Hydraulic fracturing in the hydrocarbon industry

Peter Fokker

TNO | Knowledge for business

Outline

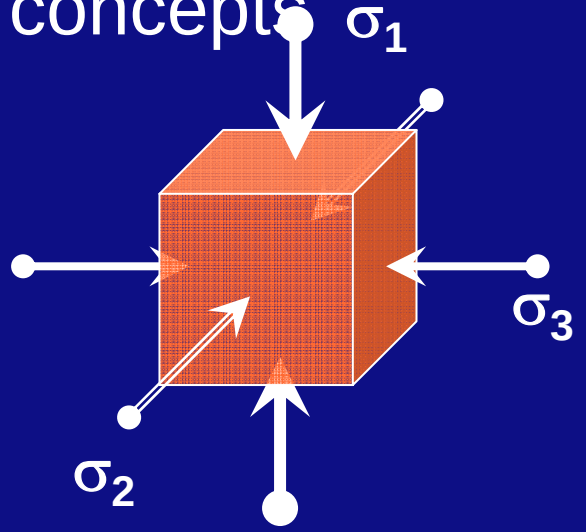
- Introduction
- Hydraulic fracturing – basics
- Types of applications
- Considerations of design
- Monitoring
- Concluding remarks

Introduction

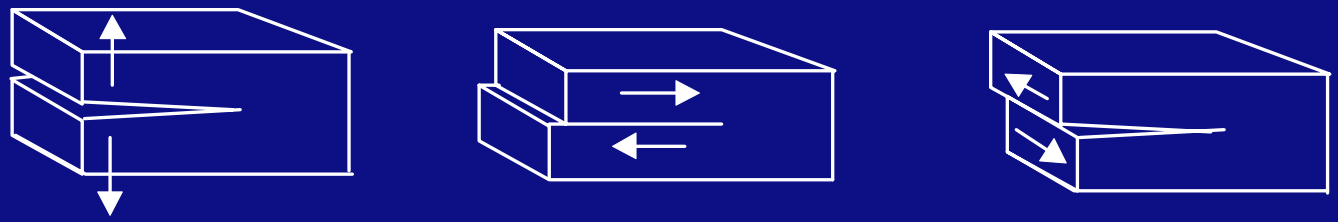
Stimulation of under-performing wells

- Matrix acidizing
  - Dissolve “skin” with acid (HCl, HF)
  - Not working with all kinds of damage
  - Concern of tubing corrosion
- Hydraulic fracturing
  - Increase inflow area
  - 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

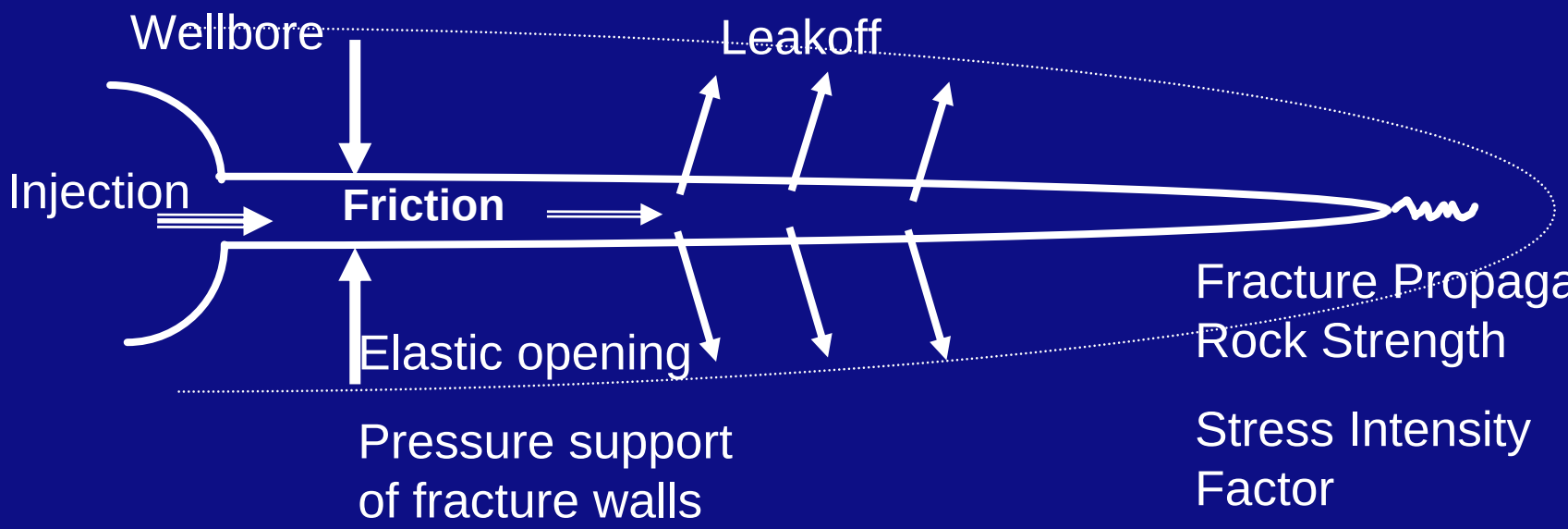


Mode I: Opening Mode II: Sliding Mode III: Tearing

- 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

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

$$w(y,z) = f\left(p(y,z) - \sigma_3\right)$$

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

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

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

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

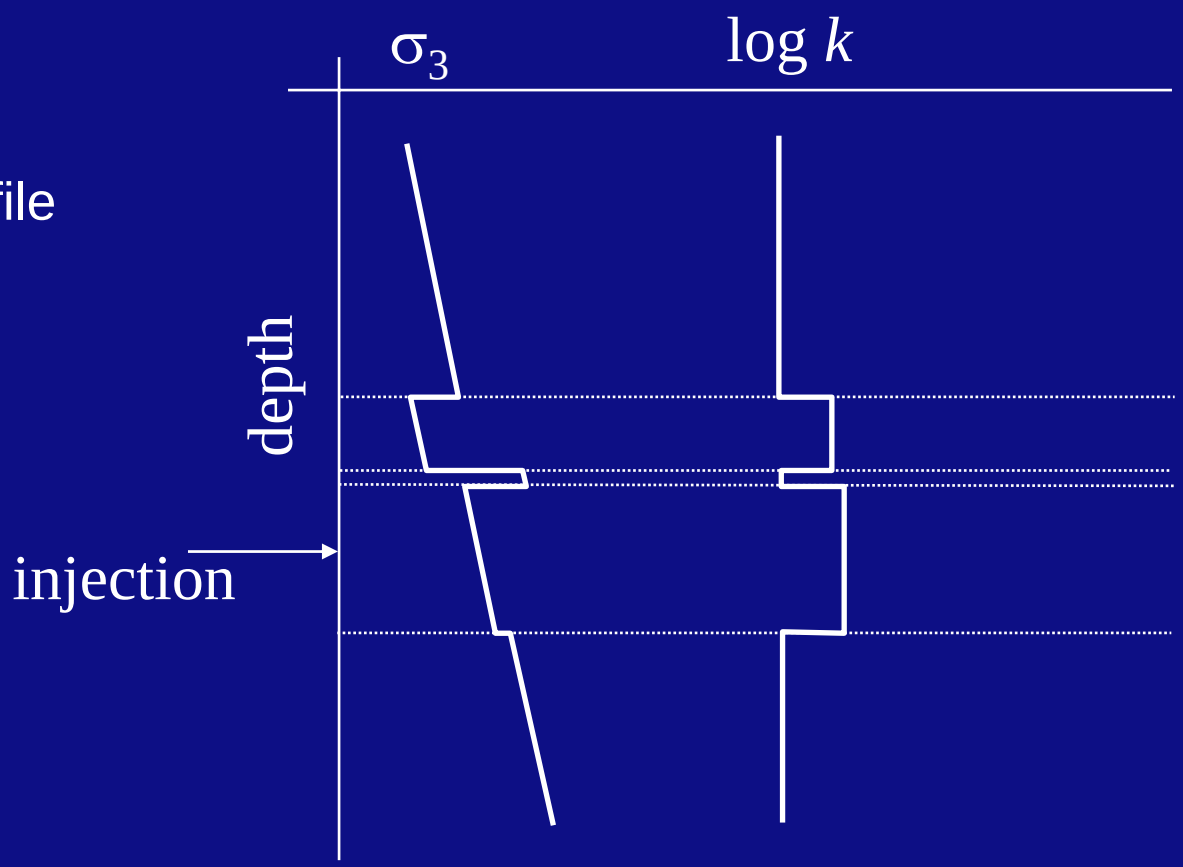
$$d_{penetrated} = \int_0^t v_{leakoff}\, dt'$$

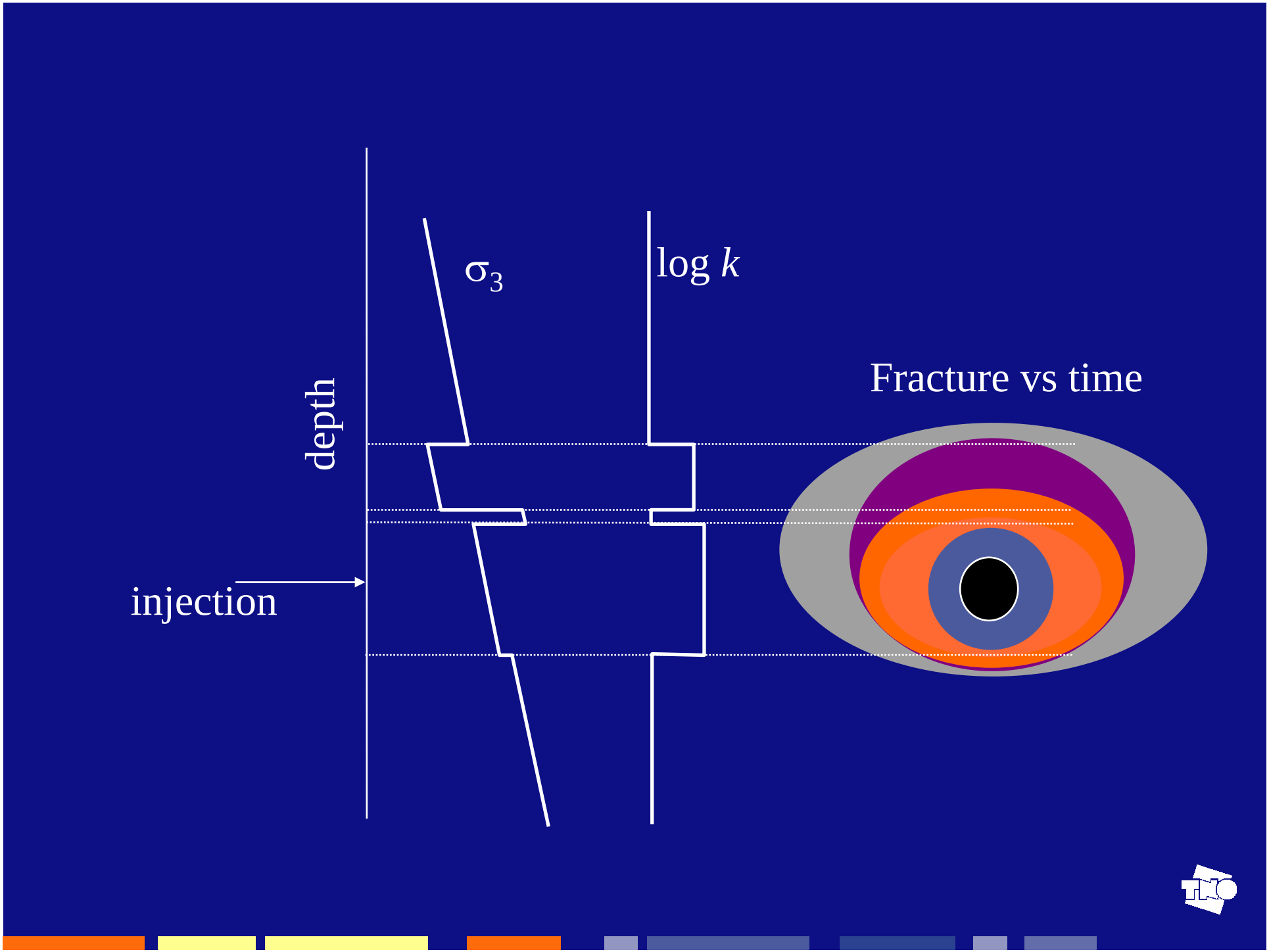
Hydraulic fracturing – Complicating issues

- 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

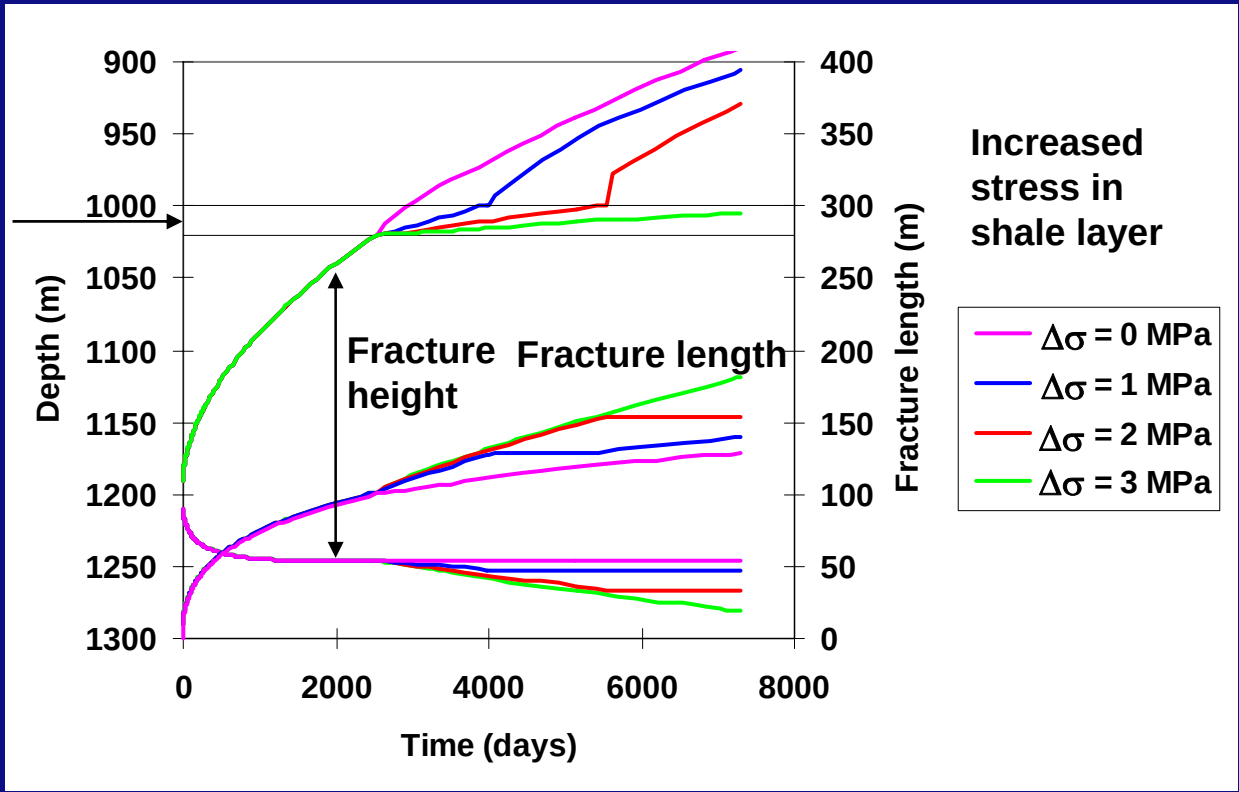
- Stress Profile
- Elasticity Profile
- Permeability Profile
- Porosity Profile



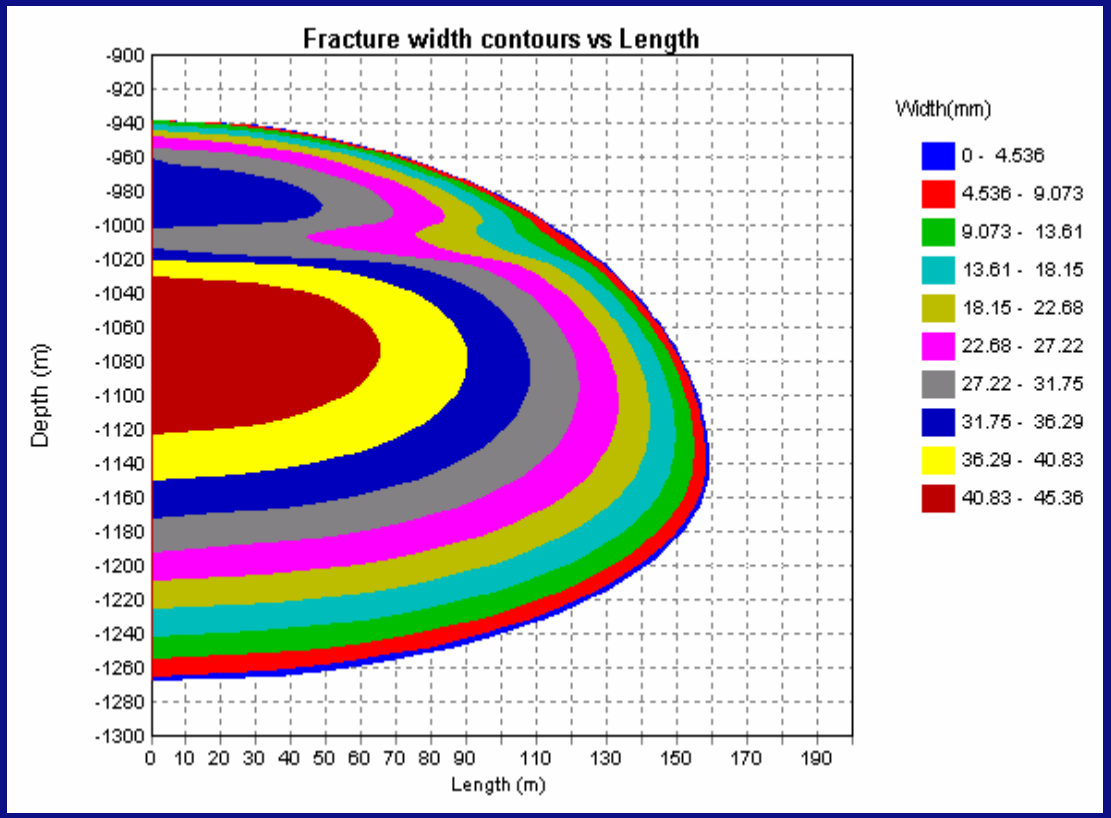

σ3
log k
depth
Fracture vs time
injection

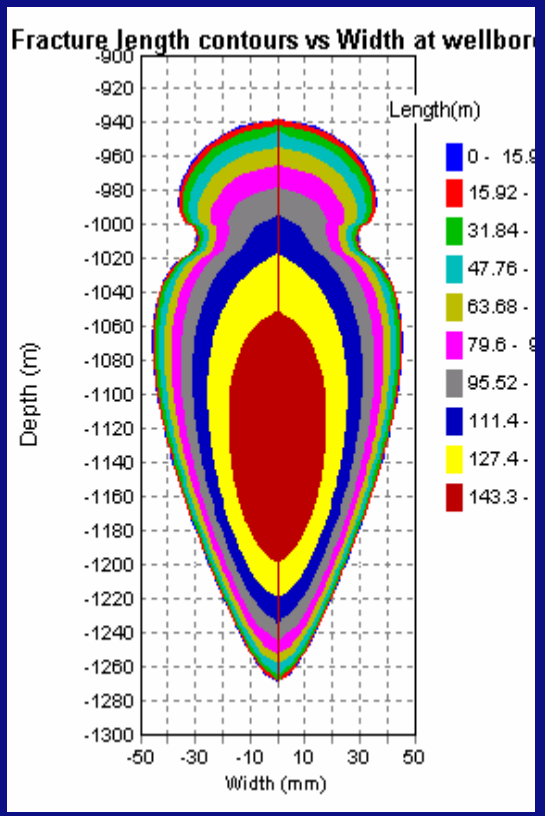
Example: Influence of a stress barrier

Shale layer



Width and length contours ($\Delta\sigma$ = 2 MPa)

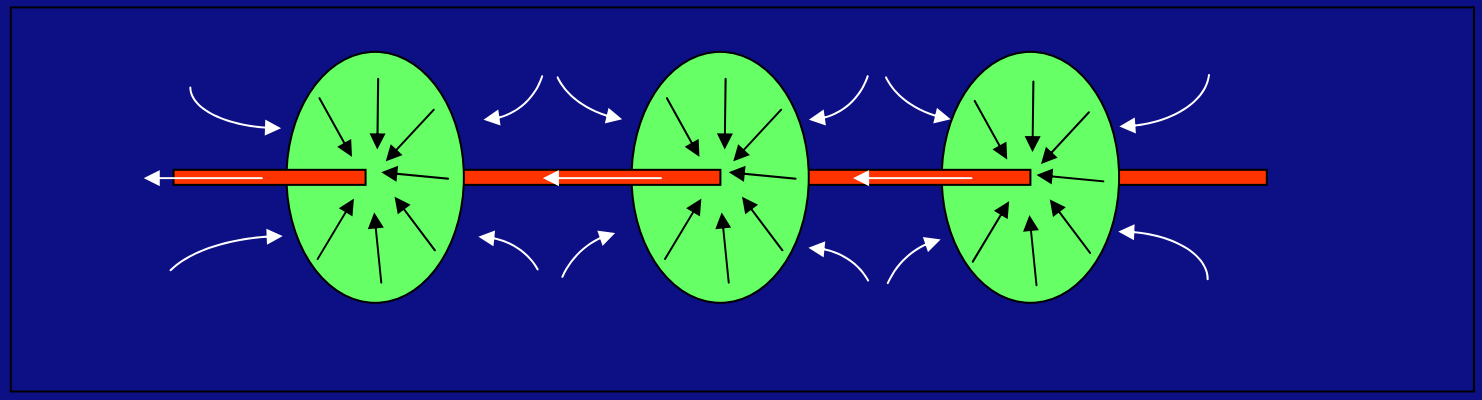




Hydraulic fracturing – Types of applications

Massive hydraulic fracturing

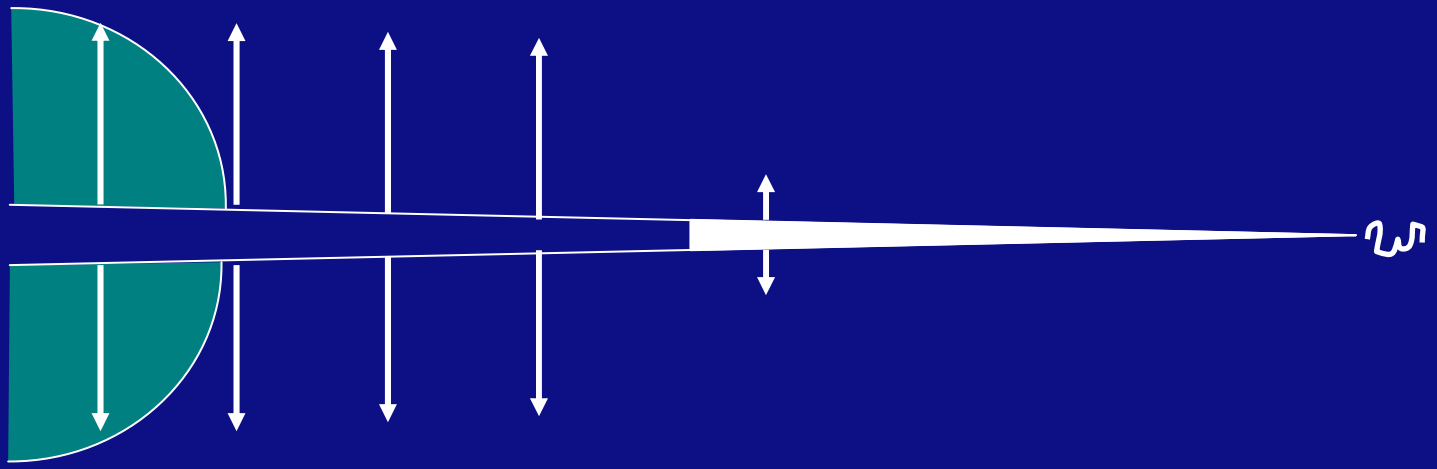
- Large treatments
- Low-permeability reservoir
- Create additional contact area
- Multiple fractures in a horizontal well



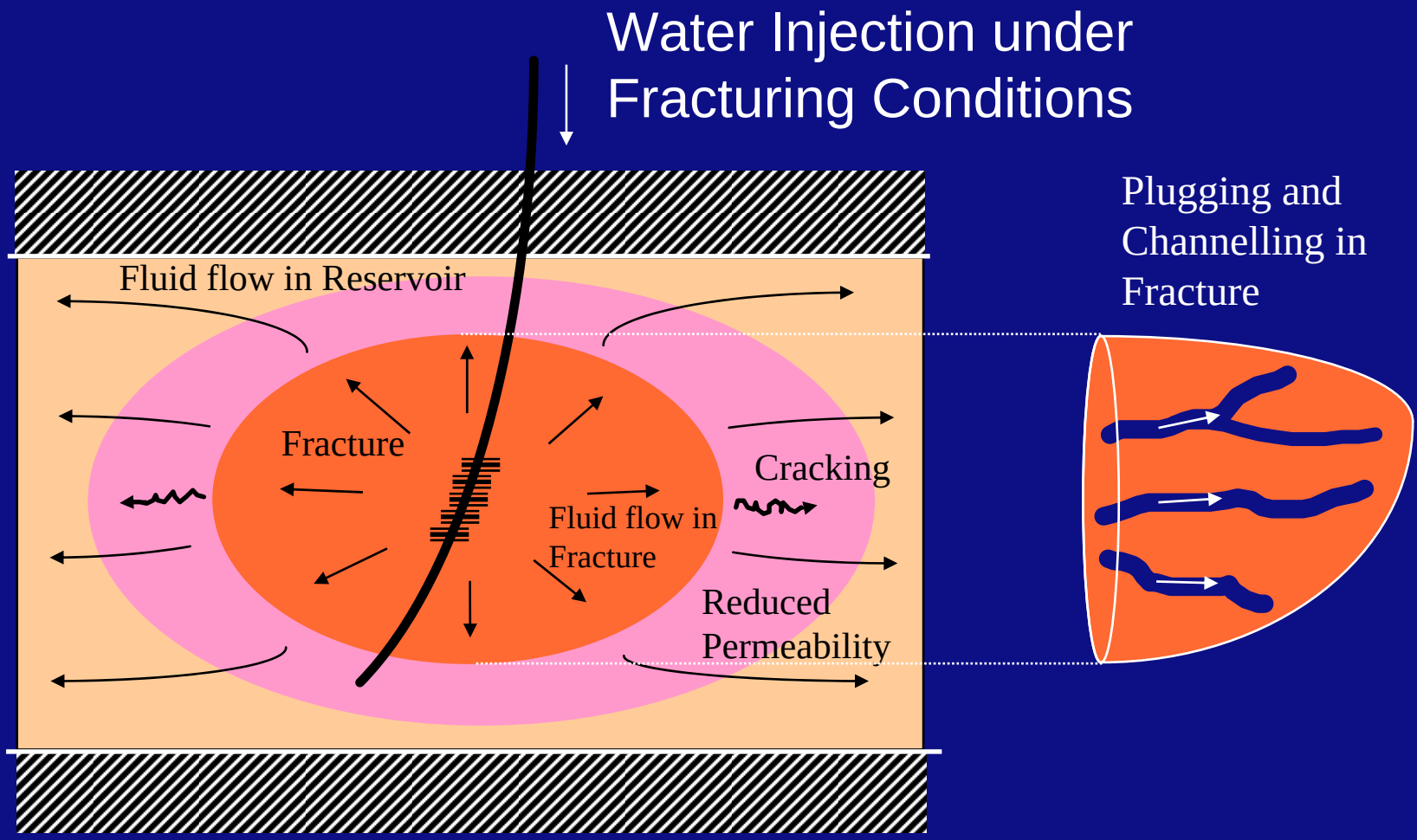
Hydraulic fracturing – Types of applications

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

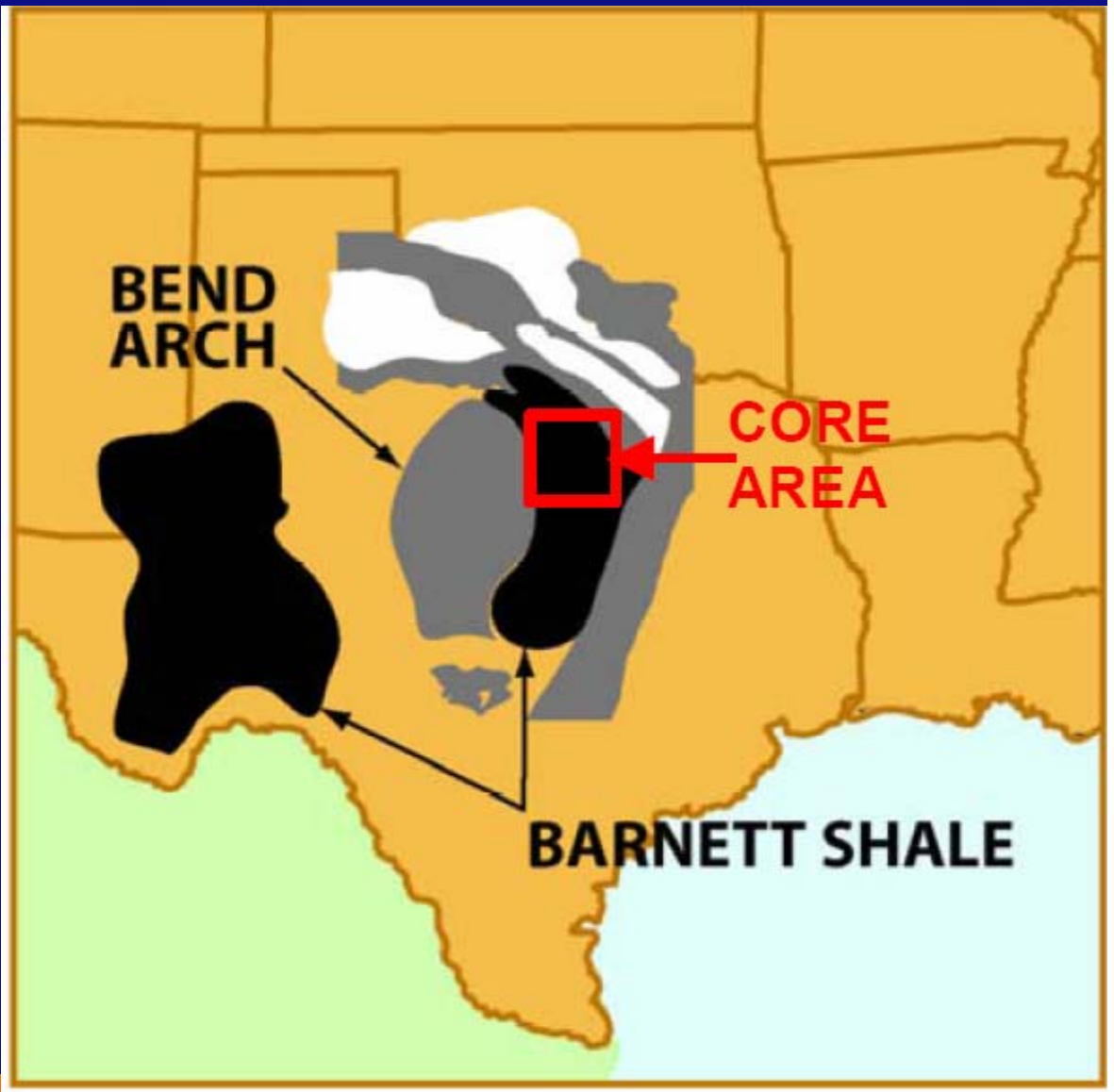


Hydraulic fracturing – Types of applications

Barnett shale

- Very low permeability
- Naturally fractured

- Goal: interconnected fracture network
- Waterfracturing
- Monitoring



Design considerations

- The goal of hydraulic fracturing is economic
- Expected production
  - Analytic expressions (Prats)
  - Semi-analytic calculations
  - Reservoir simulation
- Connection with Geology
  - Flow barriers
  - Permeability
  - Heterogeneity
  - Natural fractures

- 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
- Proppant placement

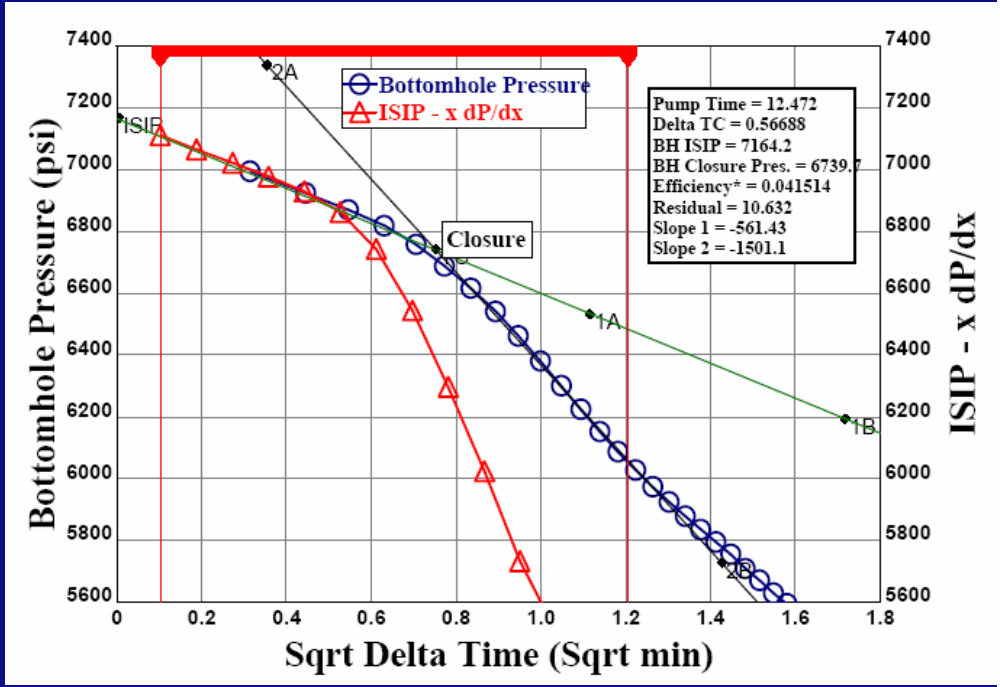
Design considerations

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



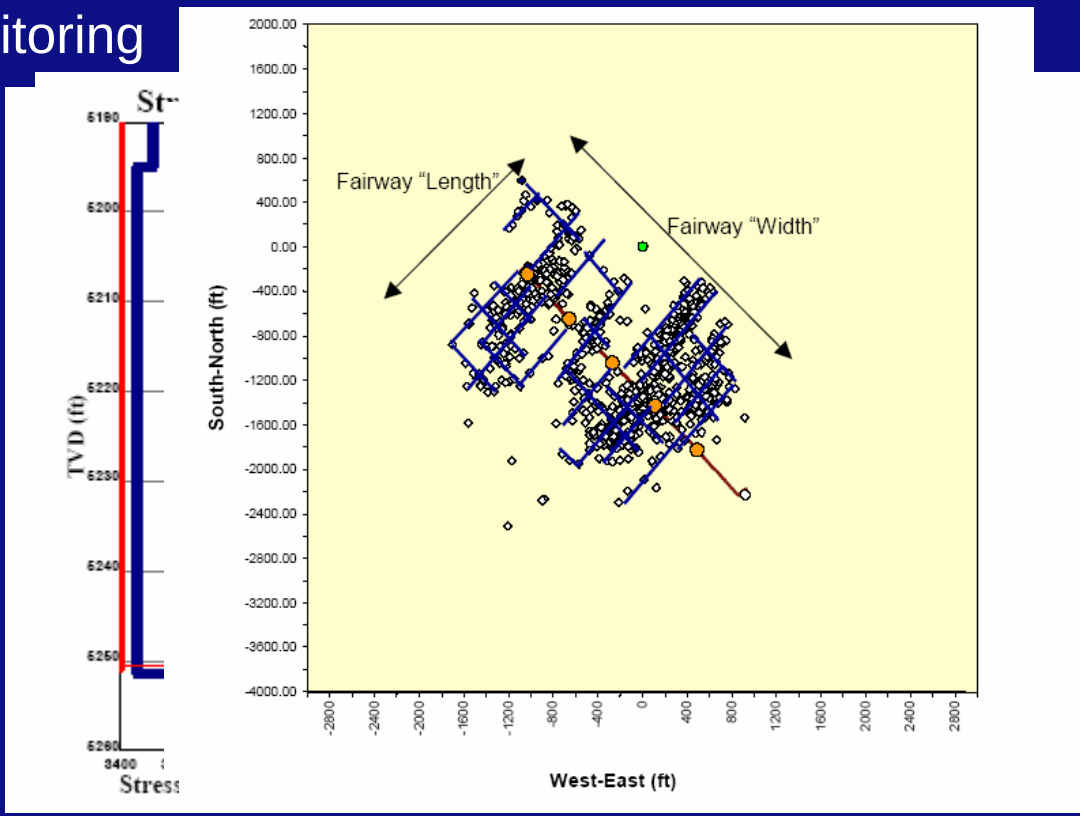
Monitoring

Build up a knowledge base:

- Treatment performance
- Productivity monitoring

Treatment performance monitoring

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



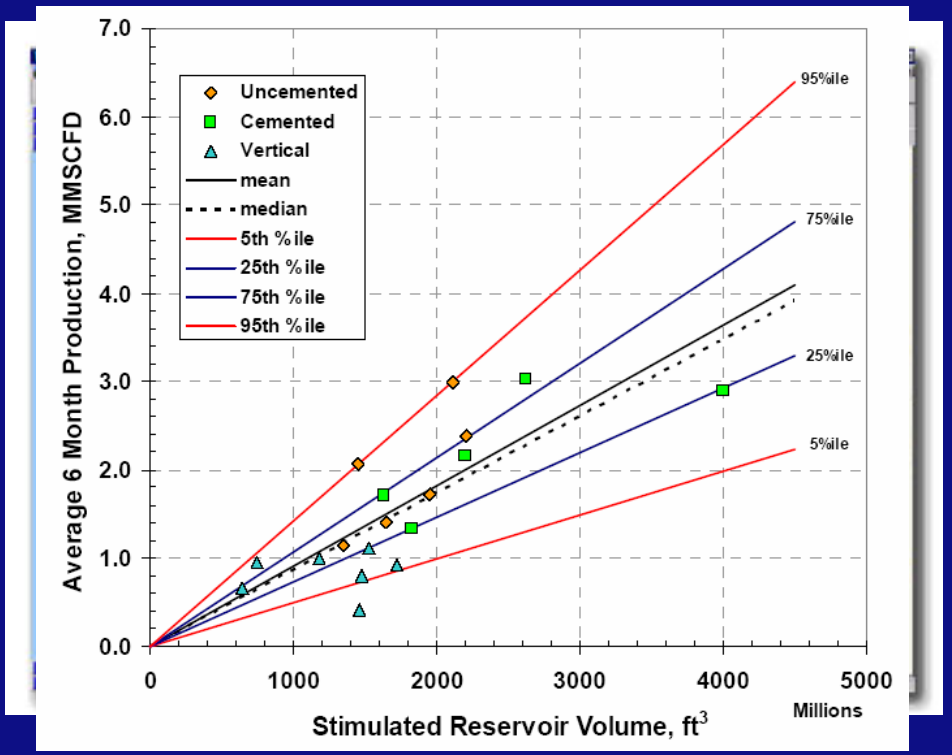
Monitoring

Build up a knowledge base:

- Treatment performance
- Productivity monitoring

Productivity monitoring

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



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
  - Fluid selection
  - Proppant selection
- Monitoring

  Build up a knowledge base
  - Rates
  - Pressures
  - Temperatures
  - Tiltmeter mapping
  - Microseismics
  - Productivity