Hydraulic fracturing

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TNO | Knowledge for business

Outline

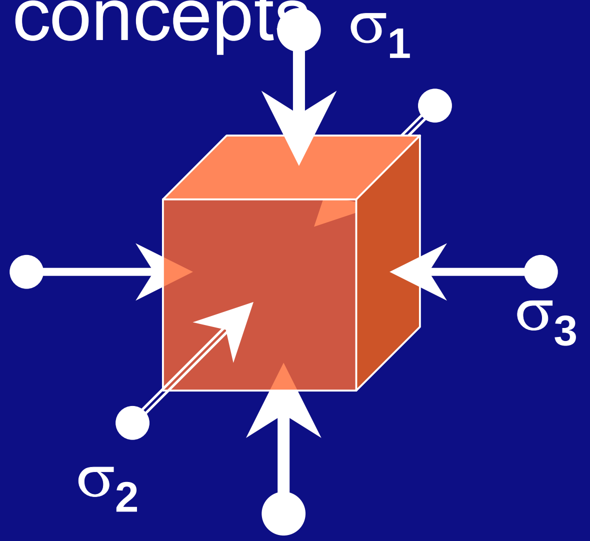
- Introduction
- Hydraulic fracturing
- Types of applications in the oil industry
- Considerations of design and monitoring
- Applications in Geothermal Energy
- Concluding remarks

Introduction

Stimulation of under-performing wells

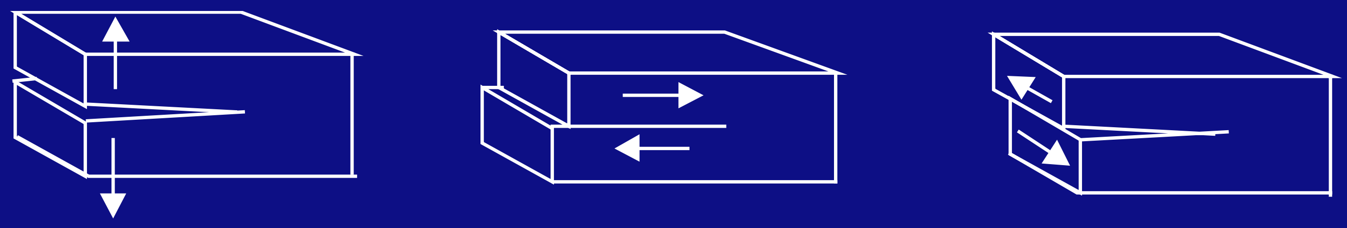
- Matrix acidizing
  - Dissolve “skin” with acid (HCl, HF)
  - Not working with all kinds of damage
  - Concern of tubing corrosion
- Hydraulic fracturing
  - Increase inflow area
  - Improve connection between well and reservoir
  - Pump fluid with high pressure – break the formation
  - Pump “proppant” in open fracture
    - Keep frac open after shutin
    - High-permeability path from reservoir to well

Hydraulic fracturing – Basic concepts



- Stress: maximum stress vertical; minimum and medium stresses horizontal

- Modes of fracturing

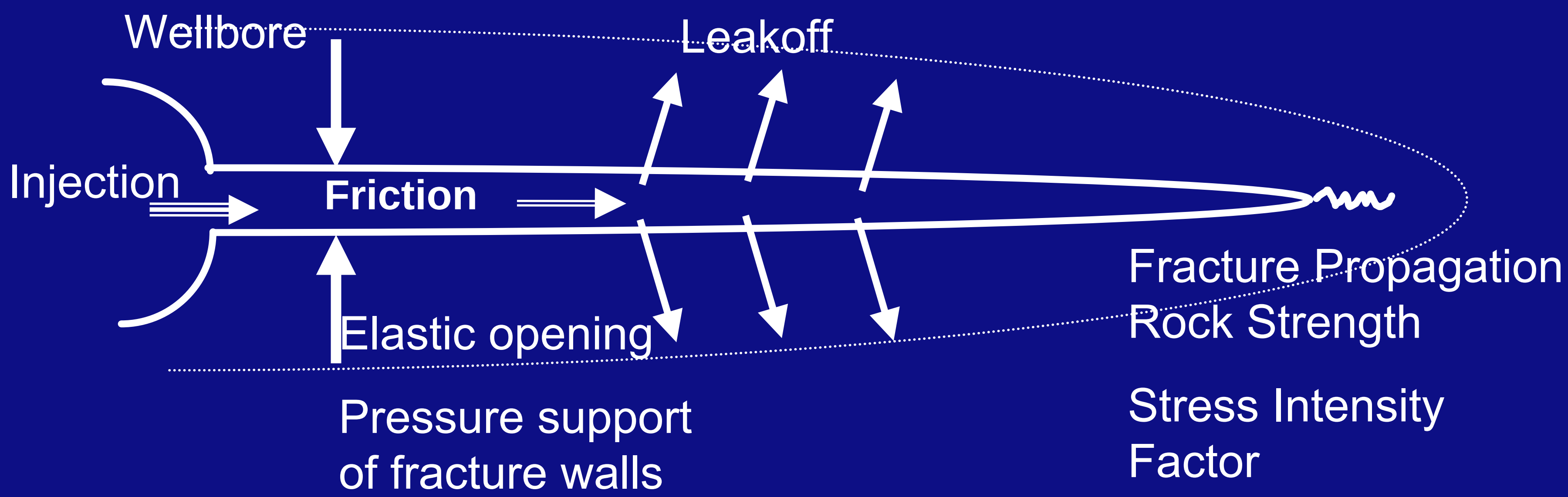


Mode I: Opening   Mode II: Sliding   Mode III: Tearing

- Hydraulic fracturing: Tensile (mode I) – Vertical fracture has least resistance

Hydraulic fracturing – Visualization of the process

- Processes in hydraulic fracturing



Hydraulic fracturing – Concept

- K_I: Stress intensity – measure of singular stress behaviour beyond the tip
- Length increases when $K_I > K_{Ic}$
- Volume balance
- Leakoff correlation

$$K_I = f(w, A)$$

$$w = \frac{V_{fracture}}{A_{fracture}}$$

$$\frac{dV}{dt} = Q_{inj} - Q_{leakoff}$$

$$Q_{leakoff} = \int_{fracture} v_{leakoff}\, dA$$

$$v_{leakoff} = (p_{frac} - p_{res}) \cdot d_{penetrated}$$

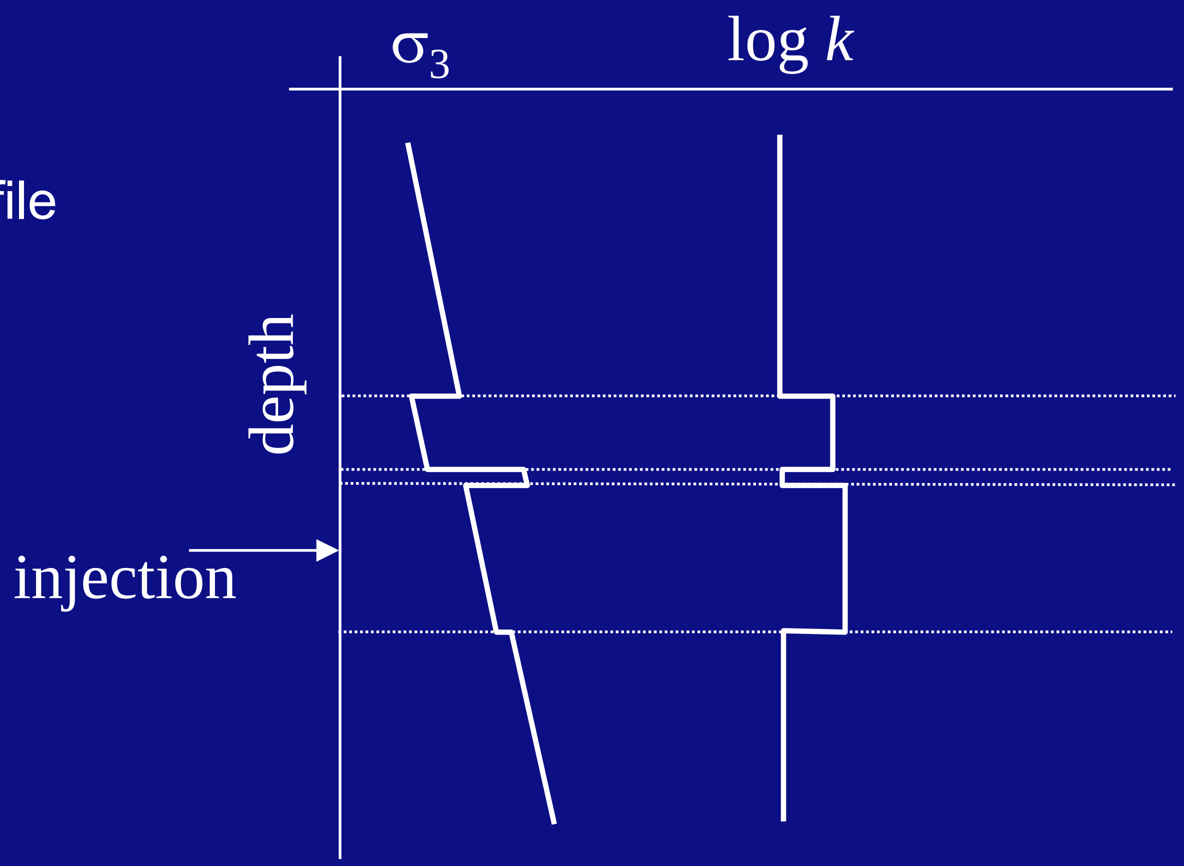
$$d_{penetrated} = \int_0^t v_{leakoff}\, dt'$$

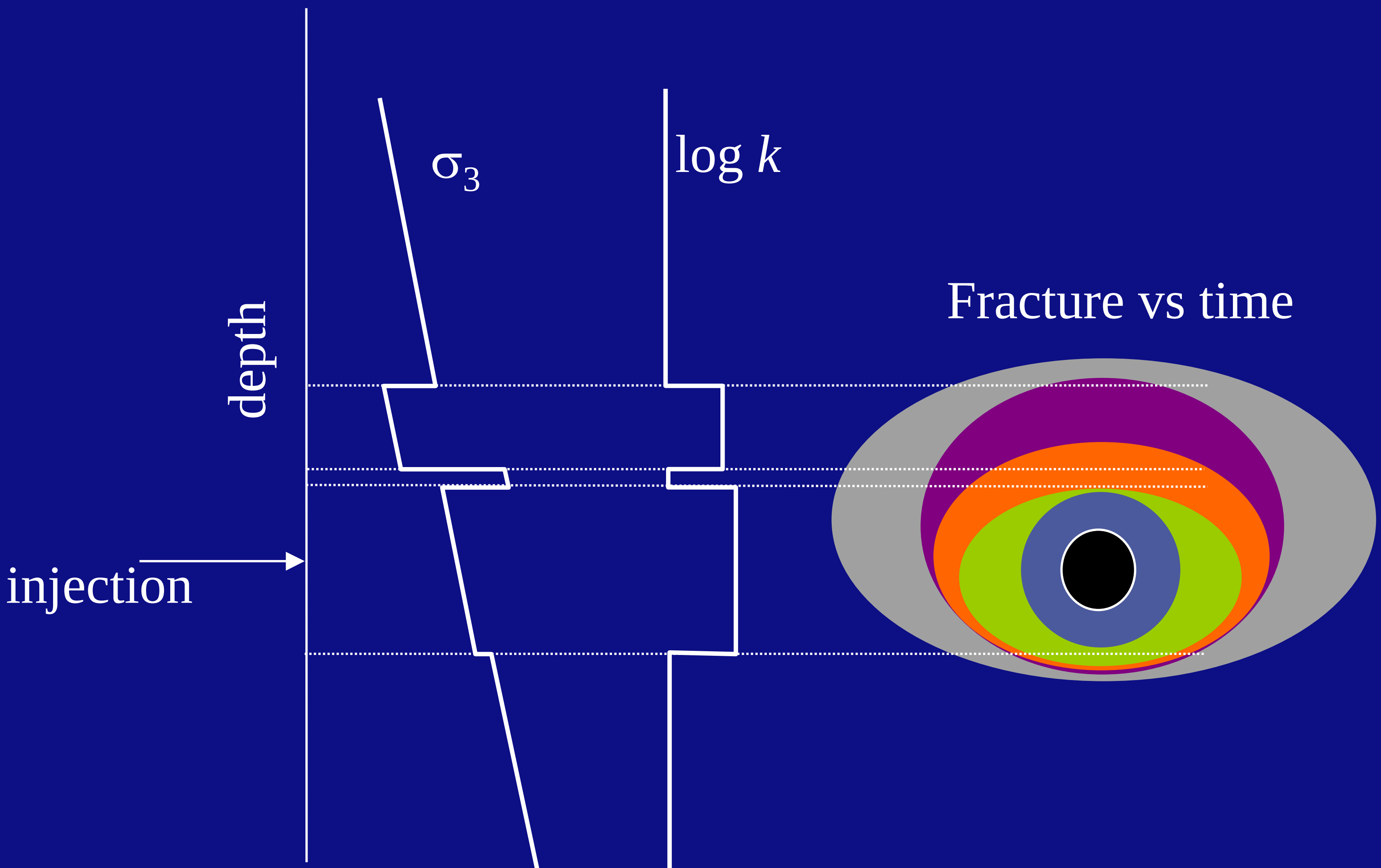
Hydraulic fracturing – Complicating issues

- Profile of the minimum in-situ stress
- Elasticity profile
- Influence of pore pressure increase and temperature decrease on stress (poro-elasticity and thermo-elasticity)
- 3D pore pressure field complicates leakoff correlation
- Plugging of the fracture interior

Layered Reservoir

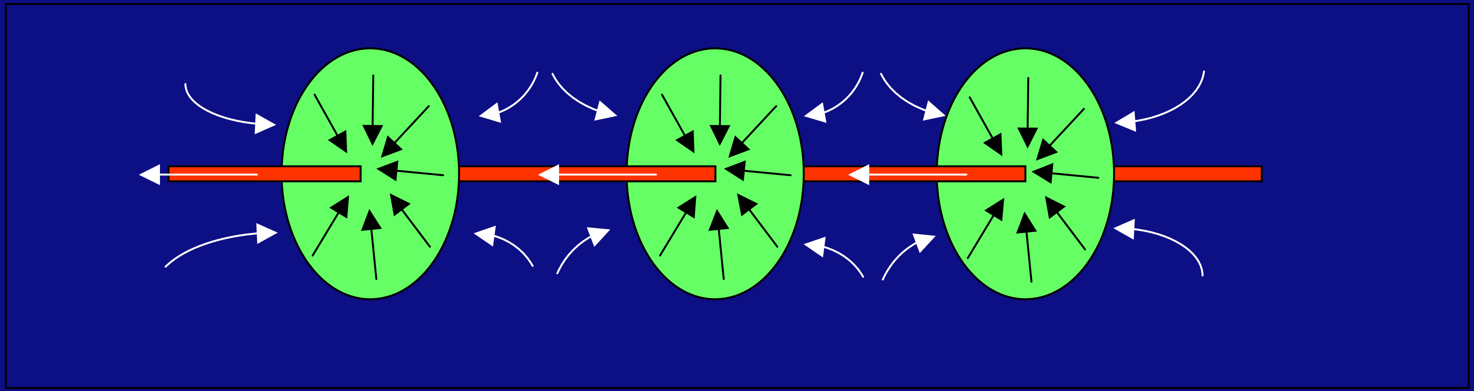
- Stress Profile
- Elasticity Profile
- Permeability Profile
- Porosity Profile




σ3
log k
Fracture vs time
depth
injection

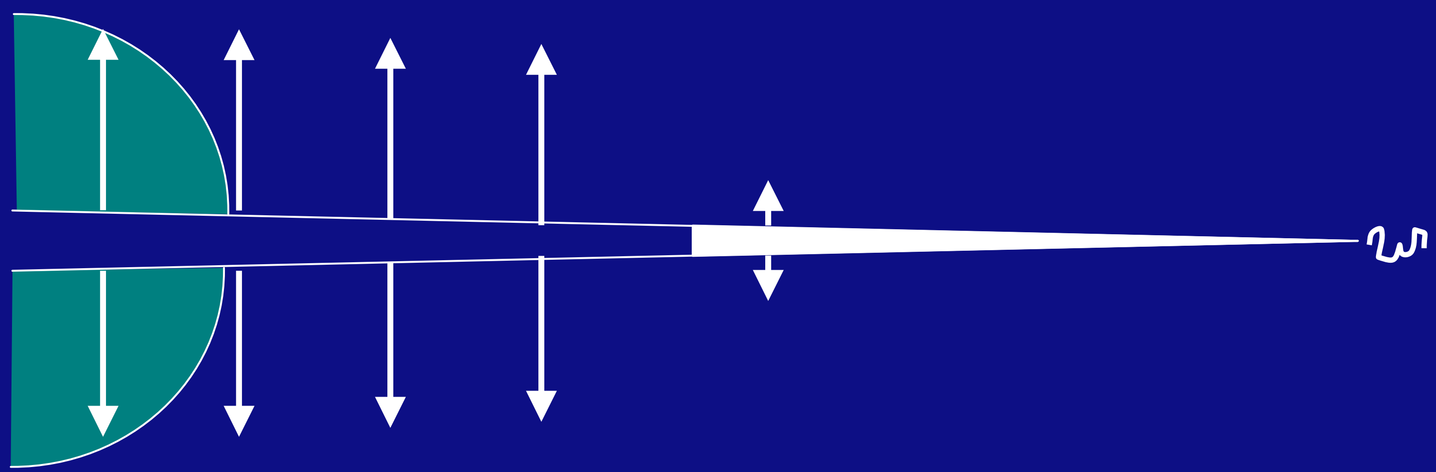
Hydraulic fracturing – Types of applications
1 Massive hydraulic fracturing

- Large treatments
- Low-permeability reservoir
- Create additional contact area
- Multiple fractures in a horizontal well

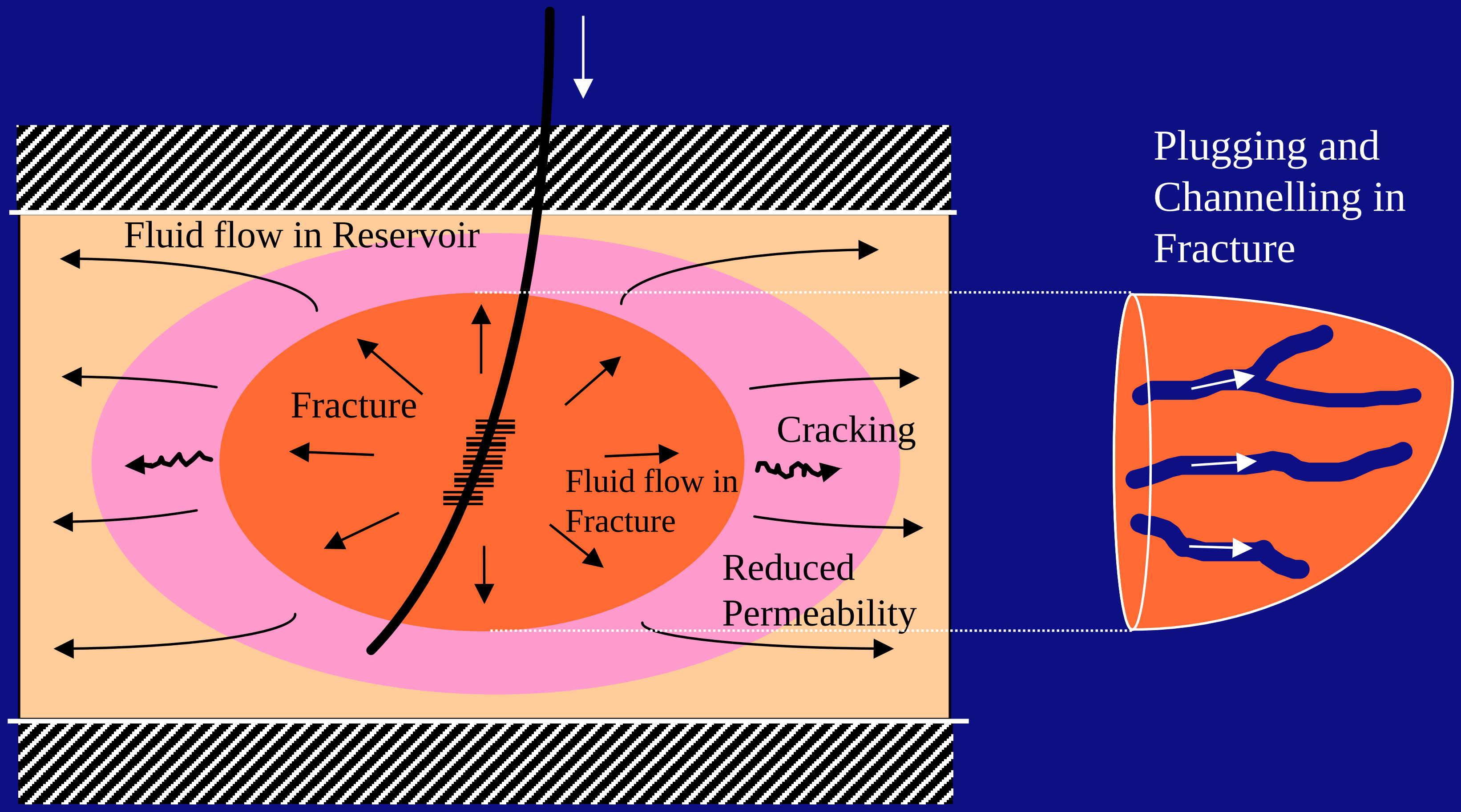


Hydraulic fracturing – Types of applications
2 Tip-Screen-Out fracturing / Frac & Pack

- Goal: Bypass damage
- Typically in higher-permeability reservoir
- Short fracture
- Tip-Screen-Out to increase fracture width



Hydraulic fracturing – Types of applications
3 Water injection under fracturing conditions

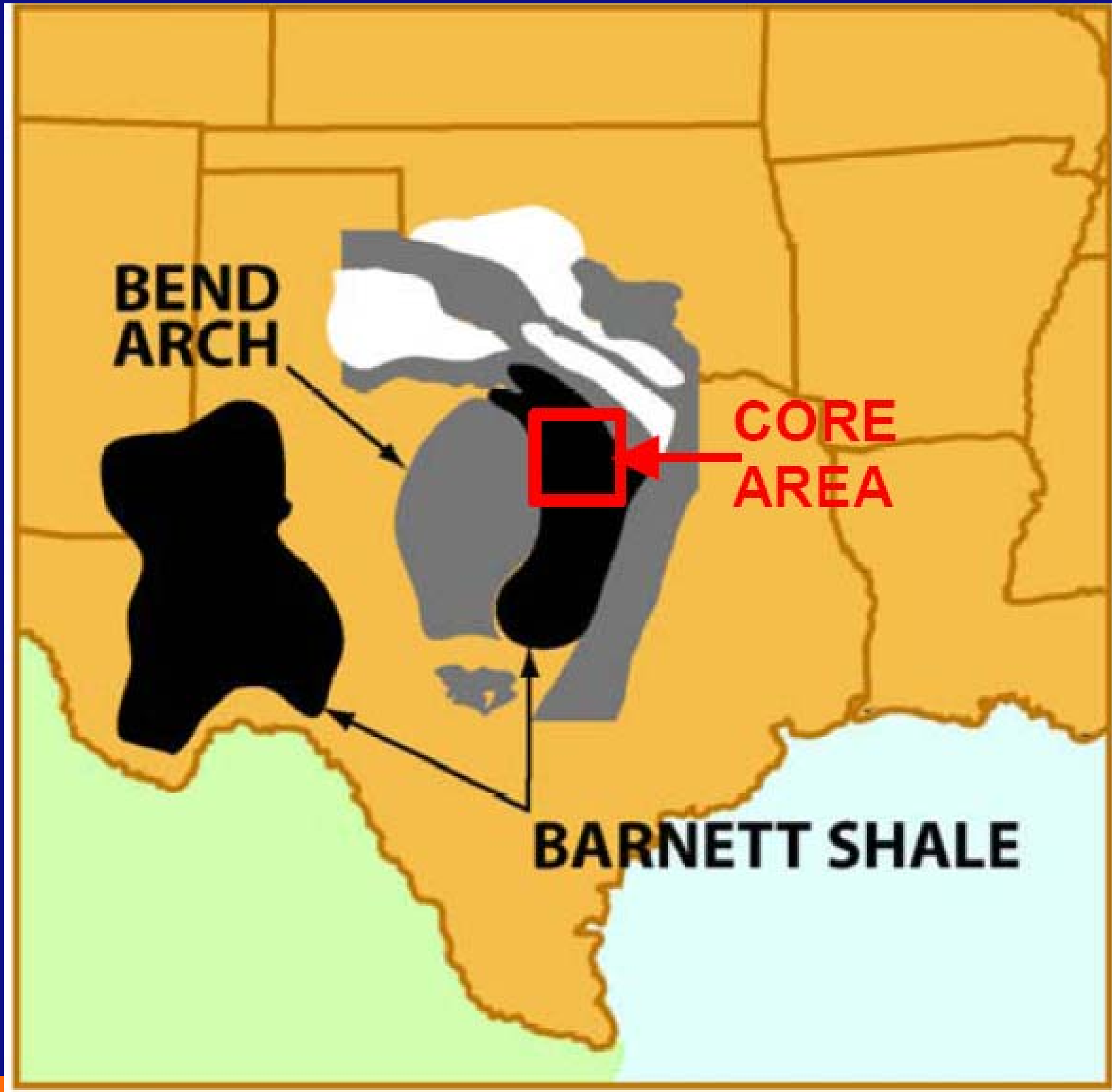


Hydraulic fracturing – Types of applications
4 Water Fracturing

Barnett shale

- Very low permeability
- Naturally fractured

- Goal: interconnected fracture network
- Waterfracturing
- Monitoring



Design considerations

The goal of hydraulic fracturing is economic

- Expected production
- Connection with Geology (Flow barriers, Permeability, Heterogeneity, Natural fractures)

Key design parameter: Dimensionless fracture conductivity

$$C_{fD} = \frac{k_f \cdot w}{k \cdot L}$$

Optimum value:

- High k: maximize width and proppant permeability
- Low k: maximize length

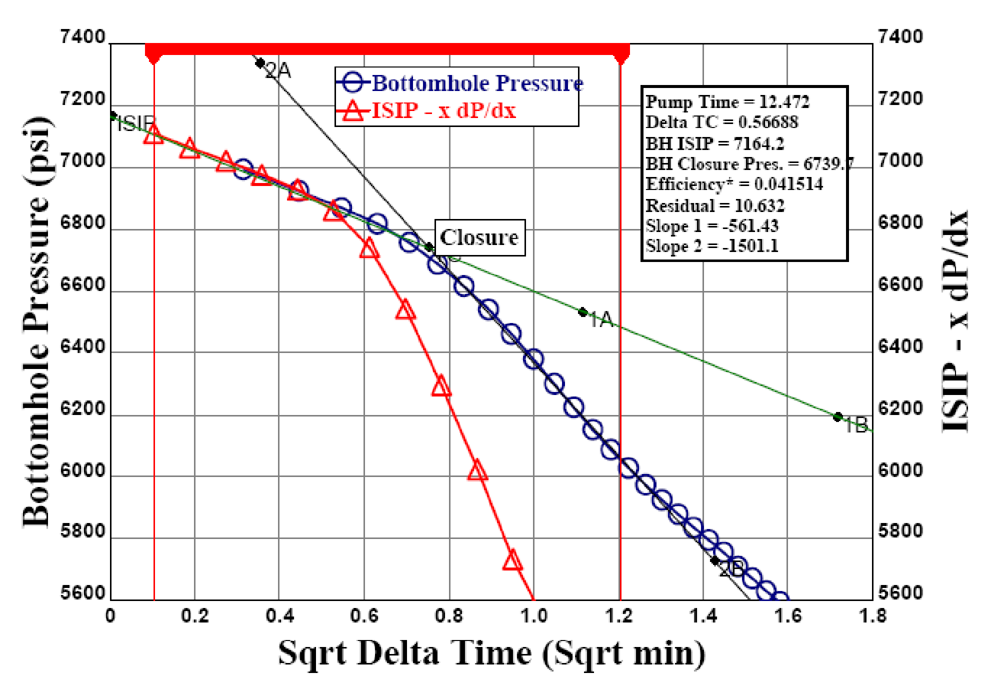
Design considerations

More input for design:

- In-situ stresses
- Fracturing pressures
- Leakoff behaviour

} Minifrac test

- Effects of layering:
  - Containing capacity
  - Connection
- Natural fractures
- Poro-elasticity
- Thermo-elasticity



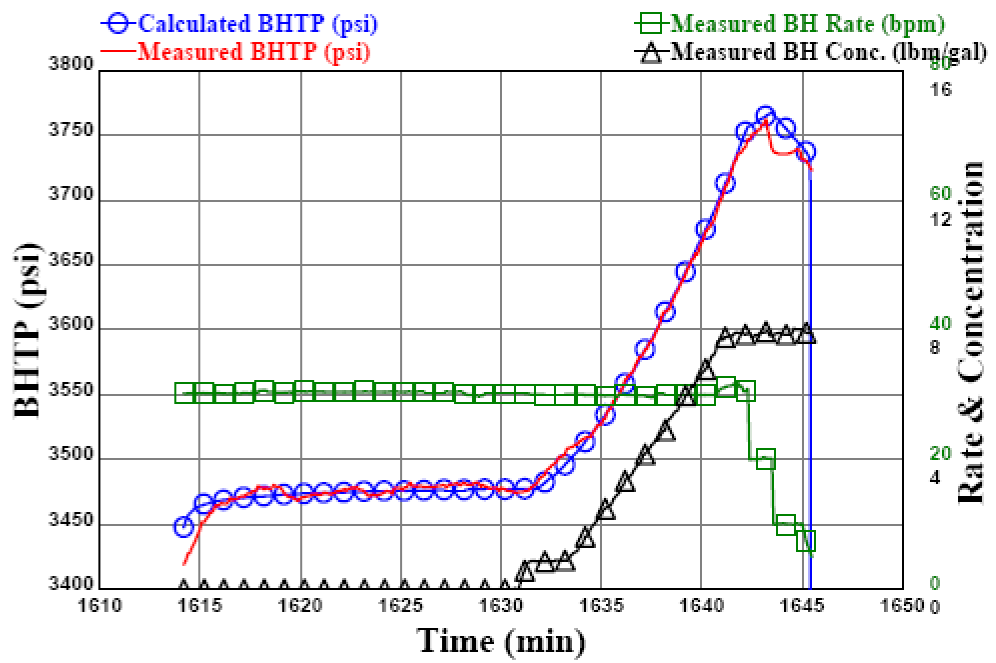
Monitoring

Build up a knowledge base:

- Treatment performance
- Productivity monitoring

Treatment performance monitoring

- Rates & Pressure traces
  (e.g. Tip-Screen-Out)



Monitoring

Build up a knowledge base:

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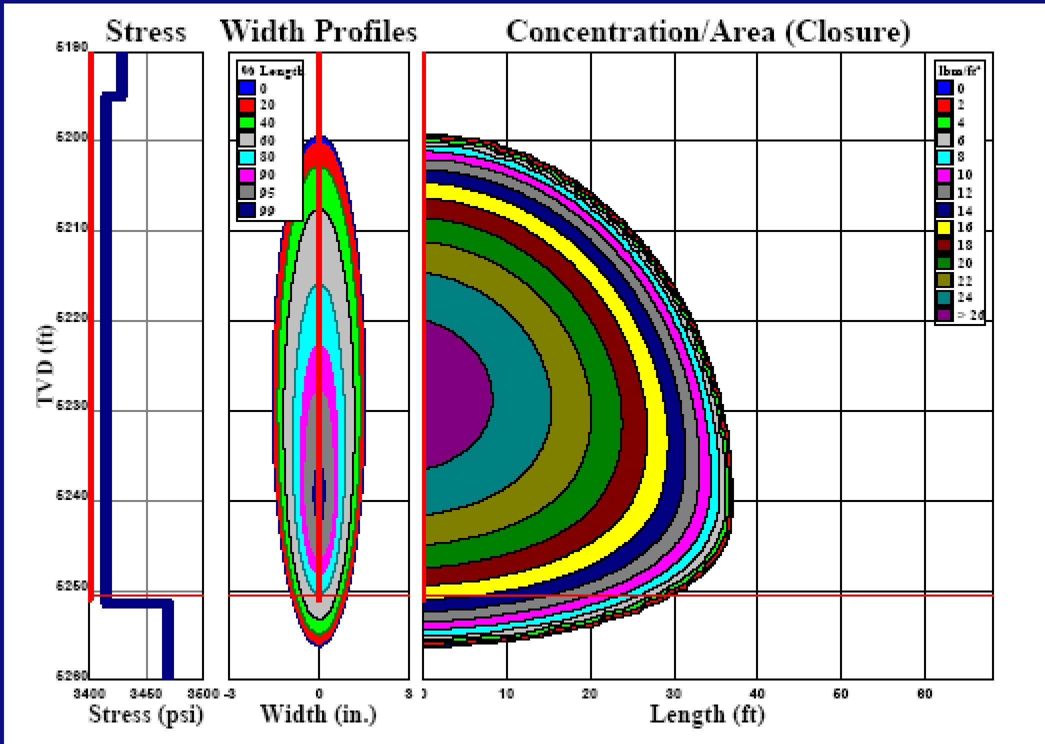
Treatment performance monitoring

- Rates & Pressure traces (e.g. Tip-Screen-Out)
- Use fracture simulator



Monitoring

Build up a knowledge base:

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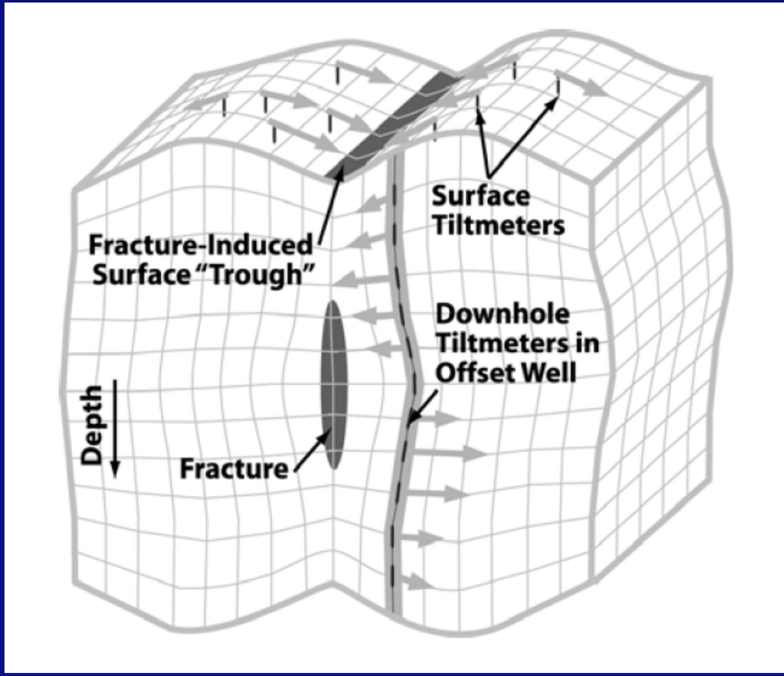
Treatment performance monitoring

- Rates & Pressure traces (e.g. Tip-Screen-Out)
- Use fracture simulator
- Tiltmeters
    - Surface
    - Offset well



Monitoring

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- Treatment performance
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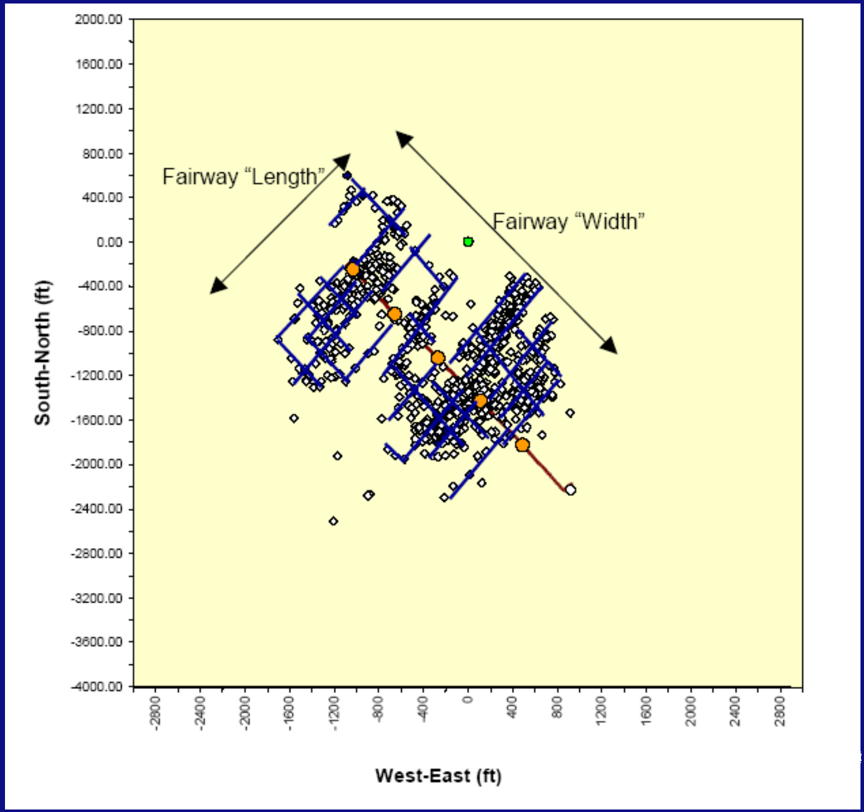
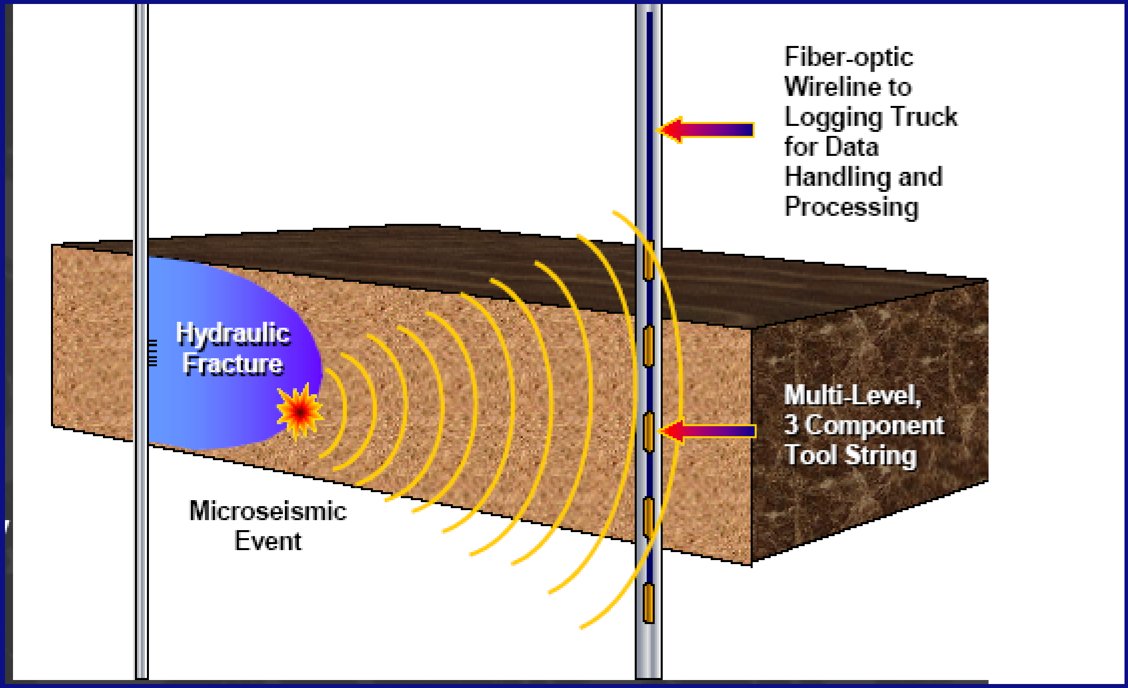
Treatment performance monitoring

- Rates & Pressure traces (e.g. Tip-Screen-Out)
- Use fracture simulator
- Tiltmeters
  - Surface
  - Offset well
- Microseismic mapping two downhole receivers



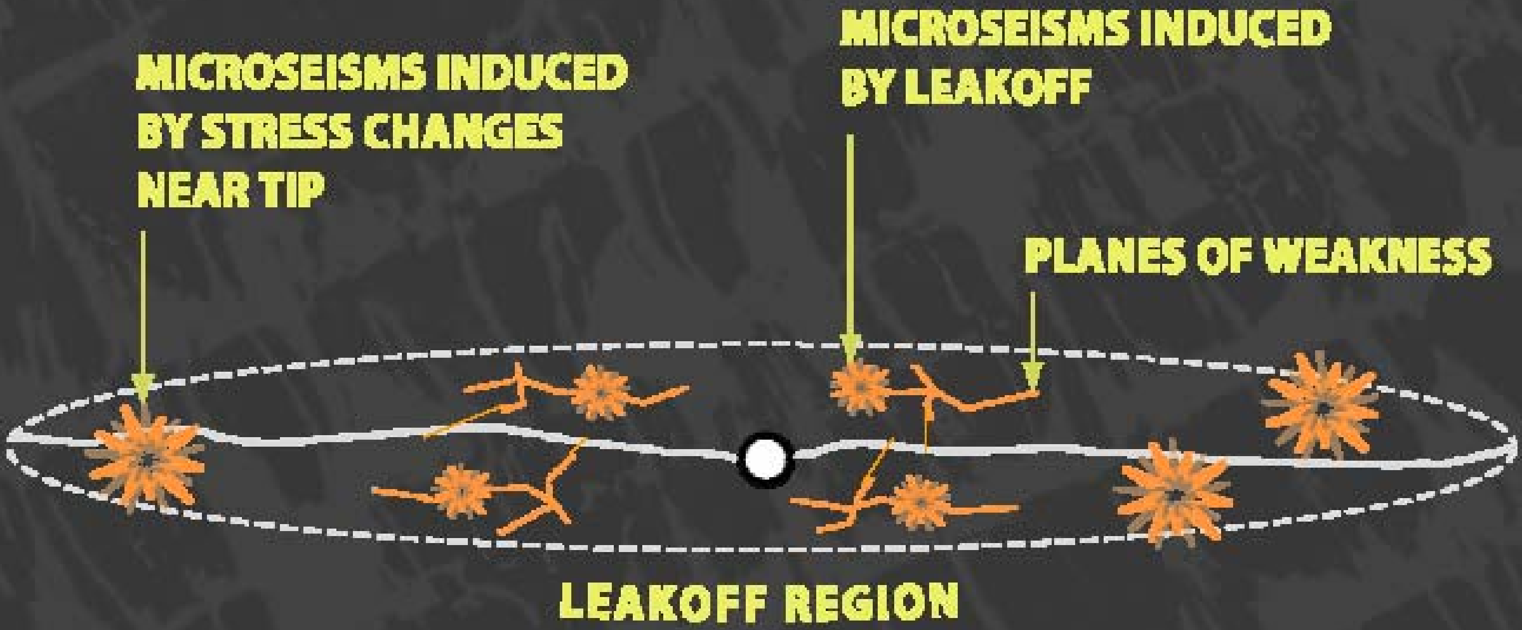
A little more on micro-seismic mapping

- Principle: micro “earthquakes” induced by σ & p changes and slippage along weak planes
- Measure orientation and distance from s and p waves



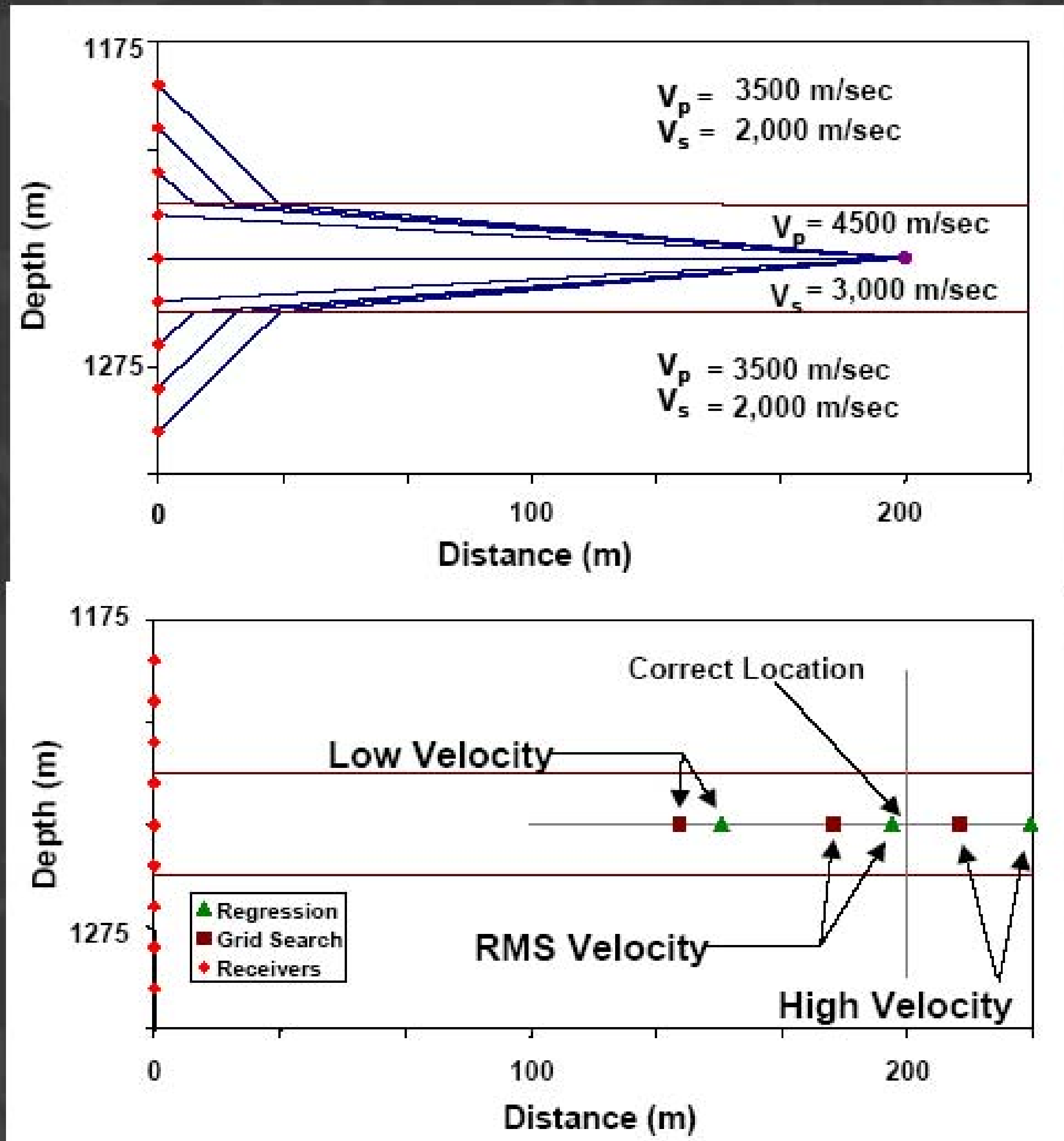
Microseism Origins

Microseisms Originate in an Envelope Surrounding the Fracture



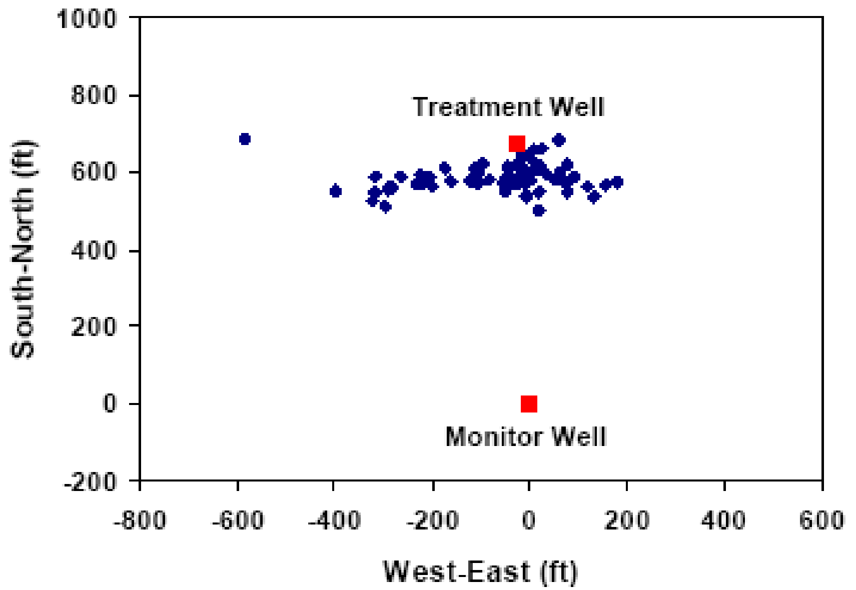
Pinnacle

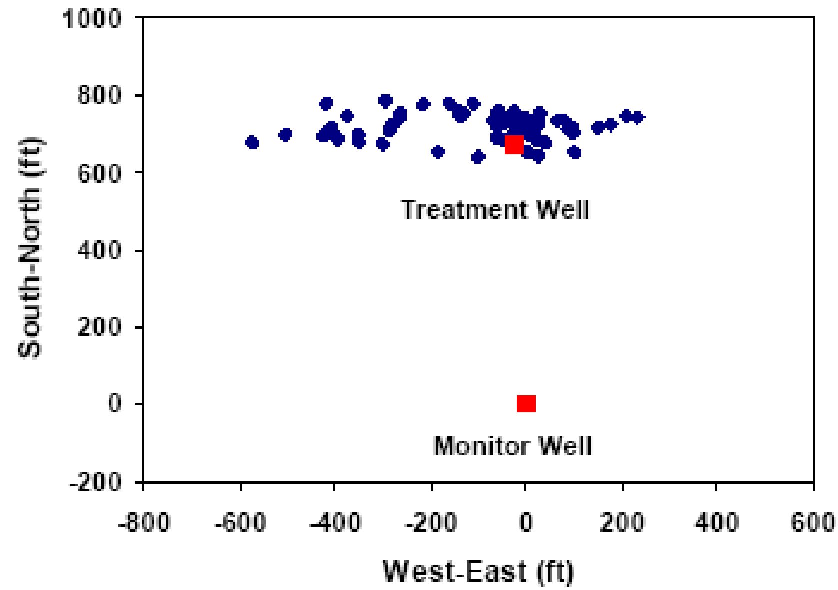
Velocity-structure example for centered array

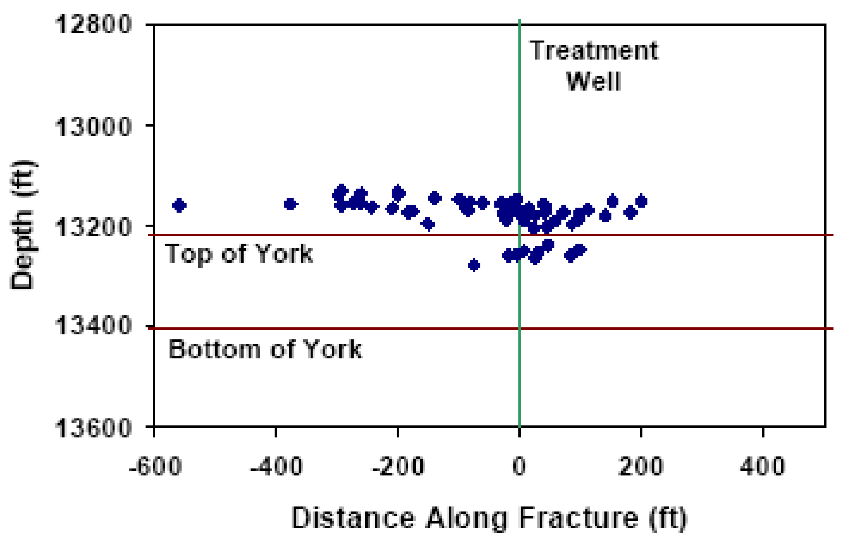


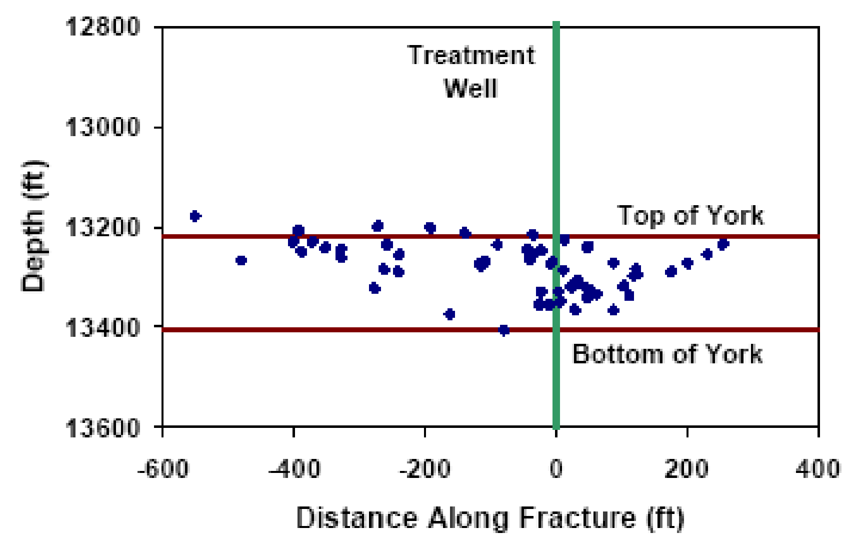
Microseismic locations using 3-layer velocity structure from dipole sonic log

Microseismic locations using 3-layer velocity structure from perforation timing

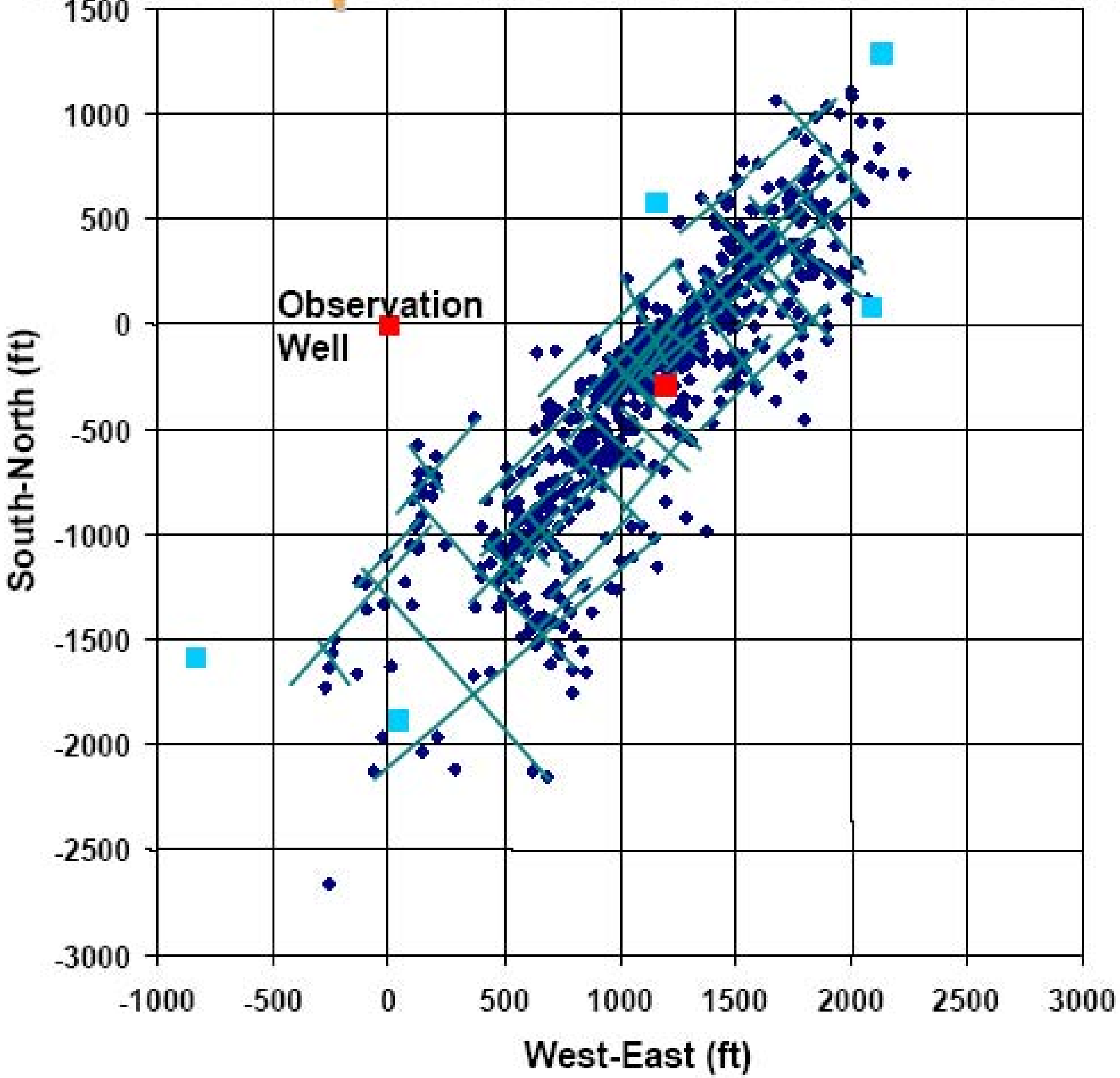








Large "Waterfracs" with Extremely Long and Complicated Fracture Growth



Plan View of Microseismic Map

Pinnacle

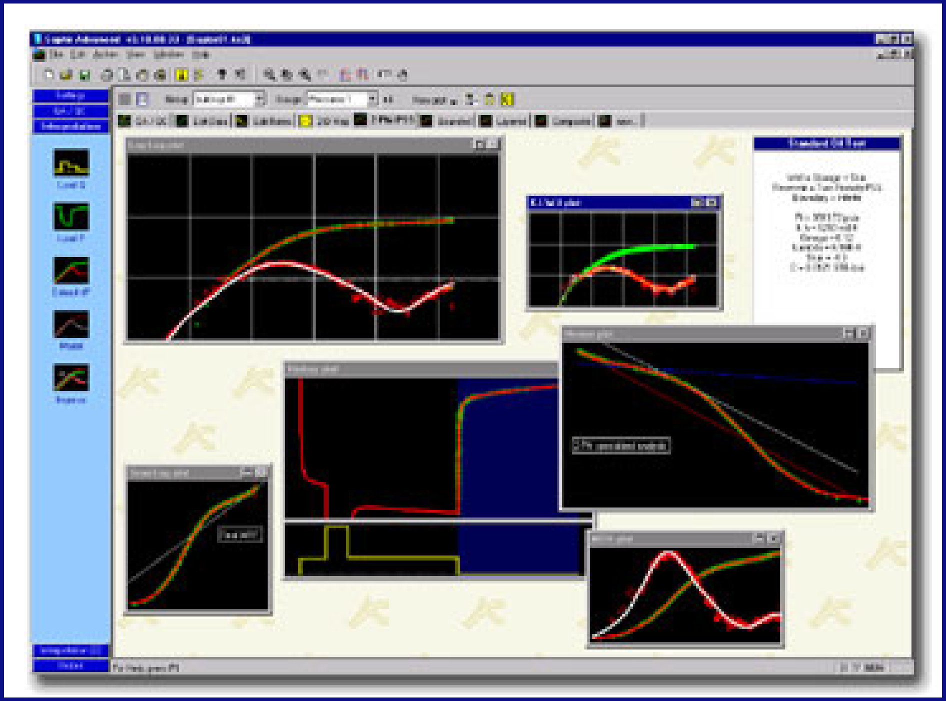
Monitoring

Build up a knowledge base:

- Treatment performance
- Productivity monitoring

Productivity monitoring

- Well testing:
  Effective fracture size



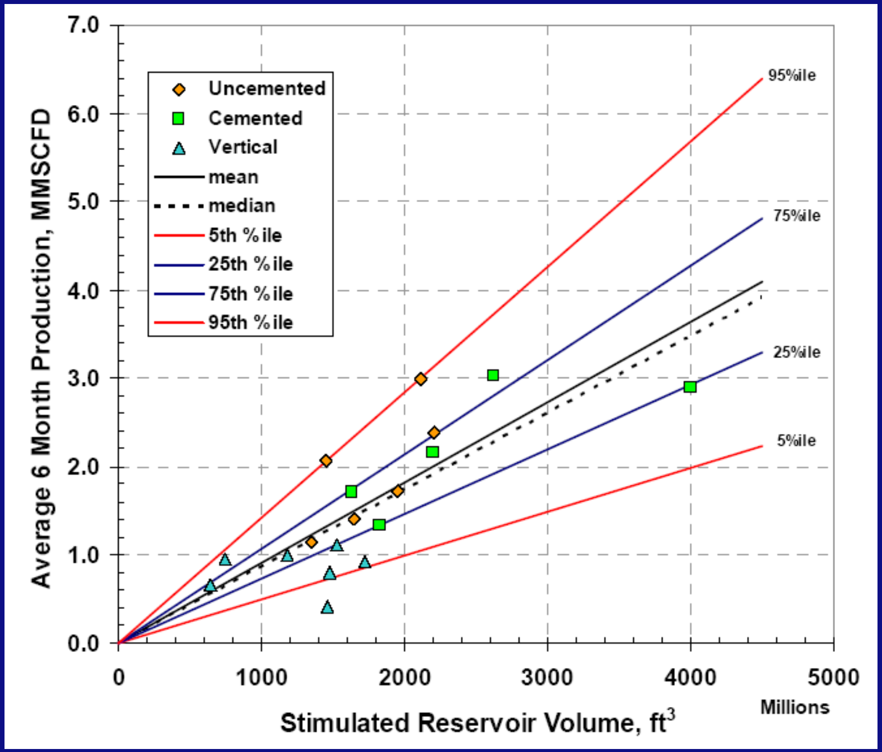
Monitoring

Build up a knowledge base:

- Treatment performance
- Productivity monitoring

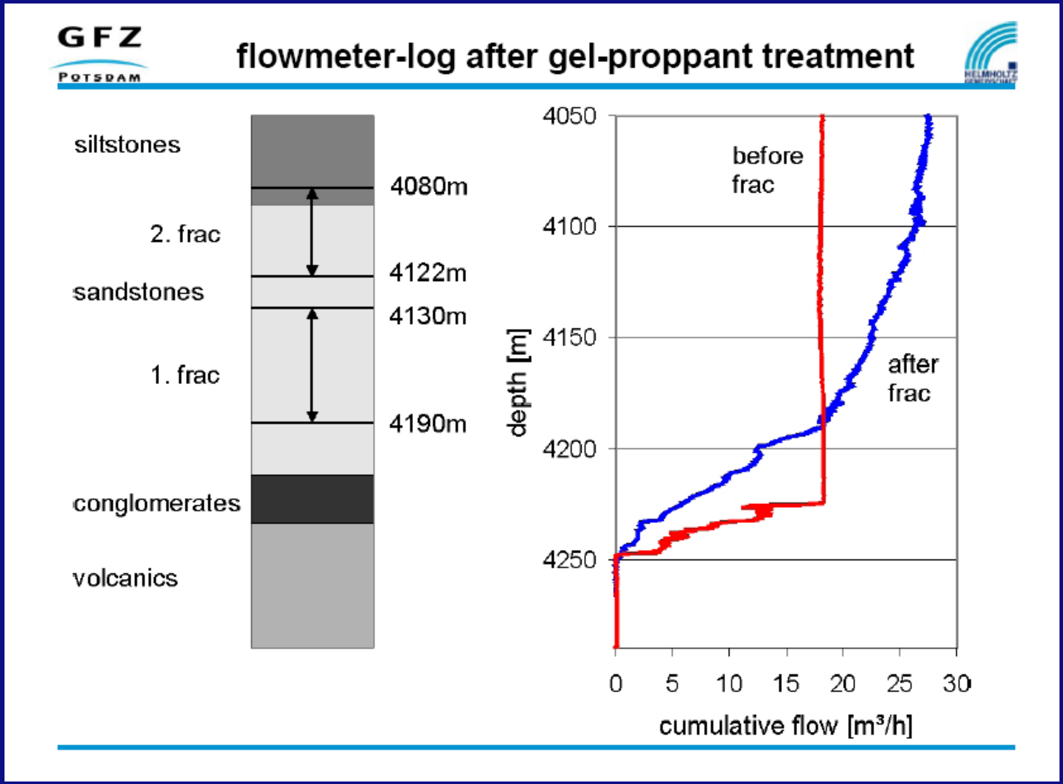
Productivity monitoring

- Well testing:
  Effective fracture size
- Productivity evaluation
  e.g. Stimulated Volume Analysis



Example: Gross Schönebeck

- Permeability 10 – 150 md → regular hydraulic fracture: Feb 2002
  - Viscous fracturing fluid
  - Proppant
- Disappointing result: Productivity increase by factor 1.8 (expected 6 – 8)
- Possible causes
  - Proppant impairment
  - Fracture face skin
  - Insufficient fluid cleanup
- Post-frac monitoring (injection test) might indicate effective fracture length



Operations overview

open hole proppant frac

Jan/Feb 2002

- production test / logging
- 4130-4190m (frac 1)
- 4080-4118m (frac 2)
- production test / logging

open hole waterfrac

start Jan/Feb 2003

- 3874-4294m, borehole instability
- production test

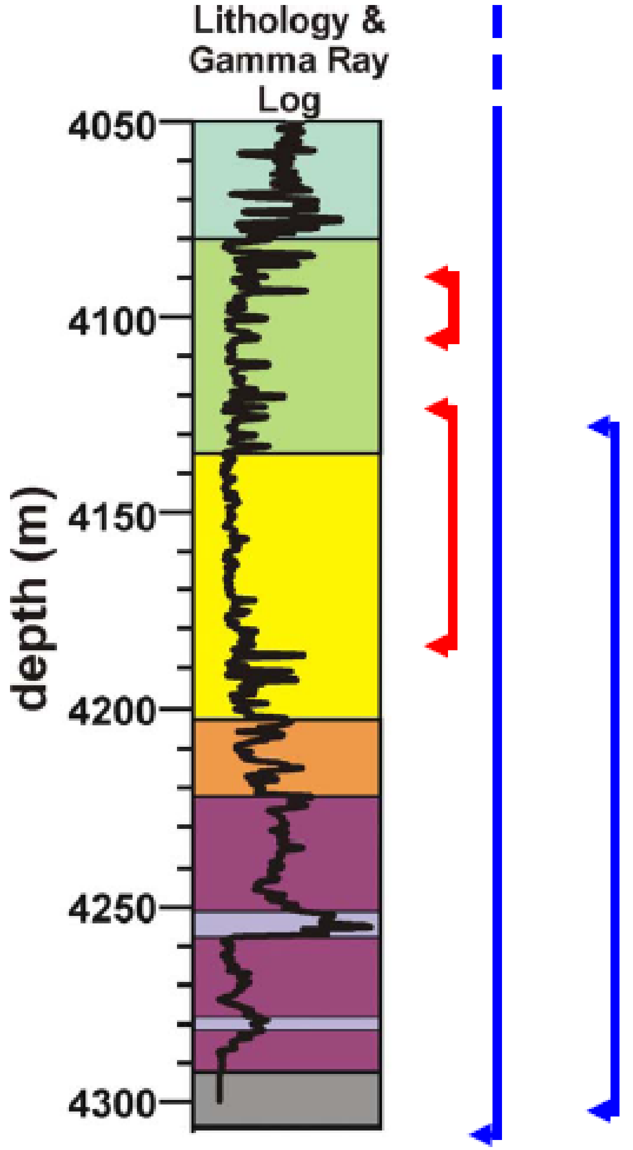
cont. Nov/Dec 2003

- 4135-4309m
- production test / logging

Dec 2004

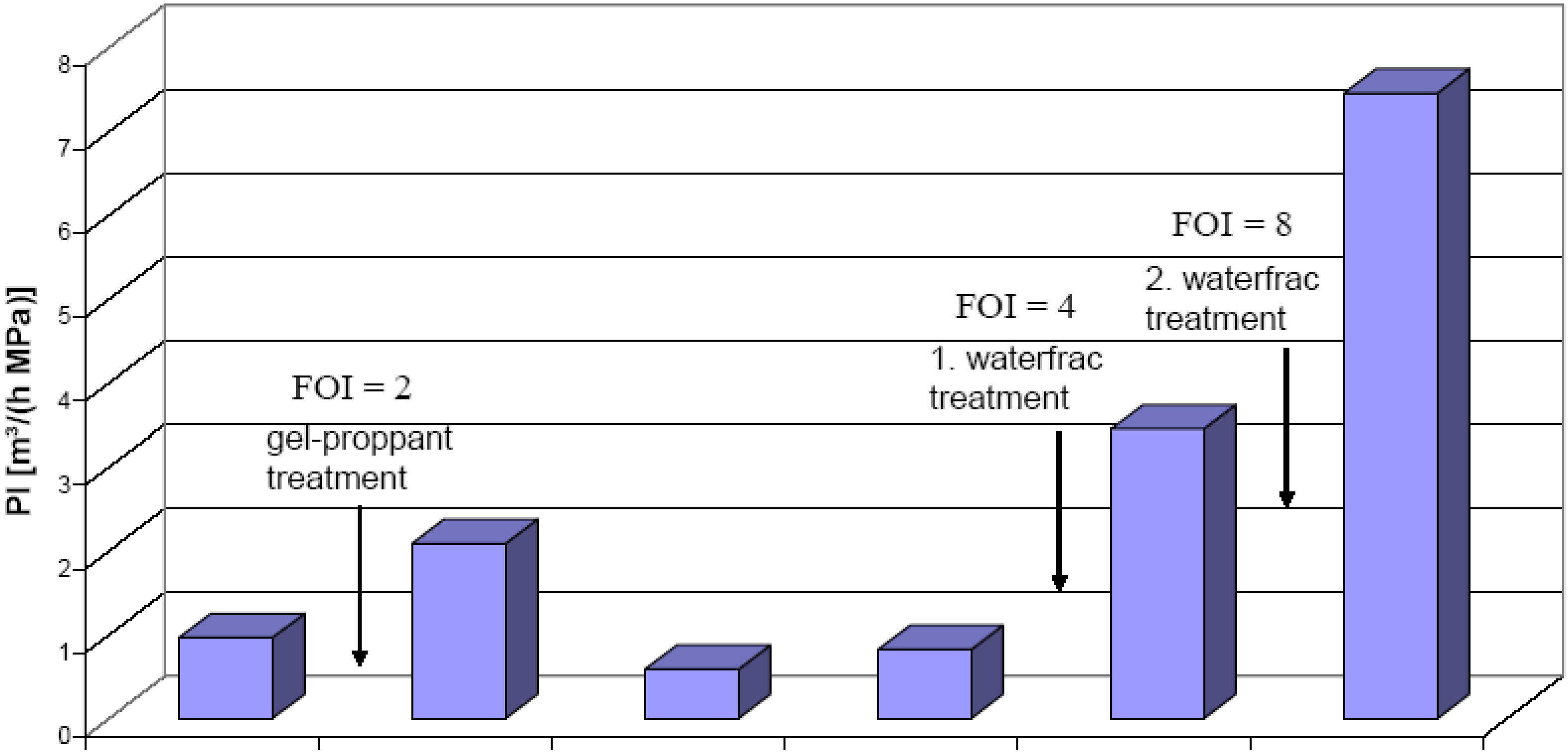
- injection test

drilling 2. well



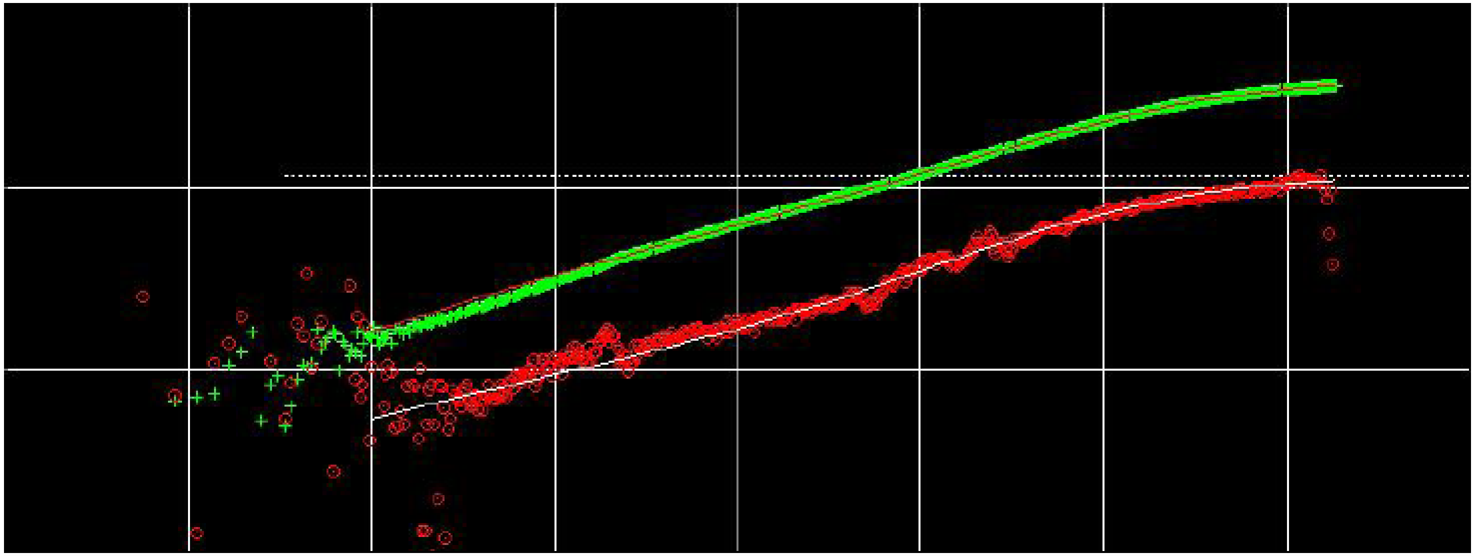
GFZ Potsdam

productivity development



	CLT Jan2001	CLT Feb2002	PT Aug2002	IT Jan2003	FB Feb2003	FB Dec2003
volume	167 m³	307 m³	580 m³	720 m³	250 m³	859 m³
time	12,3 hours	14 hours	37 days	8,3 days	5 hours	24 hours
flow rate	13,5 m³/h	22,4 m³/h	1 m³/h	3,6 m³/h	50 m³/h	50 m³/h

Injection experiment 2004/2005



Log-Log plot: dp and dp' [Pa] vs dt [hr]

Transmissibility T = k h = 4.1×10^{-14} m³ = 0.041 Dm

Fracture half length xf = 255 m

Fracture conductivity Fc = 9.6×10^{-13} m³ = 0.96 Dm

Results and conclusions from Gross Schönebeck

- Propped fracture in sand: Productivity Improvement Factor 1.8
  - No self-propping
  - Not enough proppant layers
  - Closure of fractures at low differential pressures
- 2 massive waterfrac treatments:
  productivity improvement factors of 4 and 8
  - Only in volcanic rocks
  - Closure of sandstone layers at low differential pressure
- Recommendations
  - Separate treatments in different layers:
    propped frac in sands, waterfracs in volcanics
  - Post-fracture analysis of injection tests

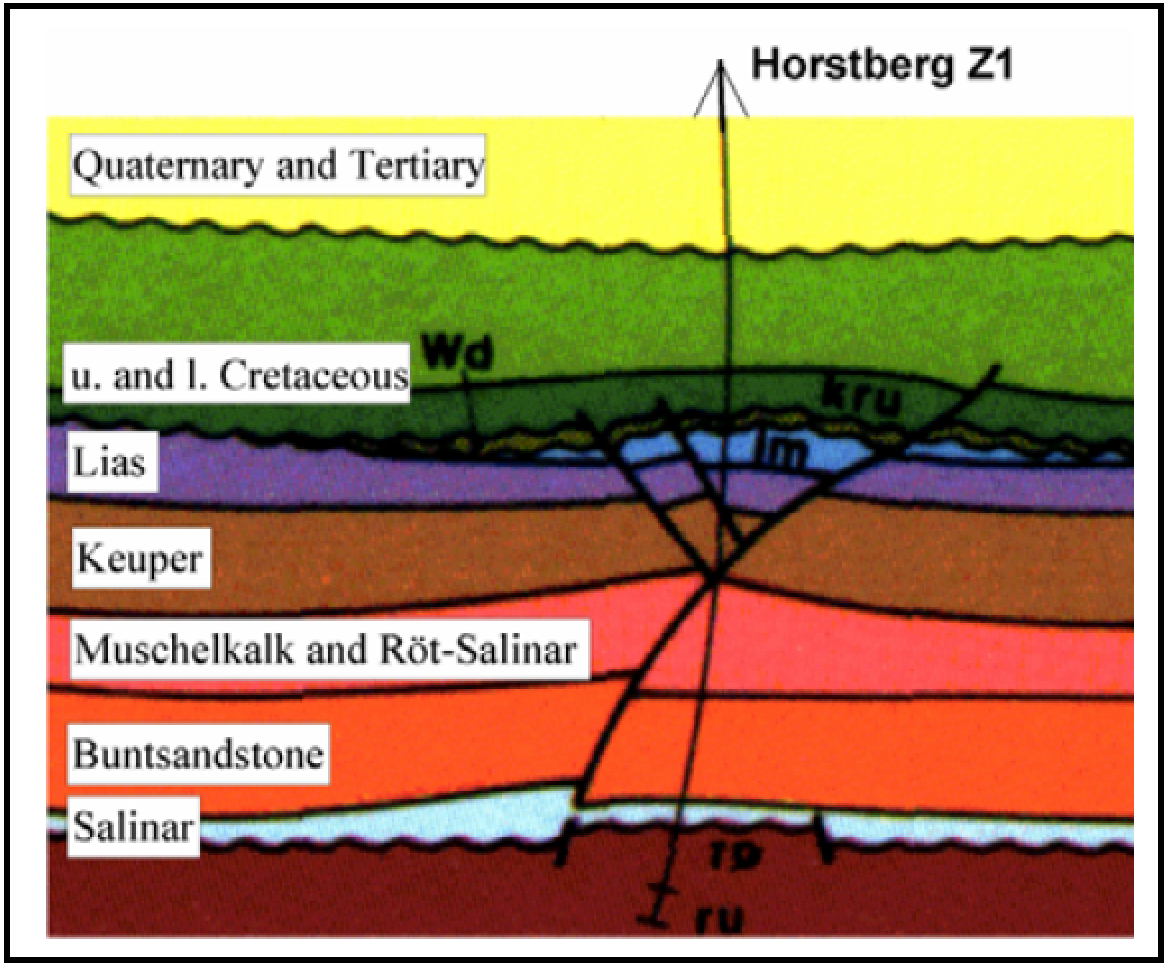
Water fracturing in the Genesys project

- Large amounts of water in low-permeability sandstone
- Fracture growth out-of-zone into clay
- Fracture self-propping
- Very few micro-seismic events

- Productivity not large enough
- Cyclic injection – production promising

Location and Geology

- Centre of N German Basin
- Target: Middle Bunter (3630 m ; 158°C; 6 – 20 m thickness)
- $\phi = 3 - 11\%$
- $k \leq 1$ md
- Re-injection in Kalkarenit (1150 – 1250 m)
- Medium & minimum stress comparable



Fracturing and test program

- Four waterfrac tests in 6-m sandstone
- Total 20,000 m^3 water injected
- Later injection increased fracture pressure
- "Venting tests"
  - No decrease in fracture conductivity
  - High temperatures
- Possibility of cyclic injection & production??
  - Injection at 10°C
  - Production at 80°C (daily cycle) / 110°C (weekly cycle)

Further testing

- Fracture storage capacity indicates fracture area: 500,000 m^2
- Pressure decline curves: fracture area 20,000 m^2 – area in active zones
  Fracture length = 20,000 / 6 = 3.3 km ??
- Temperature logging: fracture height 150 m
  Fracture length = 500,000 / 150 = 3.3 km ??
- Hardly any microseismic events at surface; No tilt at surface

Results and conclusions from Genesys test

- Large fractures created with water fracturing
- Large fracture conductivity
- Well productivity too low, but cyclic scheme promising
- How do the fractures look like?
  - Single long fracture
  - Fracture network

Concluding remarks

- What is the goal?
  - Contact area
  - Bypass damage
  - Connect to natural fractures
- Design
  - Reservoir Permeability
  - Fracture conductivity
  - Geology
  - Rock mechanics
  - Minifrac tests
  - Design software
- Monitoring
  Build up a knowledge base
  - Rates
  - Pressures
  - Tiltmeter mapping
  - Microseismics
  - Productivity
- Application in Geothermal Energy
  - Gross Schönebeck
  - Genesys