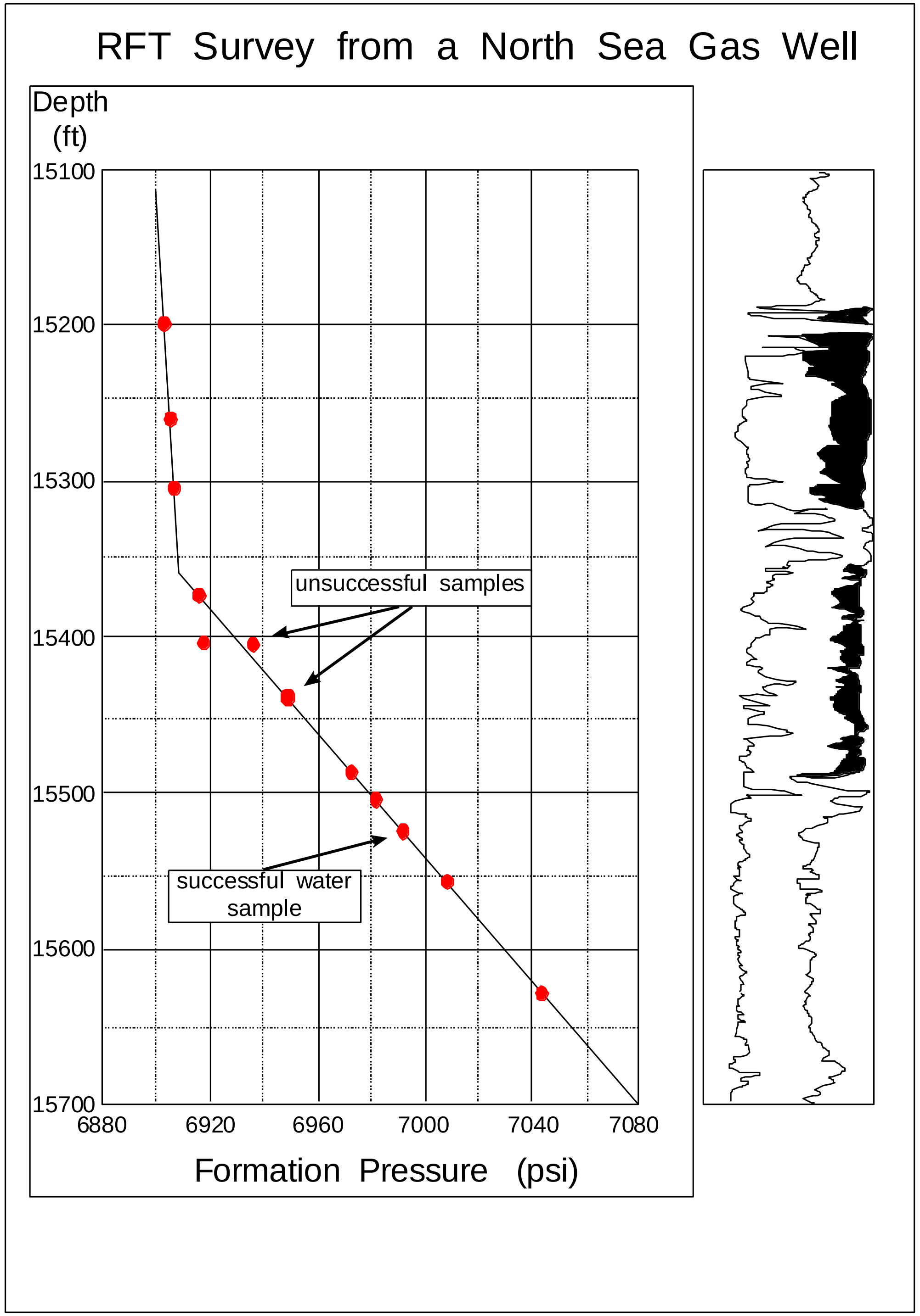
LPS One Day Seminar Dec 2017

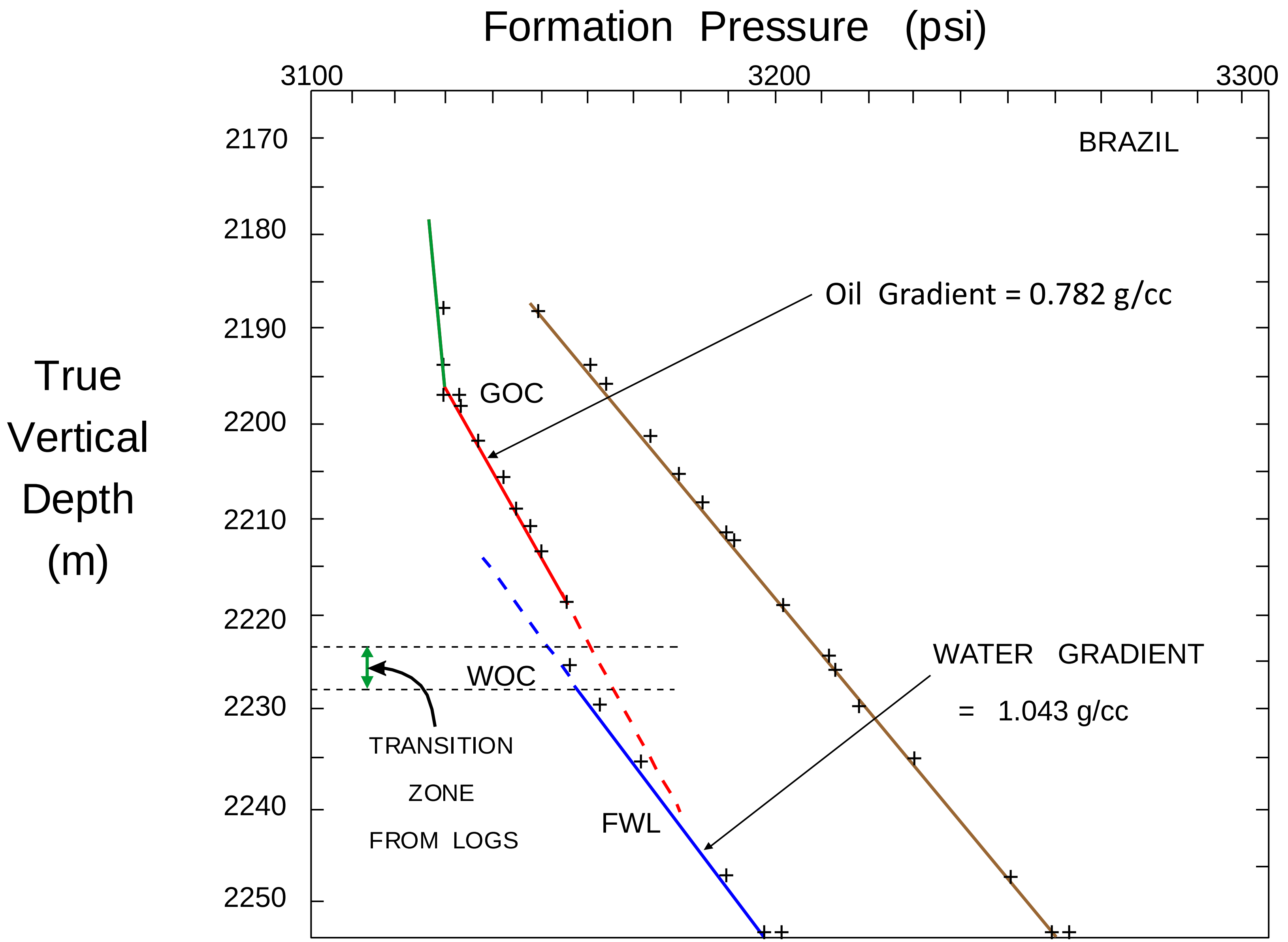
Everything Formation Testing

"Milestones in Wireline Formation Testing"

Prof George Stewart
RGS Consulting

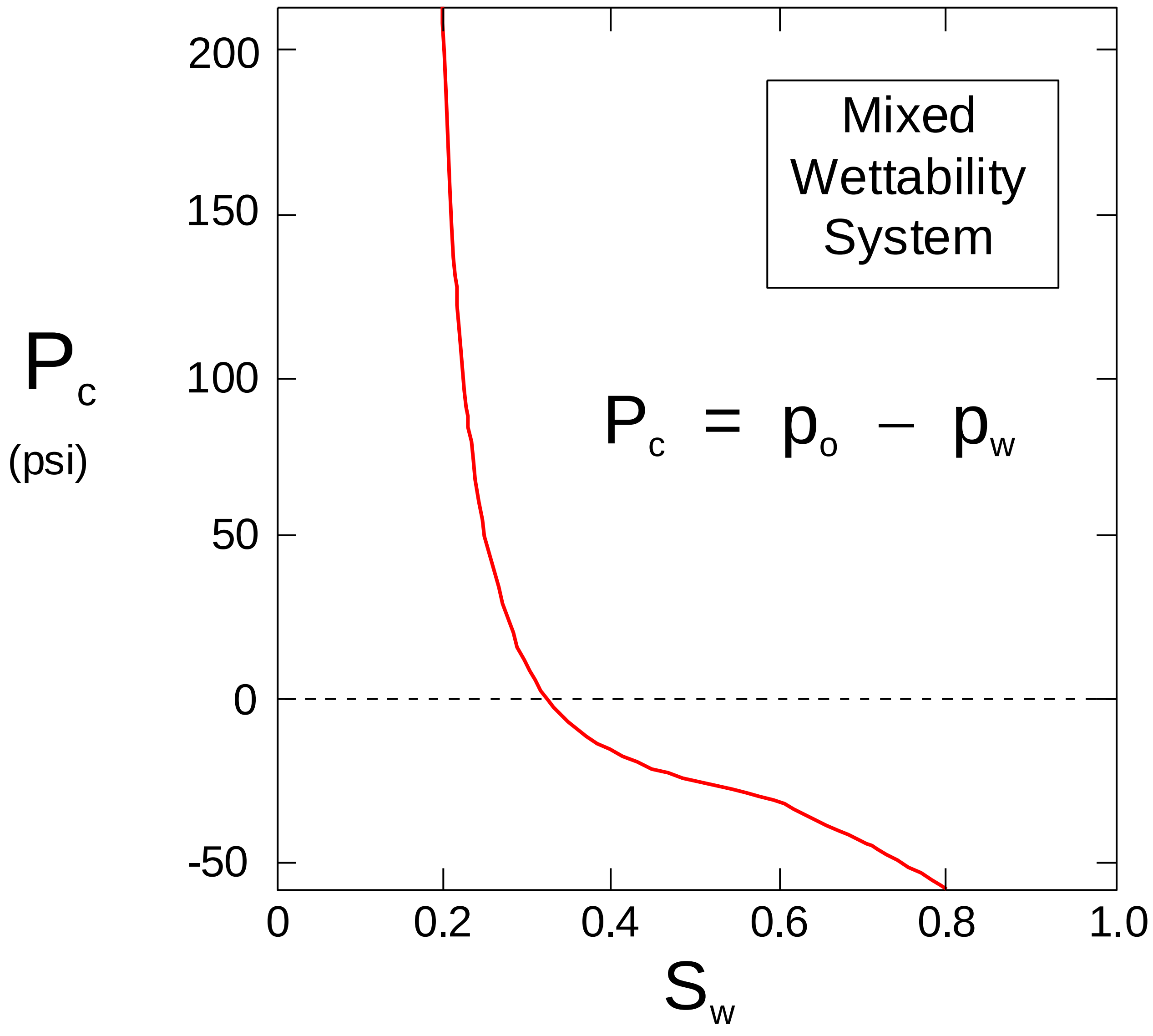


RFT Survey from a North Sea Gas Well
Depth
(ft)
15100
15200
15300
15400
15500
15600
15700
6880
6920
6960
7000
7040
7080
Formation Pressure (psi)
unsuccessful samples
successful water
sample



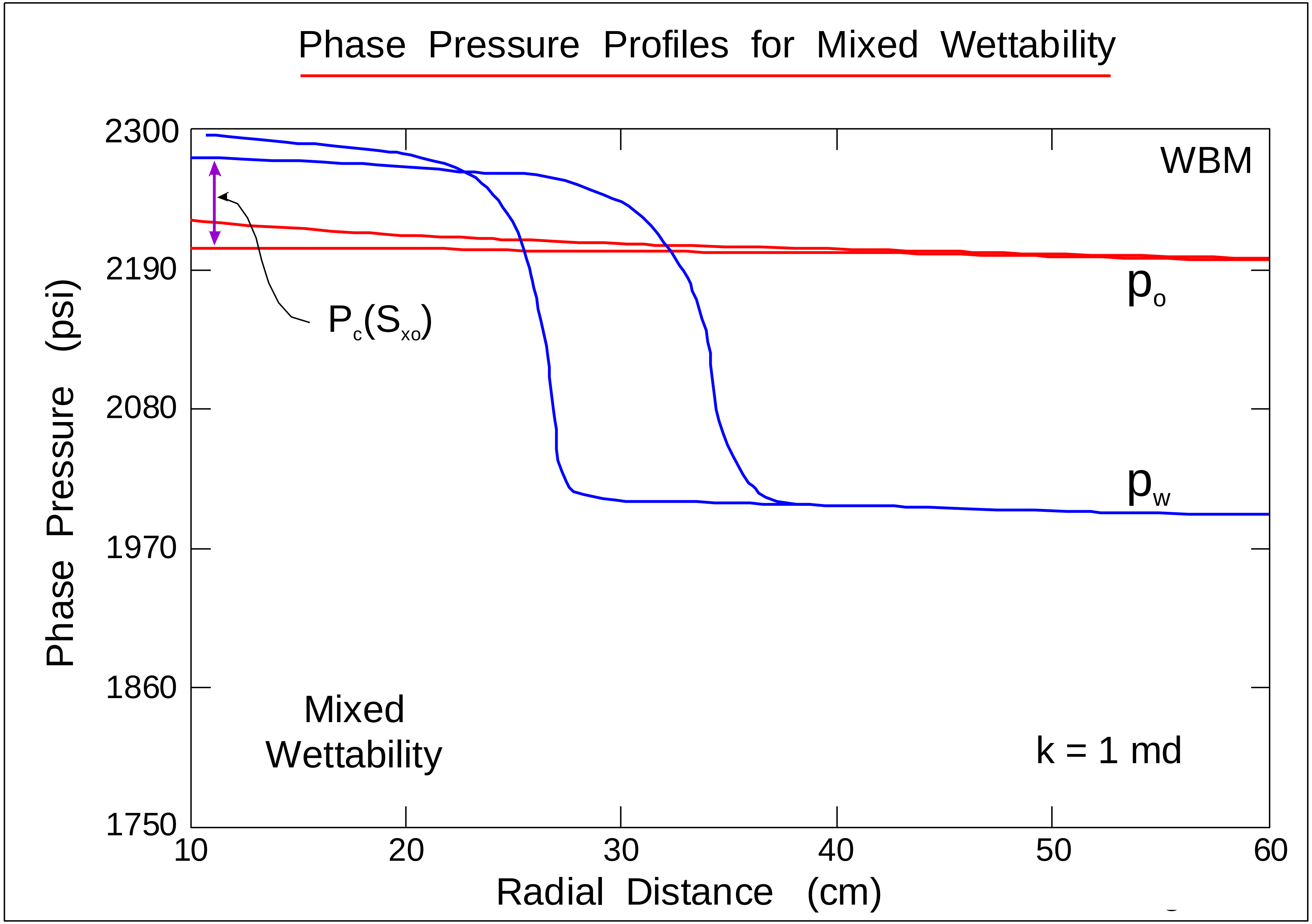
Field Example Possibly Exhibiting Oil-Wet Behaviour

Shifted Capillary Pressure Curve

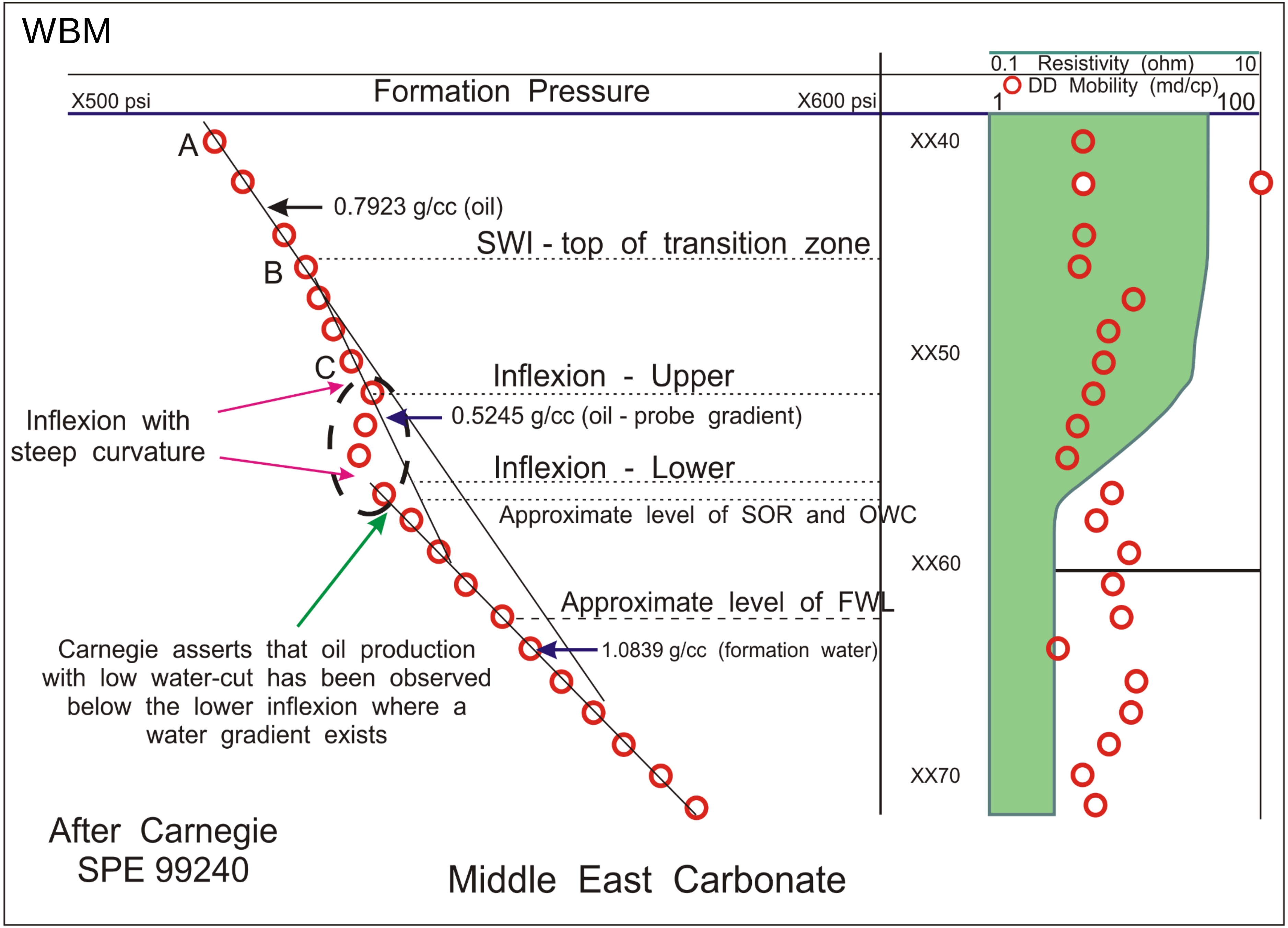


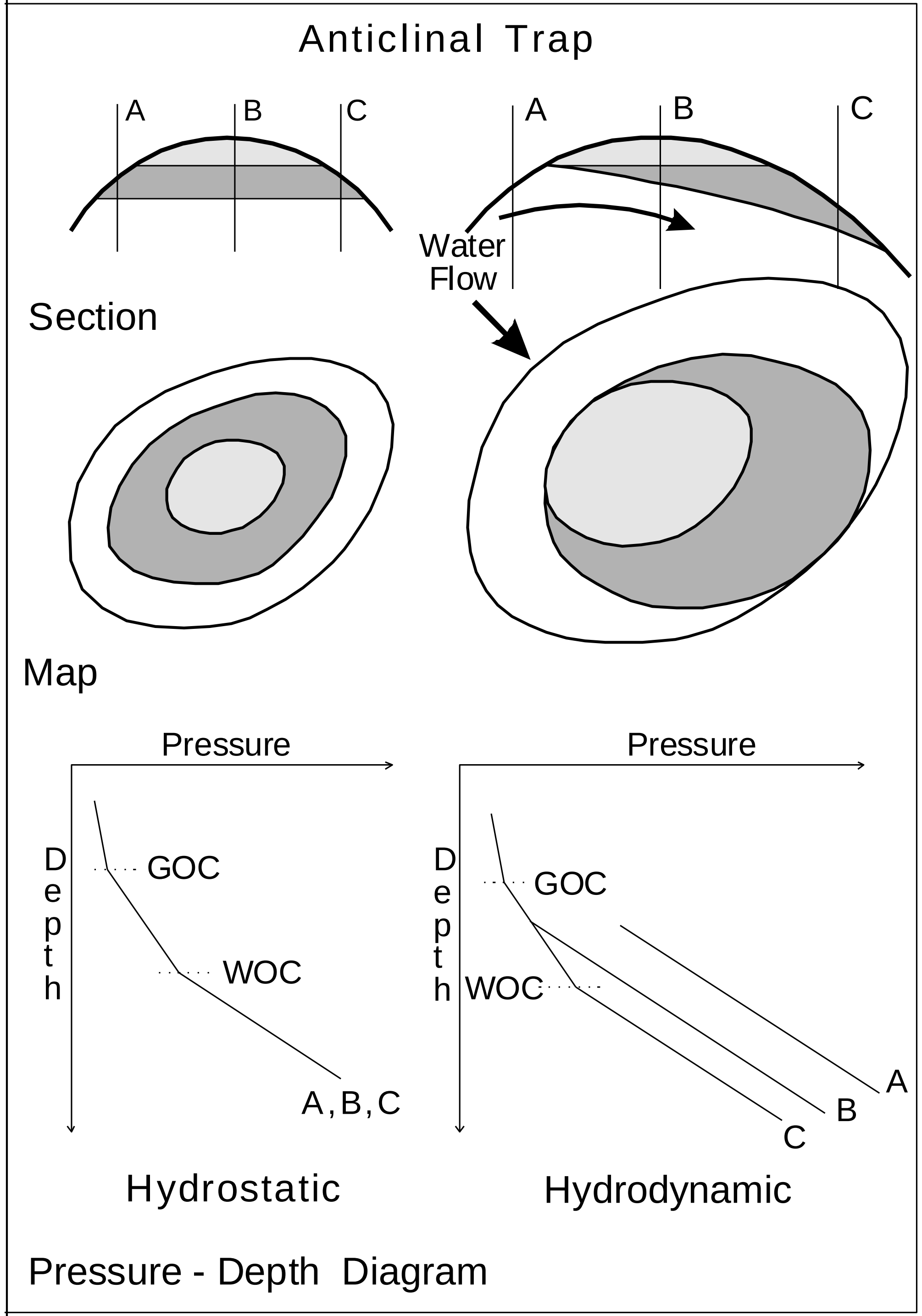
k = 1 md

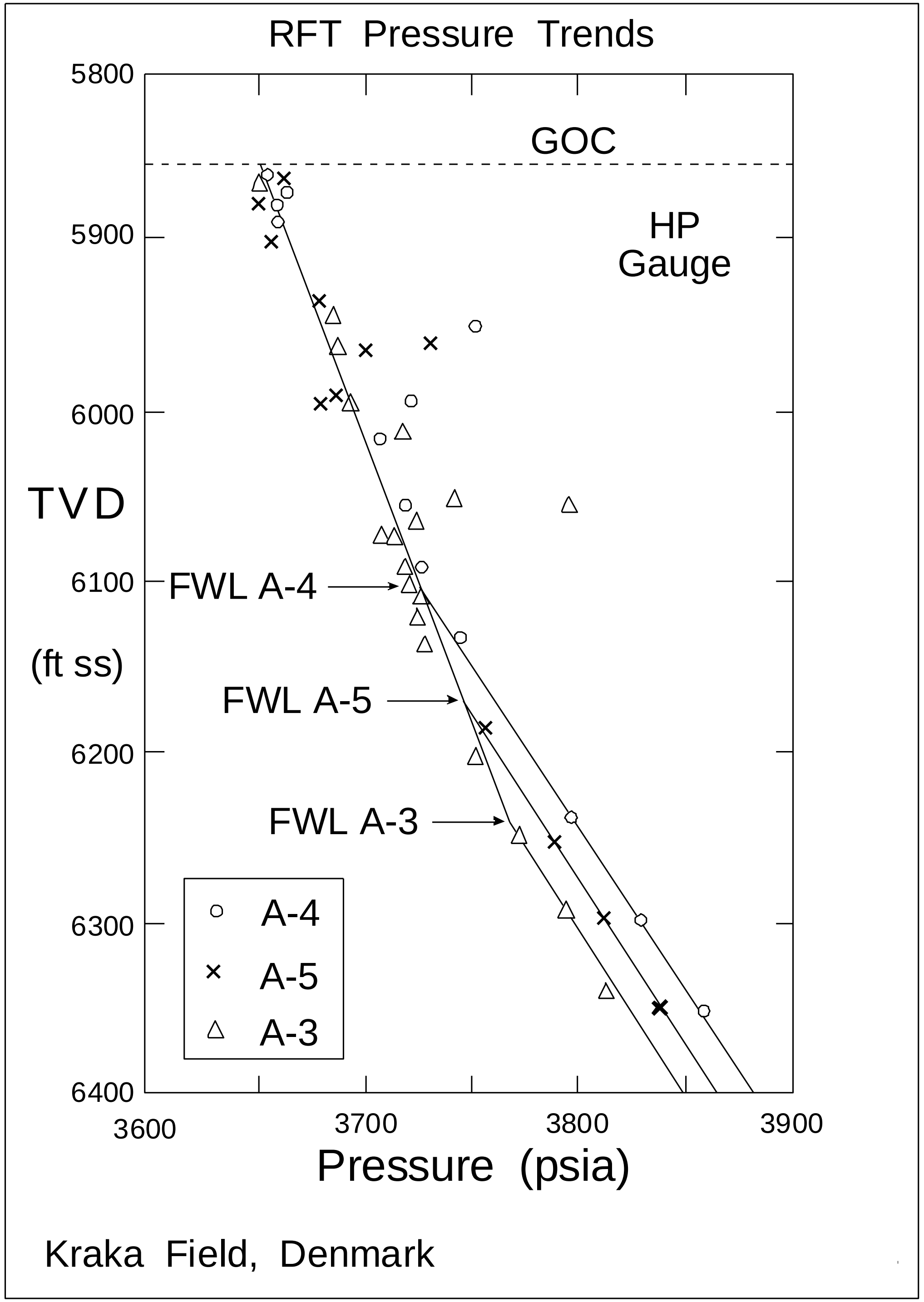
ϕ = 0.25

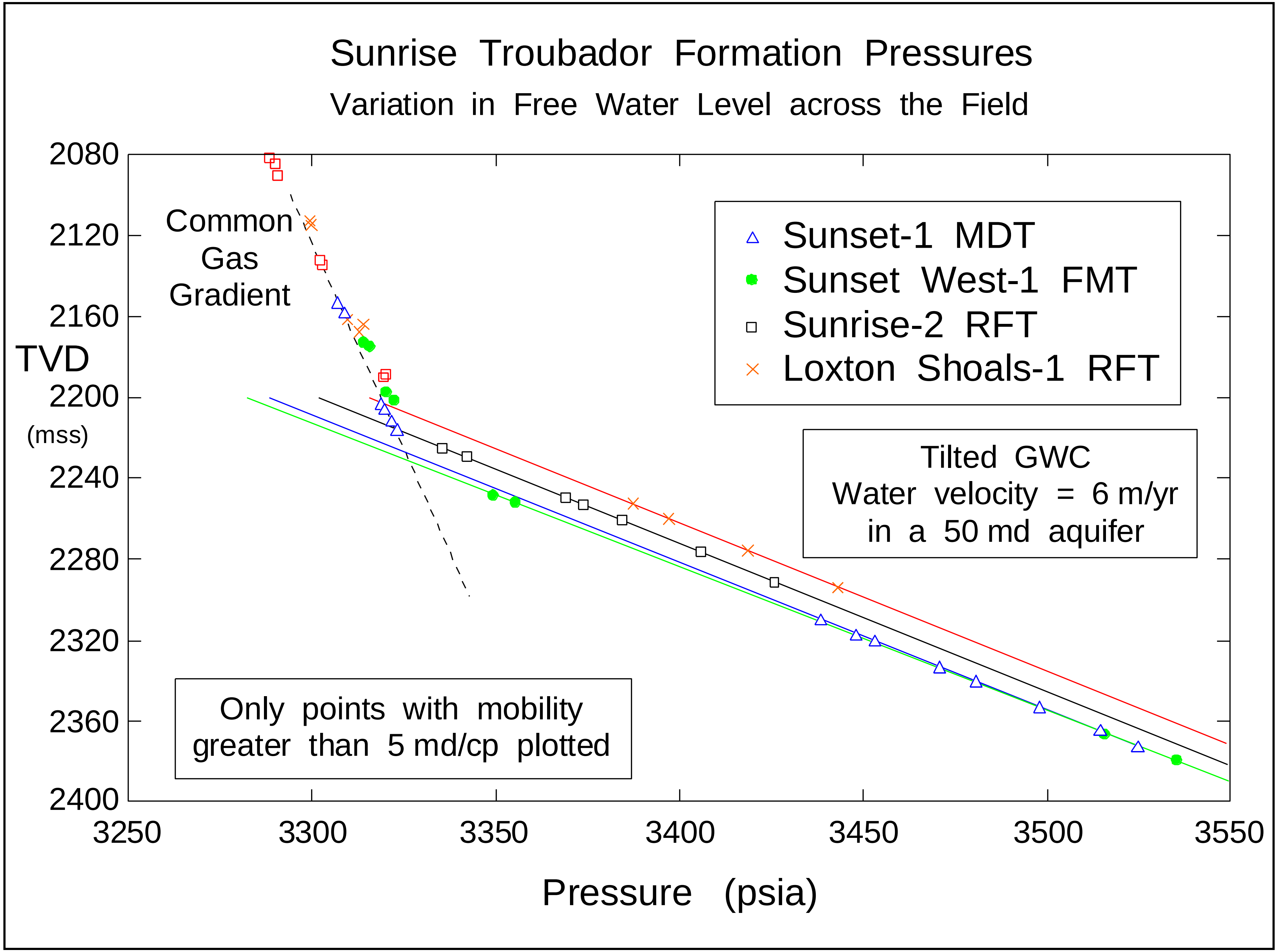


Phase Pressure Profiles for Mixed Wettability
WBM
2300
2190
2080
1970
1860
1750
10
20
30
40
50
60
Phase Pressure (psi)
Radial Distance (cm)
$P_c(S_{xo})$
p_o
p_w
Mixed Wettability
k = 1 md


WBM
Formation Pressure
X500 psi
X600 psi
0.1 Resistivity (ohm) 10
DD Mobility (md/cp)
1
100
A
B
C
0.7923 g/cc (oil)
SWI - top of transition zone
Inflexion - Upper
0.5245 g/cc (oil - probe gradient)
Inflexion - Lower
Approximate level of SOR and OWC
Approximate level of FWL
1.0839 g/cc (formation water)
Inflexion with steep curvature
Carnegie asserts that oil production with low water-cut has been observed below the lower inflexion where a water gradient exists
XX40
XX50
XX60
XX70
After Carnegie SPE 99240
Middle East Carbonate


Anticlinal Trap
A
B
C
A
B
C
Water
Flow
Section
Map
Pressure
Depth
GOC
WOC
A, B, C
Hydrostatic
Pressure
Depth
GOC
WOC
A
B
C
Hydrodynamic
Pressure - Depth Diagram


RFT Pressure Trends
GOC
HP
Gauge
TVD
(ft ss)
FWL A-4
FWL A-5
FWL A-3
A-4
A-5
A-3
5800
5900
6000
6100
6200
6300
6400
3600
3700
3800
3900
Pressure (psia)
Kraka Field, Denmark

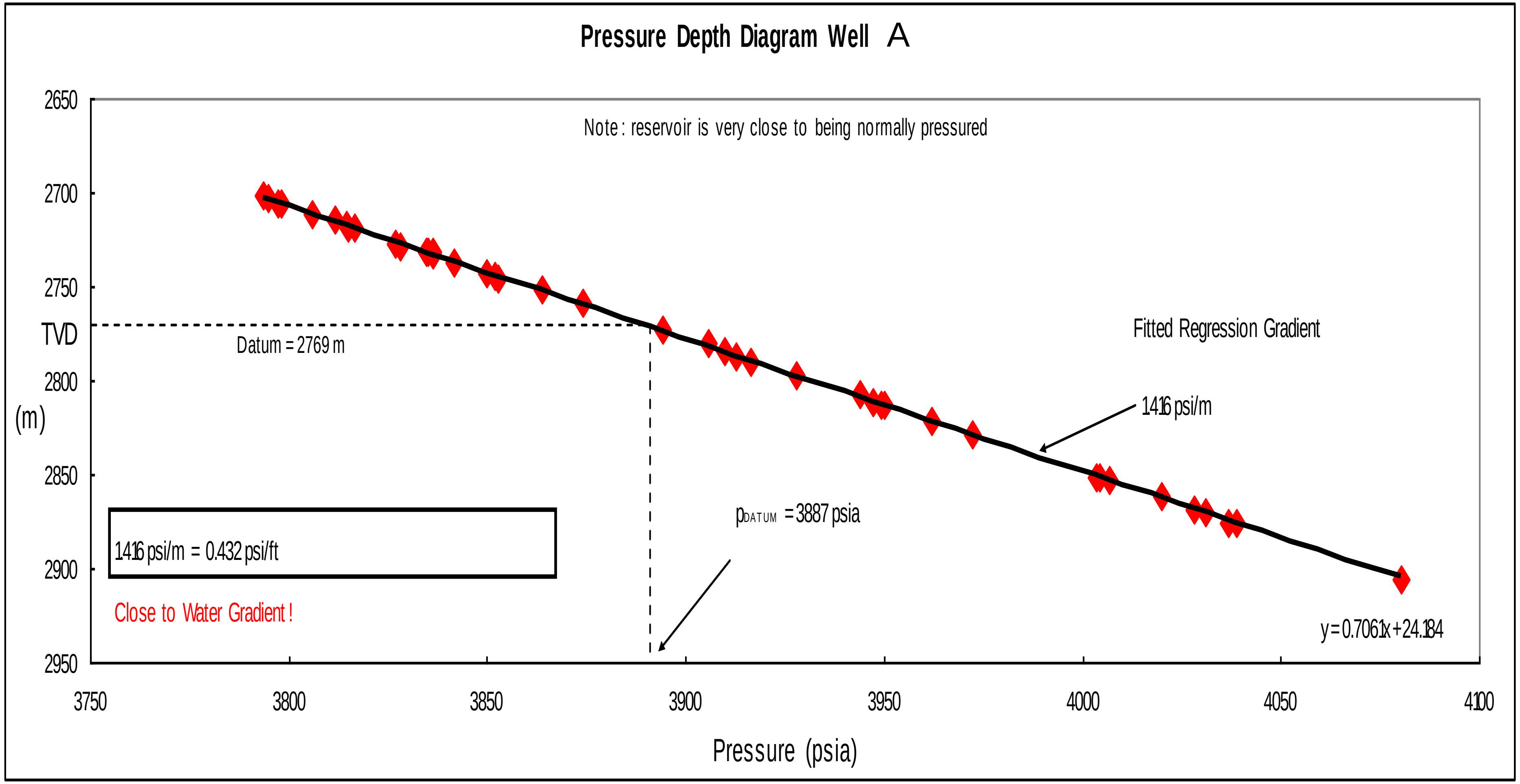


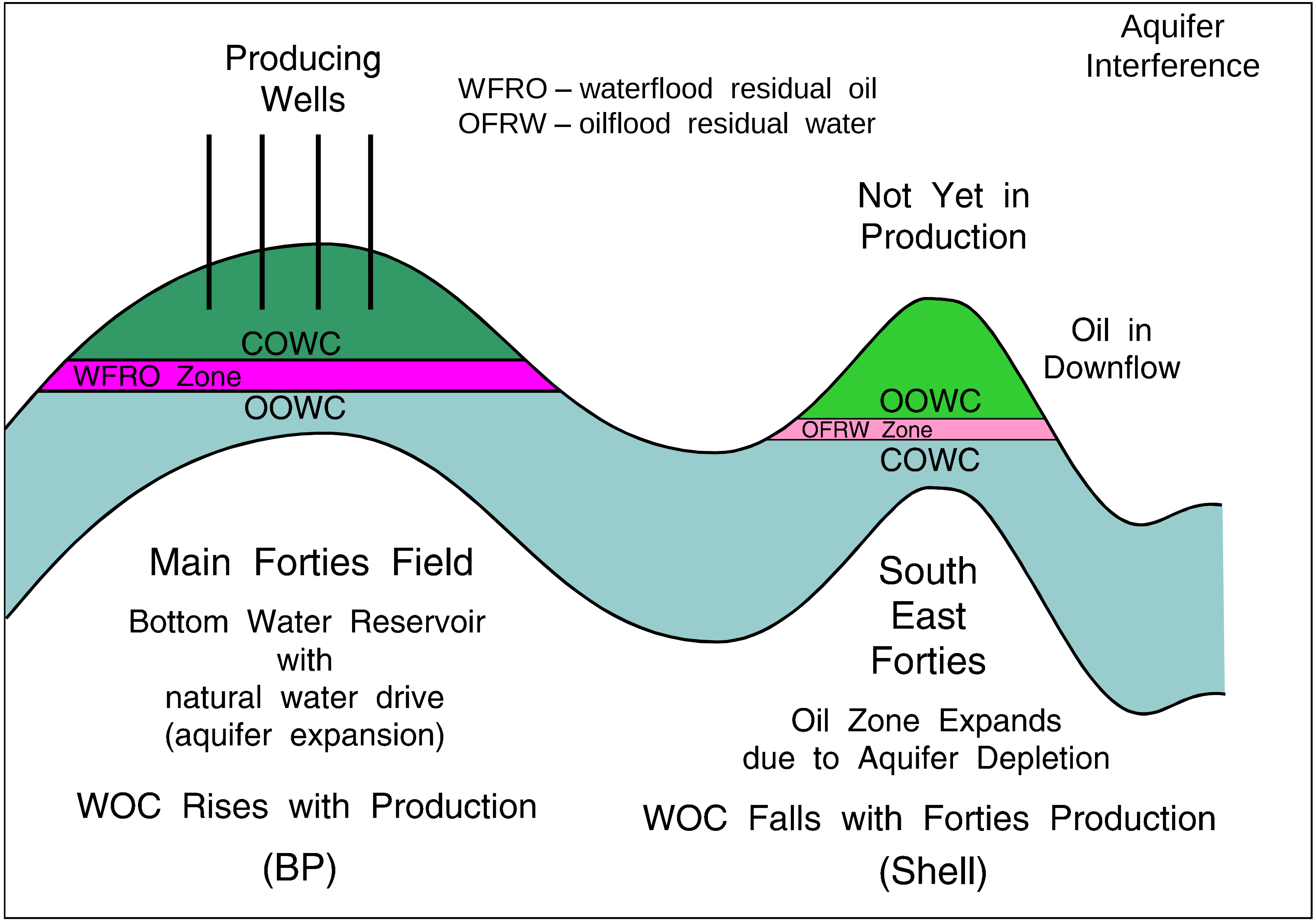
Sunrise Troubador Formation Pressures
Variation in Free Water Level across the Field
TVD (mss)
2080
2120
2160
2200
2240
2280
2320
2360
2400
3250
3300
3350
3400
3450
3500
3550
Pressure (psia)
Common Gas Gradient
Sunset-1 MDT
Sunset West-1 FMT
Sunrise-2 RFT
Loxton Shoals-1 RFT
Tilted GWC
Water velocity = 6 m/yr
in a 50 md aquifer
Only points with mobility
greater than 5 md/cp plotted

Leaky Trap Hypothesis

Potential Explanation of Observed Near Water Gradient

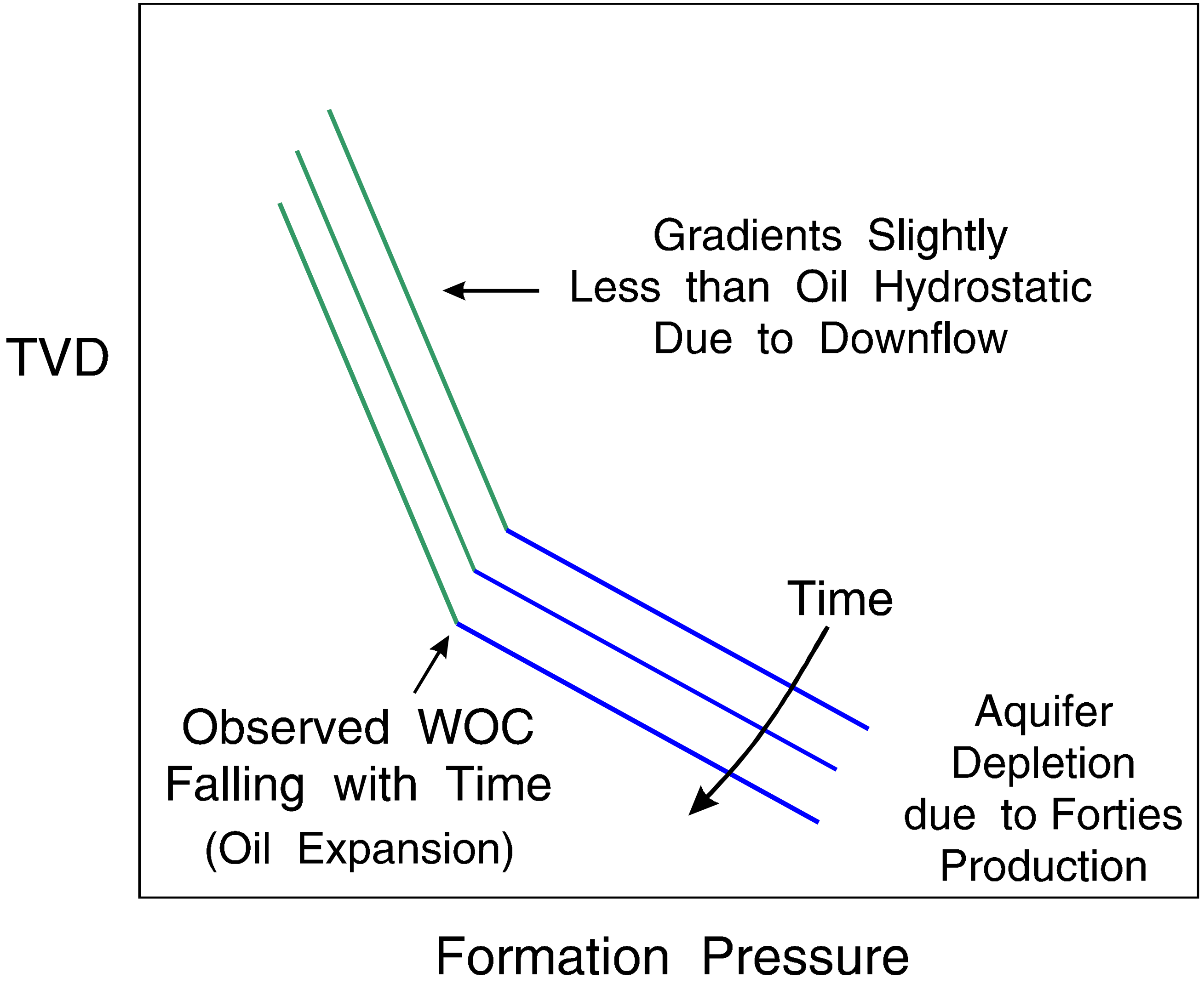
In the Oil Zone in a Far East Reservoir


Pressure Depth Diagram Well A
Note: reservoir is very close to being normally pressured
TVD (m)
2650
2700
2750
2800
2850
2900
2950
Datum = 2769 m
Fitted Regression Gradient
14.16 psi/m
p_{DATUM} = 3887 psia
14.16 psi/m = 0.432 psi/ft
Close to Water Gradient!
y = 0.7061x + 24.184
3750
3800
3850
3900
3950
4000
4050
4100
Pressure (psia)


Aquifer Interference
Producing Wells
WFRO – waterflood residual oil
OFRW – oilflood residual water
Not Yet in Production
COWC
WFRO Zone
OOWC
Oil in Downflow
OOWC
OFRW Zone
COWC
Main Forties Field
Bottom Water Reservoir with natural water drive (aquifer expansion)
WOC Rises with Production
(BP)
South East Forties
Oil Zone Expands due to Aquifer Depletion
WOC Falls with Forties Production
(Shell)

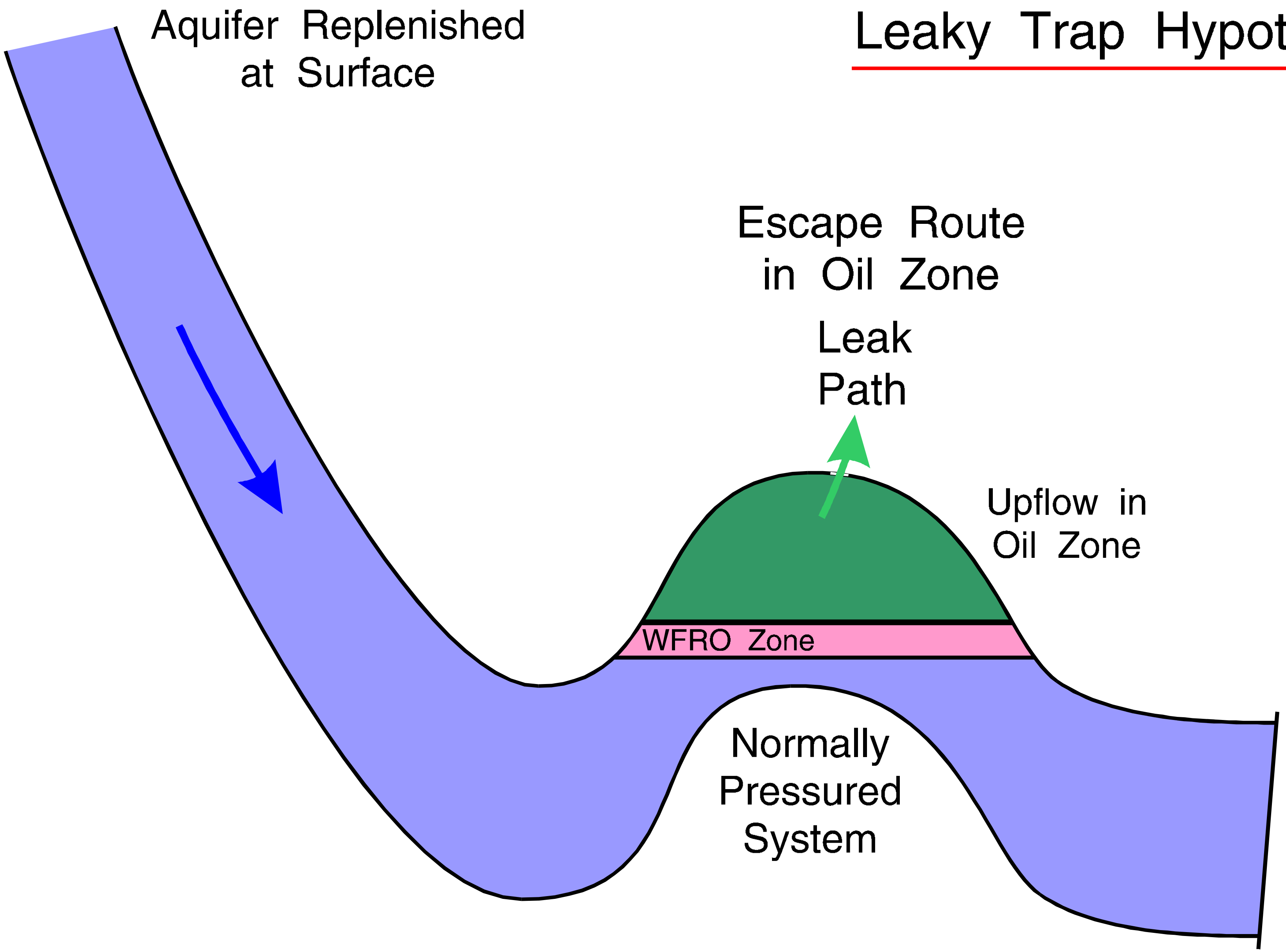
South-East Forties Appraisal Wells

WFT Data



NTS

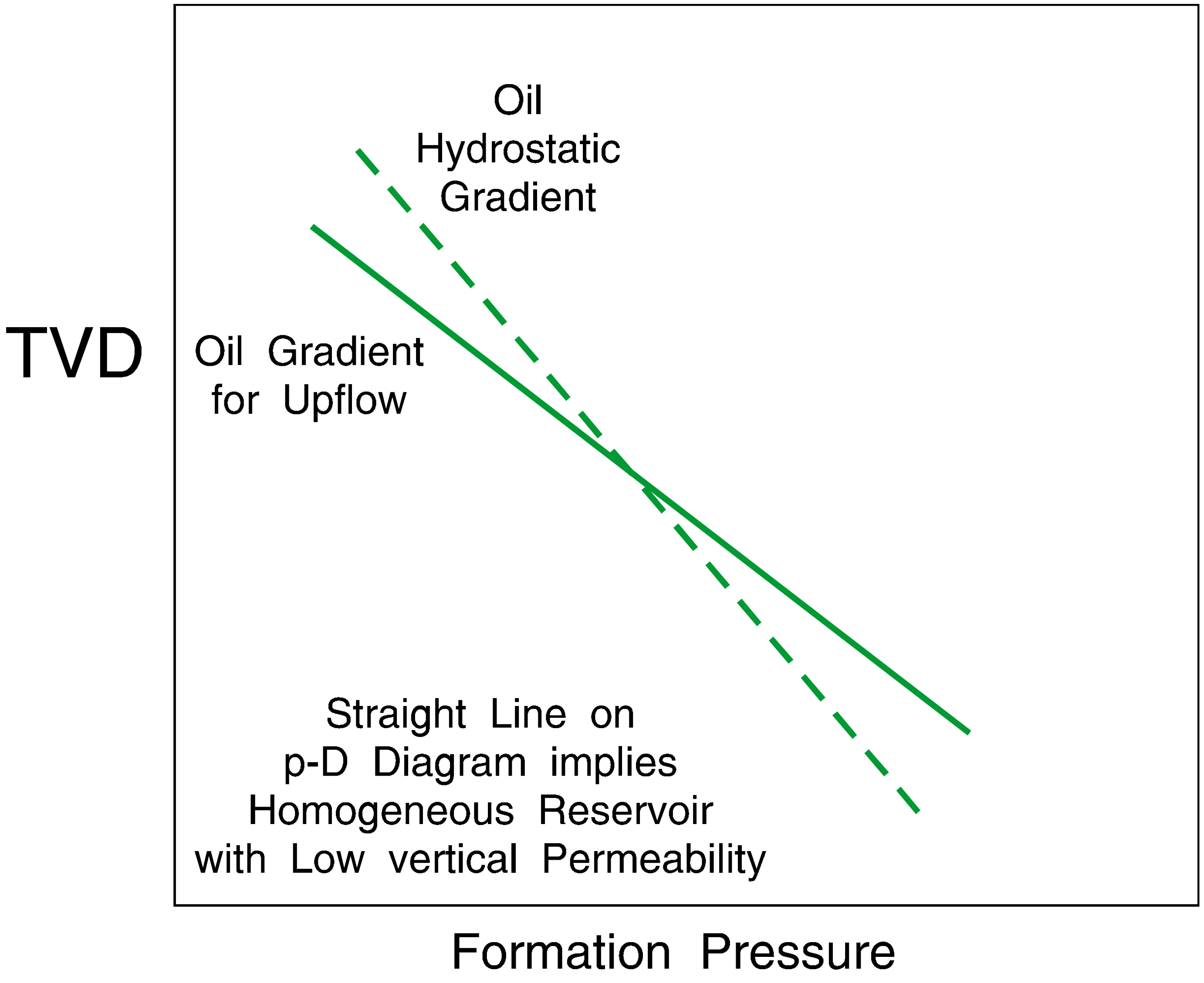
Leaky Trap Hypothesis



Diagrammatic

WFRO – waterflood residual oil

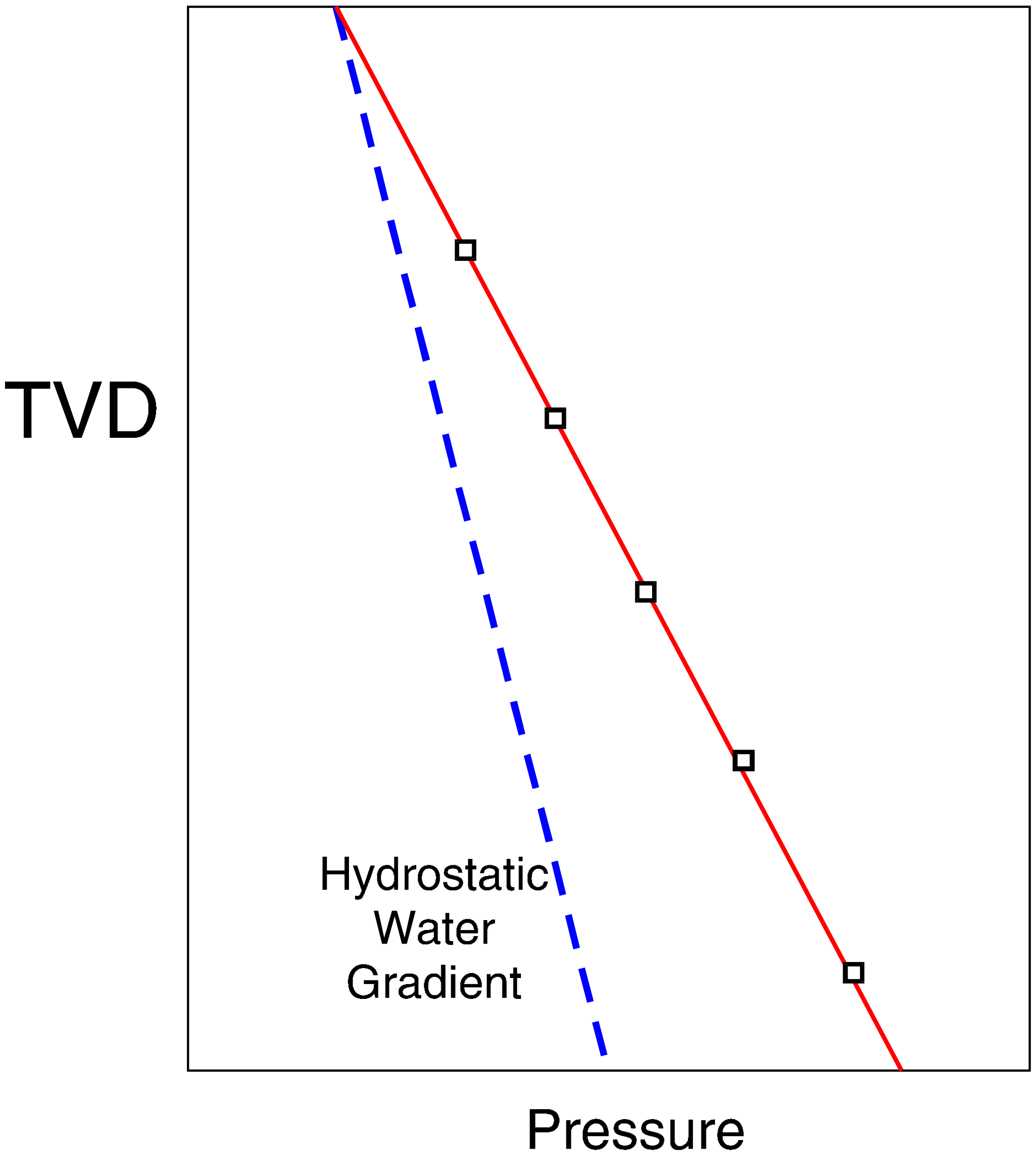
Pressure-Depth Diagram for Upflowing Oil Zone



Is there any geologic backup for the hypothesis? Has the idea of leaky traps ever been postulated by the geolgists?

Yes, in fact the third appraisal well drilled (TGT-4X) to test a separate fault block due north of the TGT-3X encountered what appeared to be residual saturations in the ILBH5.2 formation. The consensus explanation given by the G&G team was the trap had been compromised by a leaking fault, which clearly extends into the shallower measures, something that we do not see with majority of the other bounding faults in the TGT trend. We never tested the 4X well in the ILBH5.2, but did core it and the saturations appeared residual or close to it.

Halford "Heavy" Water Gradient

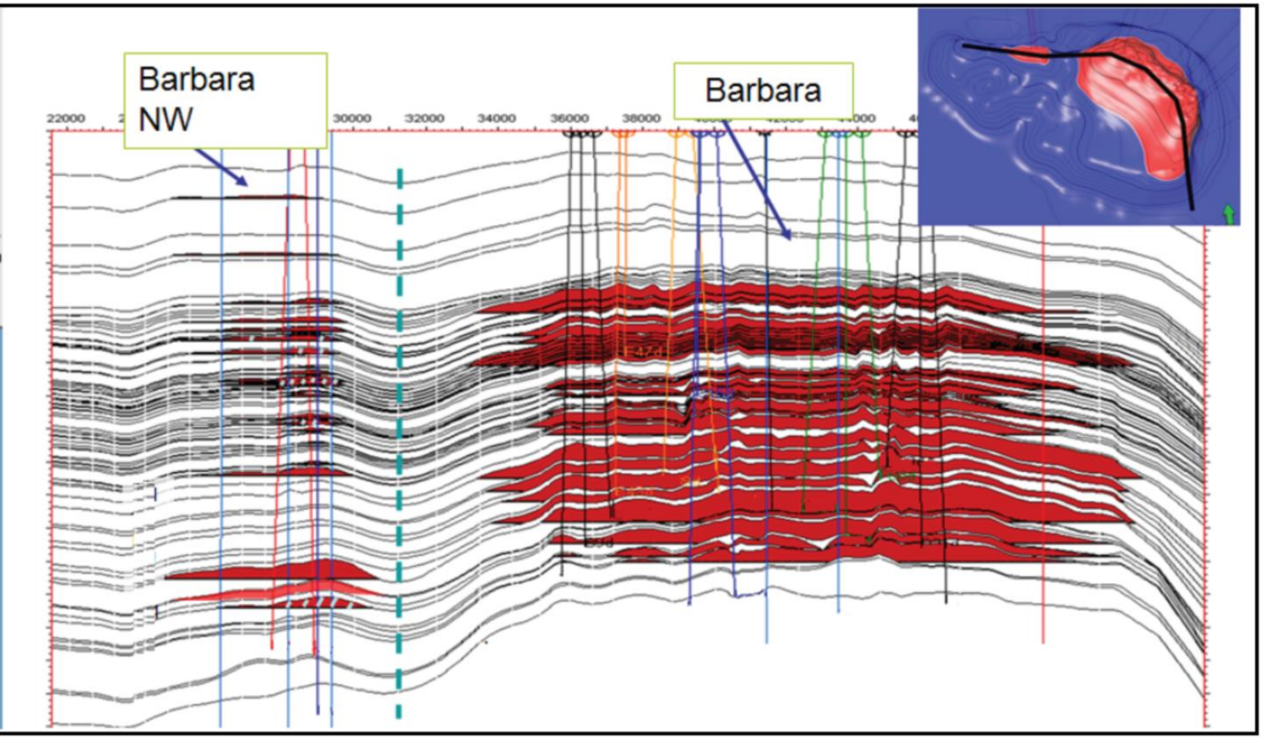


Very Deep Overpressured Aquifer

Overpressure Increasing Linearly with Depth Giving Straight Line on p-D Plot

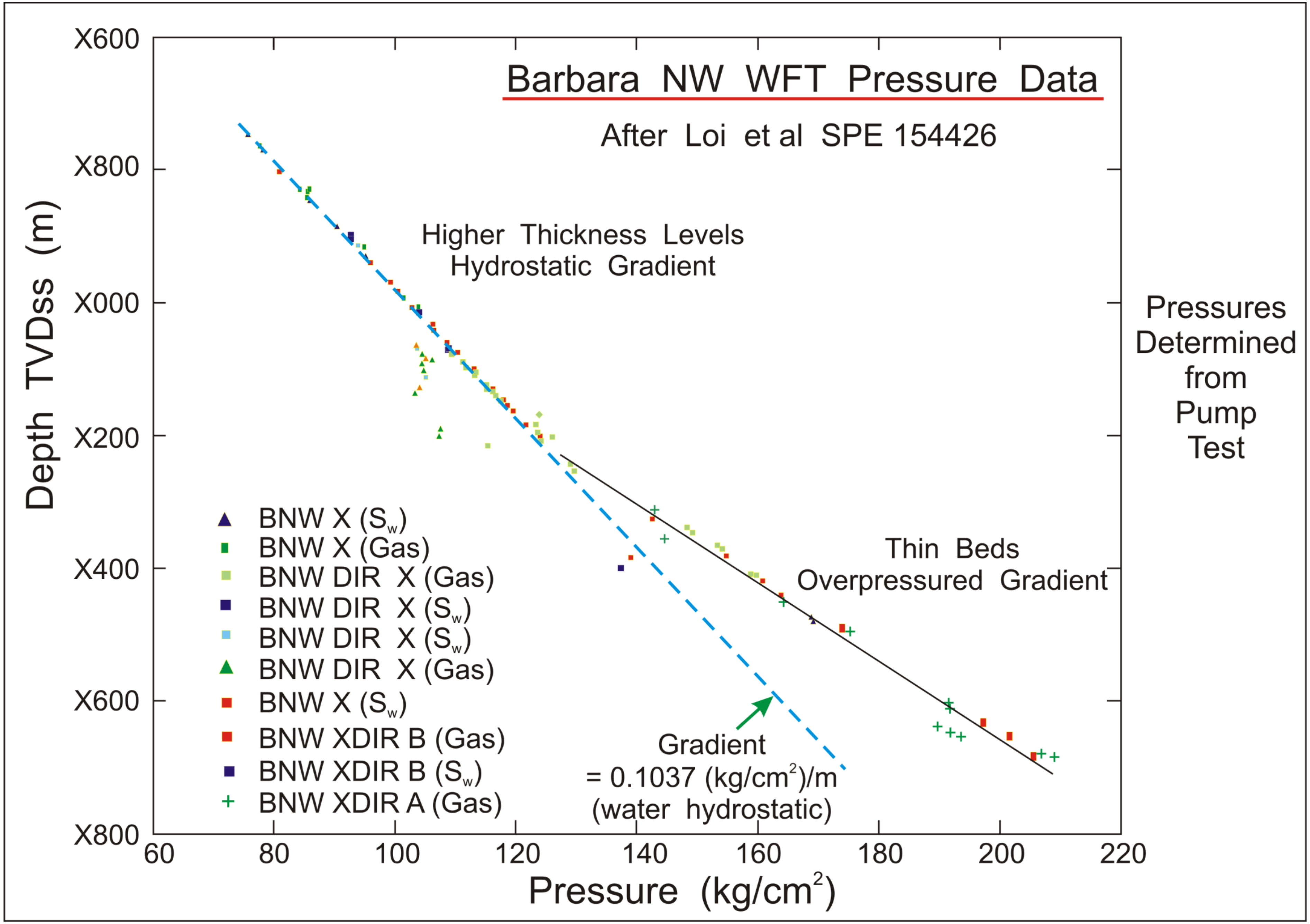
New Generation Wireline Formation Tester (NGWFT) in the Barbara NW Field

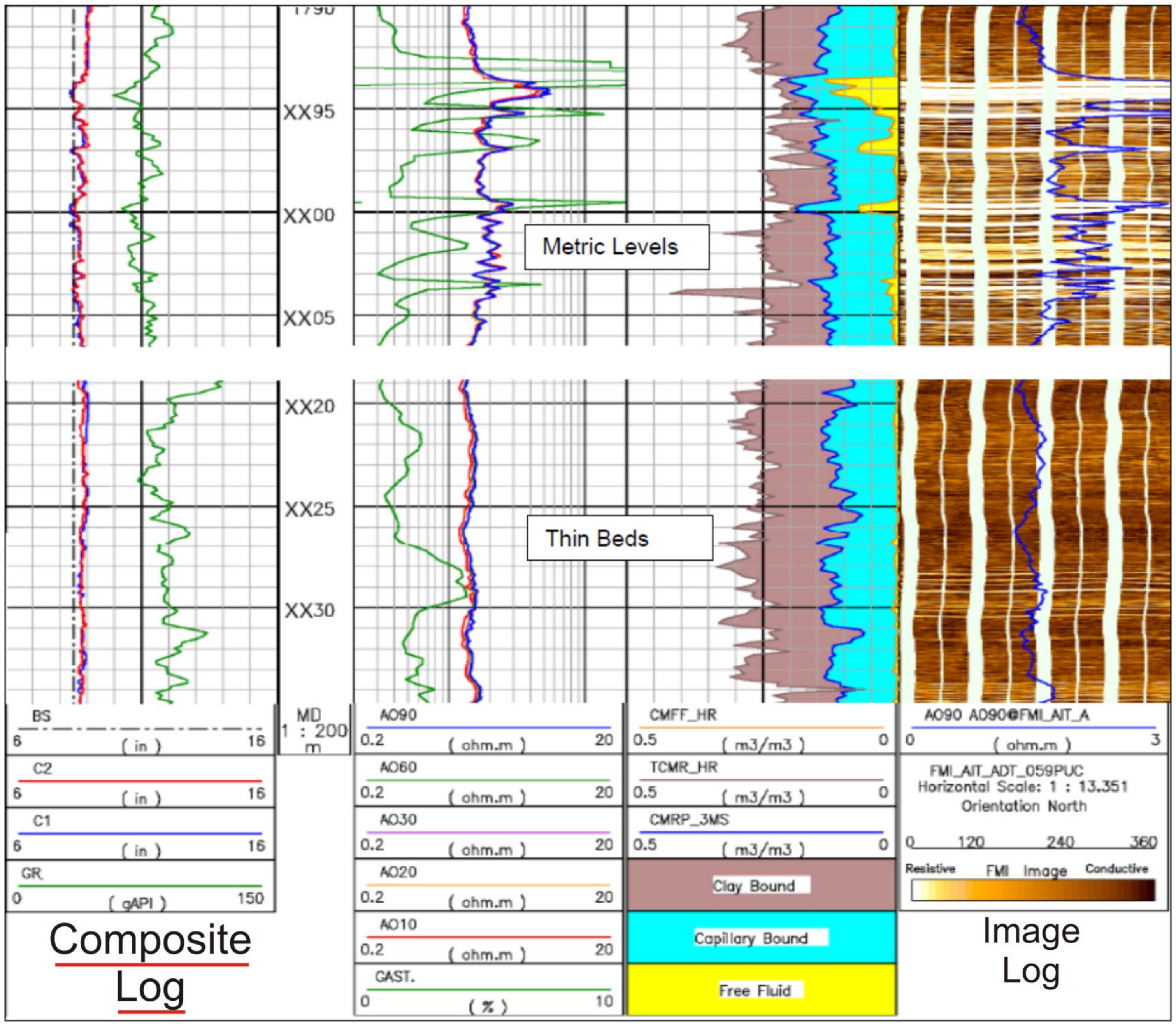
Overview of Oil and Gas Fields in Italy



Cross-Section Showing Separation between the main Barbara Field and the Satellite Field, Barbara NW

After Loi et al SPE 154426 (2012)

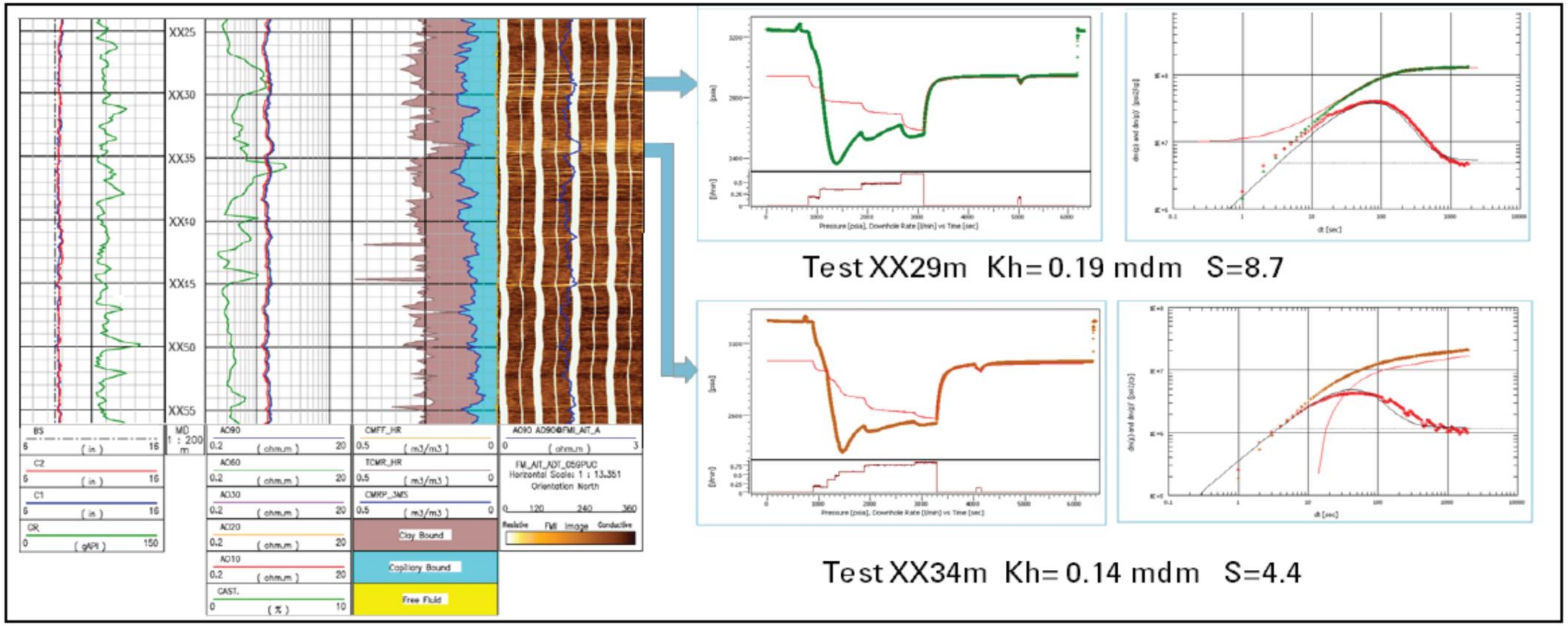

Barbara NW WFT Pressure Data
After Loi et al SPE 154426
Higher Thickness Levels
Hydrostatic Gradient
Thin Beds
Overpressured Gradient
Gradient
= 0.1037 (kg/cm2)/m
(water hydrostatic)
Pressures Determined from Pump Test
Depth TVDss (m)
Pressure (kg/cm2)
X600
X800
X000
X200
X400
X600
X800
60
80
100
120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



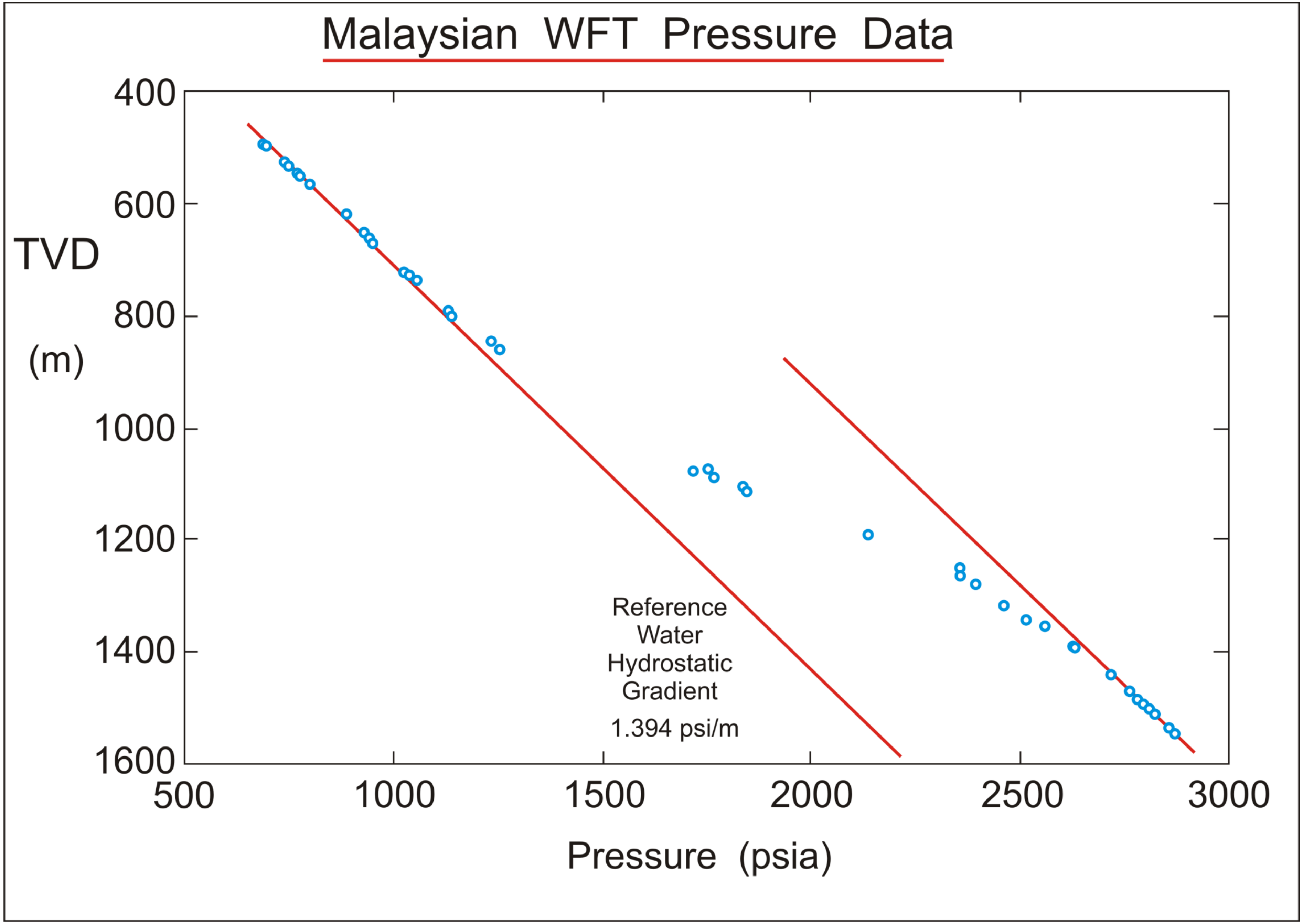
Standard Metric Levels Reservoirs

Thin Beds

Permeability-Thickness Determination from Mini-DSTs over Thin Beds



After Loi et al SPE 145526



Malaysian WFT Pressure Data
TVD
(m)
400
600
800
1000
1200
1400
1600
500
1000
1500
2000
2500
3000
Pressure (psia)
Reference
Water
Hydrostatic
Gradient
1.394 psi/m

Review of SPE 139837

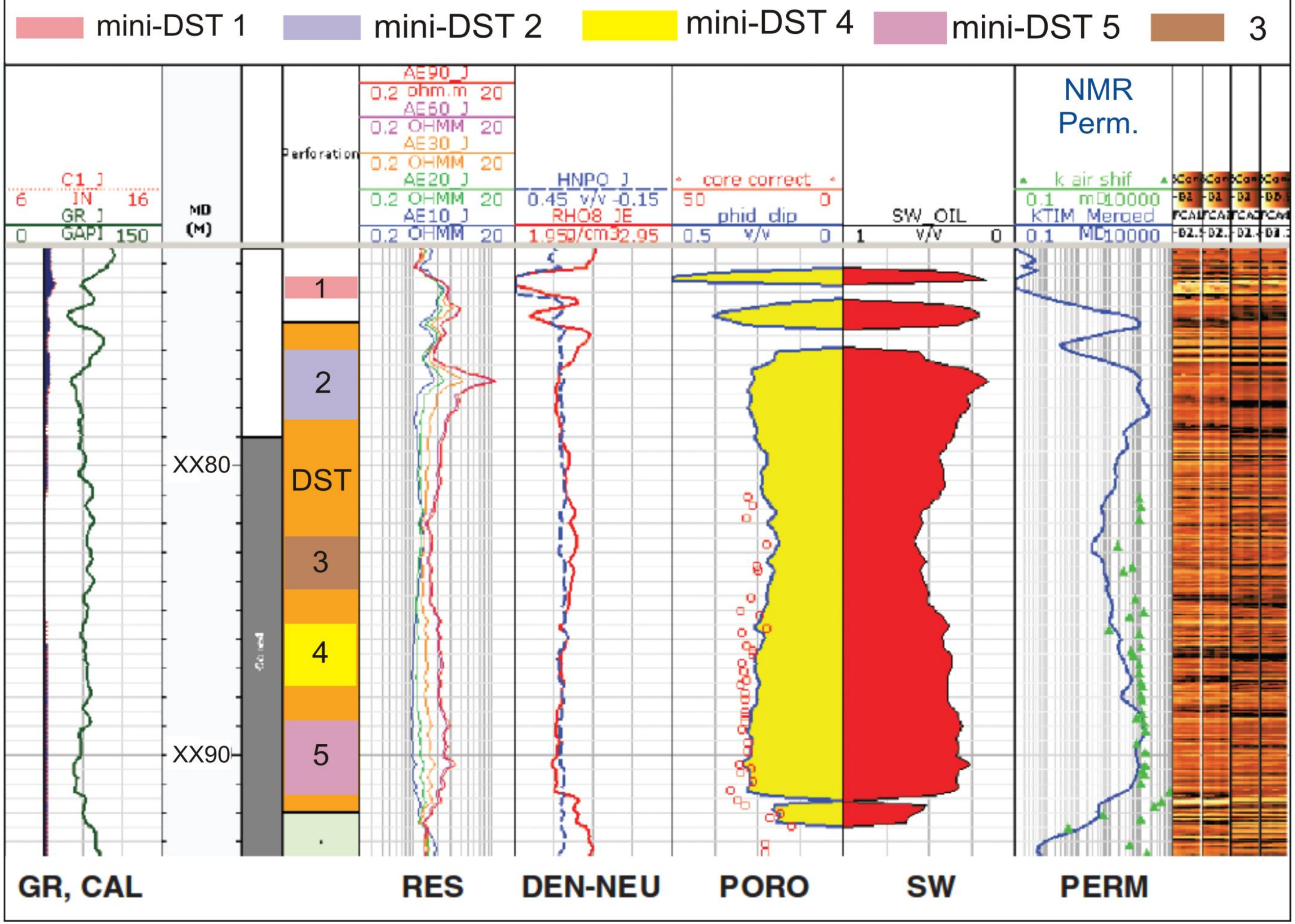
"Integration of Wireline Formation Testing and Well Test Evaluation - an Example from the Caspian", Ramaswami, S., Elshahawi, H. and El Battawy, A. SPE Reservoir Evaluation and Engineering, June 2012

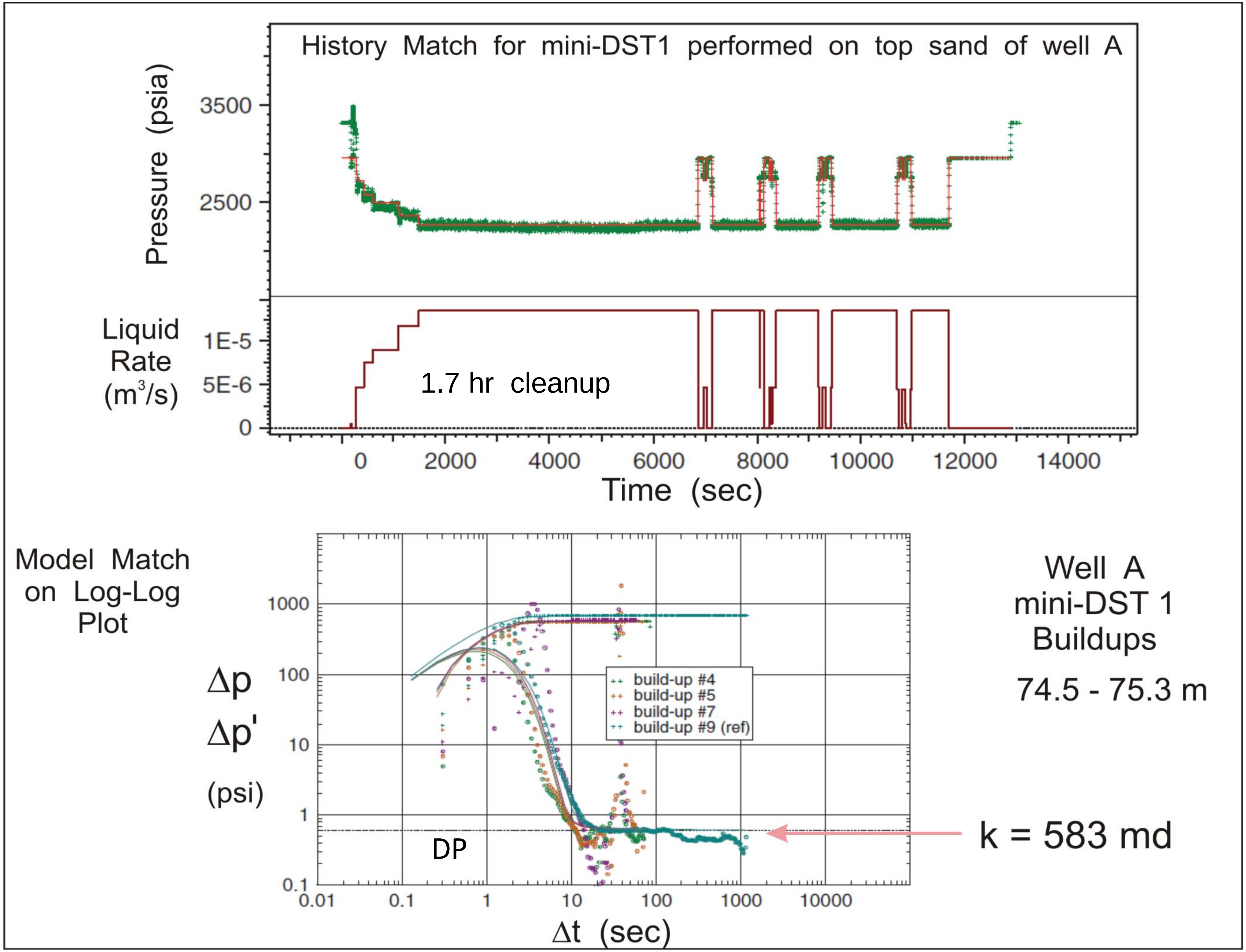
- Demonstrates that mini-DSTs can successfully forecast well deliverability
- Multiple mini-DSTs is now the prevalent form of layered well testing
- Focused on WFT methods to extract productivity parameters of formations
- Model employed is the familiar limited entry analytical solution

Well A

- Vertical exploration well drilled in a clastic reservoir
- Water based mud (WBM)
- 110 probe tests recorded
- 16 PVT samples collected
- Higher permeability at top and bottom from NMR log

Conventional Openhole Logs Over the Zone of Interest Well A



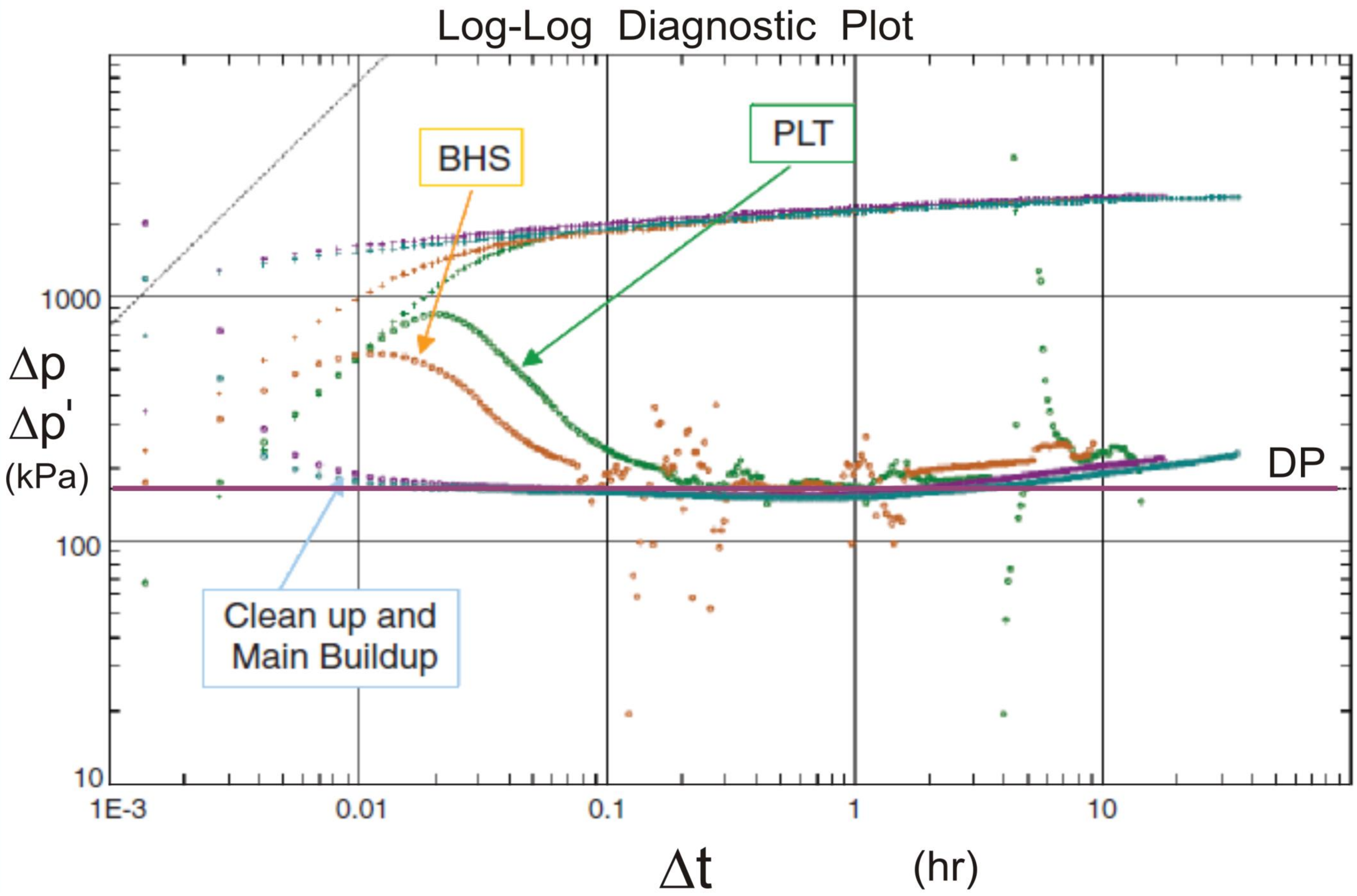


History Match for mini-DST1 performed on top sand of well A
Pressure (psia)
3500
2500
Liquid Rate (m^3/s)
1E-5
5E-6
0
1.7 hr cleanup
0
2000
4000
6000
8000
10000
12000
14000
Time (sec)
Model Match on Log-Log Plot
Δp
$\Delta p'$
(psi)
1000
100
10
1
0.1
0.01
0.1
1
10
100
1000
10000
Δt (sec)
build-up #4
build-up #5
build-up #7
build-up #9 (ref)
DP
Well A mini-DST 1 Buildups
74.5 - 75.3 m
k = 583 md

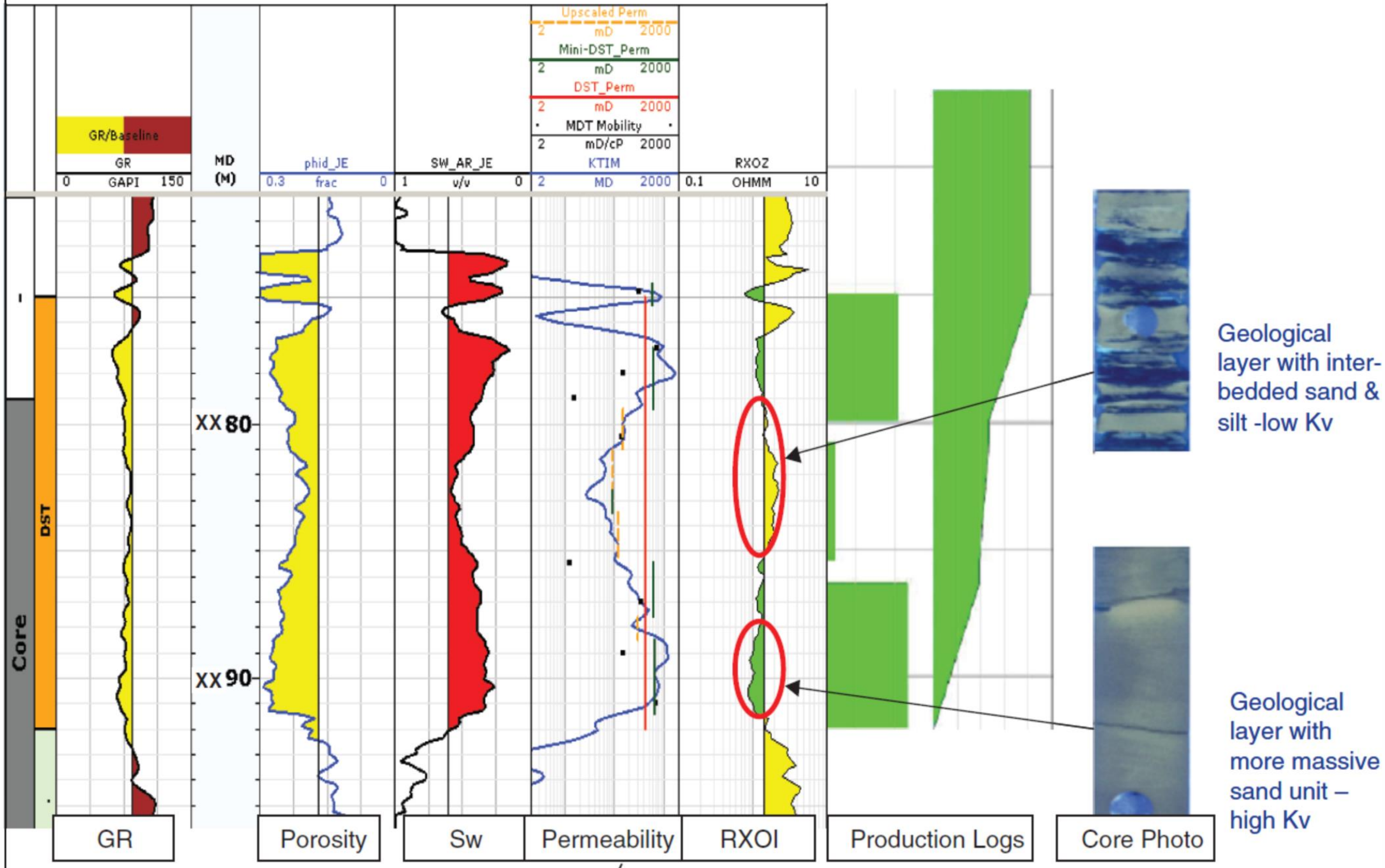
Well A DST Production Test

First BU

kh = 6948 md.m



Permeability Results for Well A

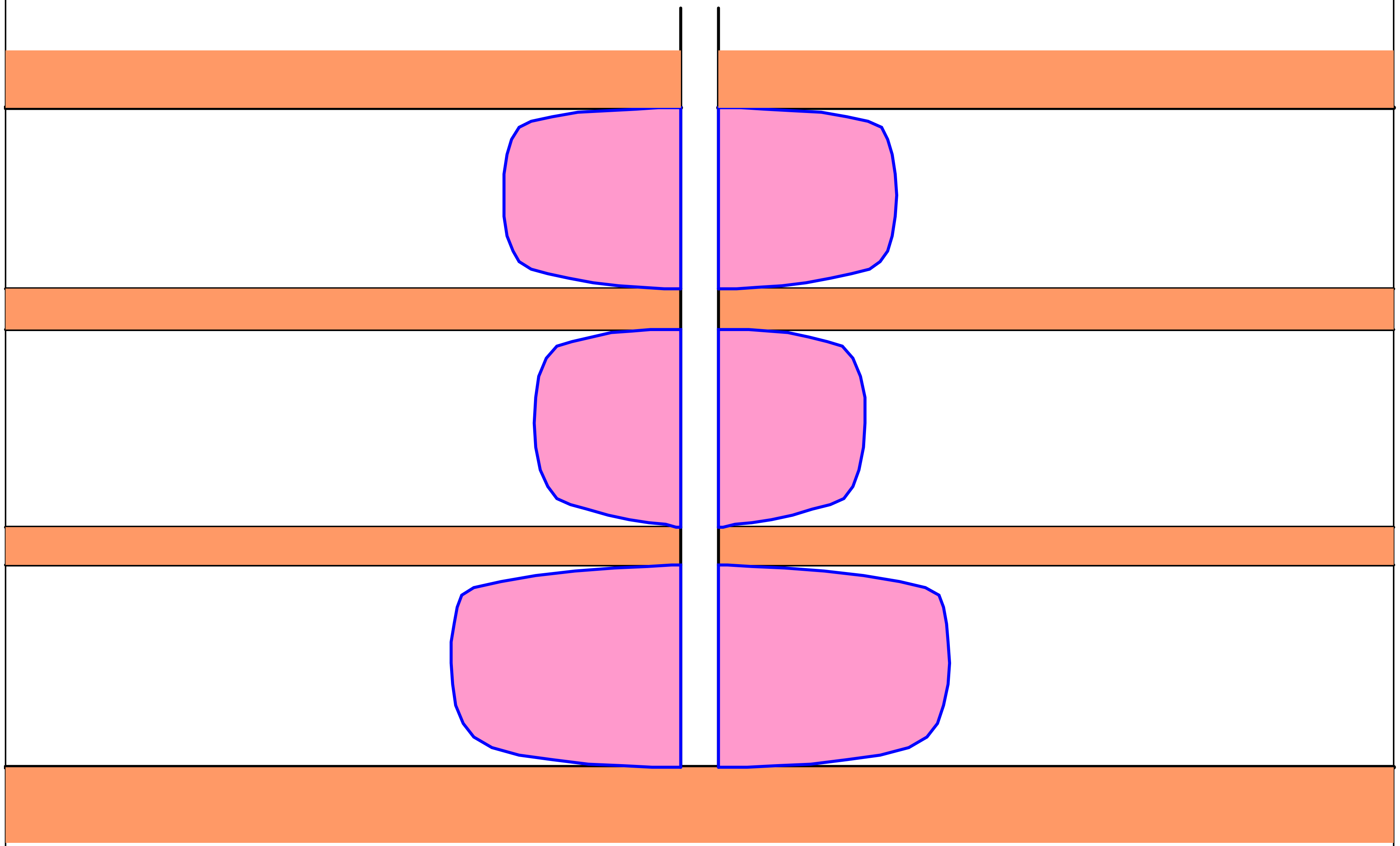


Permeability –Blue:NMR Perm; Red:DST Perm; Green:MiniDST Perm; Orange:Additional permeability thickness upscaled using NMR Perm

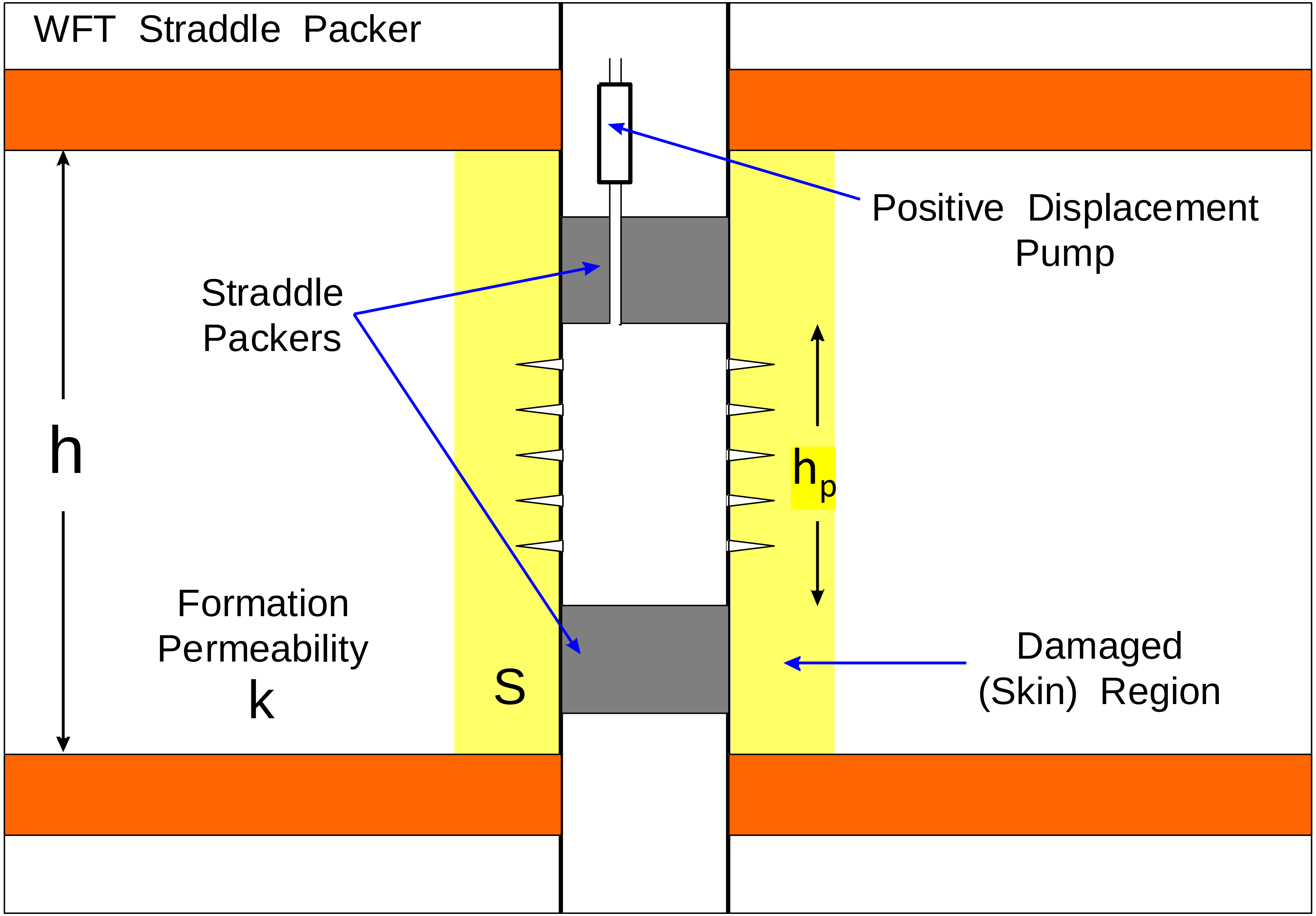
Comparison of Permeability-Thickness and Permeability Between Mini-DST and DST Results in Well A

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

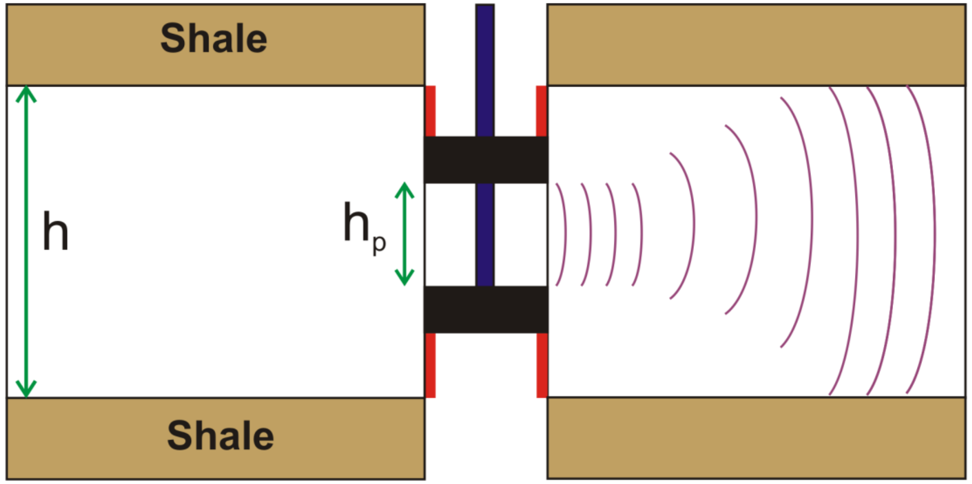
- Unfortunately the authors give no results regarding the skin factor

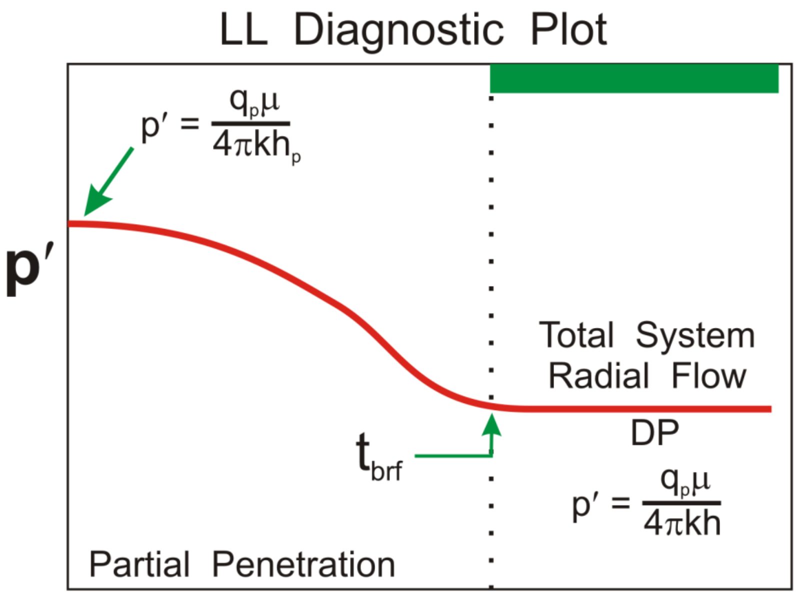


“Pin-Point” Fracturing Using Coiled Tubing


WFT Straddle Packer
Positive Displacement Pump
Straddle Packers
h
h_p
Formation Permeability k
S
Damaged (Skin) Region

Case where $h_p < h$





Time to the Beginning of Total System Radial Flow, t_{brf}

$$t_{Db} = \frac{0.000263679 \times k_z t_{brf}}{\phi \mu c_t h^2} = 0.083$$

Characteristic Dimensionless Time

Based on k_z and h

$$t_{brf} = \frac{0.083 \times \phi \mu c_t h^2}{0.000263678 \times k_z}$$

Correlation for Predicting the onset of Radial Flow based on Formation Thickness, h

Mini DSTs

Case 1

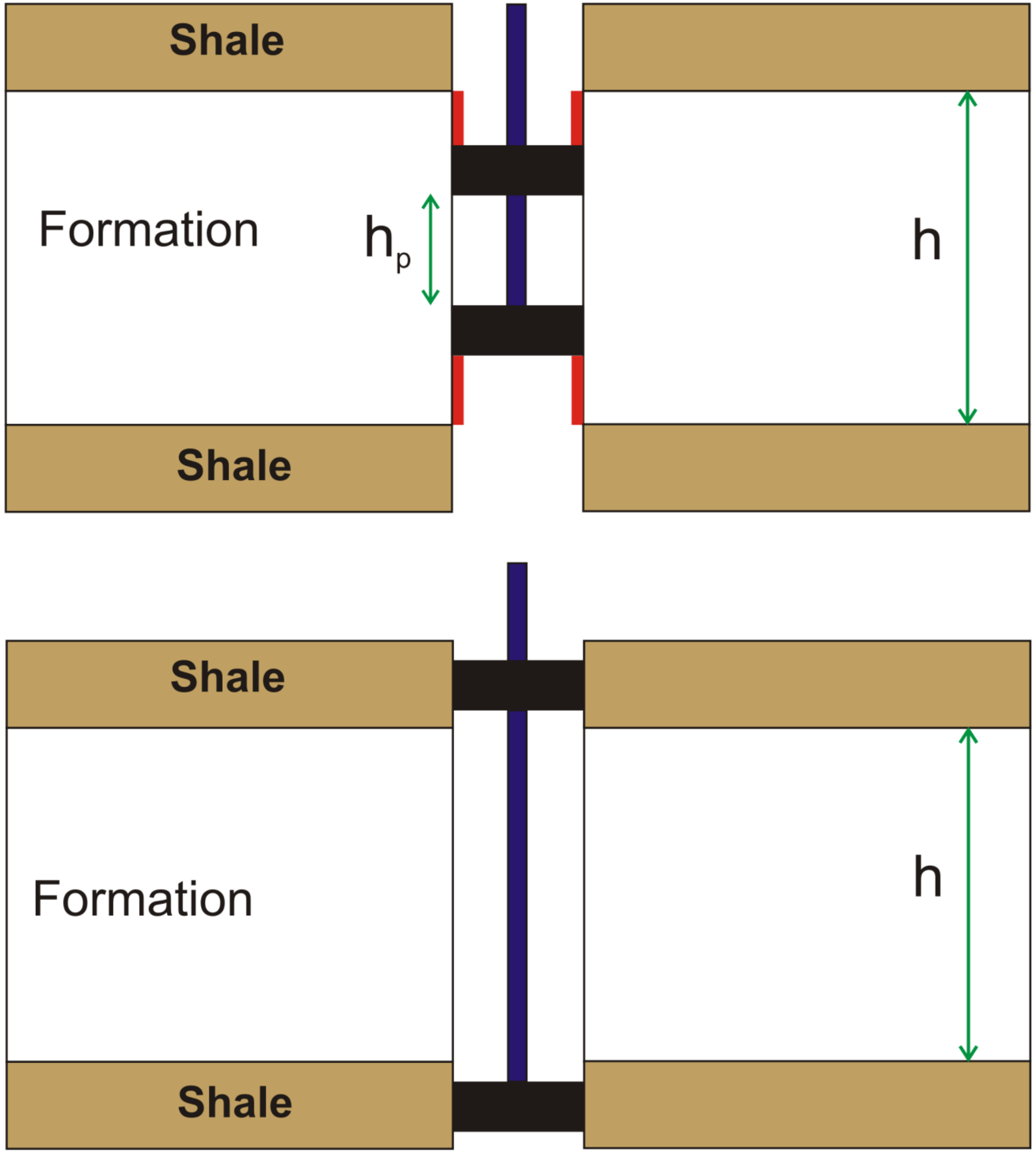
Limited Entry Situation

Assumes Impermeable Mud Cake

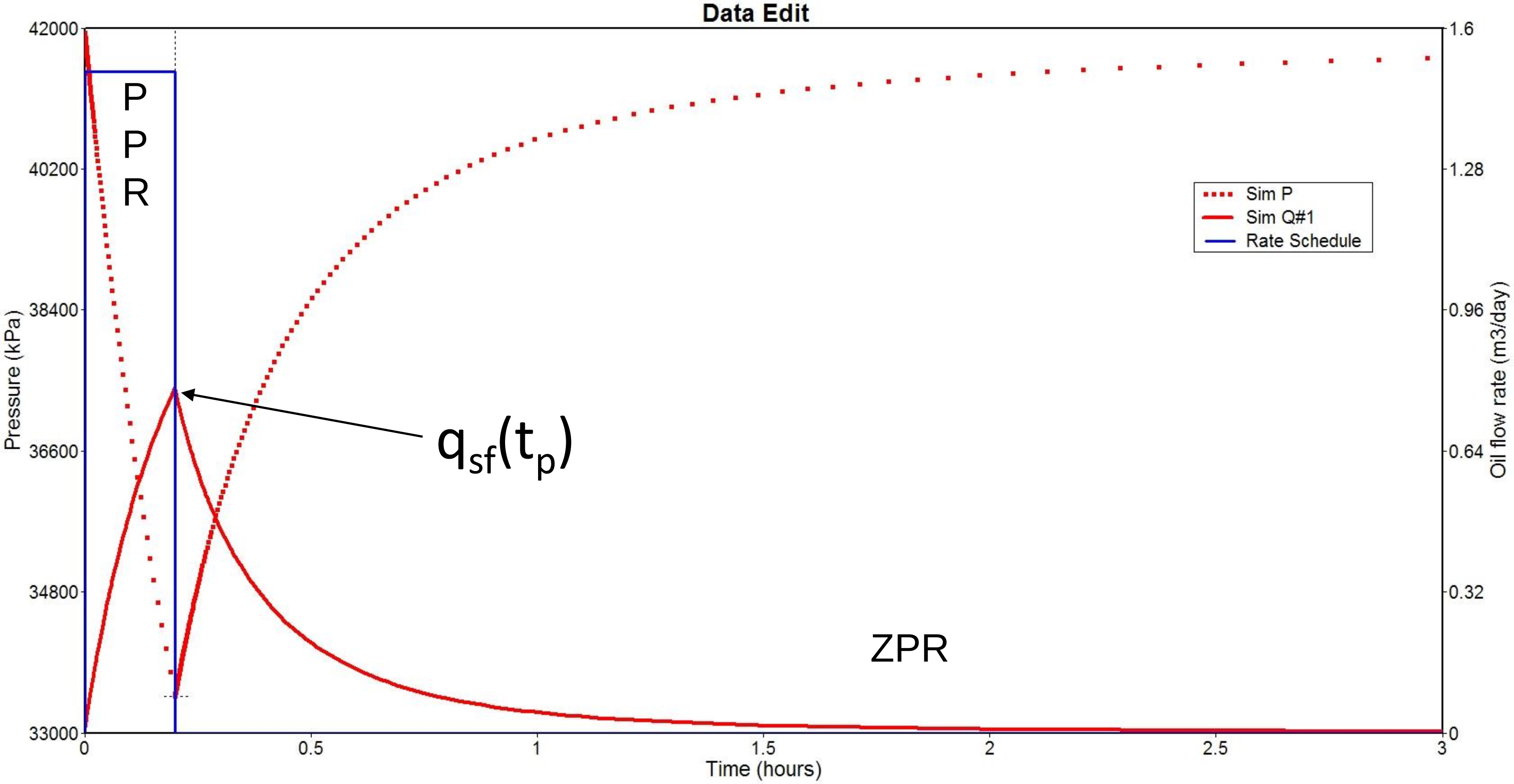
Case 2

Complete Straddle Packer

Better Arrangement

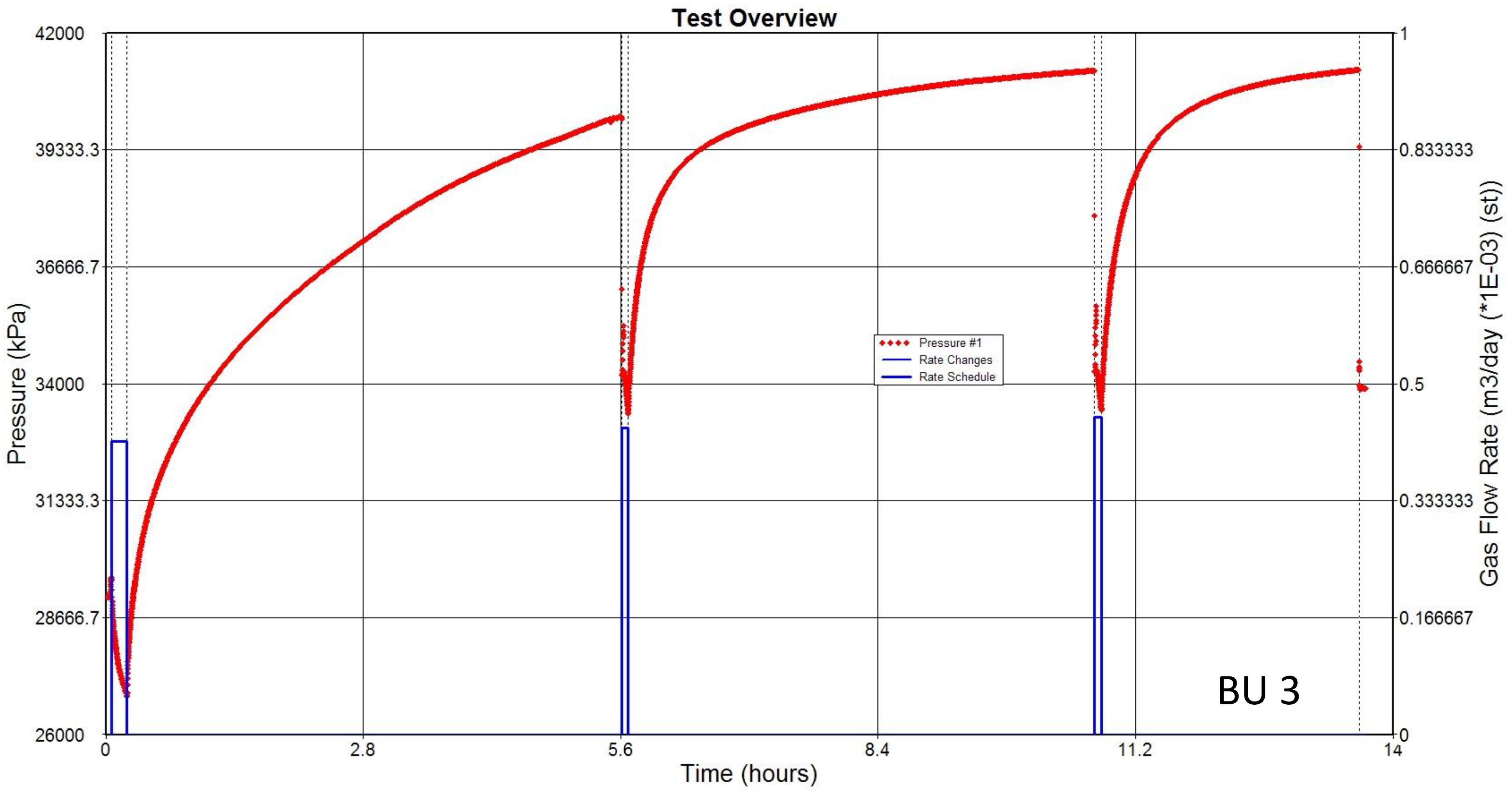


WFTSP Case 2 Situation



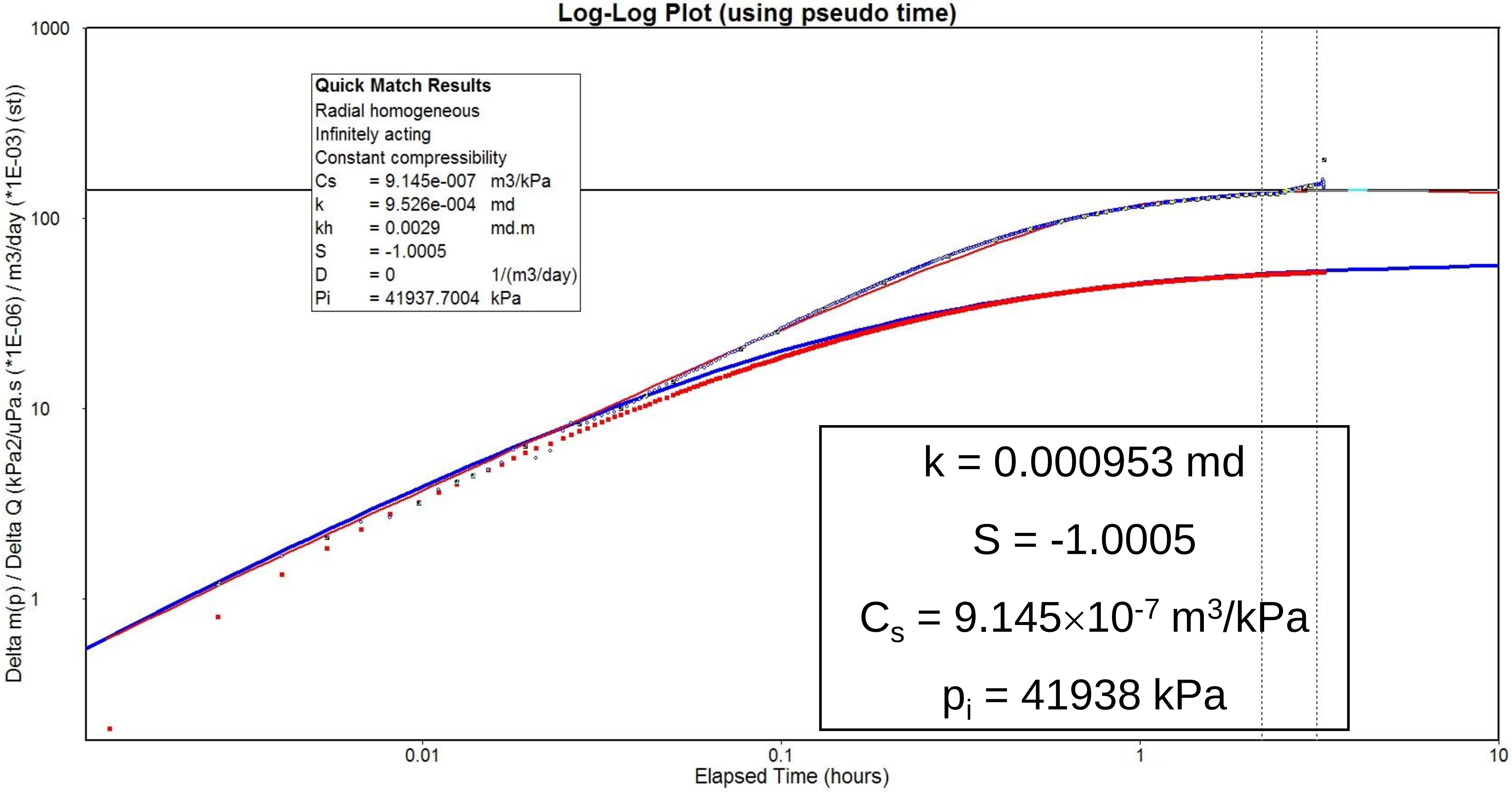
Storage Controlled Test (SCT)

Cased Hole Test C



Cased Hole Test C

Buildup 3



$k = 0.000953$ md

$S = -1.0005$

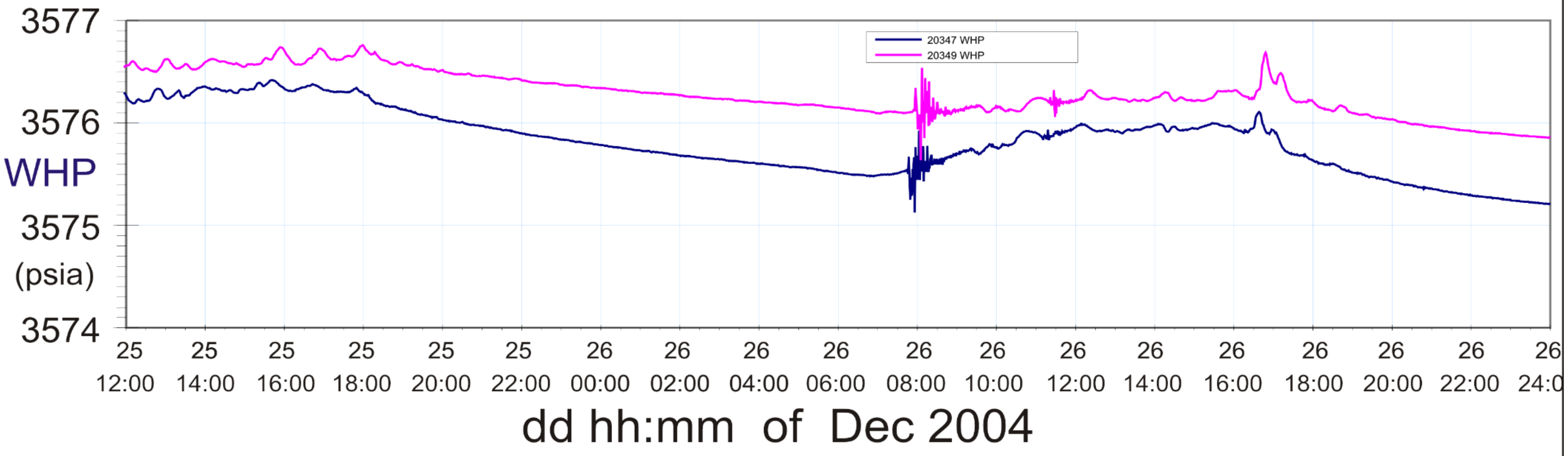
$C_s = 9.145\times10^{-7}$ m^3/kPa

$p_i = 41938$ kPa

Nonlinear Regression Automatch

Wellhead Pressure Data from Sumatra

Suban 5



Suban 7