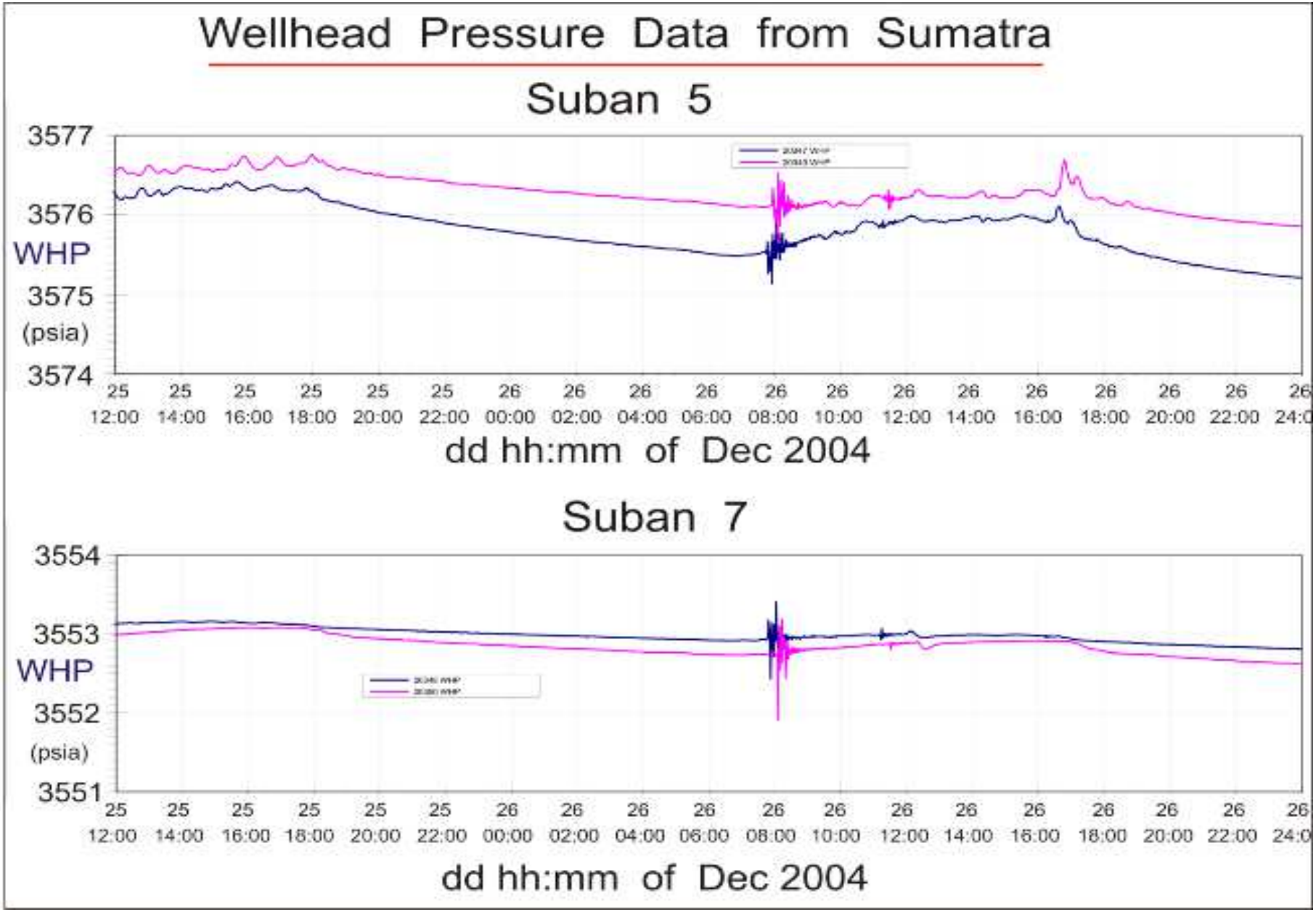
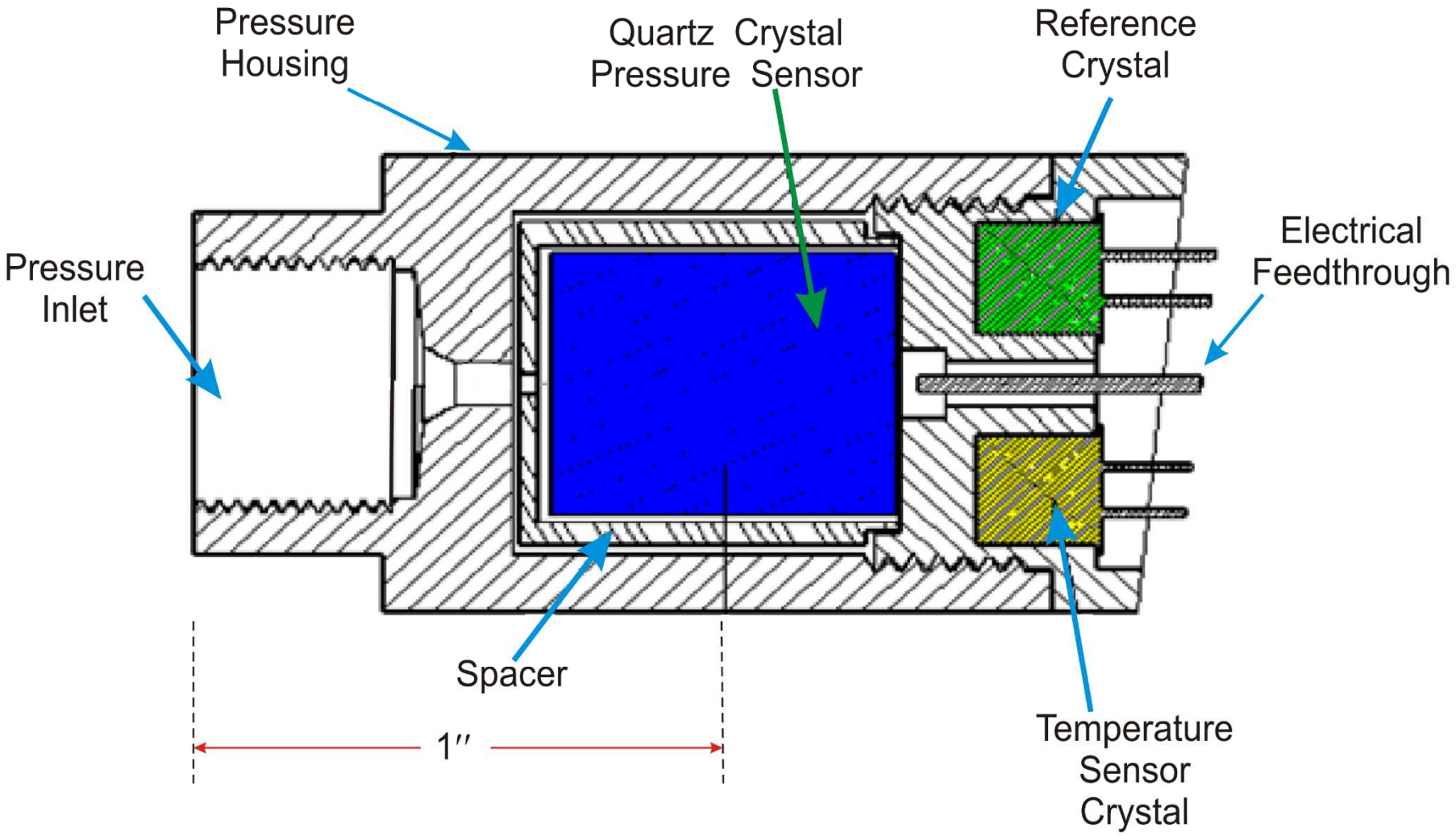
DEVEX Presentation
on
Well Testing

Prof George Stewart
RGS Consulting

Wellhead Pressure Data from Sumatra

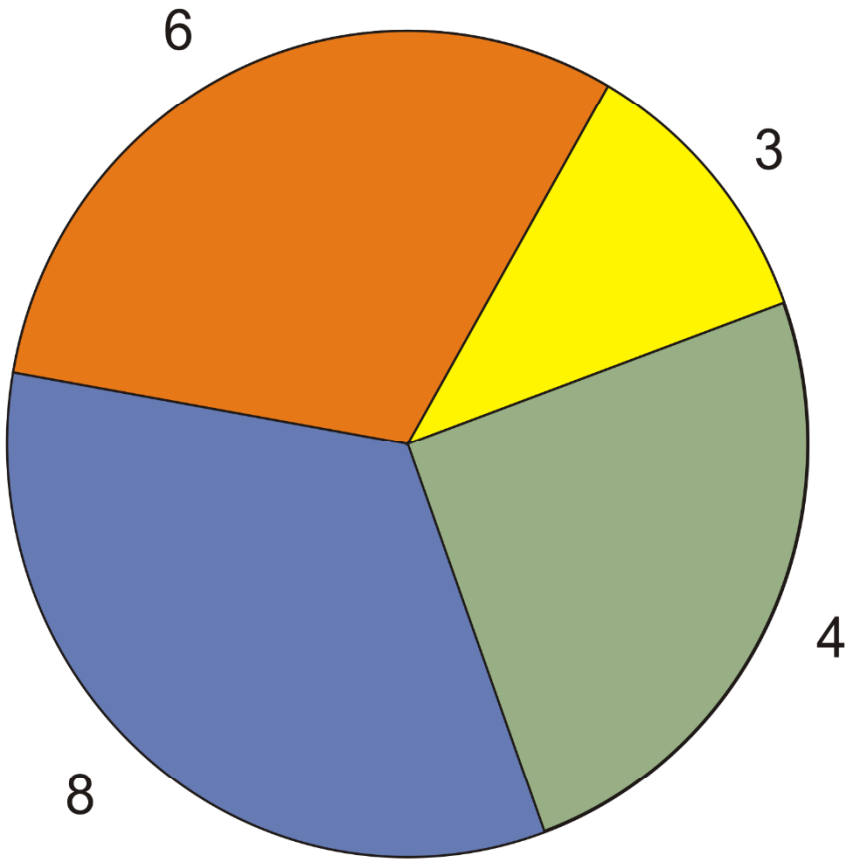


Quartz Pressure Transducer



After Quartzdyne/Metrolog

Reasons for Well Testing



Rate-Reservoir

Rate-Completion

Fluid

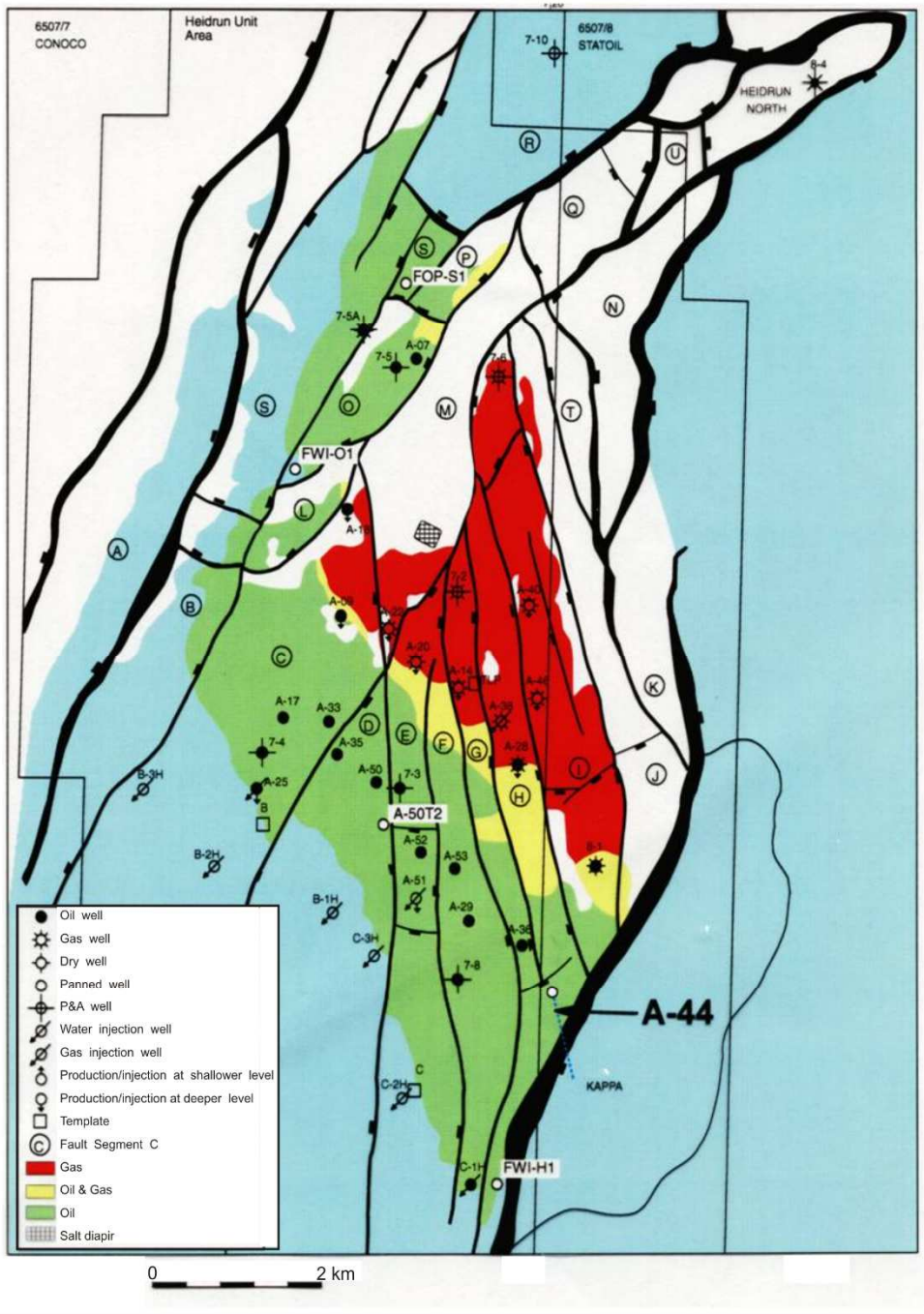
Continuity

!993
Case Studies

Shell GOM

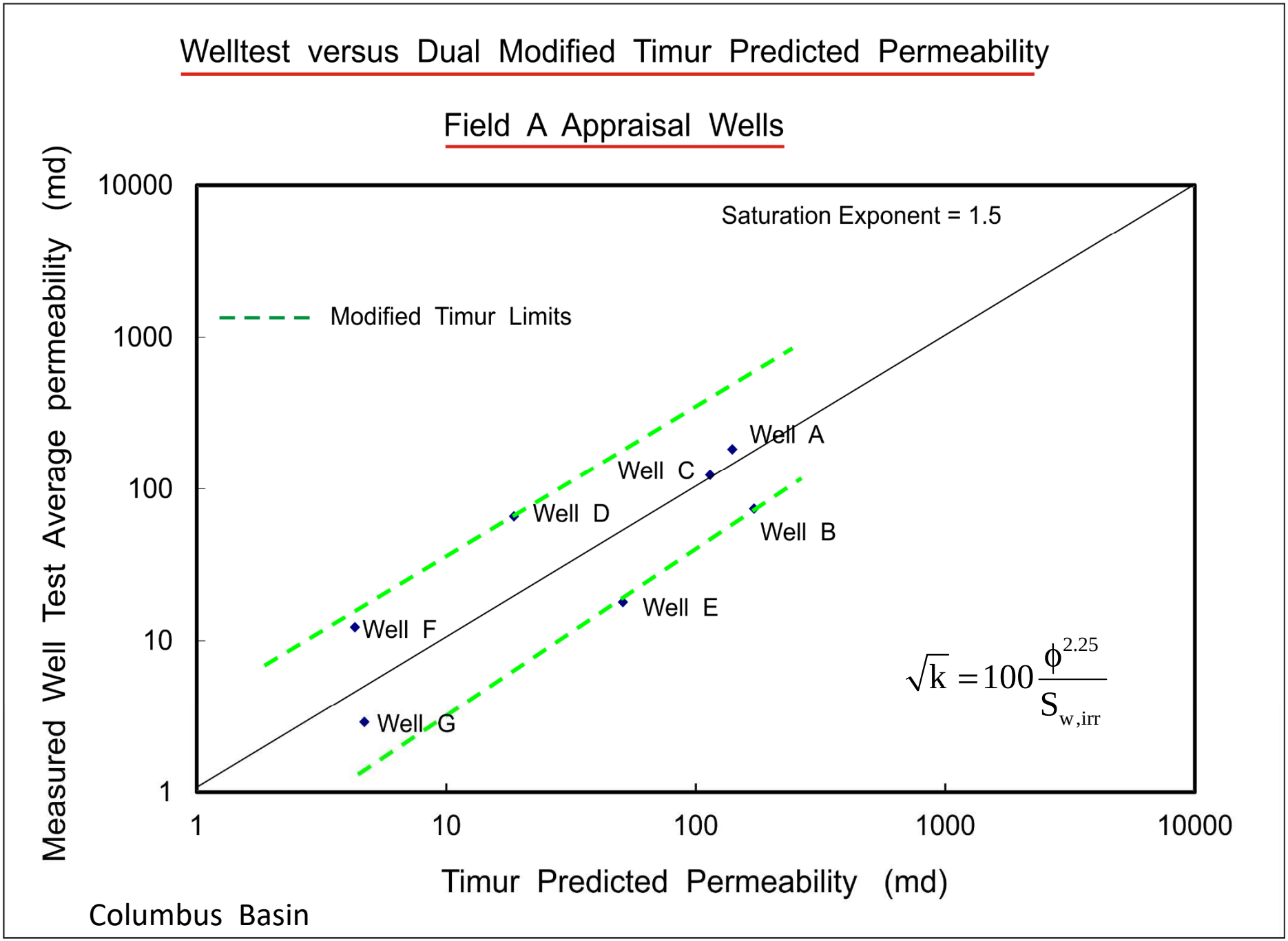
Heidron Field

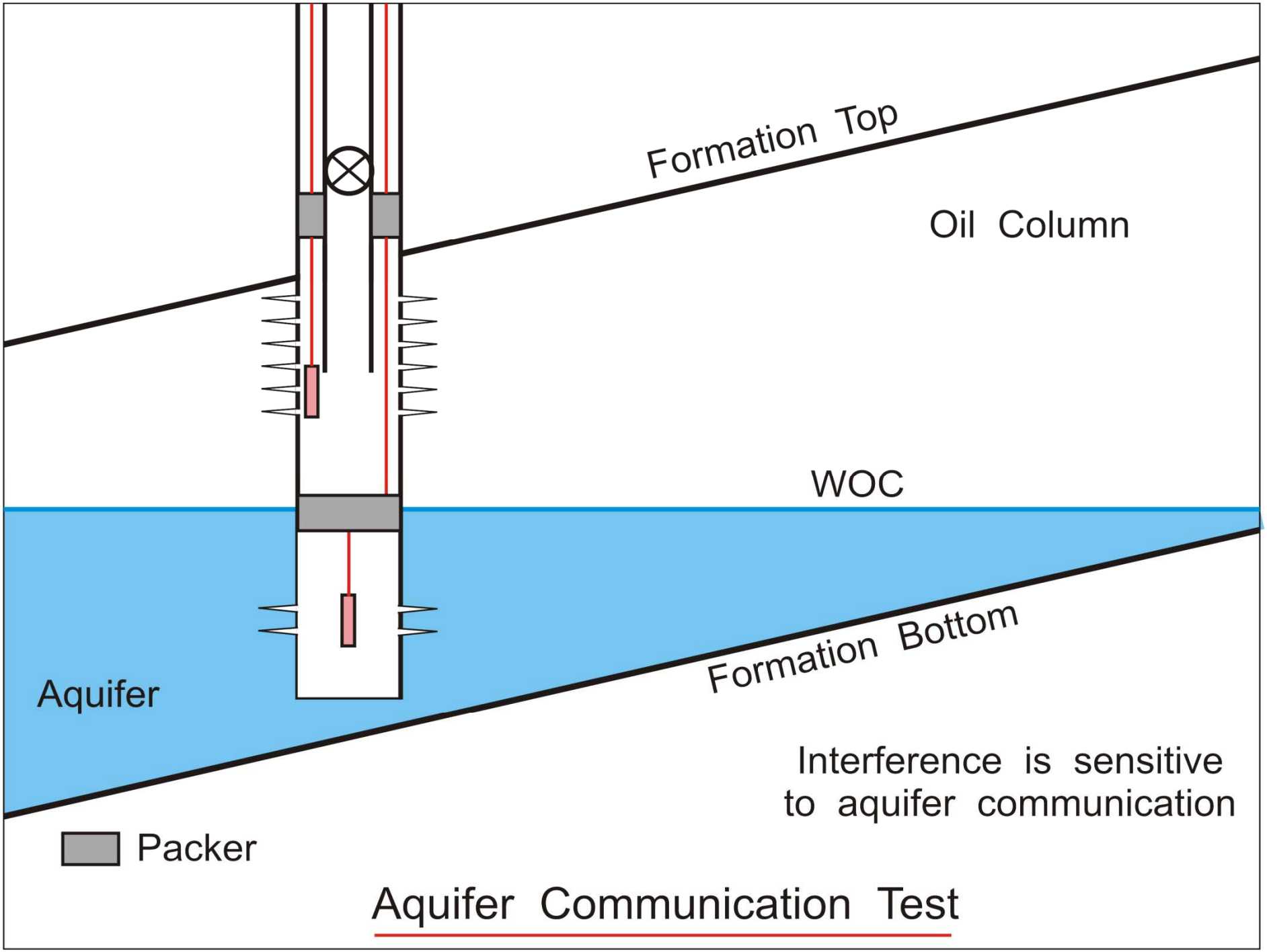
North Sea



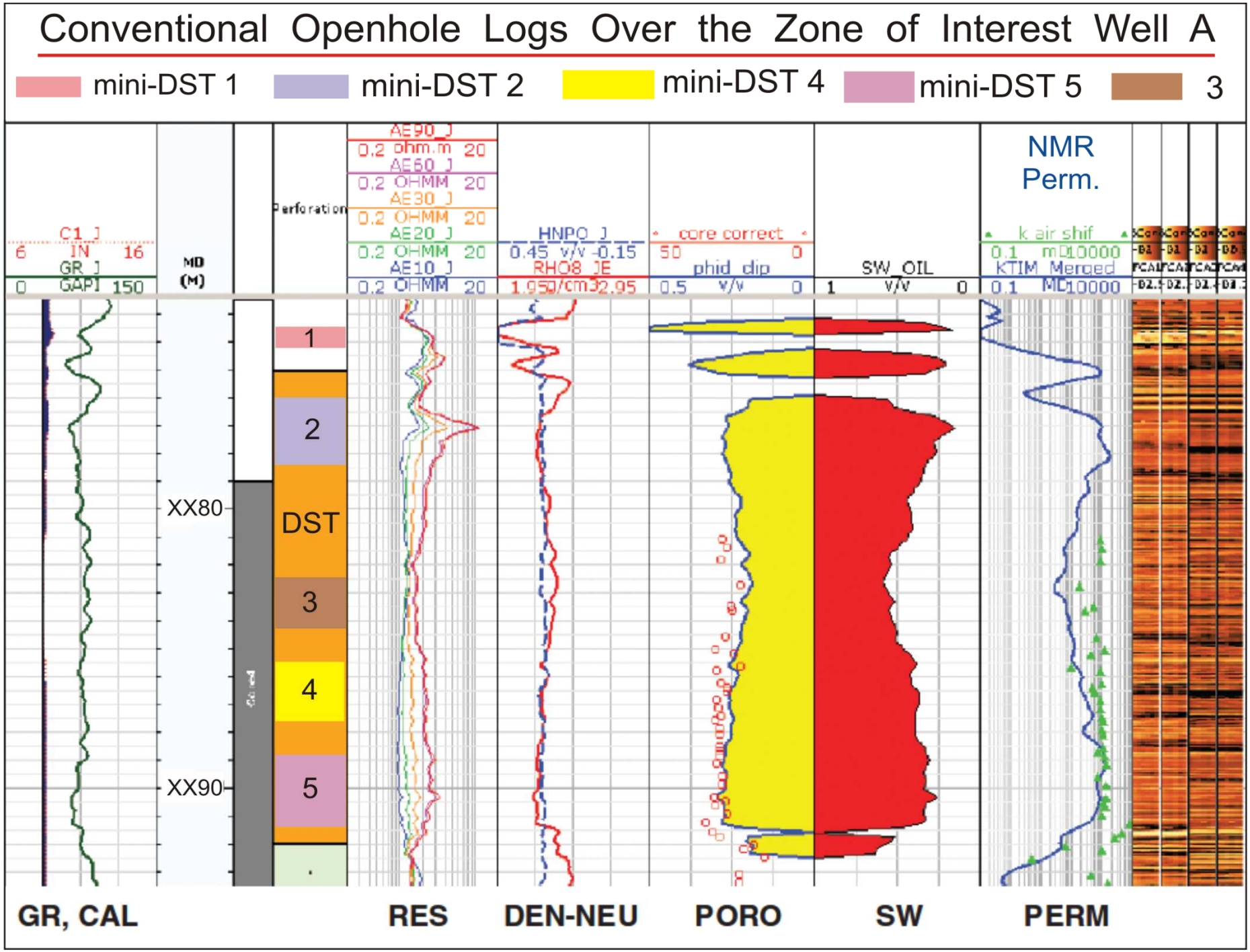
Fangst Group

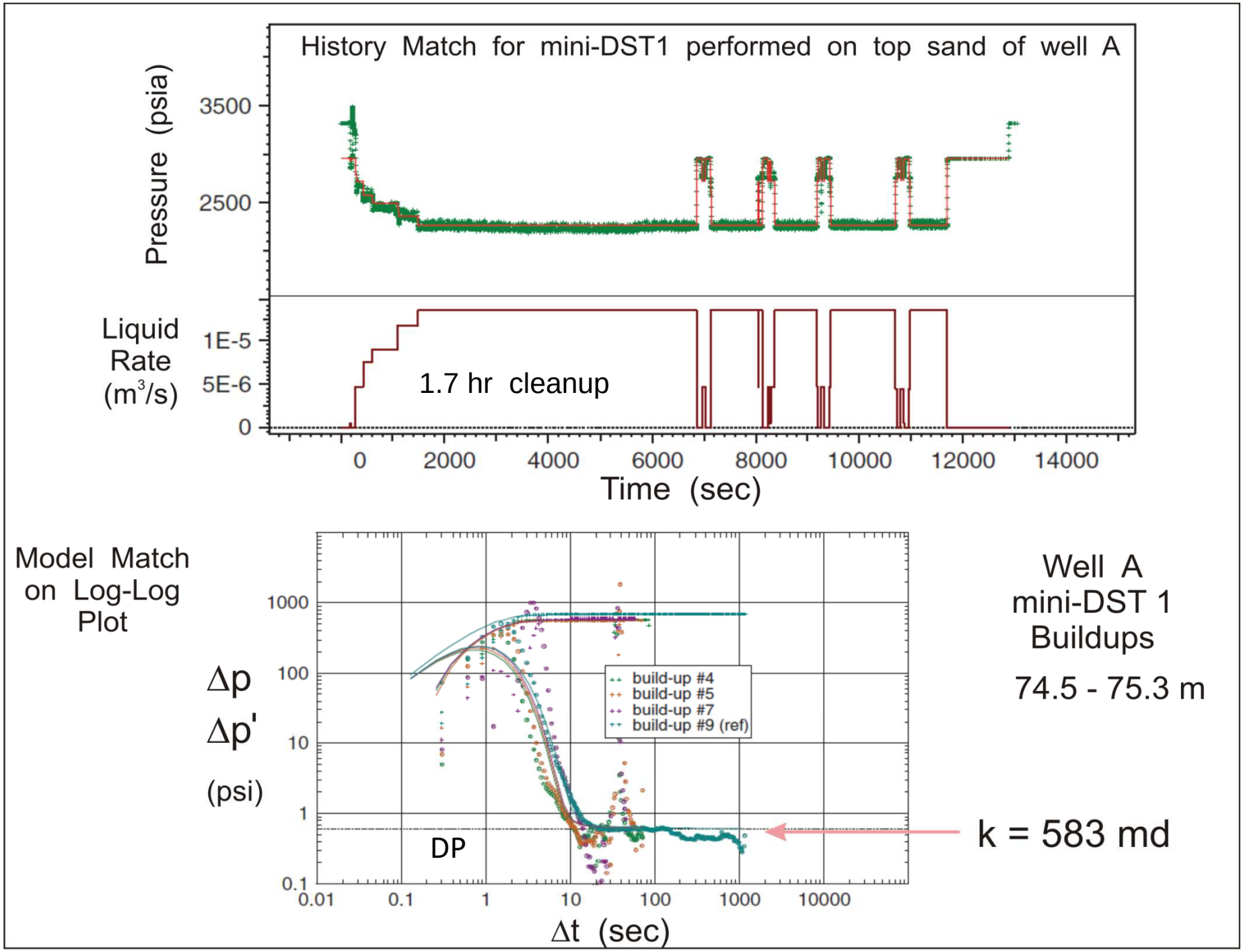
Drilled Wells and Planned Wells

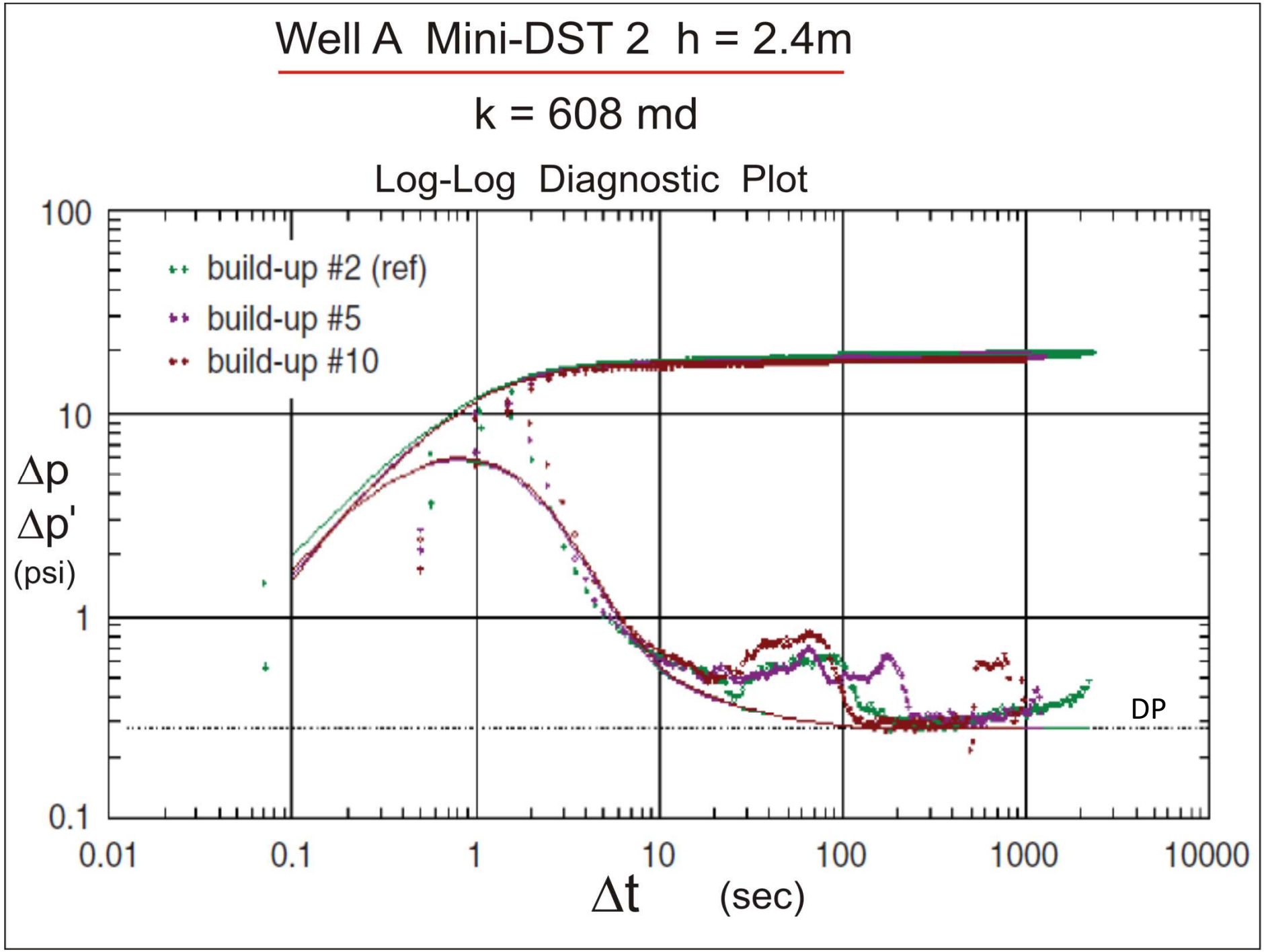

Welltest versus Dual Modified Timur Predicted Permeability
Field A Appraisal Wells
Measured Well Test Average permeability (md)
10000
1000
100
10
1
Saturation Exponent = 1.5
Modified Timur Limits
Well A
Well C
Well D
Well B
Well E
Well F
Well G
$\sqrt{k} = 100 \frac{\phi^{2.25}}{S_{w,irr}}$
1
10
100
1000
10000
Timur Predicted Permeability (md)
Columbus Basin


Formation Top
Oil Column
WOC
Formation Bottom
Aquifer
Interference is sensitive
to aquifer communication
Packer
Aquifer Communication Test

Conventional Openhole Logs Over the Zone of Interest Well A




History Match for mini-DST1 performed on top sand of well A
Pressure (psia)
3500
2500
Liquid Rate (m³/s)
1E-5
5E-6
0
1.7 hr cleanup
0
2000
4000
6000
8000
10000
12000
14000
Time (sec)
Model Match on Log-Log Plot
Δp
Δp'
(psi)
1000
100
10
1
0.1
build-up #4
build-up #5
build-up #7
build-up #9 (ref)
DP
0.01
0.1
1
10
100
1000
10000
Δt (sec)
Well A
mini-DST 1
Buildups
74.5 - 75.3 m
k = 583 md


Well A Mini-DST 2 h = 2.4m
k = 608 md
Log-Log Diagnostic Plot
build-up #2 (ref)
build-up #5
build-up #10
Δp
Δp'
(psi)
100
10
1
0.1
0.01
0.1
1
10
100
1000
10000
Δt (sec)
DP

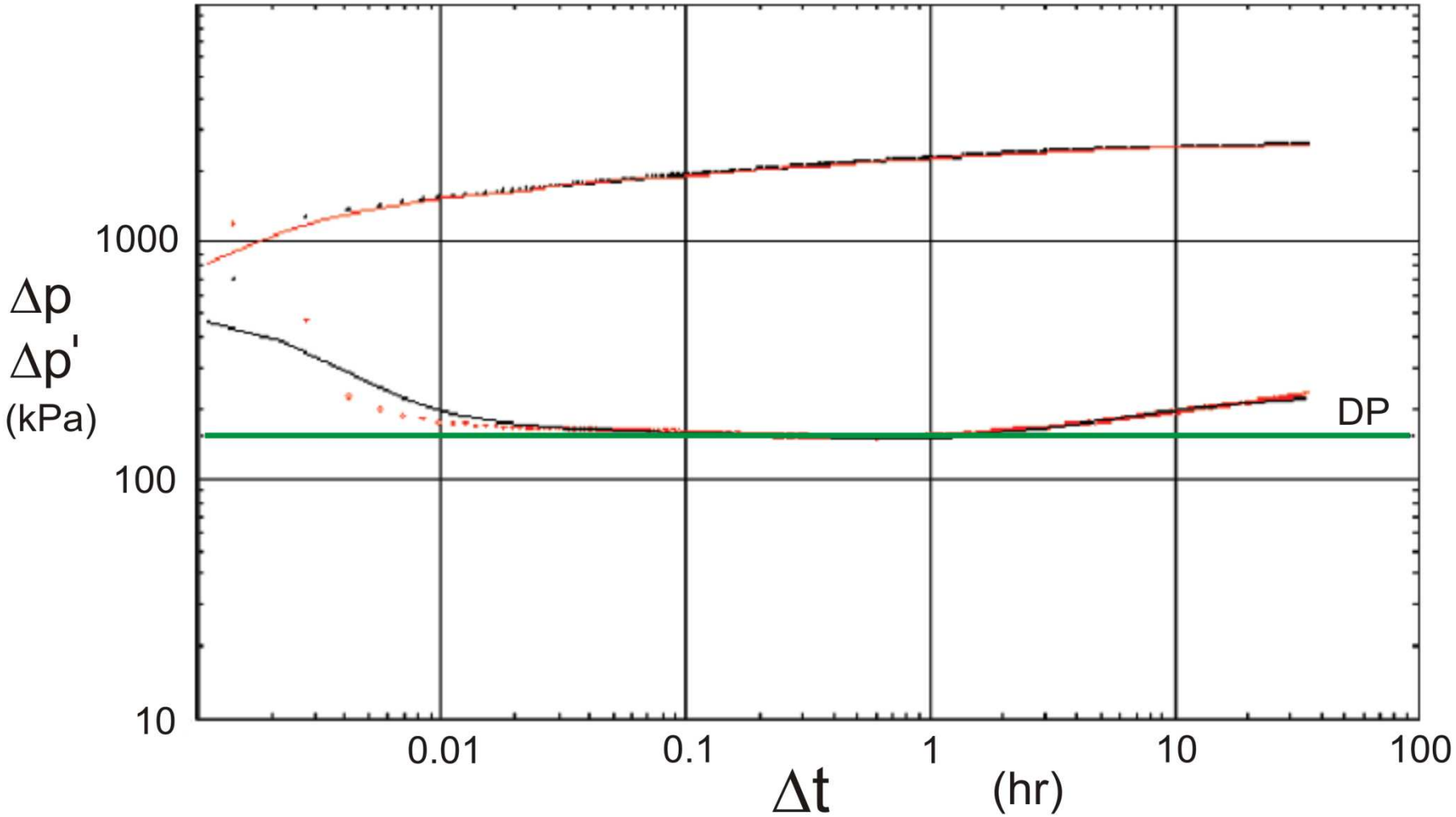
Well A DST Production Test

Data and Model Match

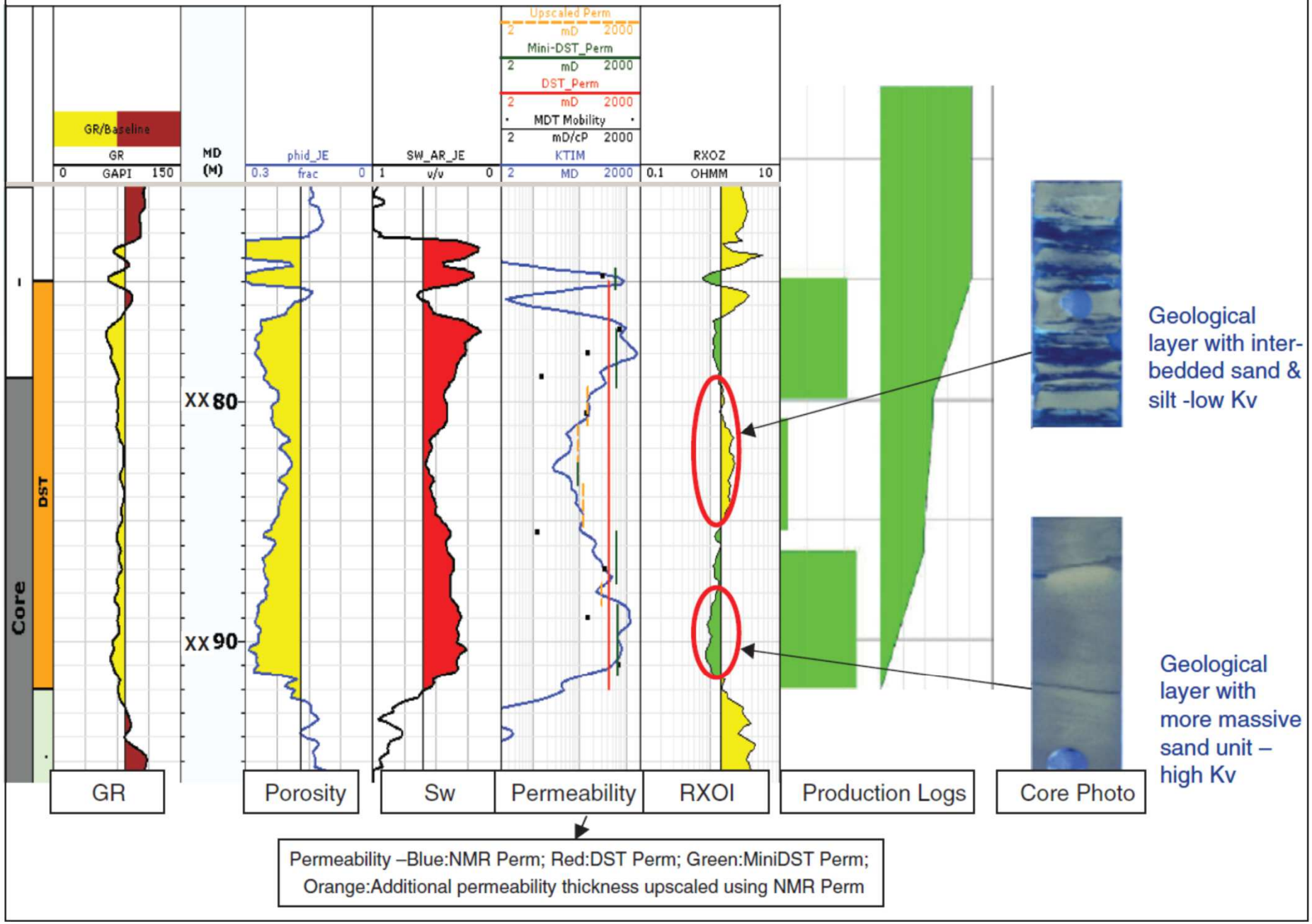
kh = 6948 md.m

Main Buildup

Log-Log Diagnostic Plot



Permeability Results for Well A



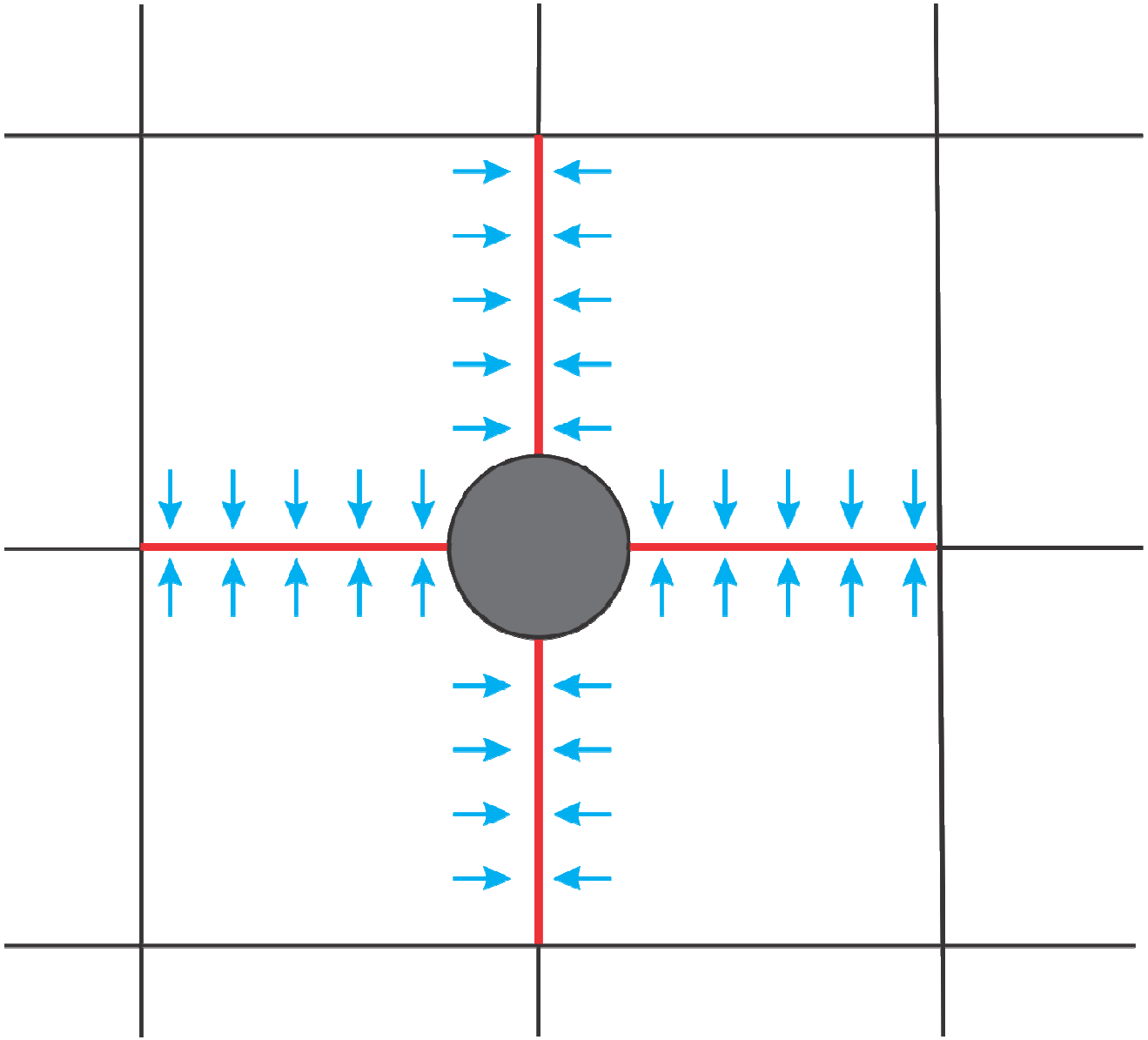
Comparison of Permeability-Thickness and Permeability Between Mini-DST and DST Results in Well A

	Upscaled Mini-DST	DST
Thickness, m	15.2	16.5
Permeability Thickness, md.m	6149	6948
Average Permeability, md	405	421

- Unfortunately the authors give no results regarding the skin factor

Early Time Linear Flow to Enhanced, Connected Fractures

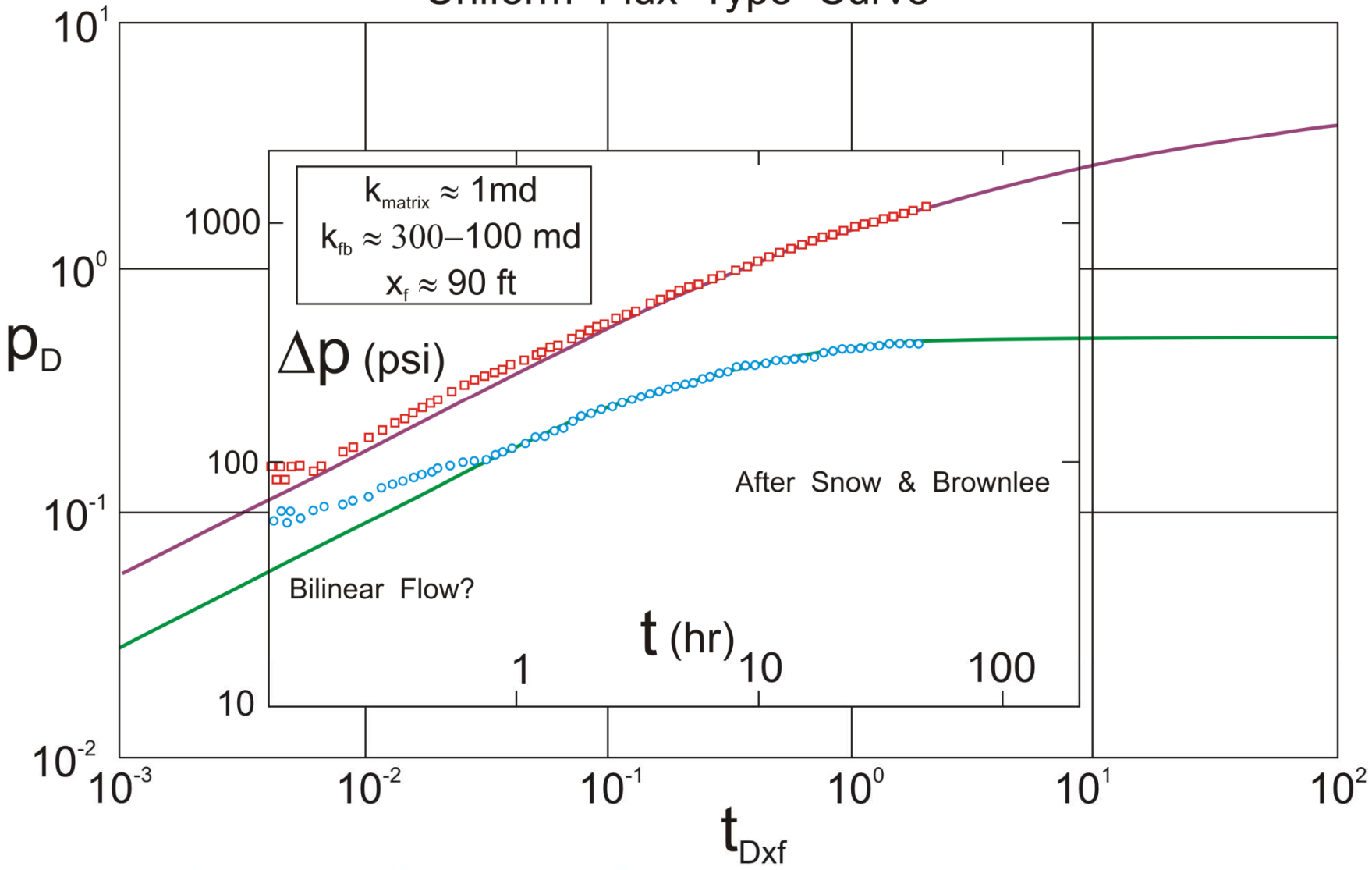
Ideal
Cubic
Network



Ekofisk Test - Acidised Well

SPE 19776
1989

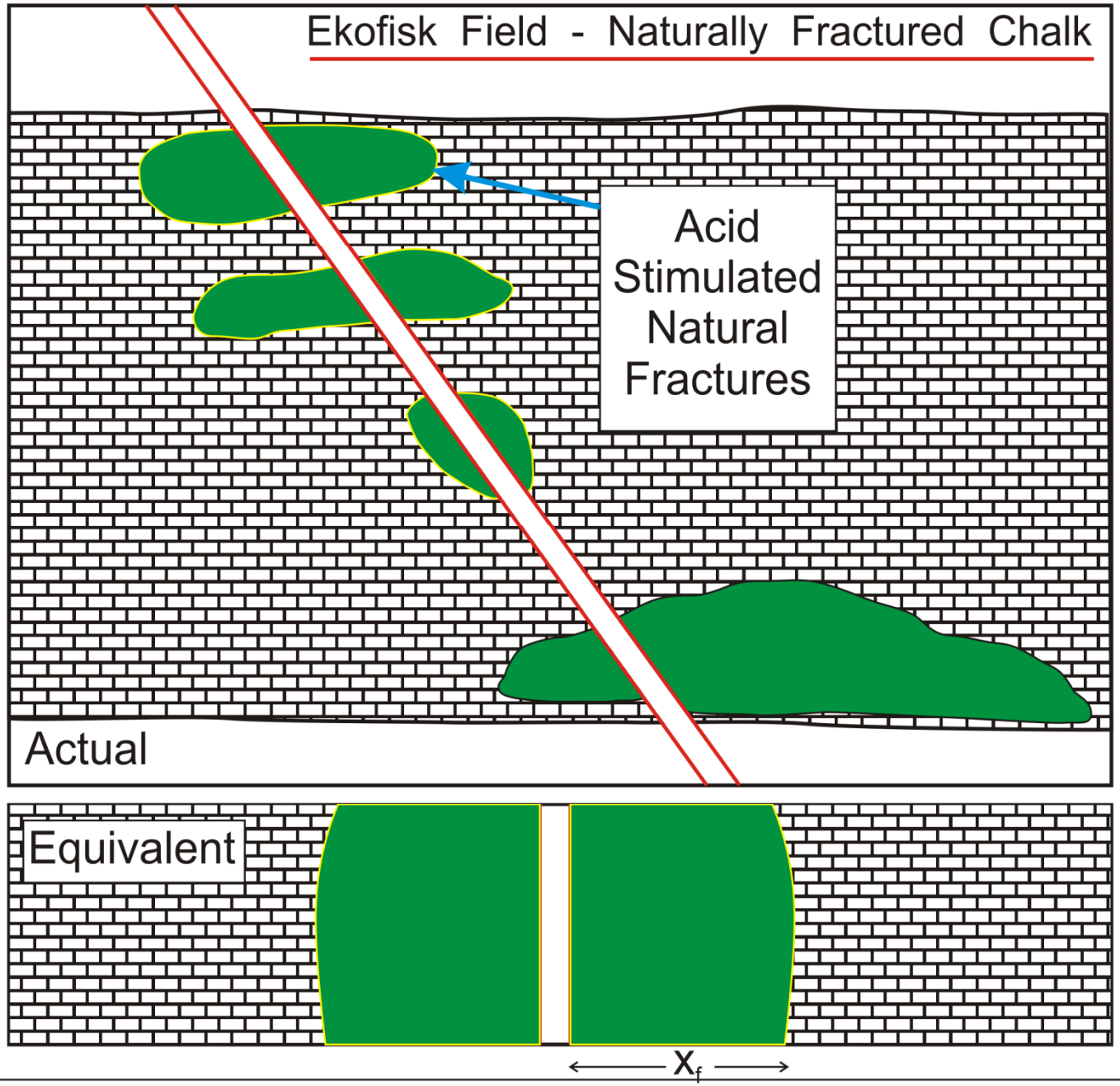
Uniform Flux Type Curve



Naturally Fractured Reservoir (Chalk)

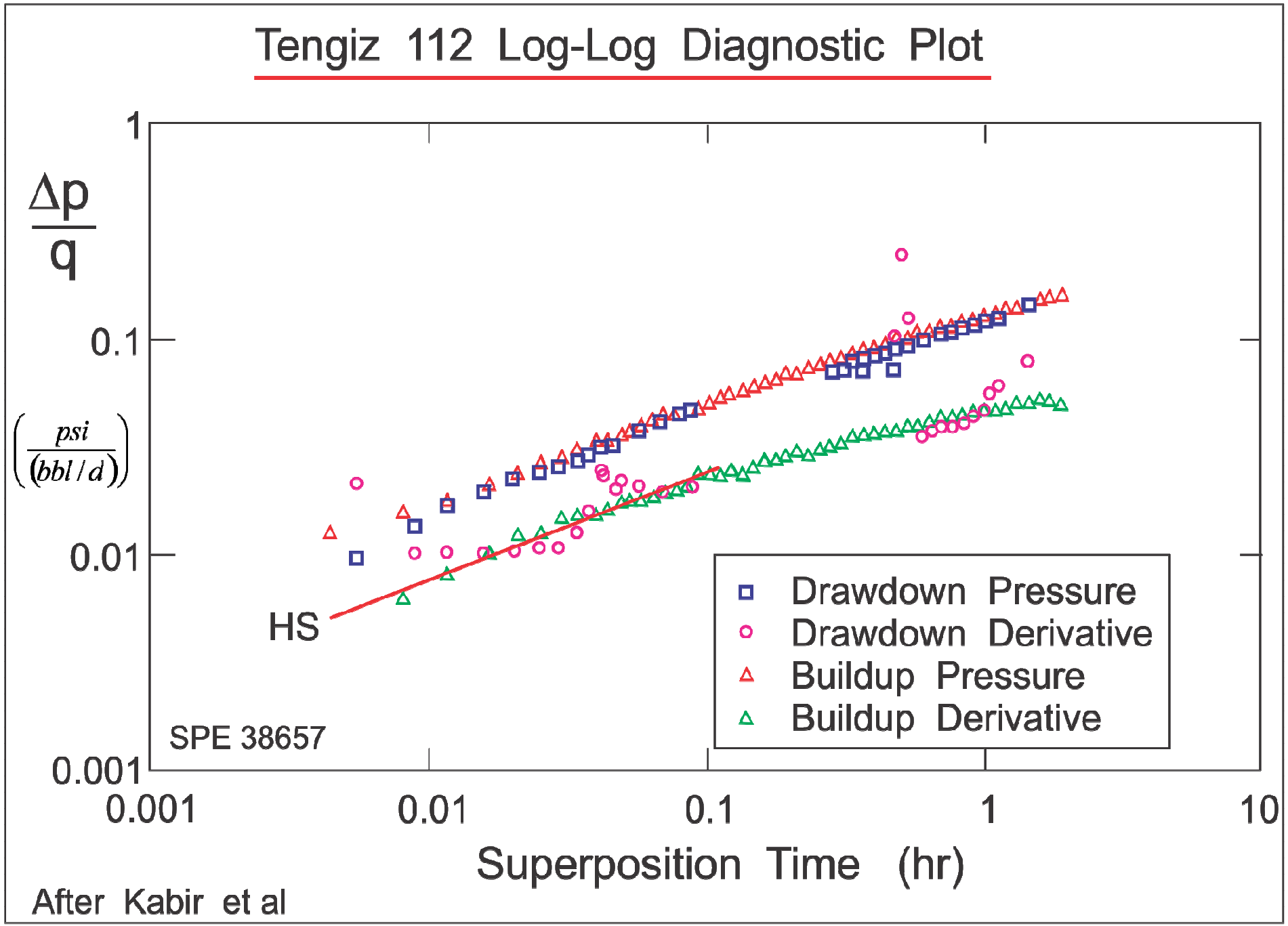
SPE
19776
1989

Varying Fracture Conductivity with distance from wellbore also postulated

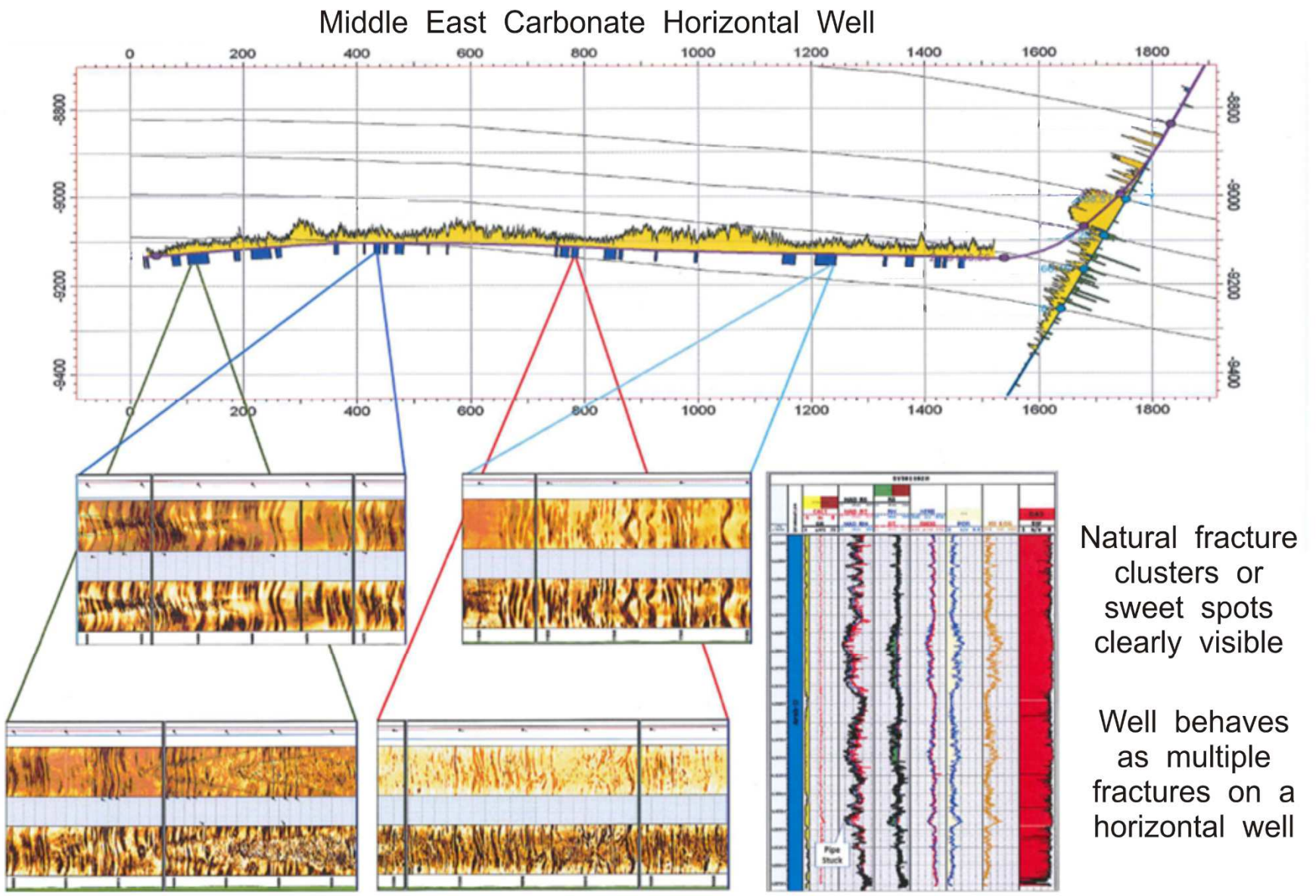


Note Area Corres-pondence of Actual and Equivalent Fracture Systems

After Snow and Brownlee

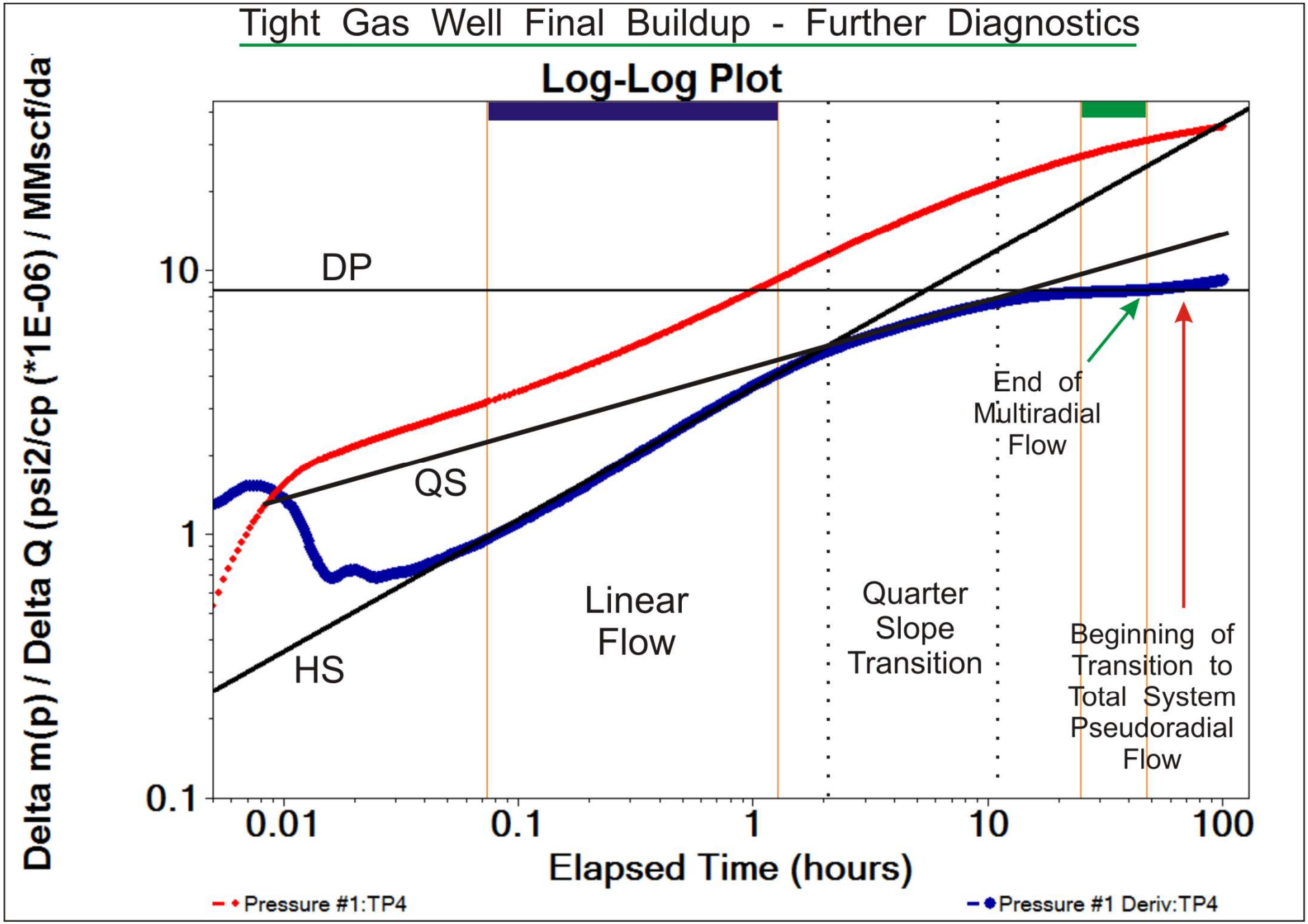

Tengiz 112 Log-Log Diagnostic Plot
1
0.1
0.01
0.001
Δp/q
(psi/(bbl/d))
HS
SPE 38657
Drawdown Pressure
Drawdown Derivative
Buildup Pressure
Buildup Derivative
0.001
0.01
0.1
1
10
Superposition Time (hr)
After Kabir et al

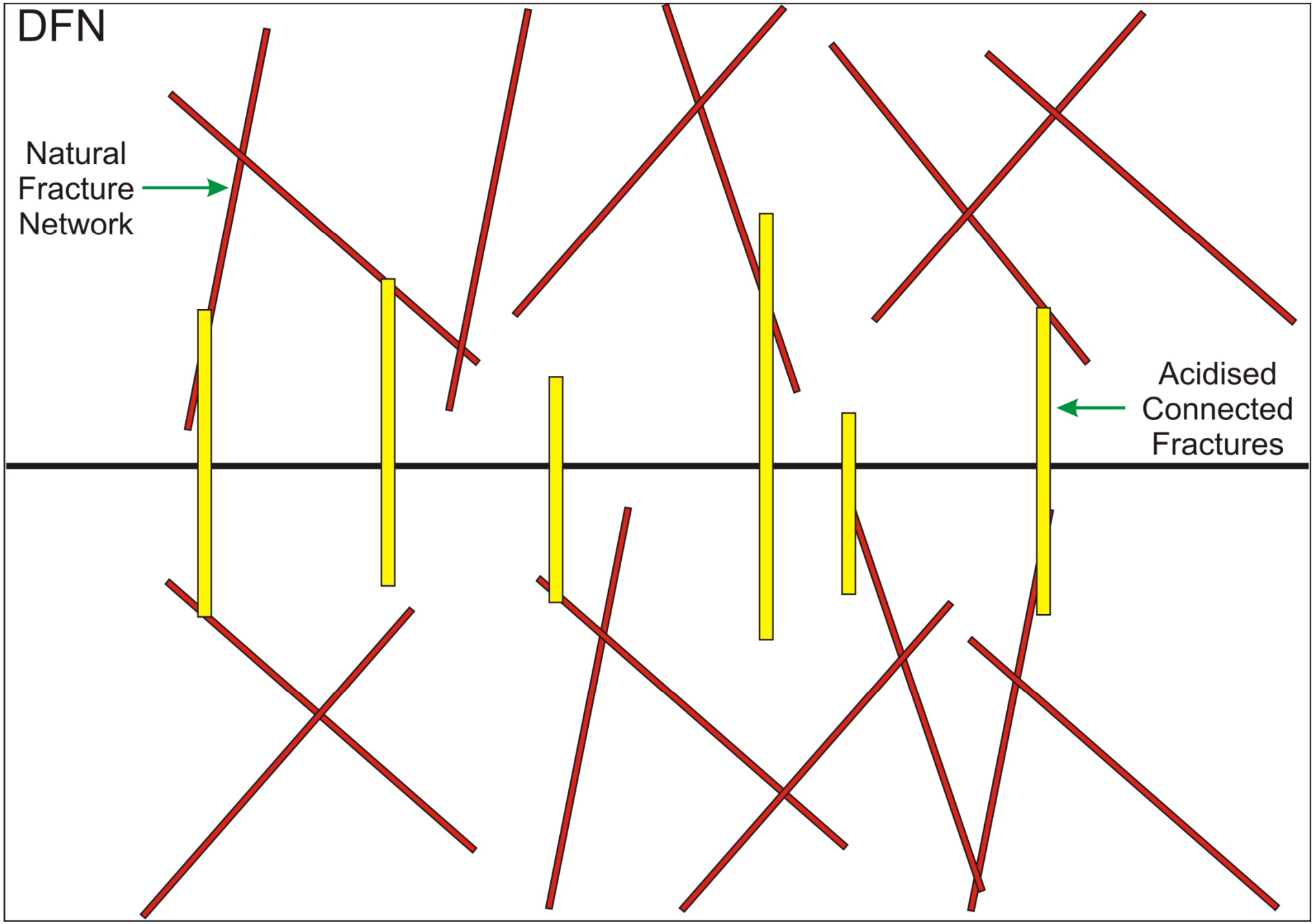
Fracture Frequency from Image Logs



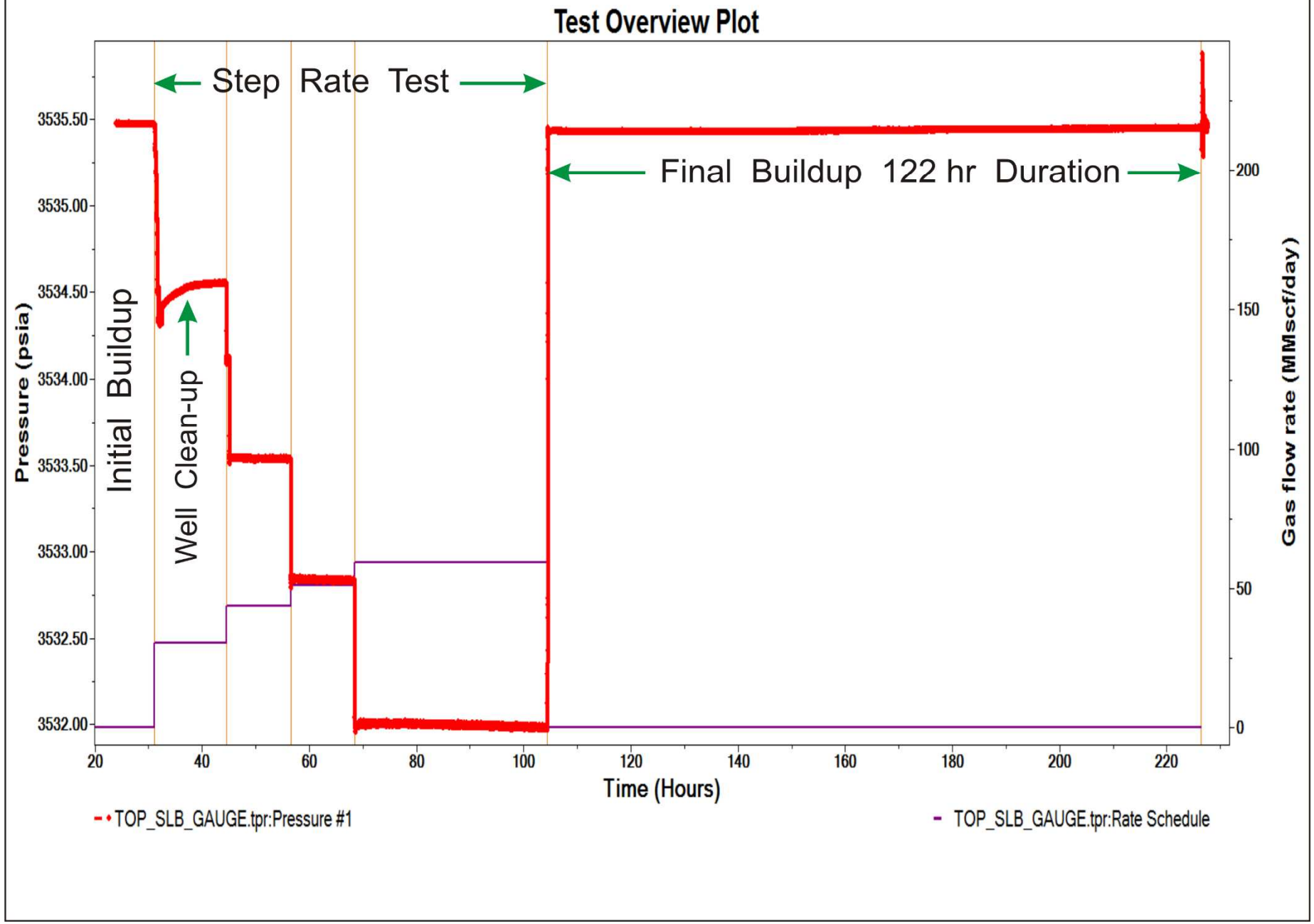
Natural fracture clusters or sweet spots clearly visible

Well behaves as multiple fractures on a horizontal well

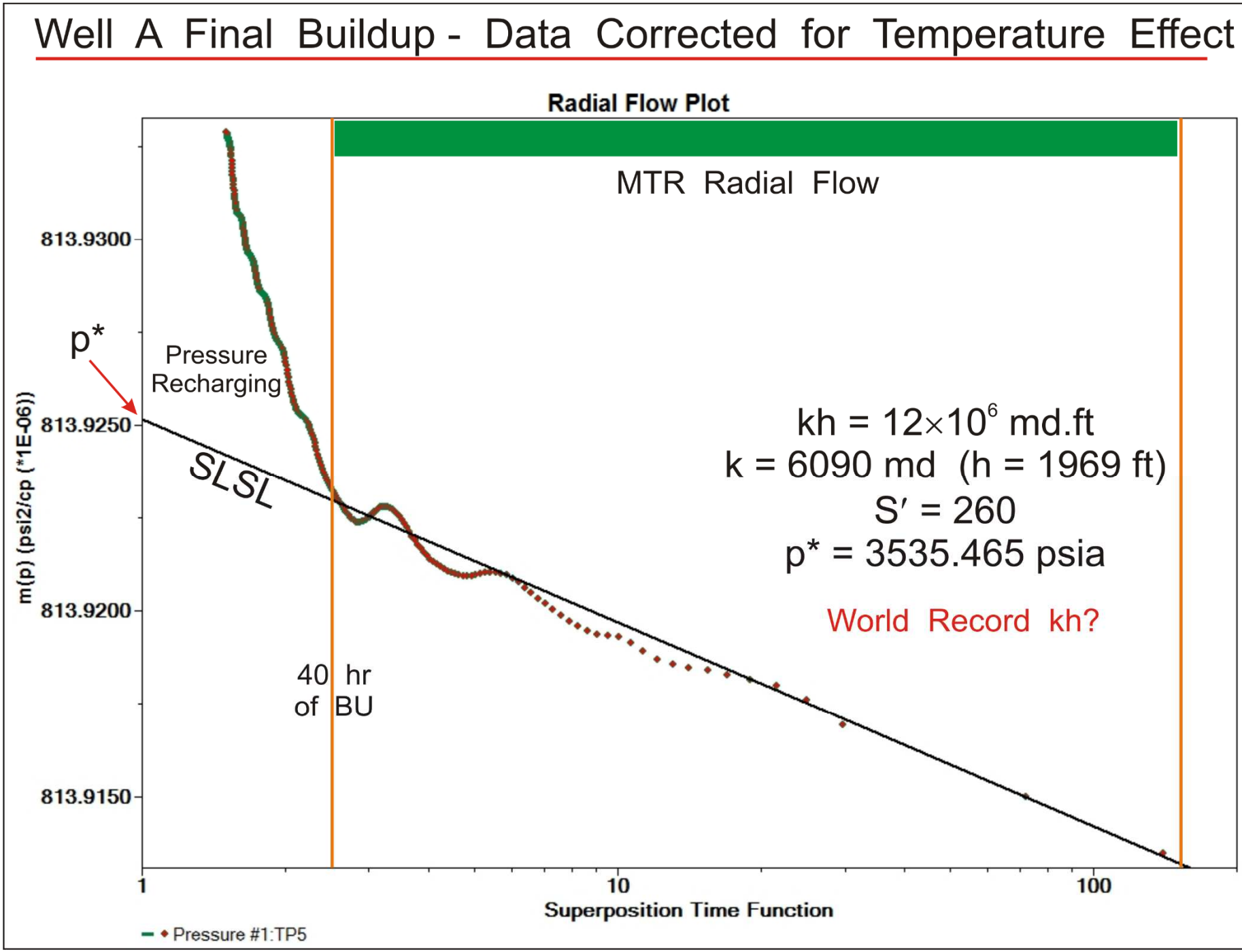

Tight Gas Well Final Buildup - Further Diagnostics
Log-Log Plot
Delta m(p) / Delta Q (psi2/cp (*1E-06) / MMscf/da
10
1
0.1
DP
QS
HS
Linear Flow
Quarter Slope Transition
End of Multiradial Flow
Beginning of Transition to Total System Pseudoradial Flow
0.01
0.1
1
10
100
Elapsed Time (hours)
Pressure #1:TP4
Pressure #1 Deriv:TP4

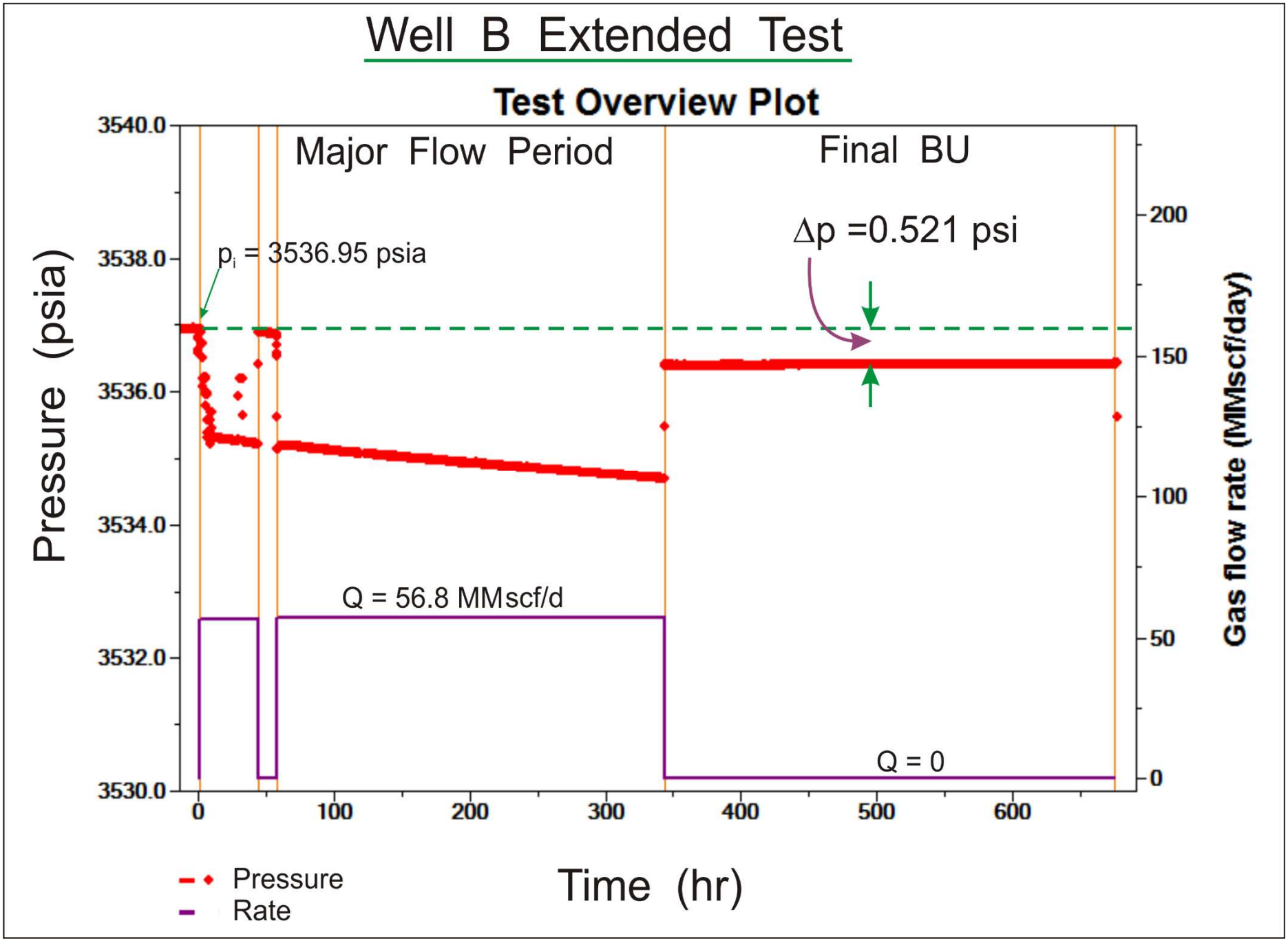

DFN
Natural
Fracture
Network
Acidised
Connected
Fractures

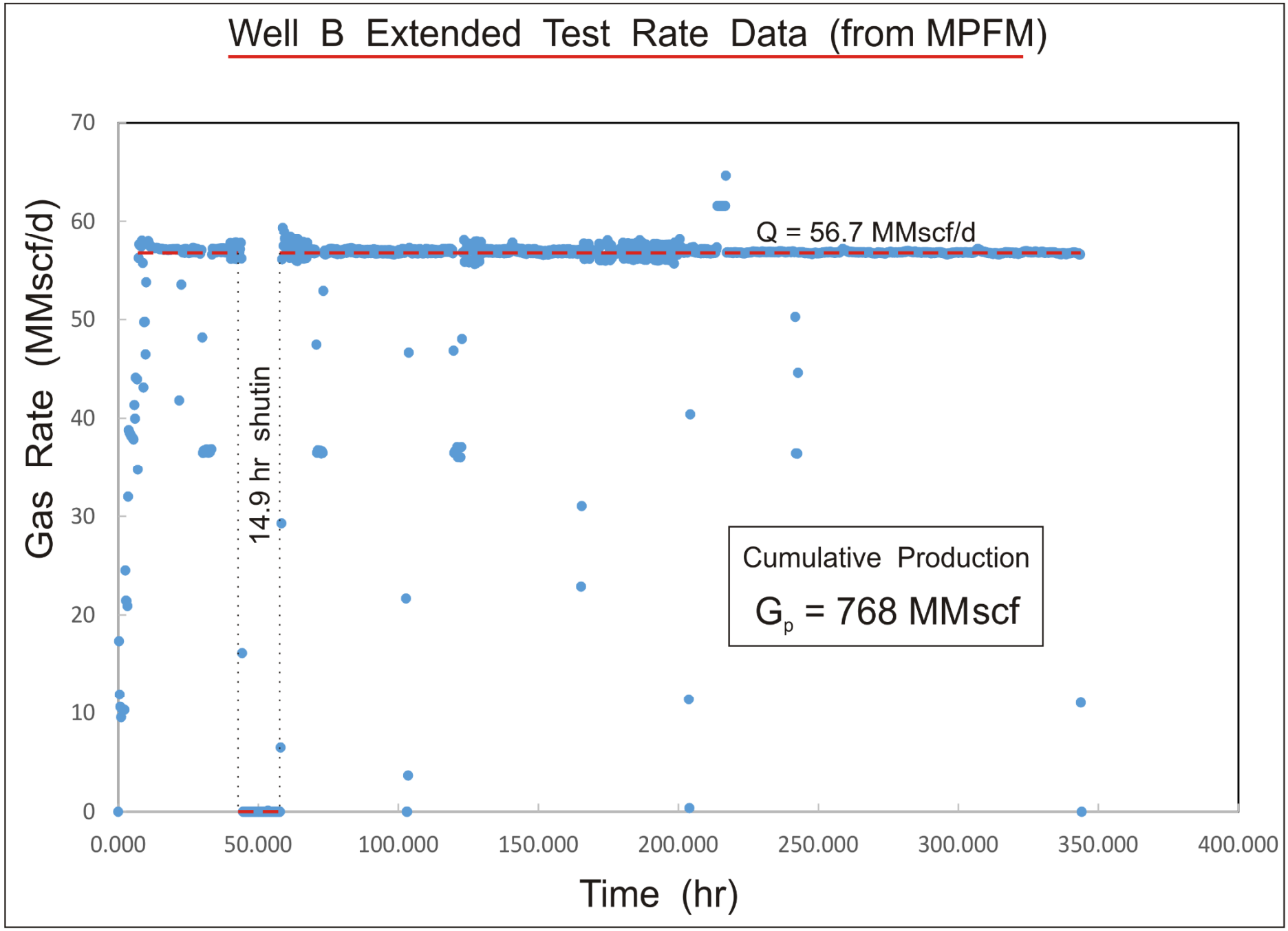
Well B Appraisal Test



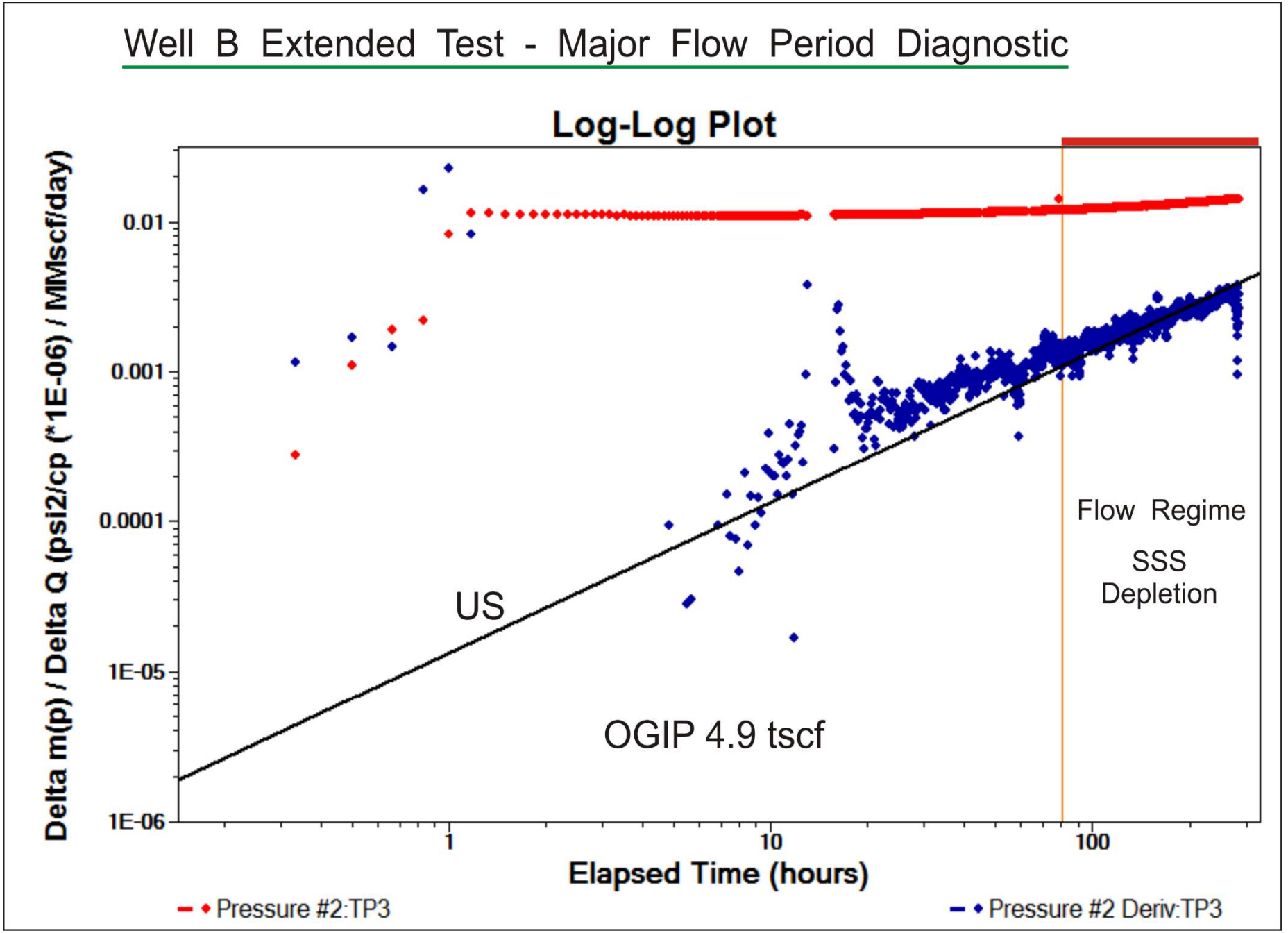
Well A Final Buildup - Data Corrected for Temperature Effect

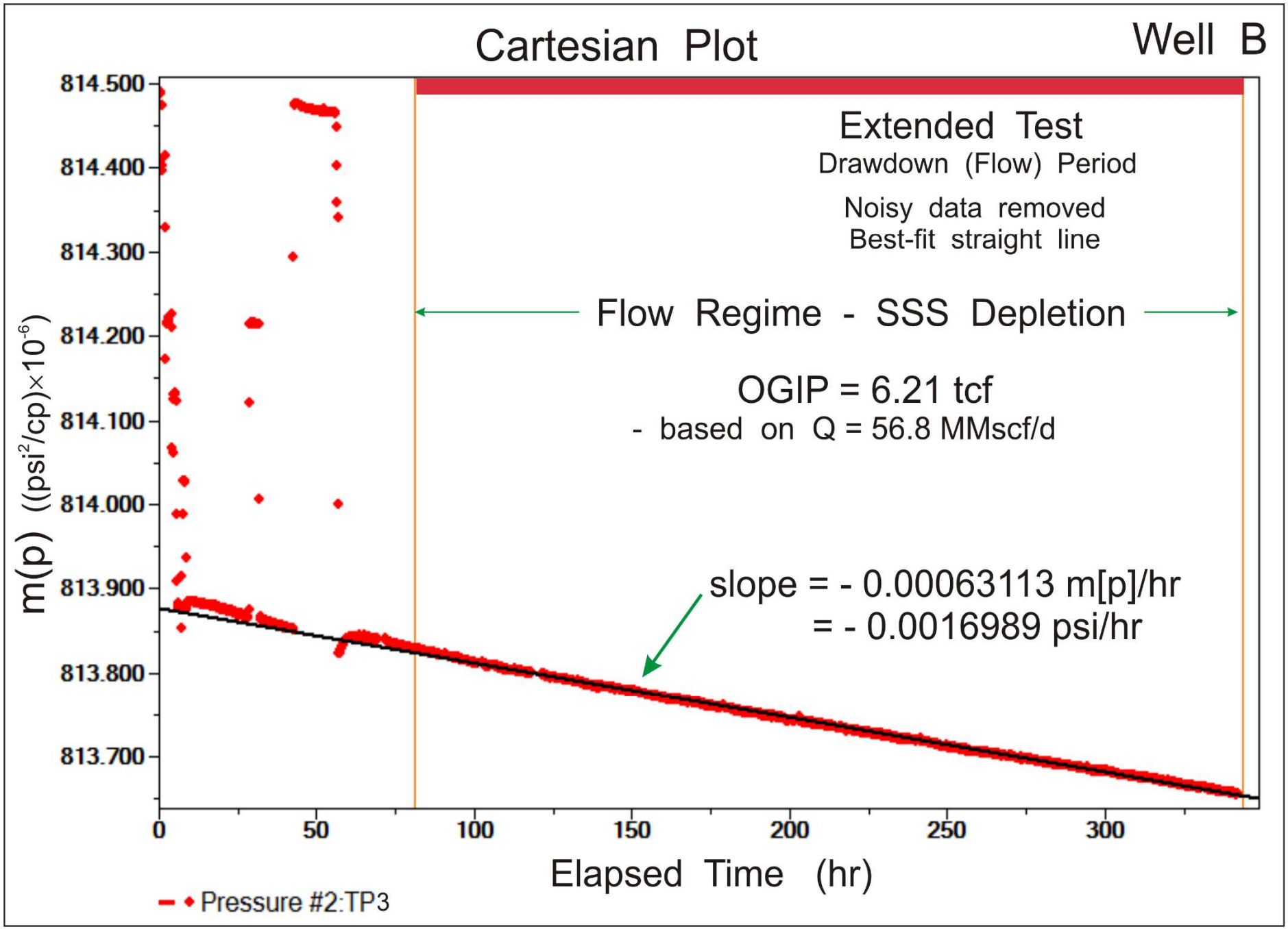



Well B Extended Test
Test Overview Plot
Major Flow Period
Final BU
Δp =0.521 psi
p_i = 3536.95 psia
Q = 56.8 MMscf/d
Q = 0
Pressure (psia)
Gas flow rate (MMscf/day)
Time (hr)
Pressure
Rate
3540.0
3538.0
3536.0
3534.0
3532.0
3530.0
200
150
100
50
0
0
100
200
300
400
500
600

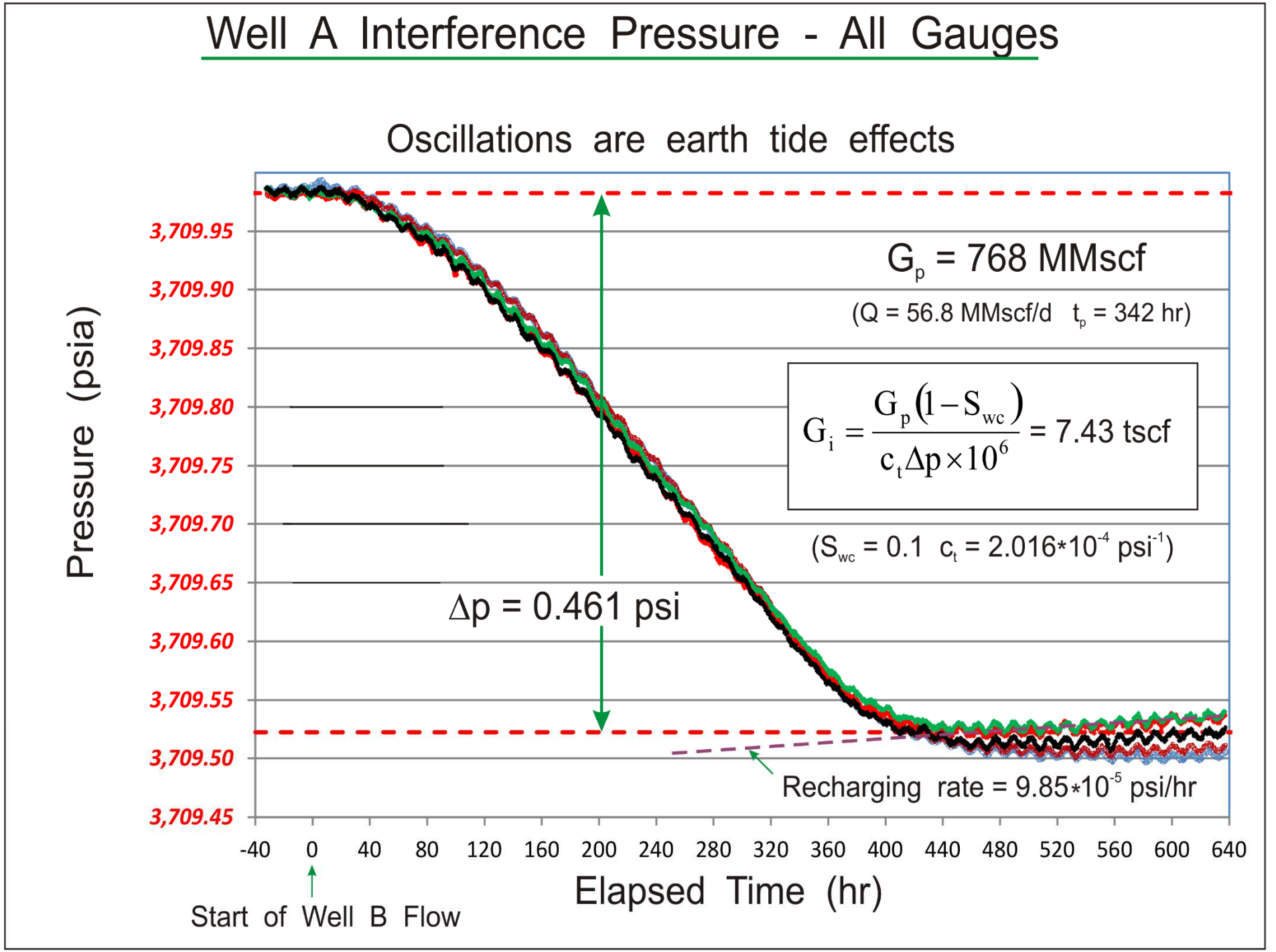

Well B Extended Test Rate Data (from MPFM)
Gas Rate (MMscf/d)
70
60
50
40
30
20
10
0
0.000
50.000
100.000
150.000
200.000
250.000
300.000
350.000
400.000
Time (hr)
Q = 56.7 MMscf/d
14.9 hr shutin
Cumulative Production
G_p = 768 MMscf

Well B Extended Test - Major Flow Period Diagnostic

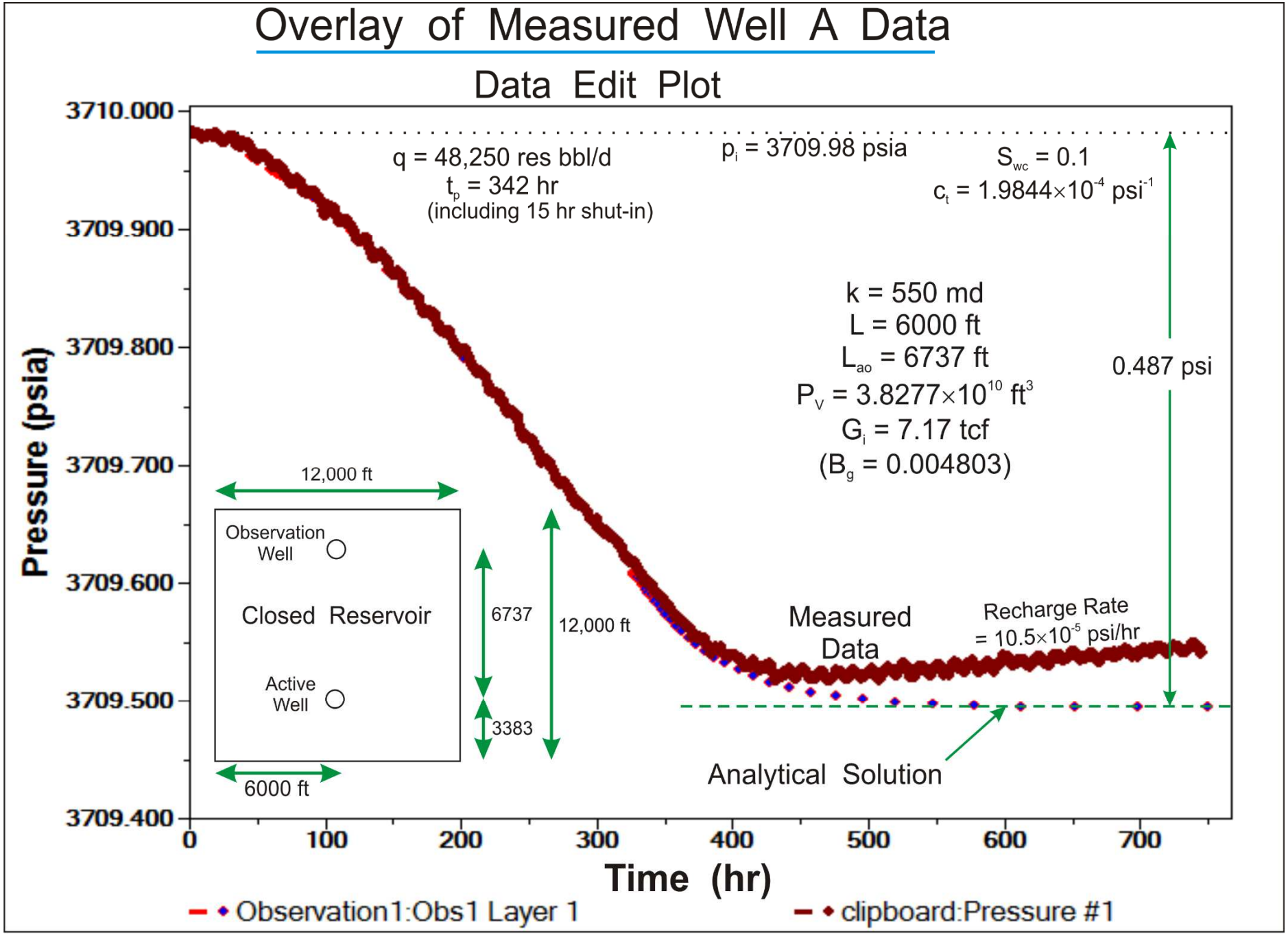


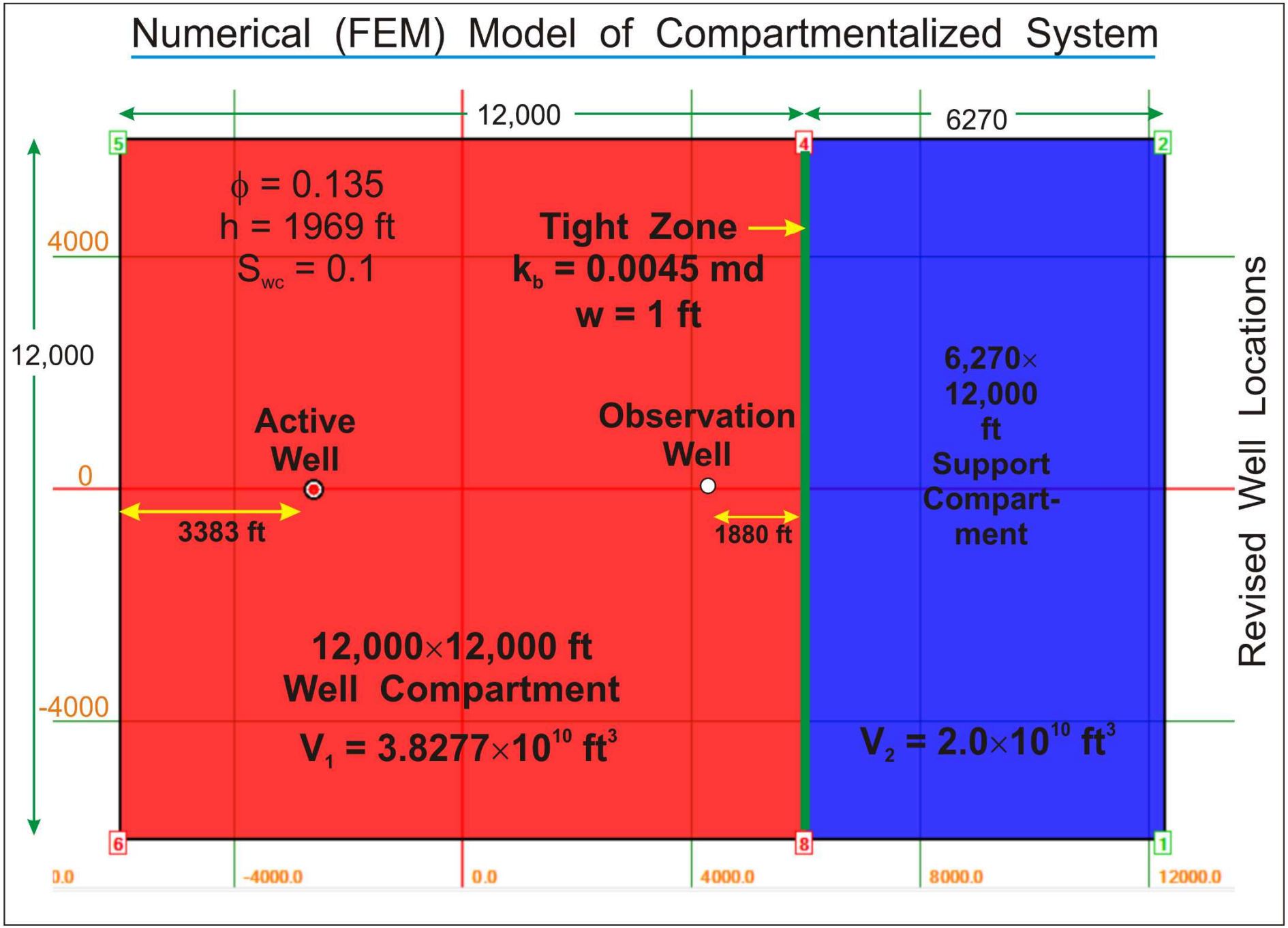

Cartesian Plot
Well B
Extended Test
Drawdown (Flow) Period
Noisy data removed
Best-fit straight line
Flow Regime - SSS Depletion
OGIP = 6.21 tcf
- based on Q = 56.8 MMscf/d
slope = - 0.00063113 m[p]/hr
= - 0.0016989 psi/hr
m(p) ((psi²/cp)×10⁻⁶)
814.500
814.400
814.300
814.200
814.100
814.000
813.900
813.800
813.700
0
50
100
150
200
250
300
Elapsed Time (hr)
Pressure #2:TP3

Well A Interference Pressure - All Gauges



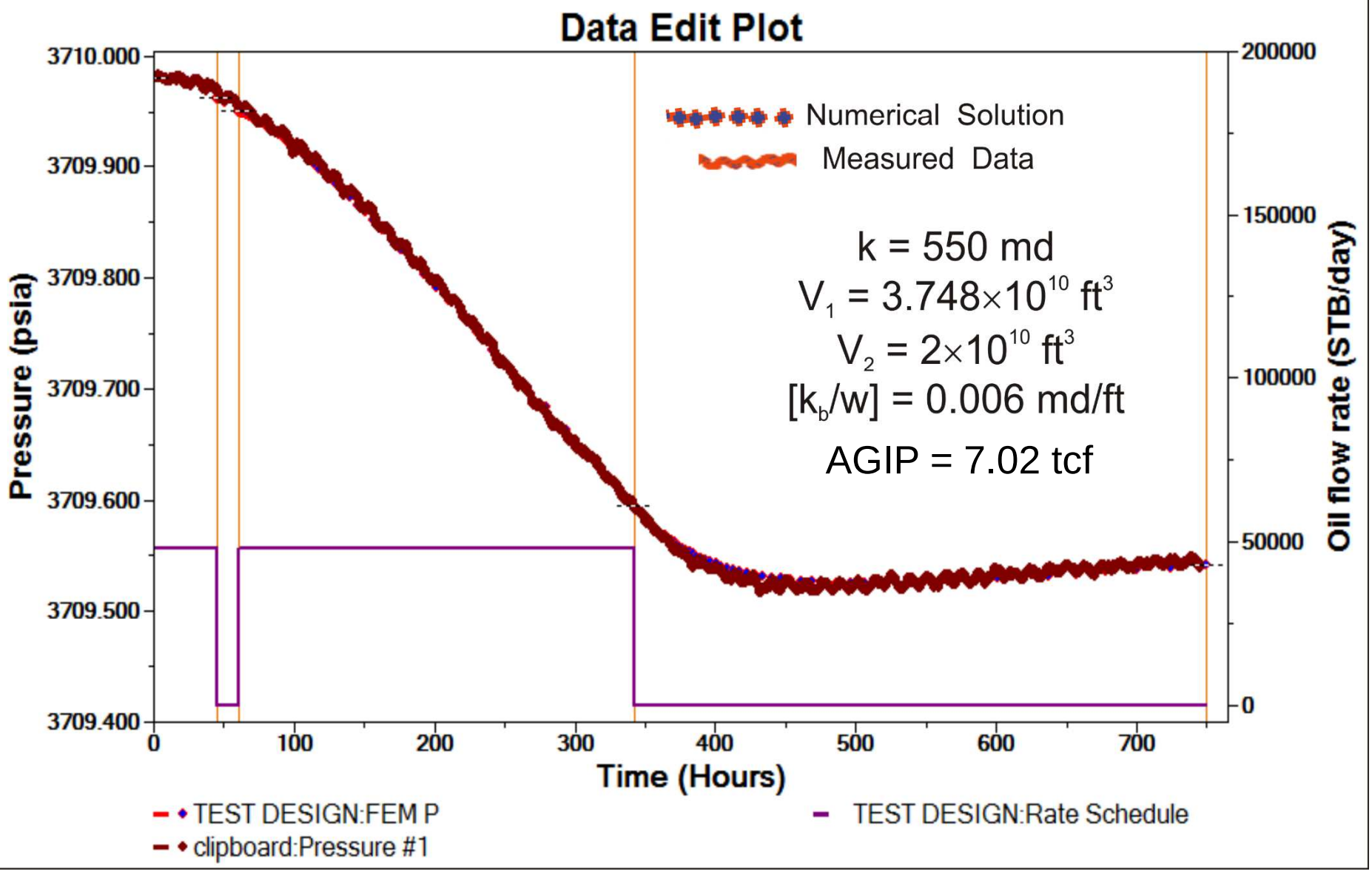
Overlay of Measured Well A Data



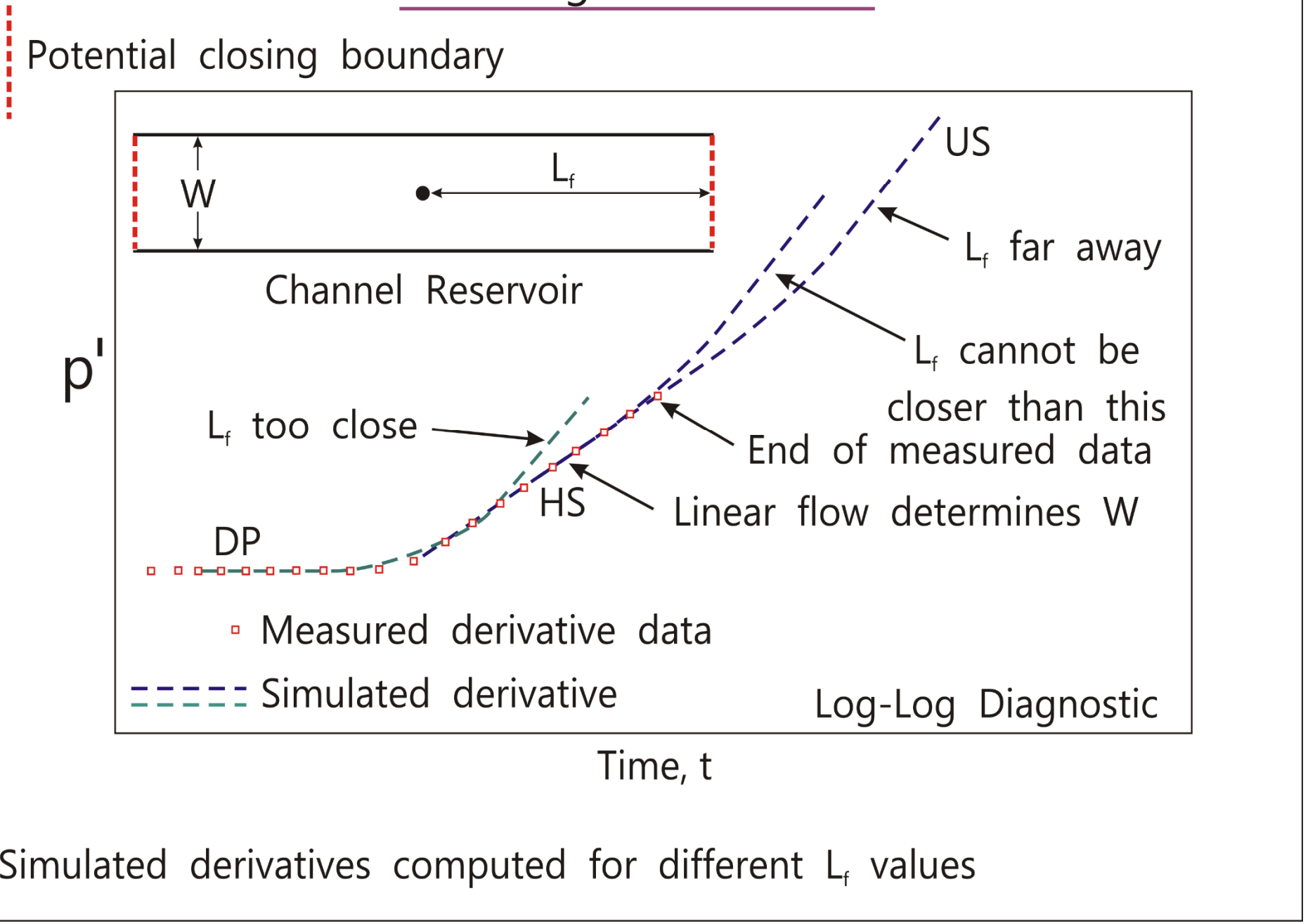

Numerical (FEM) Model of Compartmentalized System
12,000
6270
5
4
2
ϕ = 0.135
h = 1969 ft
S_{wc} = 0.1
Tight Zone
k_b = 0.0045 md
w = 1 ft
4000
12,000
0
-4000
Active Well
Observation Well
3383 ft
1880 ft
6,270× 12,000 ft Support Compart-ment
12,000×12,000 ft Well Compartment
$V_1 = 3.8277\times10^{10}$ ft^3
$V_2 = 2.0\times10^{10}$ ft^3
6
8
1
0.0
-4000.0
0.0
4000.0
8000.0
12000.0
Revised Well Locations

Match of Well A Data Using the FEM Compartmentalized Model

Best Match to Well A Interference Data

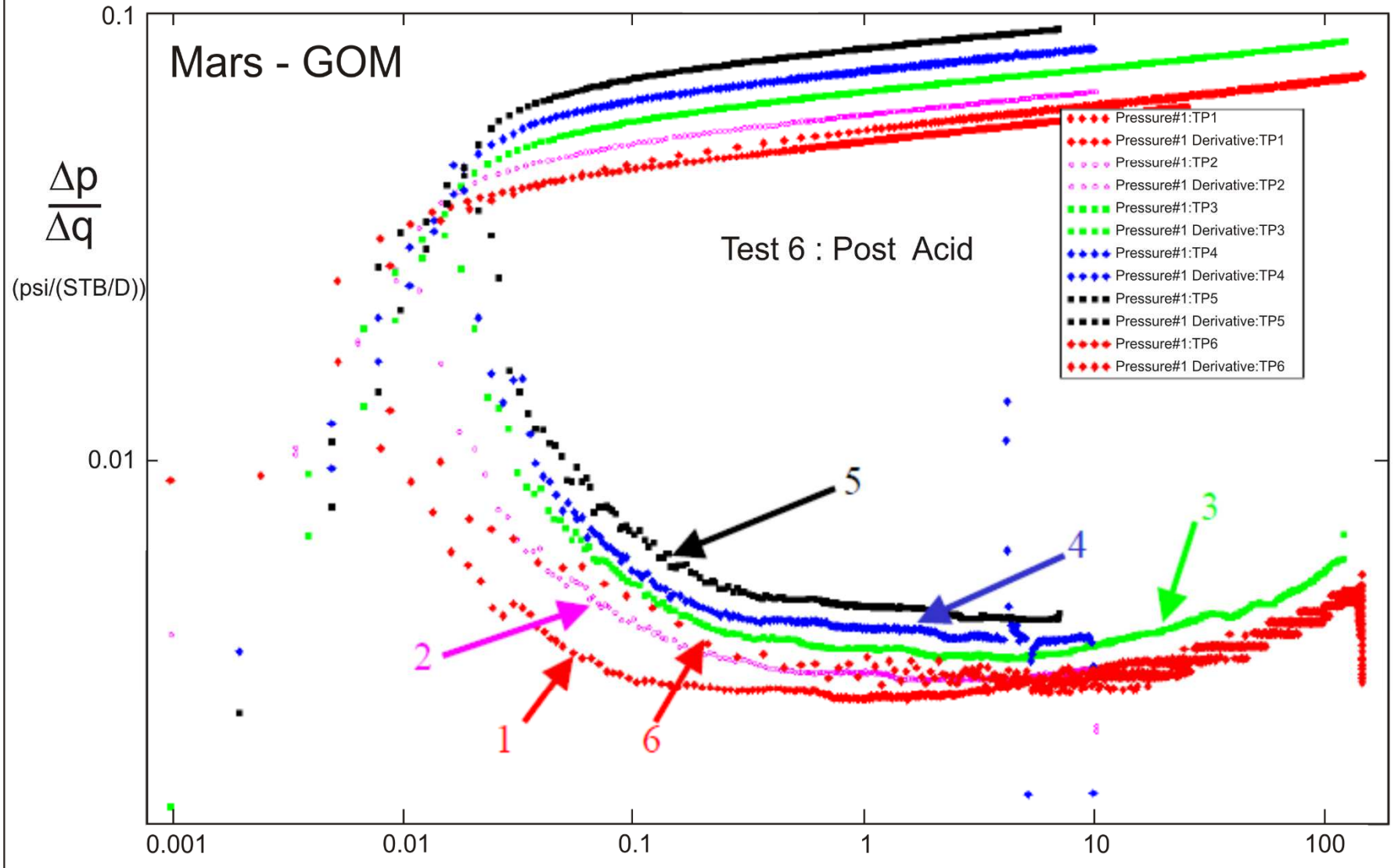


Shrinking Box Method

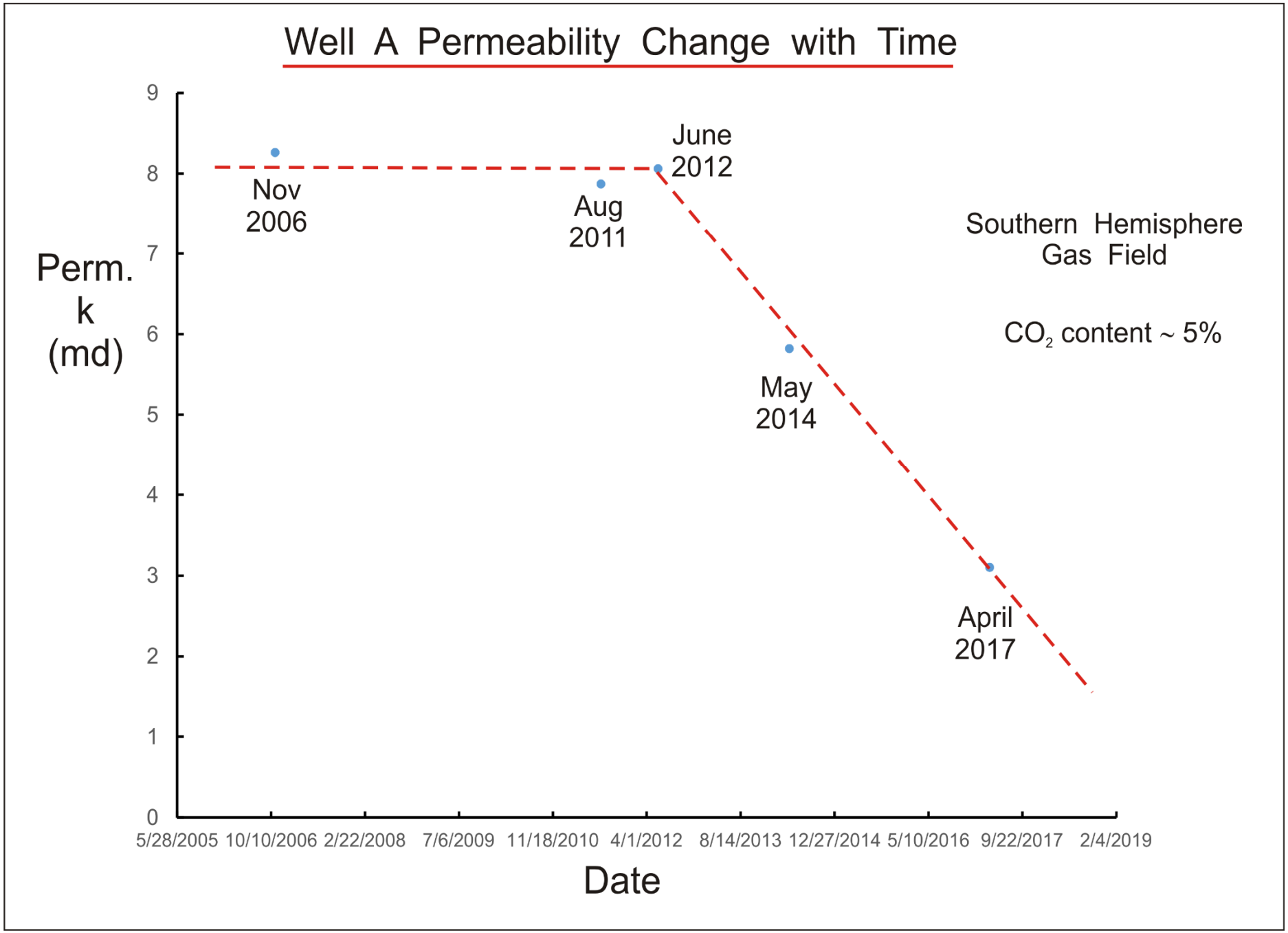


Simulated derivatives computed for different L_f values

Apparent kh Loss in GOM Well



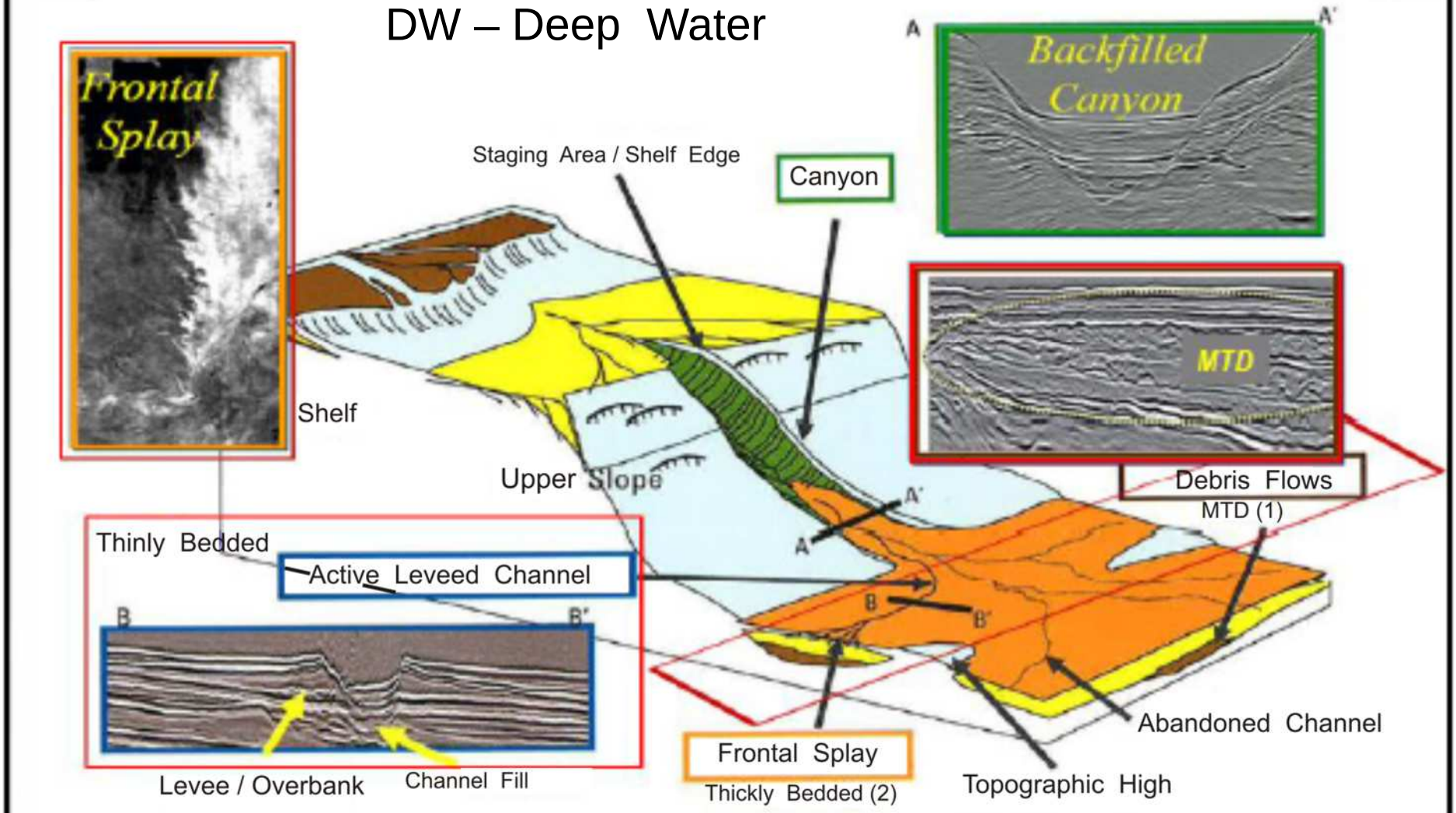
After Fair *et al* SPE 104480 (2008)


Well A Permeability Change with Time
Perm. k (md)
9
8
7
6
5
4
3
2
1
0
Nov 2006
Aug 2011
June 2012
May 2014
April 2017
Southern Hemisphere Gas Field
CO_2 content ~ 5%
5/28/2005
10/10/2006
2/22/2008
7/6/2009
11/18/2010
4/1/2012
8/14/2013
12/27/2014
5/10/2016
9/22/2017
2/4/2019
Date

SPE 159628

Thinly Bedded Depositional Model : Turbidite DW Fan with MTD Complex

DW – Deep Water

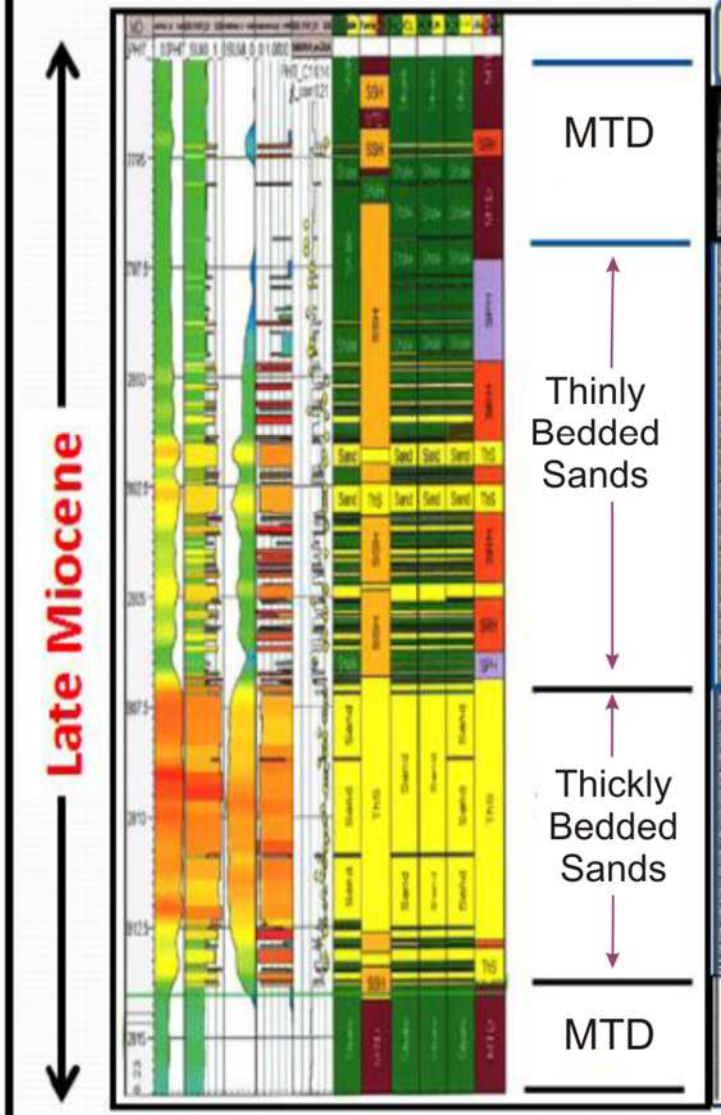


Conceptual Model of DW Thinly Bedded Reservoir (After Budi)

SPE
159628

Stratigraphy Setting - MTD Fan Complex

After Kantaatmadja et al



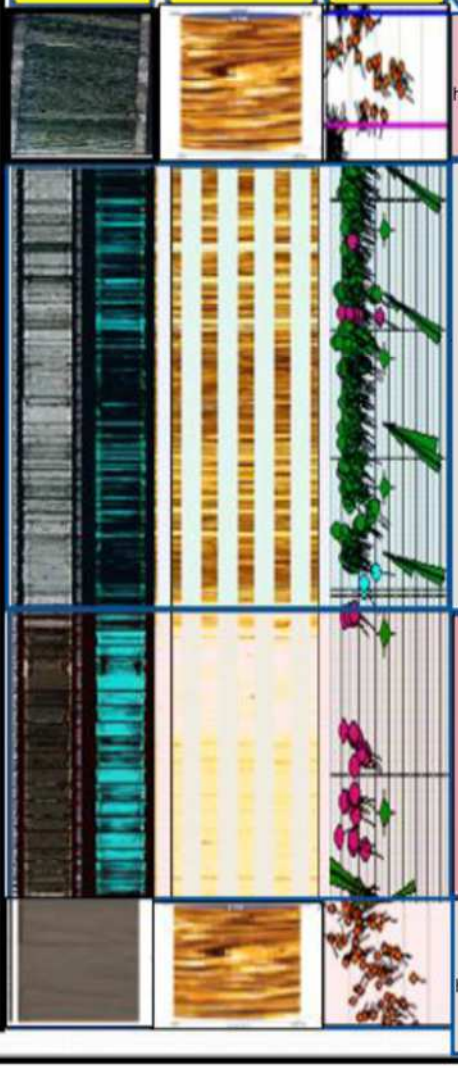
Late Miocene

MTD

Thinly Bedded Sands

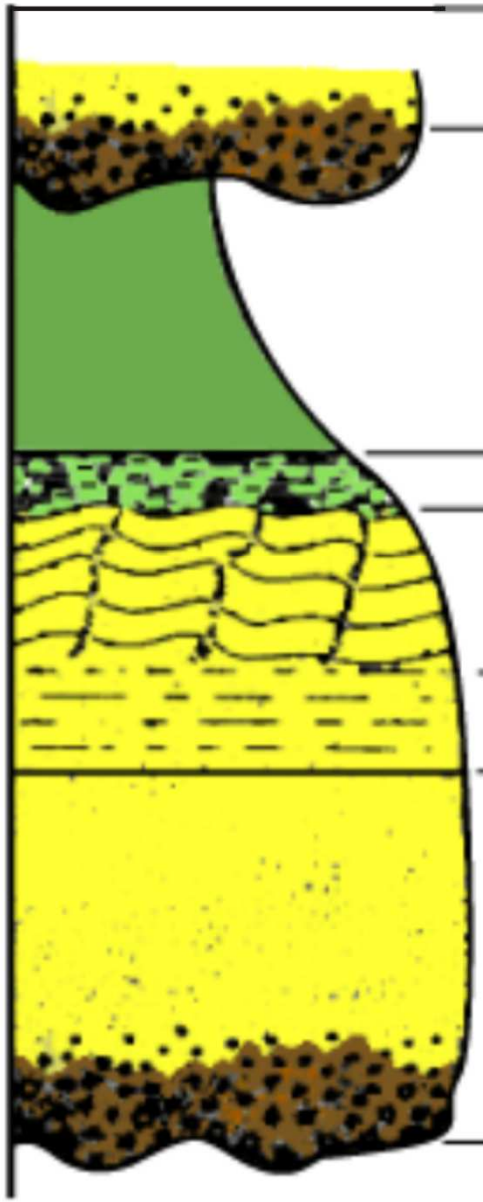
Thickly Bedded Sands

MTD

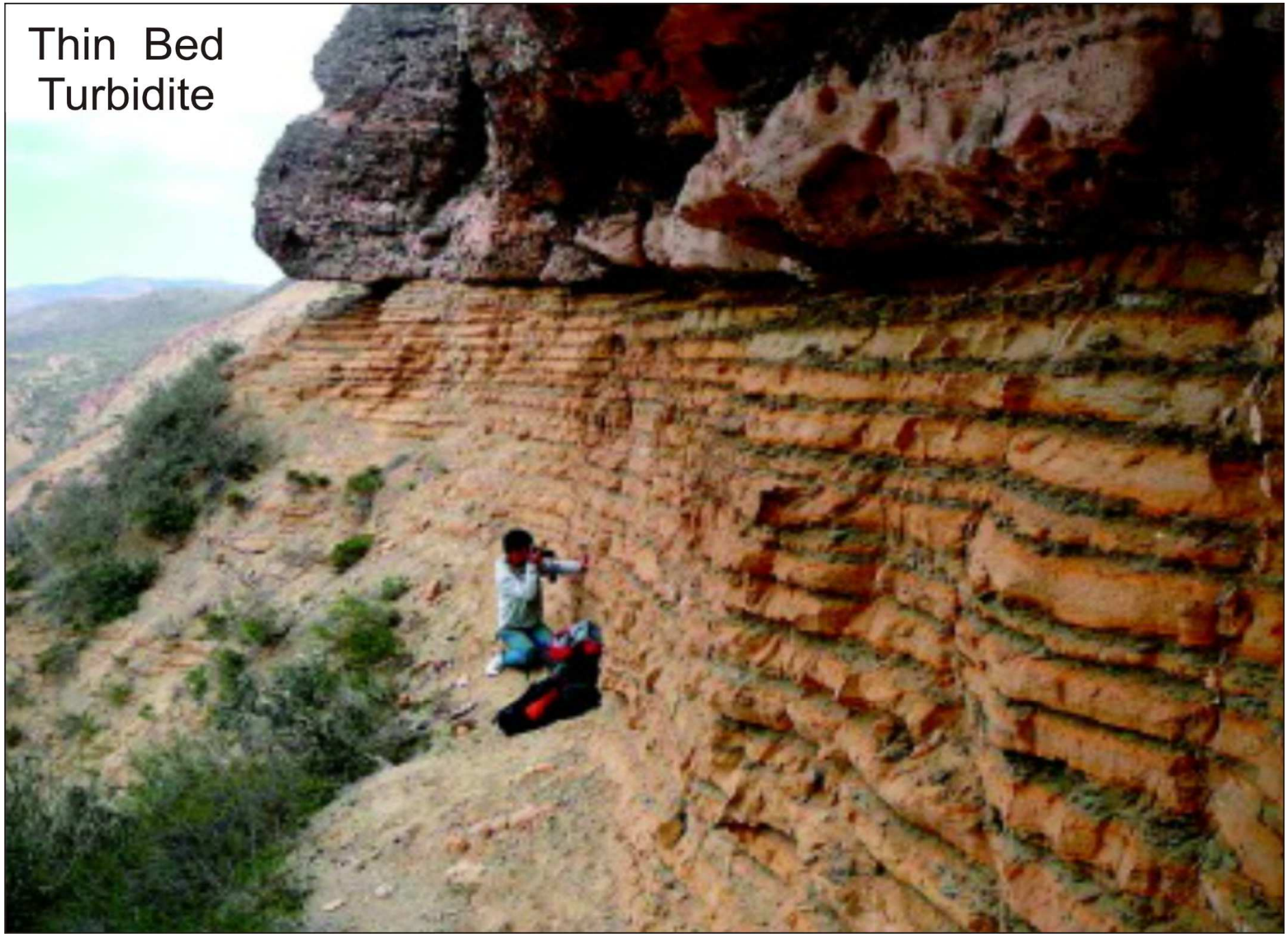


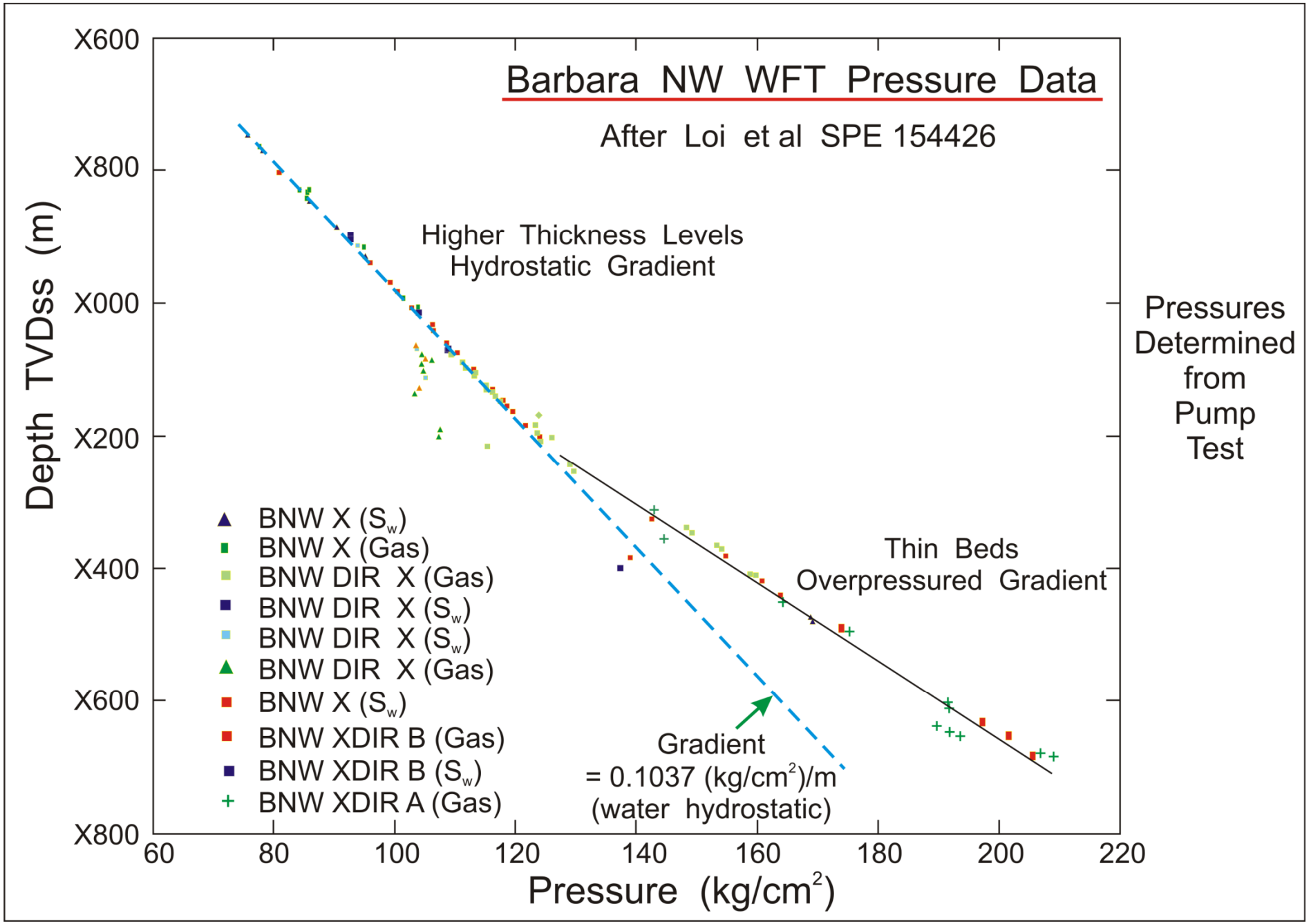
Core	Image	Dips	Lithology Descriptions
			MTD: Deposits generally completely chaotic although in places sufficiently large blocks have been incorporated, sometimes containing hydrocarbon Logs characteristics: High angle and chaotic dips on OEMI, very low variance in the density low, high GR
			Thinly Bedded Sands (Levee Overbank Complex) Classic problematic petrophysics analysis Log characteristics: Constant dips from OBMI, high variance of multiple logs
			Thickly Bedded Sand (Frontal Splay) Deposition controlled (partially/fully) by the structureof the preceding MTD surface Log characteristcs: Low GR, good denity neutron cross-over
			MTD: Deposits generally completely chaotic although in places sufficiently large blocks have been incorporated, sometimes containing hydrocarbon Logs characteristics: High angle and chaotic dips on OEMI, very low variance in the density low, high GR

Bouma Turbidite Sequence



Grain Size		**Bouma (1962) Divisions**	Interpretation
Mud	T_{ep}	Pelite	Pelagic Sedimentation
Mud	T_{ef}	Massive or graded Turbidite	fine grained, low density turbidity current deposition
		Upper Parallel Laminae	? ? ?
Sand / Silt	T_c	Ripples, wavy or concoluted Laminae	Lower part of Lower Flow Regime
Sand	T_b	Plane parallel laminae	Upper Flow Regime Plane Bed
Sand (to granule at base)	T_a	Massive graded	(?) Upper Flow Regime Rapid Deposition and Quick Bed (?)


Thin Bed
Turbidite


Barbara NW WFT Pressure Data
After Loi et al SPE 154426
Higher Thickness Levels
Hydrostatic Gradient
Thin Beds
Overpressured Gradient
Gradient
= 0.1037 (kg/cm²)/m
(water hydrostatic)
BNW X (Sw)
BNW X (Gas)
BNW DIR X (Gas)
BNW DIR X (Sw)
BNW DIR X (Sw)
BNW DIR X (Gas)
BNW X (Sw)
BNW XDIR B (Gas)
BNW XDIR B (Sw)
BNW XDIR A (Gas)
Depth TVDss (m)
X600
X800
X000
X200
X400
X600
X800
60
80
100
120
140
160
180
200
220
Pressure (kg/cm²)
Pressures Determined from Pump Test