

# SPE Distinguished Lecturer Program



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**Additional support provided by AIME**



# The Determination of Minimum Tested Volume and Future Well Production from the Deconvolution of Well Test Pressure Transients
















**Tim Whittle**  
**Bg Group**

# Well Test Objectives

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- Fluid Characterisation (PVT)
- Well Performance (Flow)
- Reservoir Description (Model)
- Reservoir Deliverability (Flow)
- Flow Assurance (Facilities)
- Clean Up (Production)

# Types of Well Test

	Fluid Characterisation	Well Flow	Reservoir Description	Reservoir Flow
Exploration				
Appraisal				
Extended (EWT)				
Production				

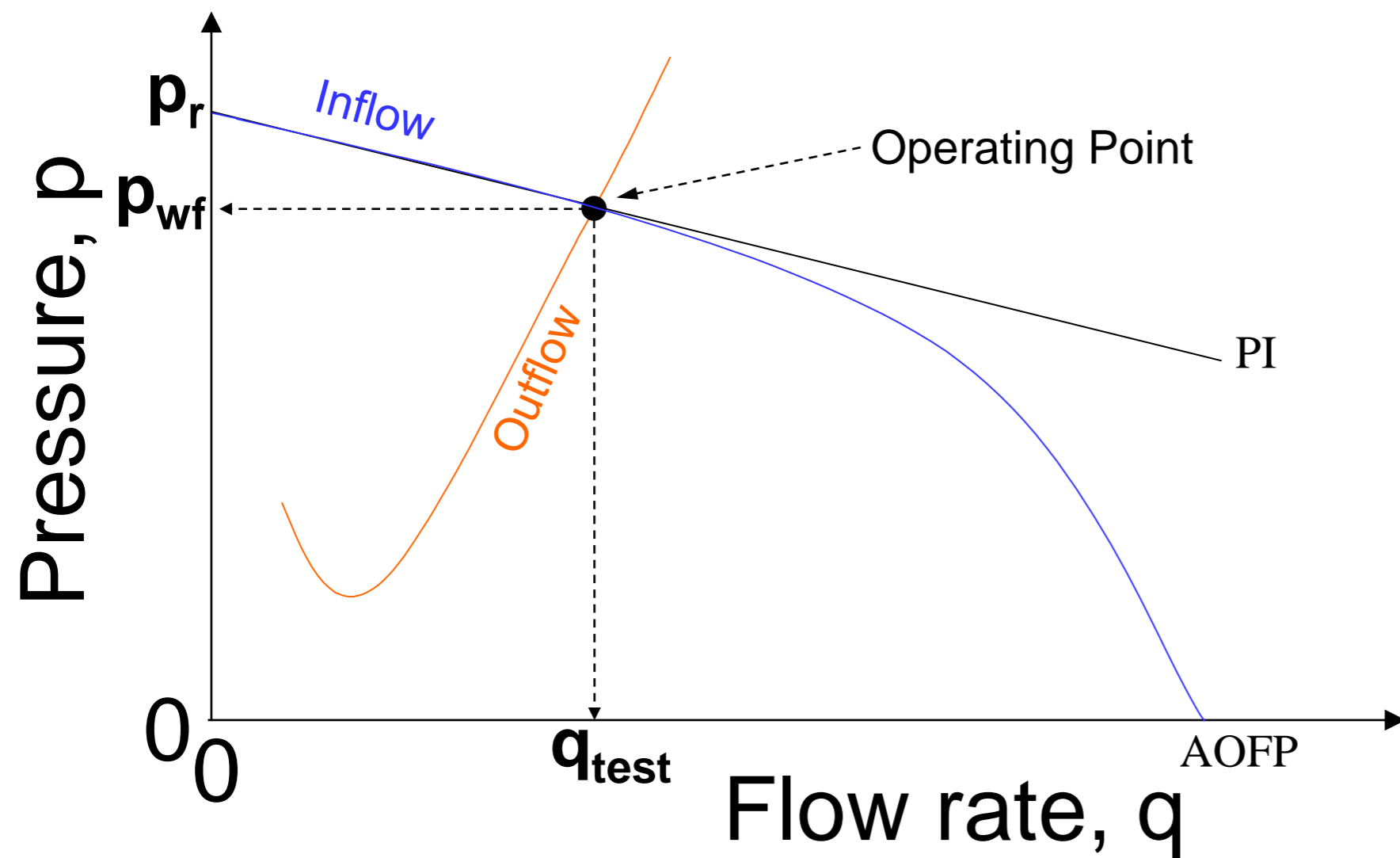
Primary objectives depend on the type of test

# Wireline Formation Tests

Objective		WT	WFT
Fluid	Small Volume	✓	✓
	Large Volume	✓	✗
Well Flow		✓	✗
Reservoir Flow		✓	✗
Reservoir Description	Versus Depth	✗	✓
	Formation	✓	✓
	Boundaries	✓	✗

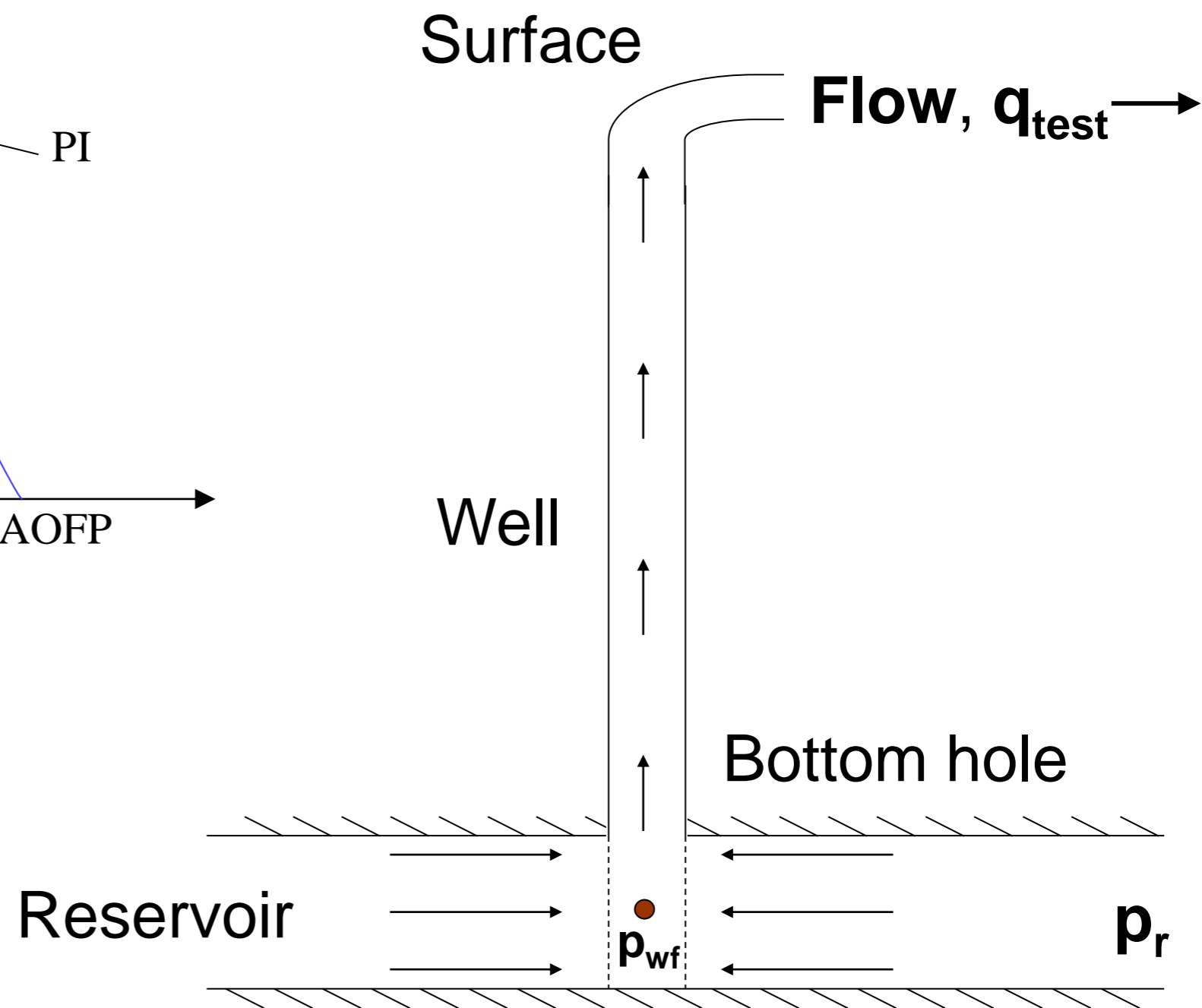
WFT and WT are not equivalent

# Well Performance

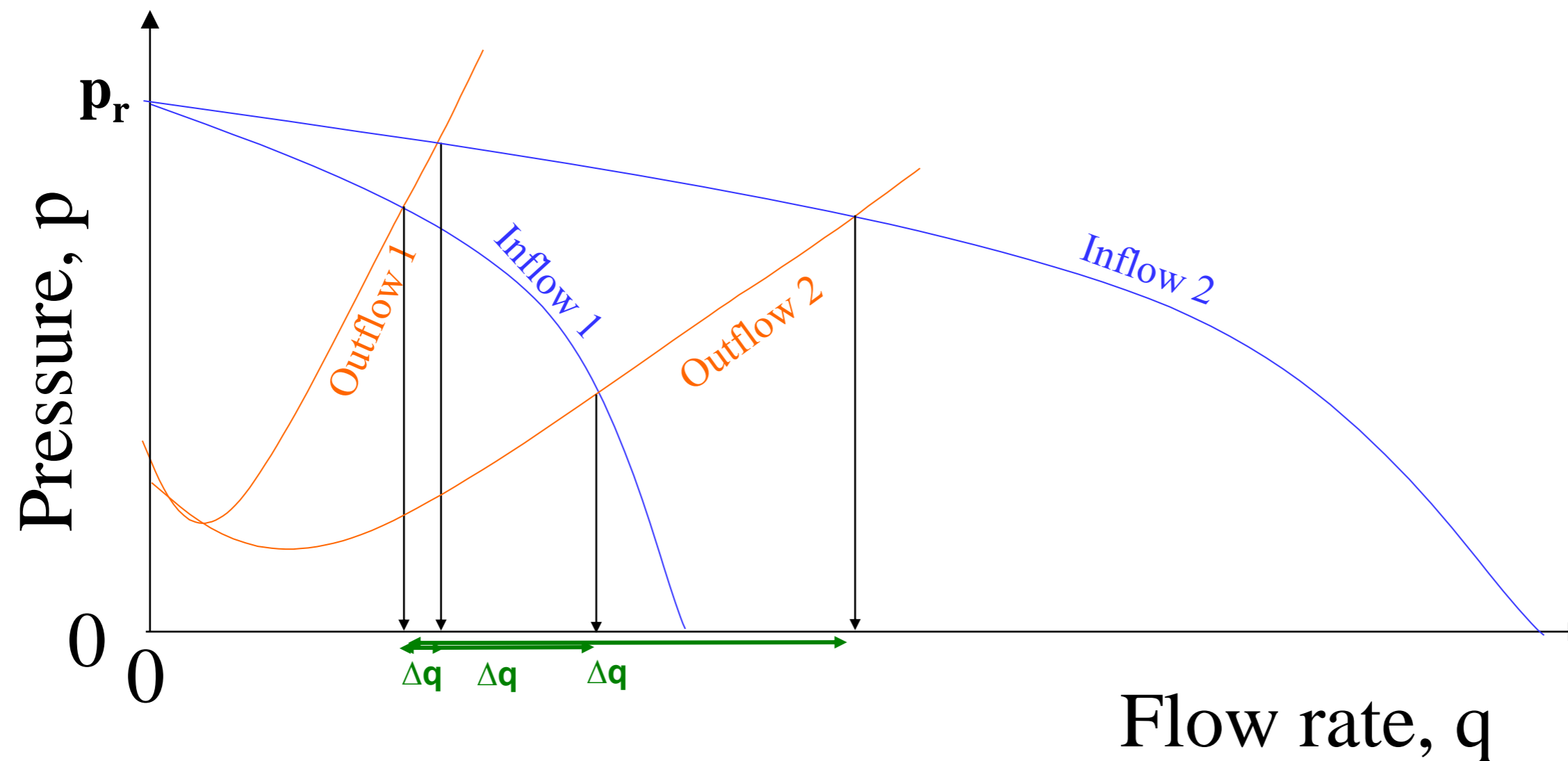


Productivity Index

$$PI = \frac{q_{test}}{\bar{p}_r - p_{wf}}$$



# How to Improve Well Performance?

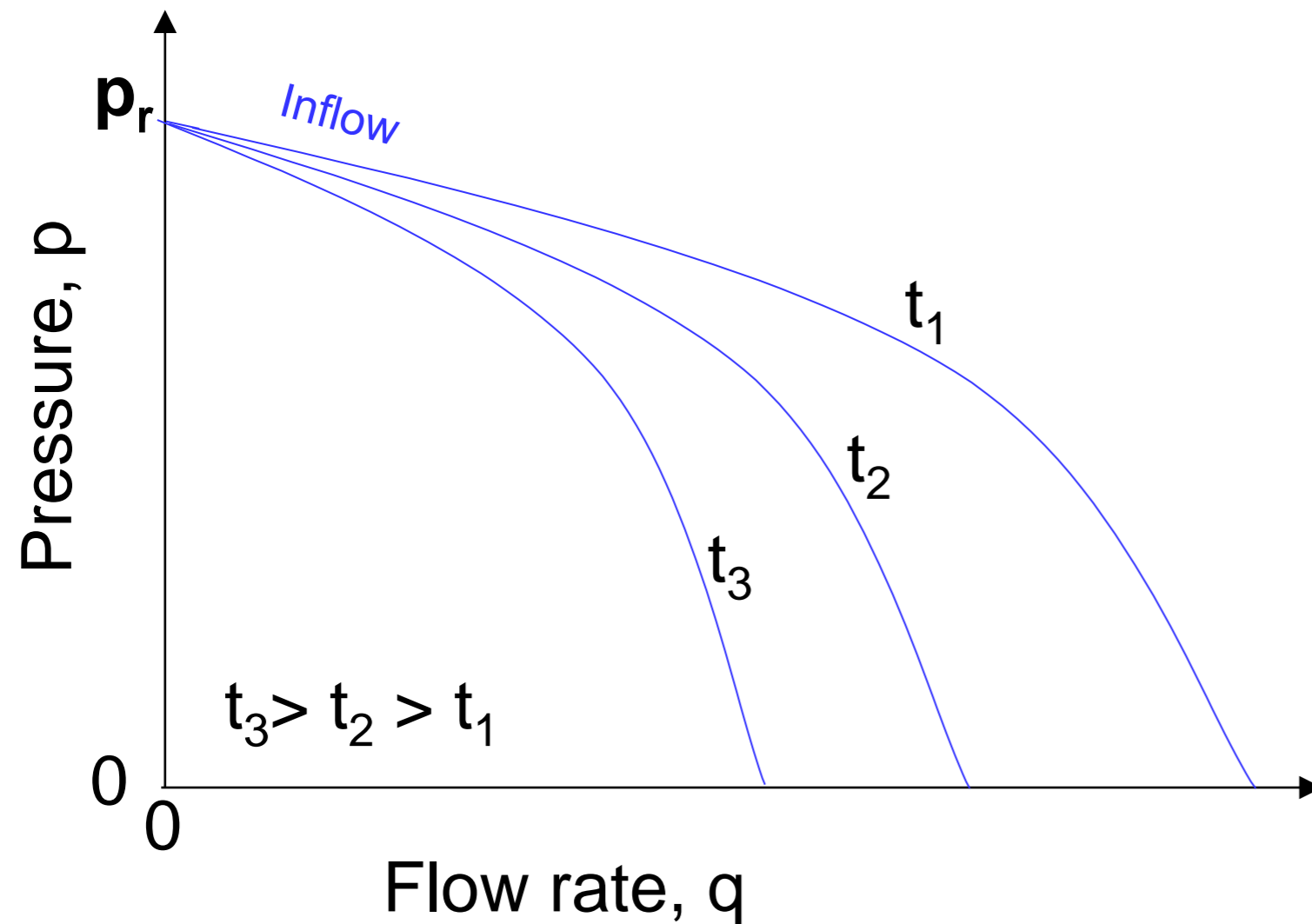


**Outflow 1** to **Outflow 2** → Change in completion (tubing, choke, artificial lift...)

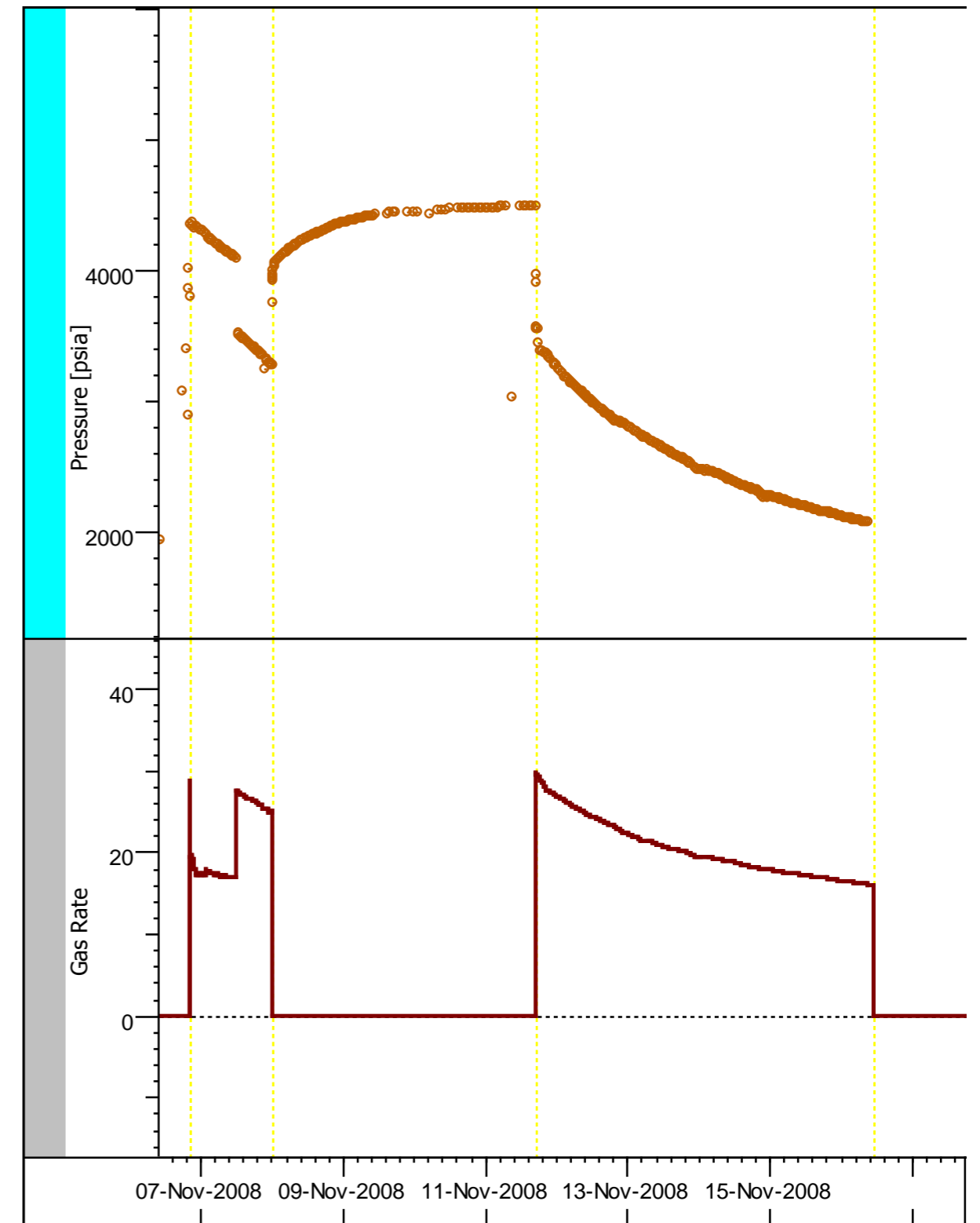
**Inflow 1** to **Inflow 2** → Change in well/reservoir (perfs, acid, frac, well type...)

**Need to understand Inflow to see if improvement is possible...**

# Reservoir Deliverability

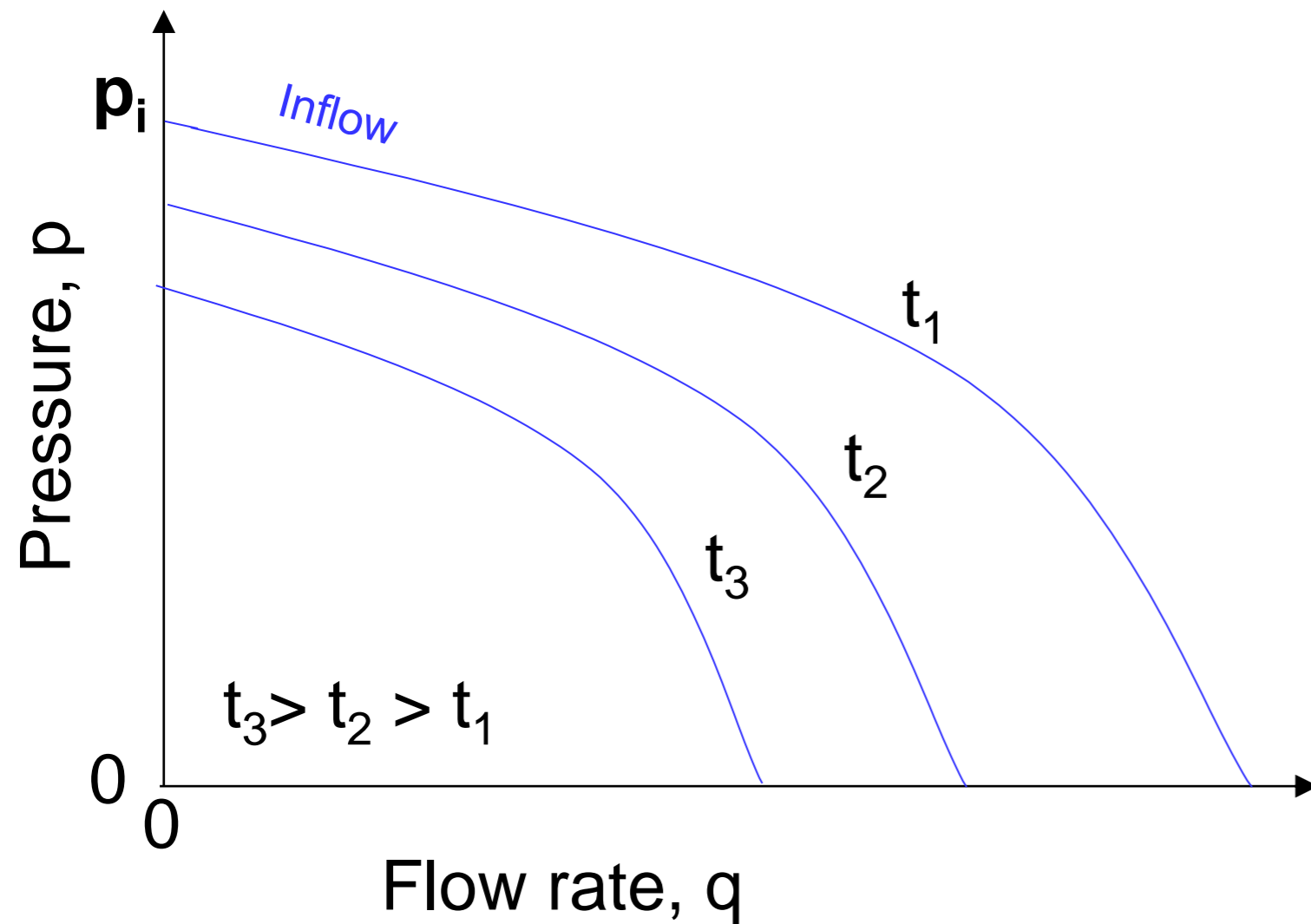


- Reservoir constrained
  - Complex boundaries (e.g. channel sands)
  - Low permeability

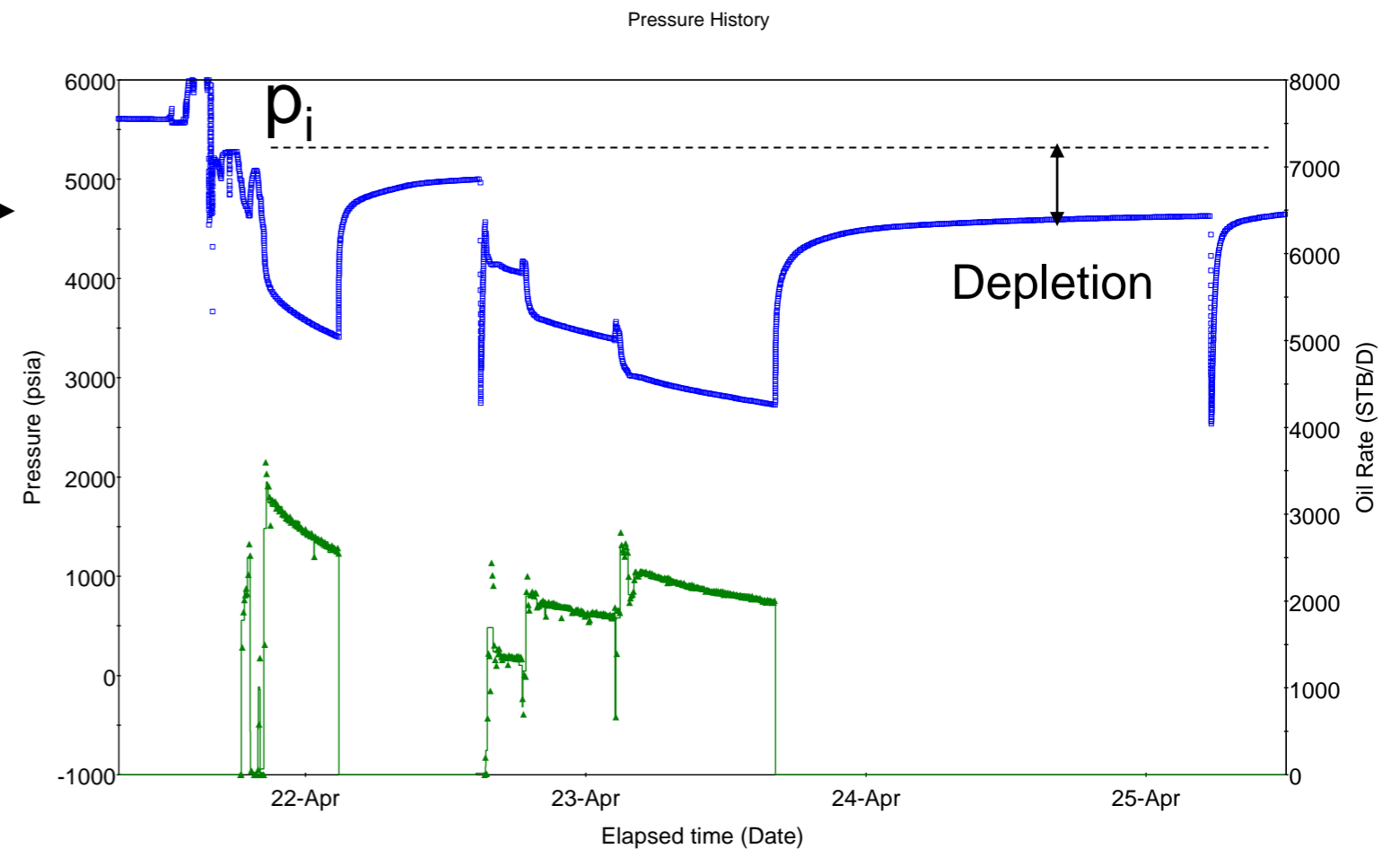


Pressure [psia], Gas Rate [MMscf/D] vs Time [ToD]

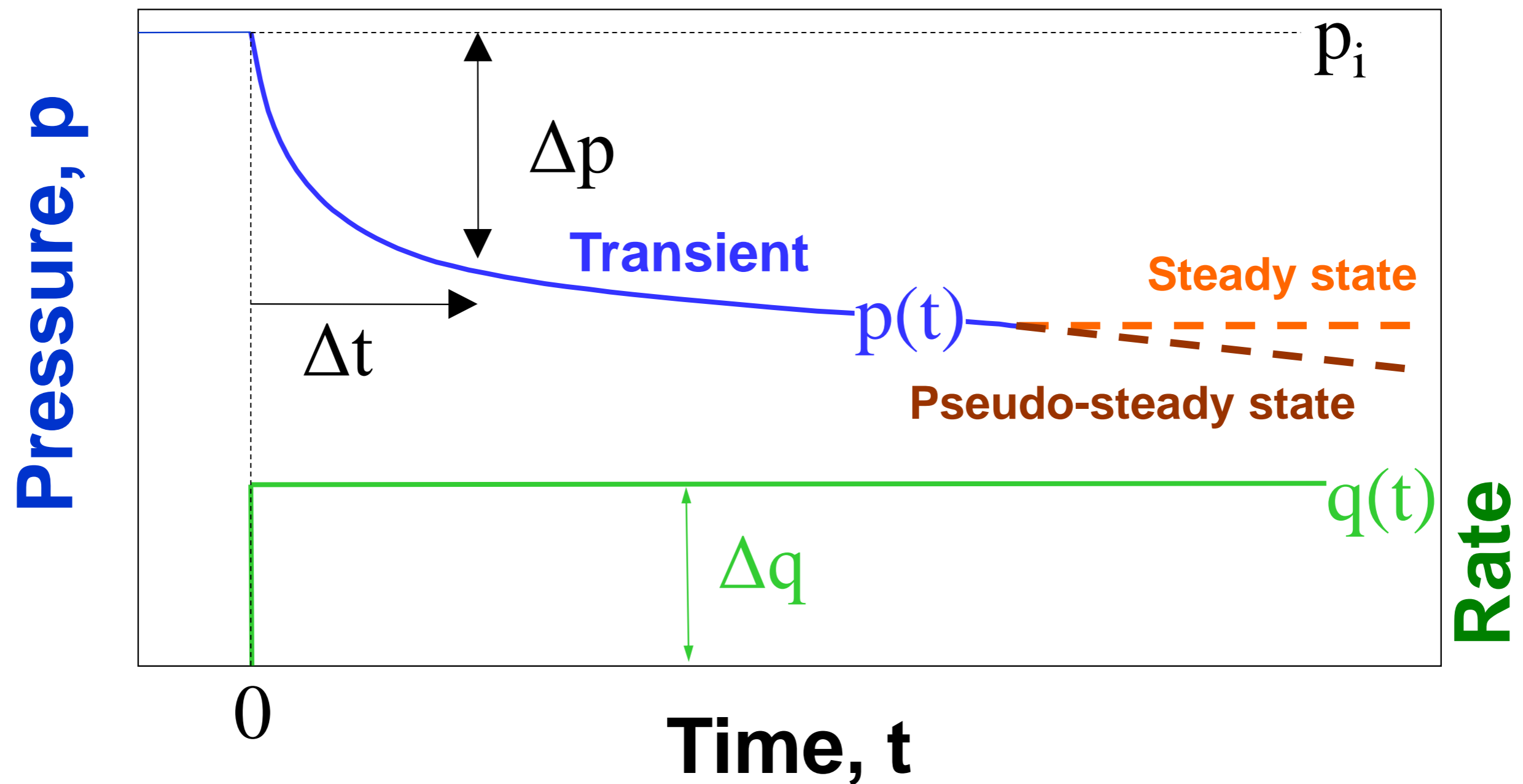
# Reservoir Deliverability



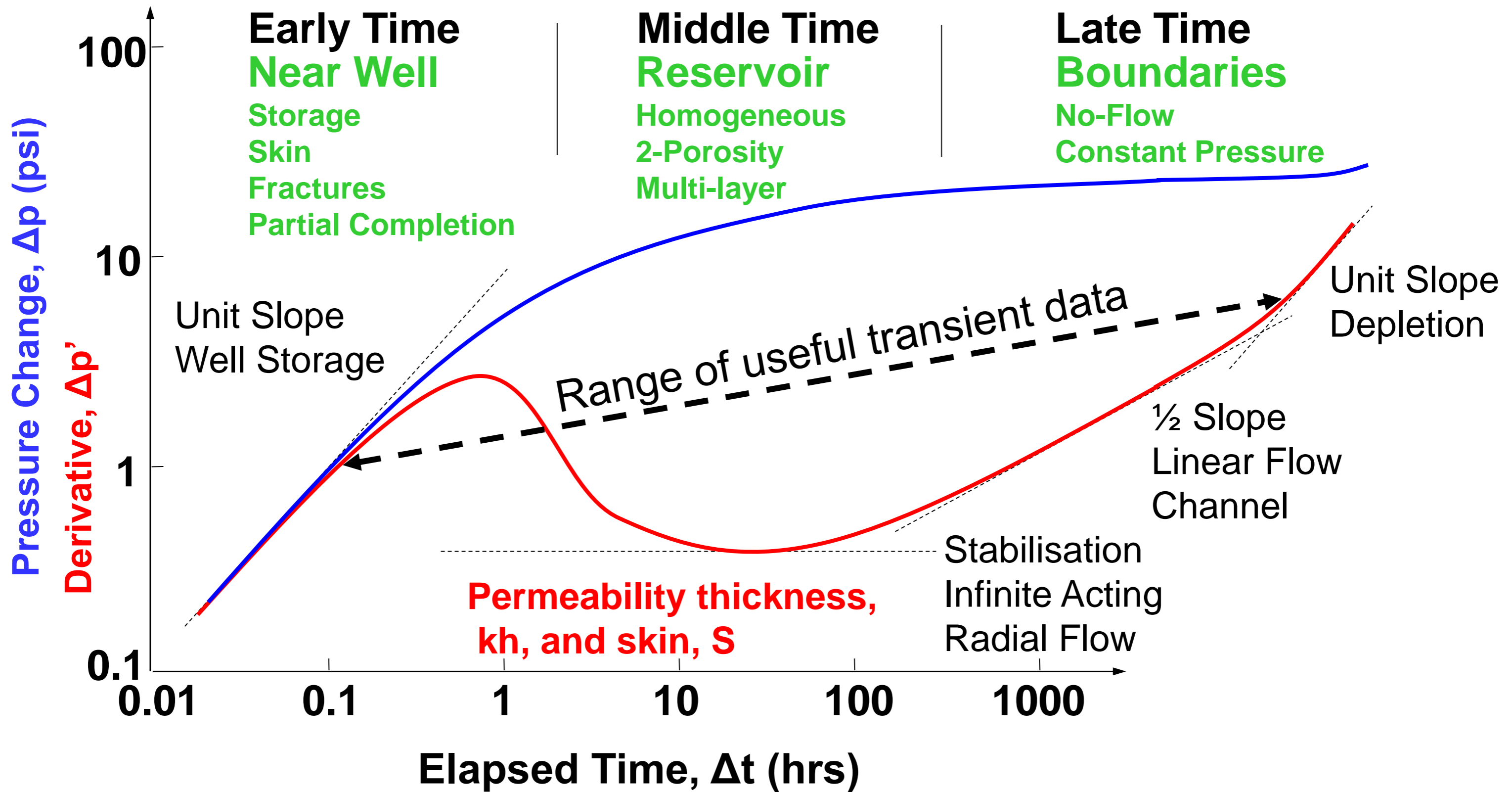
- Depletion
- Hopefully not seen in a well test!



# Pressure Transient Analysis



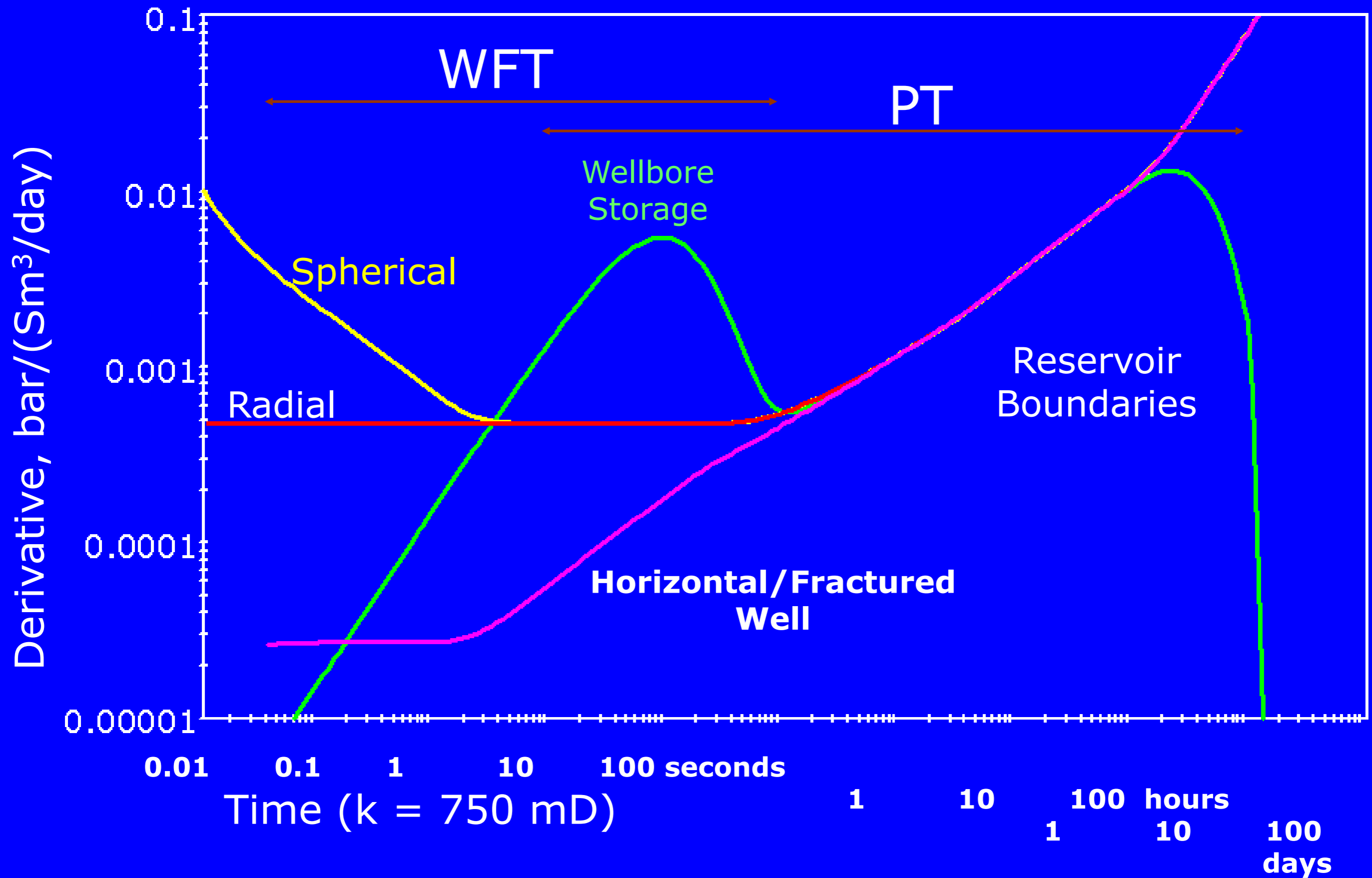
# Log-log Diagnostic Plot



$$\Delta p' = dp/d(\ln t) = t dp/dt$$

Assuming single constant rate drawdown...

# Pressure Transient Derivative Response



# Scale

(Mini-frac)

	While Drilling	Wireline		Well Test
		Pressure Test	Sampling	
Volumes	1-10 cc	5-50 cc	10-100 l	1-10000 m <sup>3</sup>
x-factor	1	5	10000	10 <sup>6</sup> -10 <sup>9</sup>
Times	1-5 min	1-15 min	1-5 hr	12hrs – 12days
x-factor	1	1-3	60	720-20000

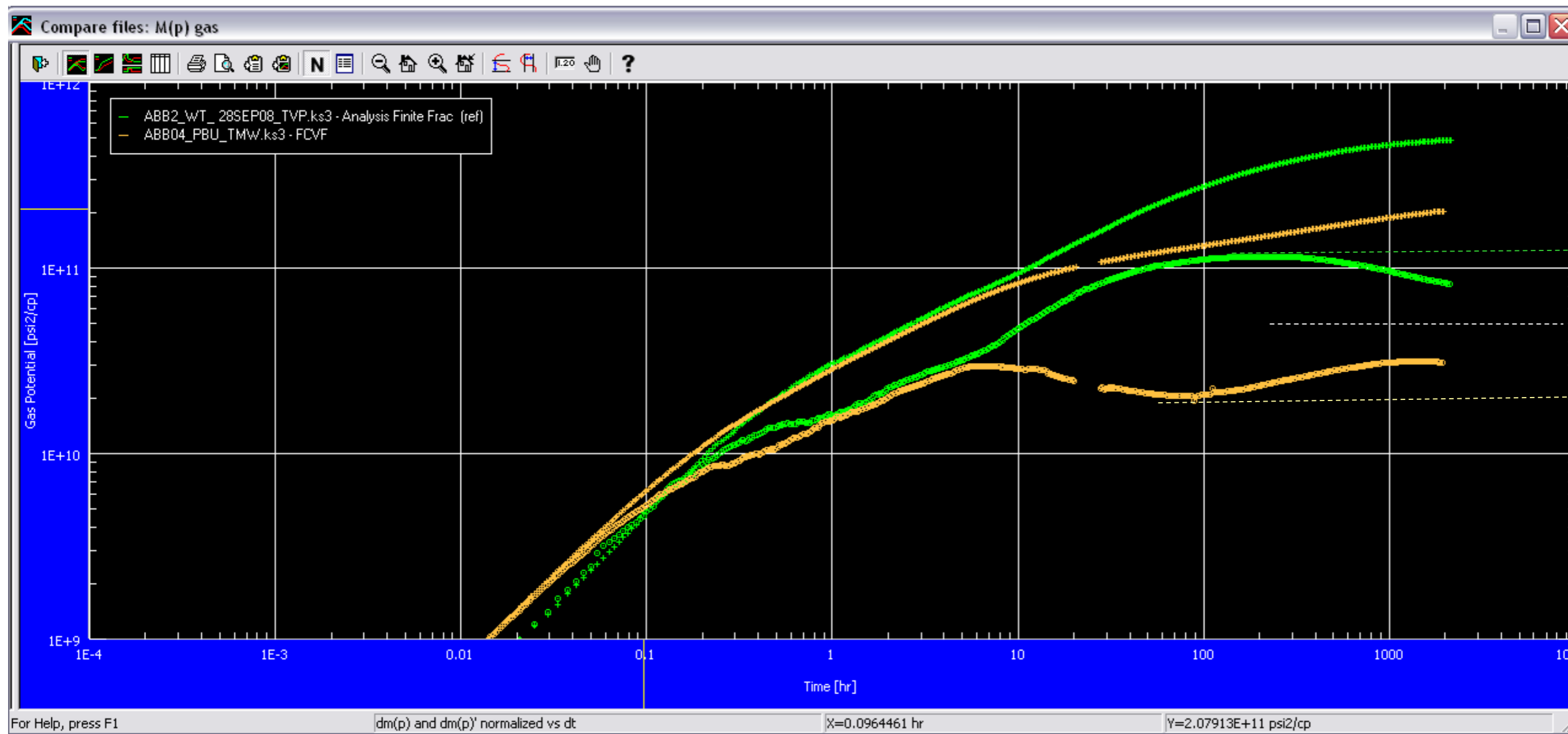
# Scale

Radius of investigation:  $r_i \propto \sqrt{\frac{k\Delta t}{\phi\mu ct}}$  (Mini-frac)

k/μ = 10 mD/cp ∅ct = 0.15x10 <sup>-5</sup> 1/psi h = 75 ft	While Drilling	Wireline		Well Test
		Pressure Test	Sampling/ Mini DST	
Flow Time	5 s	10 s	15 min	12 hr
Flow Volume	5 cc	10 cc	3000 cc	40x10 <sup>6</sup> cc (250 bbl)
Shut Time	30 s	3 min	5 min	24 hr
Δp/Δt (psi/min)	0.18	0.003	0.06	0.018
Theoretical r <sub>i</sub> (ft)	5	17	23	300
Practical r <sub>i</sub> * (ft)	2	4	15	250

\* Assuming a gauge resolution/noise of 0.03 psi

# Example – Low Permeability – Two Wells



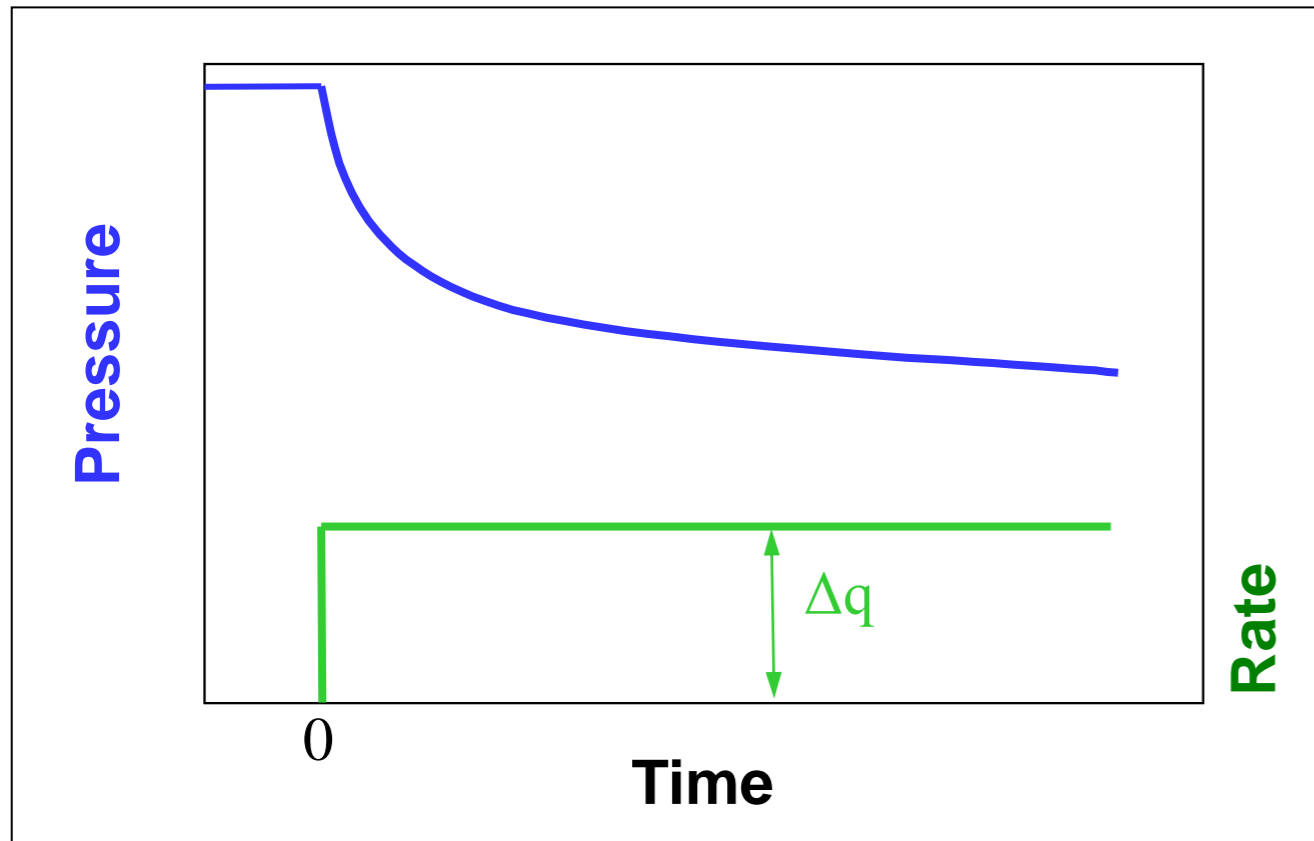
kh=2.5 mDft

kh=6 mDft

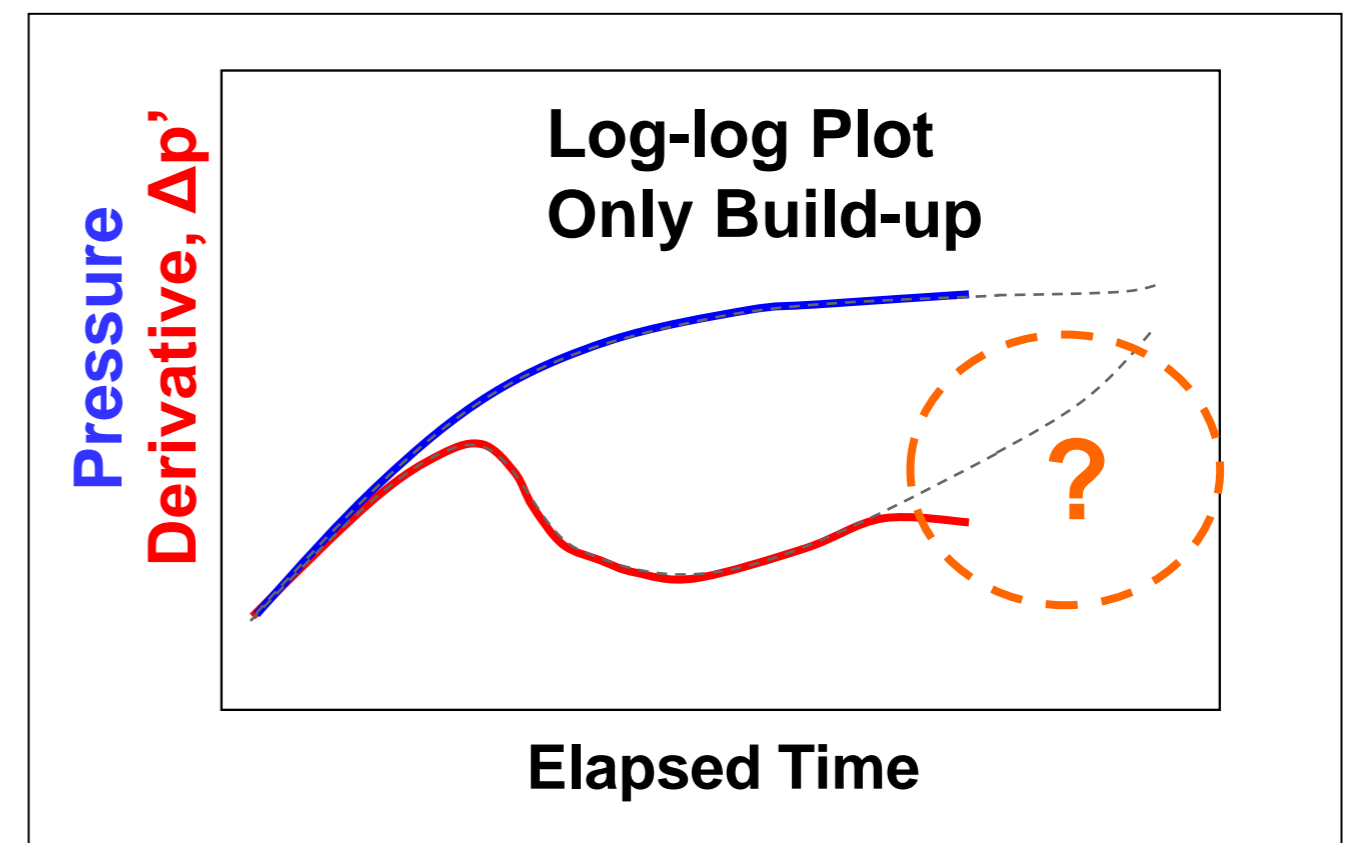
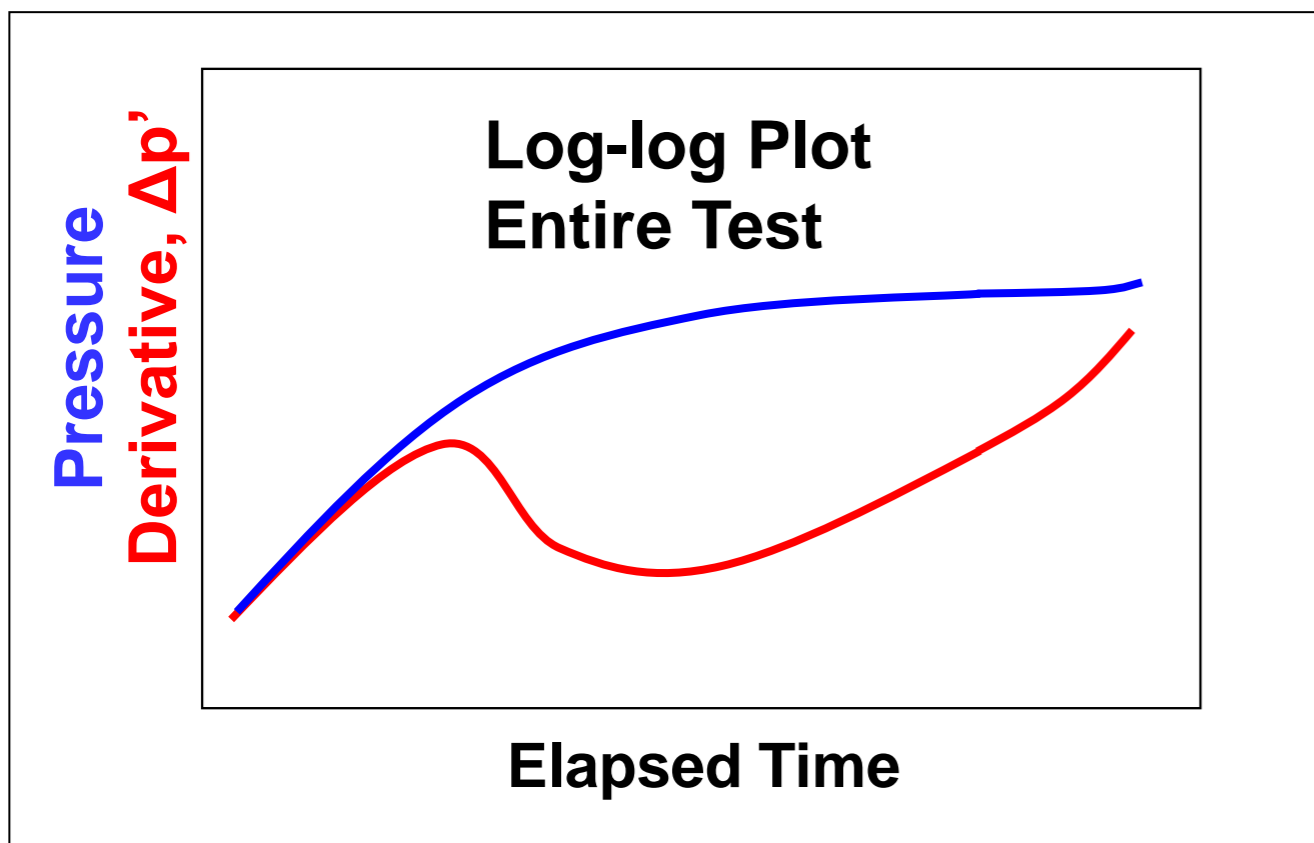
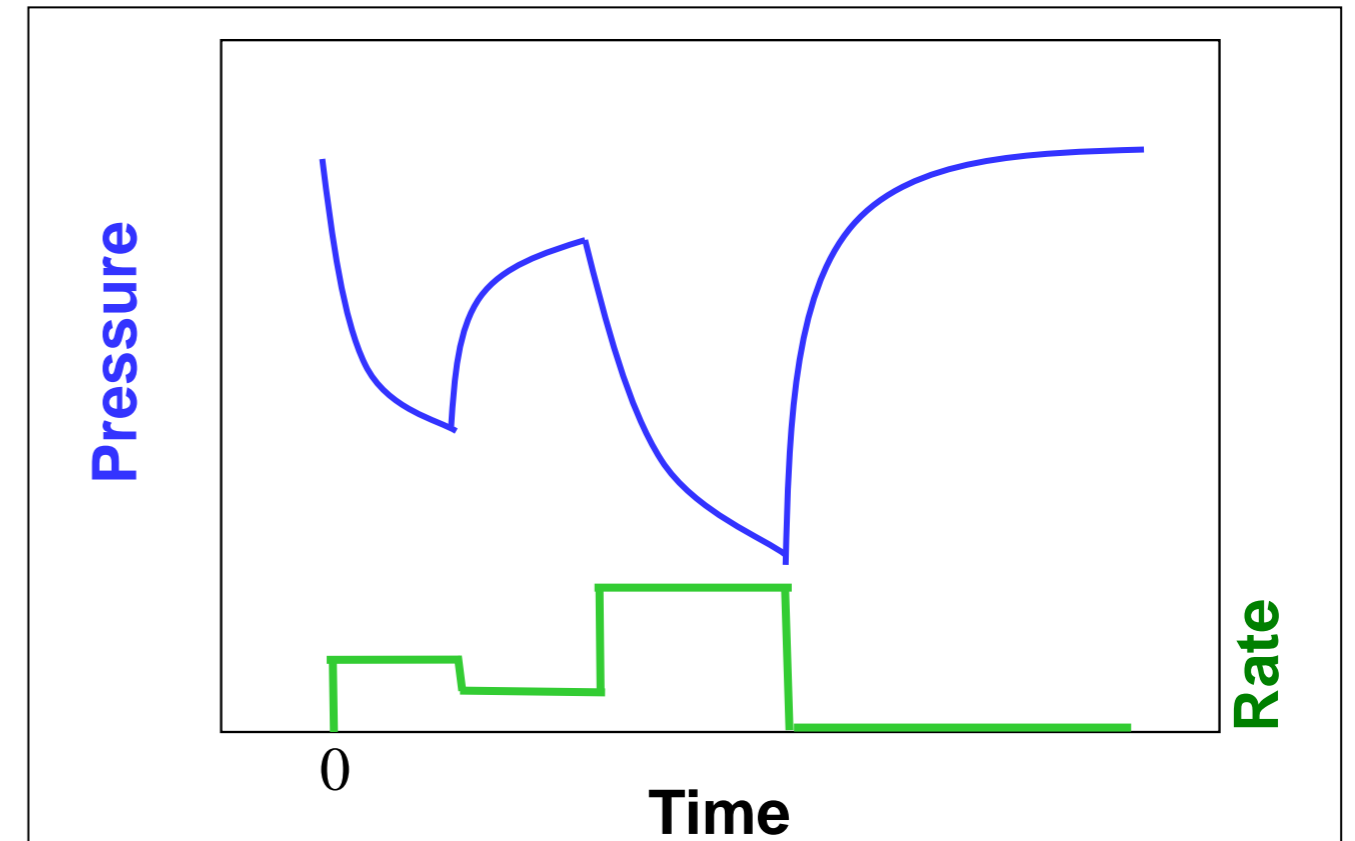
kh=16 mDft

# Data Acquisition: Well Test Sequence of Events

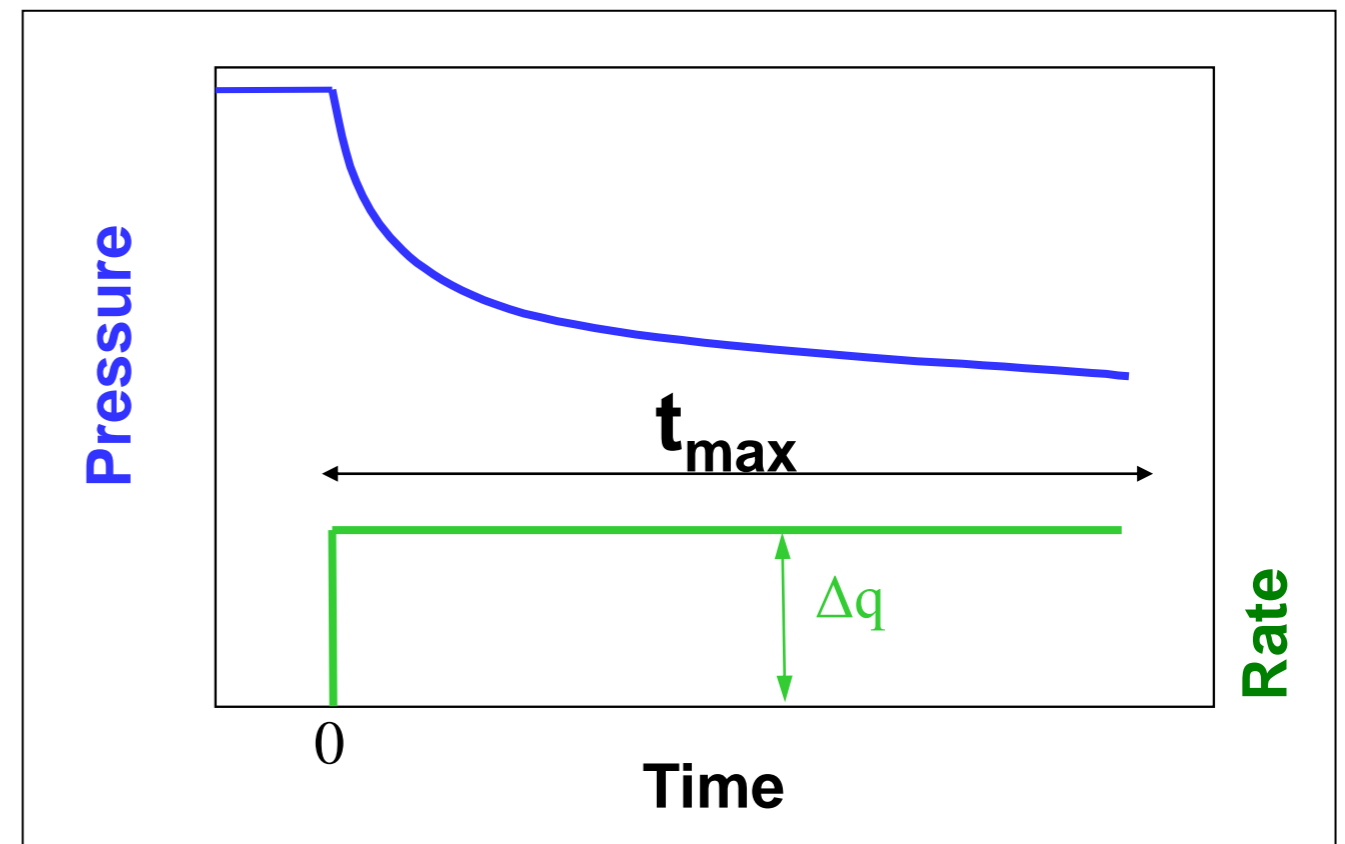
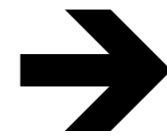
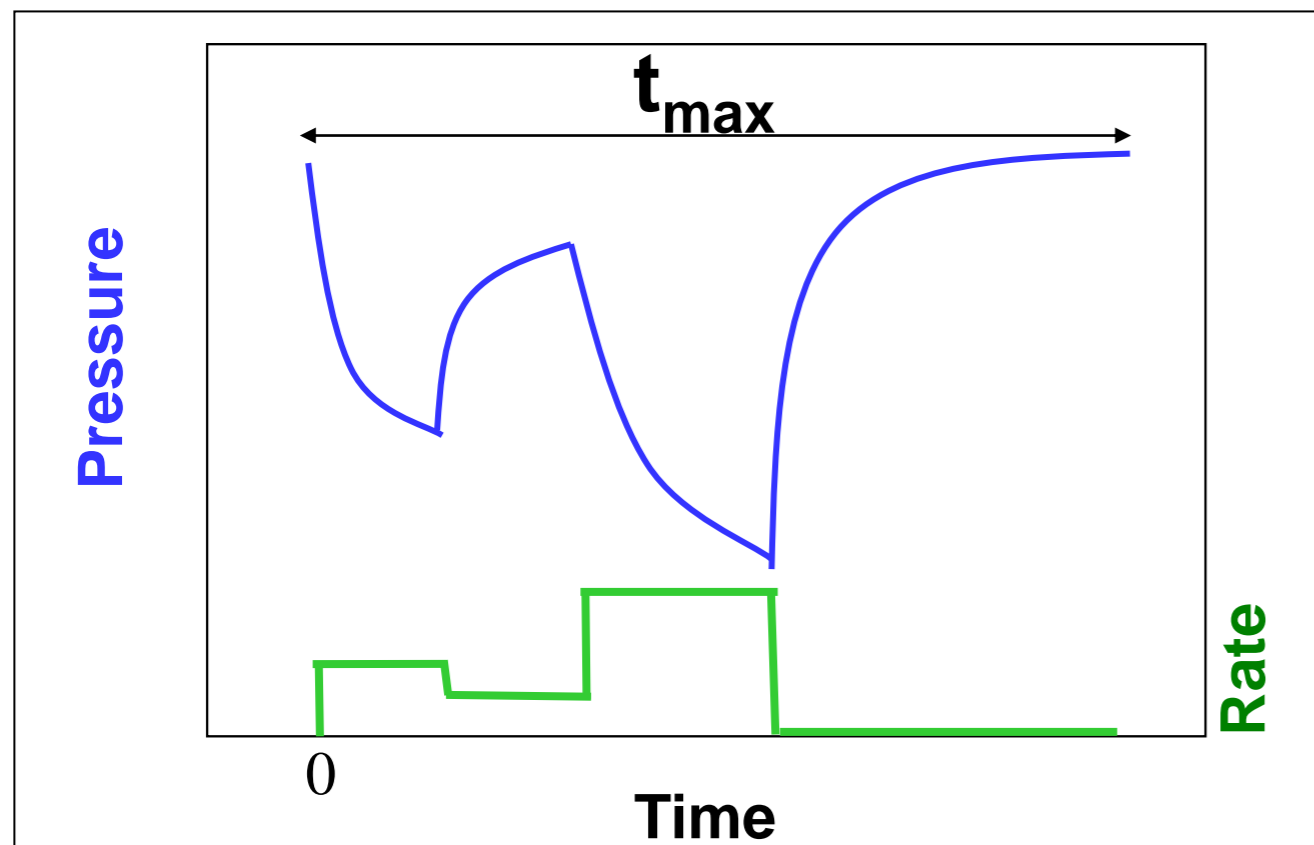
## Ideal Case



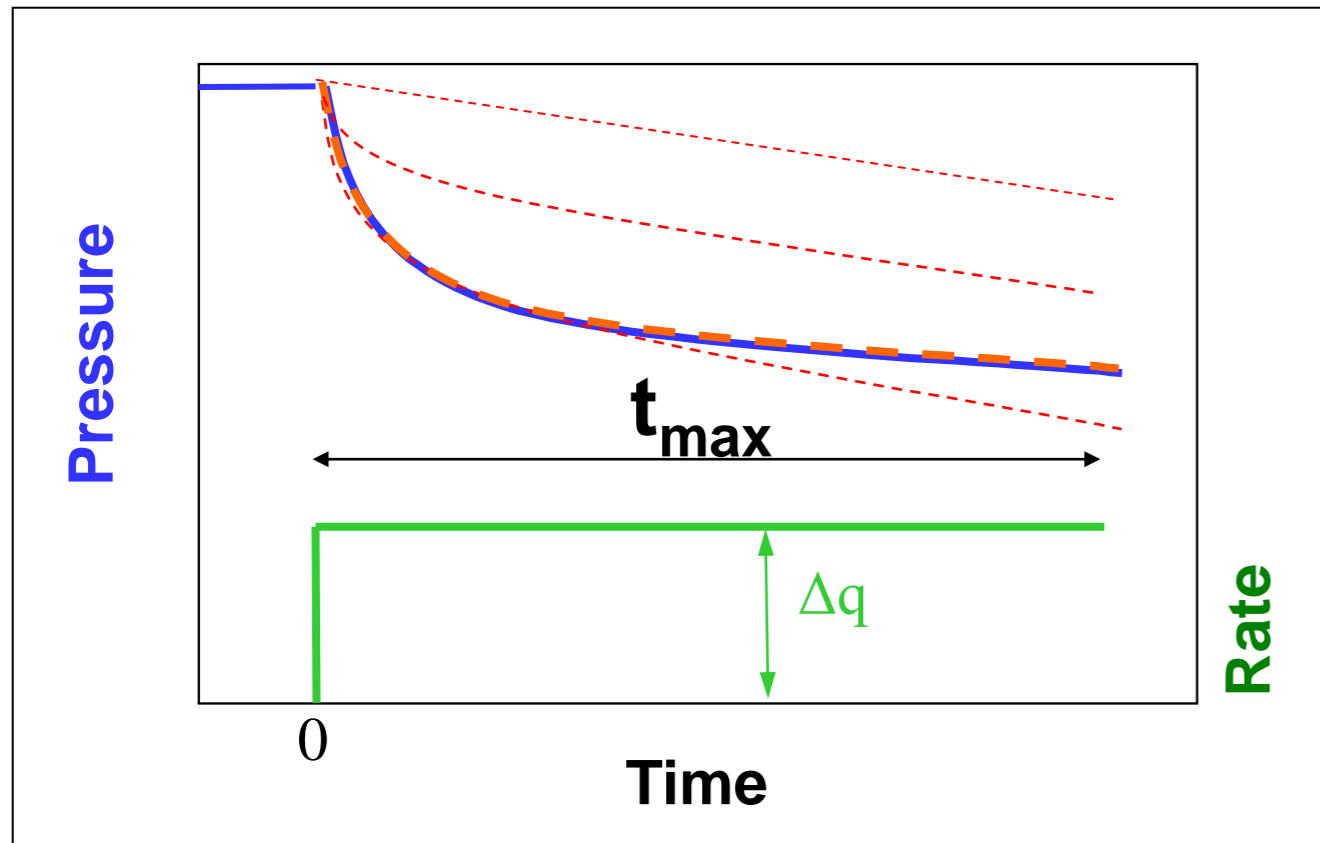
## Actual Case



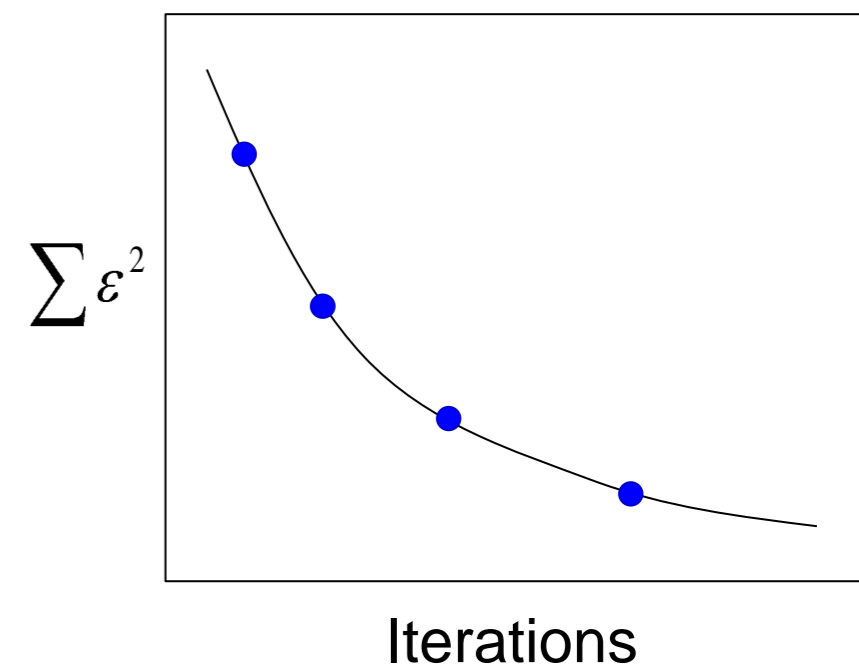
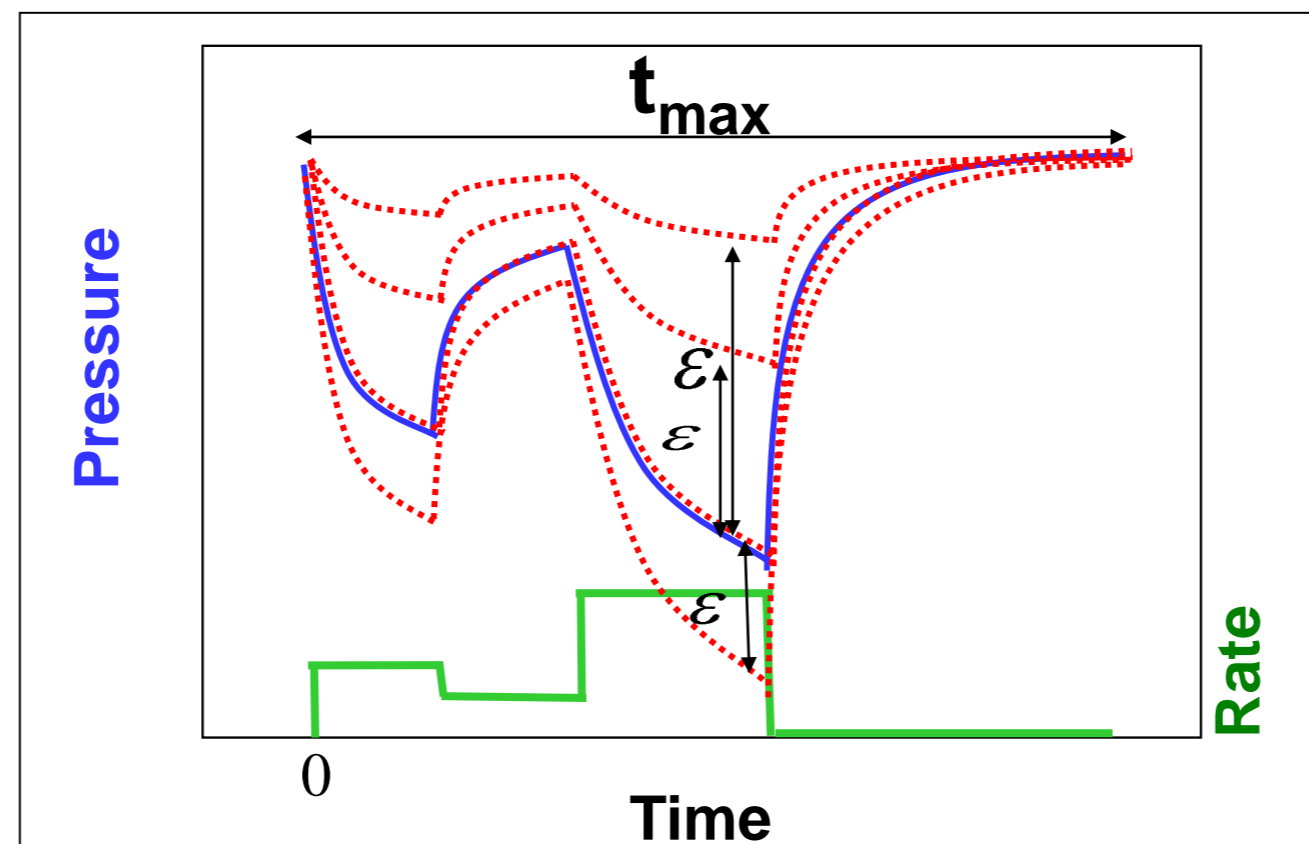
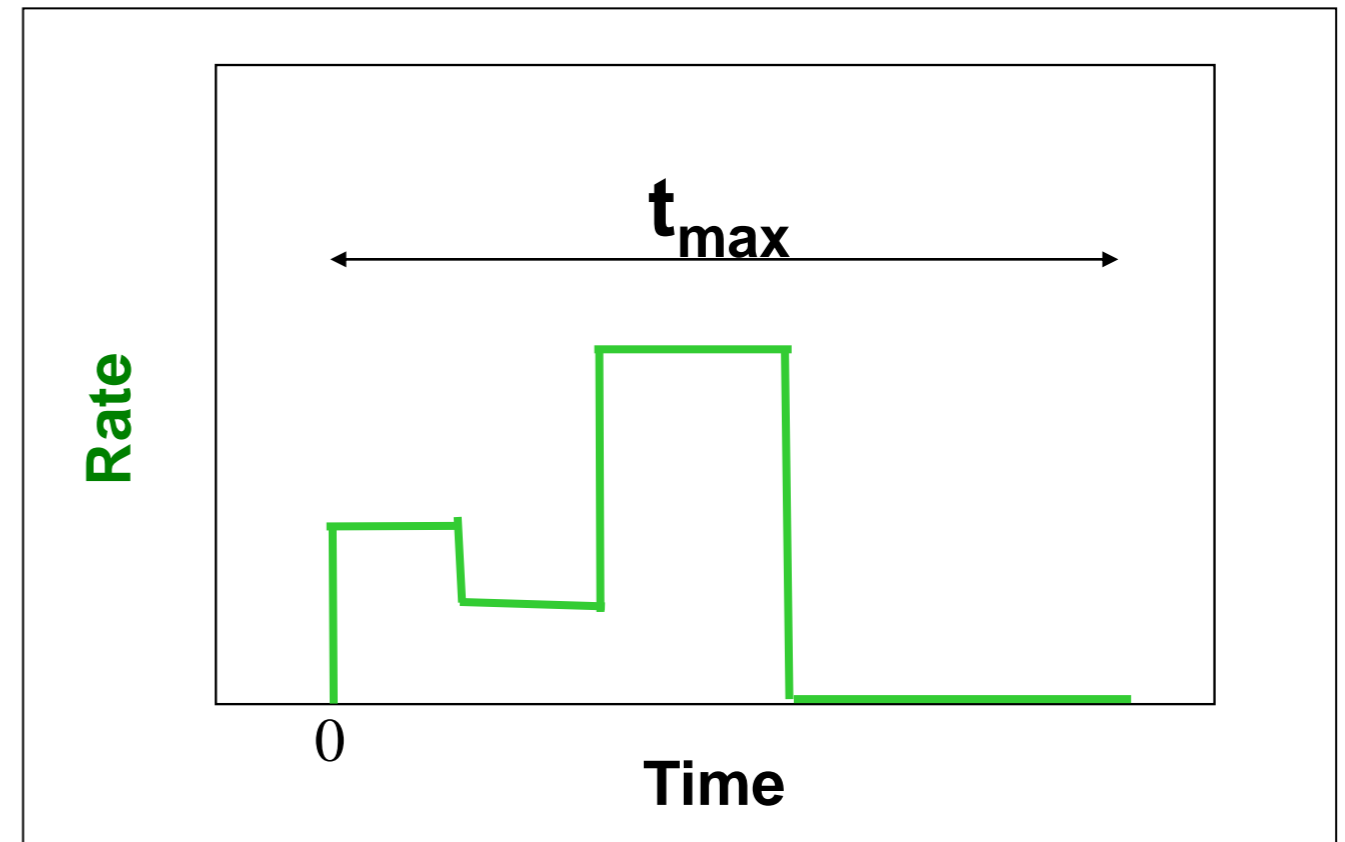
# Deconvolution



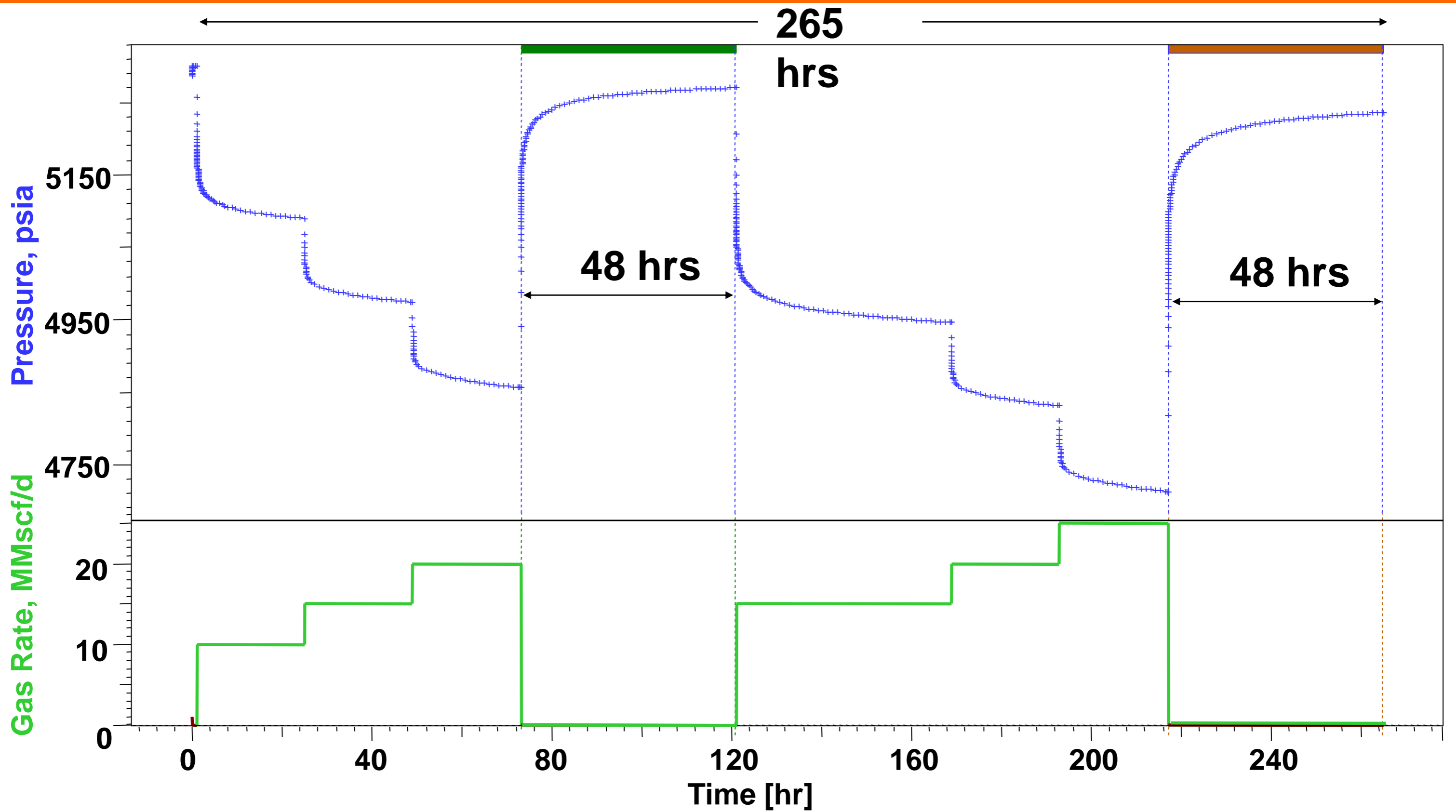
# Deconvolution by Iteration using superposition



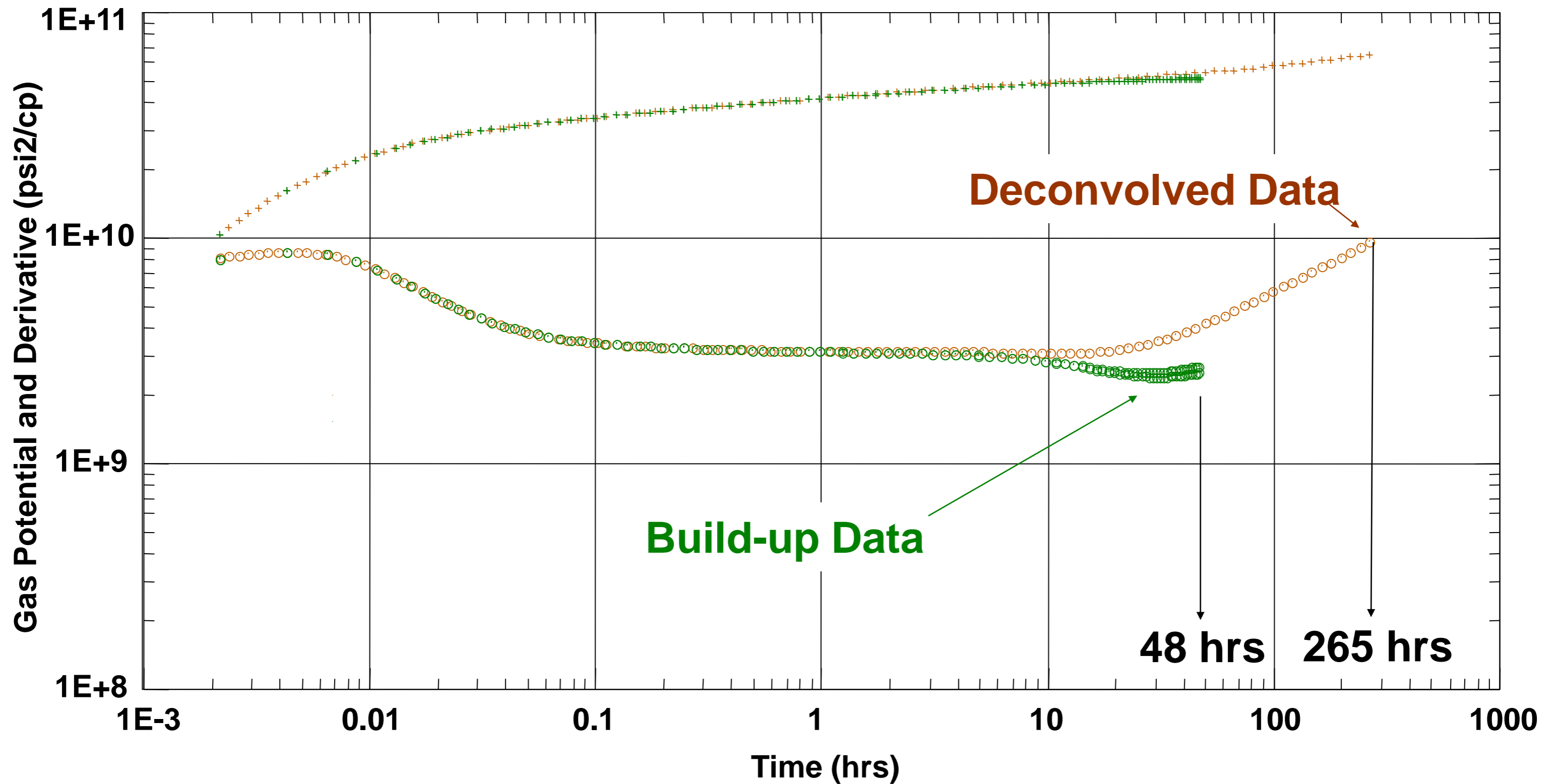
+



# Example

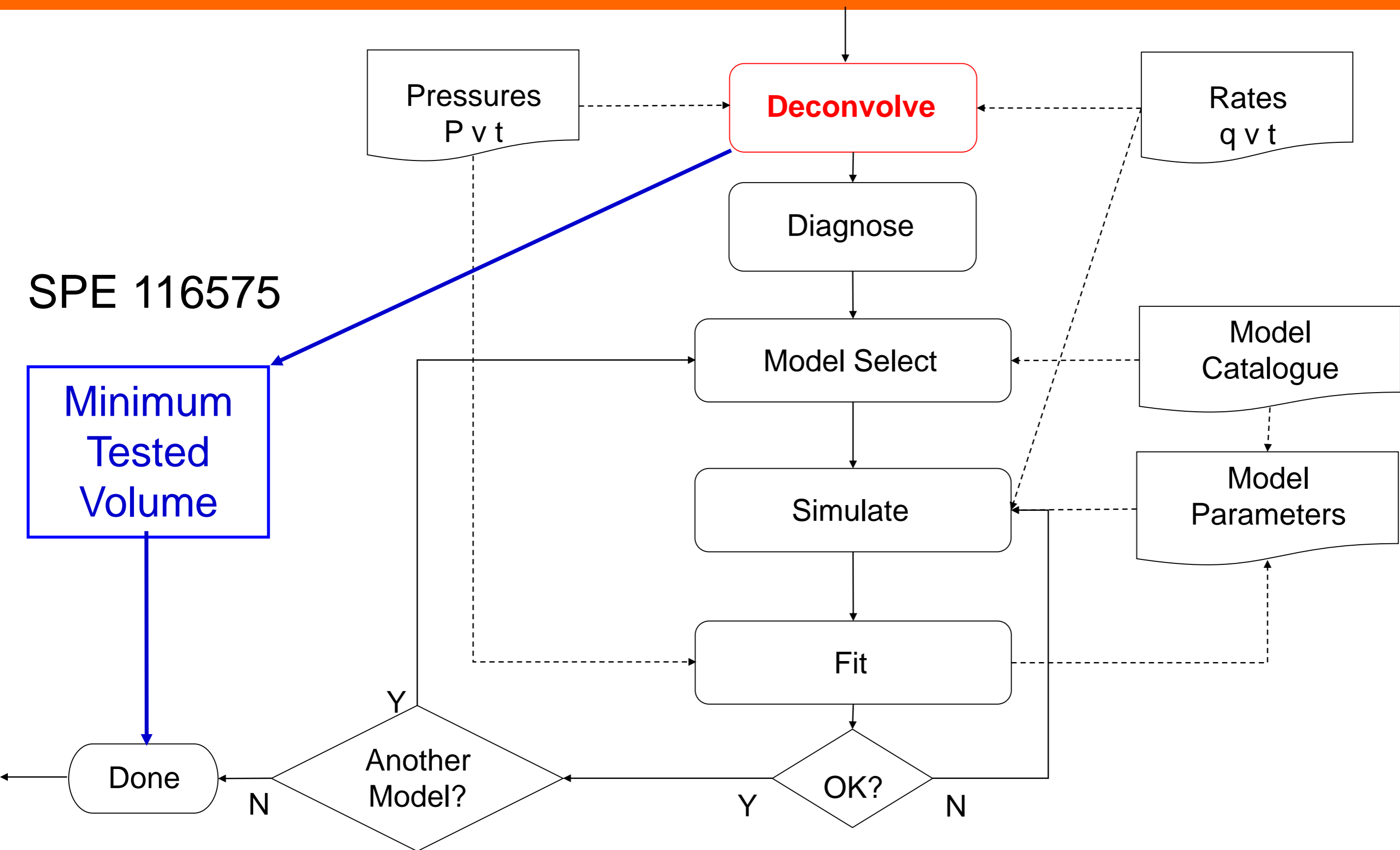


# Example - DST

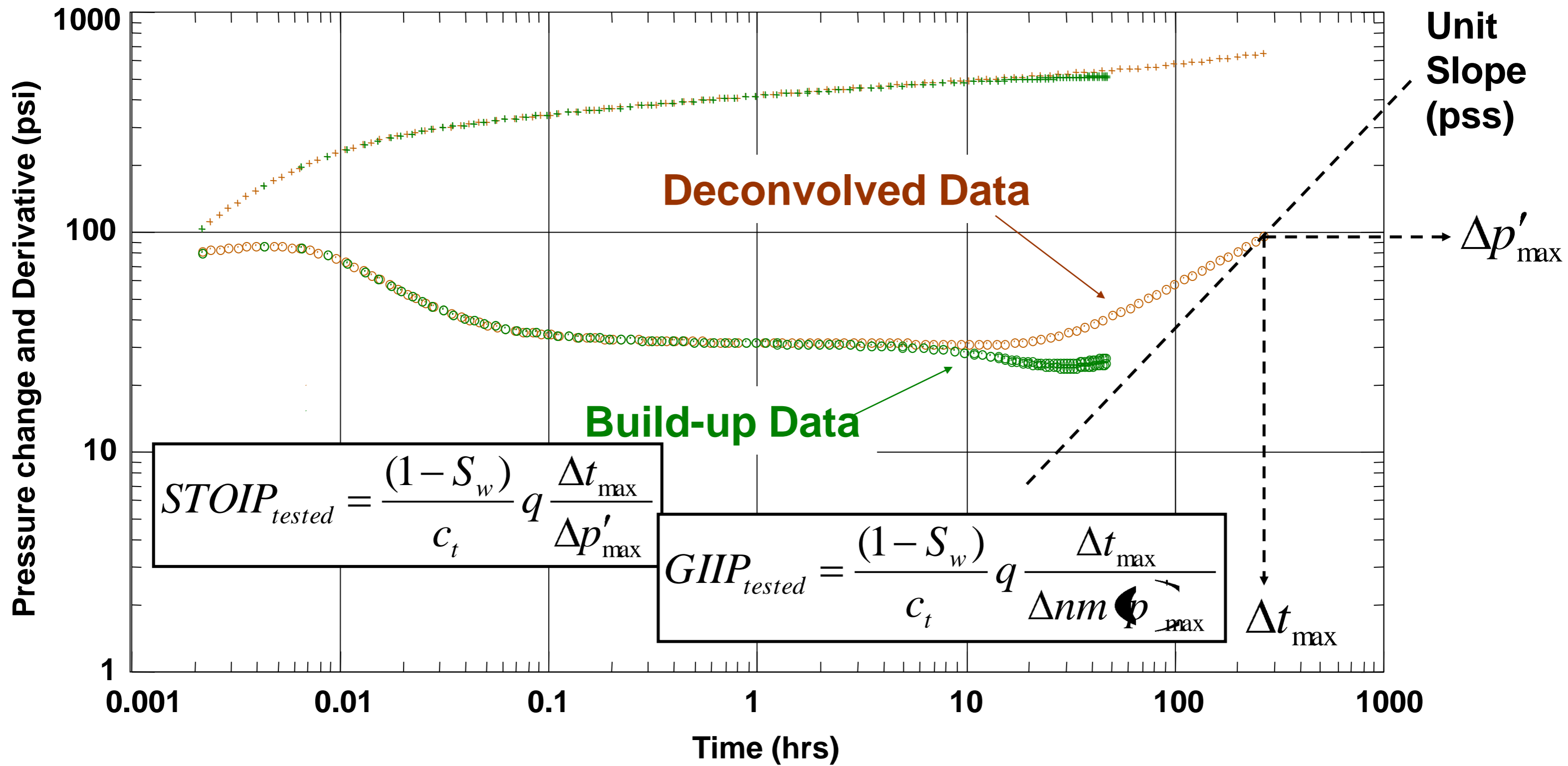


Longer duration of deconvolved data → larger radius of investigation?

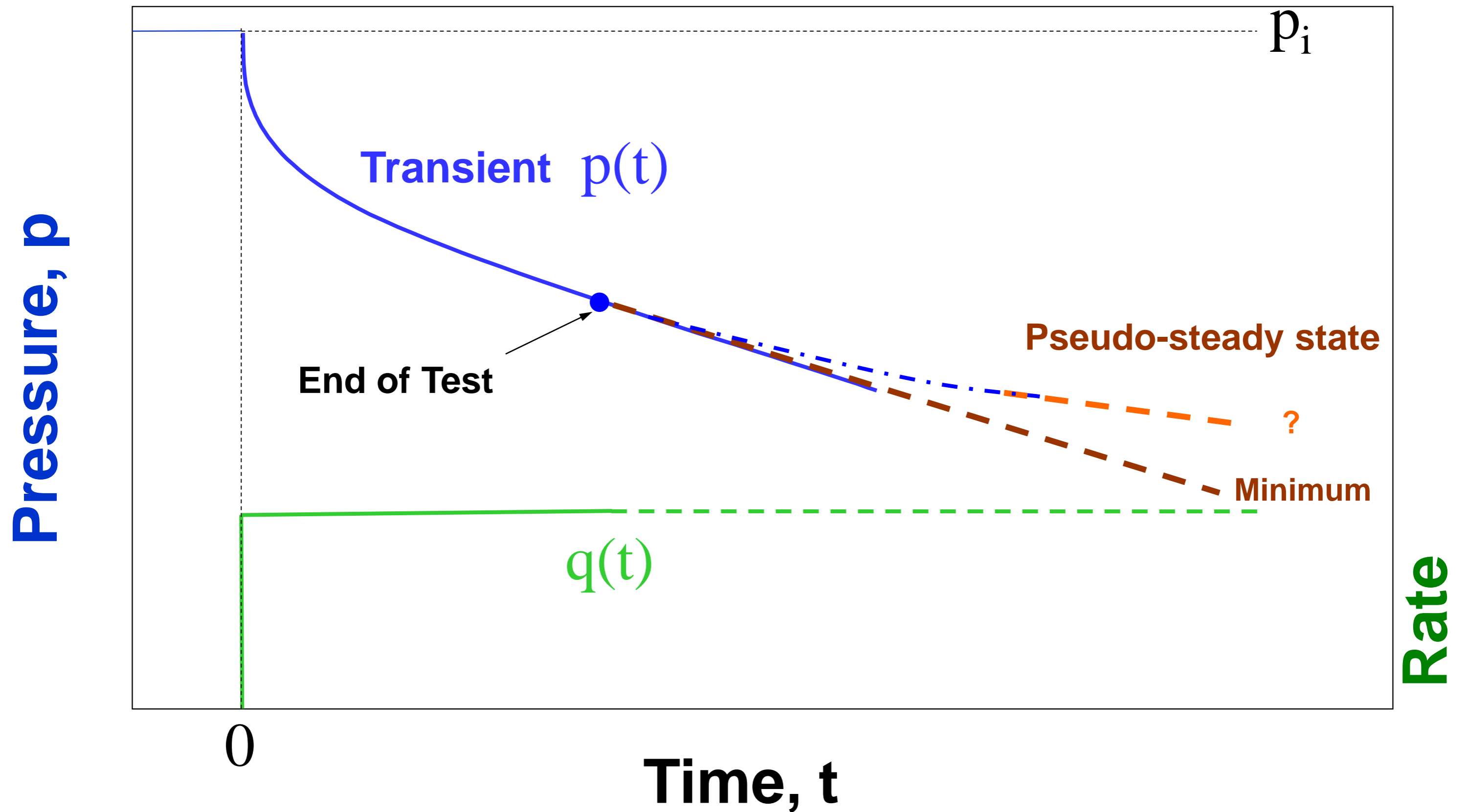
# Pressure Transient Analysis Workflow



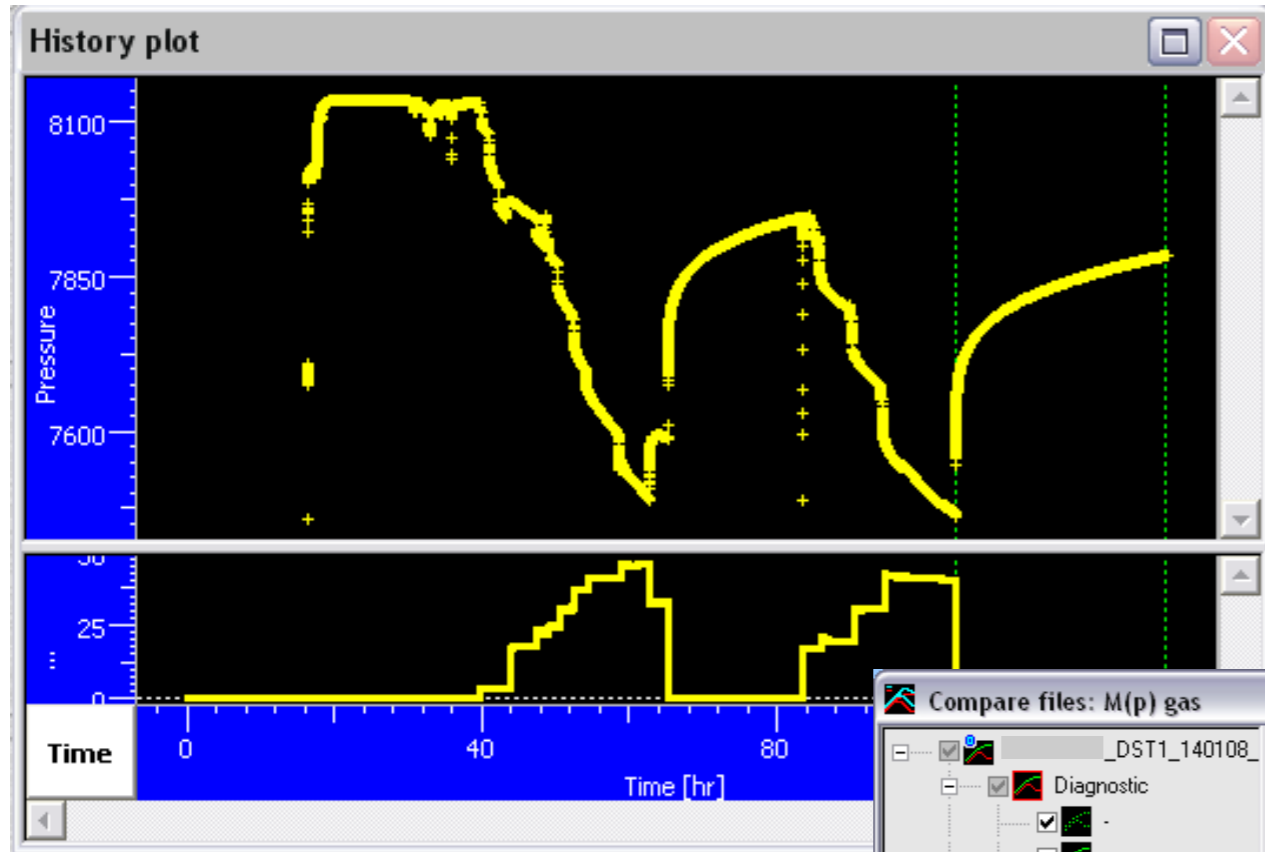
# Minimum Tested Pore Volume



# Same Principle as Reservoir Limits Test (MBH)



# Example 1 - Gas



$$GIIP_{tested} = \frac{(1 - S_w)}{c_t} q \frac{\Delta t_{max}}{\Delta m(p)_{max}} \frac{2\bar{p}}{\bar{\mu}z}$$

$$GIIP_{tested} = \frac{(1 - 0.15)}{6.625E-5} \times 40.4 \times \frac{93.6/24}{2.30E8} \times \frac{2 \times 8135.32}{0.032 \times 1.247}$$

$$= 3534 MMscf = 3.53 bscf$$

Input:

$$S_w = 0.15$$

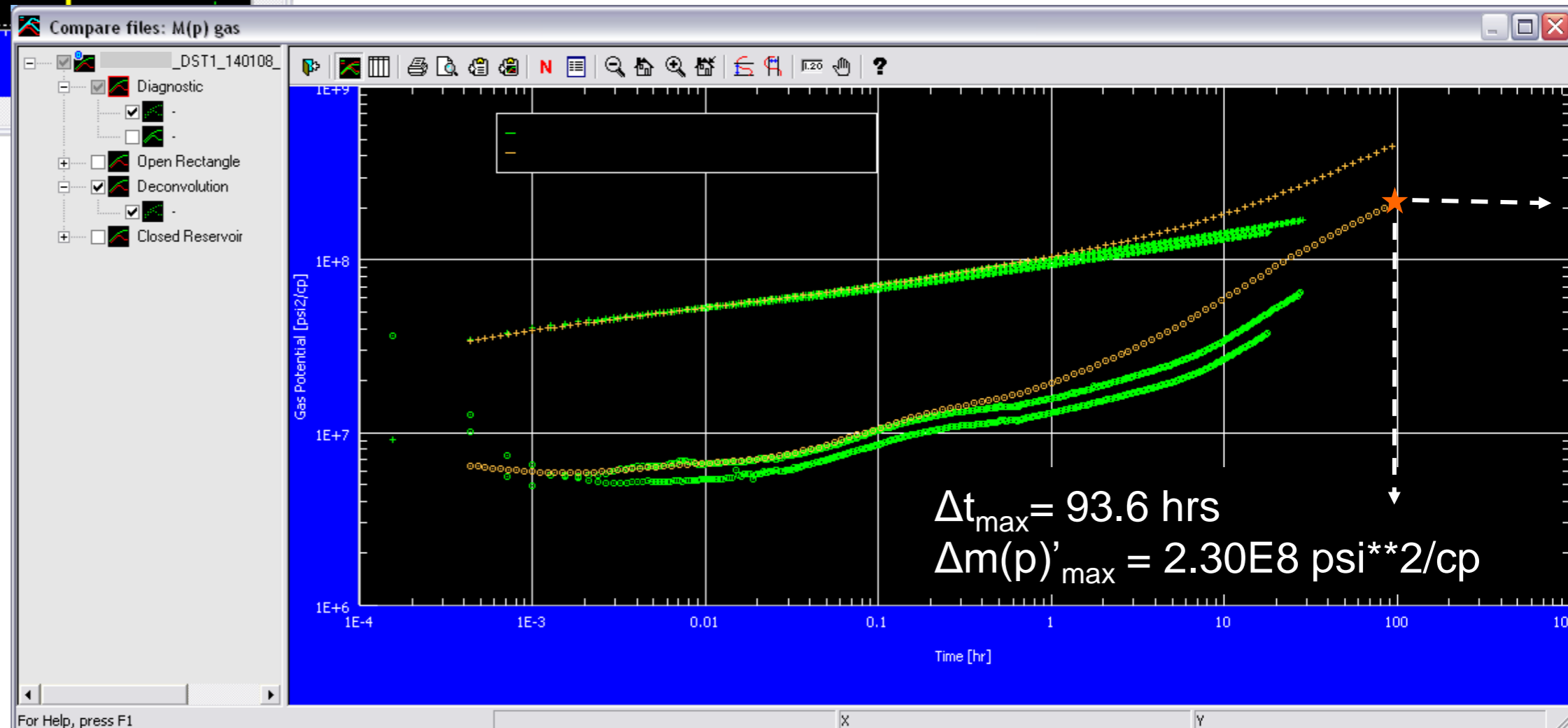
$$c_t = 6.62E-5 \text{ 1/psi}$$

$$q = 40.4 \text{ MMscf/d}$$

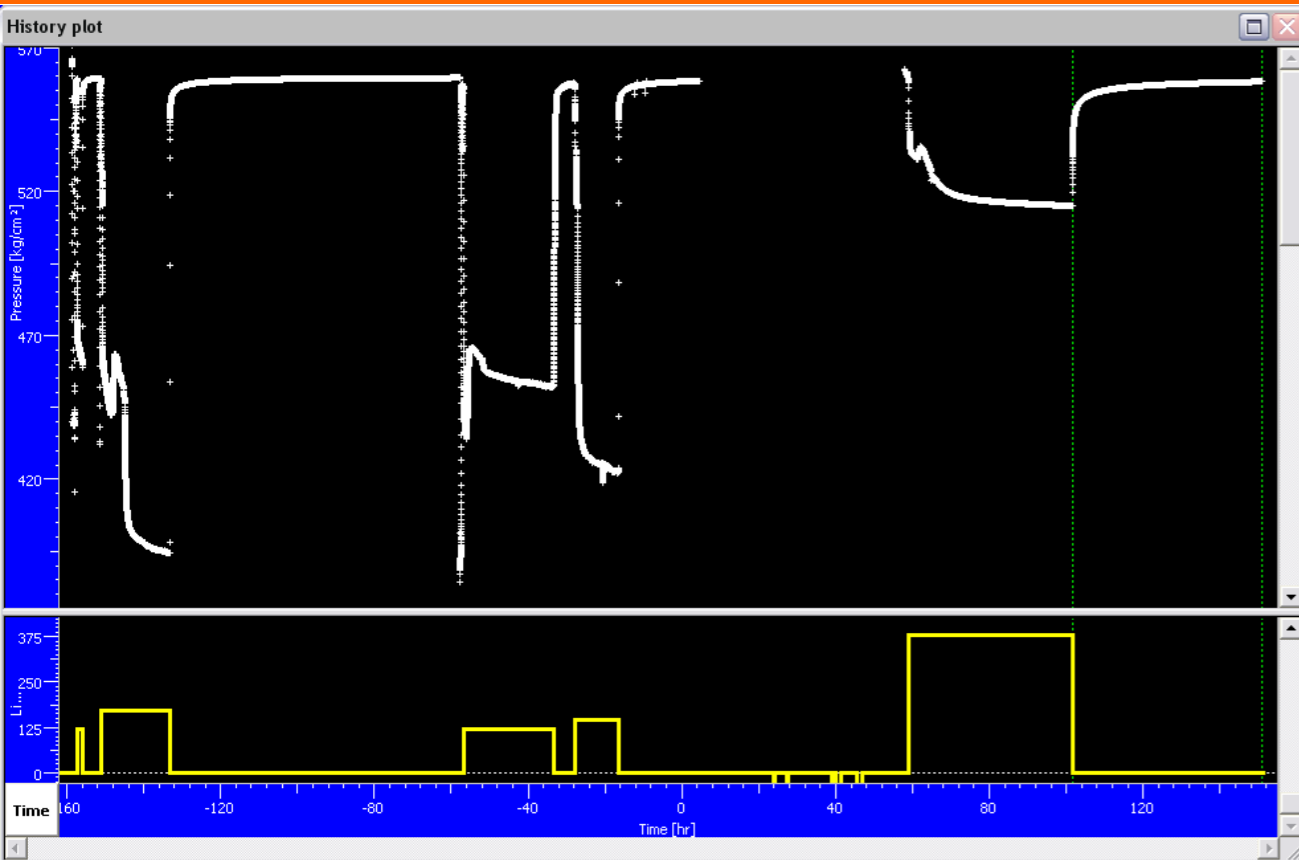
$$p_{bar} = 8135.32 \text{ psia}$$

$$\mu_{bar} = 0.032 \text{ cp}$$

$$z_{bar} = 1.247$$



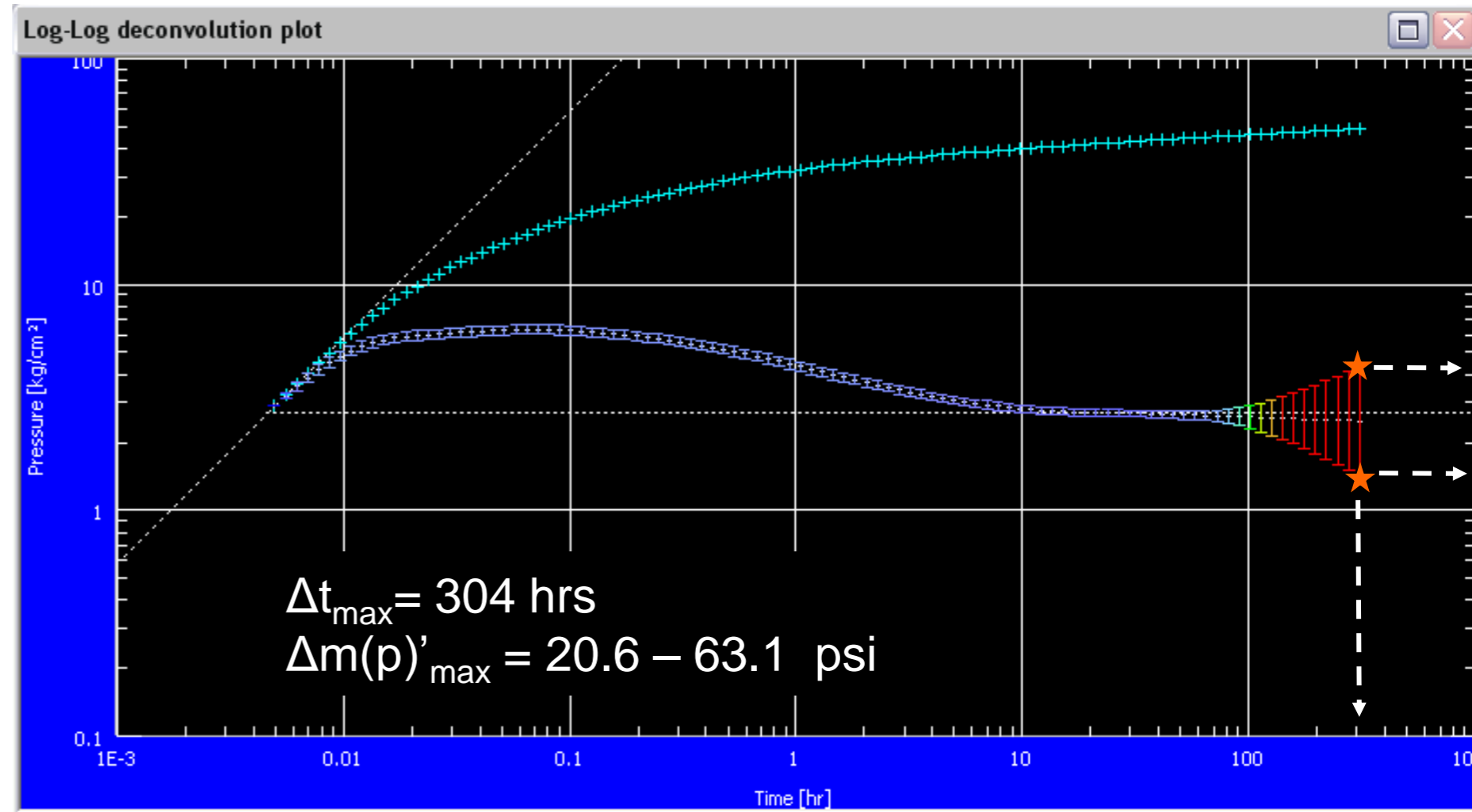
# Example 2 - Oil



Input:  
 $S_w = 0.129$   
 $c_t = 9.44E-6$  1/psi  
 $q = 2380$  stb/d

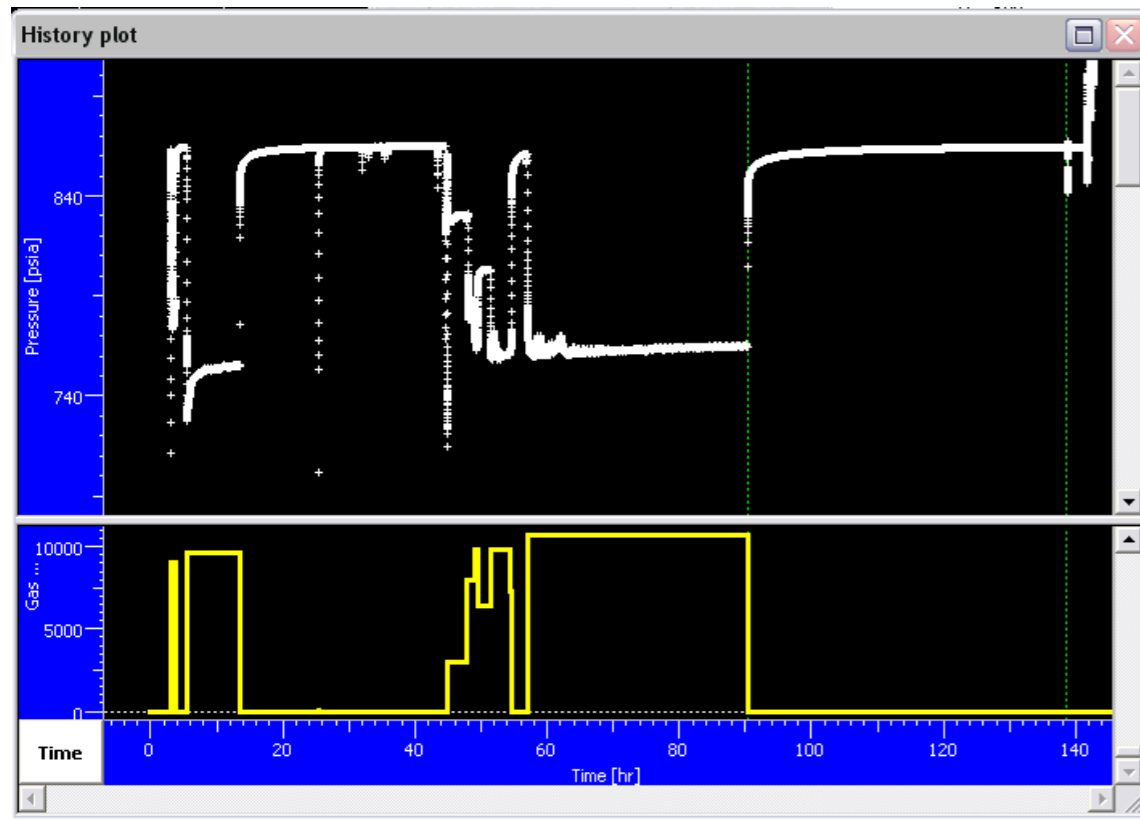
$$STOIP_{tested} = \frac{(1 - S_w)}{c_t} q \frac{\Delta t_{max}}{\Delta p'_{max}}$$

Max	Min
$STOIP_{tested} = \frac{(1 - 0.129)}{9.44E-6} \times 2380 \times \frac{304/24}{20.6}$ $= 139,39,843 stb = \underline{\underline{135 MMstb}}$	$STOIP_{tested} = \frac{(1 - 0.129)}{9.44E-6} \times 2380 \times \frac{304/24}{63.1}$ $= 44,053,261 stb = \underline{\underline{44.1 MMstb}}$



Uncertainty in deconvolution → uncertainty in connected volume

# Example 3 - Gas



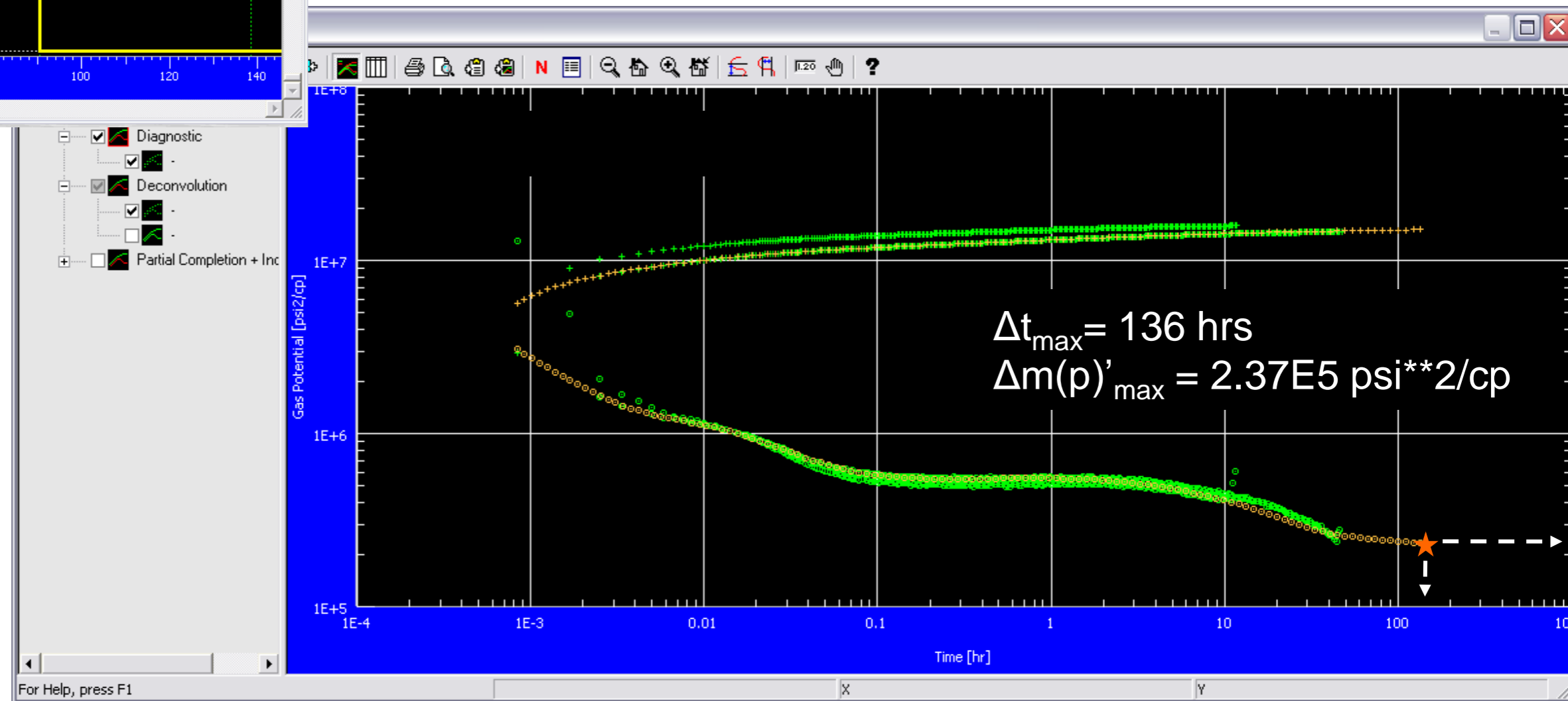
$$GIIP_{tested} = \frac{(1 - S_w)}{c_t} q \frac{\Delta t_{max}}{\Delta m(p)_{max}} \frac{2\bar{p}}{\bar{\mu}z}$$

$$GIIP_{tested} = \frac{(1 - 0.1)}{1.31E - 3} \times 10.7 \times \frac{136 / 24}{2.37E5} \times \frac{2 \times 865.2}{0.0128 \times 0.873}$$

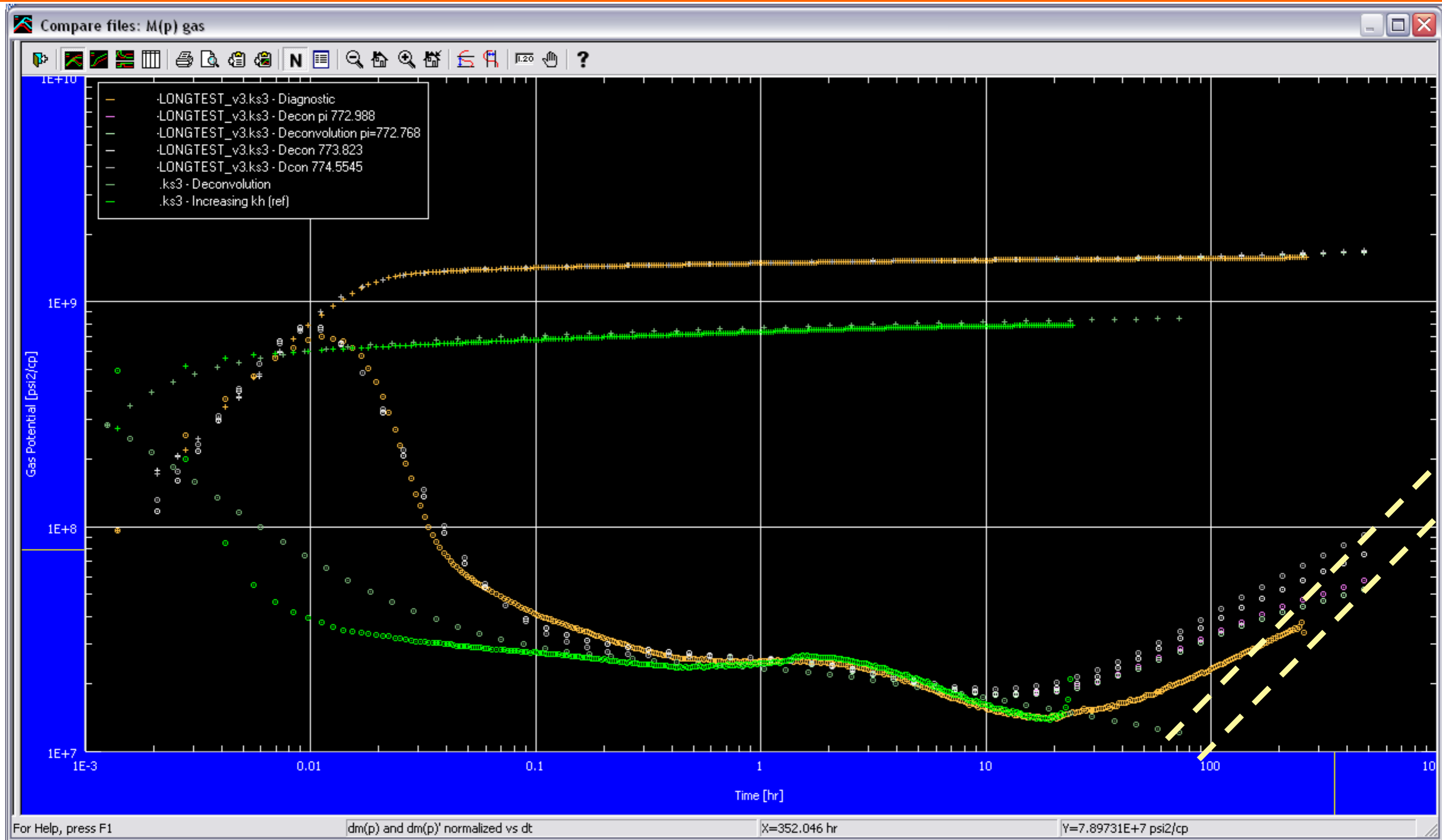
$$= 27,200 MMscf = 27.2 bscf$$

Input:  
 $S_w = 0.1$   
 $c_t = 0.00131 \text{ 1/psi}$   
 $q = 10.7 \text{ MMscf/d}$

$p_{bar} = 865.2 \text{ psia}$   
 $\mu_{bar} = 0.0128 \text{ cp}$   
 $z_{bar} = 0.873$

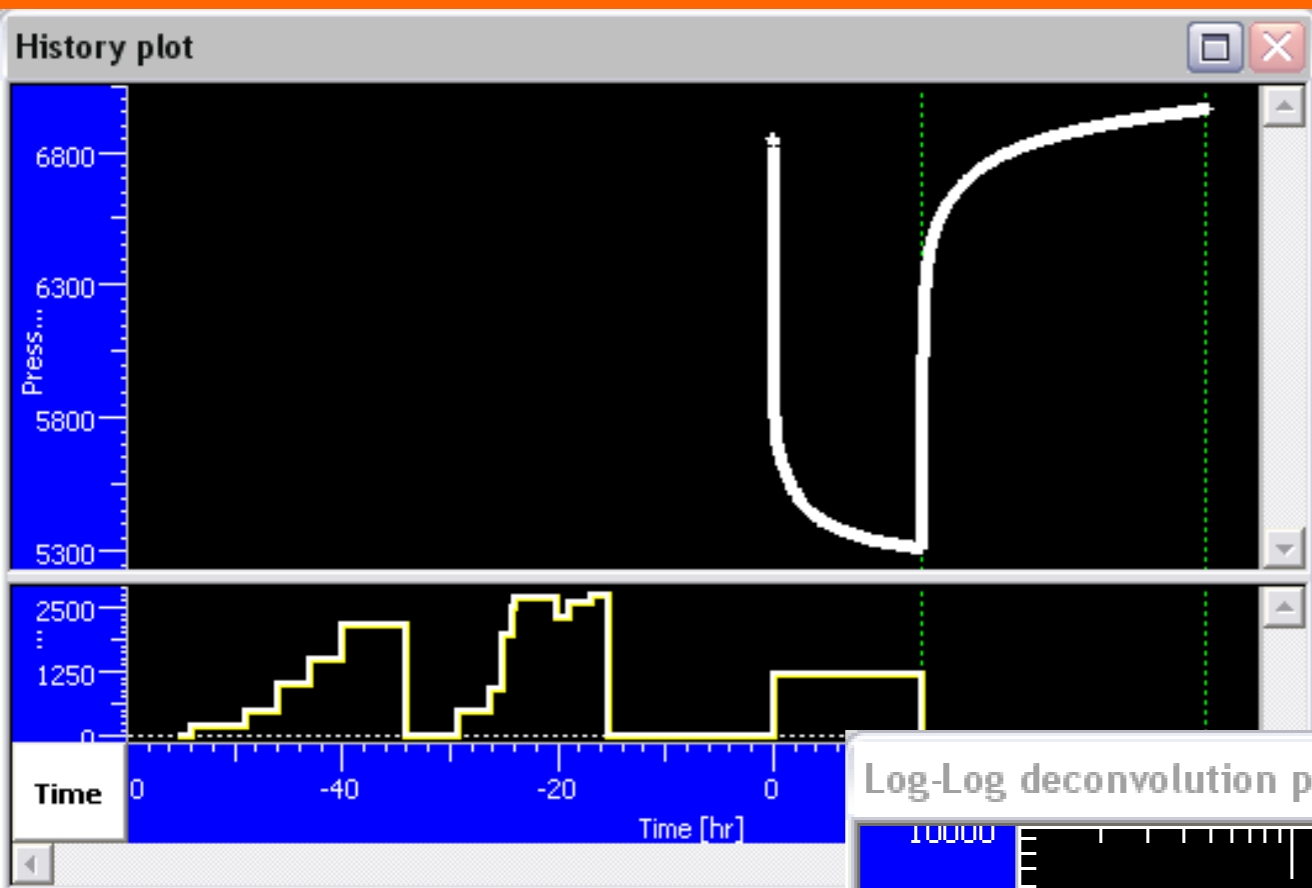


# Example 3b: Gas - DST versus EWT



Boundaries reduced anticipated tested volume

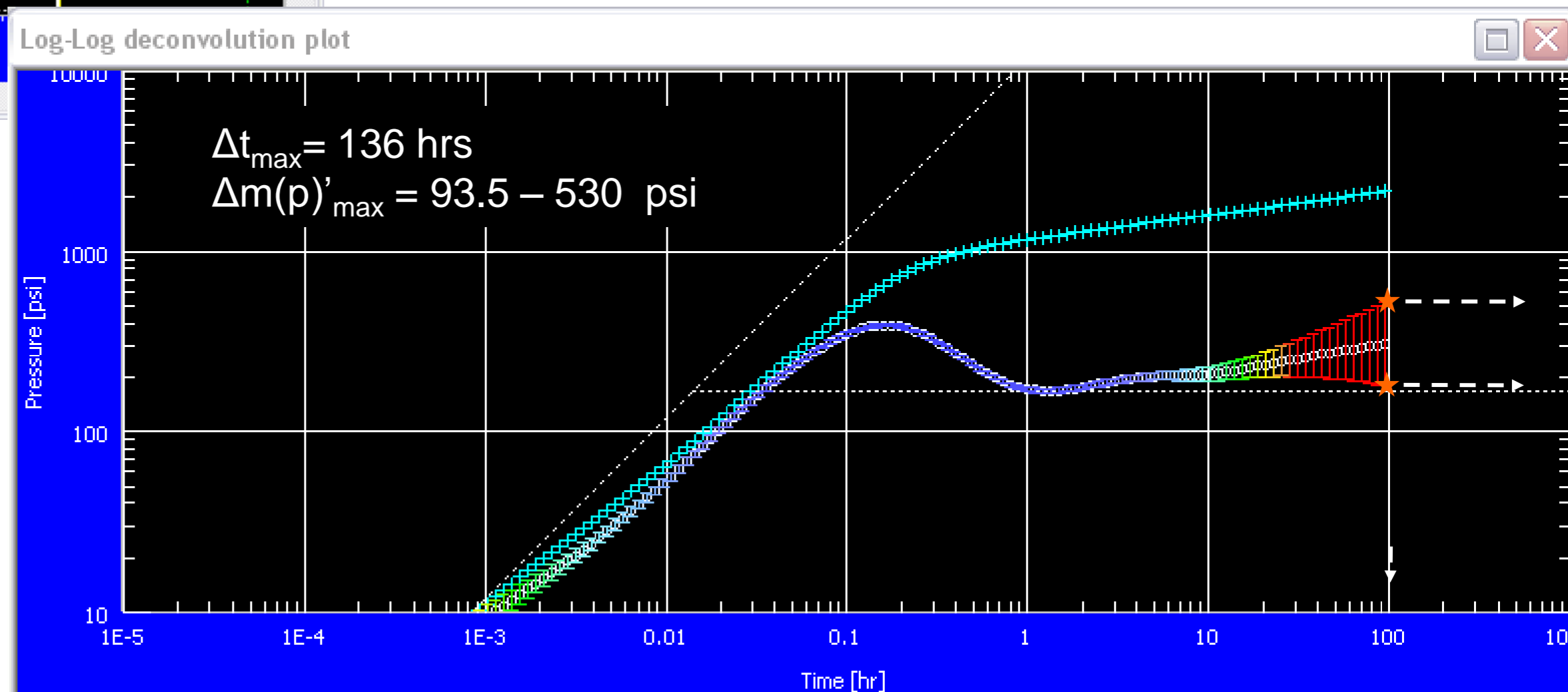
# Example 4 - Oil



$$STOIP_{tested} = \frac{(1 - S_w)}{c_t} q \frac{\Delta t_{max}}{\Delta p'_{max}}$$

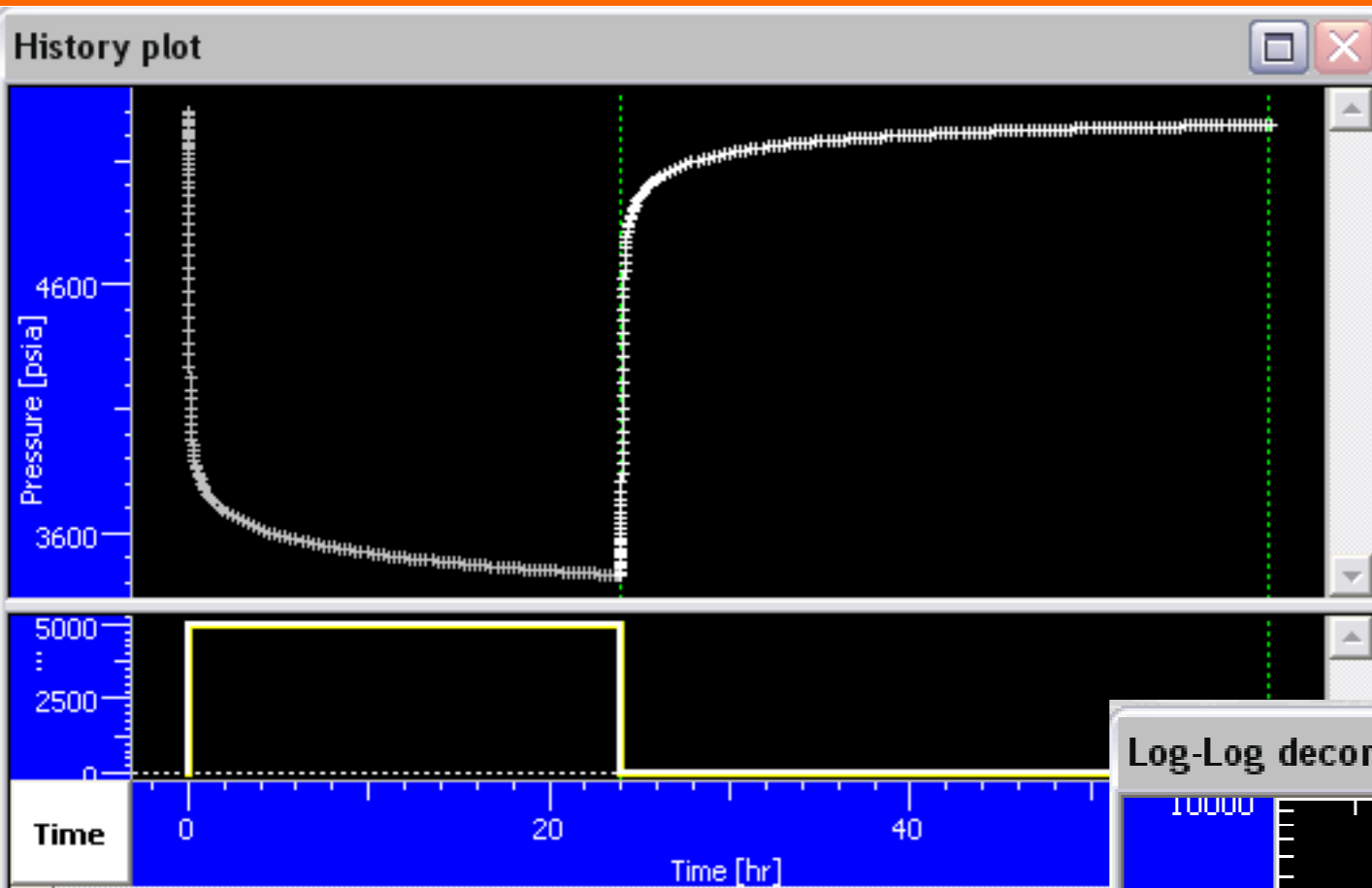
Max	Min
$STOIP_{tested} = \frac{(1 - 0.15)}{1.5E-5} \times 1220 \times \frac{94/24}{93.5}$	$STOIP_{tested} = \frac{(1 - 0.15)}{1.5E-5} \times 1220 \times \frac{94/24}{530}$
$= 2,894,000 stb = \underline{\underline{2.89 MMstb}}$	$= 510,564 stb = \underline{\underline{0.51 MMstb}}$

Input:  
 $S_w = 0.15$   
 $c_t = 1.5E-5 \text{ 1/psi}$   
 $q = 1220 \text{ stb/d}$



Uncertainty in deconvolution → uncertainty in connected volume

# Example 5 – Oil Design



$$STOIP_{tested} = \frac{(1 - S_w)}{c_t} q \frac{\Delta t_{max}}{\Delta p'_{max}}$$

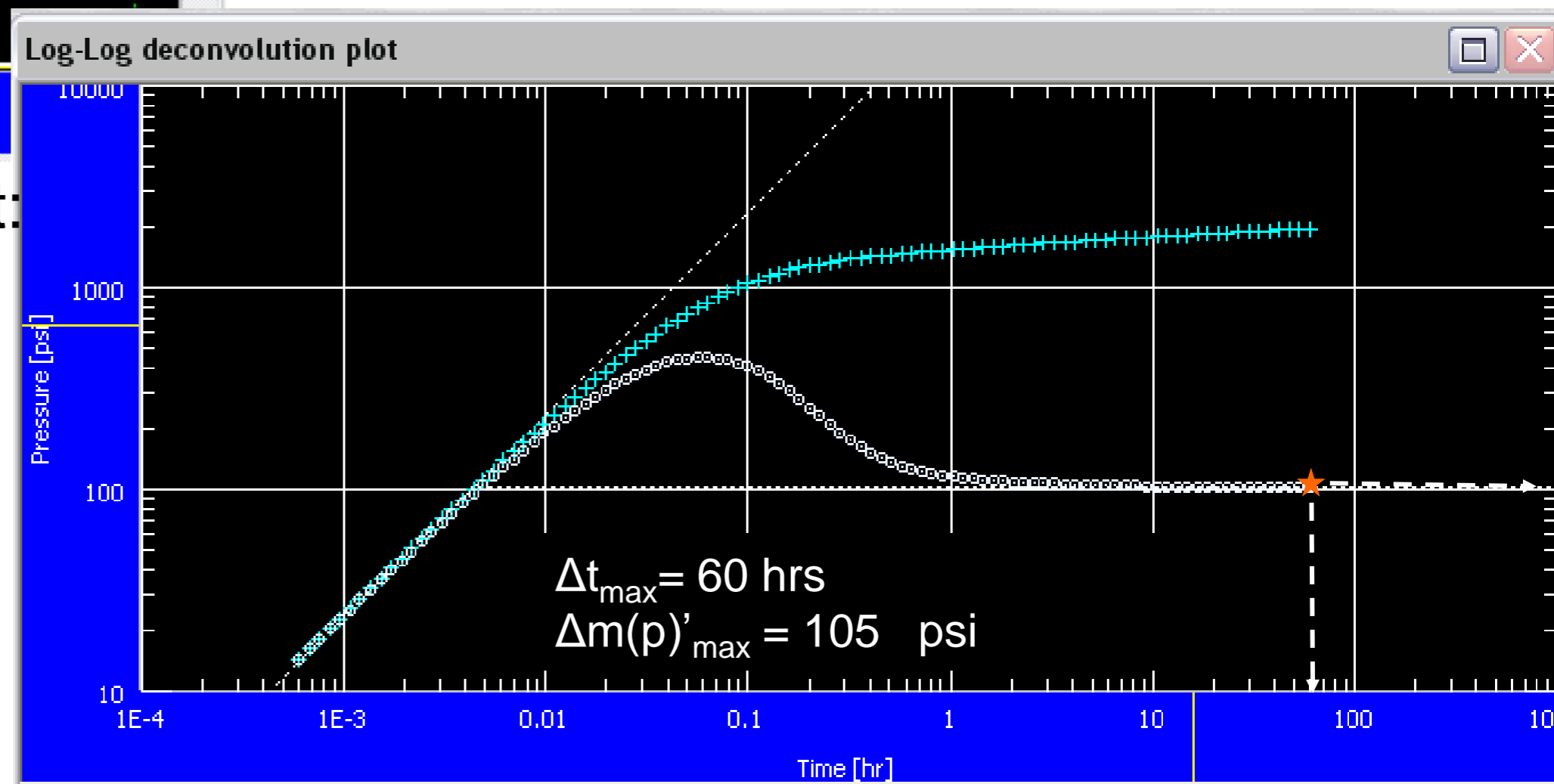
$$STOIP_{tested} = \frac{(1 - 0.15)}{3E-6} \times 5000 \times \frac{60/24}{105}$$

$$= 33708571 \text{ stb} = \underline{\underline{33.7 MMstb}}$$

Input:  
 $S_w = 0.15$   
 $c_t = 1E-5 \text{ 1/psi}$   
 $q = 5000 \text{ stb/d}$

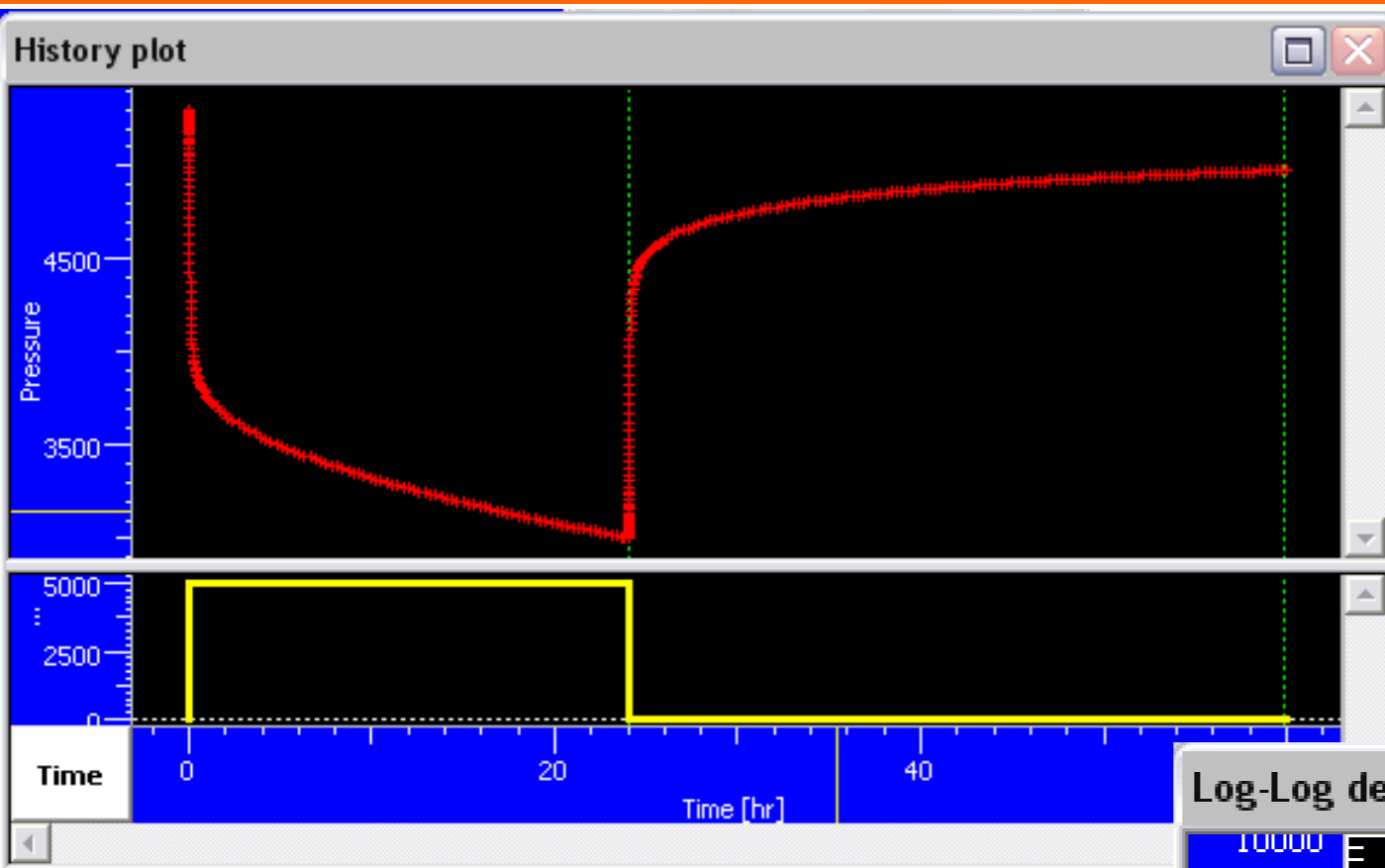
Design Input:  
 $k = 90 \text{ mD}$   
 $h = 7 \text{ m}$   
 $\phi = 0.11$   
 $r_w = 0.3 \text{ ft}$   
 $\mu = 0.5 \text{ cp}$   
 $p_i = 5300 \text{ psia}$

$(r_{inv} = 5250 \text{ ft})$



No Boundaries

# Example 5 – Oil Design



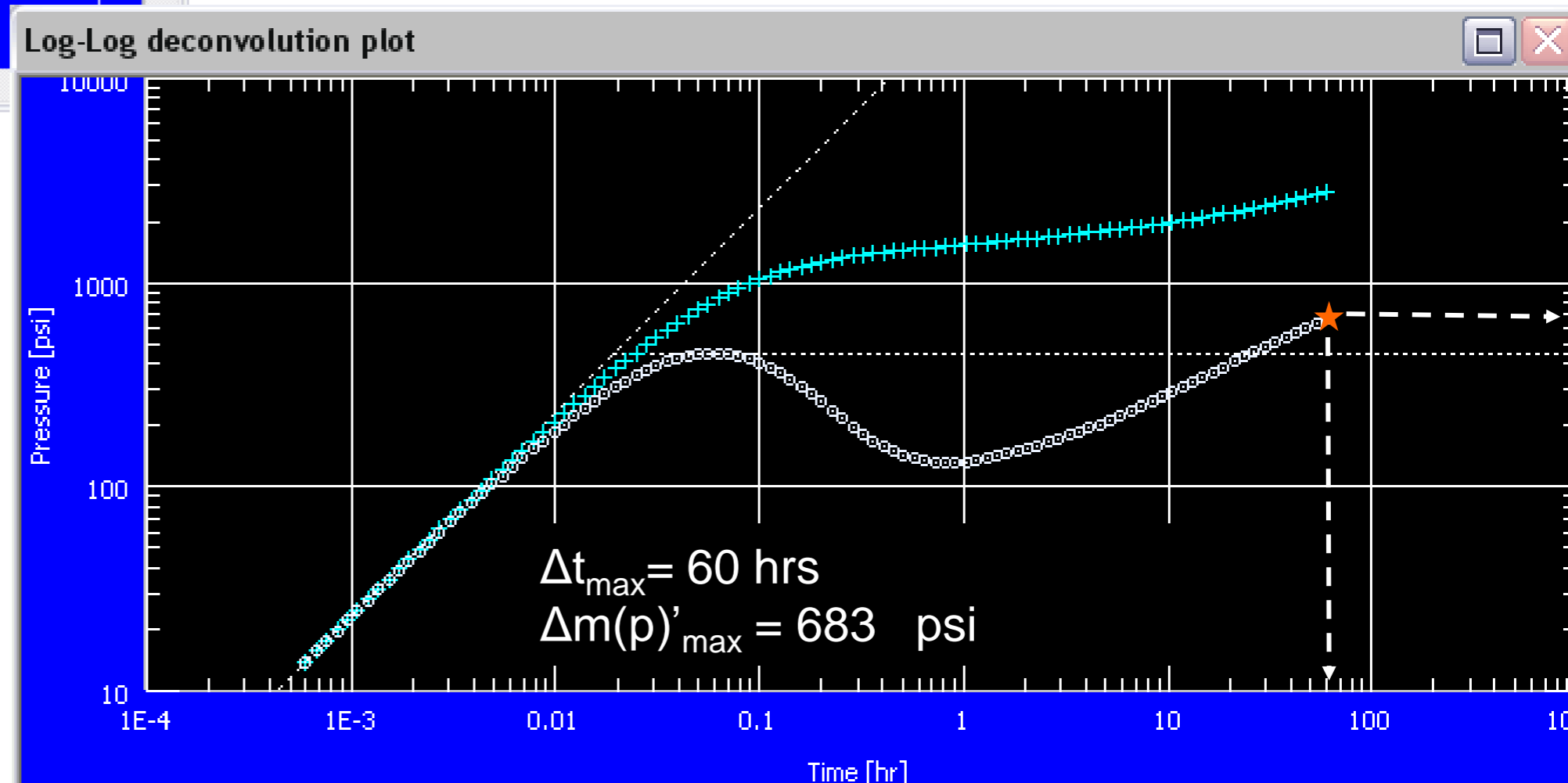
$$STOIP_{tested} = \frac{(1 - S_w)}{c_t} q \frac{\Delta t_{max}}{\Delta p'_{max}}$$

$$STOIP_{tested} = \frac{(1 - 0.15)}{3E-6} \times 5000 \times \frac{60/24}{683}$$

$$= 5182138 \text{ stb} = \underline{\underline{5.2MMstb}}$$

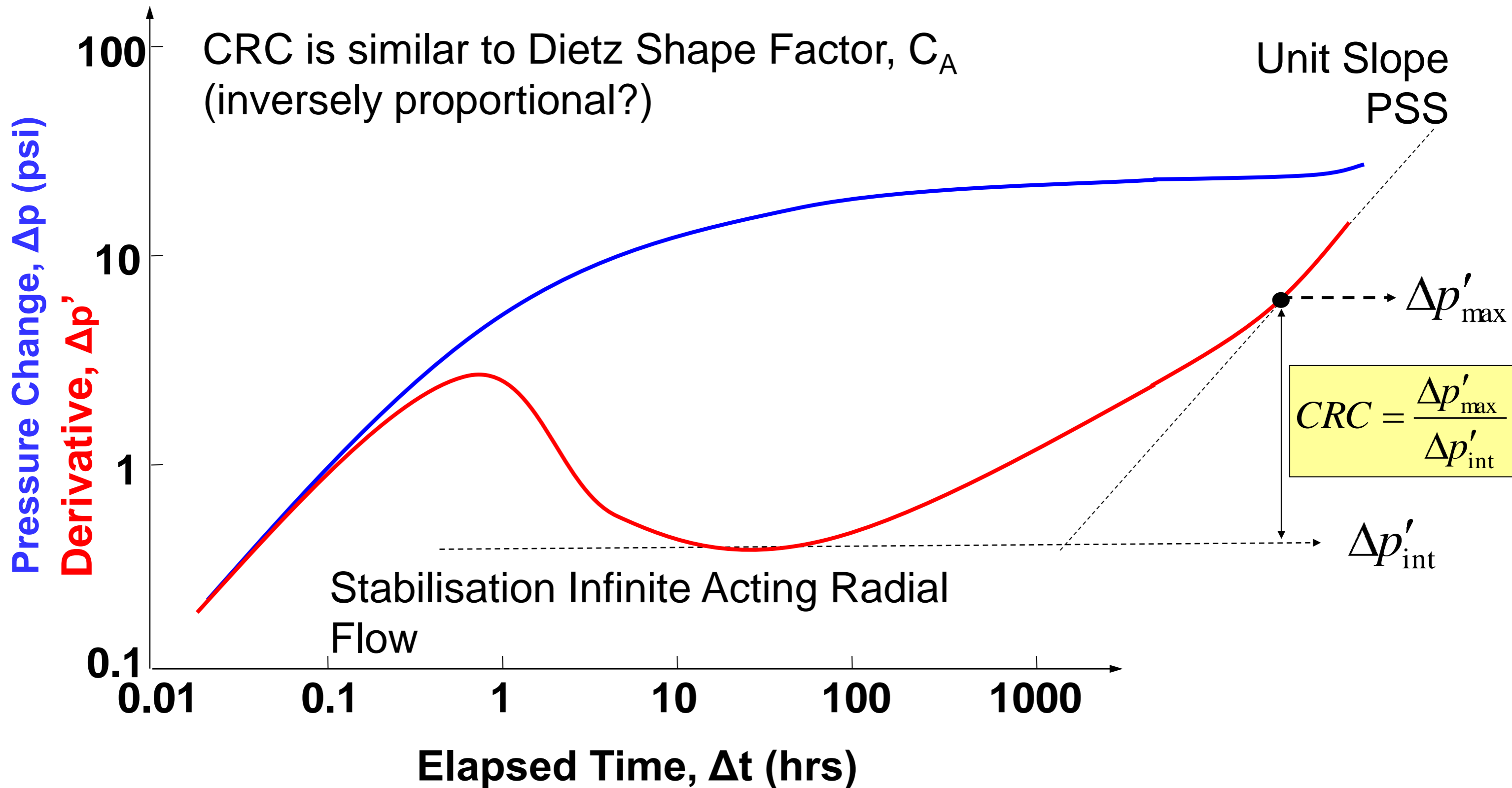
Input:  
 $S_w = 0.15$   
 $c_t = 1E-5 \text{ 1/psi}$   
 $q = 5000 \text{ stb/d}$

Design Input:  
 $k = 90 \text{ mD}$   
 $h = 7 \text{ m}$   
 $\phi = 0.11$   
 $r_w = 0.3 \text{ ft}$   
 $\mu = 0.5 \text{ cp}$   
 $p_i = 5300 \text{ psia}$   
 $d_1 = 500 \text{ ft}$   
 $d_2 = 1000 \text{ ft}$



**Channel Boundaries : Significantly reduces tested volumes**

# Coefficient of Reservoir Complexity (CRC)



Applies to deconvolved data

# Comparison of CRC with Dietz Shape Factor, CA (Tom Street – May 2009)






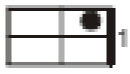







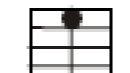




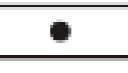
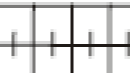







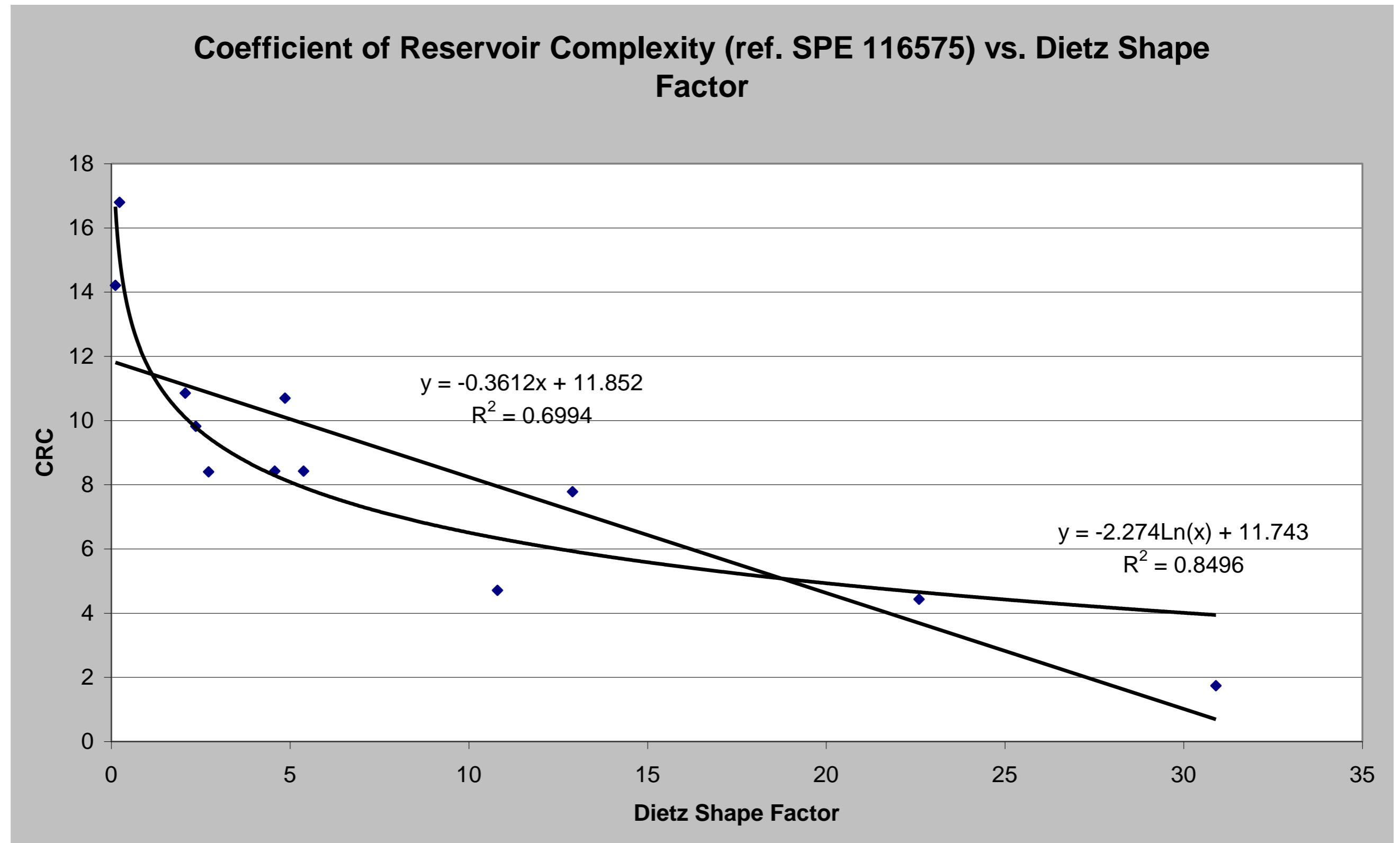
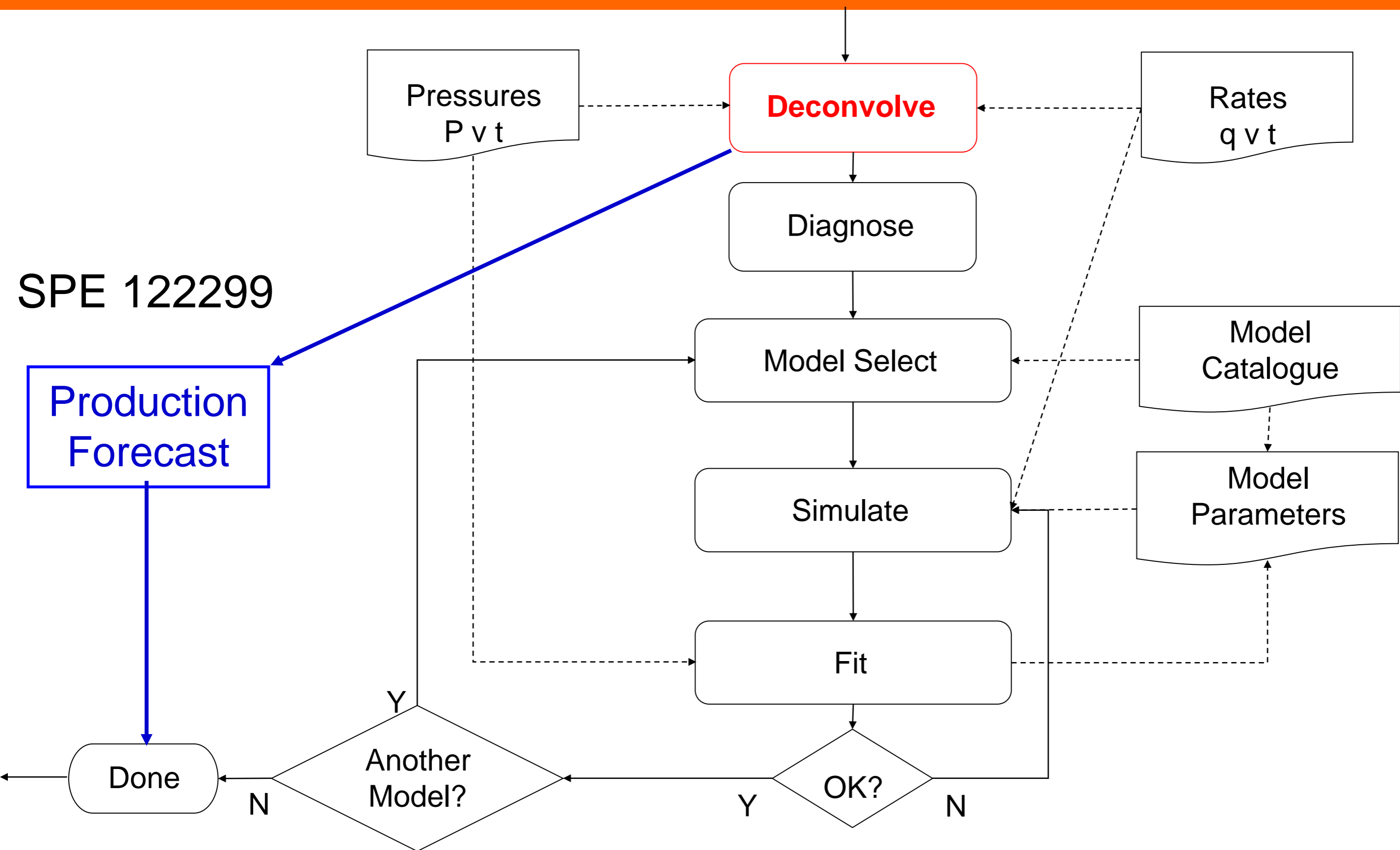
	Stabilized conditions			Stabilized conditions			
	$\ln C_s$	$C_s$	for $\frac{kt}{\phi\mu c_A} \gg 1$	$\ln C_s$	$C_s$	for $\frac{kt}{\phi\mu c_A} \gg 1$	
bounded reservoirs							
	3.45	31.6	0.1	 1	2.38	10.8	0.3
	3.43	30.9	0.1	 2	1.58	4.86	1.0
	3.45	31.6	0.1	 1	0.73	2.07	0.8
	3.32	27.6	0.2	 2	1.00	2.72	0.8
	3.30	27.1	0.2	 4	-1.46	0.232	2.5
	3.12	21.9	0.4	 4	-2.16	0.115	3.0
	3.12	21.9	0.4	 4	1.22	3.39	0.6
	3.12	22.6	0.2	 2	1.14	3.13	0.3
	1.68	5.38	0.7	 2	-0.50	0.607	1.0
	0.86	2.36	0.7	 1	-2.20	0.111	1.2
	2.56	12.9	0.6	 2	-2.32	0.098	0.9
	1.52	4.57	0.5	 3			
				 4			
				In water-drive reservoirs			
					2.95	19.1	0.1
				In reservoirs of unknown production character			
					3.22	25	0.1

Fig. 6.4 Dietz shape factors for various geometries<sup>3</sup> (Reproduced by courtesy of the SPE of the AIME).

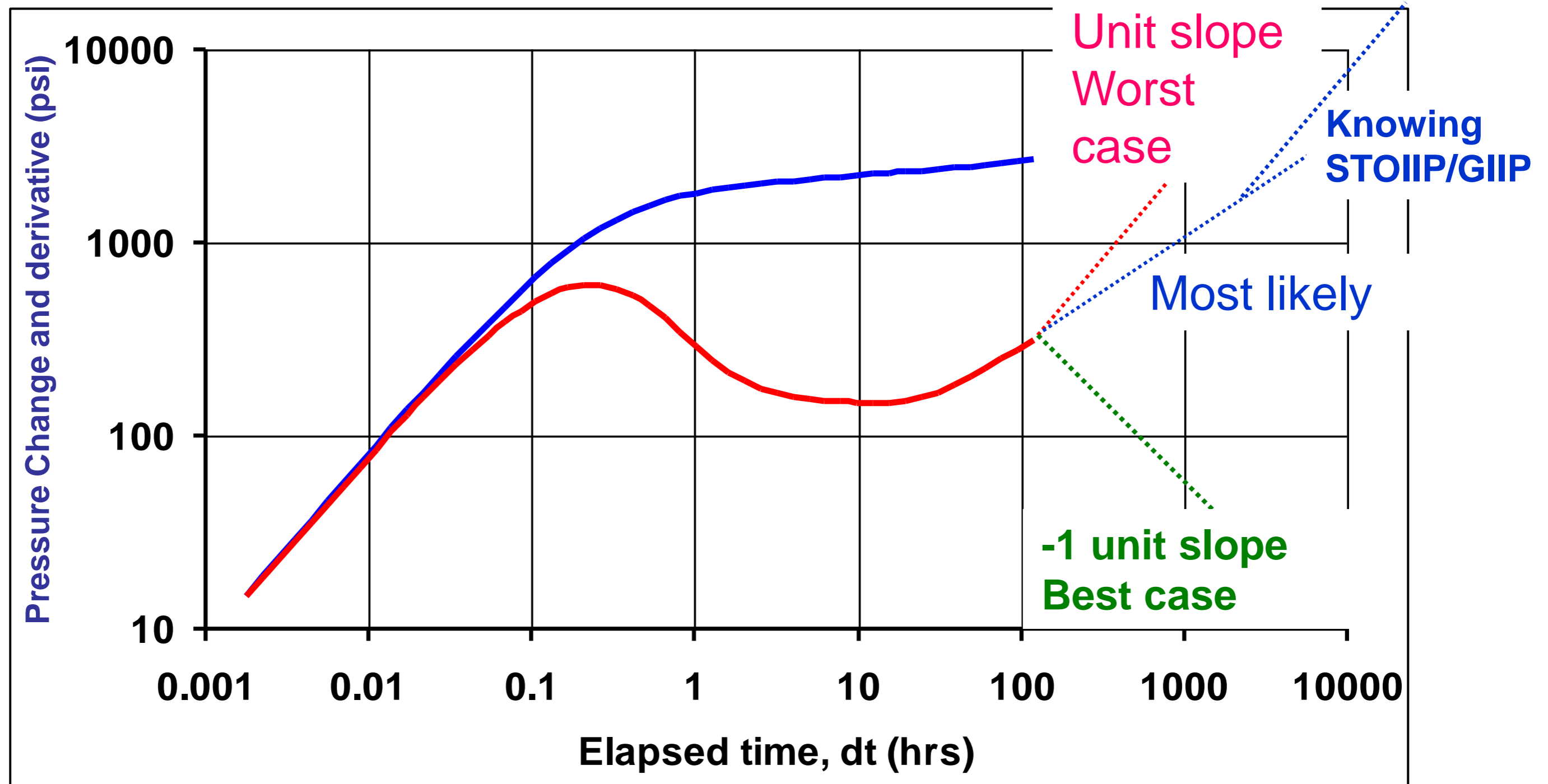
# Comparison of CRC with Dietz Shape Factor, $C_A$ (Tom Street – May 2009)



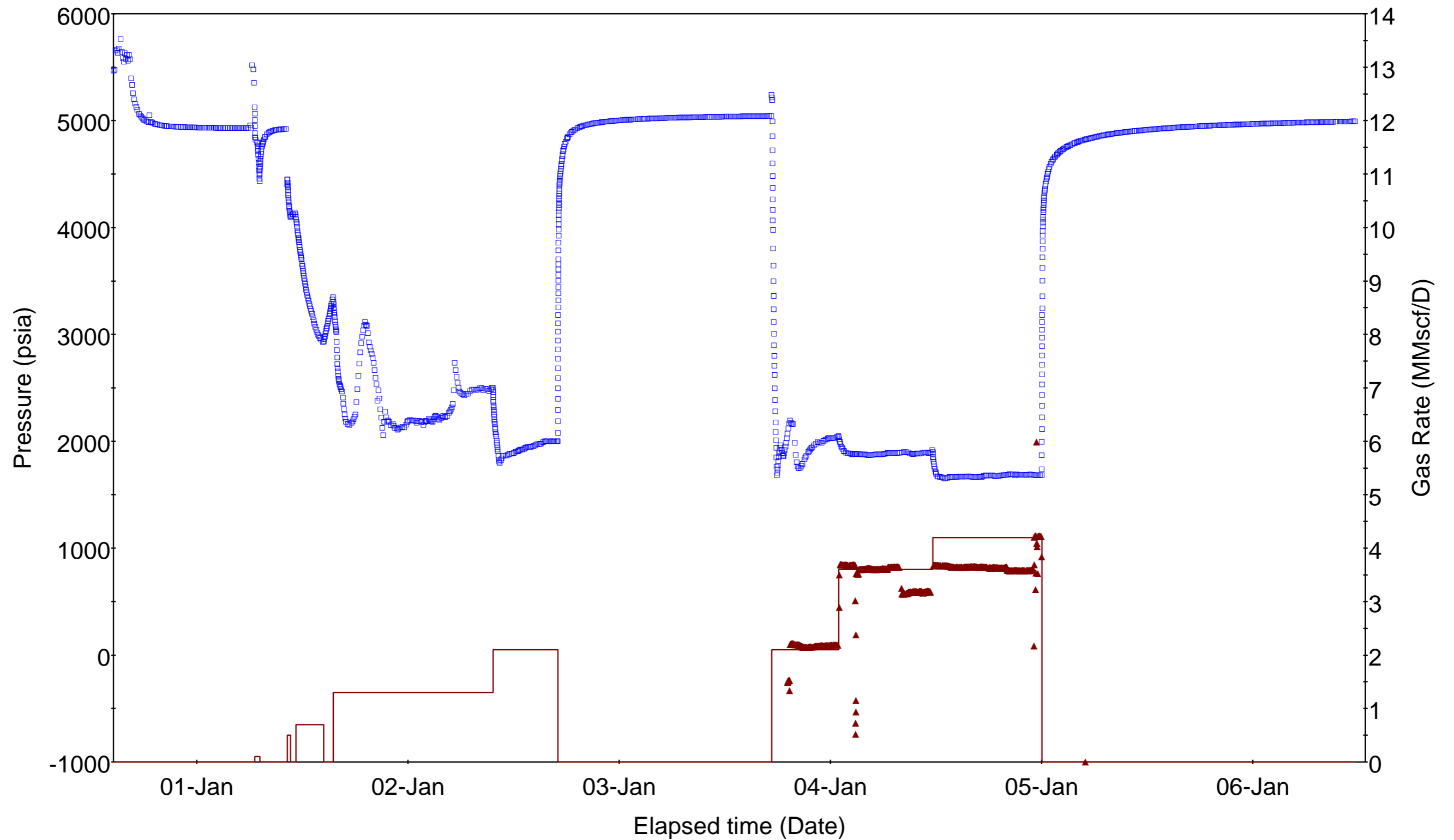
# Pressure Transient Analysis Workflow



# Extrapolation methods for Production Forecast

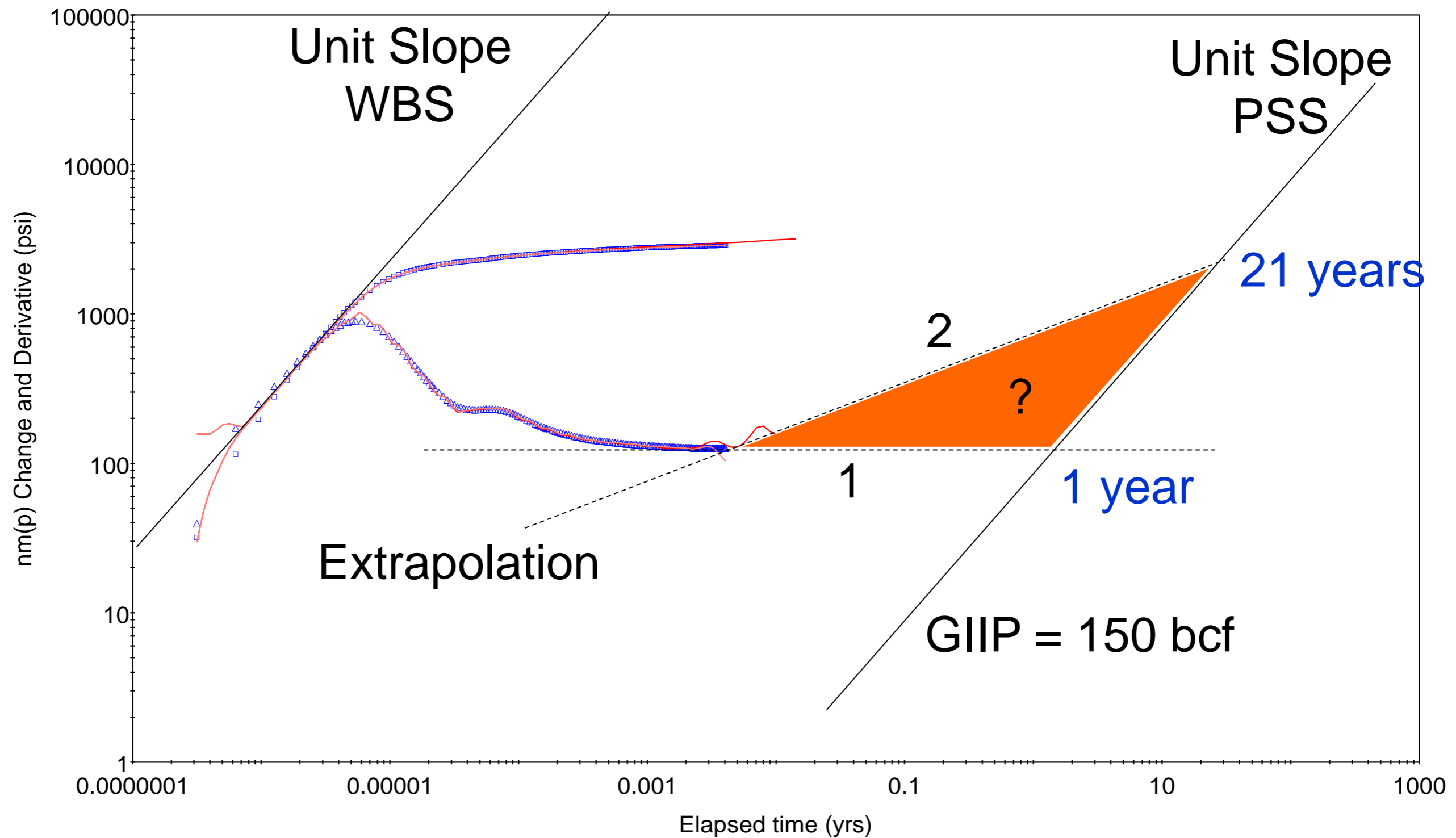


# Example 6: Gas – Prediction from DST

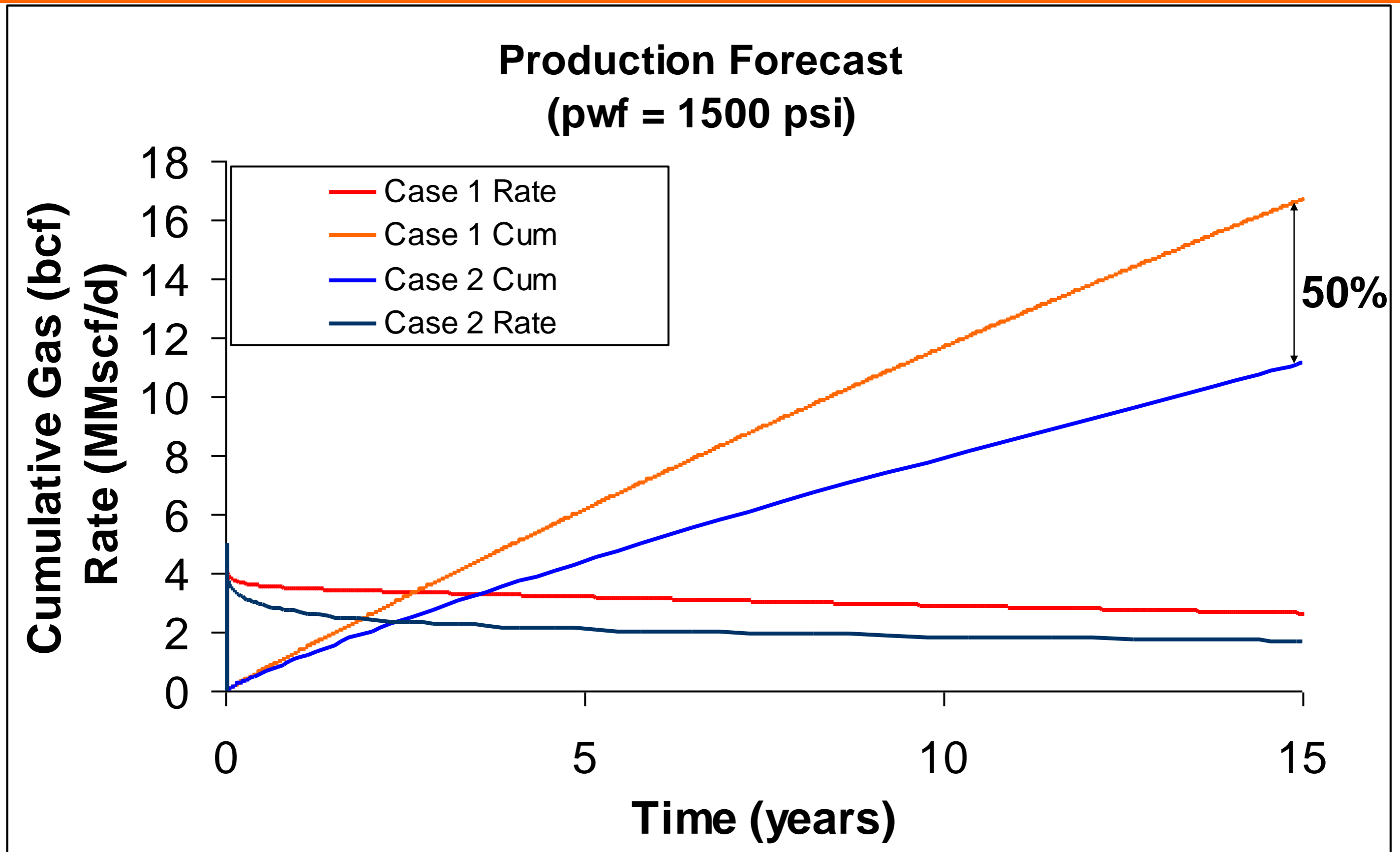


# Example 6: Gas – Prediction from DST

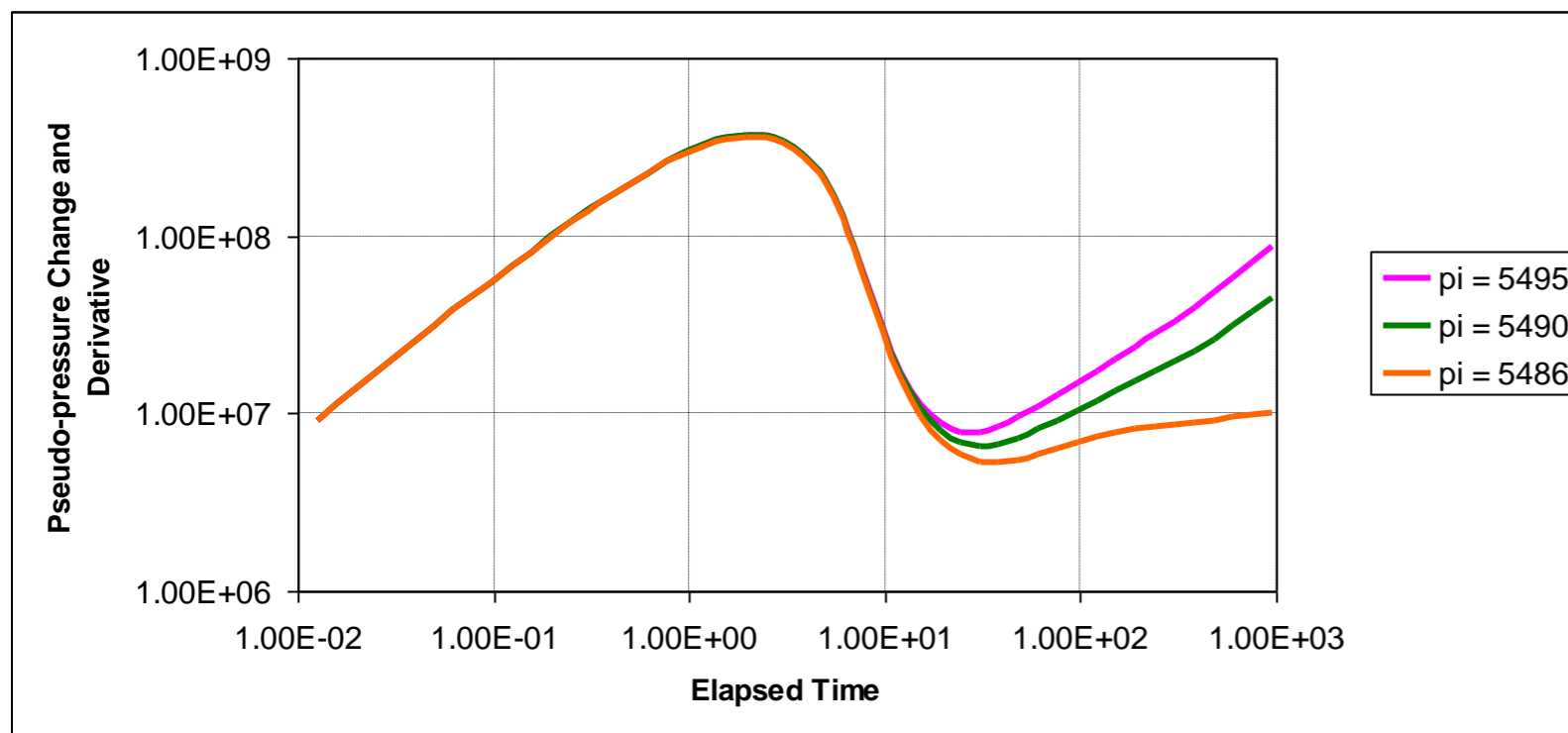
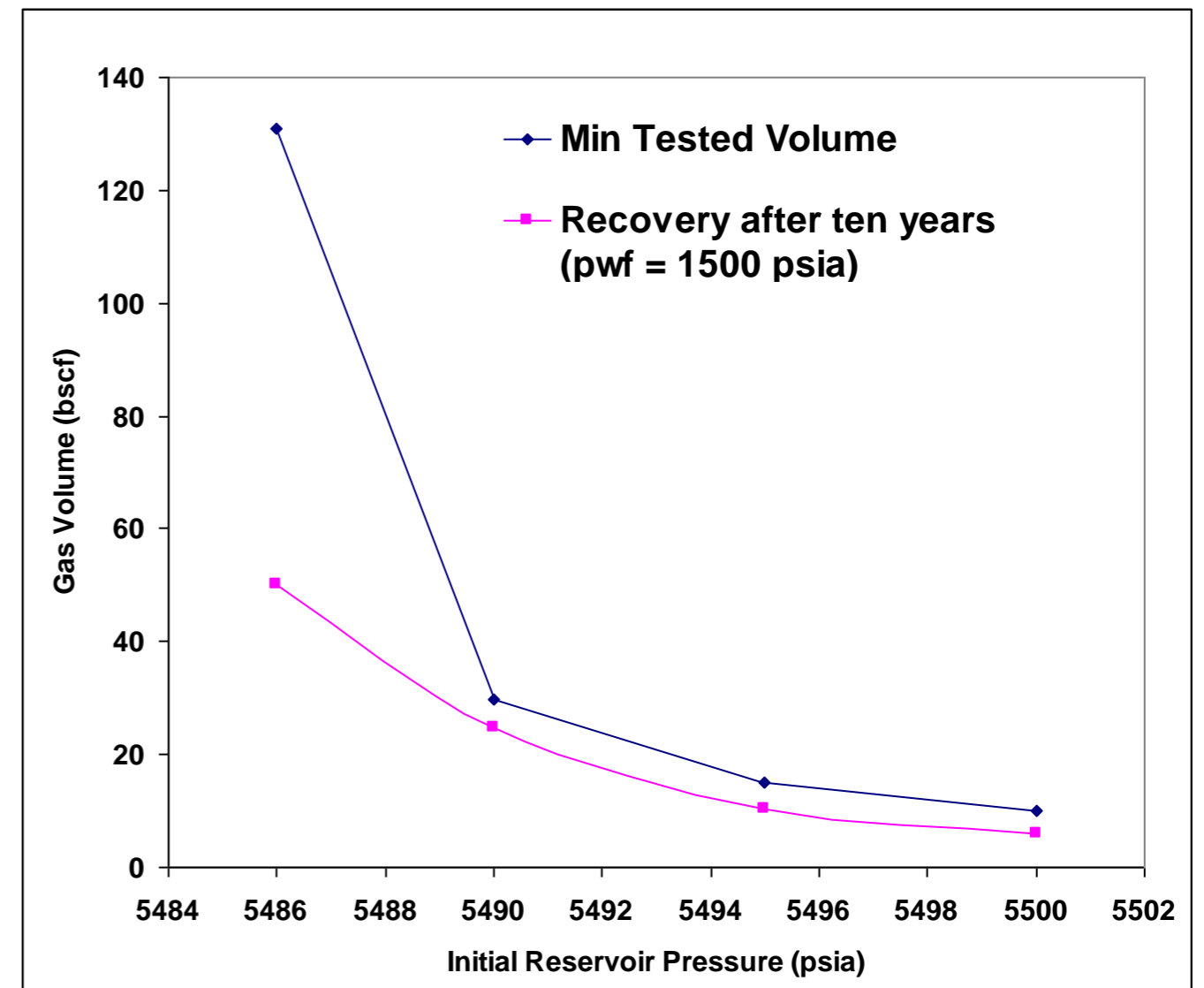
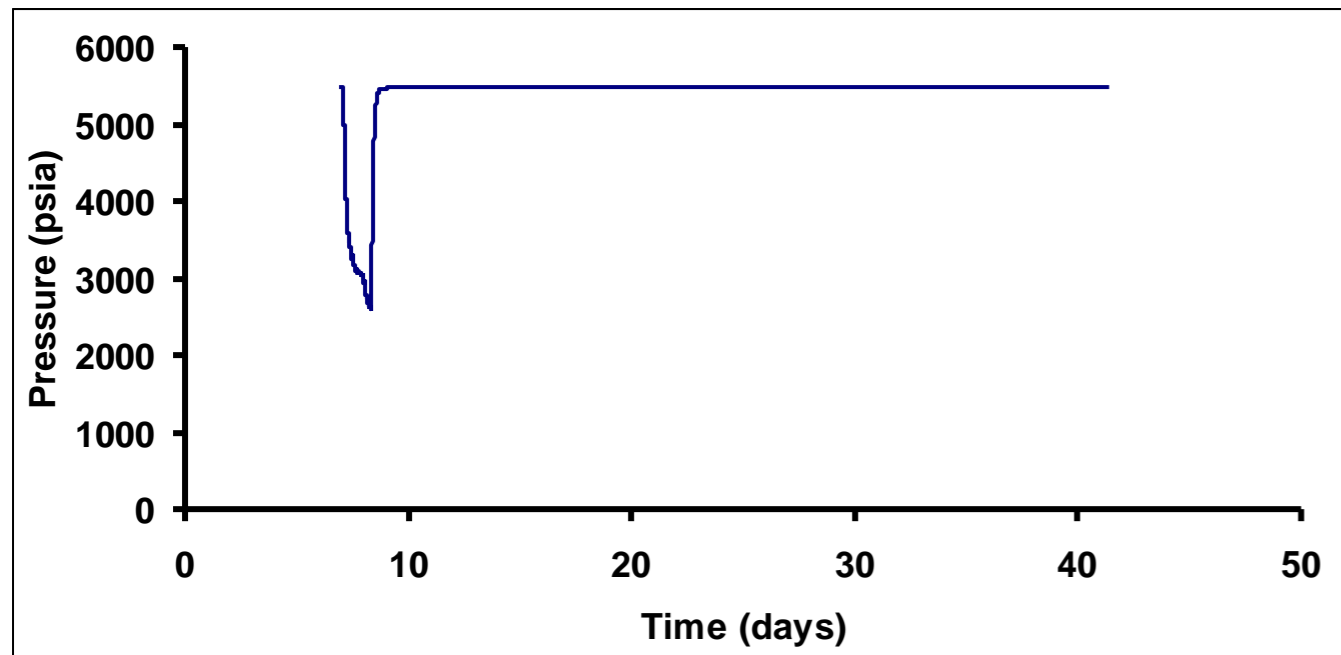
## Deconvolution



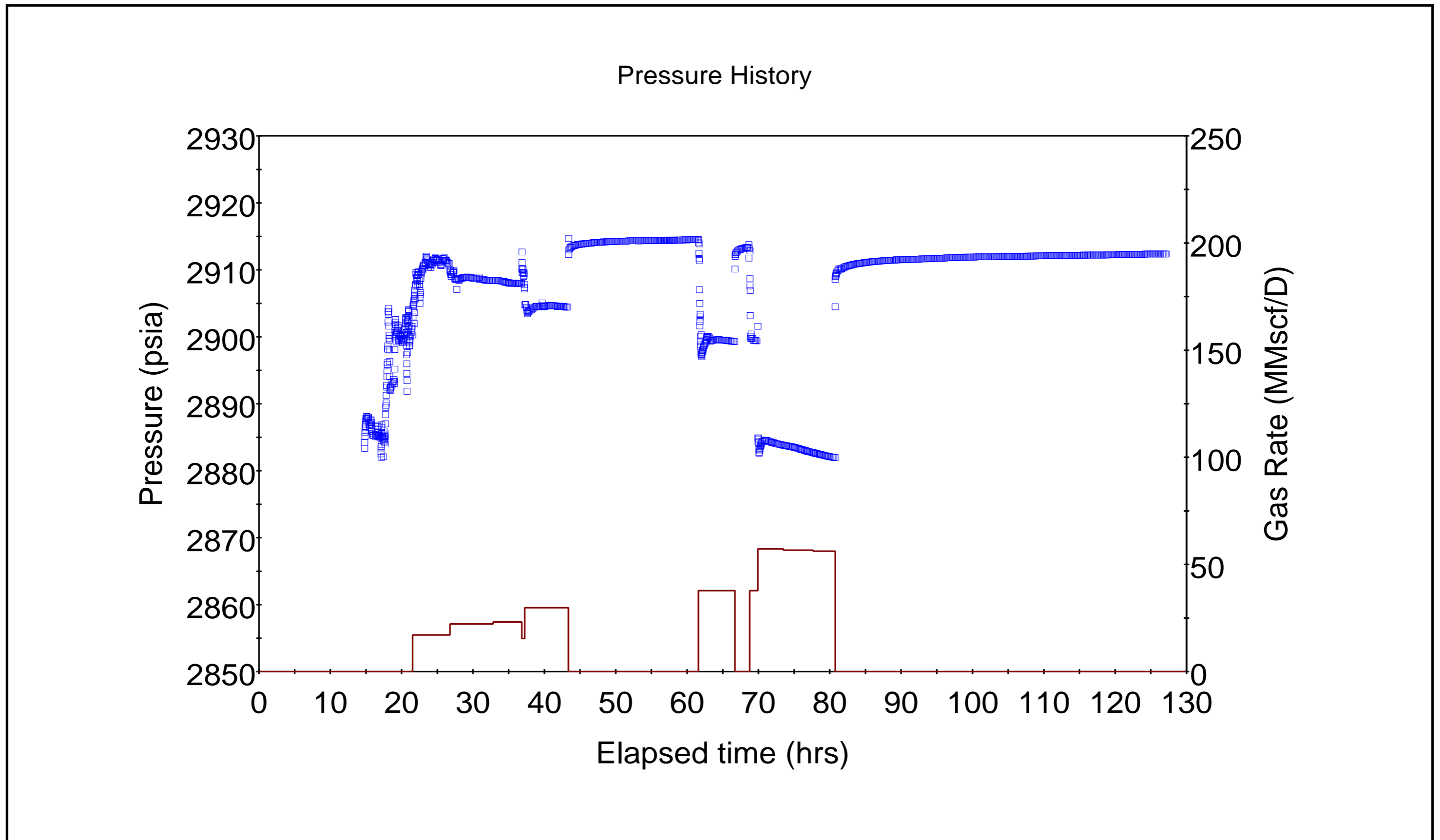
# Example 6: Gas – Prediction from DST



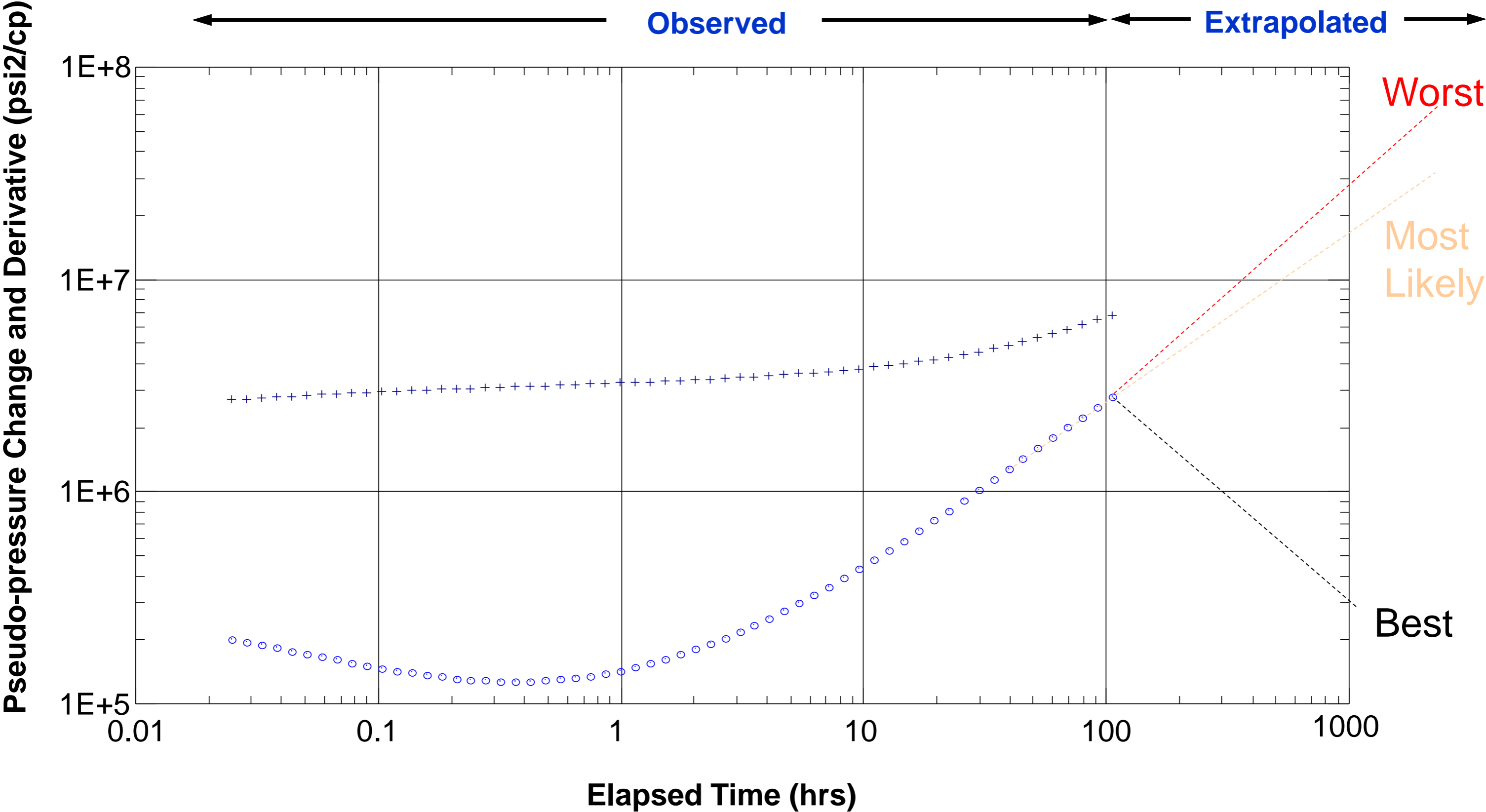
# Example 7: Sensitivity to Initial Pressure



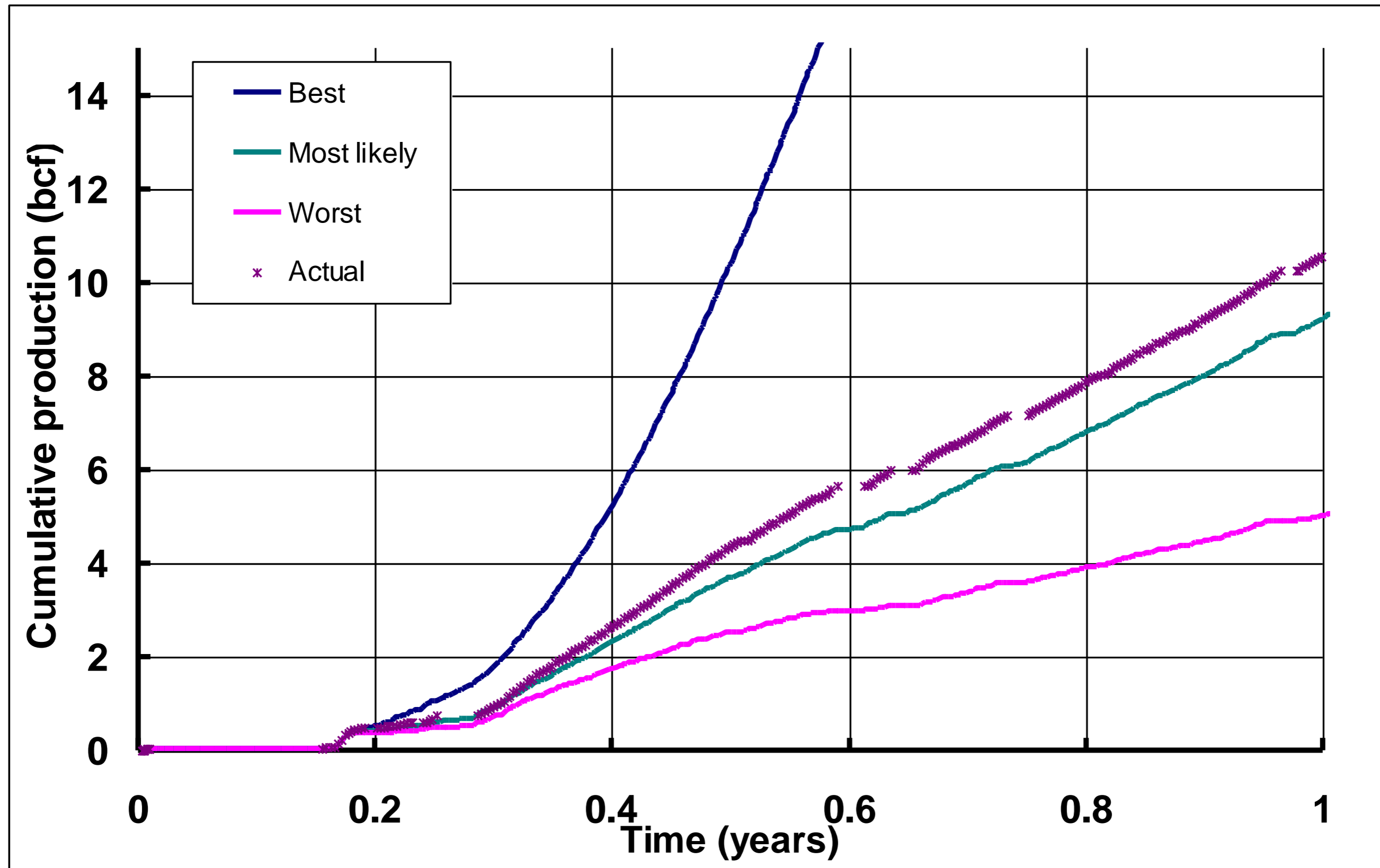
# Example 7: Gas – Prediction from Initial Production Test



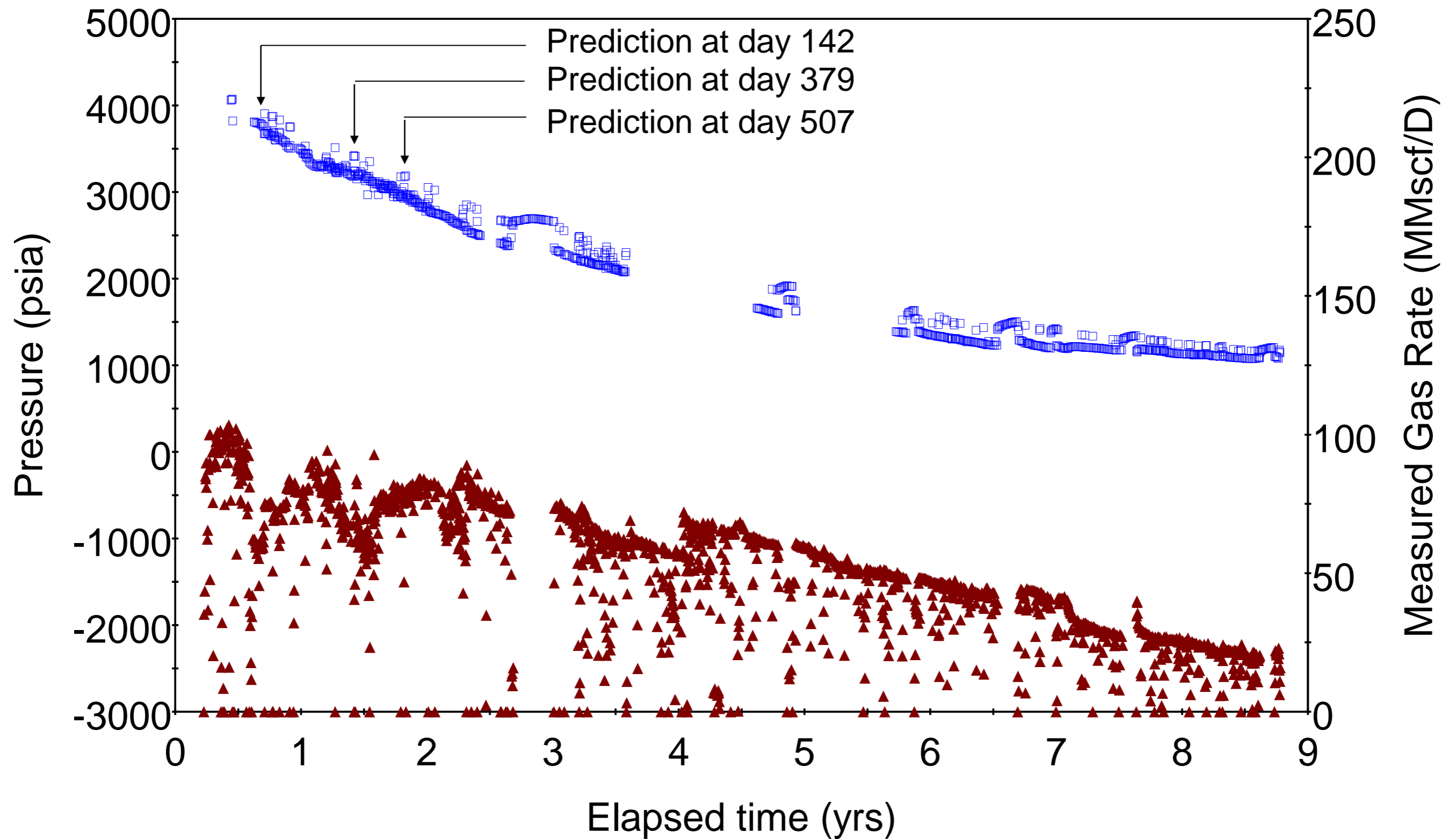
# Example 7: Gas – Prediction from Initial Production Test

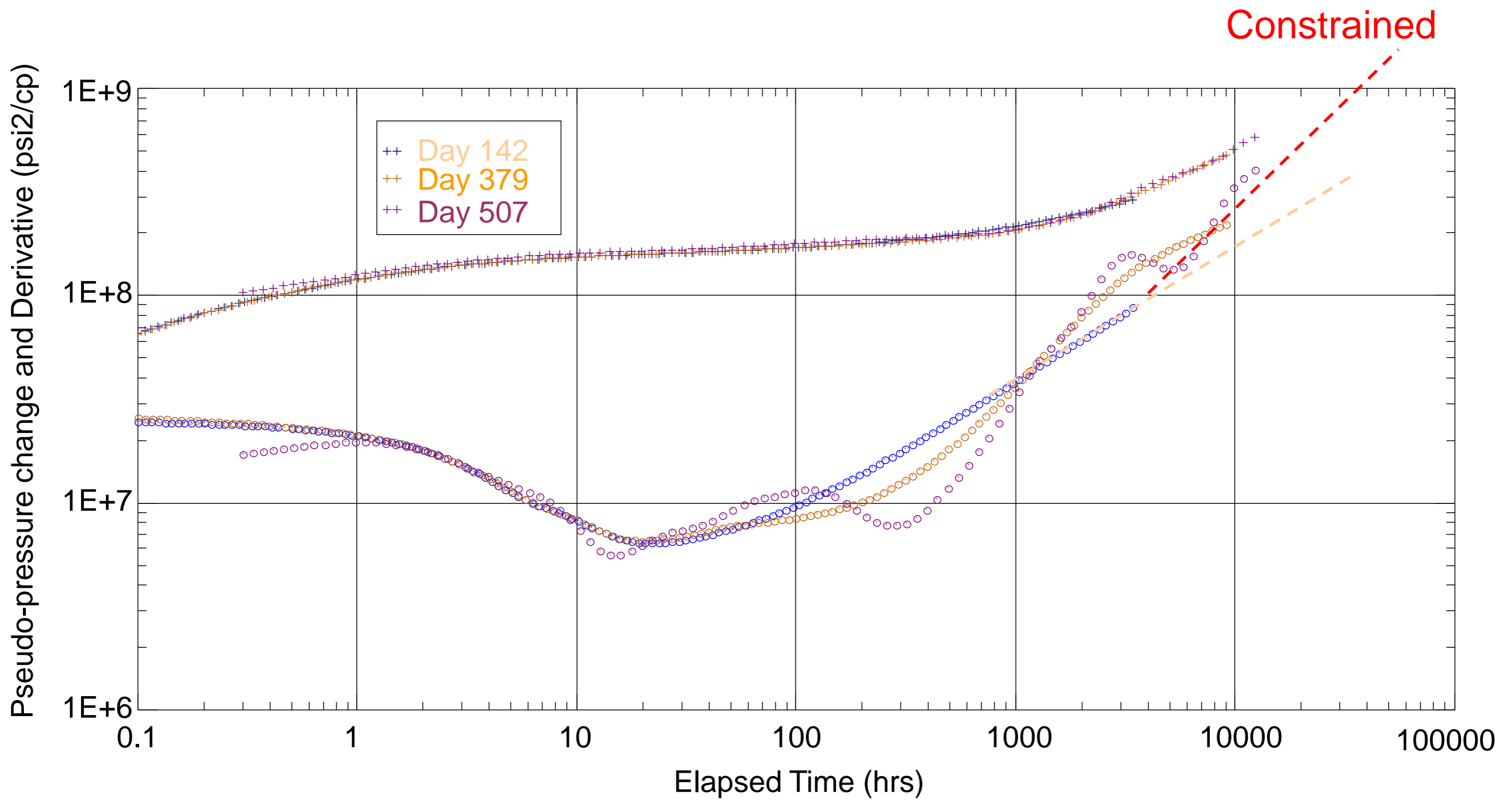


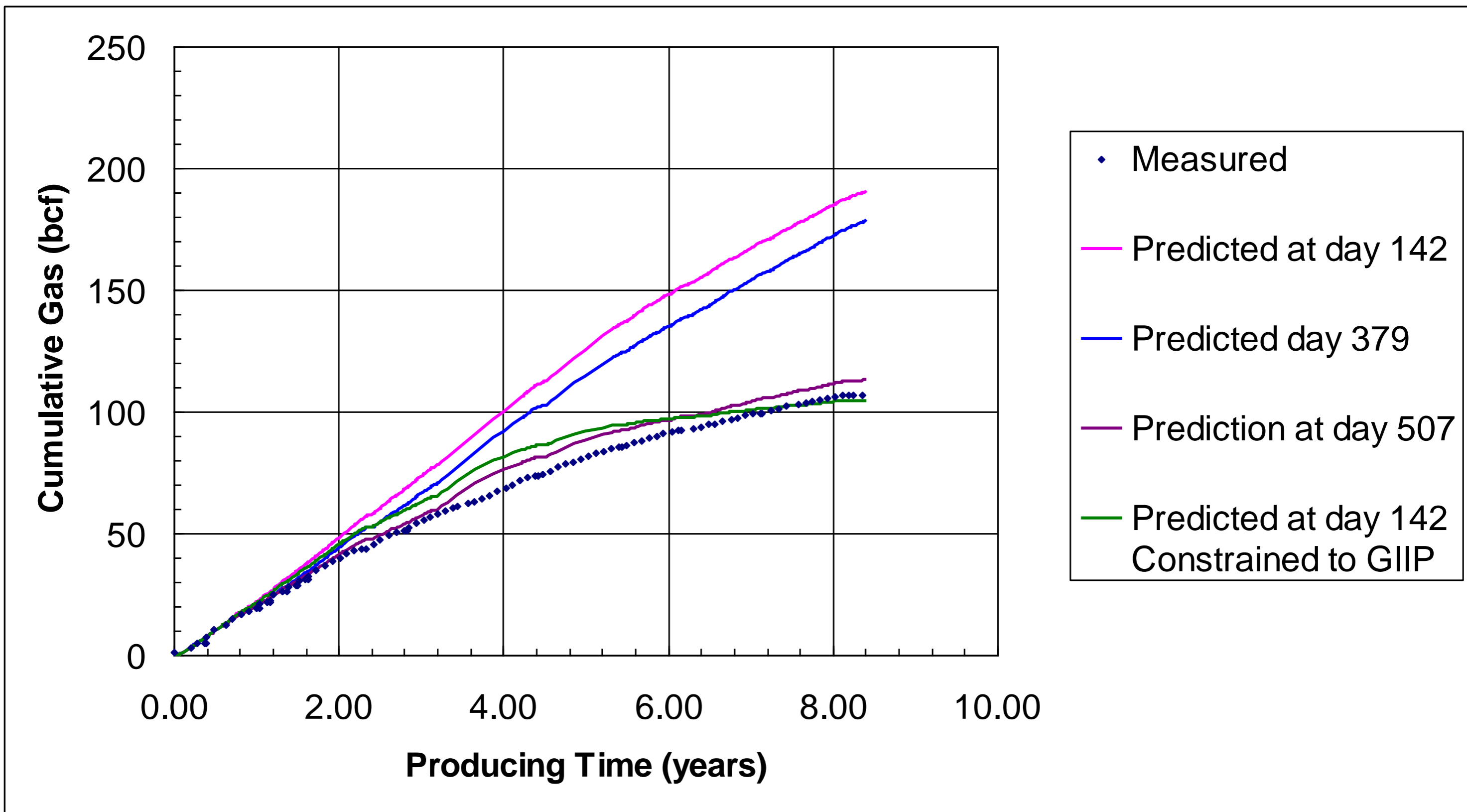
# Example 7: Gas – Prediction from Initial Production Test



# Example 8: Gas – Prediction from Permanent Gauge Data







# Limitations

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- Deconvolution assumes single phase flow in the reservoir and therefore cannot be used to predict e.g. water breakthrough.
- Deconvolution currently only works for single wells; i.e. it does not take into account the influence of nearby producers and injectors.

(These limitations do not prevent the use of deconvolution but need to be considered when examining results).

# Conclusions

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- With the availability of robust deconvolution, it is possible to extract important information from well test data quickly and easily prior to any further analysis or models.
- Uncertainty in the deconvolution carries through to uncertainty in results.
- The deconvolved derivative provides the signature of the dynamic behaviour of a well which can be extrapolated to predict future well production.
- The late time derivative response defines the long term well and reservoir performance.
- Permanent downhole pressure gauges allow continuous updating of the deconvolution which reduces the uncertainty in future well performance.

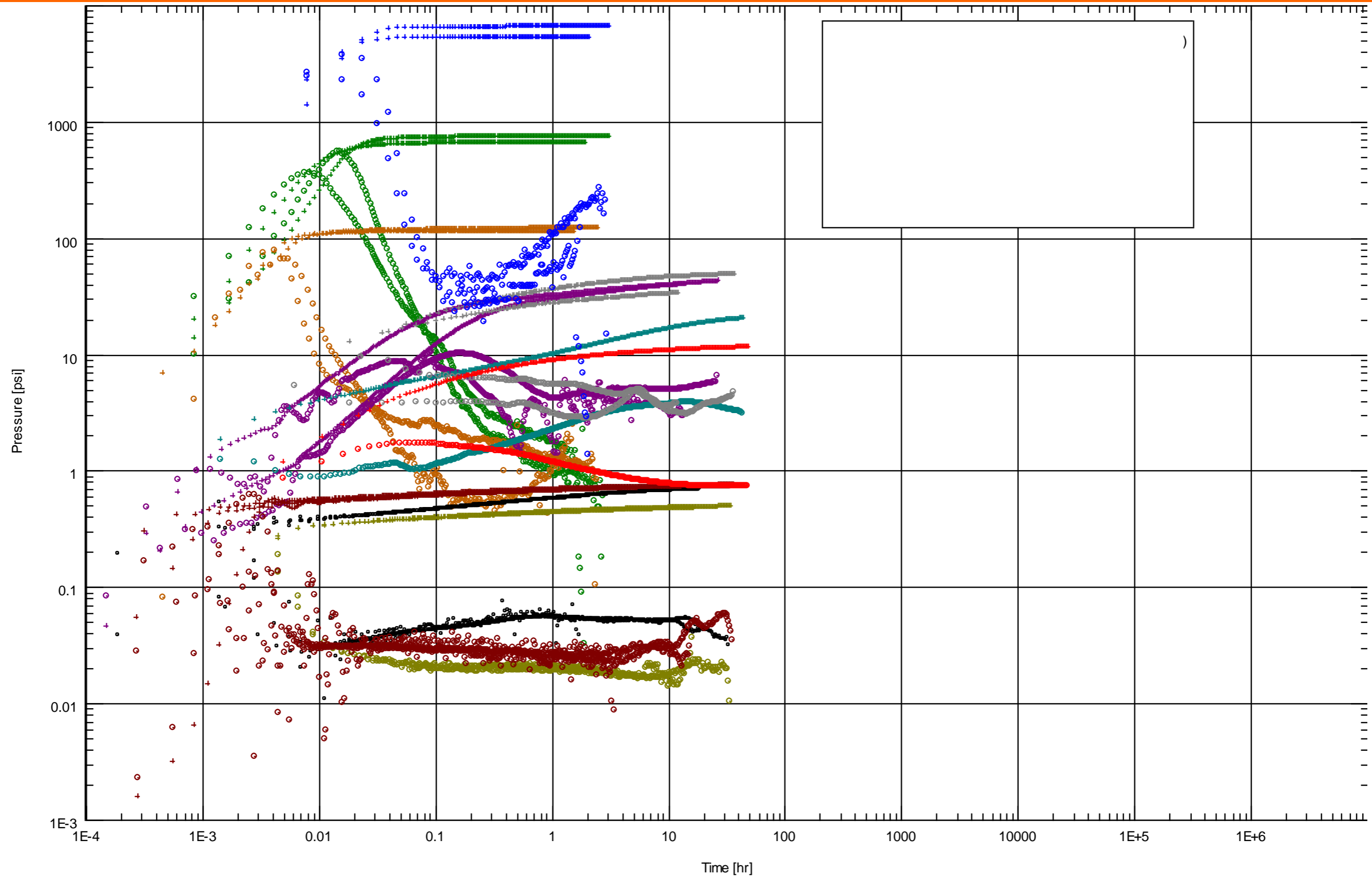
# Summary

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Tested volumes and future well production can be estimated from pressure transient data prior to building complex models.

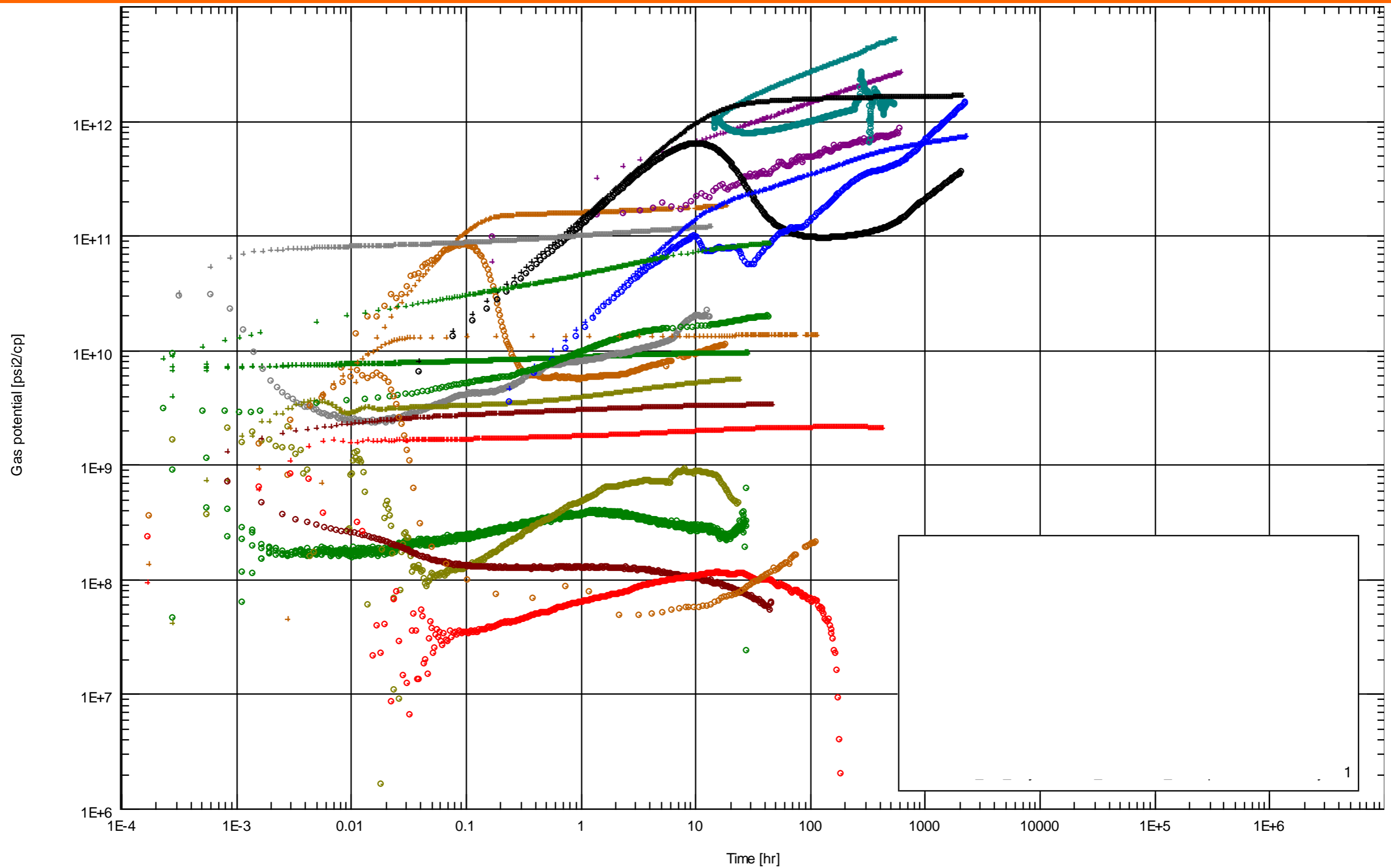
Use the rate normalized log-log derivative plot to compare the response between build-ups and between wells...

# Derivative Comparison – Oil and Water



Compare files: Log-Log plot (dp and dp' normalized [psi] vs dt)

# Derivative Comparison - Gas



Compare files: Log-Log plot (dm(p) and dm(p)' normalized [psi<sup>2</sup>/cp] vs dt)