ENGINE mid-term Conference

Recent progress in Discrete Fracture Network modelling for EGS development in tight fractured rocks

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Rationales for choosing Discrete Fracture Networks models
Our experience comes from : (1/2)

- Nuclear waste management studies in hard rocks
  - EC programs (FI4W-CT96-0033, EUC19134 EN)
  - Benchmark DECOVALEX (NIREX data base, SKI Report 98:39)
  - ANDRA (HAVL granite, report GRPF DBG 05.0001.B)
- Water resources in semi arid granite areas
  - CEFIPRA projects in alterated basements, NGRI institute, India.
- Liquid-gas storage /water curtain systems, (GEOSTOCK/Tafjord reservoir, …)
- Early HDR modelling experiences in shallow systems
  - french project (Mayet de Montagne)
  - UK project (Rosemanowes quarry)
- Soultz project, intermediate 3 km deep reservoir
  - EC programs (JOR3-CT95-0054, CT98-0313, STREP FP6-EGS)
  - Partnership EDRF, BRGM, ADEME

Rationales for choosing Discrete Fracture Networks models
Lessons learned (2/2)

- Fractures exist at any scale
  - Very dense populations can be observed along wells
  - They reflect tectonic history (a classification is possible)
- Few fracture control flow along bore holes
  - Transport is highly heterogeneous
- Rock matrix is of very little importance for flow
- Interactions with stress regime are high (module+orientation)
  - Impact on global flow properties can be low
  - High pressures can be accommodated
  - Shear mechanism is not well understood
  - Released seismic energy can be large
- Role of rock damaged/alterated zones not properly accounted for

Main assumptions to simulate fracture networks in rock blocks(1/2)

- Fractures are planar, disc shaped, and assemble in 3D networks
  - Density (from scan lines)
  - Size distribution
    - lognormal
    - Power law (R_0, a)
  - No matrix
- Flow is not evenly 2D distributed in plane but concentrated in 1D channels
  - Fracture aperture
    - Cubic law: $T \sim e^3$
    - Porous material: $T \sim e$

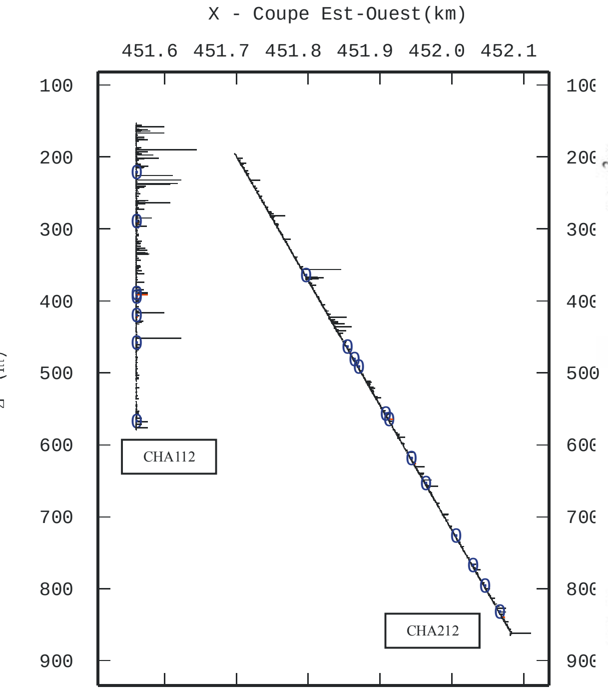
Main Assumptions
Possible couplings on each fracture (2/2)

- Normal compliance versus normal effective stress
  - Normal closure law
- Shear rupture + normal dilation versus shear stress
  - Mohr-Coulomb criterion – pre/post rupture friction, cohesion
- Thermal exchange – conduction across adjacent rock blocks
  - Fluid density
  - Fluid viscosity
  - Induced thermo-elastic stress components
- Possibly two non-miscible fluids
  - Natural heavy brine – fresh water

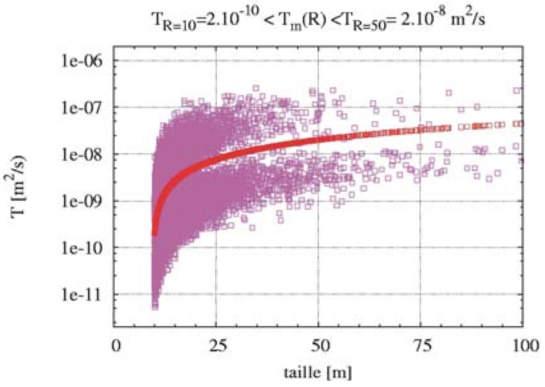
Example of the DFN application in very tight systems (Rad Waste Management)

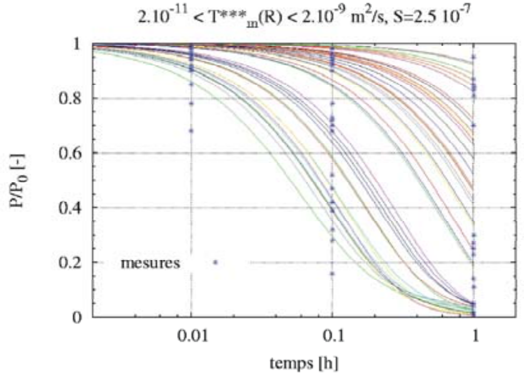
Many local flow experiment are available – Upscaling ?

Straddle packer investigations in two wells (Charoux Civray site, ANDRA)

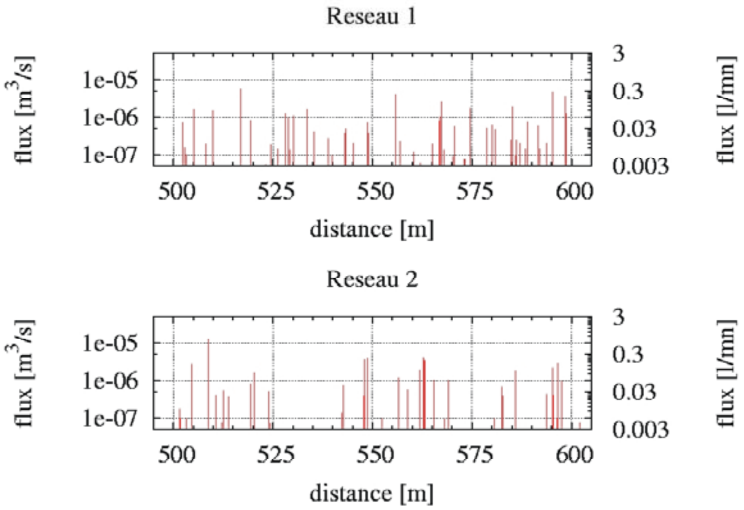


Slug test analysis. A bimodal size-transmissivity distribution seems appropriate)



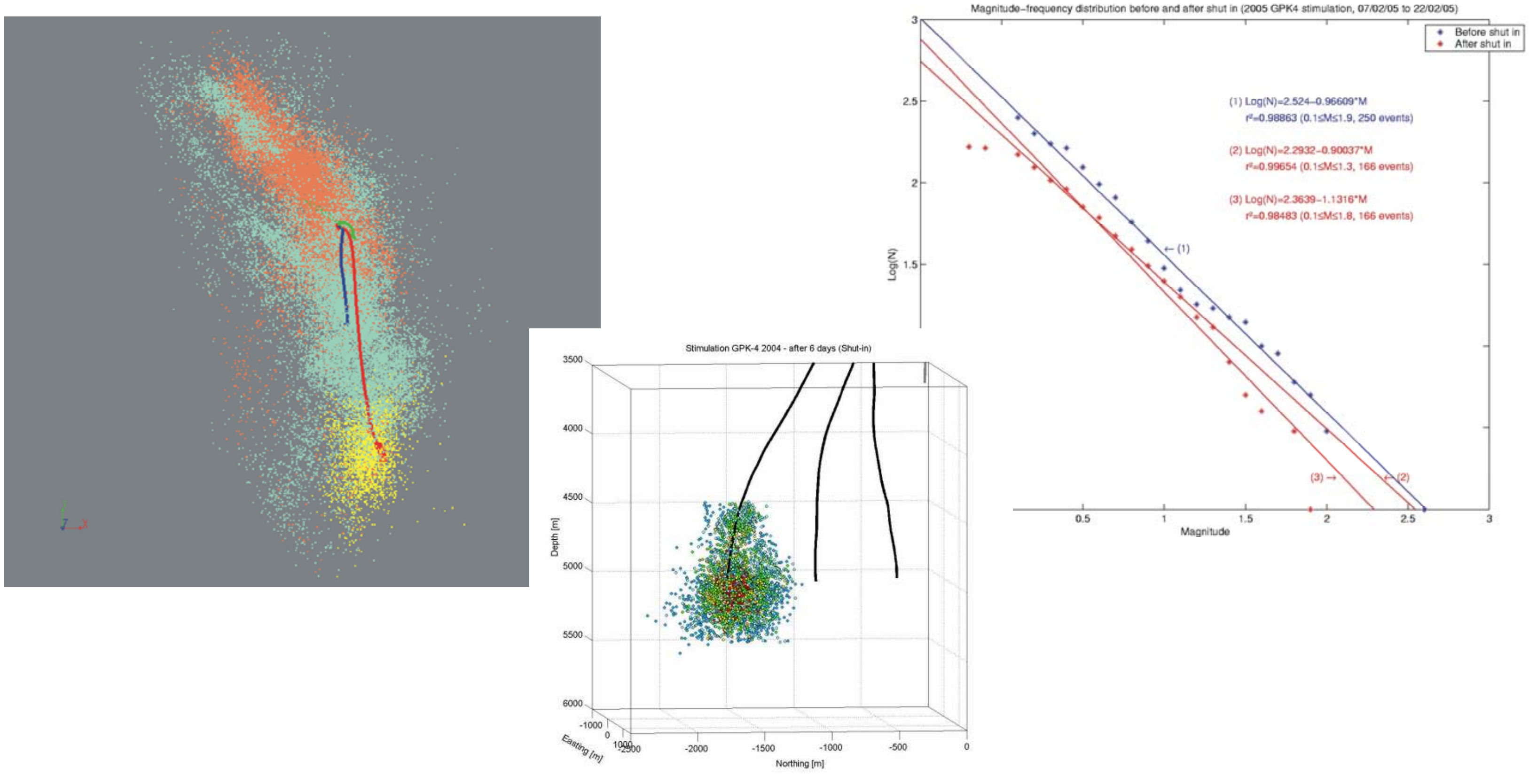


Upscaling: Flow log simulation at intermediate scale



Conclusion: 80% of the joints are partly sealed. Probable correlation between infillings and orientation. Non direct correlation between fract -ure size and hydraulic aperture.

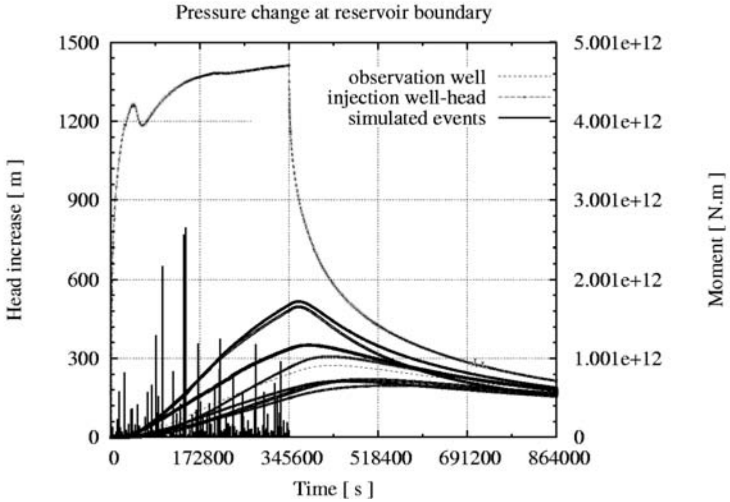
EGS studies (Soultz sous Forêts site)
Local hydraulic tests are sparse (hot/expensive/risky) but Some large scale indirect characterization is available

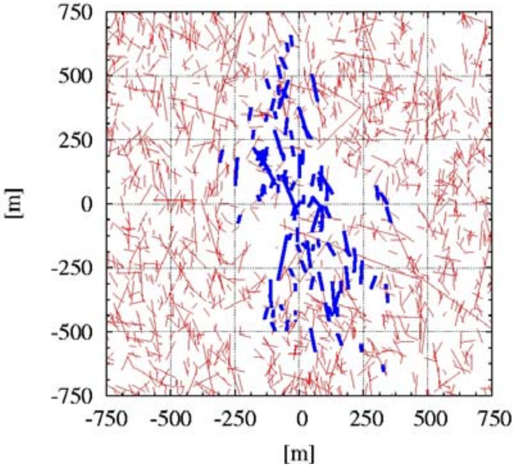


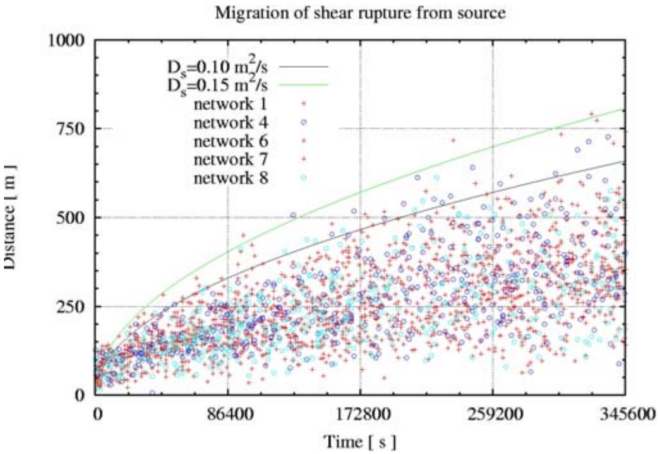
3D DFN geometry and initial transmissivity can be constrained by the observed micro-seismic migration . Magnitude frequency diagrams gives information on the size distribution of the fractures. Identified large structures can be superimposed

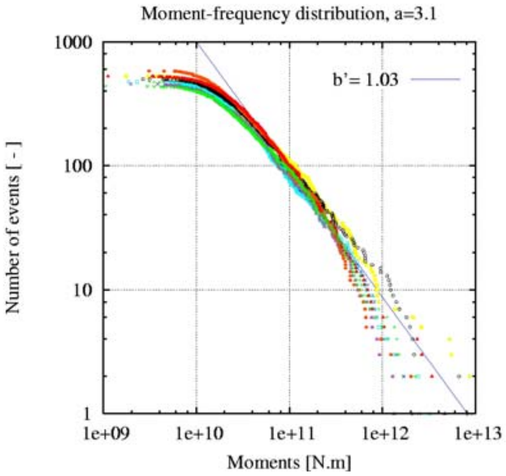
Discussion of network properties against seismic data (after Bruel, in *Int. J. Rock Mech. & Abstr*. In press 2007)

3D Random networks are generated and hydraulic tests at high rates are performed (GPK4 stimulation in 2004 as an example) Shear rupturing processes are simulated and analysed as a diffusion process. Hydraulic diffusivity is in the order of 0.15 m^2/s (K ~1.10^{-17} m/s) and a power law exponent for the fracture size is proposed. (a=2.7)



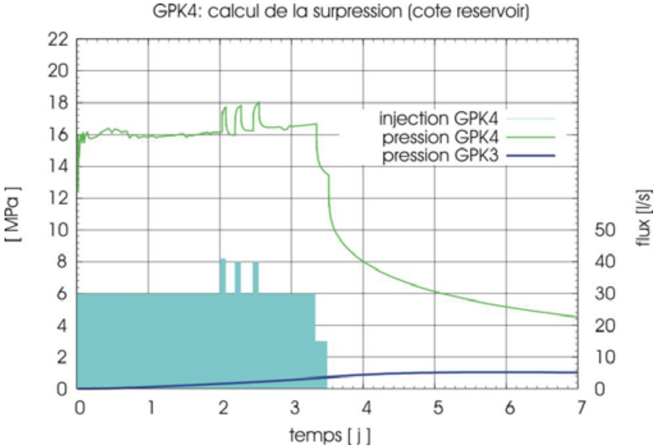


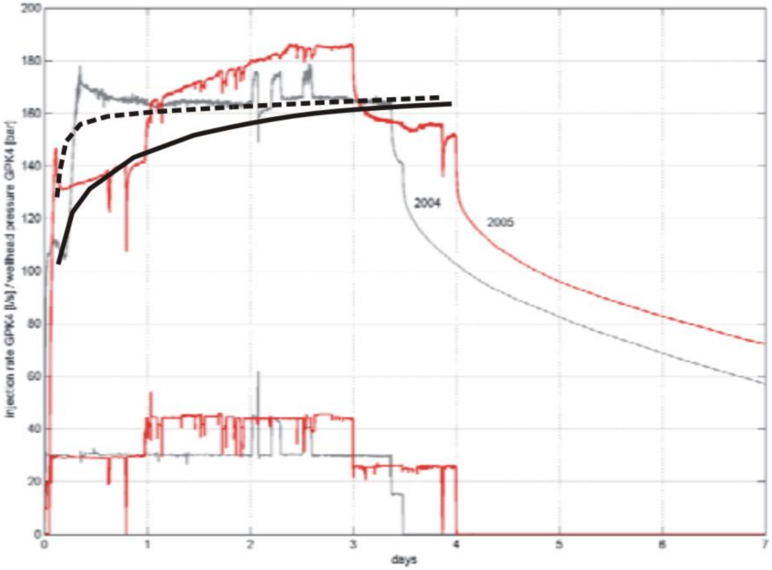


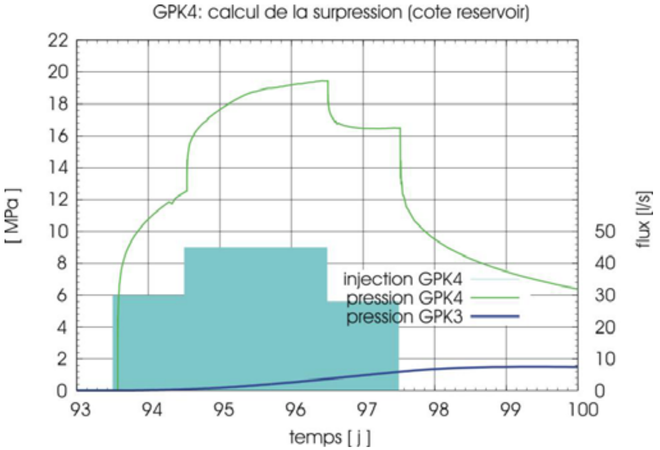


Discussion on hydraulic efficiency of hydraulic stimulations against GPK4 measurements (2004,2005) (1/2)

GPK4 was stimulated in 2004 and again in 2005 (~30000 m^3 each). No structure was developed at large scale. The model is used to understand the increase of hydraulic capacity of the fracture network around the well. The role of a nearby structure delineated as a ‘no seismic zone ’can be discussed. This zone would separate the reservoir into two adjacent compartments.

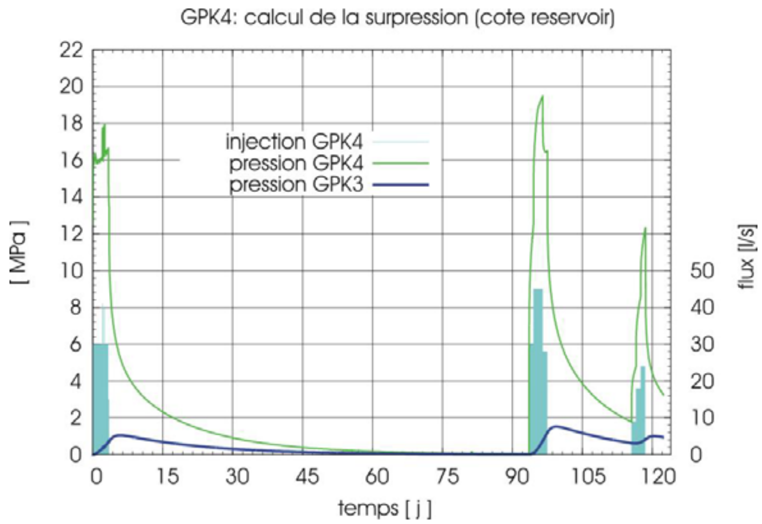


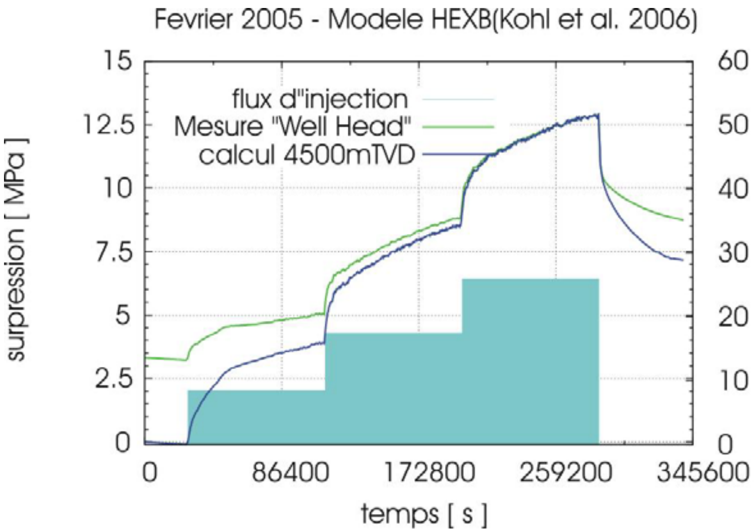


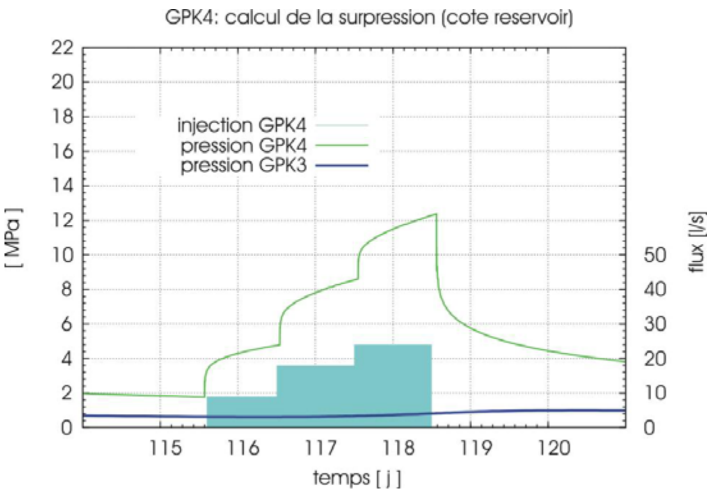


Discussion on hydraulic efficiency of hydraulic stimulations against GPK4 measurements (2004,2005) (2/2)

Post stimulation tests were performed to evaluate the impact on fluid injectivity. (Below a step rate test, involving ~ 10000 m^3 of water).
The model used in step 1 is run for the entire period. Step rates responses are well reproduced. However no steady state can be obtained within 3 days and no solid conclusions can be drawn from this test, regarding the gain in hydraulic injectivity of this well.


GPK4: calcul de la surpression (cote reservoir)


Fevrier 2005 - Modele HEXB(Kohl et al. 2006)


GPK4: calcul de la surpression (cote reservoir)

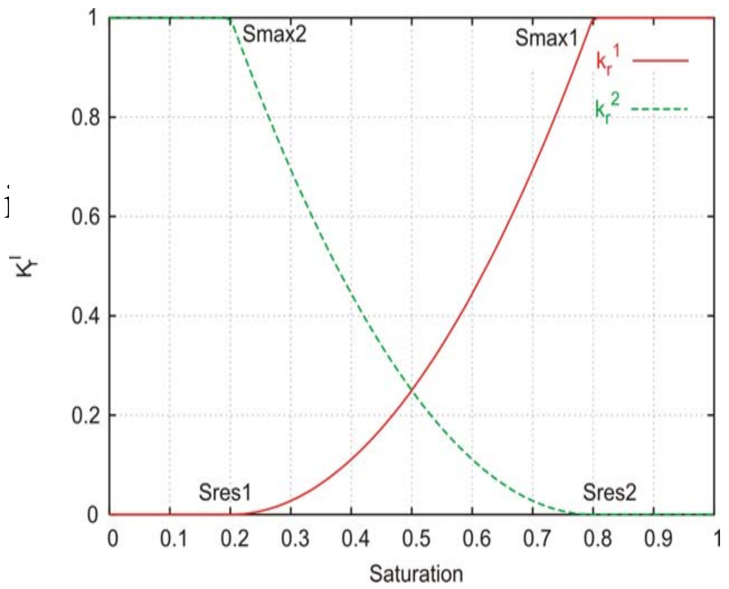
Importance of alterations within the fractures. Role of fracture porosity in mass transfer: a two phase flow approach (1/3)

- Pressure /saturation formulation , for each fluid, assumed non miscible

$$\begin{cases}\sum_j k_{ij}\dfrac{k_{ij}^{l1}}{\mu_{ij}^{l1}L_{ij}}\left(\left(P_i^{l1}-P_j^{l1}\right)+\left(\rho_i^{l1}gz_i-\rho_j^{l1}gz_j\right)\right)=S_i^{l1}C_i\dfrac{\partial P_i^{l1}}{\partial t}+\Phi_i\dfrac{\partial S_i^{l1}}{\partial t}\\ \sum_j k_{ij}\dfrac{k_{ij}^{l2}}{\mu_{ij}^{l2}L_{ij}}\left(\left(P_i^{l2}-P_j^{l2}\right)+\left(\rho_i^{l2}gz_i-\rho_j^{l2}gz_j\right)\right)=S_i^{l2}C_i\dfrac{\partial P_i^{l2}}{\partial t}+\Phi_i\dfrac{\partial S_i^{l2}}{\partial t}\end{cases}$$

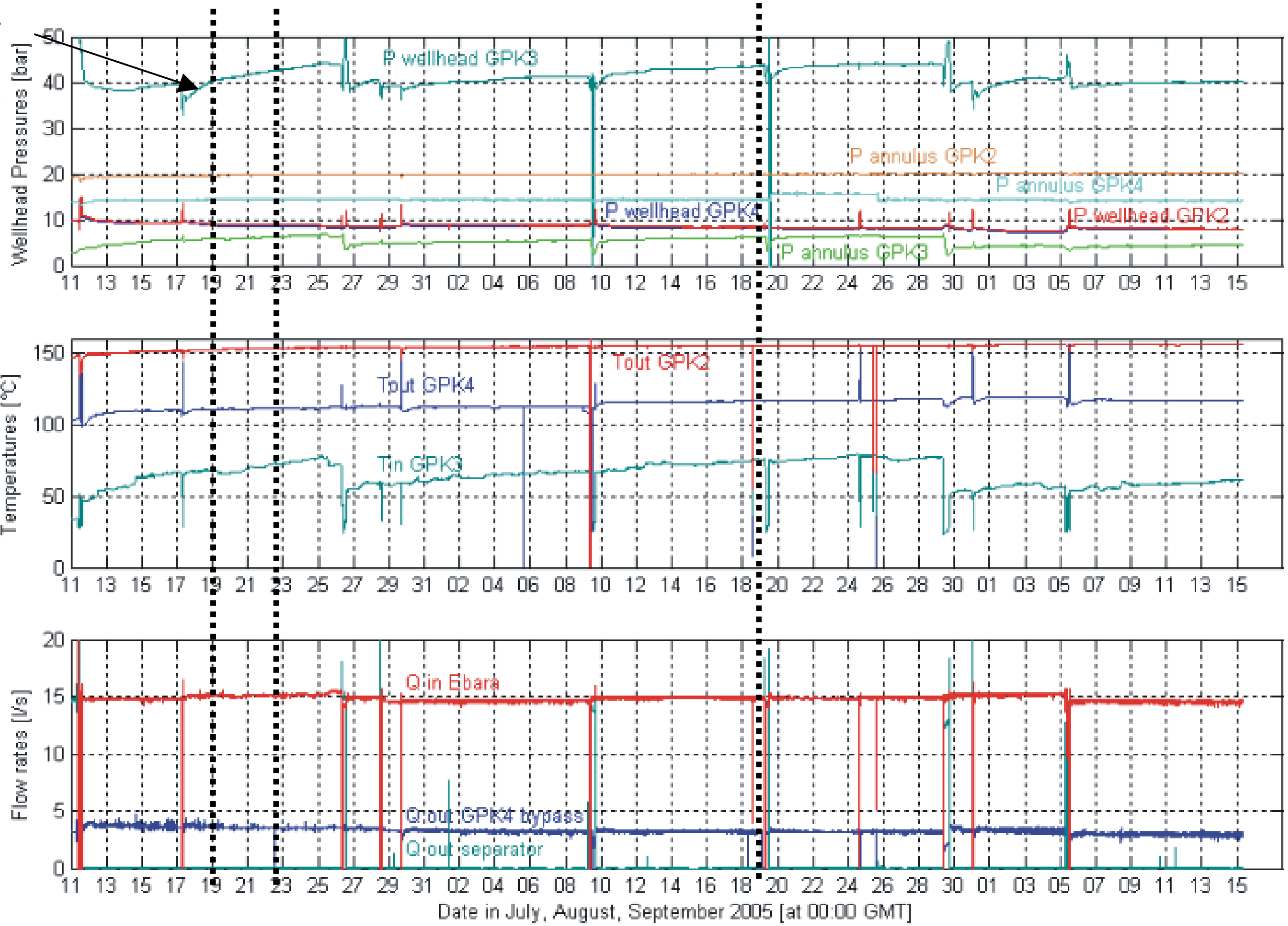
- ρ, μ fluid density and viscosity
- S_0 initial saturation in in-situ fluid
- Φ fracture porosity → volume for fluid storage i each fracture
- k^l_{ij} relative fluid perméability

- *IMPES numerical scheme+ Newton Raphson iterates on pressure*



Using the two phase flow module to discuss fracture volume. Application to the circulation test (Aug. Oct. 2005) (2/3)

After Baujard et al. *Geothermics*, In press, 2007



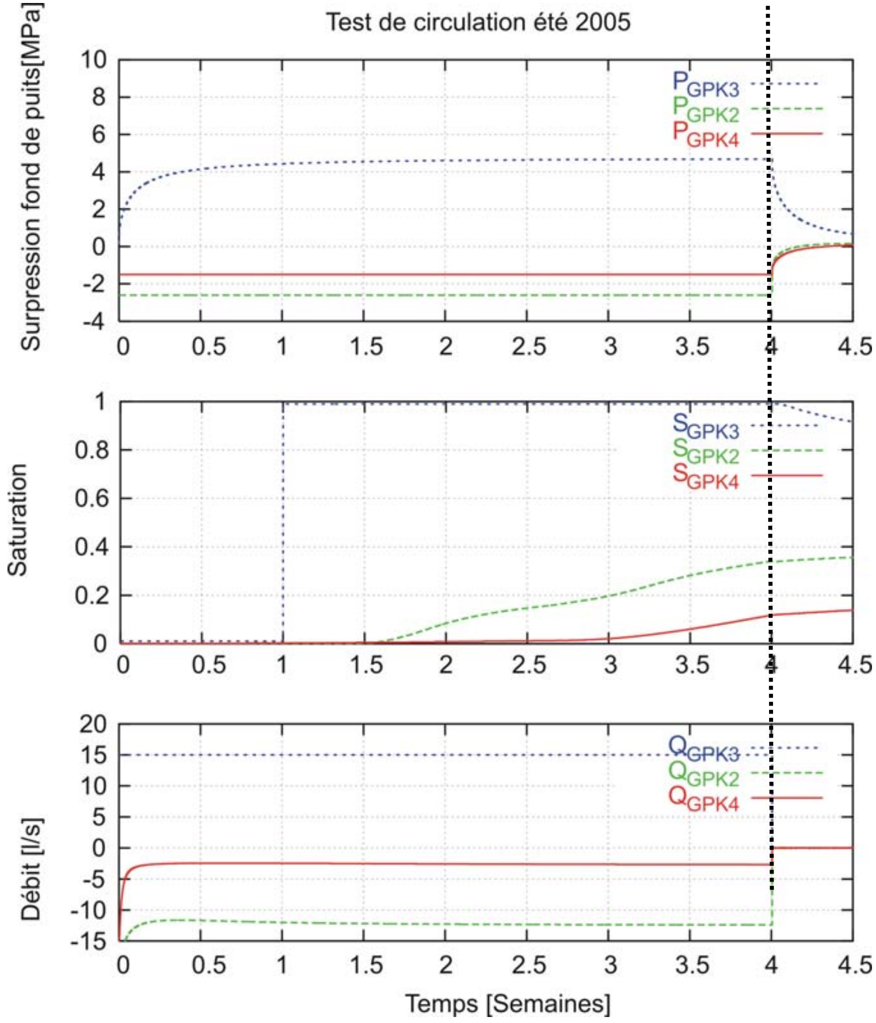
Breakthrough GPK2

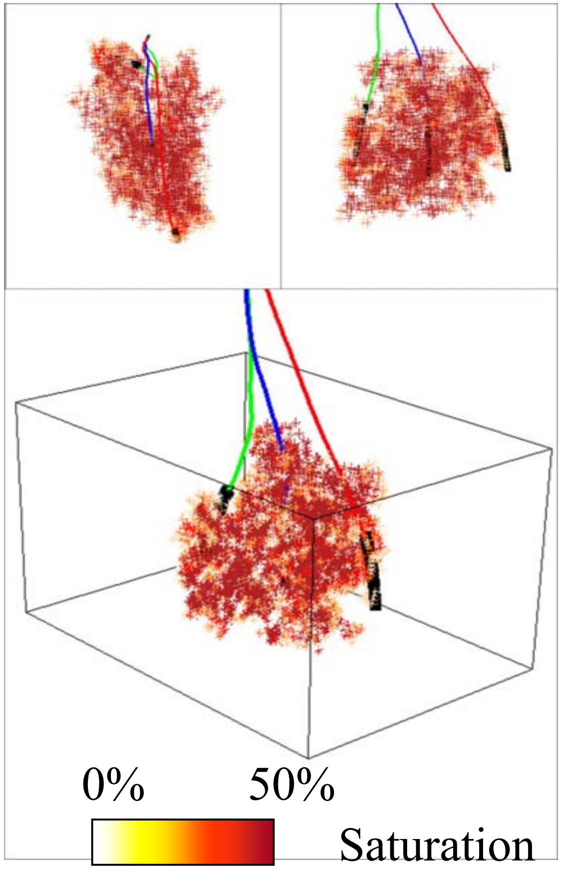
Breakthrough GPK4

Tracer injection (fluoresceine)

Using the two phase flow module to discuss fracture volume. Application to the circulation test (Aug. Oct. 2005) (3/3)

After Baujard et al. *Geothermics*, In press, 2007





Discussion and Conclusion

- Discrete Fracture Network is a valuable approach because :
  - It captures heterogeneity of structure and hydraulic responses
    - Open thin fractures and planar porous zones can be mixed as ‘objects’
  - It allows some non-reversible interactions between hydraulic and mechanical parameters
  - It provides a basis for a first interpretation of seismic activity
    - Delayed activity is obtained as a result of low diffusivity
    - Fracture size and large events could be linked
  - It is appropriate for mass transfer predictions and long term thermal calculations
- Progress are still required, among them
  - The understanding of coupled processes during shear motion
  - The response of rock damaged/alterated zones, in conjunction with thermal exchange and acidization experiments