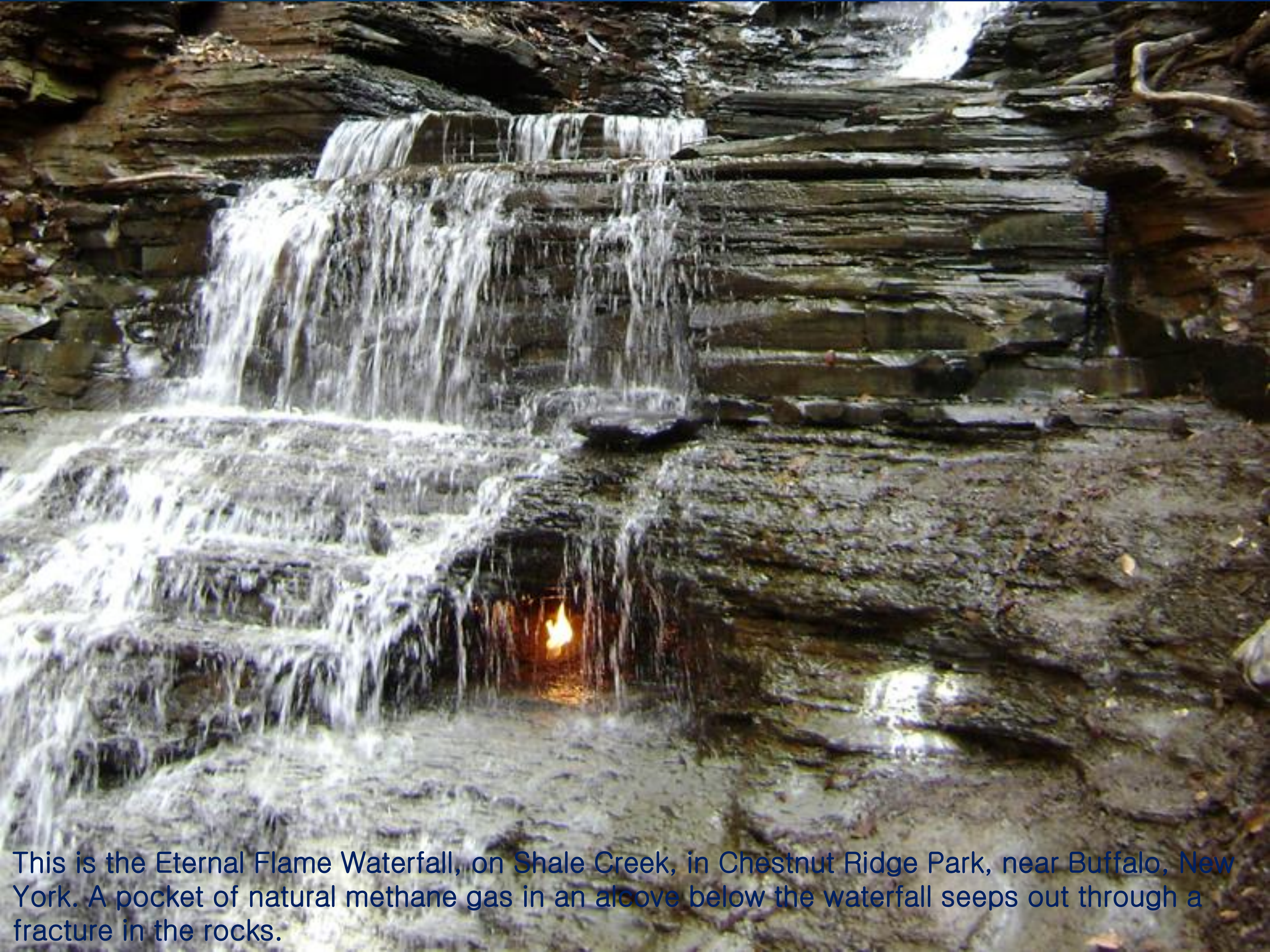
The evaluative methods on shale gas productivity using the DFIT

2014. 9. 18

Dr. Sangyup Jang
T.H. Kim, G.S. Lee
C.H. Shin

KOGAS
KOREA GAS CORPORATION

HANYANG UNIVERSITY 한양 1939



This is the Eternal Flame Waterfall, on Shale Creek, in Chestnut Ridge Park, near Buffalo, New York. A pocket of natural methane gas in an alcove below the waterfall seeps out through a fracture in the rocks.

Contents

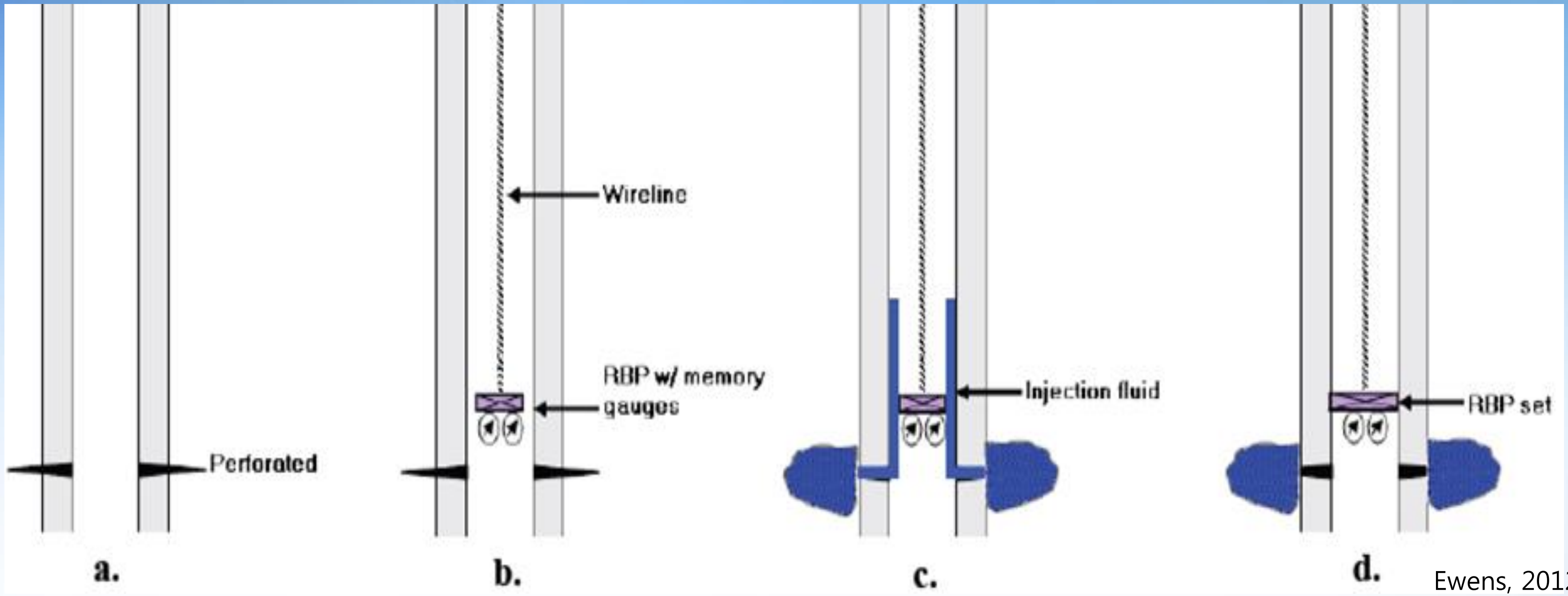
Introduction

Sand stone Formations	Tight Formations	Shale Formation

The limit of conventional well test method for shale formation.

- Low permeability, Long transient time
- Build-up, Draw-down, flow test is impossible
- Needs for rapid test method for shale/tight formation.
  → Mini fracture test(DFIT)
- Effective permeability using DFIT(diagonal fracture injection test)

DFIT or Mini frac test



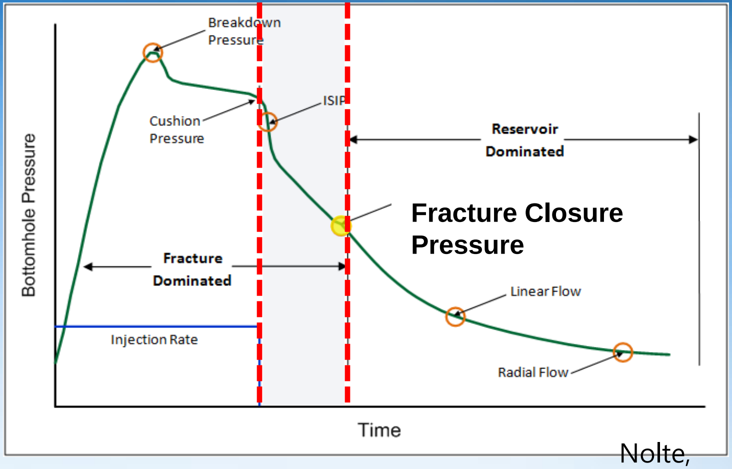
Perforation

Installation of pressure gauge

Injection

Shut-in and record

Diagonal Fracture Injection Test (Mini frac test)



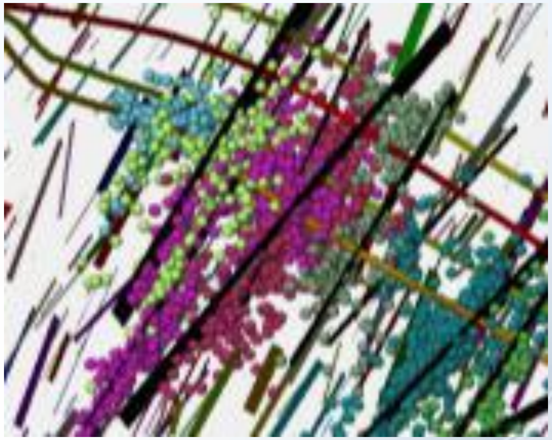
Nolte, 1982

PRE CLOSURE ANALYSIS

- Formation Breakdown Pressure
- Fracture Closure Pressure
- Instantaneous Shut in Pressure(ISIP)
- Fracture Gradient = ISIP / Formation Depth
- Net Fracture Pressure (Δp_{net}) = ISIP - Closure Pressure
- Fluid efficiency = Gc/(2+Gc) : G_c is the G-function time at fracture closure
- Formation Leak Off Characteristics

AFTER CLOSURE ANALYSIS

- Formation permeability (k)
- Reservoir pressure (p_i)
- Net Horizontal Stress(closure – pore pressure)



Research Trend

Nolte (1979)

- G-function and fracture pressure decline analysis

Castillo(1987), Mukherjee(1996), Baree(1998)

- Pressure dependent leak-off vs. G-function, dP/dG, GdP/dG plot

Gu et al(1993), Nolte(1997), Benelkadi and Tiab (2004)

- After closure time function, Impulse fracture test

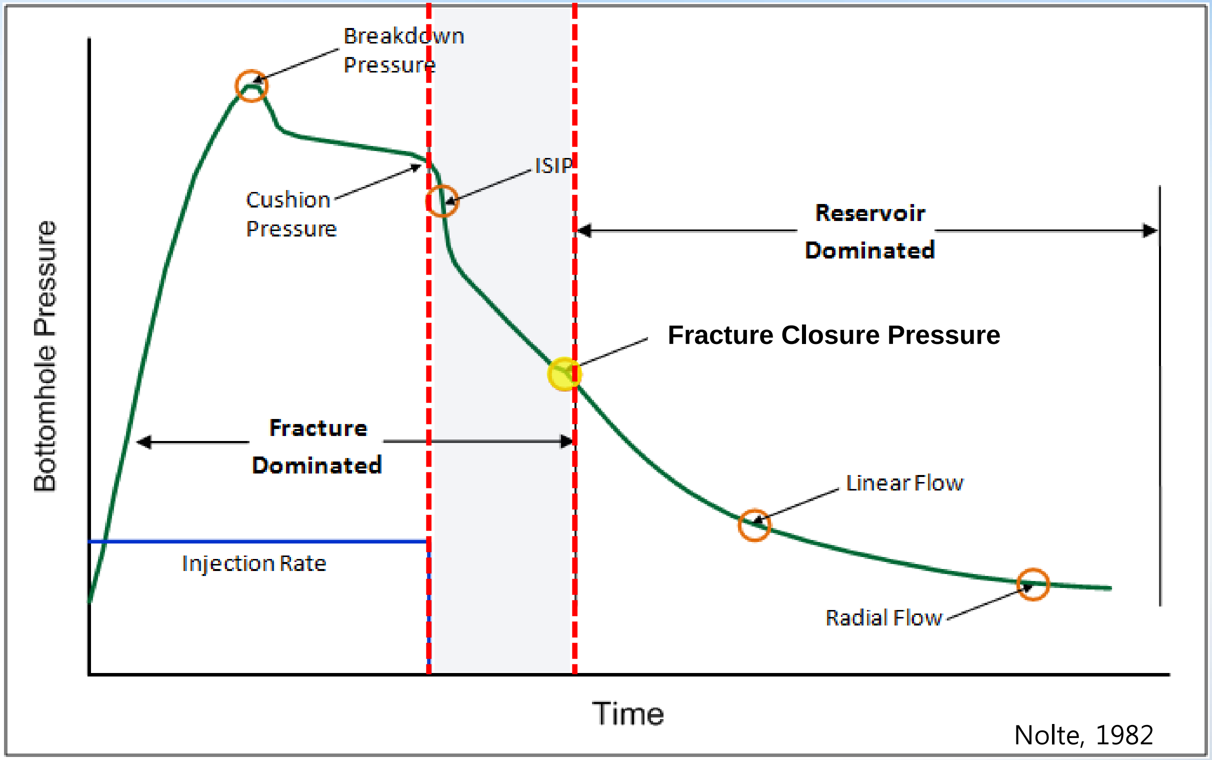
Soliman et al. (2005) / Craig and Blasingame (2006)

- Short term test

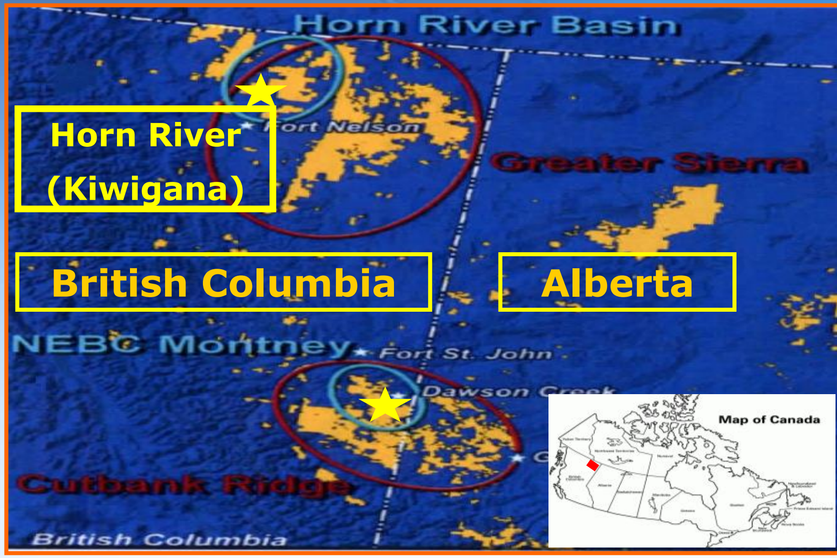
Meyer (2007)

- Mass and momentum equation for 2D-fracture

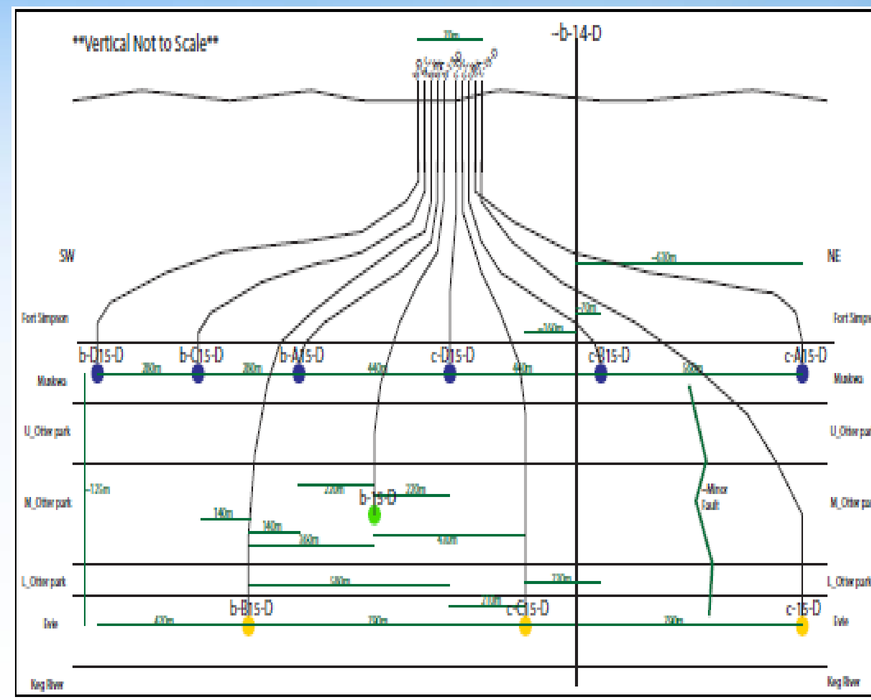
PRE-CLOSURE ANALYSIS



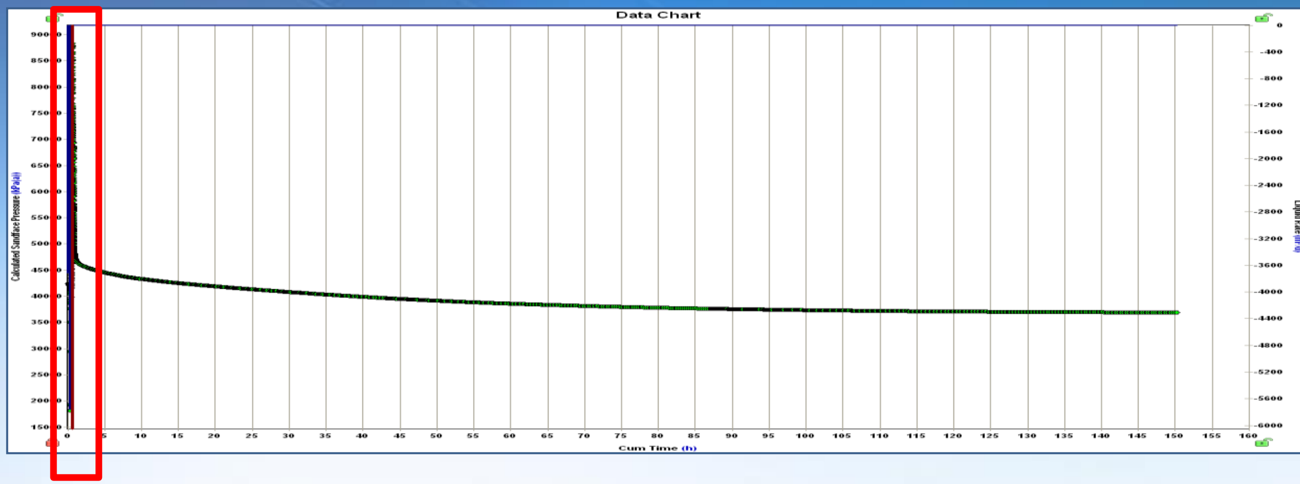
General information

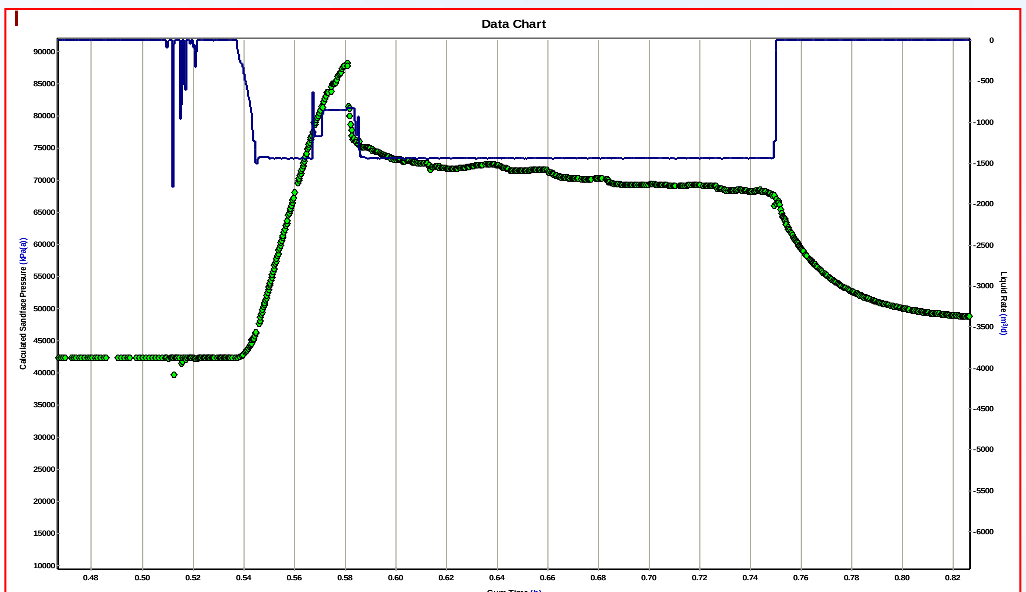


- Located in north eastern British Columbia
- Horn River Group(Muskwa Fm., Otter Park Fm., Evie Fm.)
- Approximately 2,500m below surface
- Average 170m thick, Average TOC : 4.3%
- Composed of siliceous, organic rich shale (high quartz content)



Injection data for Well A





Definition of G-function

- **G function : dimensionless time function relating shut-in time to total pumping time**

$$G(\Delta t_D) = \frac{4}{\pi}(g(\Delta t_D) - g_o)$$

$$g(\Delta t_D) = \frac{4}{3}\left[(1+\Delta t_D)^{1.5} - \Delta t_D{}^{1.5}\right]$$ (For low leak−off)

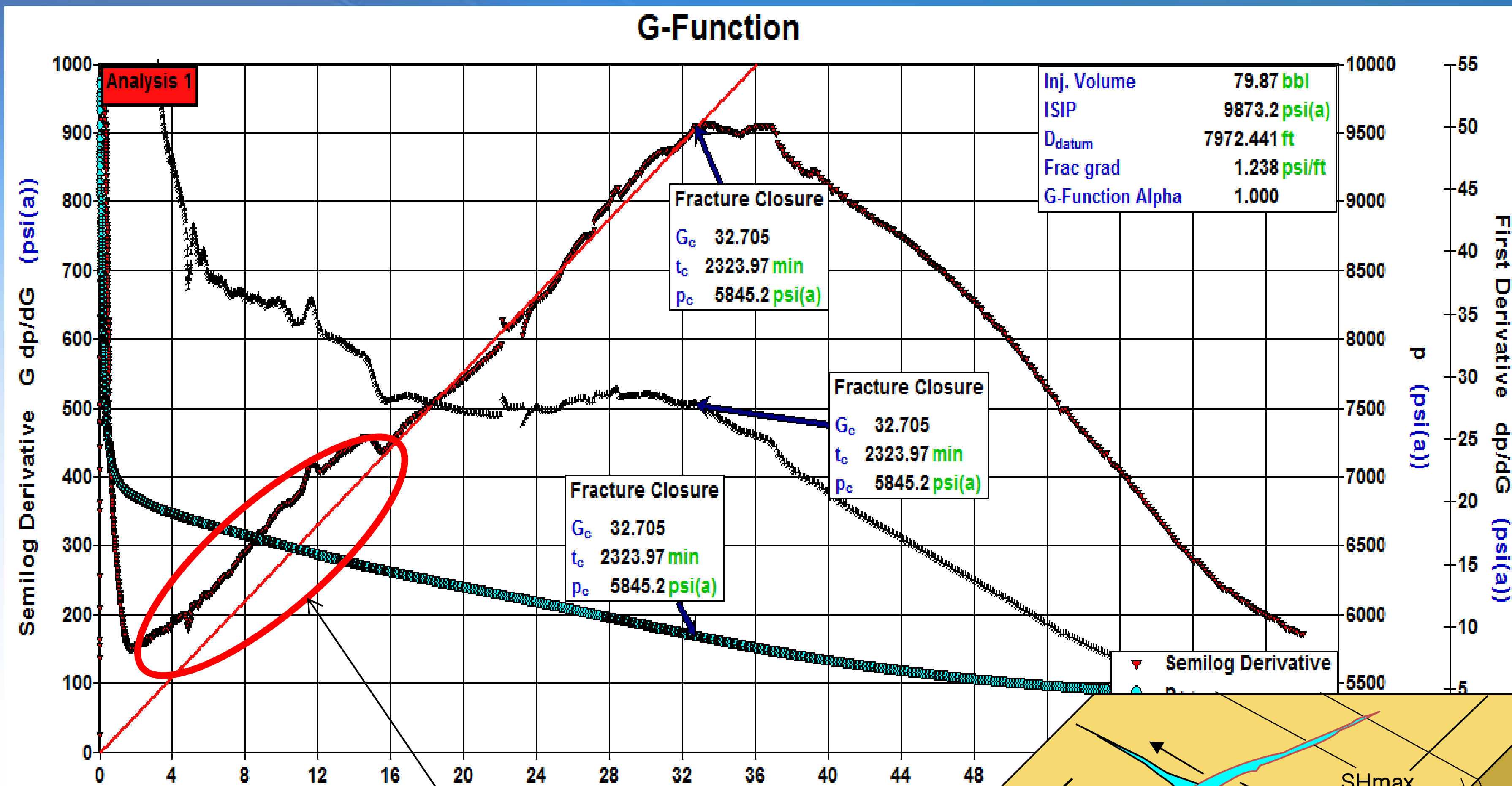
$$g(\Delta t_D) = (1+\Delta t_D)\sin^{-1}((1+\Delta t_D)^{-0.5}) + \Delta t_D{}^{0.5}$$ (For high leak−off)

$$\Delta t_D = \frac{(t - t_p)}{t_p}$$

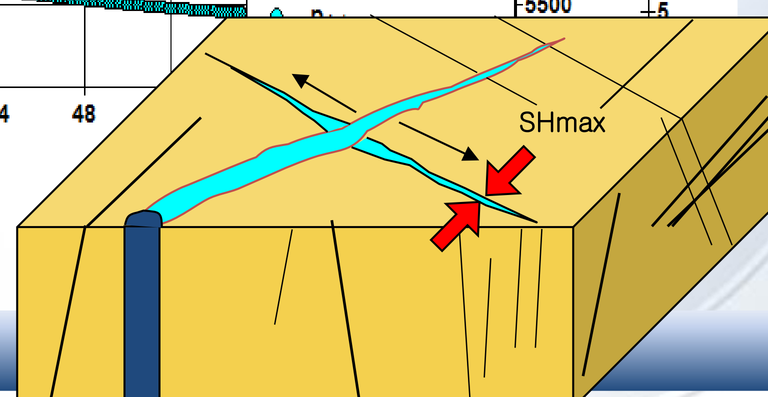
$$g_o = \frac{\pi}{2}$$ (For high leak−off)

$$g_o = \frac{4}{3}$$ (For low leak−off)

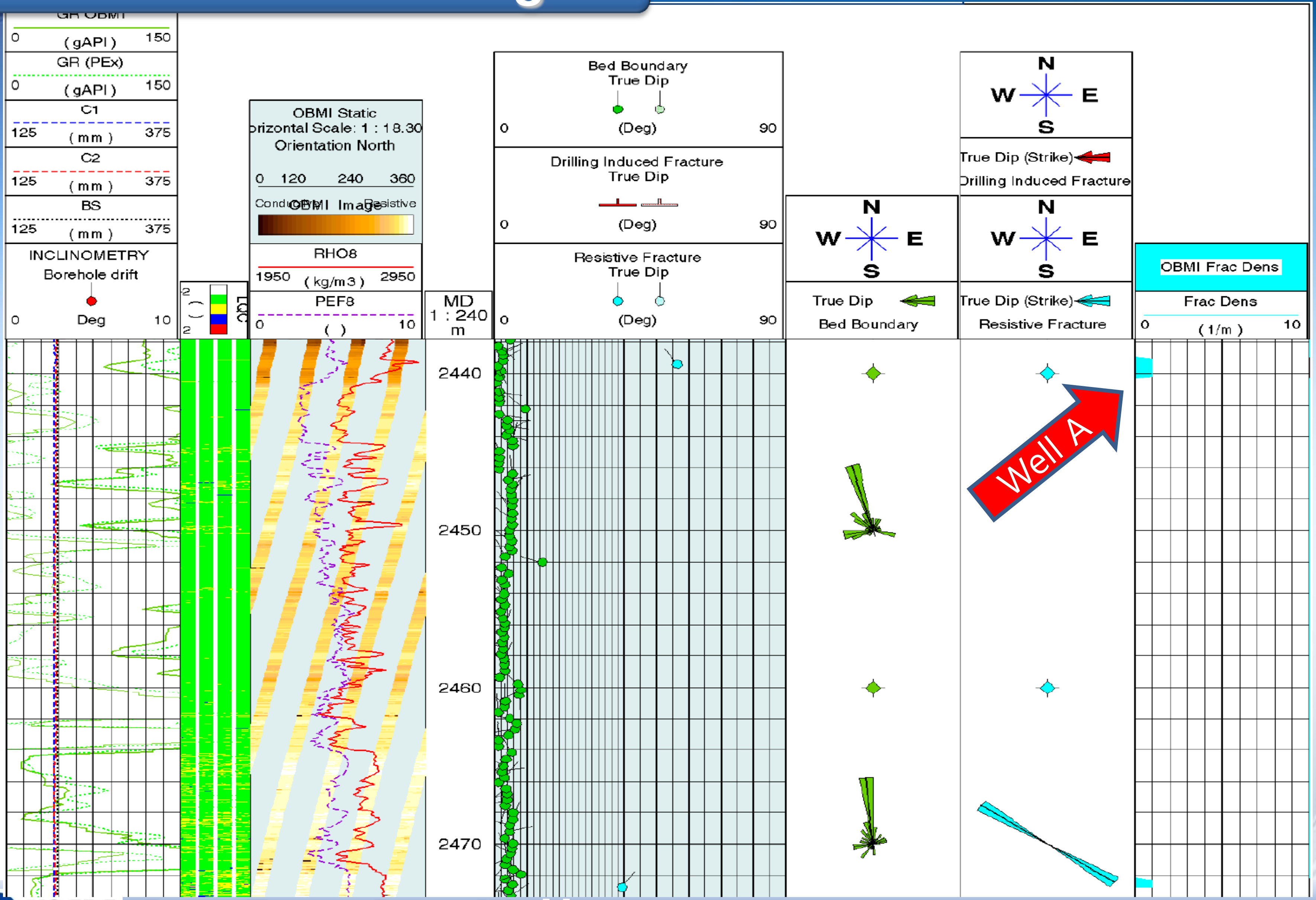
G-function analysis of Well-A



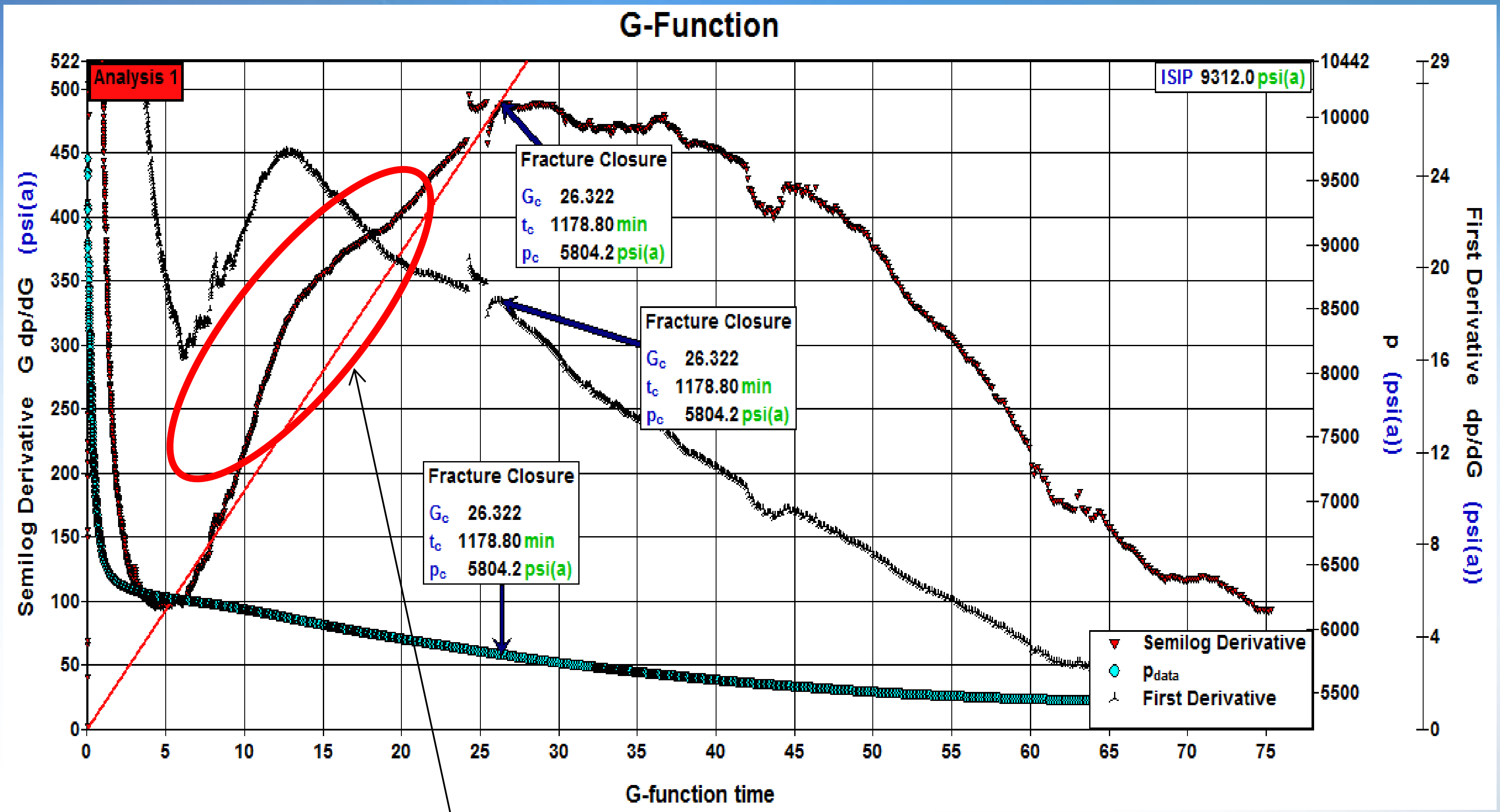
Pressure dependent leak-off
-> Existence of fracture!



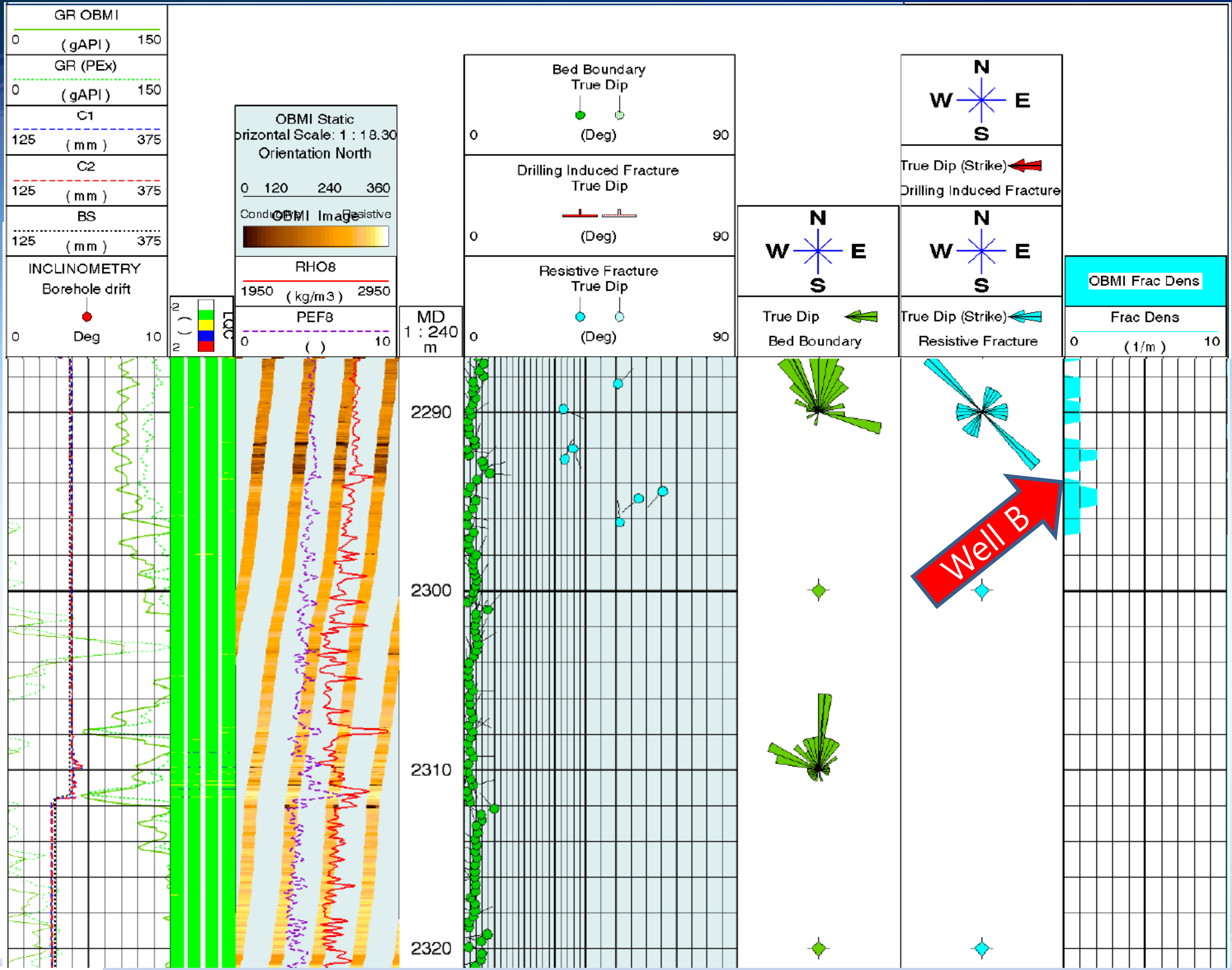
Oil base micro-imager



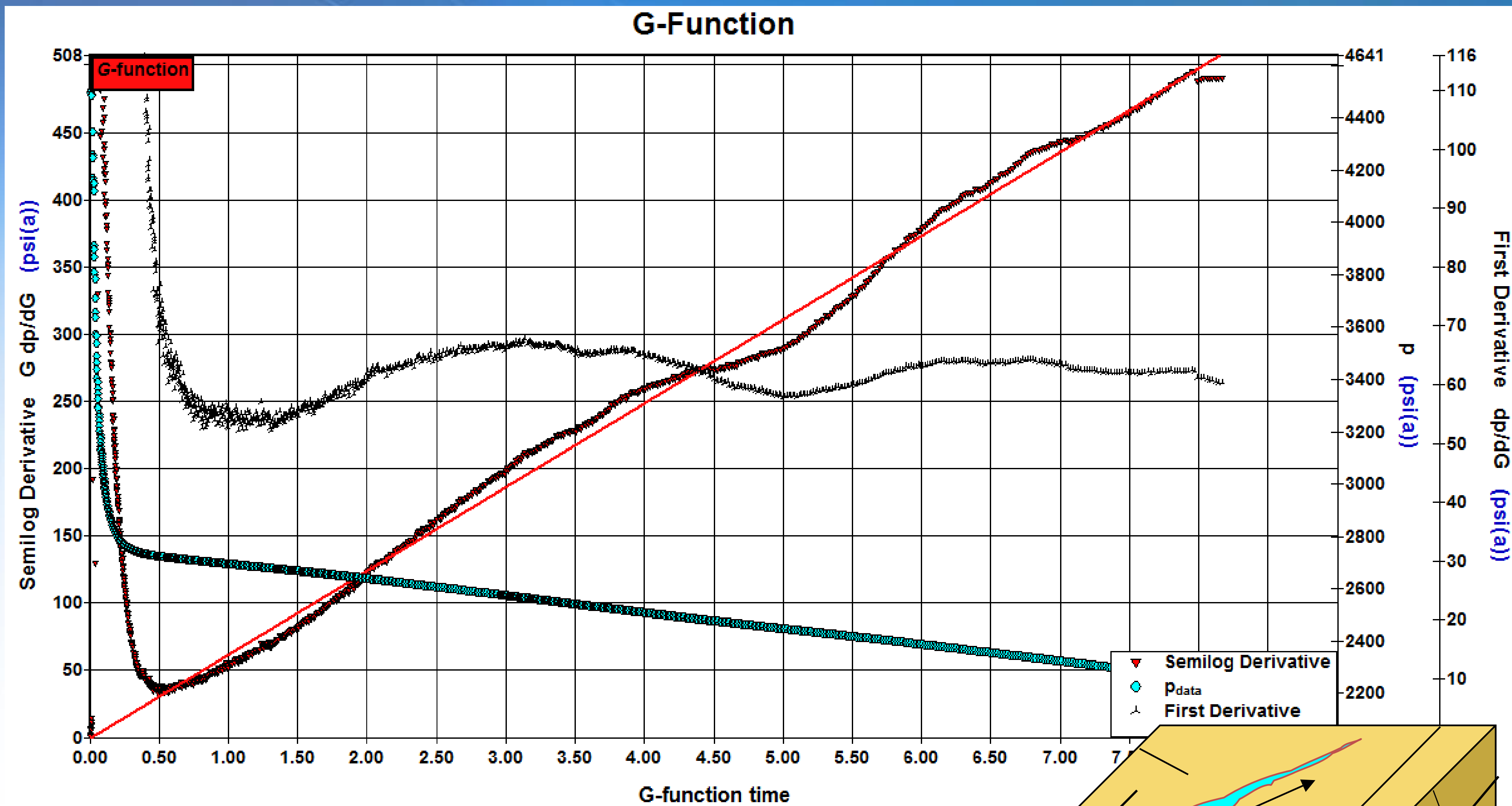
G-function analysis of Well-B



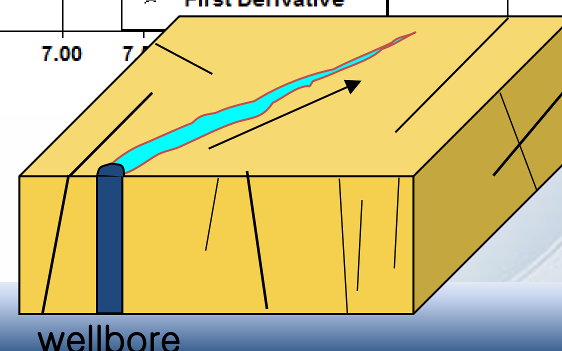
Pressure dependent leak-off


GR OBMI
0 (gAPI) 150
GR (PEx)
0 (gAPI) 150
C1
125 (mm) 375
C2
125 (mm) 375
BS
125 (mm) 375
INCLINOMETRY
Borehole drift
0 Deg 10
LQC
OBMI Static
Horizontal Scale: 1 : 18.30
Orientation North
0 120 240 360
Conductive OBMI Image Resistive
RHO8
1950 (kg/m3) 2950
PEF8
0 ( ) 10
MD
1 : 240
m
2290
2300
2310
2320
Bed Boundary
True Dip
0 (Deg) 90
Drilling Induced Fracture
True Dip
0 (Deg) 90
Resistive Fracture
True Dip
0 (Deg) 90
N
W E
S
True Dip
Bed Boundary
True Dip (Strike)
Drilling Induced Fracture
True Dip (Strike)
Resistive Fracture
OBMI Frac Dens
Frac Dens
0 (1/m) 10
Well B

G-function analysis of Well-C



Normal leak–off

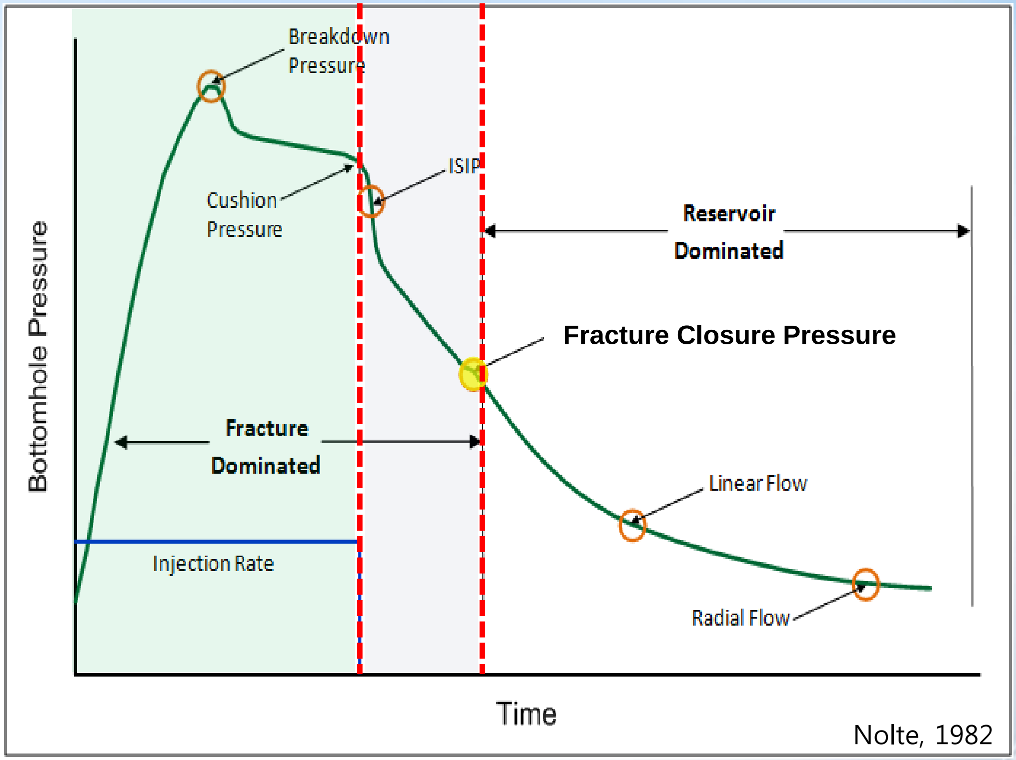


Summary

- It could be possible to find out the leak-off behavior and fracture related reservoir properties for shale formation by pre-closure analysis

- G-function analysis data and OBMI data were compared to validate the existence of natural fracture near well bore and reliable correlation is found with this methods.

AFTER CLOSURE ANALYSIS



Conventional gas well test

- Combing the continuity equation, the equation of motion, and the EOS

Diffusivity eqn.

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial p}{\partial r}\right)=\frac{\phi\mu c_t}{k}\frac{\partial p}{\partial t}$$

Real gas law

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{p}{\mu z}\frac{\partial p}{\partial r}\right)=\frac{\phi\mu c_t}{k}\frac{p}{\mu z}\frac{\partial p}{\partial t}$$

Gas compressibility, pseudo state (ϕ, μ, z constant)

$$m(P_{wf})=m(P_i)-\frac{711QT}{kh}\left[\ln t_a+\ln\left(\frac{k}{\phi\mu C_t r_w^{\ 2}}\right)-7.43173+s'\right]$$

Nolte

- Linear flow

$$p_w(t) - p_i = C_L \sqrt{\frac{\pi\mu}{k\phi C_t}} F_L$$

- Radial flow

$$p_w(t) - p_i = 251{,}000 \frac{Q_t \mu}{kht_c} F_{R1}$$

$$m_{R1} = 251{,}000 \frac{Q_t \mu}{kht_c}$$

$$kh = 251{,}000 \frac{Q_t \mu}{m_{R1} t_c}$$

$$p_i = p_w(F_{R1} \to 0)$$

Soliman-Craig

- Linear flow

$$p_w(t) - p_i = 31.05 \frac{V_{inj}\mu}{\phi C_t k h x_f^2} \left[\frac{1}{t_p + \Delta t} \right]^{0.5}$$

- Radial flow

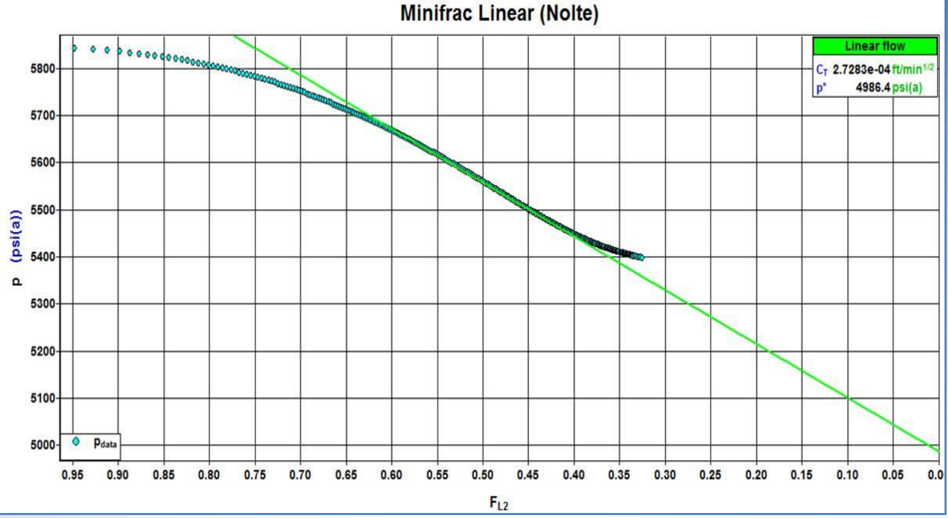
$$p_w(t) - p_i = (1694.4) \frac{V_{inj}\mu}{kh} \left[\frac{1}{t_p + \Delta t} \right]$$

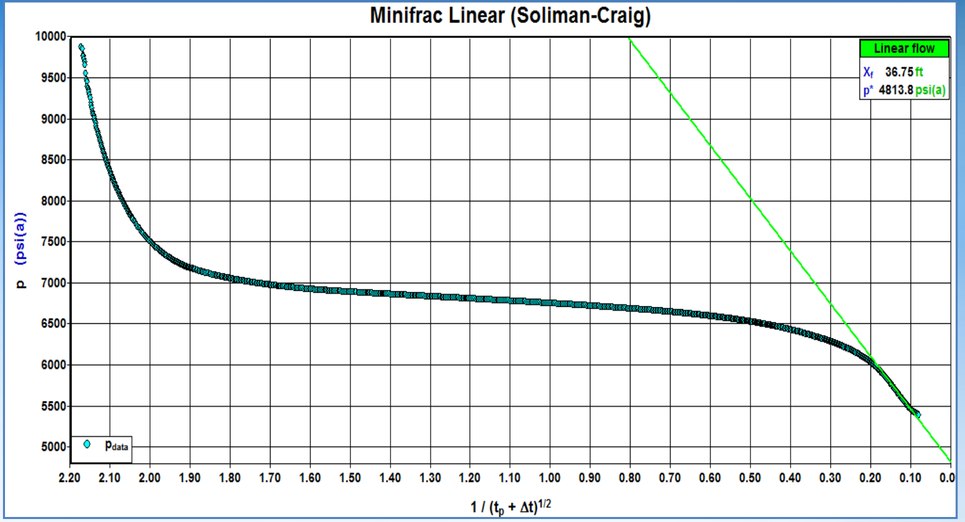
$$m_{R2} = (1694.4) \frac{V_{inj}\mu}{kh}$$

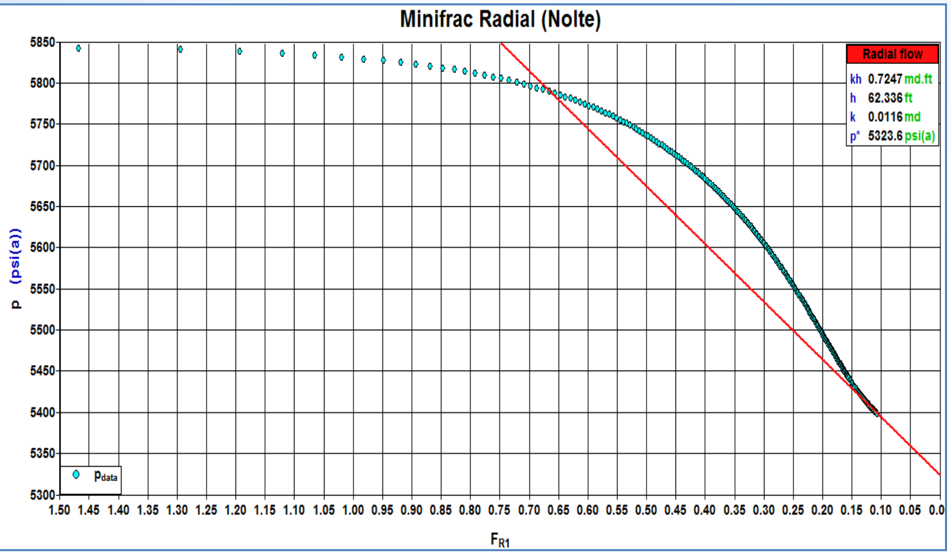
$$kh = (1694.4) \frac{V_{inj}\mu}{m_{R2}}$$

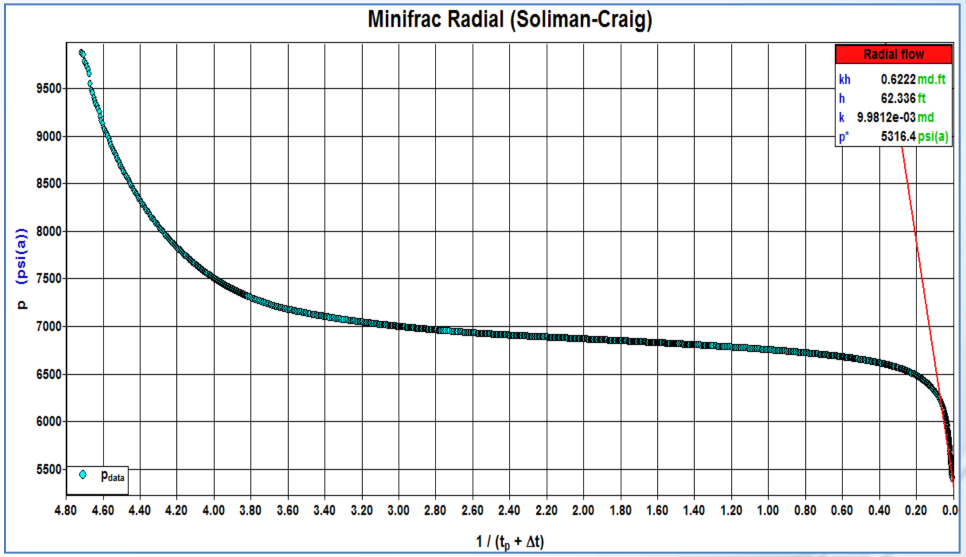
$$p_i = p_w\left(\frac{1}{t_p + \Delta t} \to 0\right)$$

Linear and Radial flow plot for well A



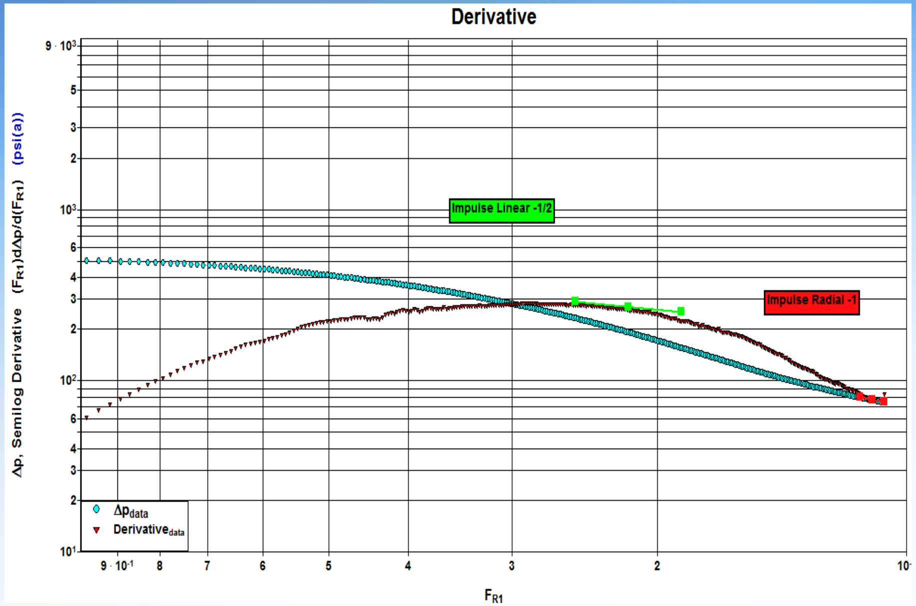






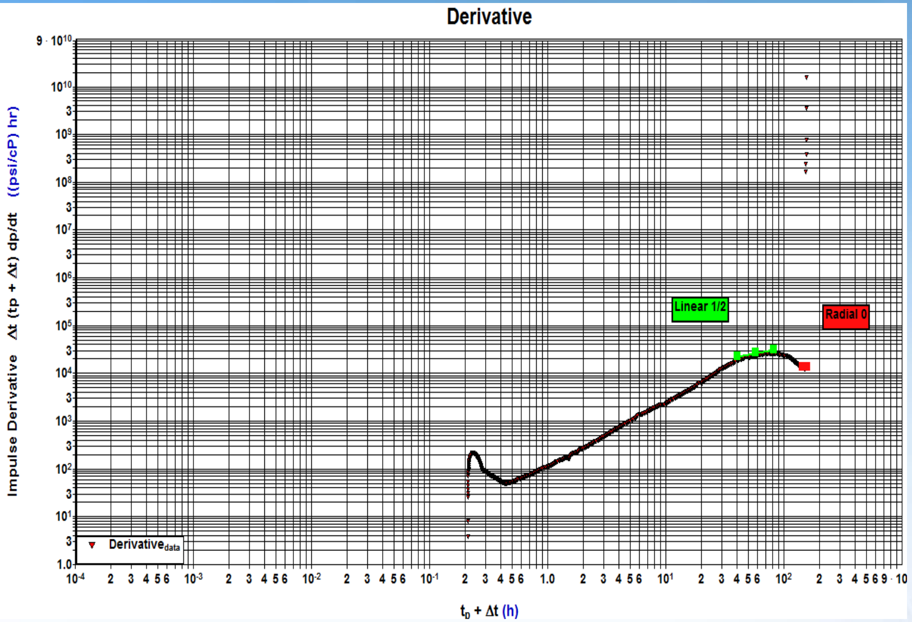
Reservoir properties from 2 methods(well A)

Nolte method



- Permeability : 11.6 μd
- Initial pressure for radial flow : 5,324 psi
- Leak-off coefficient : 6.0519×10^{-4} ft/min$^{1/2}$

Soliman-Craig method



- Permeability : 9.98 μd
- Initial pressure for radial flow : 5,317 psi
- Fracture half-length : 16.6 ft

Permeability estimation

$$k = \frac{0.086\mu_f \sqrt{0.01 p_z}}{\phi c_t \left(\frac{G_c E r_p}{0.038} \right)^{1.96}}$$

μ_f: Viscosity of injected fluid (=1 cp, assumption)
p_z: Net fracture extension pressure above closure pressure(9873 psi)
G_c: G-function closure time (=32.705h)
E: Young's modulus(=3.35Mpsi)
r_p: Storage ratio(=1)
ø : porosity(=0.04)
C_t : Total compressibility(=5.09X10^{-5} /psi)
Calculate K = 4.4351uD

Case	G-function(Baree)	Nolte	Soliman
Well A(μD)	4.4351	11.6	9.98

Summary and further study

DFIT results in the Kiwigana shale formation were presented.

- The results have good consistency between other analytical methods and will be used for hydraulic fracturing job effectively.
- The need for the prolonged shut-in time is realized to analyze the radial flow regime in DFIT.
- Permeability estimation equation is useful for rough calculation.
- Many production characteristics of shale gas reservoir need to be monitored to correlate reservoir properties.
- Influence on adsorbed gas and stress dependent rock properties should be considered to evaluate more precisely.

Thank you for your attention!