The PT Borehole Simulator HEX-B2

Thomas Mégel
Thomas Kohl
GEOWATT AG
Dohlenweg 28, CH-8050 Zürich

Introduction

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Pressure / Temperature are key parameters in reservoir characterization

Borehole Measurements are expensive and require a proper data quality control

P/T downhole data can be imprecise under EGS conditions

Accuracy and Risk of Logging

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Measurements in Boreholes:

- What goals should be achieved?
- How can the data be controlled?
- What happens during high flow rate experiments?
- Is accessibility in boreholes ensured?
  - High Temperature
  - Broken Casing
  - High Mineralization

High Costs associated to data acquisition

- Logging operation
- Cleaning boreholes from cable/squeezed instruments

New Possibility in Downhole Measurements

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Requirements for data extrapolation to downhole conditions

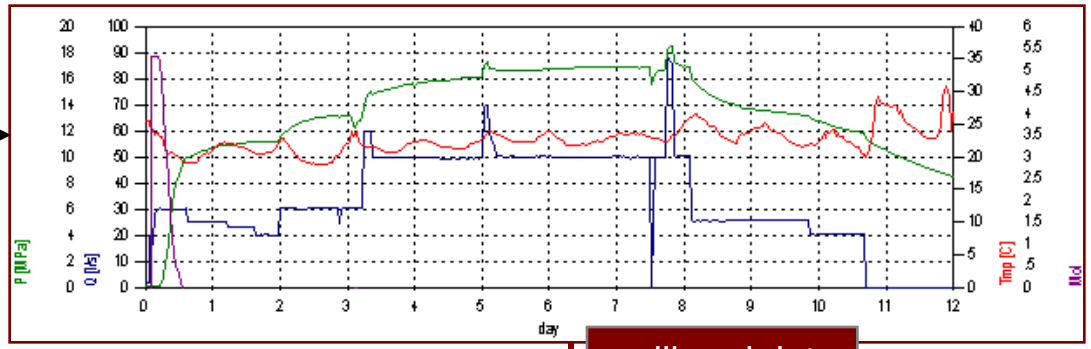
- Require P/T information to travel from borehole head to bottom or vice versa
- Processes related to fluid density distribution are most critical
- Knowledge of
  - Physical processes in borehole
  - Geometrical layout of casing / cementing
  - Rock matrix parameters

New technological developments

- Make use of use for new computer power

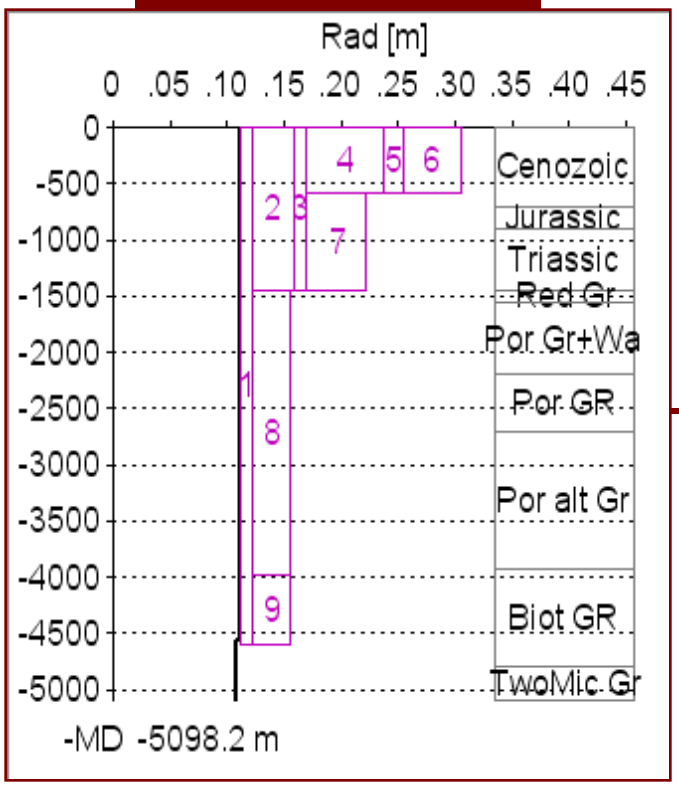
New pT- Simulator HEX-B2

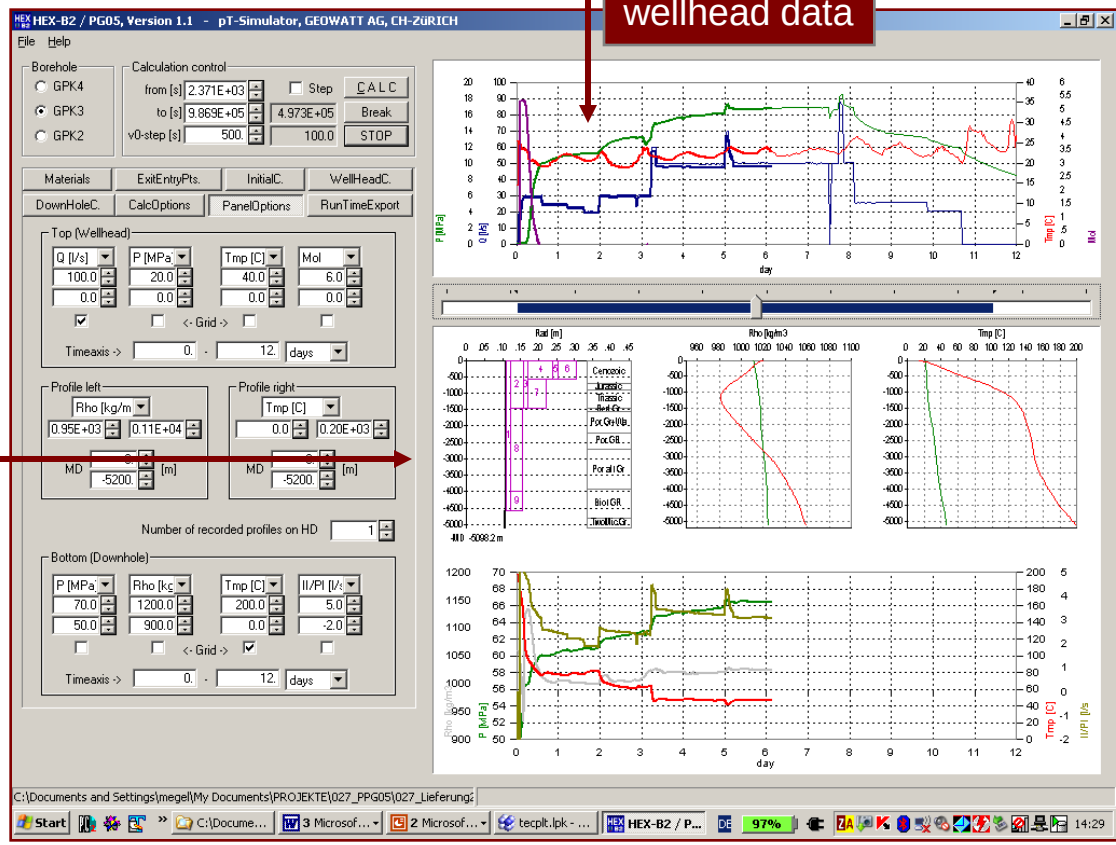
Wellheads GPK2/GPK3



wellhead data

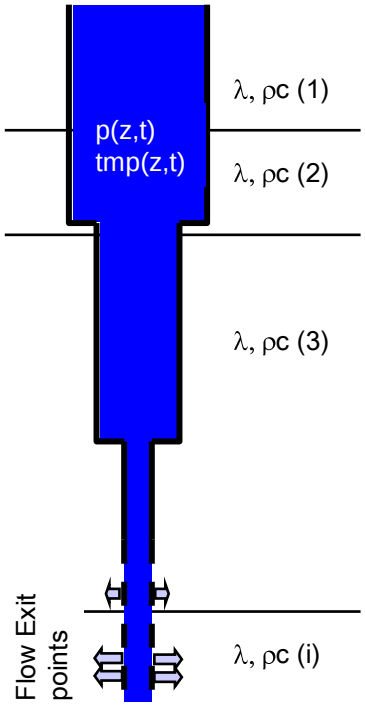
borehole model GPK3





New pT- Simulator HEX-B2

Model parameters:

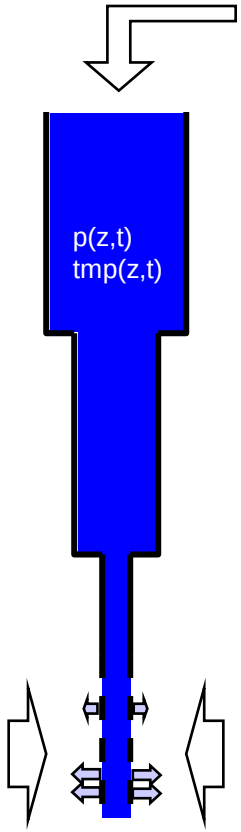


Wellhead data:
- Initial pressure

Borehole data:
- Casing diameters
- Wall roughness
- MD-TVD
- Fluid losses into rock
- Initial NaCl-molality

Rock mass data:
- Thermal conductivity λ
- Specific heat capacity ρc
- Initial temperature

Input parameters/Physical processes:



Dynamic wellhead data
1. Wellhead pressure
2. Injection rate
3. Fluid temperatur
4. Fluid NaCl-molality

Dynamic properties and processes implemented
- Heat exchange with rock mass
- Fluid heat capacity (T, NaCl-mol)
- Fluid density (T, NaCl-mol, p)
- Buoyancy forces in the borehole
- Friction forces borehole/casing
- Fluid viscosity (T, NaCl-mol)
- Fluid volume (T,p)

Results

PT (z,t)
in borehole

+

Injectivity Index II (t)

Features of HEX-B2

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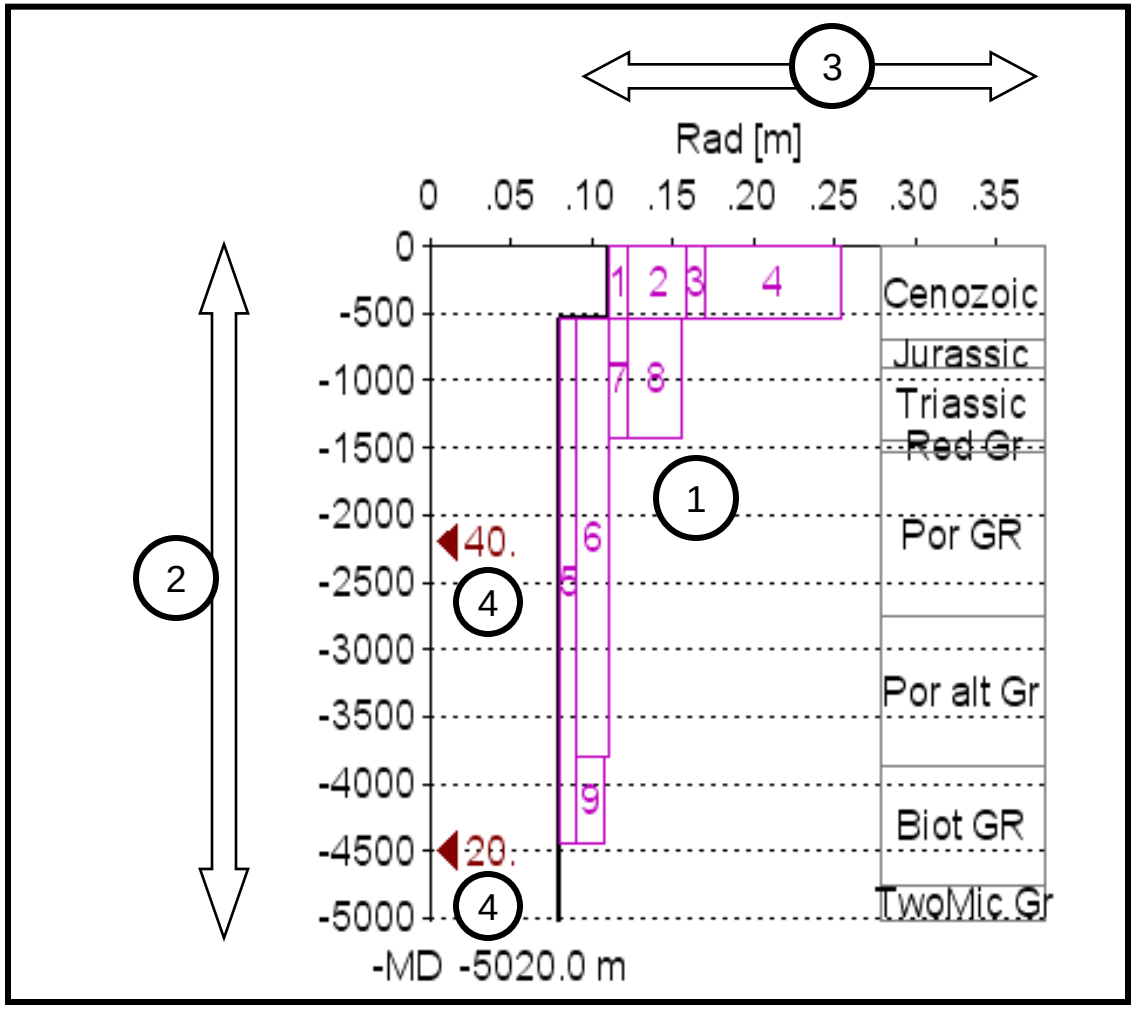
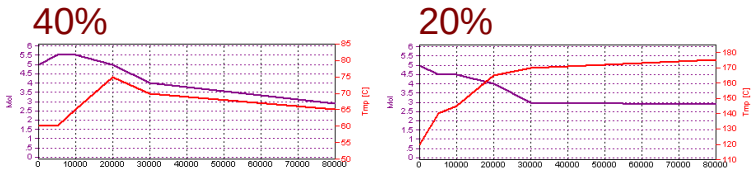
1 **Borehole model:**
- Arbitrary borehole diameters
- Well completion
- Rock mass model
- Borehole trajectory

2 **Processes in borehole:**
- Navier-Stokes equation
- Mass conservation
- Pipe friction
- Advection (NaCl-mol, T)
- Fluid density (NaCl-mol, T, p)
- Fluid viscosity (NaCl-mol, T)
- Fluid heat capacity (NaCl-mol, T)

3 **Radial thermal diffusion**
(borehole completion and rock mass)

4 **Exit-/Entry points**
At production: Inflow of T(t) and NaCl-mol(t)





Application of HEX-B2

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Possible modes

- **Reservoir response from measured wellhead data**
  - Pressure/flow rate BC at wellhead
  - Calculation of injectivity/productivity indices
  - Improvement of reservoir during stimulation
  - Variation of downhole temperature during production

- **Calculation of scenarios from reservoir parameters**
  - flow rate BC at wellhead; Reservoir parameters at bottom
  - Pressure profile
  - Production temperature
  - Failure pressure at shearing events near borehole
  - Optimization of production scenarios with thermosyphon effect (Buoyancy)
  - Design of well testing parameters

Procedure for Application

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Calibration of HEX-B2 Model

- Provide necessary borehole/rock parameters
- Calibrate model on existing dataset

Preparatory Phase

- Monitoring of wellhead data (pressure, temperature, molality)
- Evaluate transient effects from earlier tests

Calculation phase

- Set reference depth
- Calculate injectivity/productivity indices
- Perform sensitivity analysis

Examples of HEX-B2: Soultz GPK3 Stimulation 2003

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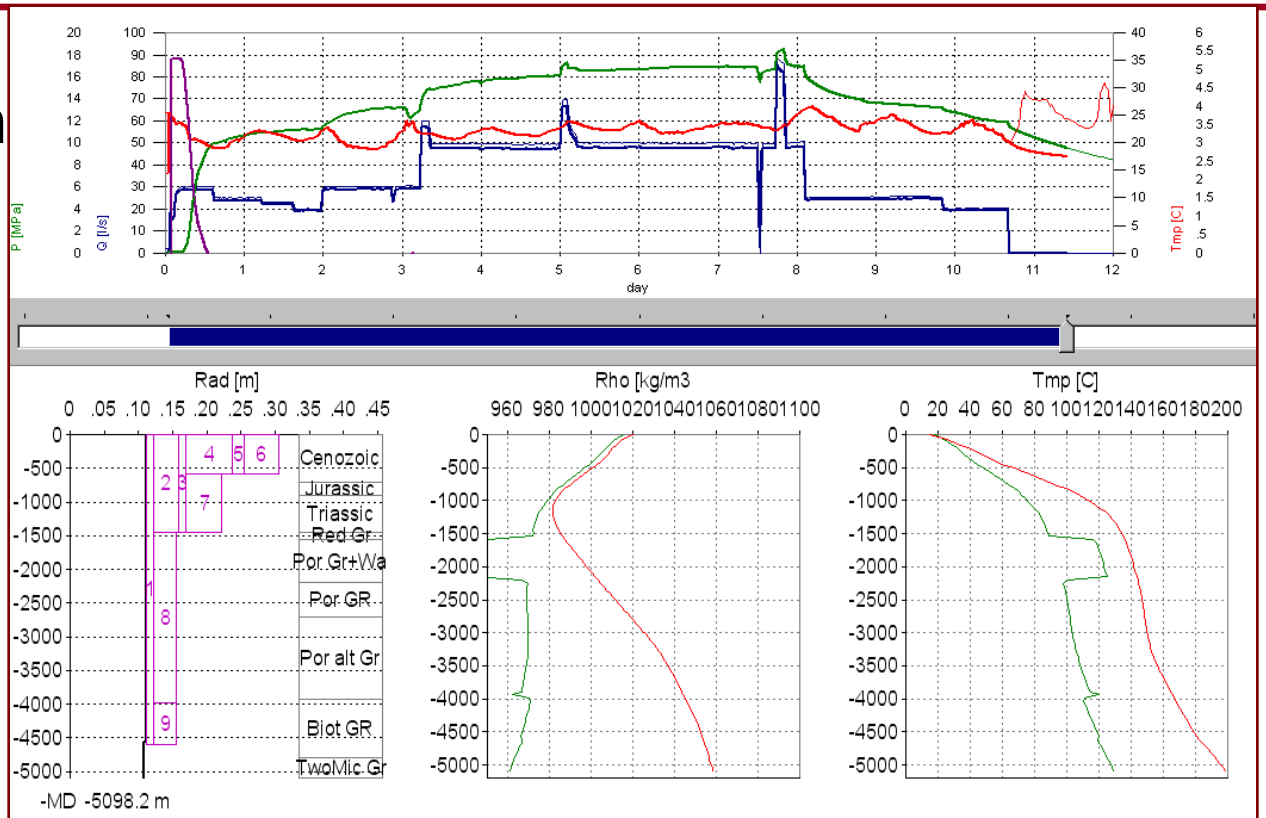
HEX-B2 calculation of injection



Examples of HEX-B2: Soultz GPK3 Stimulation 2003

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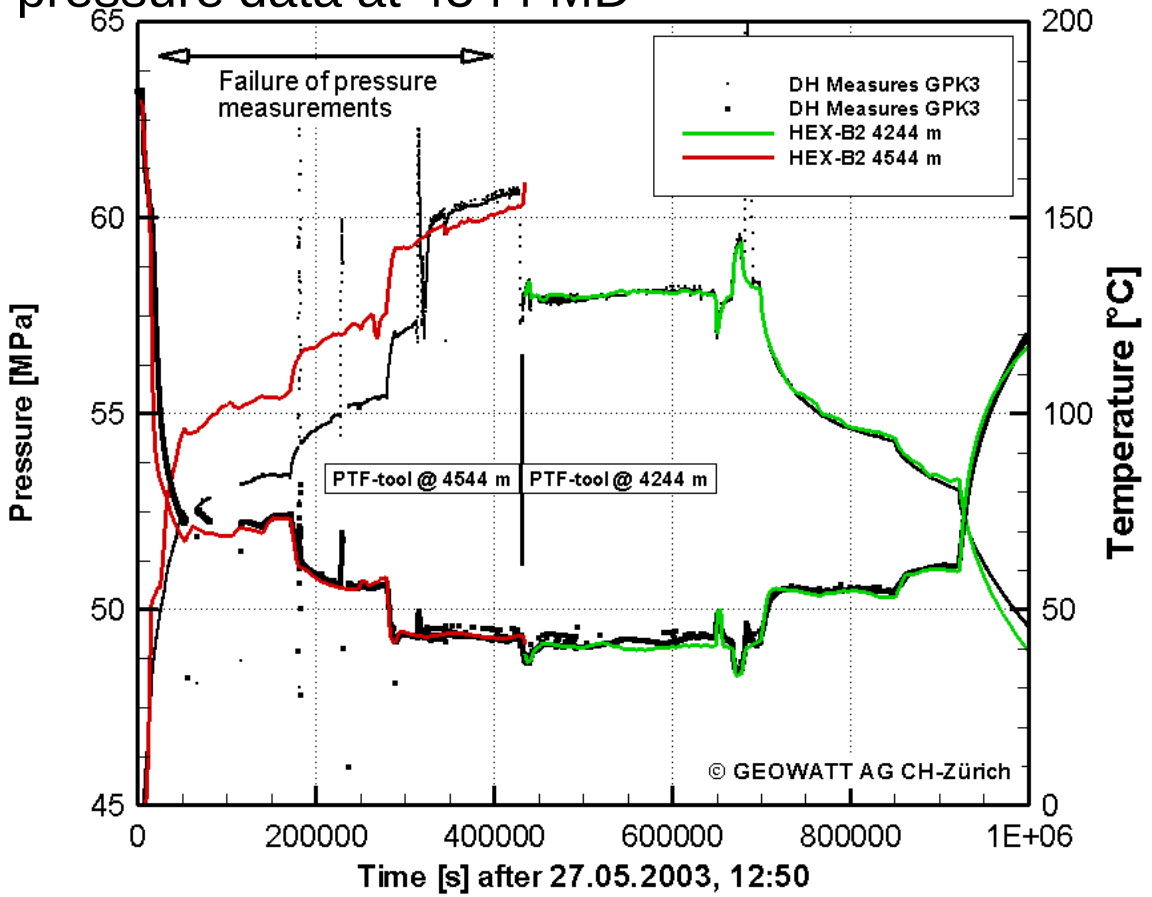
Comparison with downhole data

- pT-probe shifted from 4544 MD to 4244 MD
- good fits with measured data
- reconstruction of failed pressure data at 4544 MD



Data correction

High Accuracy!

Examples of HEX-B2: Soultz GPK3 Stimulation 2003

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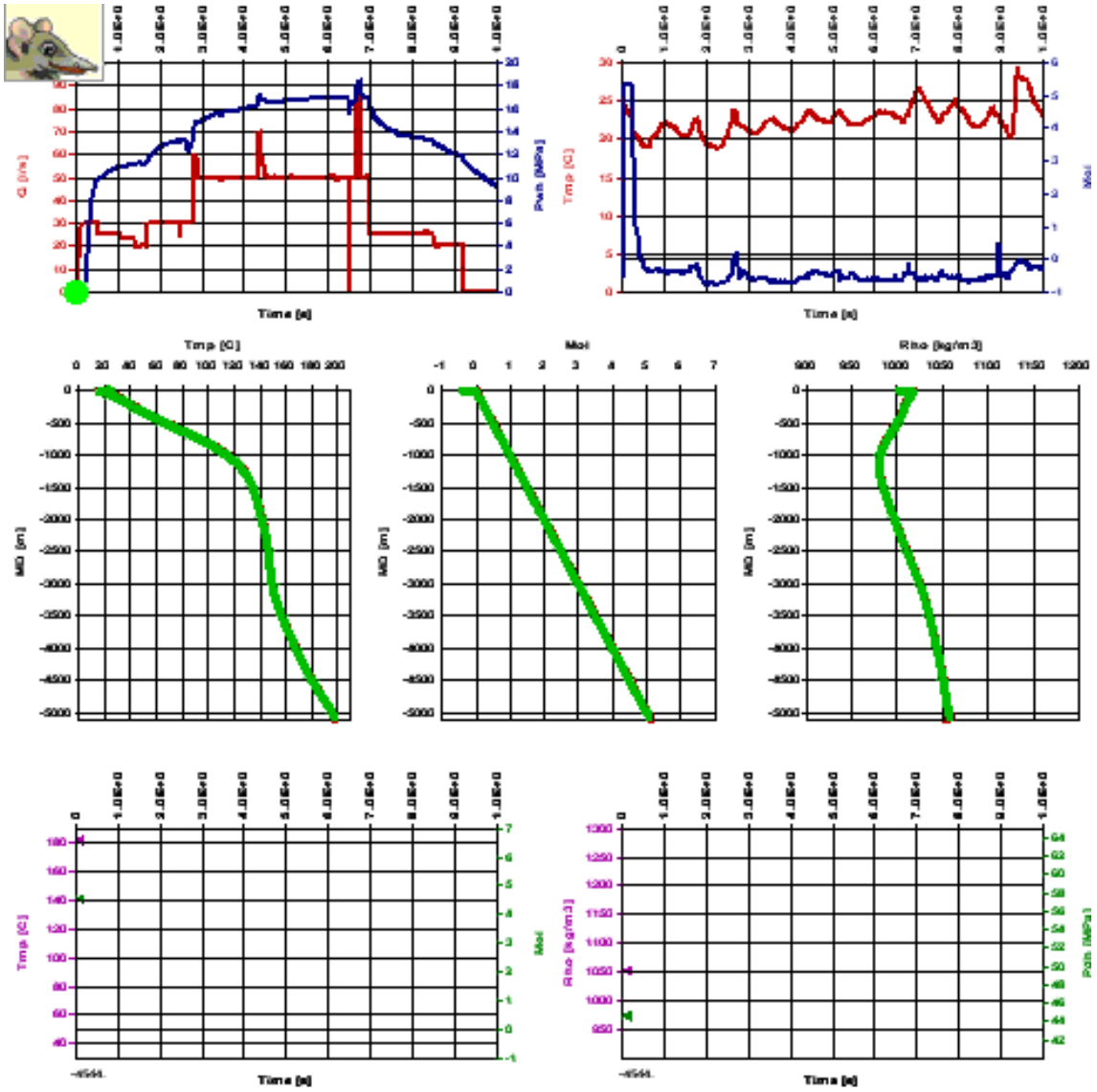
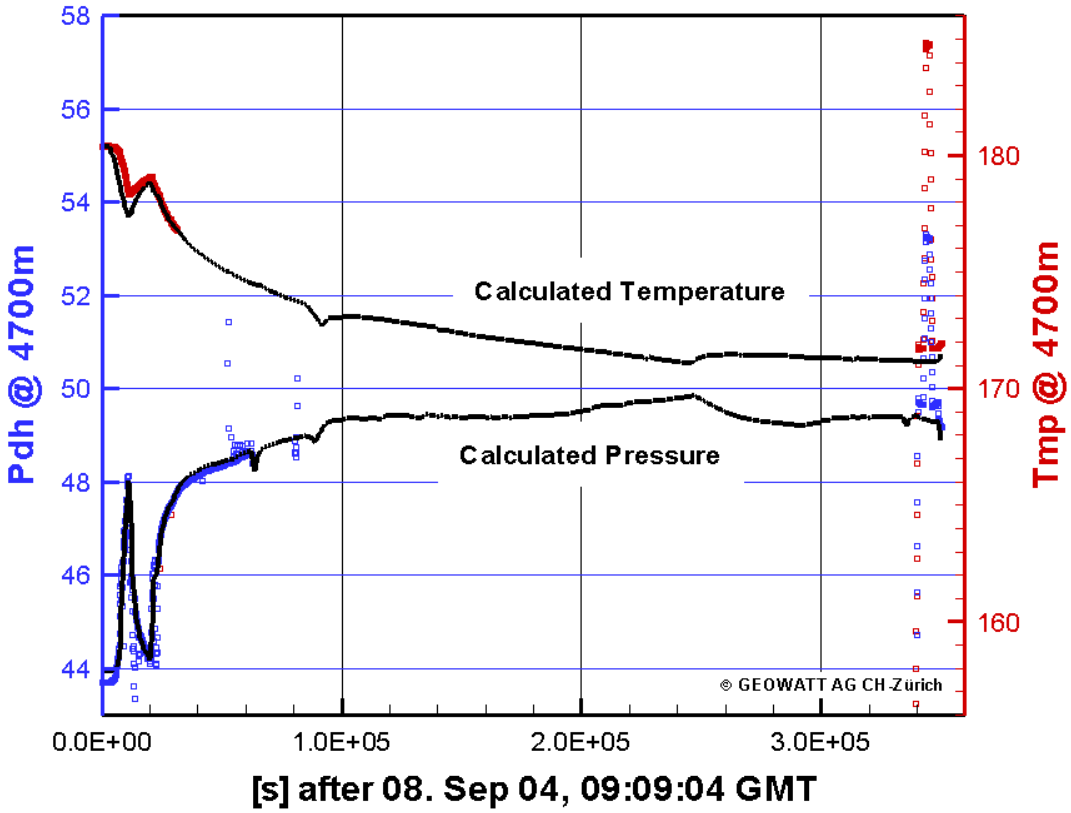
DEMO



Examples of HEX-B2: Soultz GPK4 Stimulation 2004

Completion of downhole PT-data



Examples of HEX-B2: Synthetic GPK2 Production Test

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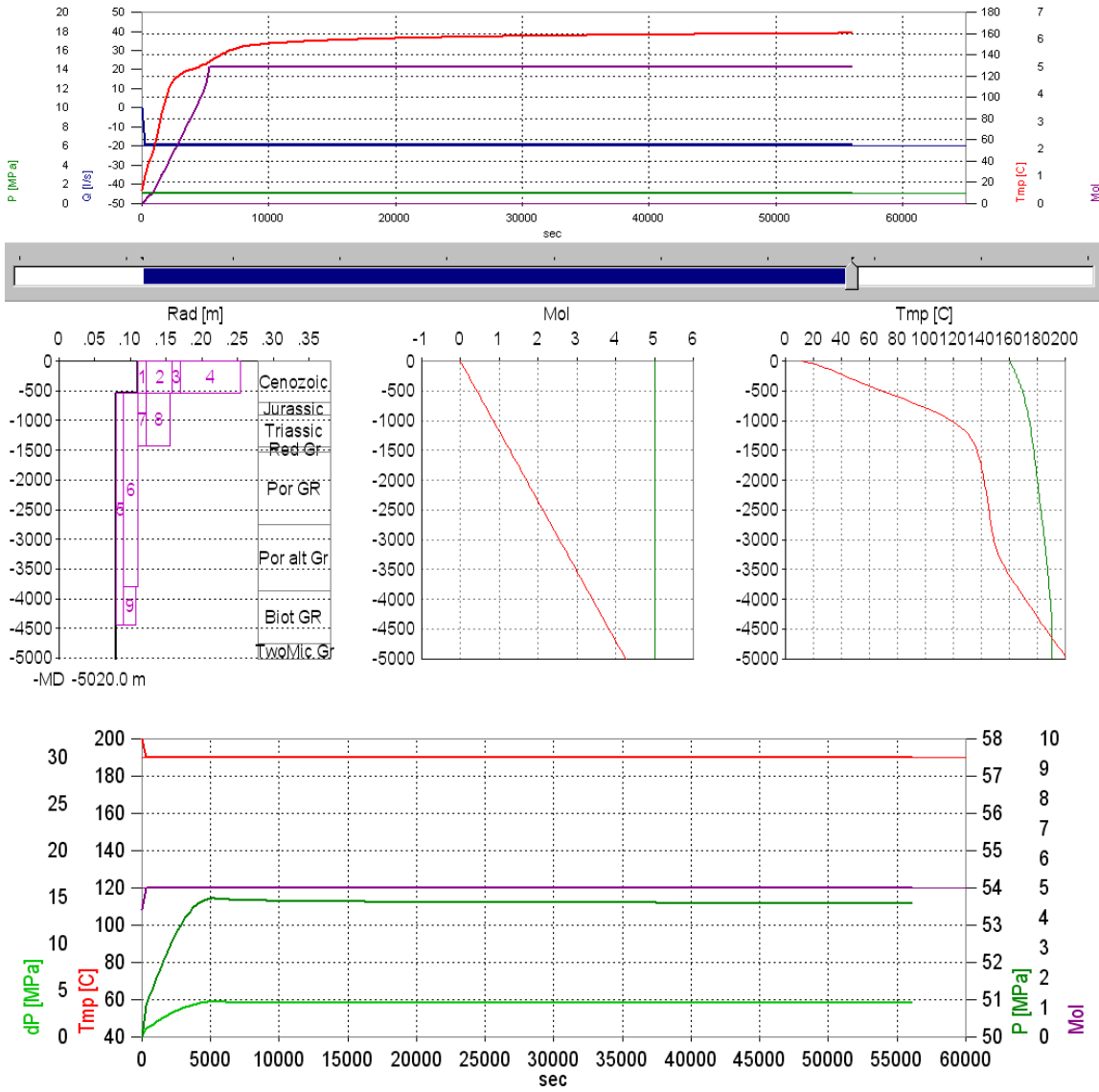
Calculation of production without additional inflows

- Tdh = 190°C
- NaCl-mol = 5



Examples of HEX-B2: Synthetic GPK2 Production Test

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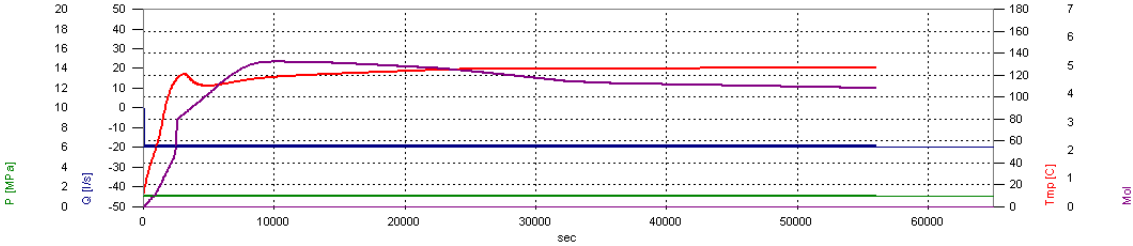
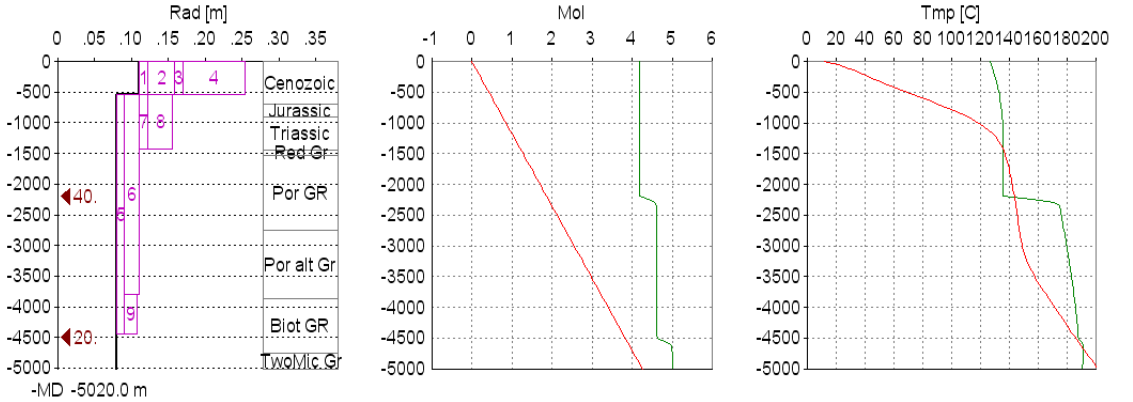
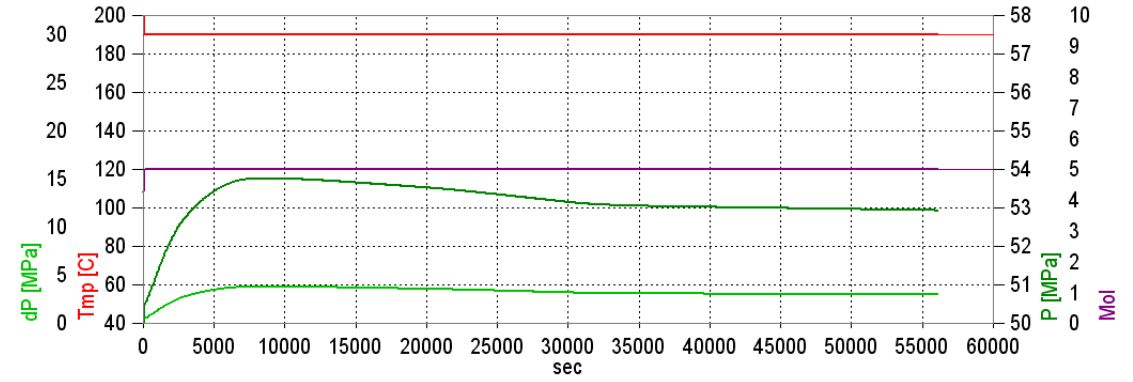
Calculation of production with assumed inflows

- Tdh = 190°C
- NaCl-mol = 5
- inflows at -2200 MD
- inflows at -4500 MD







Examples of HEX-B2: Failure Pressure of Fractures

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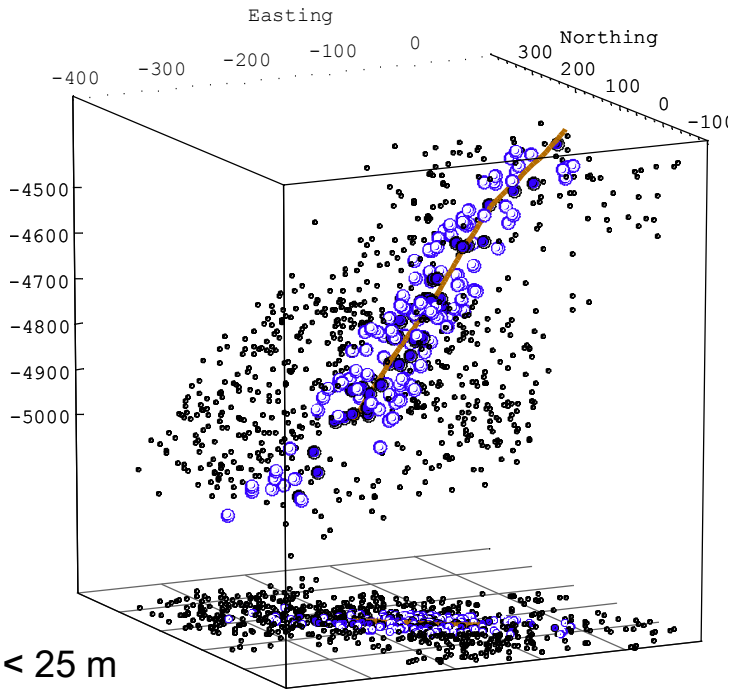
Near-borehole microseismicity

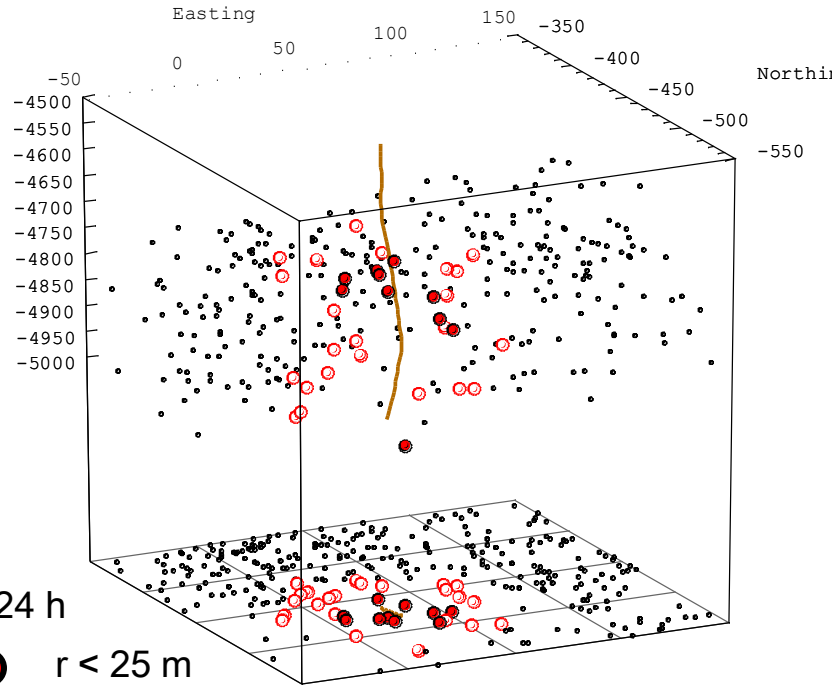
GPK2 (2000):



First 24 h

- r < 25 m
- r : 25 - 50 m
- r > 50 m

GPK3 (2003):



First 24 h

- r < 25 m
- r : 25 - 50 m
- r > 50 m

Examples of HEX-B2: Failure Pressure of Fractures

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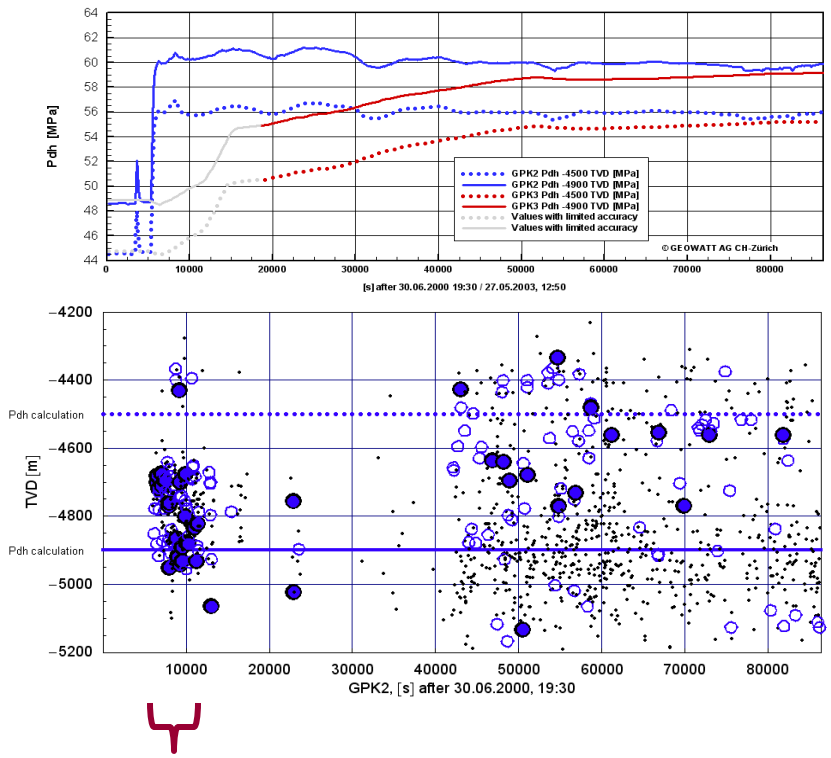
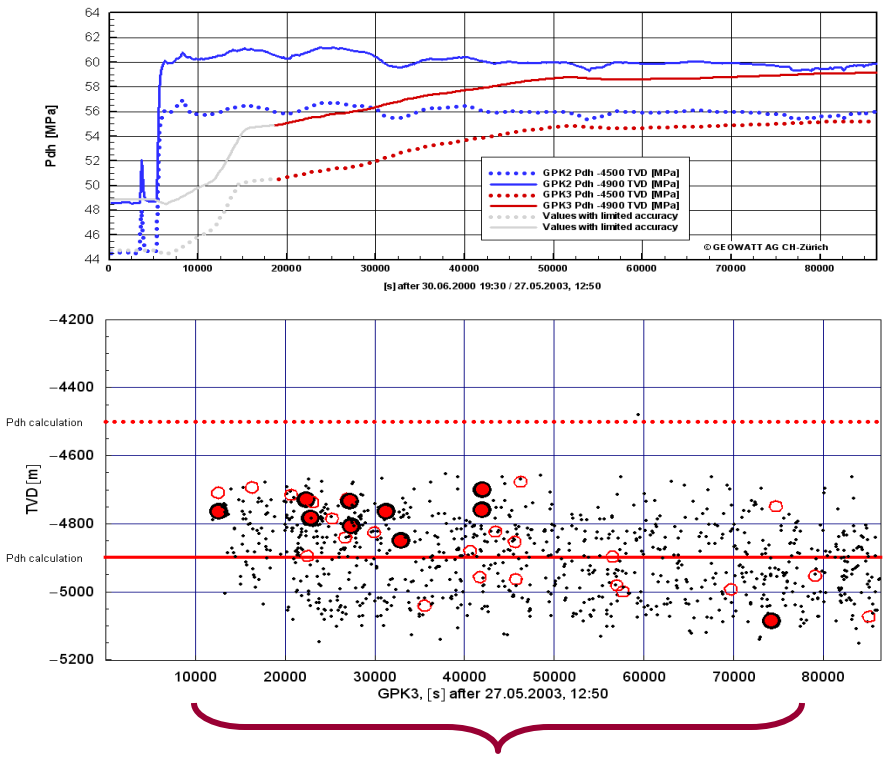
- Near-borehole microseismicity
- Downhole pressure history

GPK2 (2000):



GPK3 (2003):



Whole open hole section activated immediately

Failure pressure of all intersecting fractures **immediately** exceeded

Top-to-down activation of open hole section

Failure pressure of intersecting fractures was exceeded **slowly**

Examples of HEX-B2: Failure Pressure of Fractures

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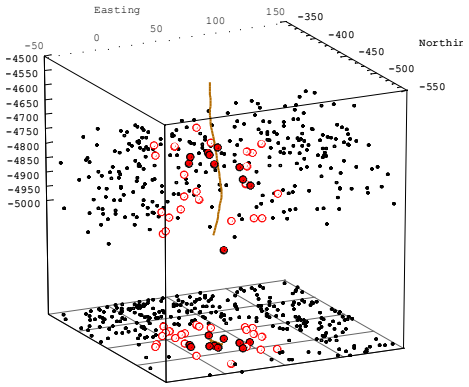
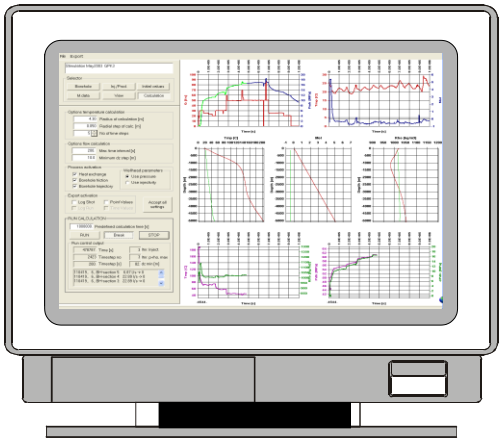
Fracture failure pressure for GPK3

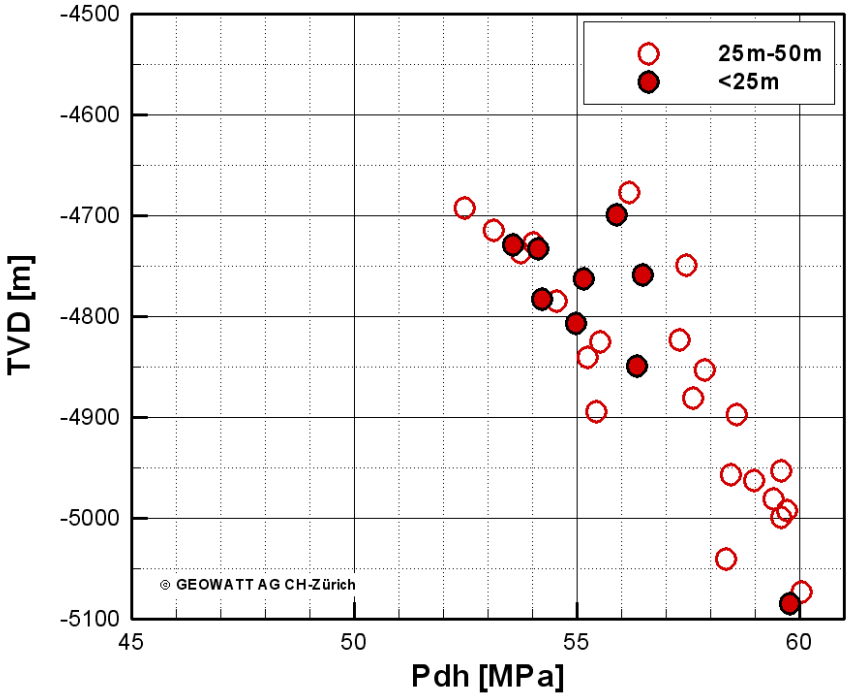


Depth + Time of near-borehole events

+



HEX-B2 Calculation of corresponding downhole pressures



- Failure pressure from 52 - 60 MPa with TVD
- Reflects depth-dependency of stress field
- Range at a given depth: fracture orientation?!
- Gradient of failure pressure: **5-10** MPa/400m

Examples of HEX-B2: Sensitivity Calculations

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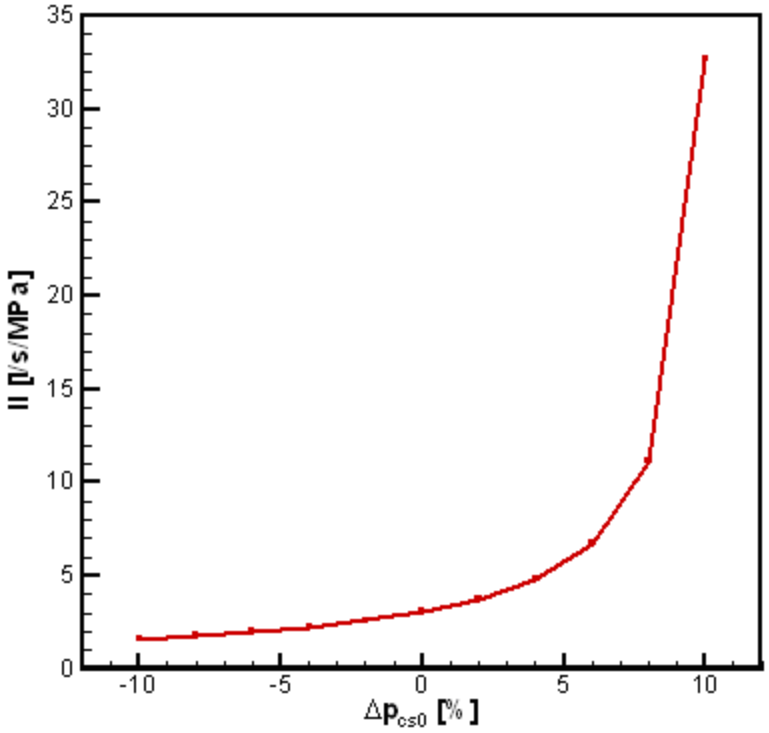
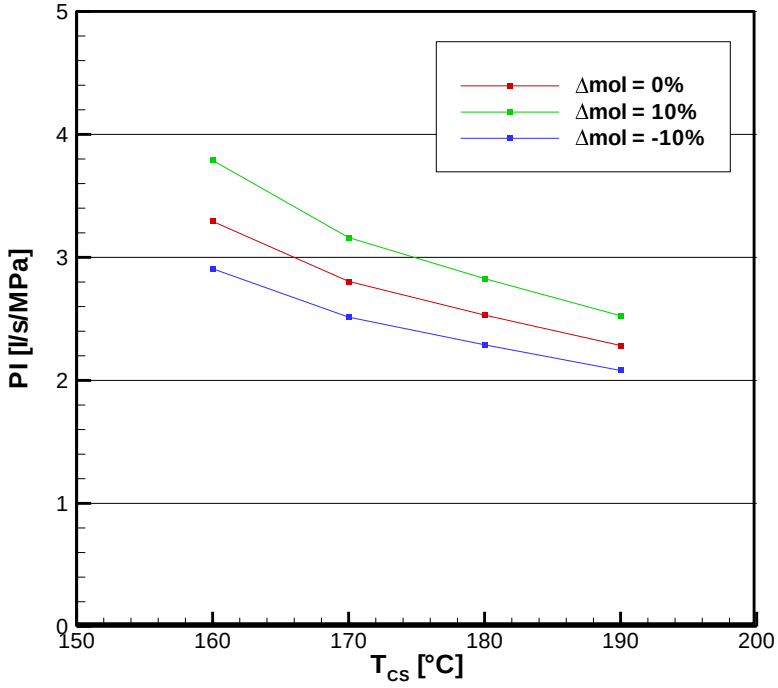
Steady-state pressure vs. Productivity Index



Molality vs. productivity index



Conclusions

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HEX-B2 was used for interpretation of Soultz testing data

Most useful features:

- Comparability of downhole pressure data
  - Different tests during exploration phase at variable flow rates
  - Extrapolation to arbitrary levels
  - Comparability of data
- Calculation of injectivity/productivity indices
- Correction and reconstruction of pT-data gaps
- Sensitivity calculation
- Scenario analysis for production temperature (heat loss in well, effect of inflow temperature,...)
- Accounting for effects of leaks in the casing (injection and production)

Cost reduction for pT-downhole measurements