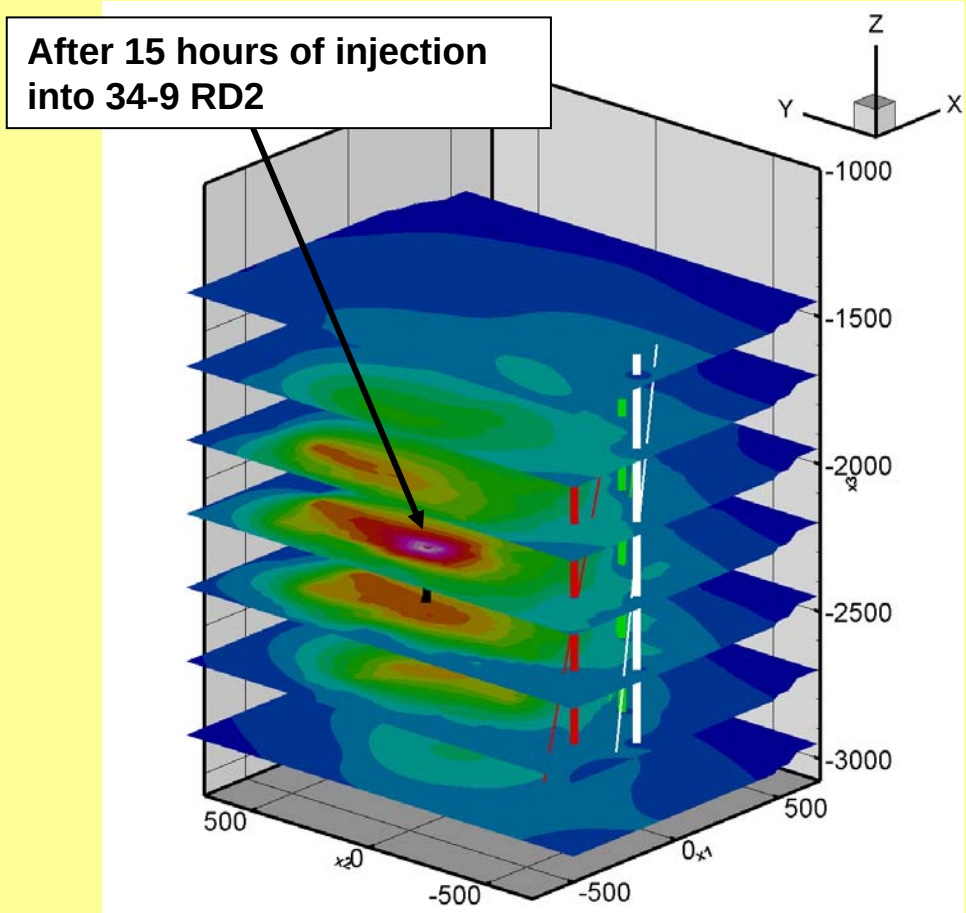
Numerical FE Grid

Element size 25m

~340‘000 elements

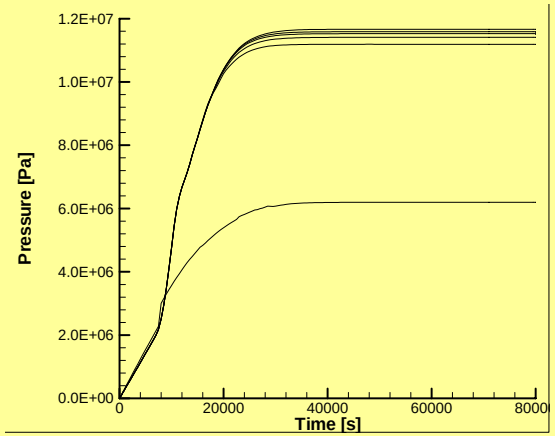
Transient hydro-mechanical calculation

Example of pressure field



- Strongly anisotropic pressure distribution
- Radial field only around injection point
- Pressure envelope oriented along fracture orientation
- Pressure wave propagation in areas with highest degree of fracturing

34-9 RD2 Example: 5 stochastic realizations



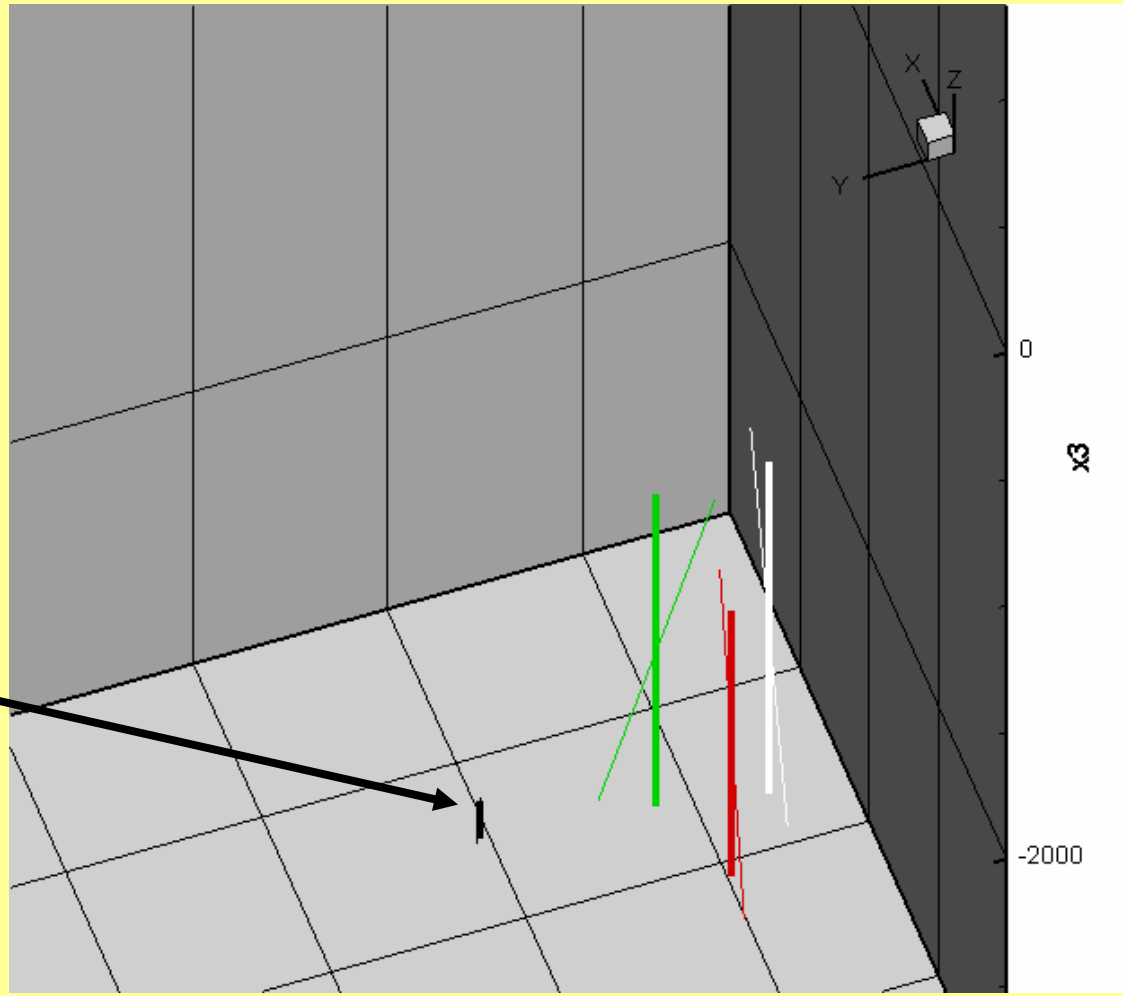
Transient hydro-mechanical calculation

Calc. fracture shearing

Injection into 34-9 RD2

Colour code
= shear displacement
(red: big displ.)

34-9 RD2



Example: Europ. EGS project Soultz, France

Transient hydro-mechanical calculation

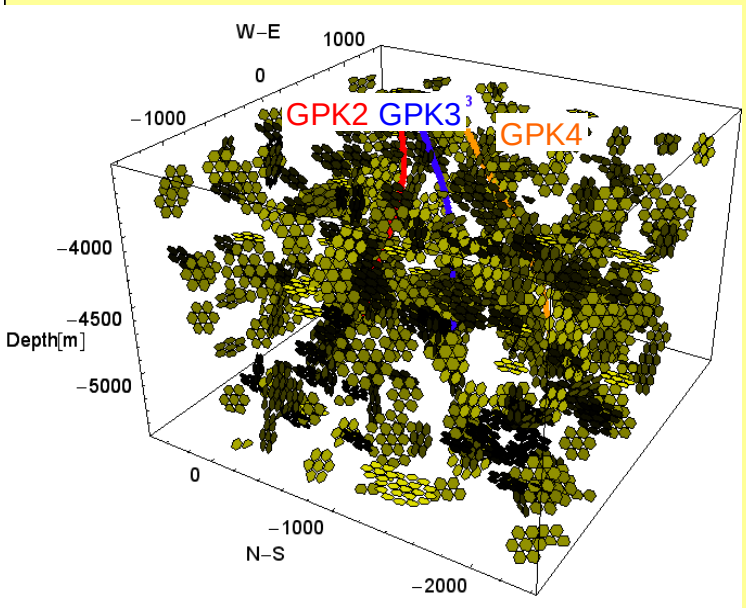
k(x,y,z)

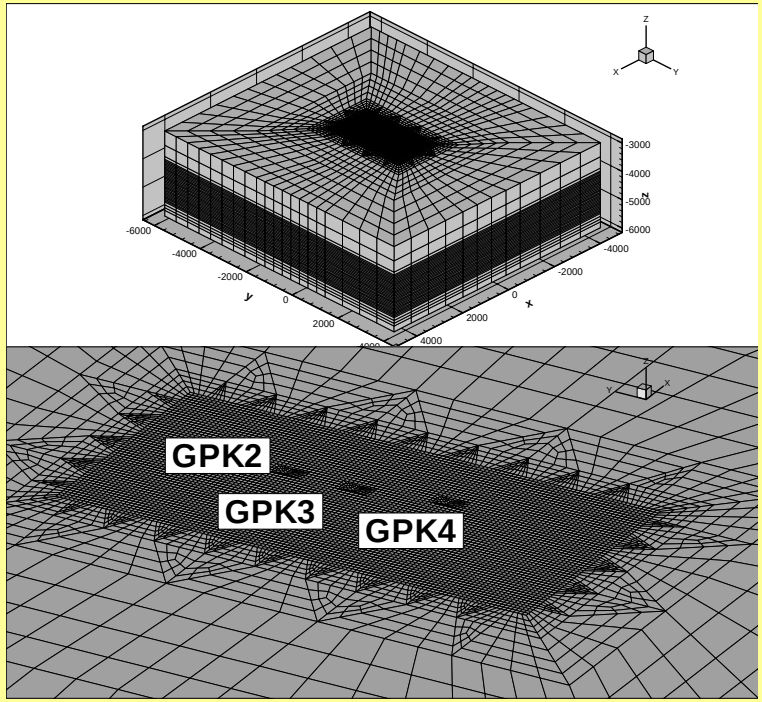
structures

- deterministically defined
- stochastically defined

ap $\xrightarrow{\text{mapping}}$ k(x,y,z,t=0)

- Numerical FE Grid
- Element size 25m
- ~400‘000 elements

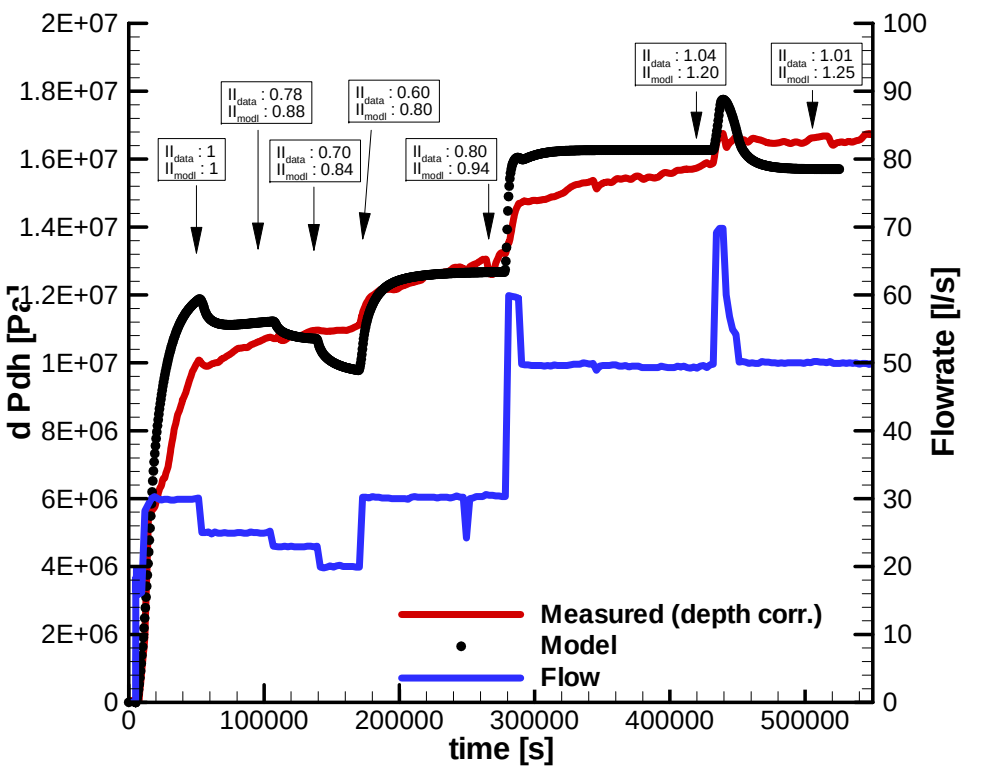




Example: Europ. EGS project Soultz, France

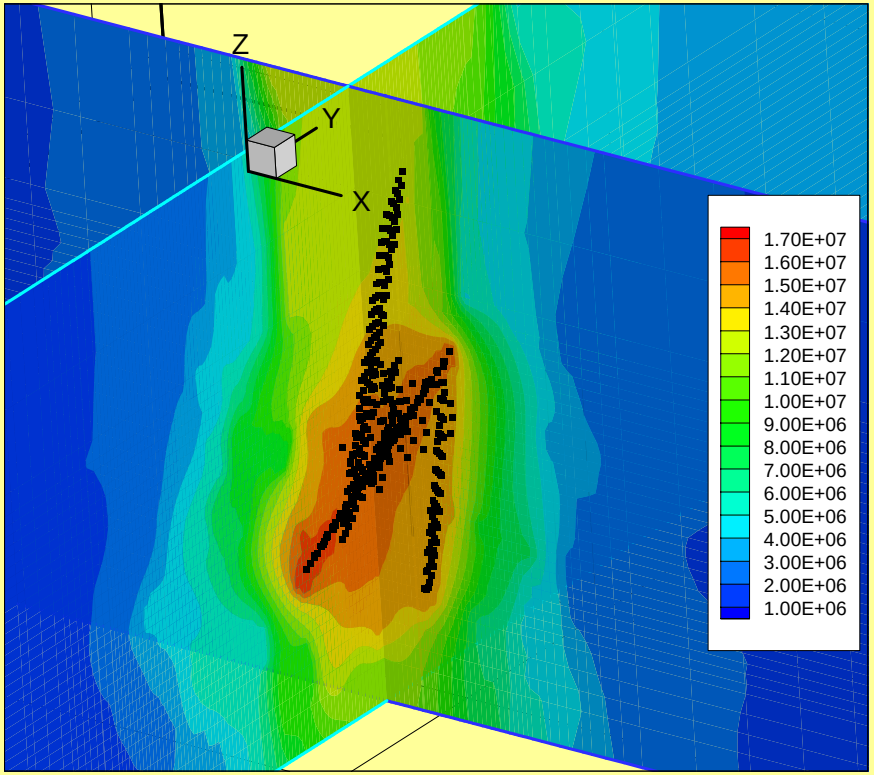
Transient hydro-mechanical calculation GPK3, 2003

At GPK3



- Fit of downhole pressure history
- Highly non-linear processes
- Permeability variation due to shearing

Around GPK3

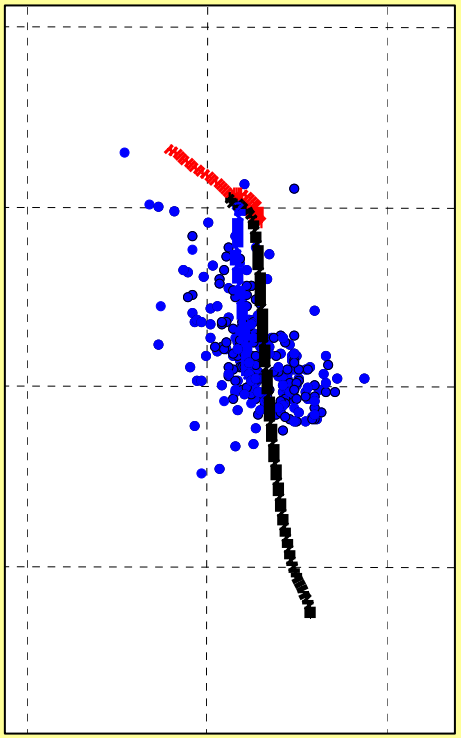


- Flow aligned along seismic structures
- Seismicity connected to zones of high pressure

Example: Europ. EGS project Soultz, France

Transient hydro-mechanical calculation GPK3, 2003

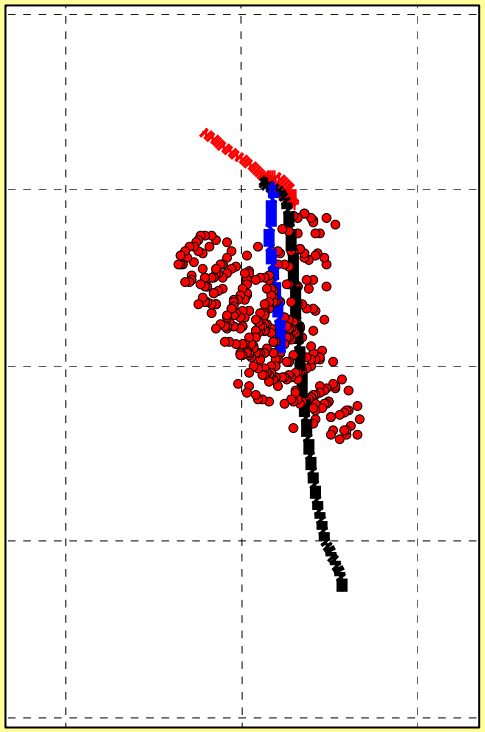
Microseis. loc. GPK3 stimulation



plan view

after 1 day injection

Fracture shearing in HEX-S model



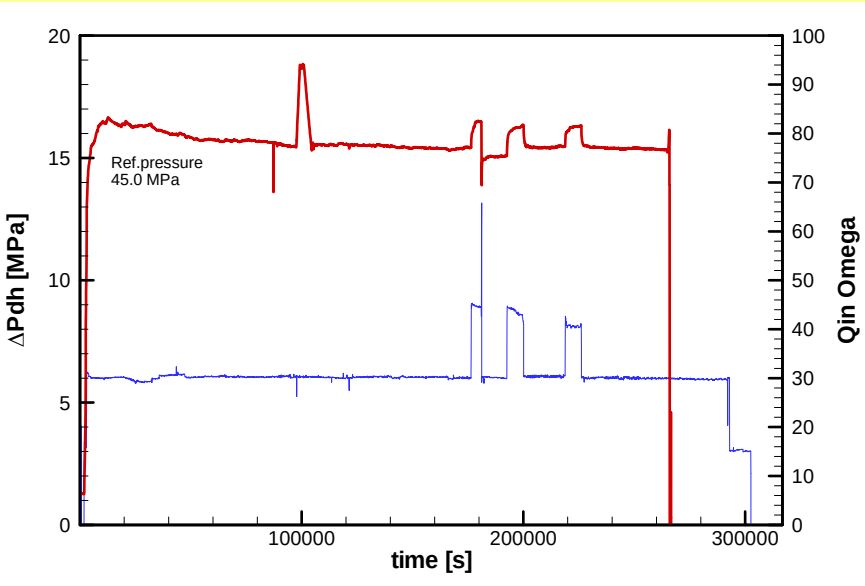
plan view

Similar spatial extension

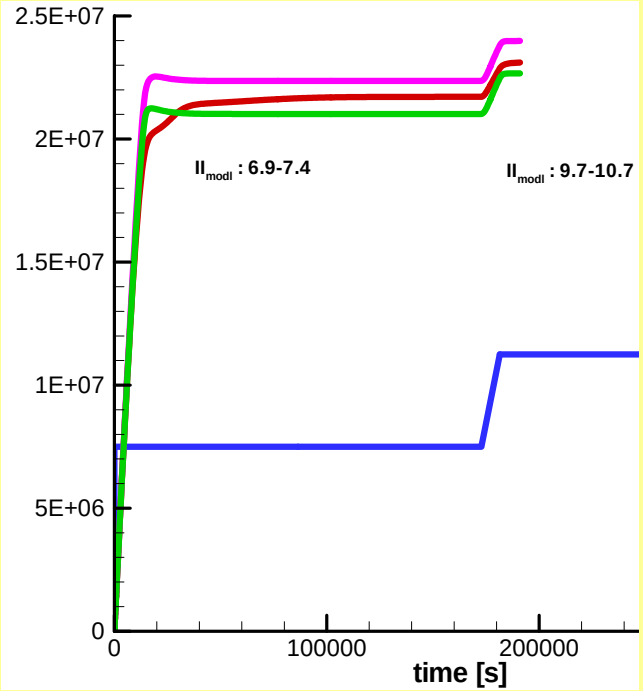
Example: Europ. EGS project Soultz, France

Transient hydro-mechanical calculation GPK4, 2004

Pressure measured



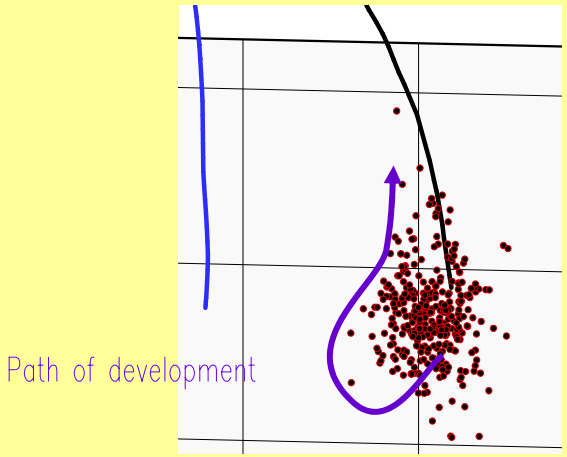
Pressure from HEX-S model



	Measurements	HEX-S prediction
$\Delta P_{dh \text{ at } 30 \text{ l/s}}$	15.5 MPa	21 MPa
increasing to 45 l/s	+ 1.05 MPa	+ 1.5 MPa
Maximum P_{dh}	at t = 16’600 s	at t = 15’500 s
general characteristics	short transients	short transients

Transient hydro-mechanical calculation GPK4

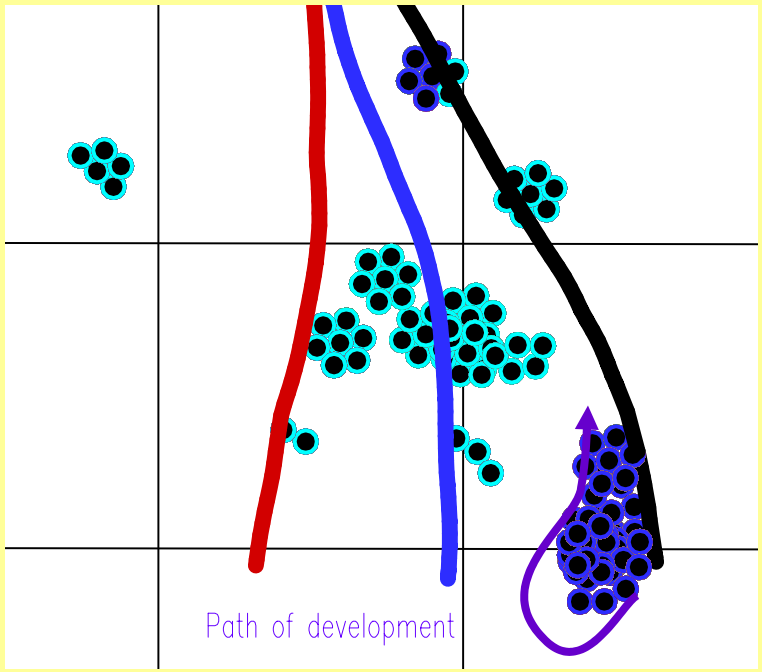
Microseis. loc. GPK4 stimulation



view from west

1 day of injection

Fracture shearing in HEX-S model (predicted before stimulation test)



view from west

- Similar spatial extension
- Similar path of development

Conclusions

- Production must become sufficiently <u>predictable</u> for conditions at a given site
- Production parameter Q [l/s] depends on reservoir impedance = fkt { k(x,y,z,t) }
- Production parameter T [°C] depends on heat exch.surfaces = fkt { k(x,y,z,t) }
- Task 1: Making production [MW] predictable
  = sufficient characterisation of k(x,y,z,t) of a reservoir
- Task 2: Improve/enhance production [MW]
  = predict k(x,y,z,t) due to enhancement activities

- Methods/models/codes as HEX-S are needed to fulfil these tasks.