# Pre-frac Reservoir Characterization from Perforation Inflow Diagnostic (PID) Testing

## “Measure Twice – Frac Once”

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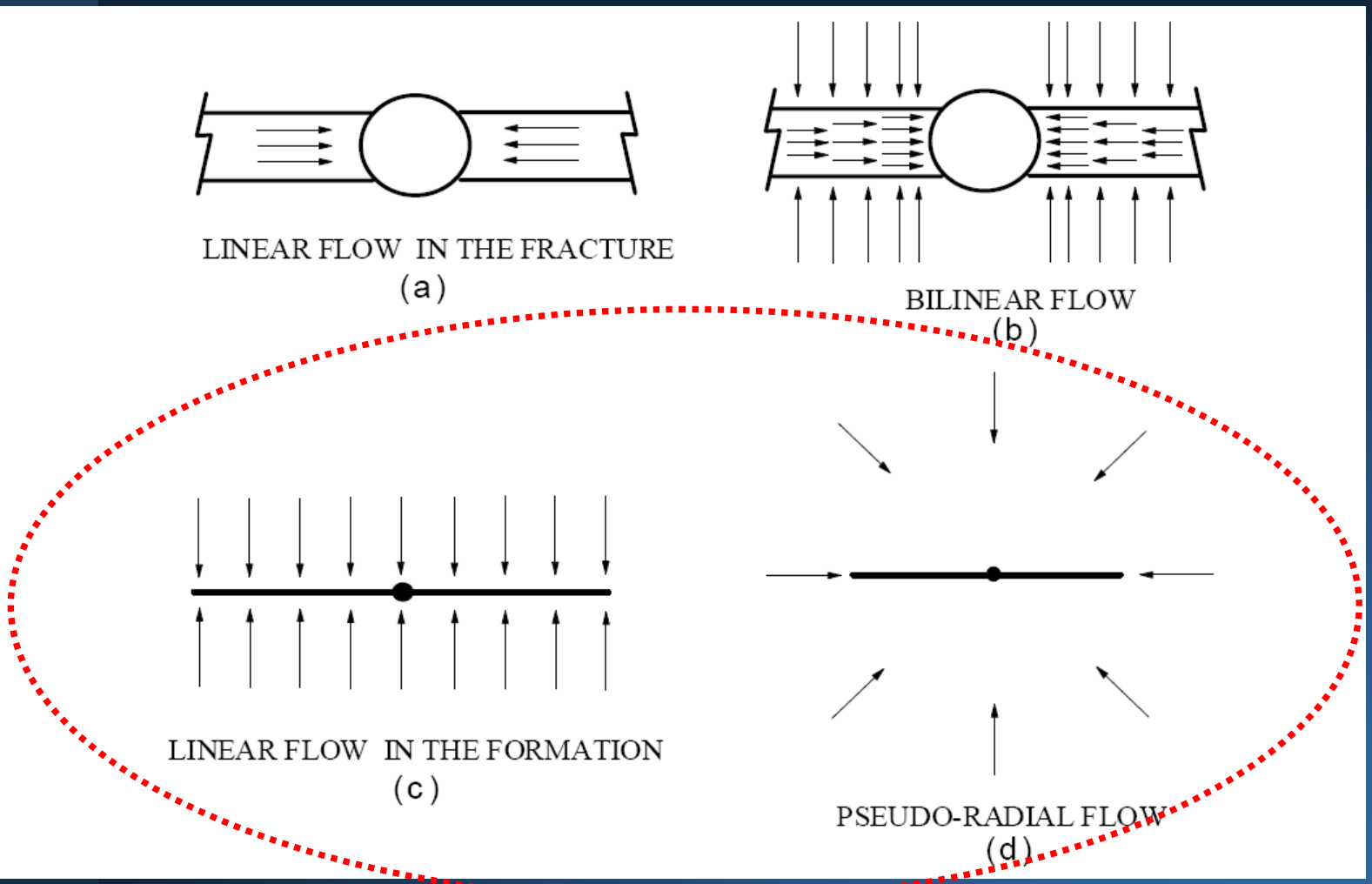
# EXECUTIVE SUMMARY

- **Initial post-frac welltest analysis OVER-ESTIMATE most tight gas well production performances.**
- **Take the time (money) to obtain initial reservoir pressure (pi) prior to your fracture treatment.**
- **Closed chamber testing is an *overlooked* pre-frac testing technique.**

# Problem

- We have completed our hydraulic fracture treatment program with *most* wells on production.
- Post frac pressure buildup analysis are finished.
- Initial production results are less than what we predicted.
- Please review the frac treatment reports and the well test analysis to determine re-frac candidates !

# General PTA Theory



# Time to End of Linear Flow

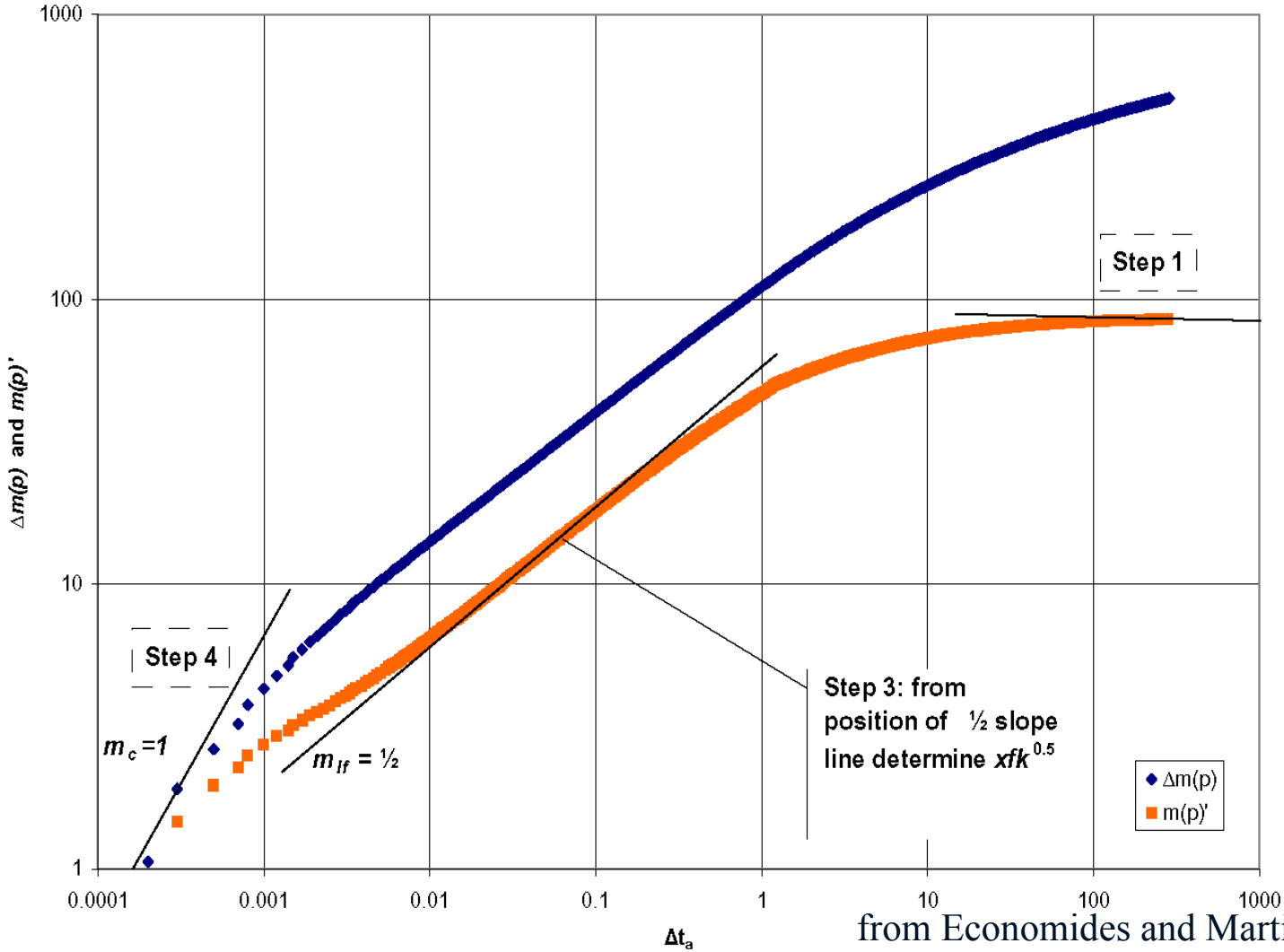
- Where the end of linear flow from a fracture is defined as $t_{Dxf}$ =0.016

$$t_{Dxf} = \frac{0.000264kt}{\phi(\mu c_t)_i x_f^2} \qquad t = hours$$

$k$ = 0.1 mD $\quad xf$ = 100m $\quad t$ = 36 h (1.5 d)

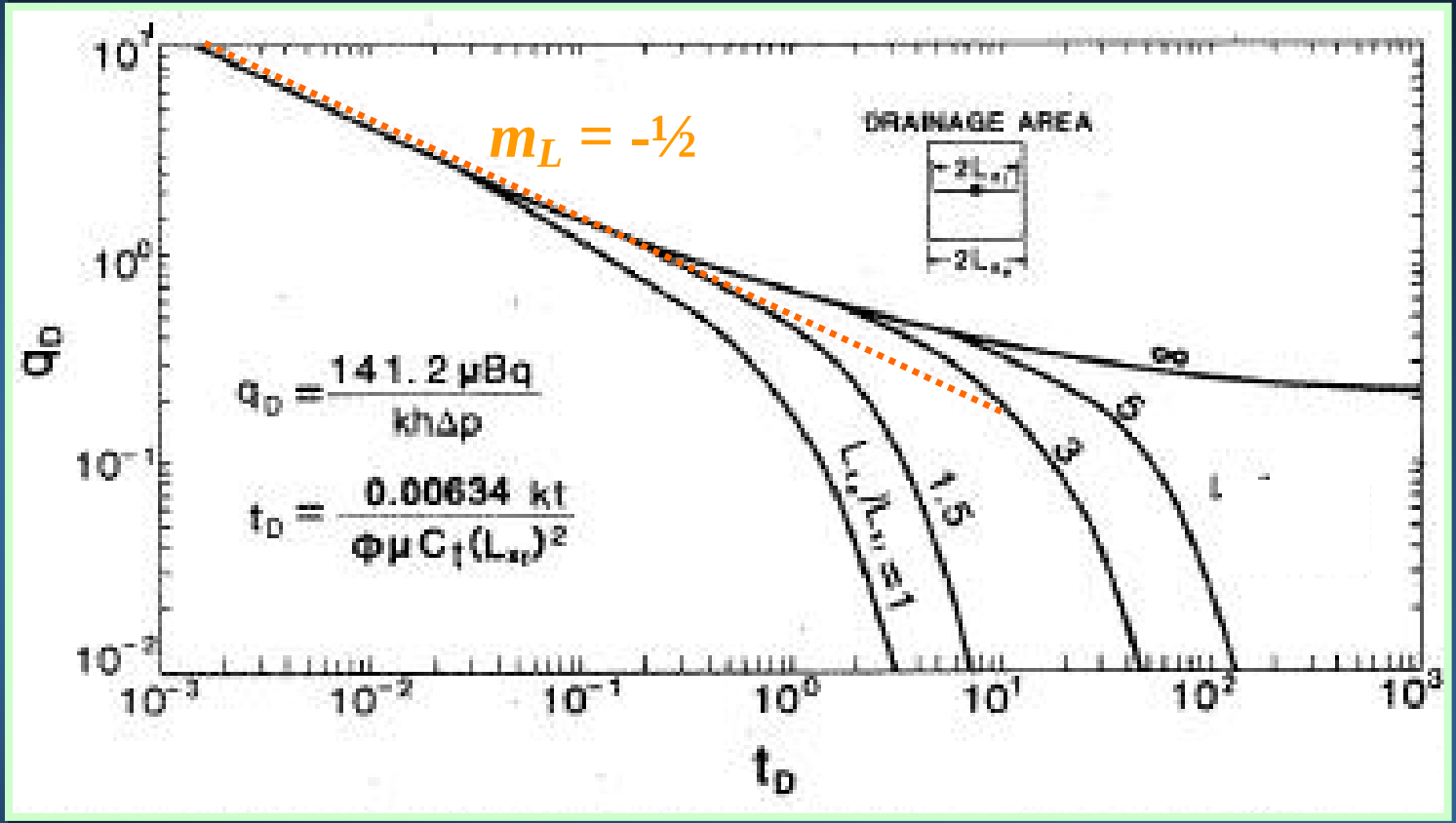
$k$ = 0.01 mD $\quad xf$ = 100m $\quad t$ = 360 h (15 d)

# Log-log Plot (Linear Flow)



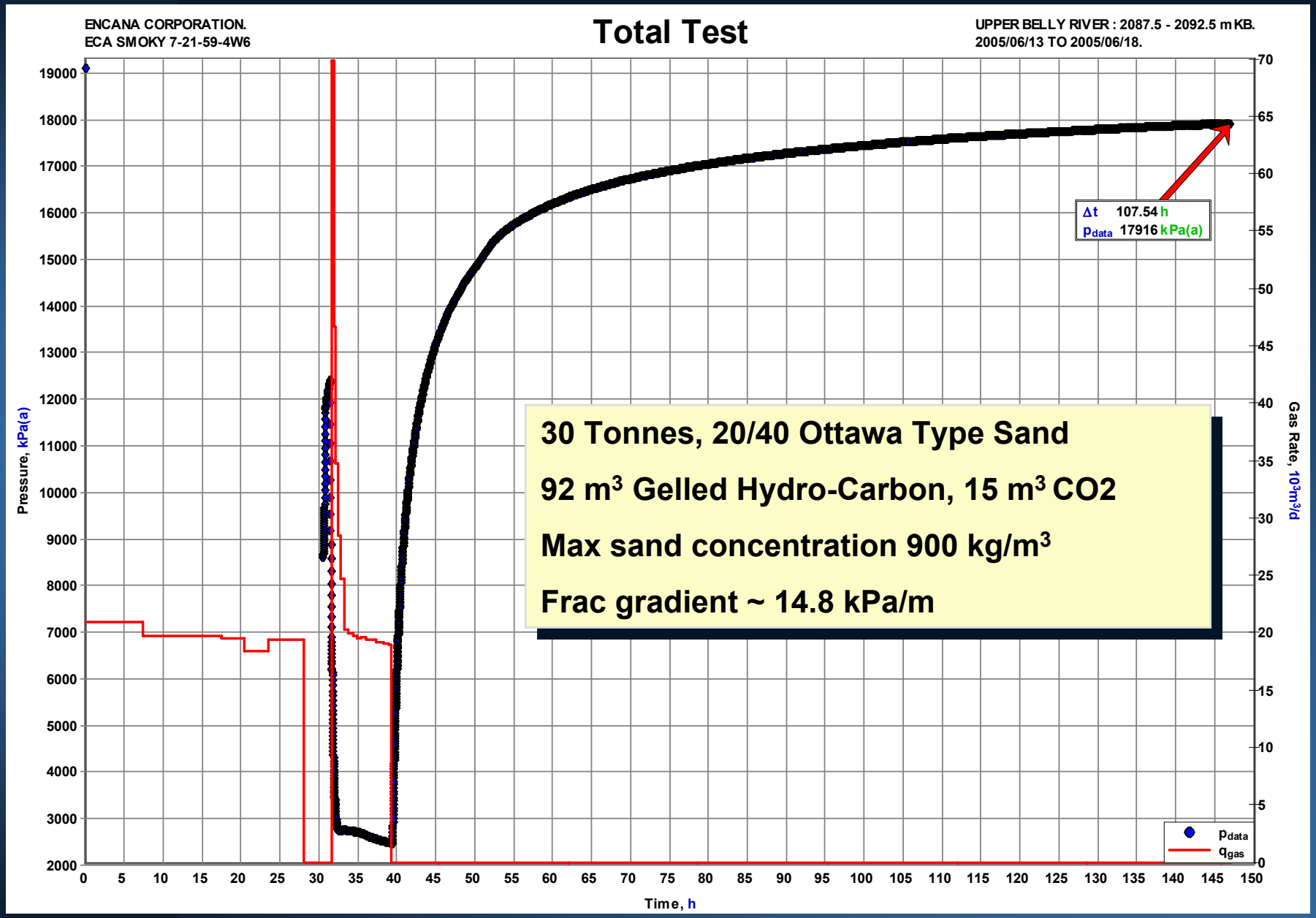

from Economides and Martin (2007)

# Production Analysis




*The Fetkovich plot is to production analysis what the log-log derivative is to the well test analysis.*

# Post-frac Flow and Buildup Test



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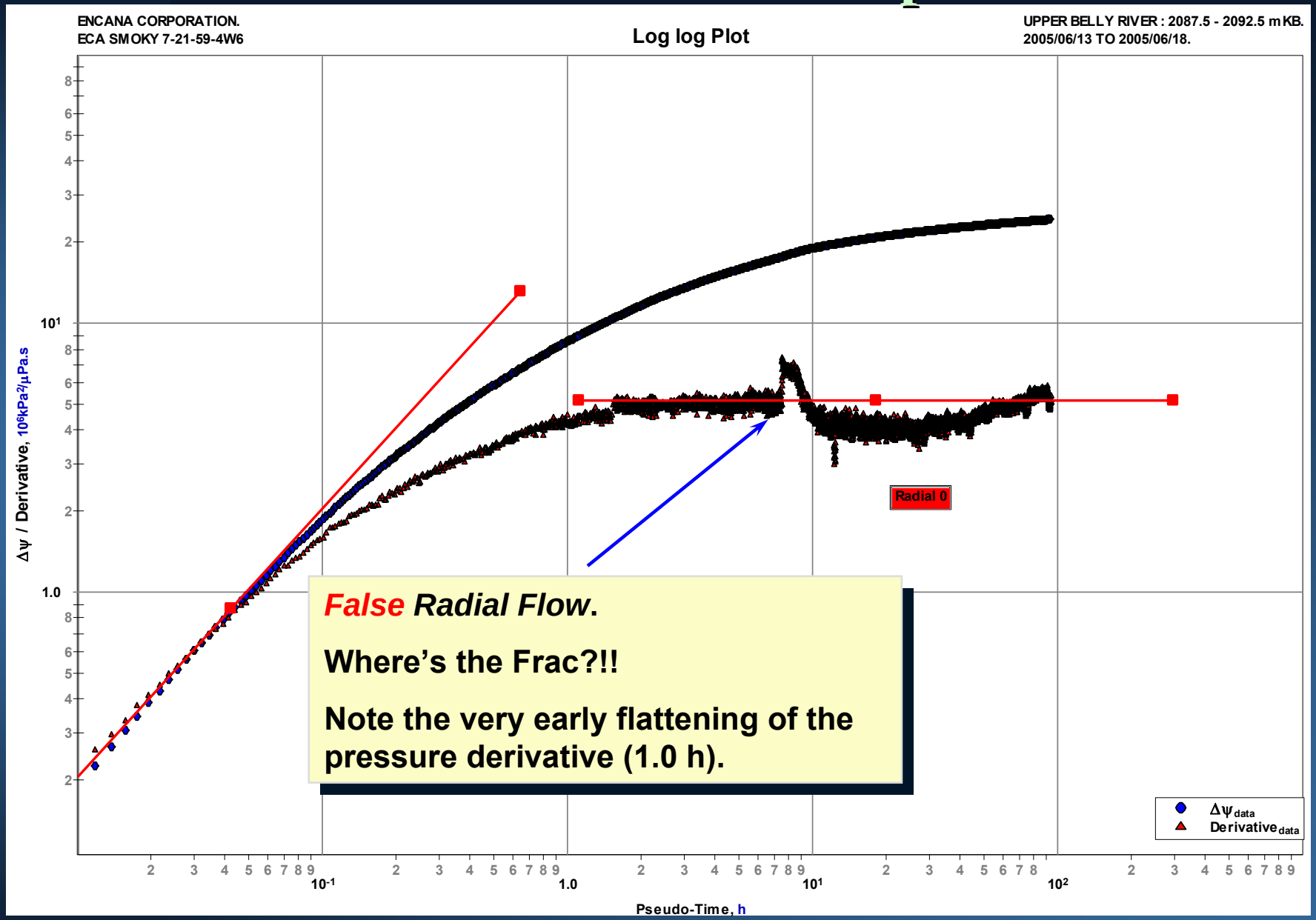

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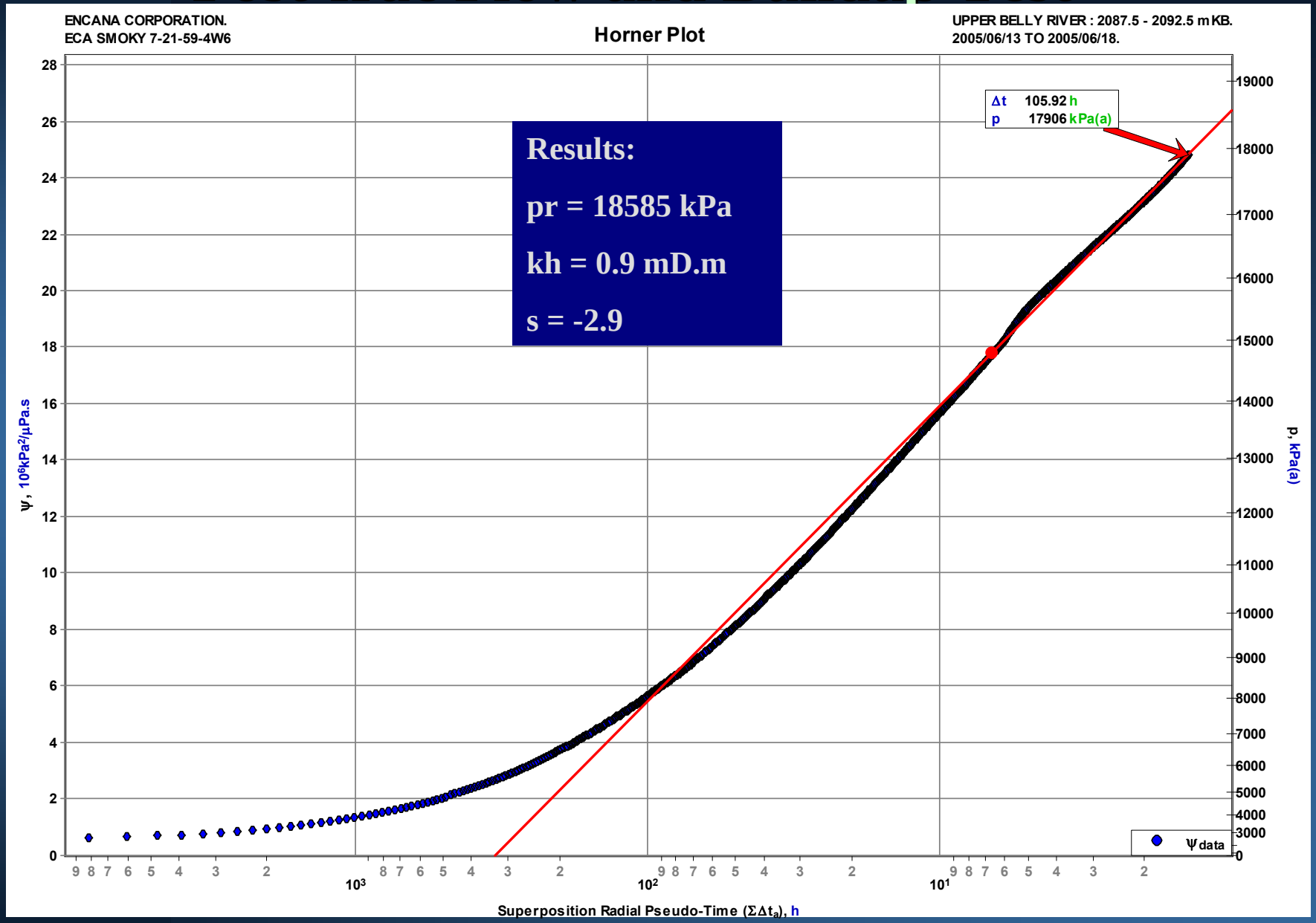
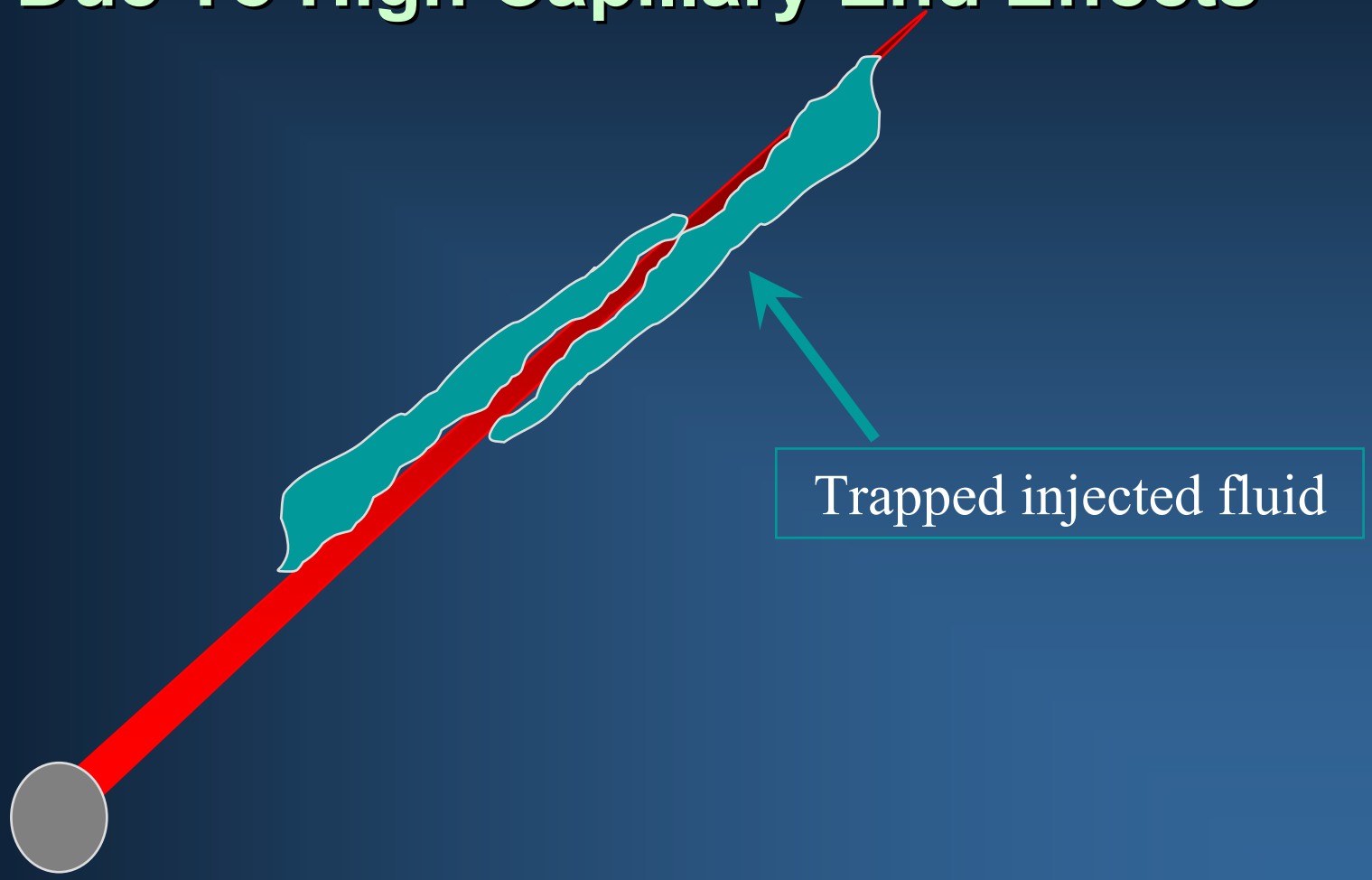
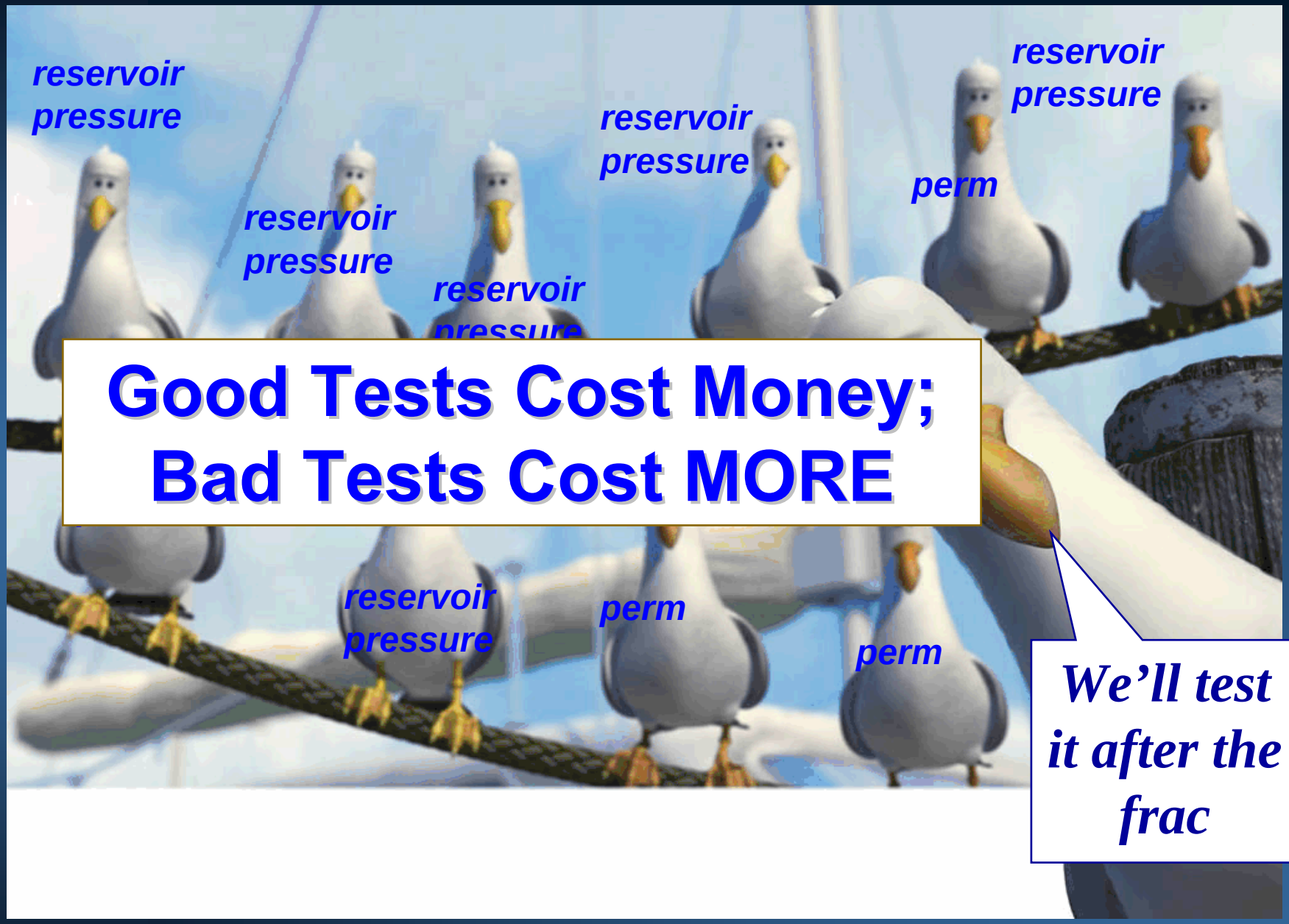


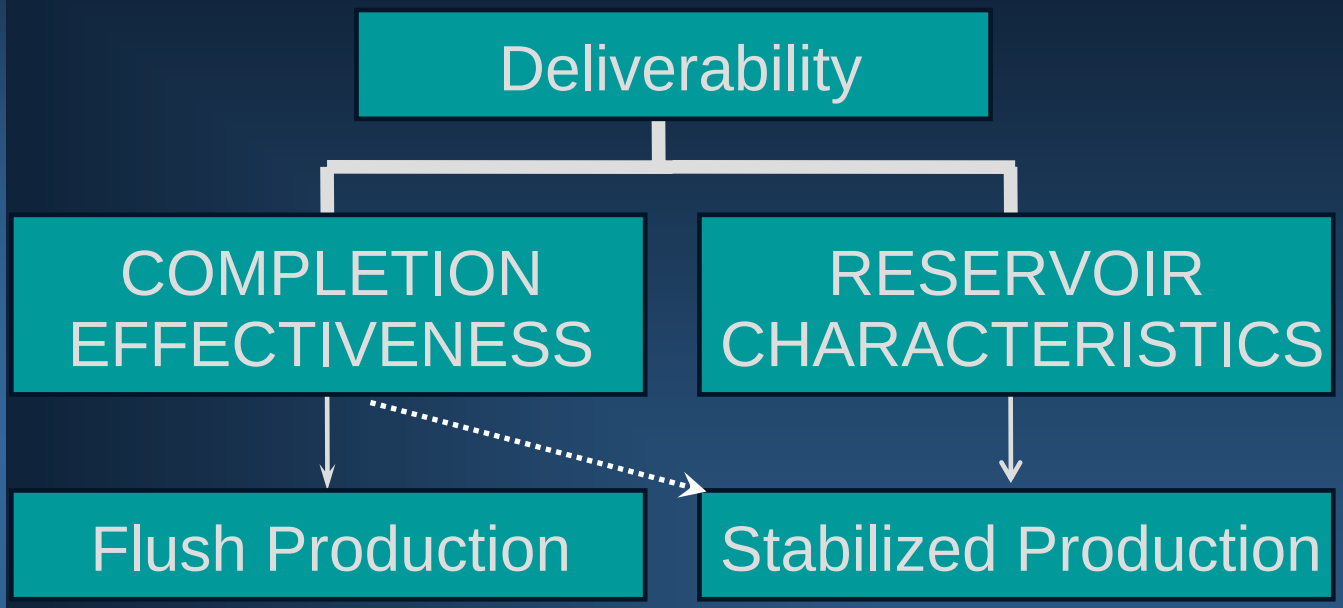
# An Idealized View Of A Propped Fracture Showing Trapped Fluid Due To High Capillary End Effects





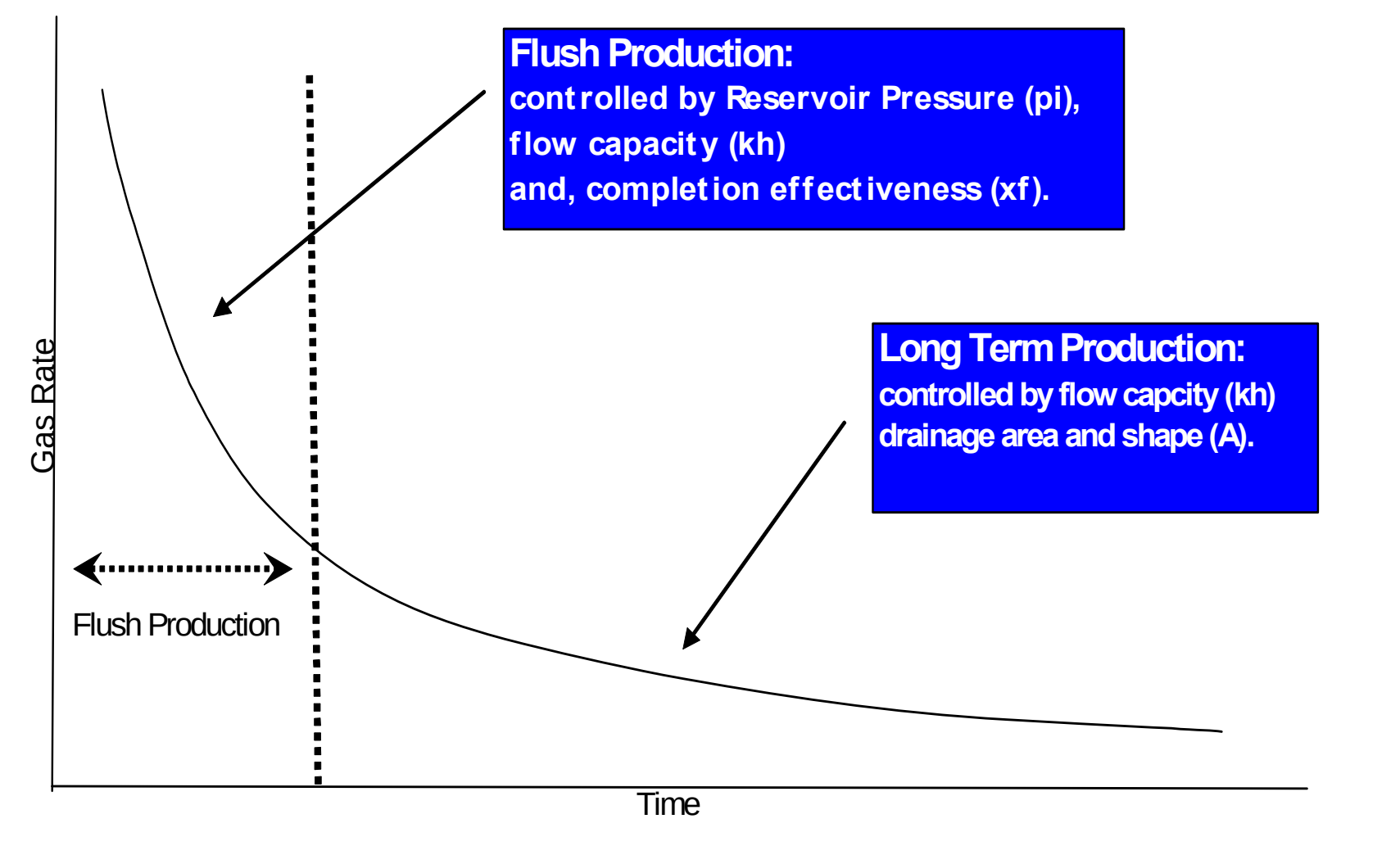

# Good Tests Cost Money; Bad Tests Cost MORE

# Concept of Tight Gas Deliverability Behaviour




The completion controls *Flush* production, were as the reservoir controls *Stabilized* production

# Concept of Tight Gas Deliverability Behaviour



# Reservoir Characteristics

- Flow Capacity (kh)
  - biggest impact on a well's deliverability
  - system kh?

- ✓ logs (static)
- ✓ cores (needs to be corrected)
- ✓ welltest (dynamic)
- ✓ production (ground truth?)

- Net Pay (h)
  - a moving target.
  - storage driven?
  - deliverability driven?

- ✓ cut-off (???)
- ✓ permeability or storage?
- ✓ gas saturation
- ✓ porosity

- Effective Porosity (ø)
  - all pores are NOT created equal

- ✓ logs
- ✓ Cores (mineralogy!!)
- ✓ material balance

# Completion Effectiveness

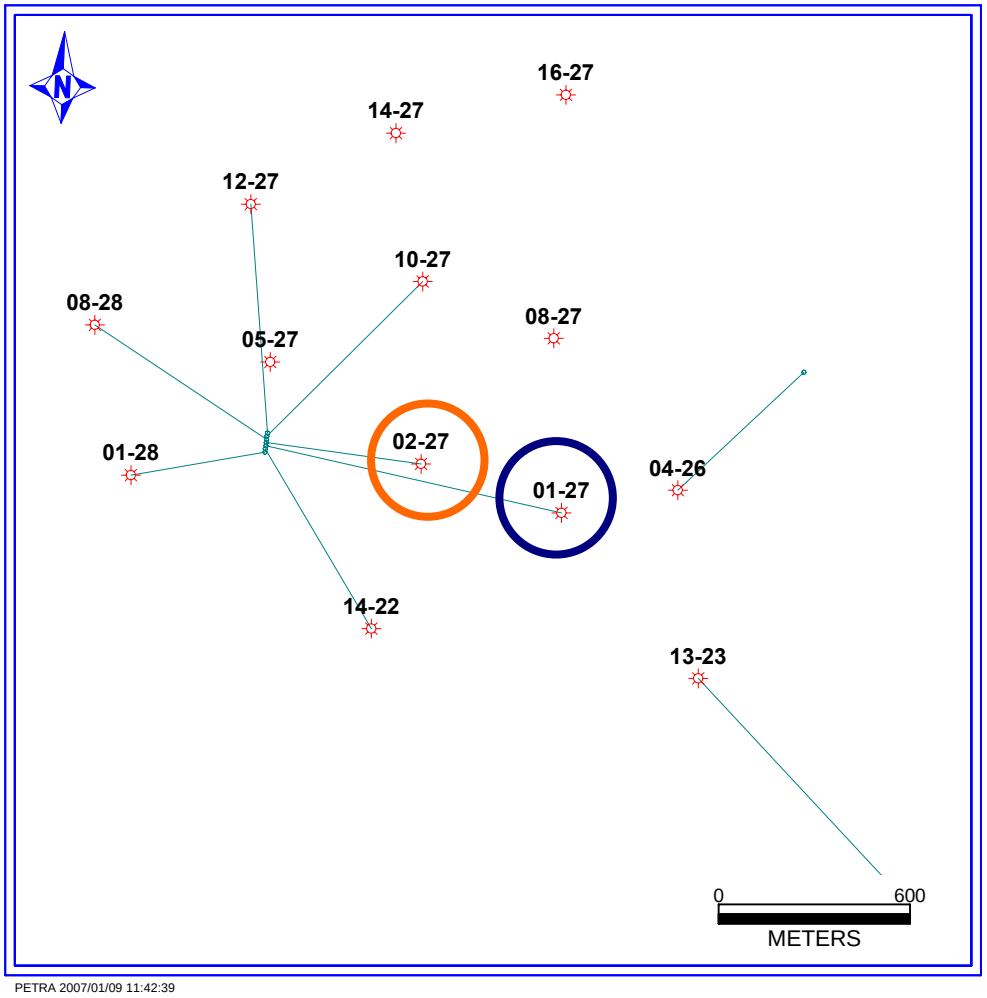
$$F_{CD} = \frac{k_f \bullet W_f}{k_m \bullet x_f}$$

- ✓ $k_f$ frac perm
- ✓ $w_f$ frac width
- ✓ $k_m$ matrix perm
- ✓ $x_f$ frac half-length

- An $F_{cd}$ of 1.6, is the optimum for ANY reservoir, well, and proppant.
- In low permeability formations, this requirement results in a long and narrow fracture.
- "Unified Fracture Design", Economides, Michael J, et al 2002.
- In high permeability formations, a short and wide fracture provides the same Fcd.

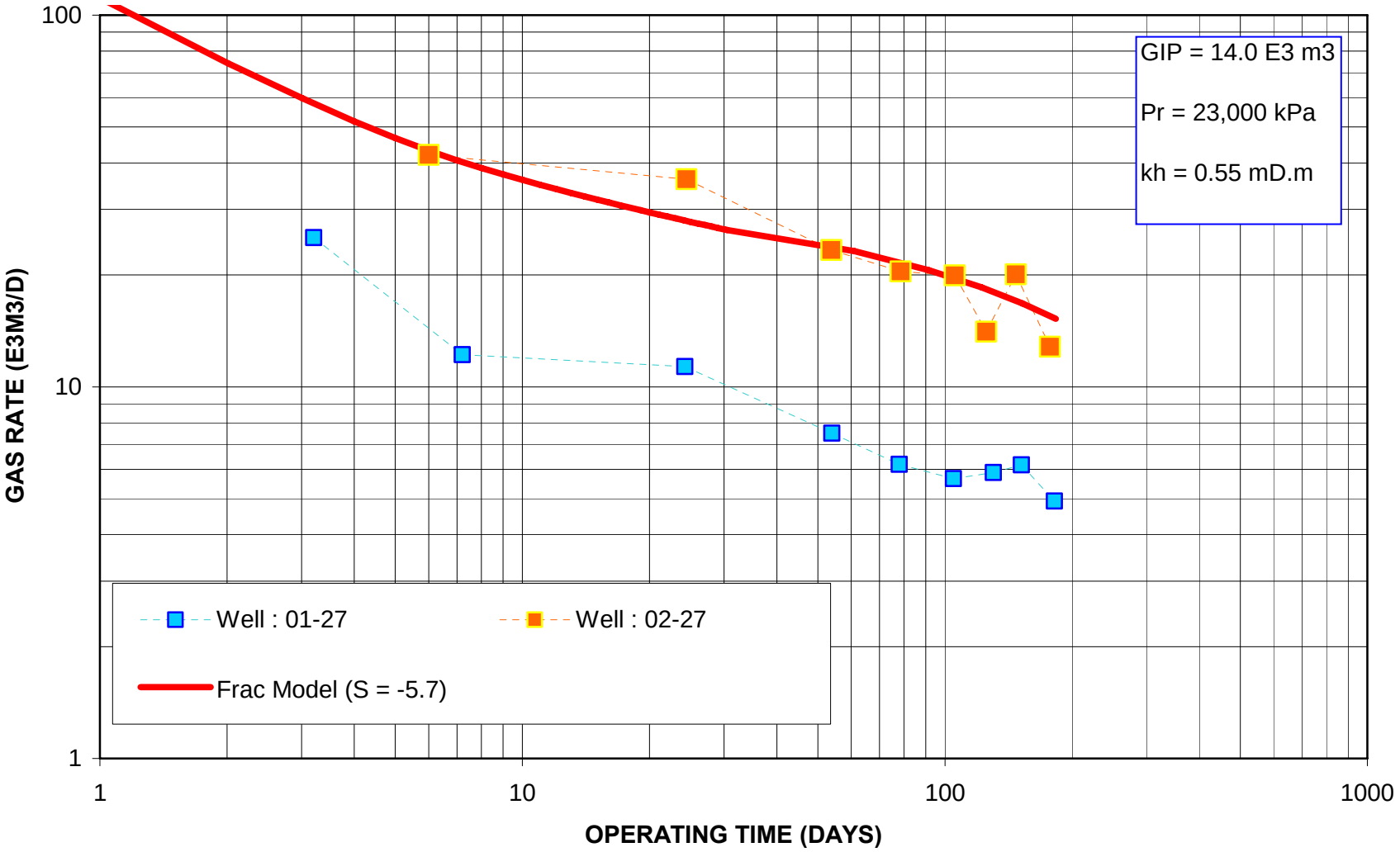
# Optimum Dimensionless Fracture Conductivity

- An accurate knowledge of the formation permeability is essential
  - More important than anything else
- Unfortunately, fracture permeability ($k_f$) is not constant for gas wells
  - Non-Darcy flow effects
  - Multiphase flow effects
- Therefore design for $F_{cd}$ of 20

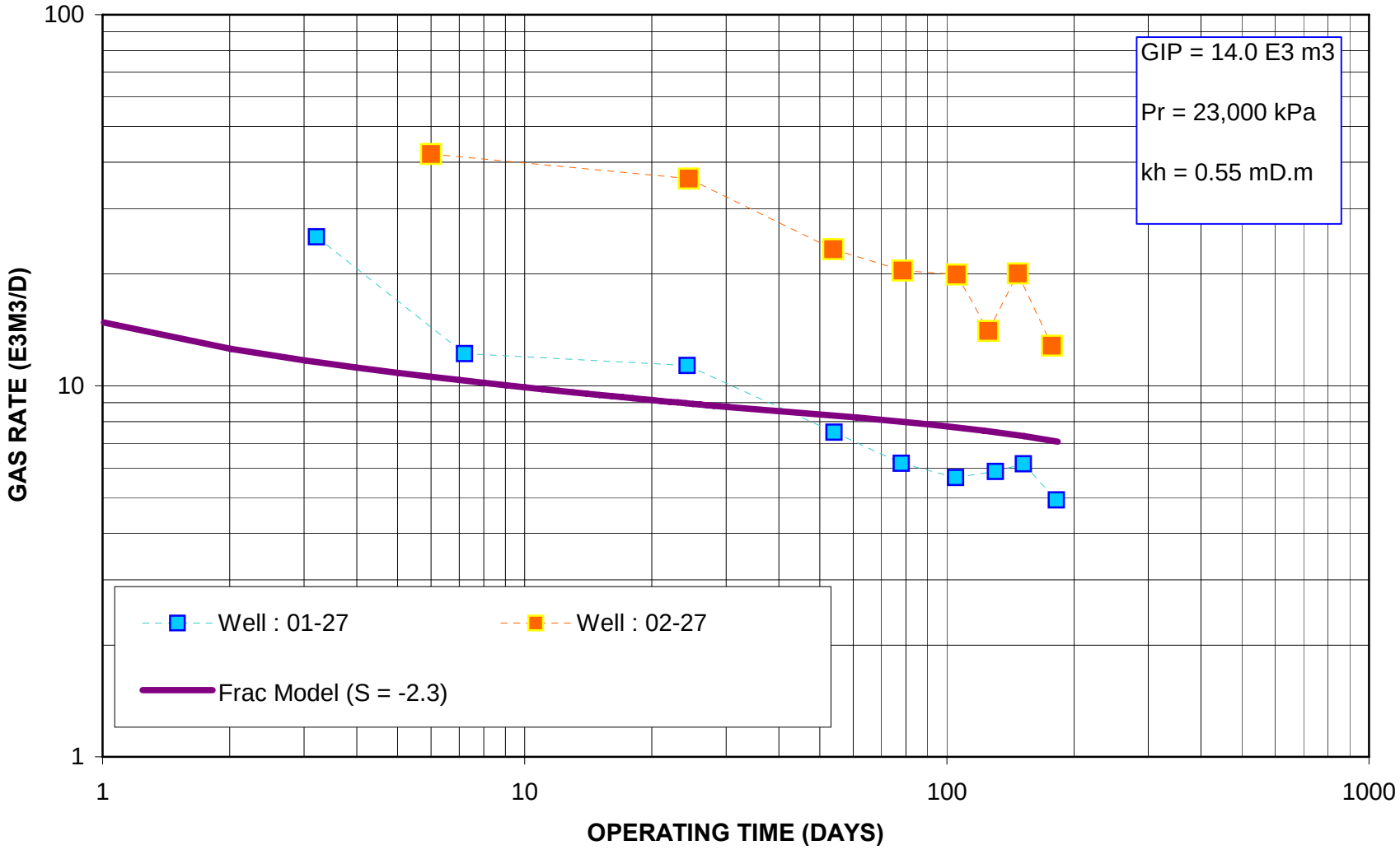



**100T Water Based Fracs**

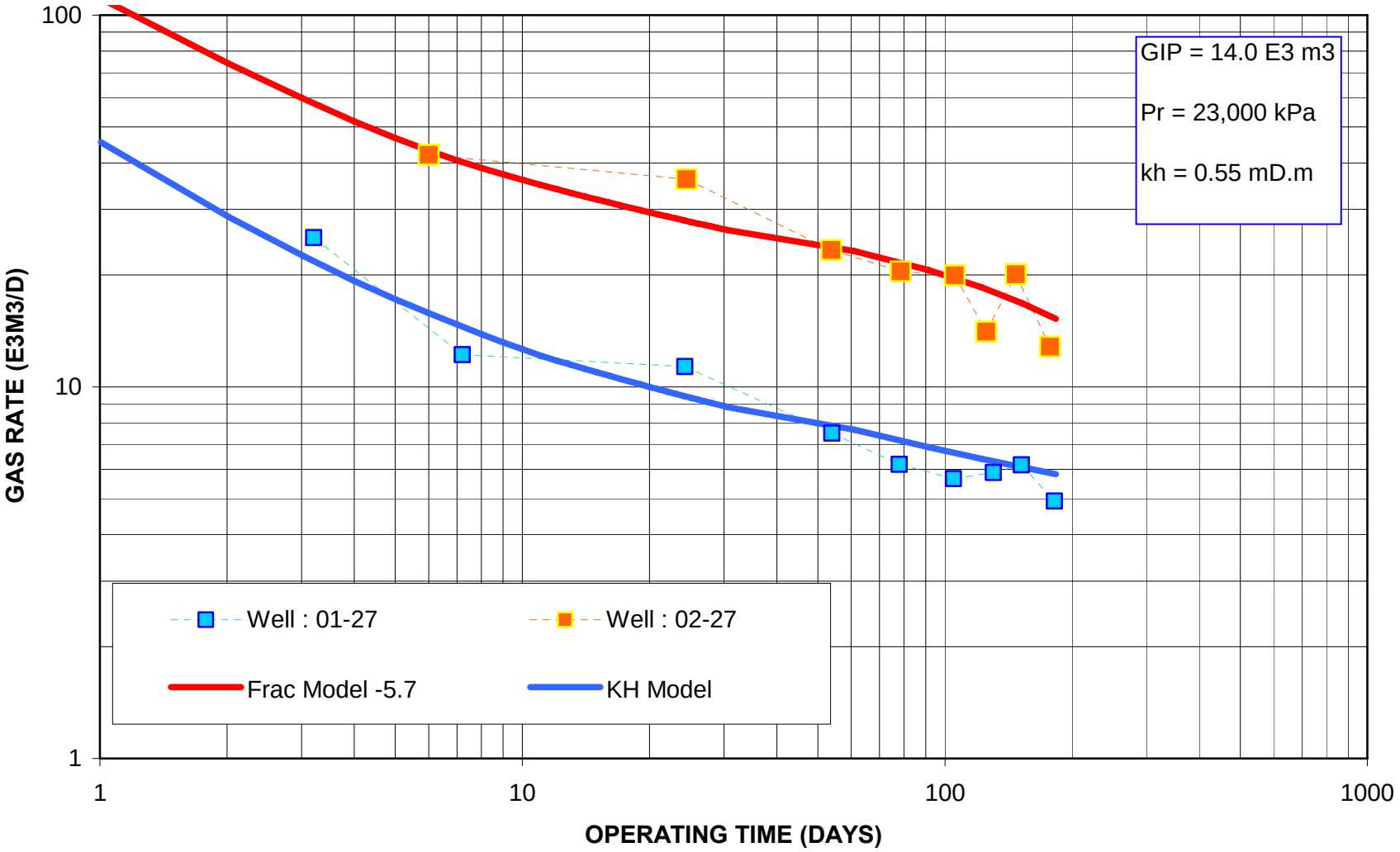
# PRODUCTION DIAGNOSTICS



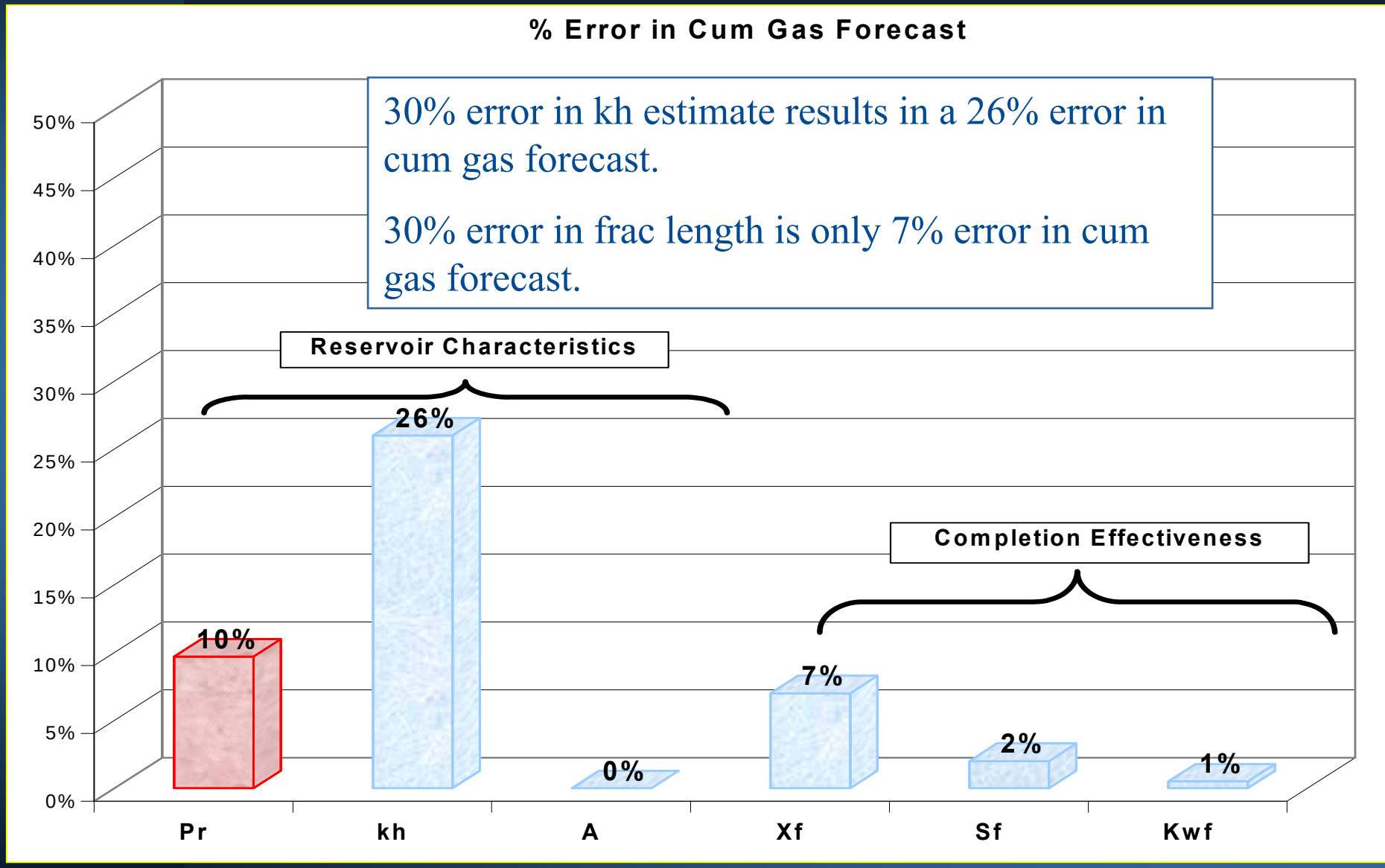
# PRODUCTION DIAGNOSTICS



# PRODUCTION DIAGNOSTICS



# Sensitivity of Production Forecast



## Productivity Index ($J$) can be expressed in the following terms:

$$J = \frac{kh}{1422T(\ln\frac{r_e}{r_w} - \frac{3}{4} + s)} = q/(m(p_{avg}) - m(p_{wf}))$$

## In it's simplified form, it can be expressed as:

$$J = \frac{kh}{(8+s)}$$

$$q_a = \frac{[8+s_b]}{[8+s_a]} \times [qb]$$

In the *rule of eights*, $s_b$ and $s_a$ represent the skin effects **b**efore and **a**fter fracture treatment, respectively. Similarly $q_b$ and $q_a$ represent the boundary-dominated flow rates **b**efore and **a**fter fracture treatment, *where….*

$$r_w' = \frac{1}{2} x_f$$

$$r_w' = r_w e^{-s}$$ **or** $$s = -\ln(r_w'/r_w)$$

# What is PID testing ?

- Perforation Inflow Diagnostics (PID).
- Pre-frac reservoir test.
- Underbalanced perforating procedures.
- Application of closed chamber testing .

# 3 Month Window for Drilling and Completions in Canada

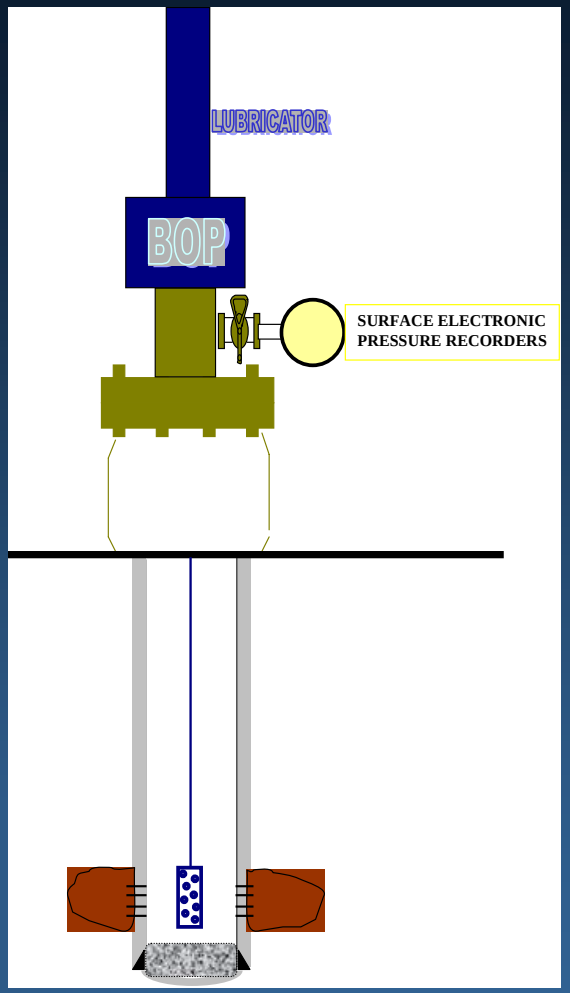

# PID Theory

## Closed Chamber Equation

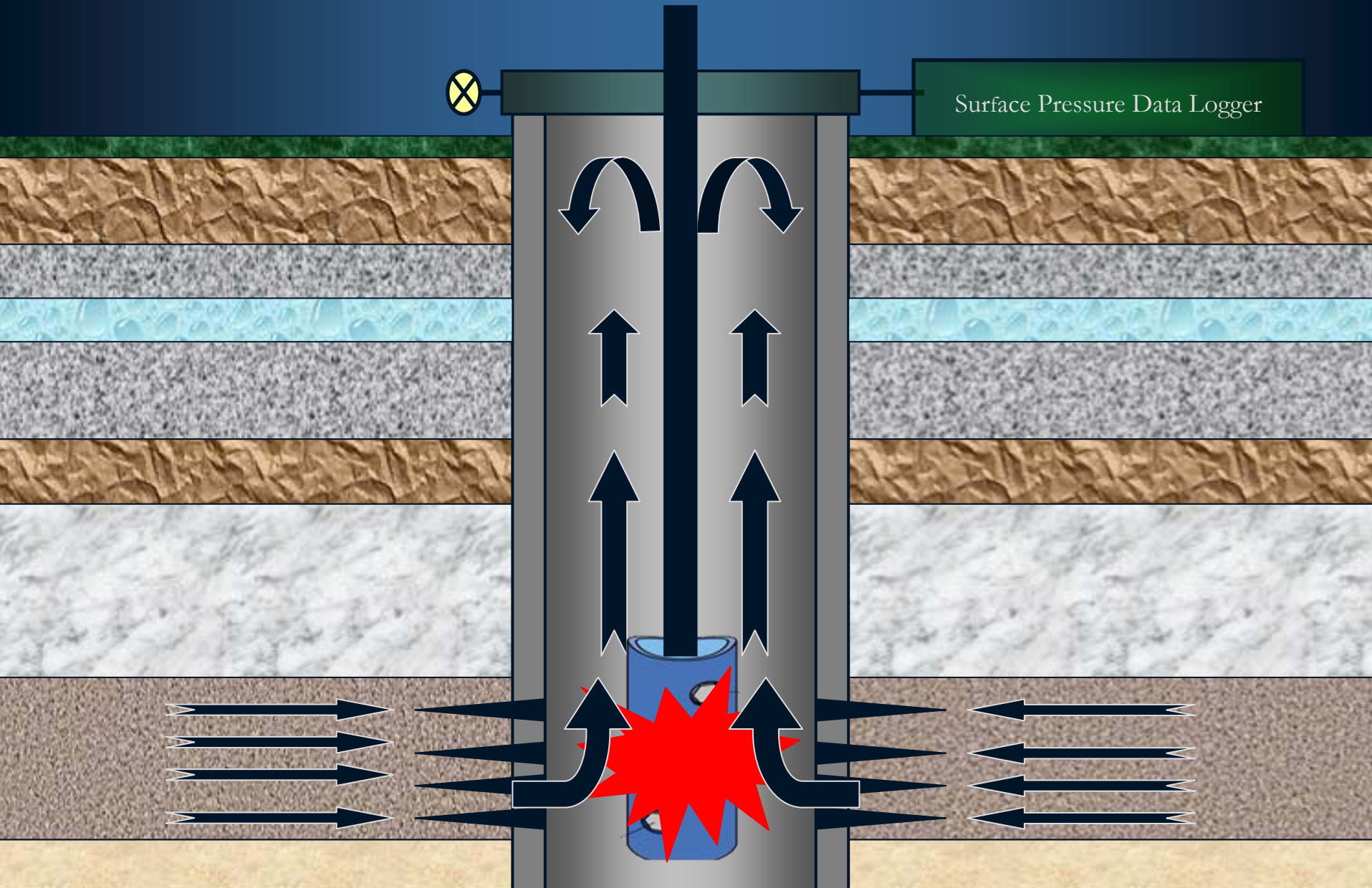
$$q_w = 24\ C\left(p_w\right)\frac{d\ p_w}{dt}$$

## PID Testing for Shallow Gas

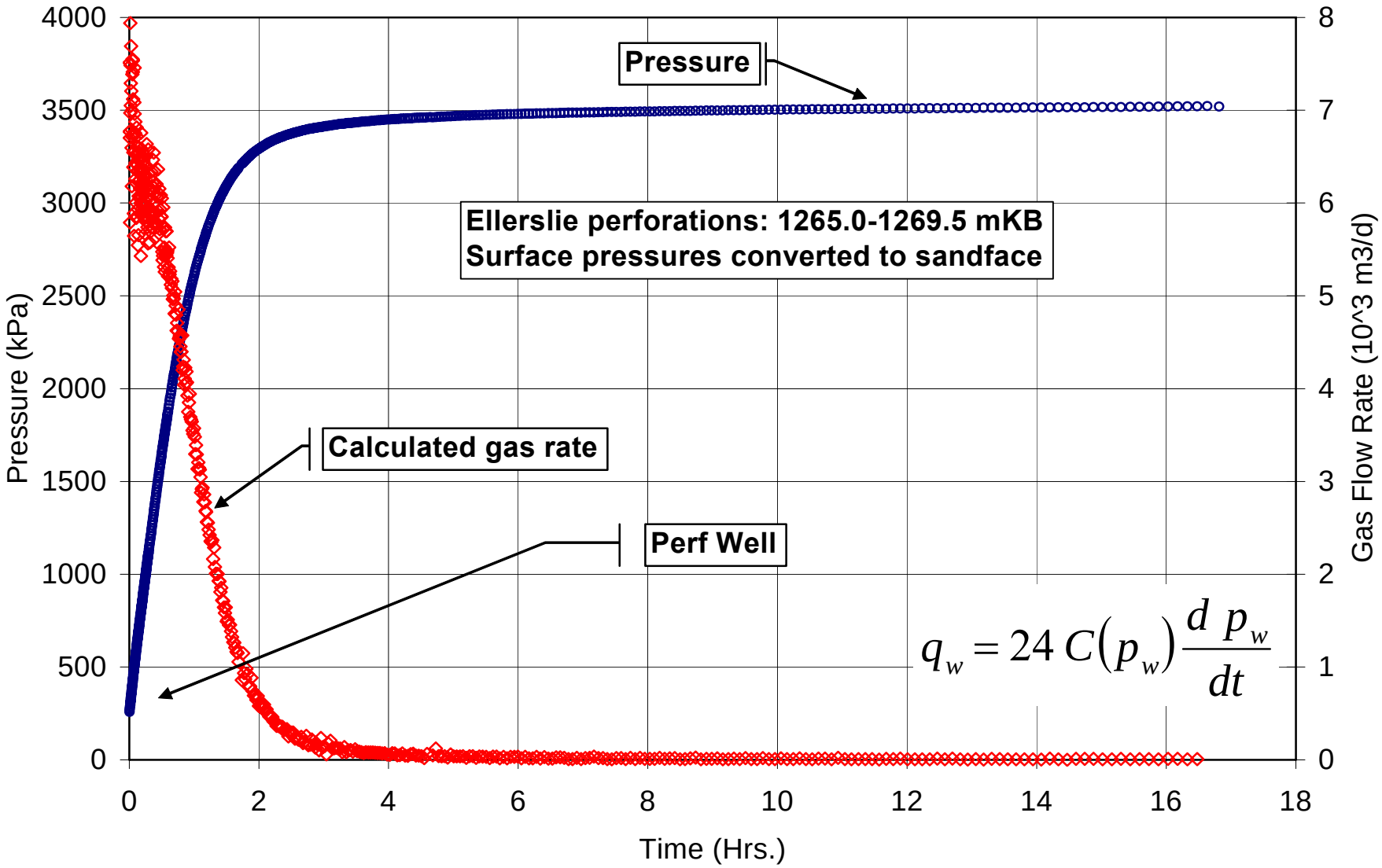
- Cost effective.
- Rigless.
- Evacuated wellbore.
- Electronic surface recorders.
- multi-zone reservoirs.



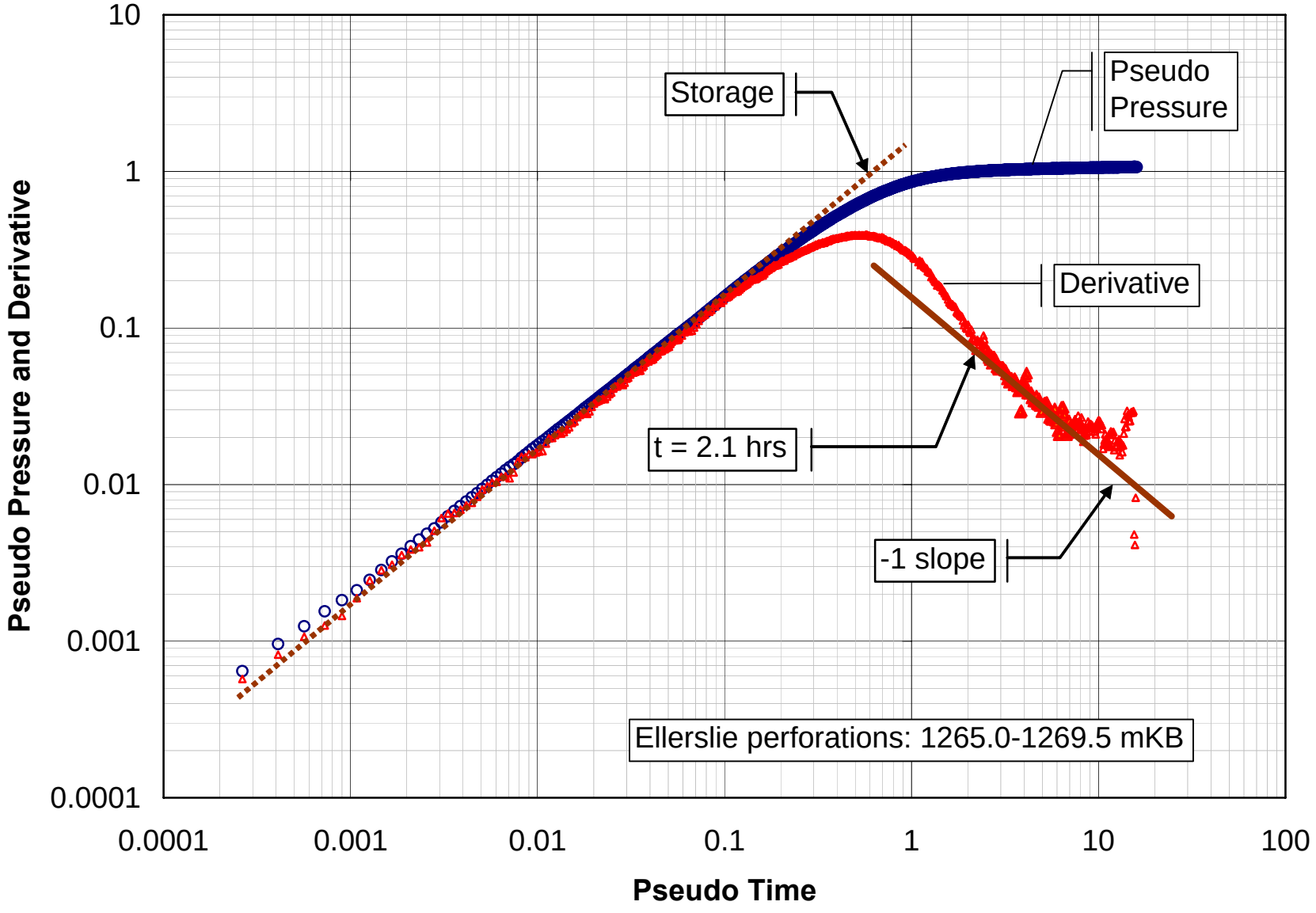
# Shallow Gas Operation



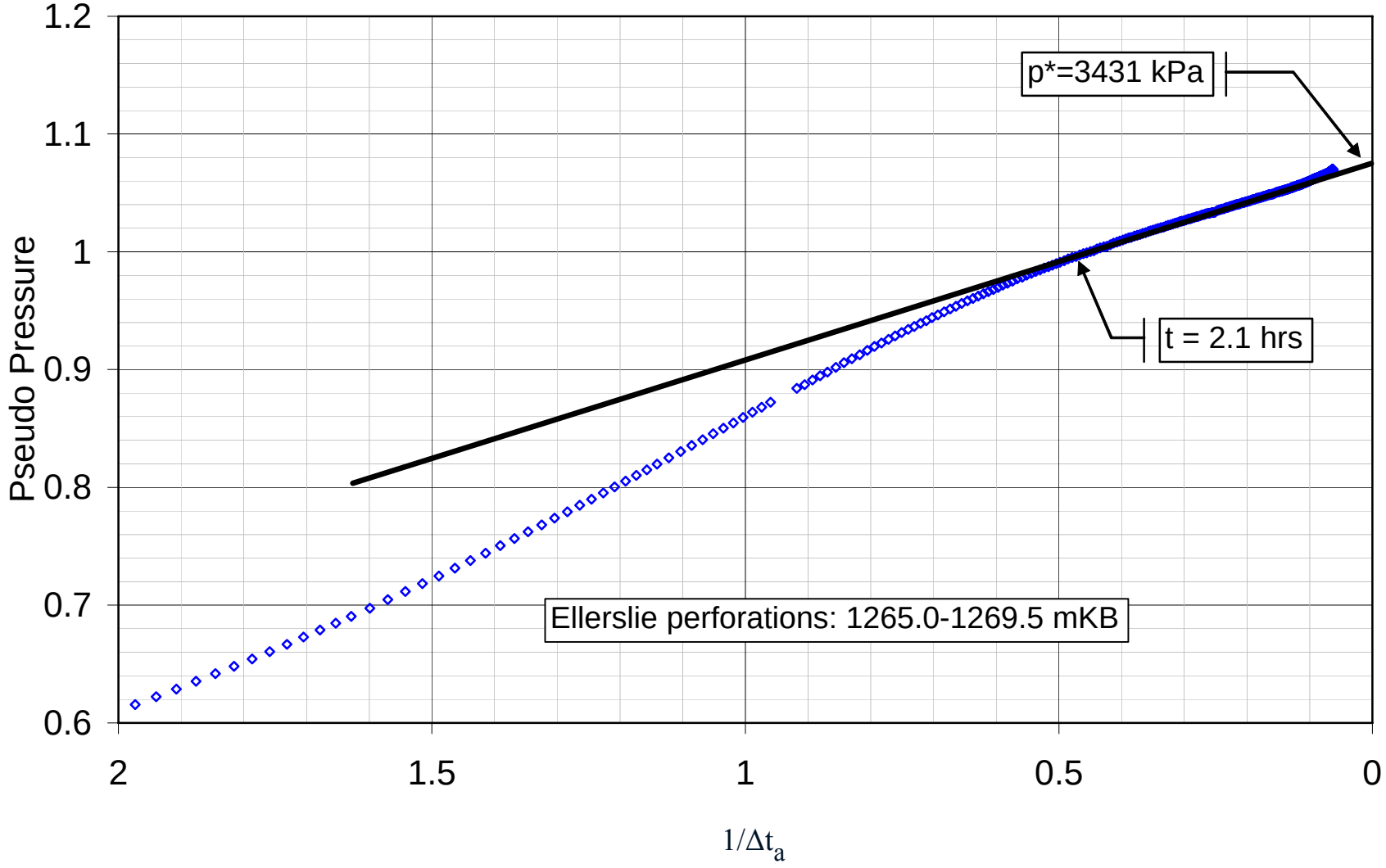
# Closed Chamber Theory



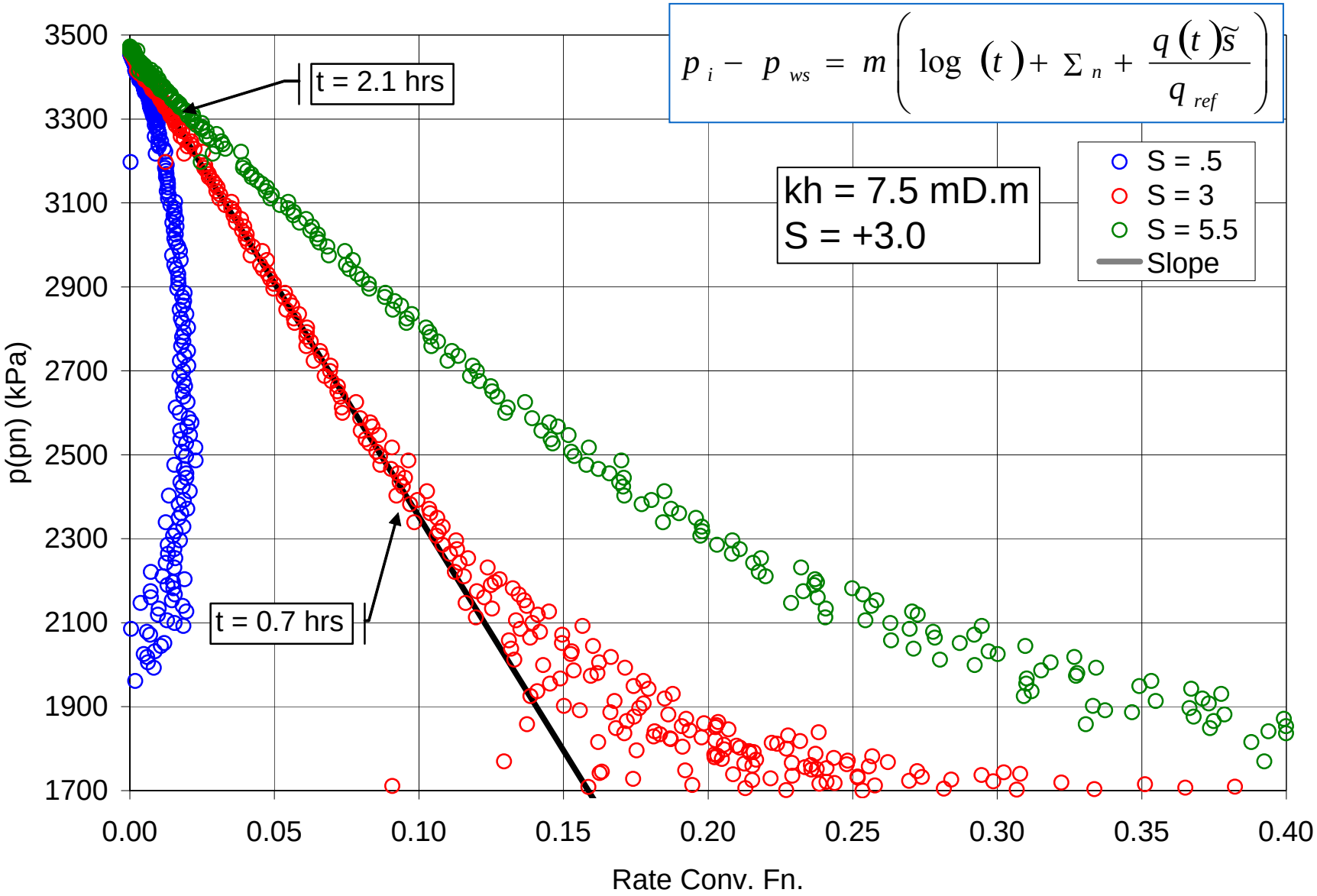
# Log-log Derivative Plot



# Inverse Time Plot



# Rate Convolution Semilog Plot

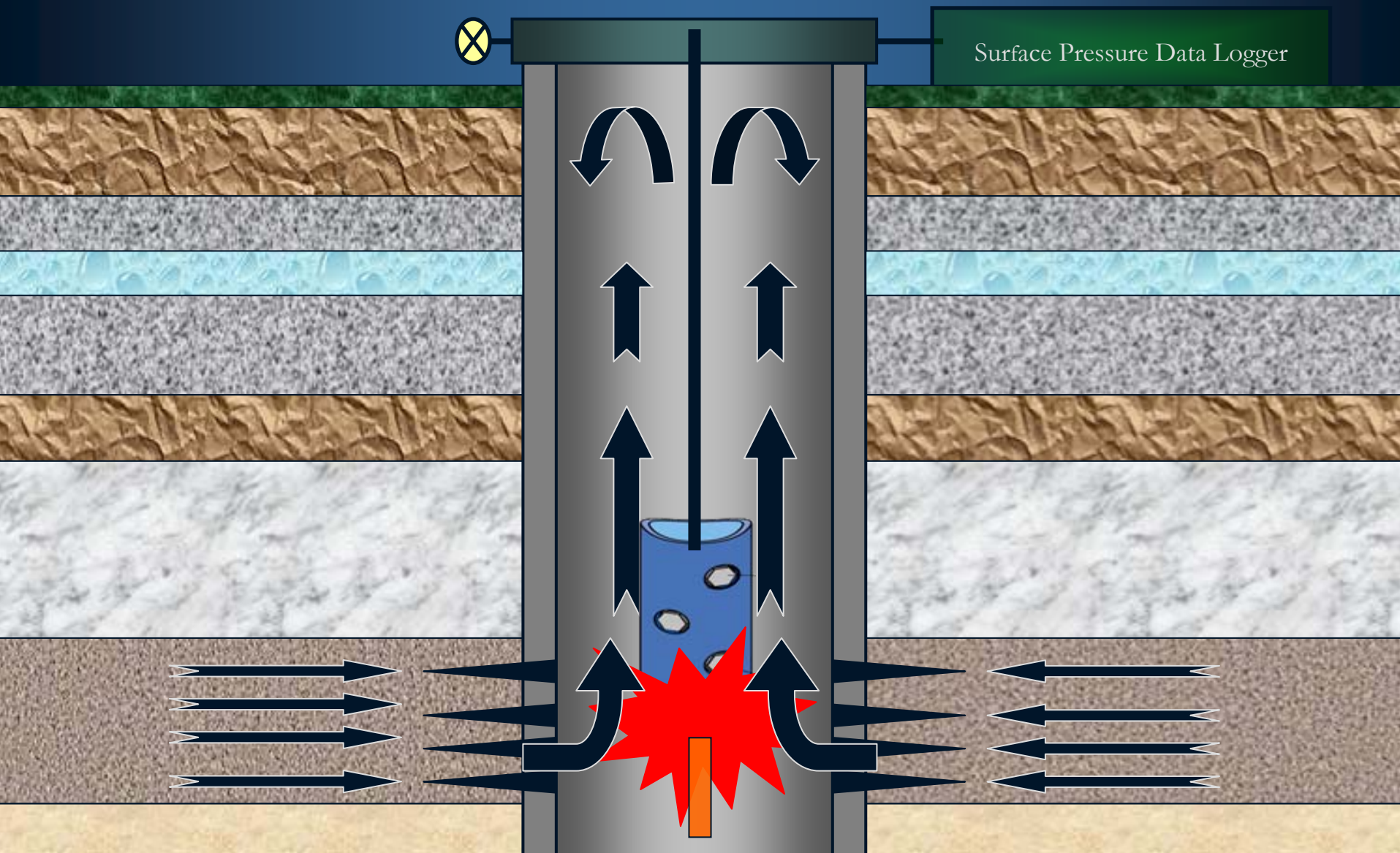


# Radius of Investigation with respect to PID Testing

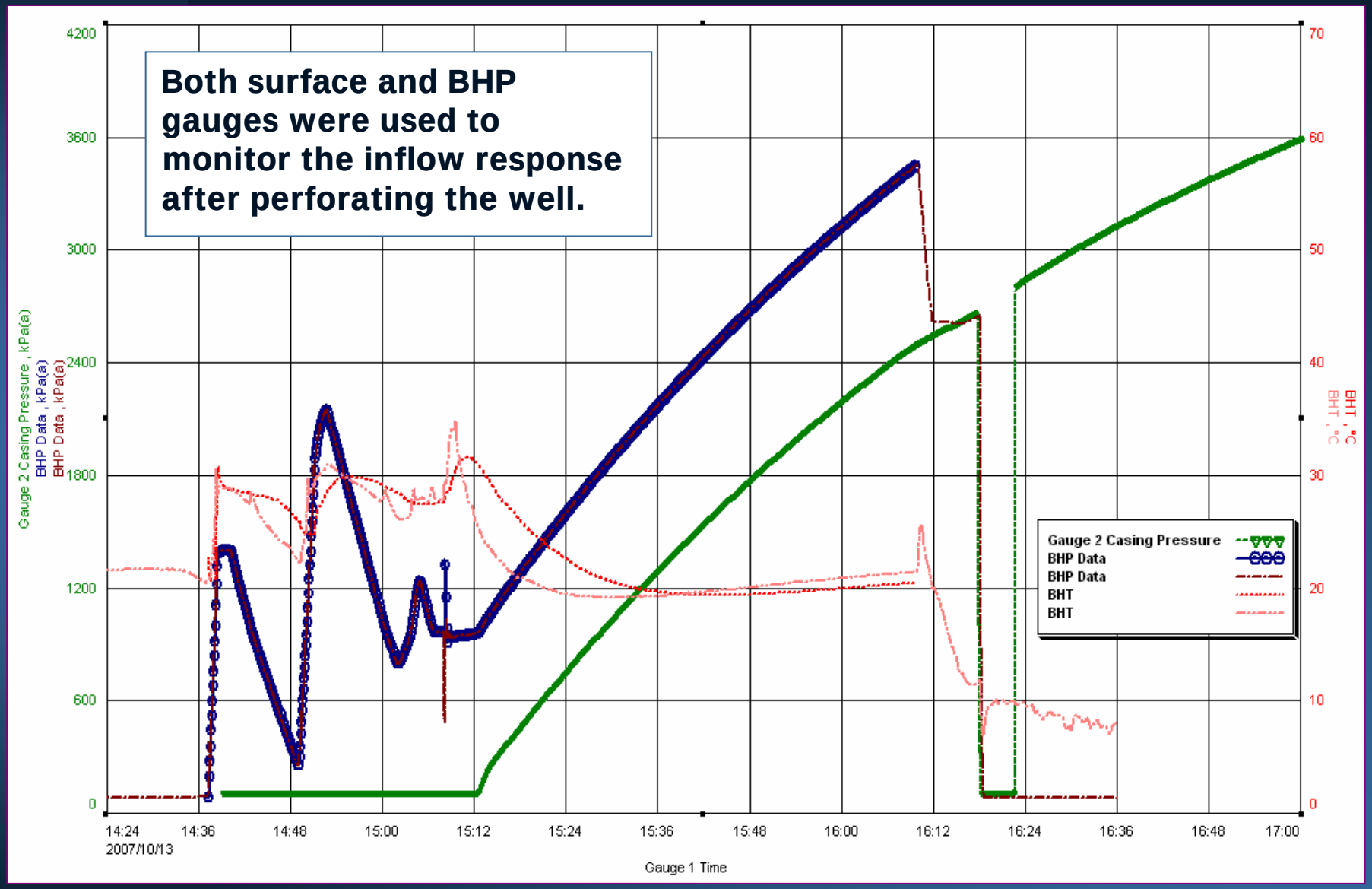
- *if* Cores investigate "inches",
- Logs investigate "feet",
- Well Tests investigates "hundreds of feet",
- as long as you can measure a change in pressure, you are *effectively flowing the well.*
- Radius of Investigation ($r_i$) is based on time ($t$) and permeability ($k$), not flow rate.

$$r_i = \sqrt{\frac{k \times t}{69.44 \times \Phi \times \mu \times c_t}}$$

# Recorders on Perf Gun Operation



# Overlay Of Perfgun Recorders and Surface Recorders



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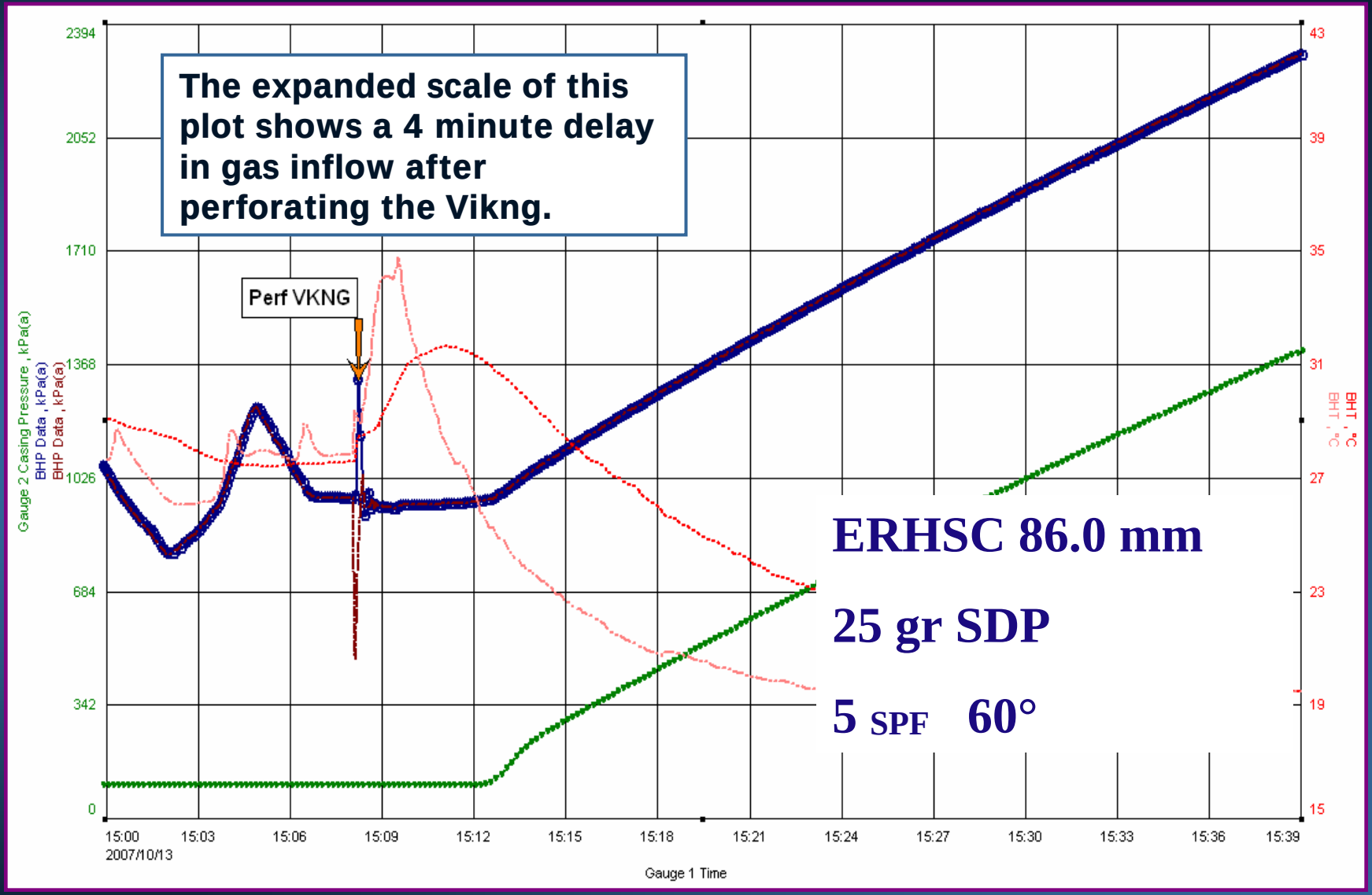
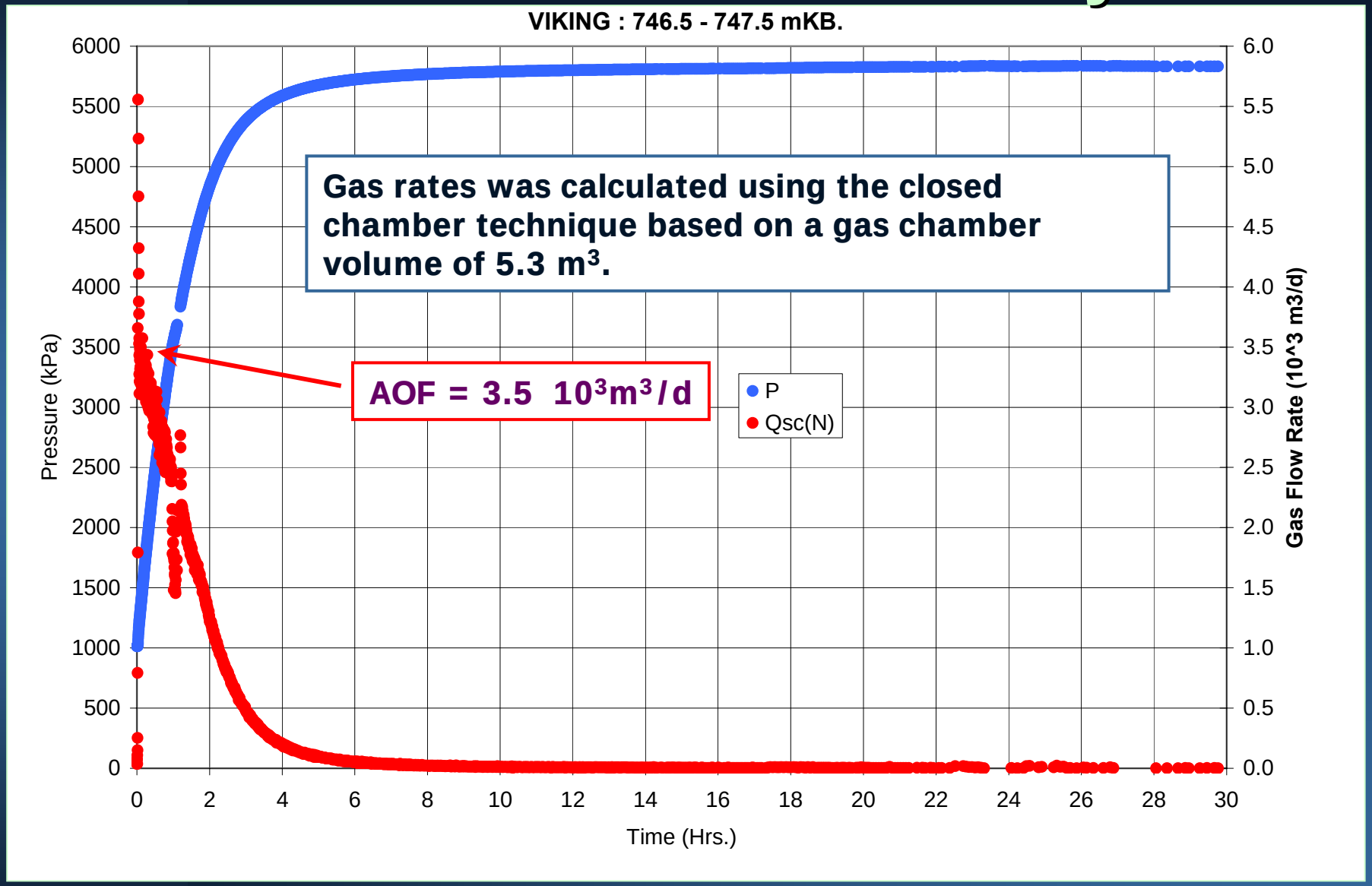
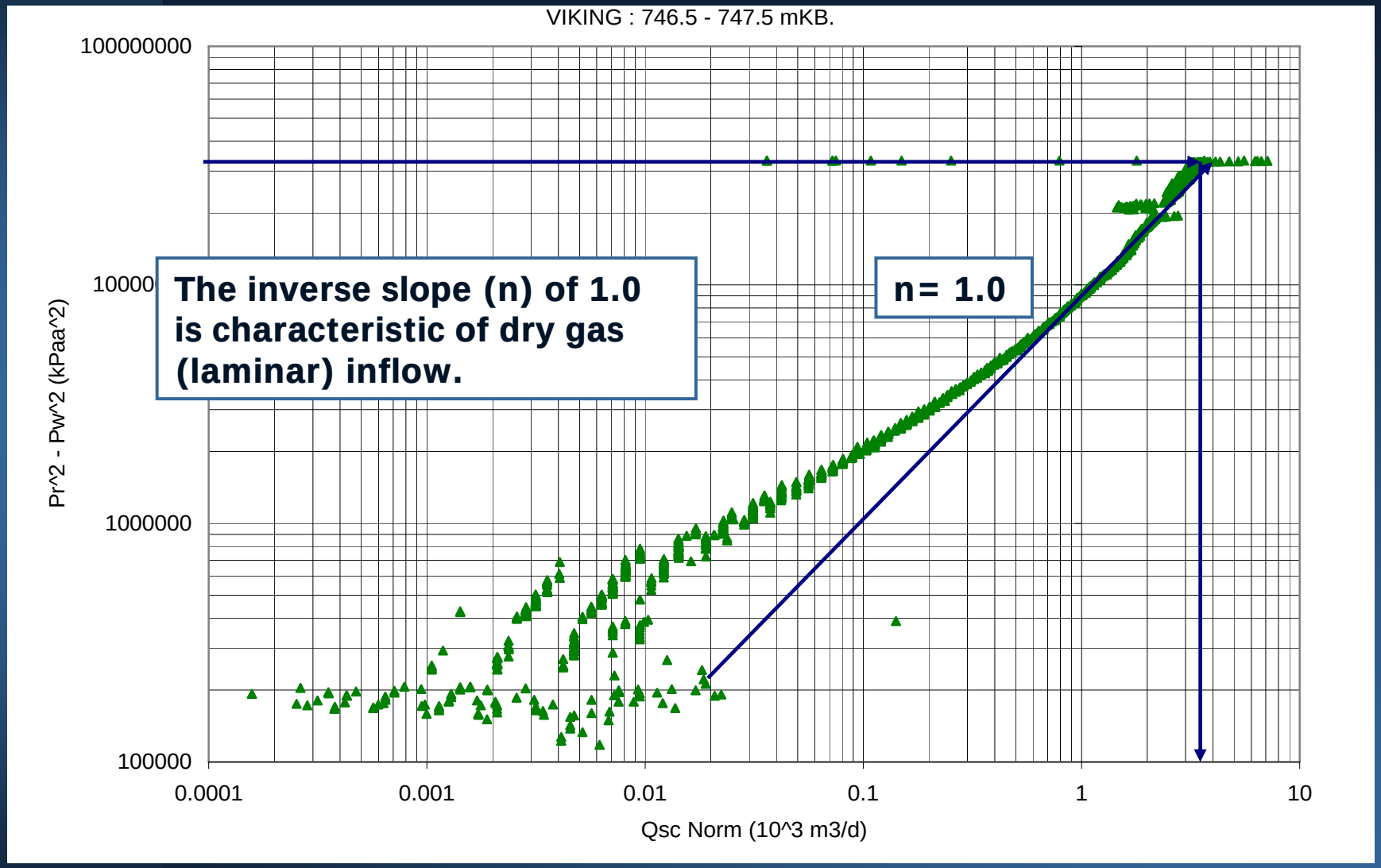


# Closed Chamber Theory

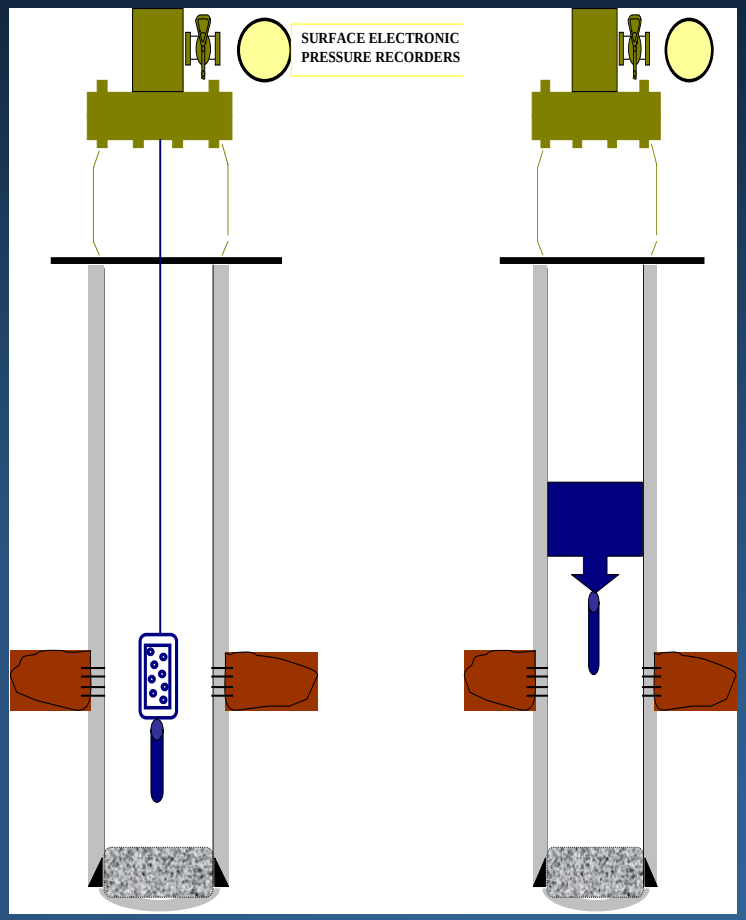


# Back Pressure Plot

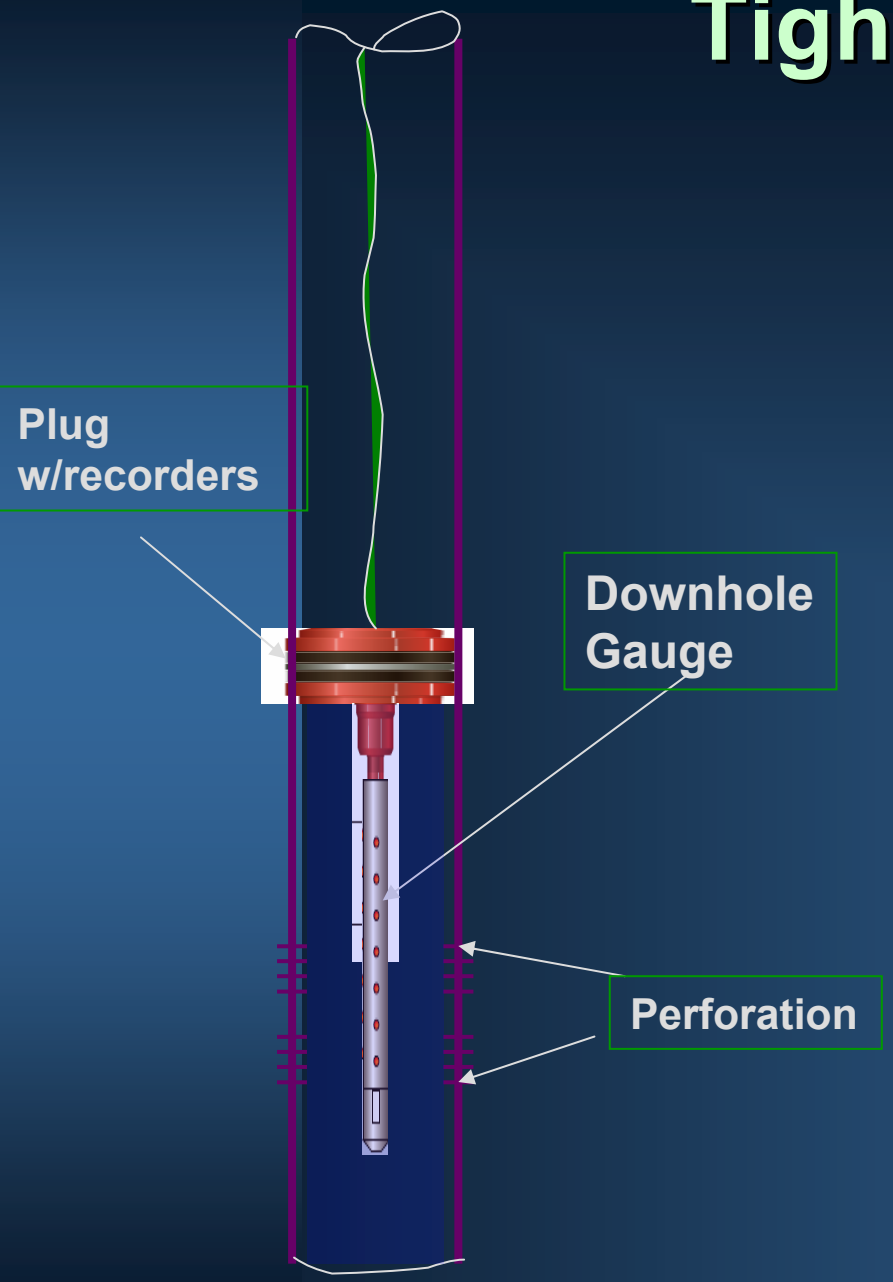


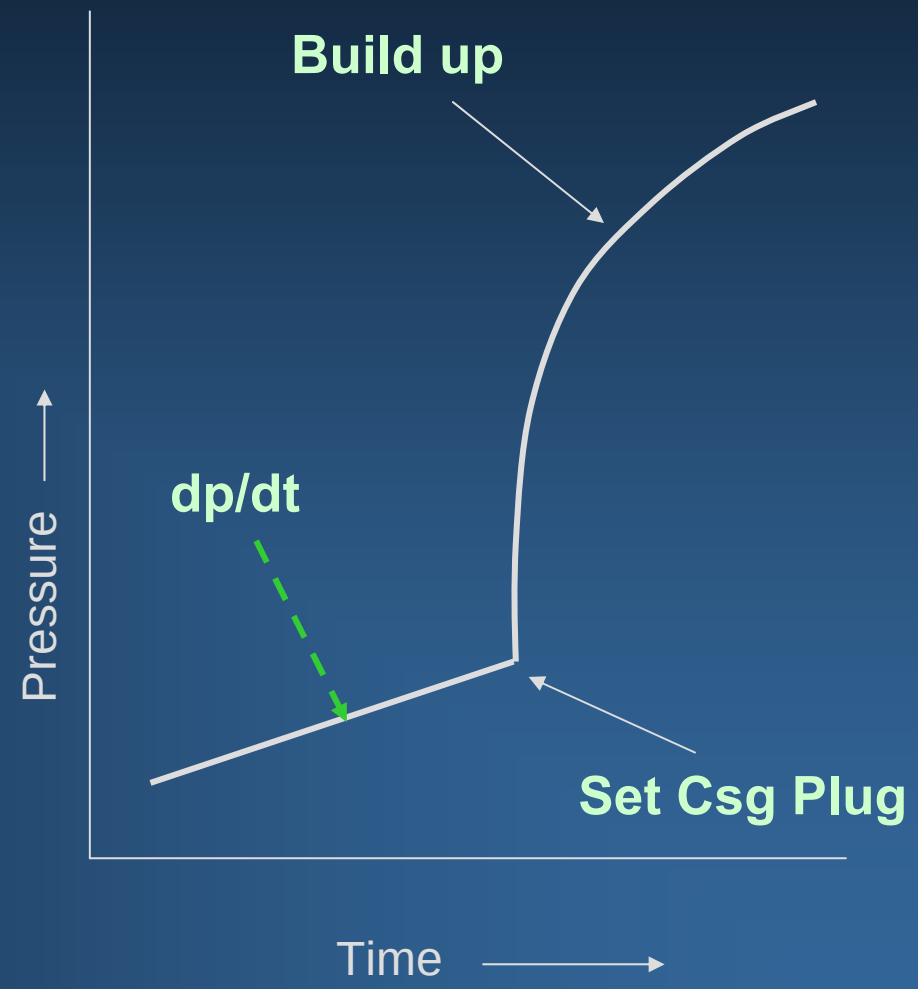
## PID Testing for Deep, Tight Gas

- Cost effective, safe.
- Electronic downhole recorders
- Downhole shut-in
- <u>Two days</u> rig time



# Tight Gas PID Test



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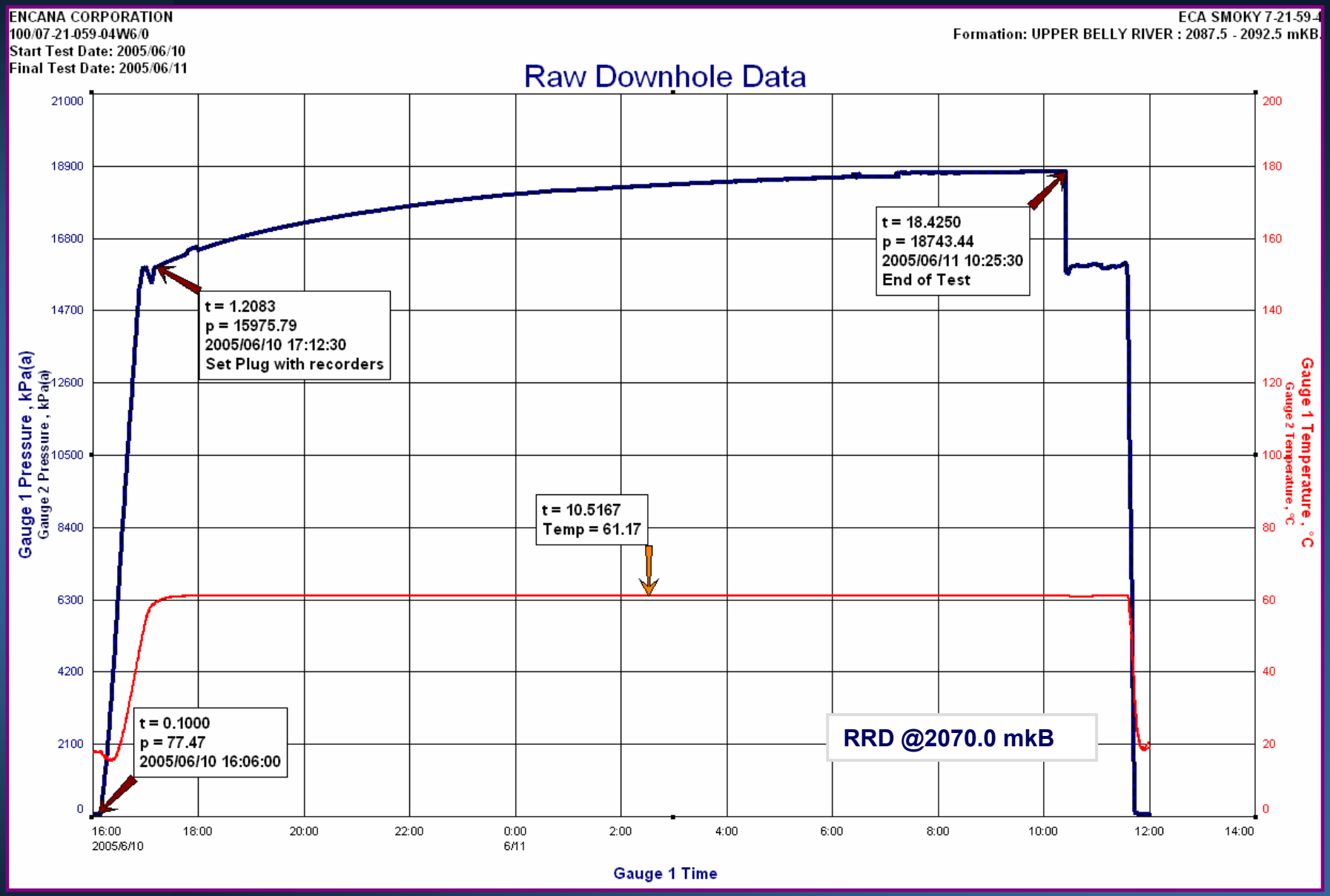
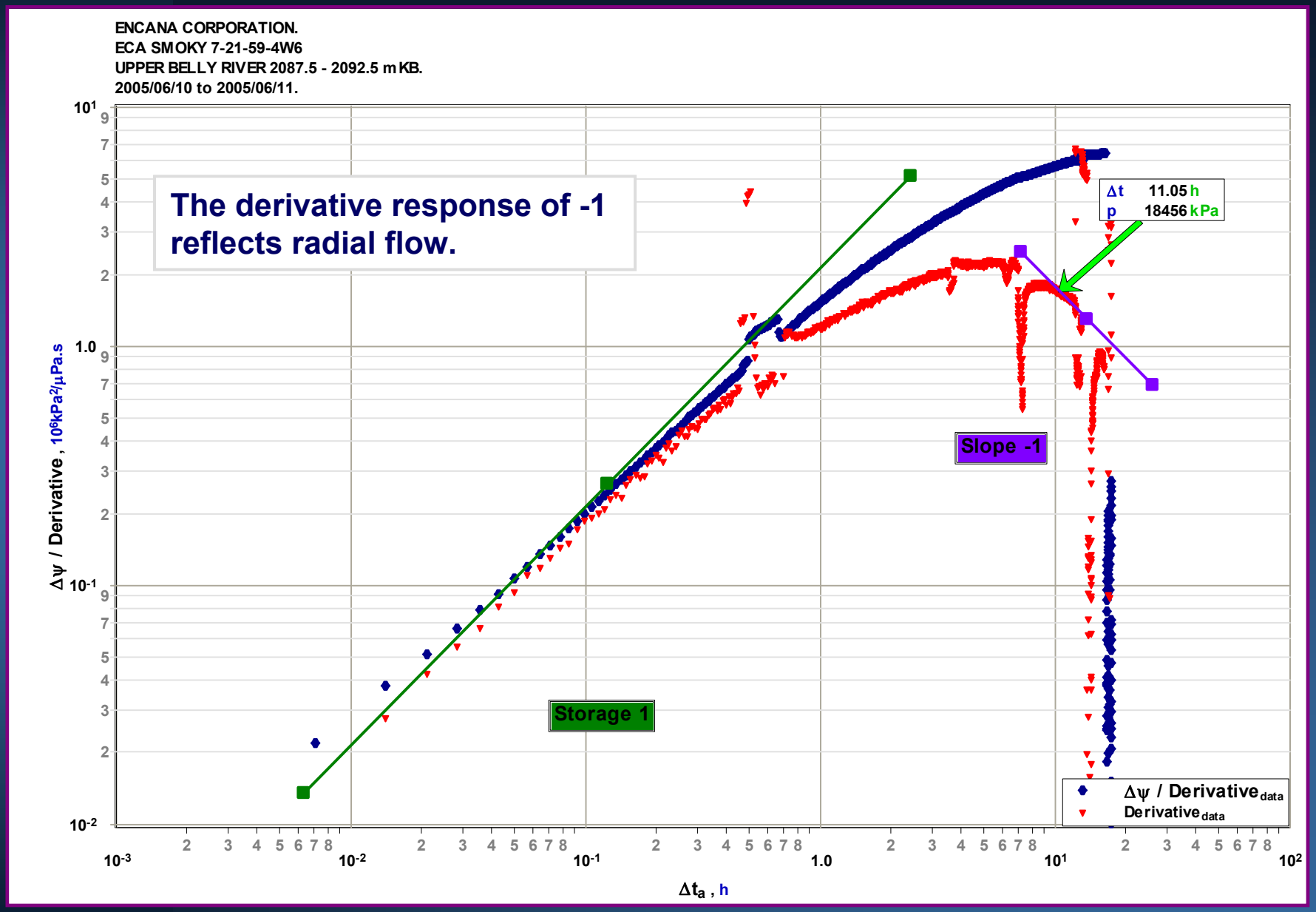
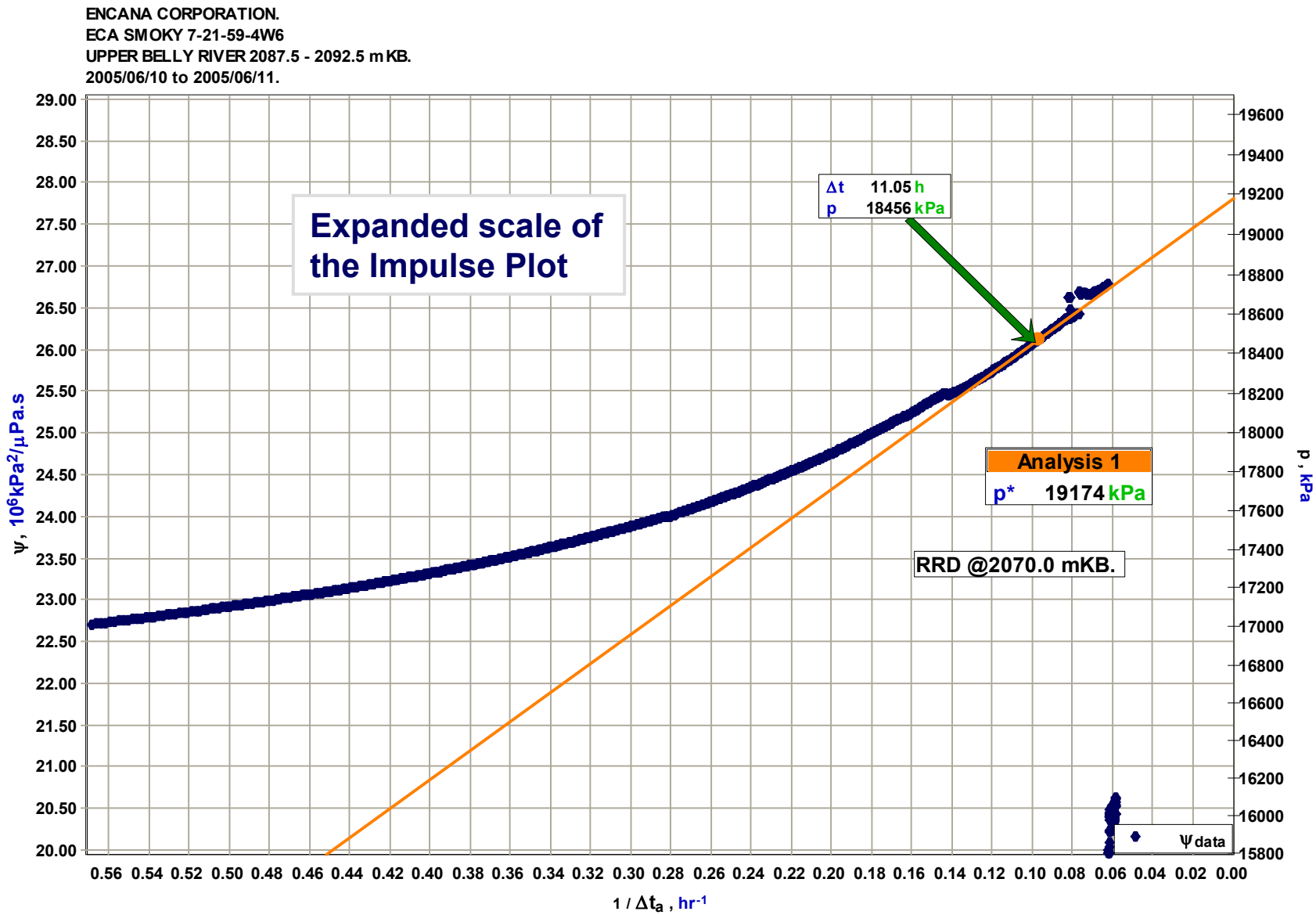

ENCANA CORPORATION
100/07-21-059-04W6/0
Start Test Date: 2005/06/10
Final Test Date: 2005/06/11
ECA SMOKY 7-21-59-4
Formation: UPPER BELLY RIVER : 2087.5 - 2092.5 mKB
Raw Downhole Data
Gauge 1 Pressure , kPa(a)
Gauge 2 Pressure , kPa(a)
Gauge 1 Temperature , °C
Gauge 2 Temperature , °C
Gauge 1 Time
t = 1.2083
p = 15975.79
2005/06/10 17:12:30
Set Plug with recorders
t = 18.4250
p = 18743.44
2005/06/11 10:25:30
End of Test
t = 10.5167
Temp = 61.17
t = 0.1000
p = 77.47
2005/06/10 16:06:00
RRD @2070.0 mkB

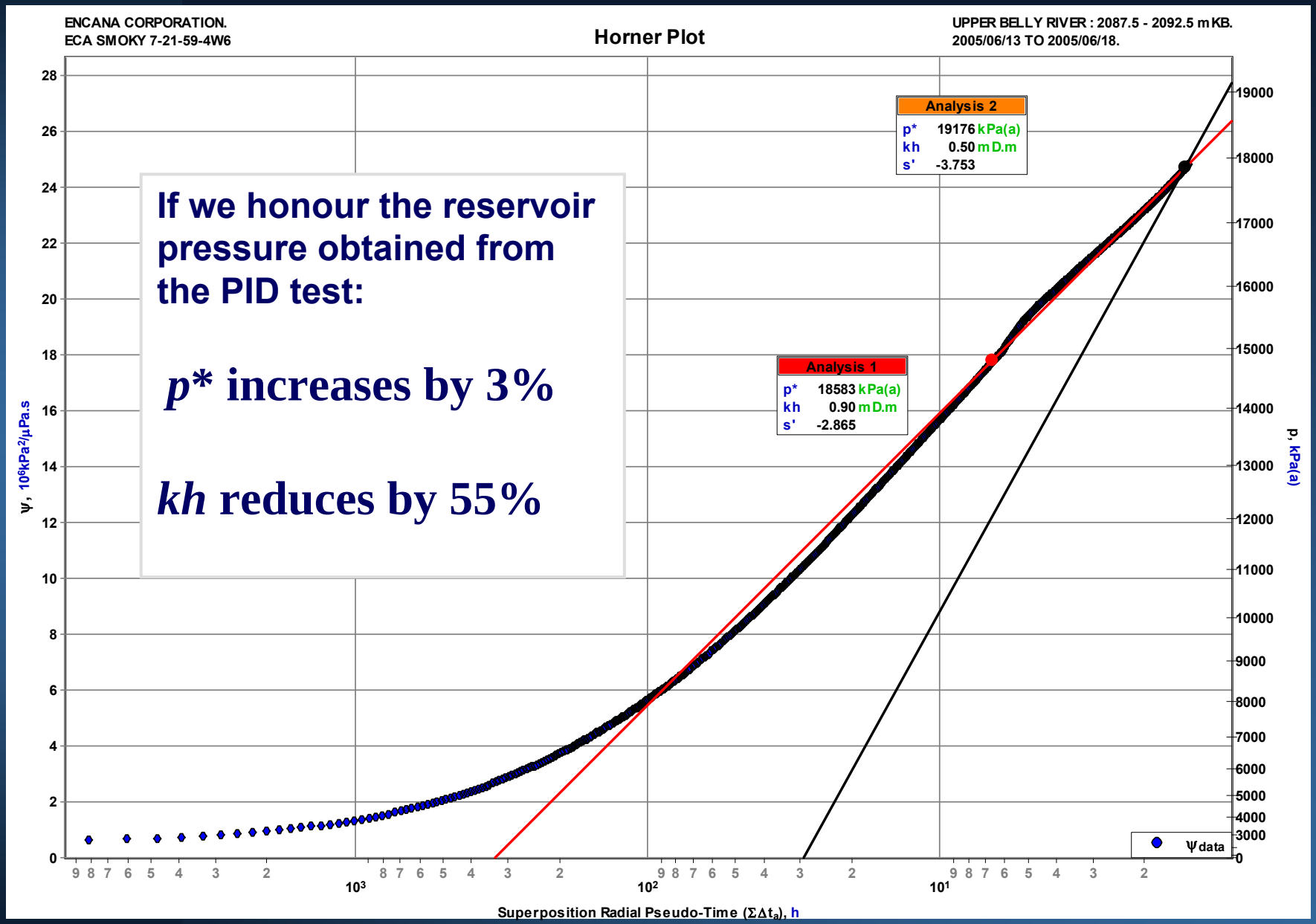
# PID Test


ENCANA CORPORATION.
ECA SMOKY 7-21-59-4W6
UPPER BELLY RIVER 2087.5 - 2092.5 m KB.
2005/06/10 to 2005/06/11.
The derivative response of -1 reflects radial flow.
Δt 11.05 h
p 18456 kPa
Slope -1
Storage 1
Δψ / Derivative data
Derivative data
Δψ / Derivative , 10⁶kPa²/μPa.s
Δta , h

# PID Test – Inverse Time Plot



# Post-frac Flow and Buildup Test




**If we honour the reservoir pressure obtained from the PID test:**

***p**** **increases by 3%**

***kh* reduces by 55%**

# Importance of *Initial* Reservoir Pressure

| CASE HISTORY* | | | |
|---|---|---|---|
| | 14 Day Buidlup | 240 Day Buildup | Error % |
| pi [kPa] | 19041 | 19293 | 1.3 |
| k [mD] | 0.05 | 0.02 | 150 |
| xf [m] | 40.1 | 66.2 | 39 |
| kf.w [mD.m] | 280 | 470 | 40 |
| **5 yrs. ΔG [MMscf]** | **100** | **65** | **54** |

* Hategan and Hawkes, 2006

# Conclusions

- Initial post-frac buildup analysis OVER-ESTIMATE most tight gas well production performances.

- Perforation Inflow Diagnostic (PID) Analysis gives us the ability to peer through the wellbore region and determine the quality of the reservoir rock lurking behind.

# Conclusions

- **Closed chamber testing during underbalanced perforating is an *overlooked* pre-frac testing technique to determine initial reservoir pressure and in-situ permeability.**

- **In tight gas reservoirs, reservoir pressure is a critical parameter for hydraulic fracturing treatments and evaluation.**

**“It is a capital mistake to theorize before one has data. Insensibly one begins to *twist* facts to suit theories, instead of theories to suit facts”**

**Sherlock Holmes**