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Formation Pressure Testing In the Dynamic Drilling Environment

SPE DISTINGUISHED LECTURER SERIES

Mark Proett

Halliburton - Drilling and Formation Evaluation

SPE DL Talks 2006

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- Sep 12 Moscow Section, Russia
- Sep 13 Nizhnevartovsk Section, Russia
- Sep 14 Western Siberia, Noyabrsk, Russia
- Sep 18 Volga Section, Almetyevsk, Russia
- Sep 21 Aktau Section, Kazakhstan
- Sep 22 BP Baku, Azerbaijan
- Oct 18 Midland Texas

SPE DL Talks 2007

- Jan 10 Houston, SPE Drilling Study Group
- Feb 21 Denver, Colorado
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- Mar 11 Dubai, UAE
- Mar 12 Abu Dhabi, UAE
- Mar 14 Cairo, Egypt
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SPE DL Talks 2007

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- Apr 11 Bridgeport, West Virginia
- Apr 12 Charleston, West Virginia
- May 14 Trans-Pecos Section, Odessa Texas
- May 15 Arkansas Section, Fort Smith Arkansas
- May 16 Mid Continent Section, Tulsa, Oklahoma
- May 17 Oklahoma City Section, Oklahoma, City

22 Talks Total

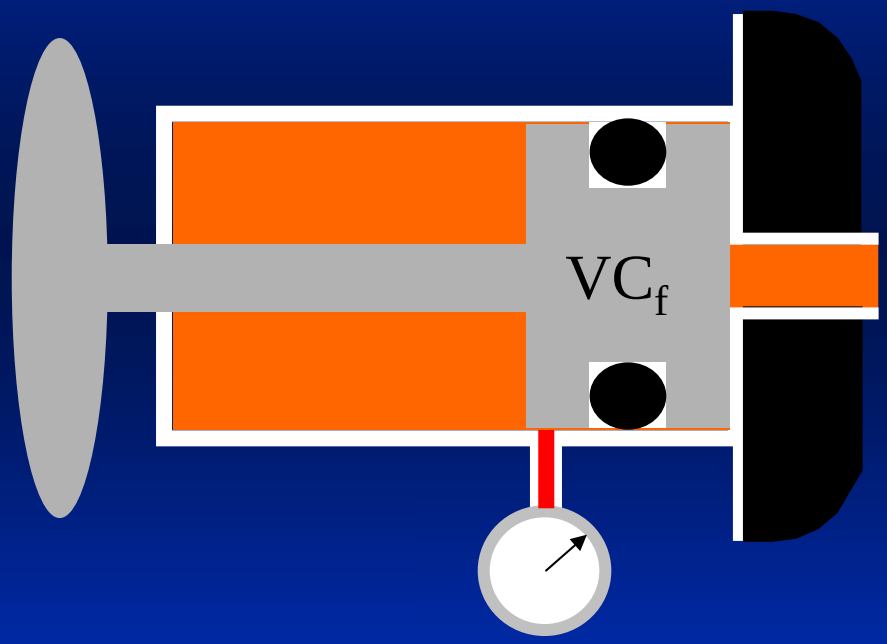
Formation Pressure Testing in the Dynamic Drilling Environment

- Formation Testing While Drilling (FTWD) tools were introduced in 2002 and this new service has raised fundamental questions.
- How does the drilling environment affect the measurement?
- How do FTWD and Wireline Formation Testers (WFT) compare?
- What new applications can FTWD address?

Formation Pressure Testing

- Evolution of Formation Testing Technology
  - Wireline Formation Testing
  - Formation Testing While Drilling (FTWD)
- FTWD Deployment & Challenges
- FTWD Applications and Examples
- Summary

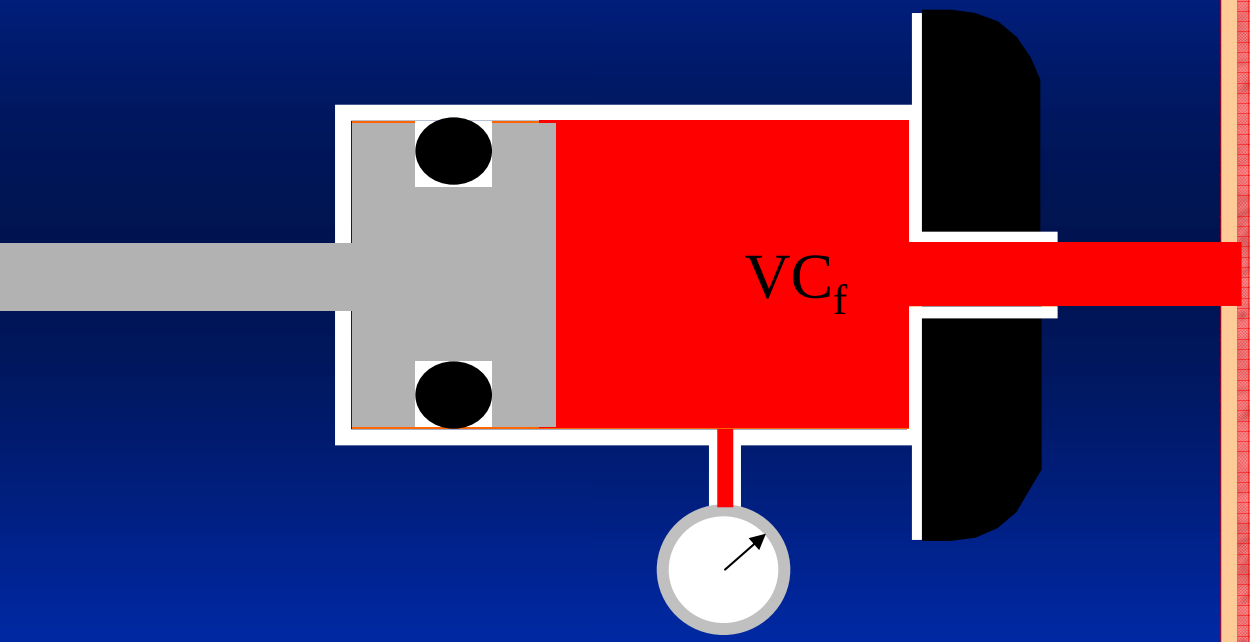
Formation Testing like a Hypodermic



Pressure Transient

Formation Testing like a Hypodermic

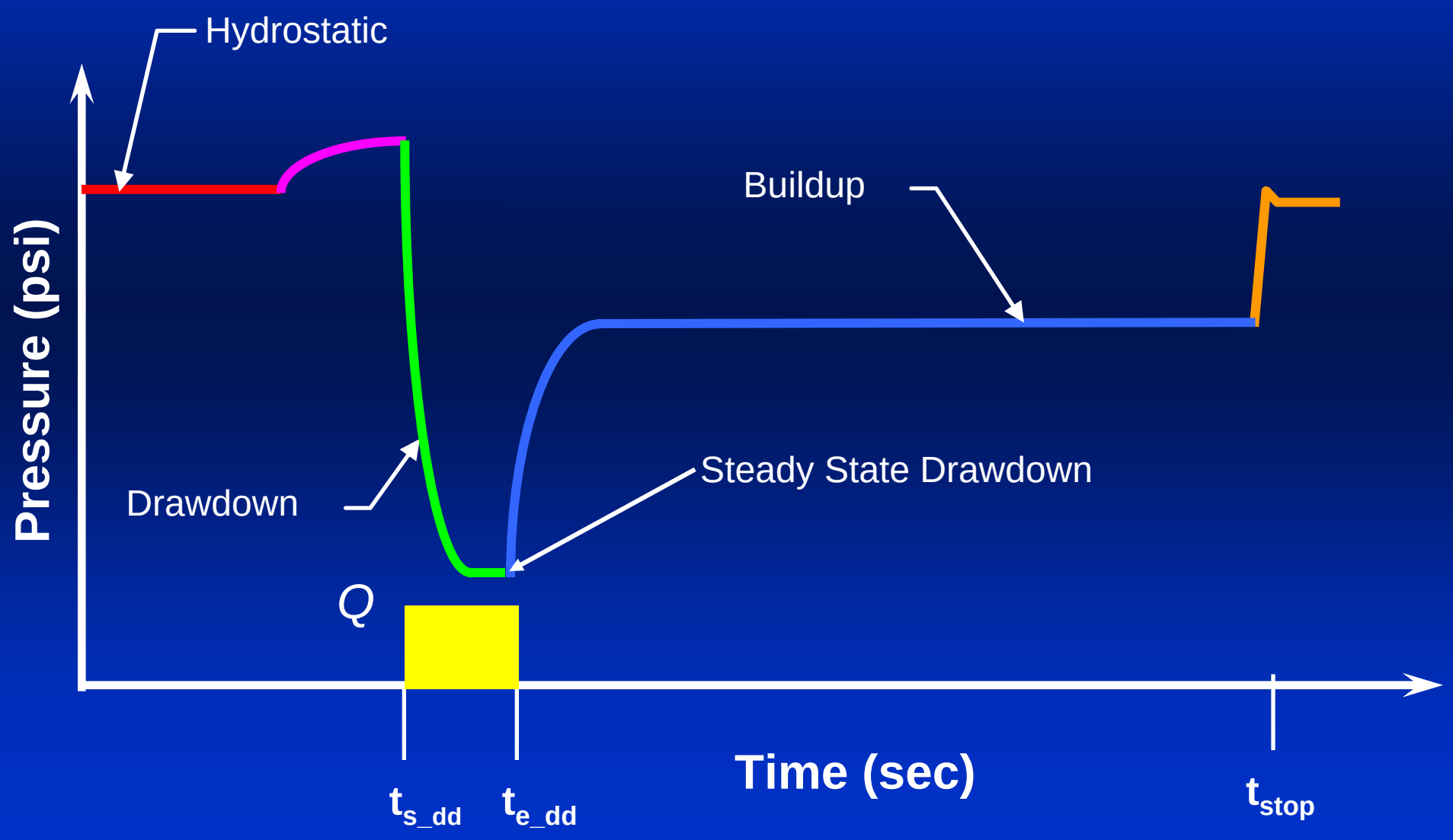
Total Flow = - Storage + Formation



$$M = \frac{k}{\mu}\left(\frac{md}{cp}\right)$$

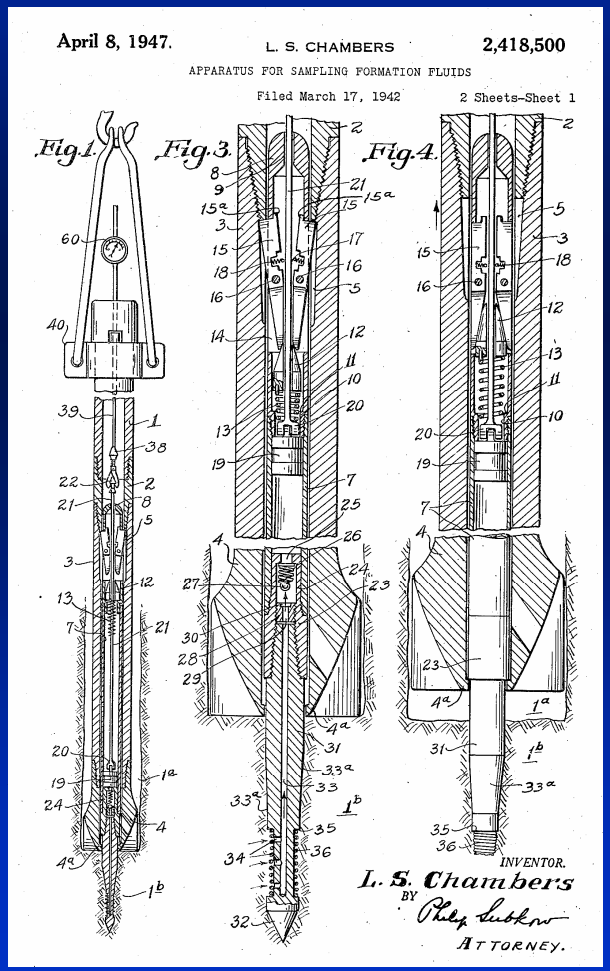
Pressure Transient

Typical Pressure Test > 1md/cp

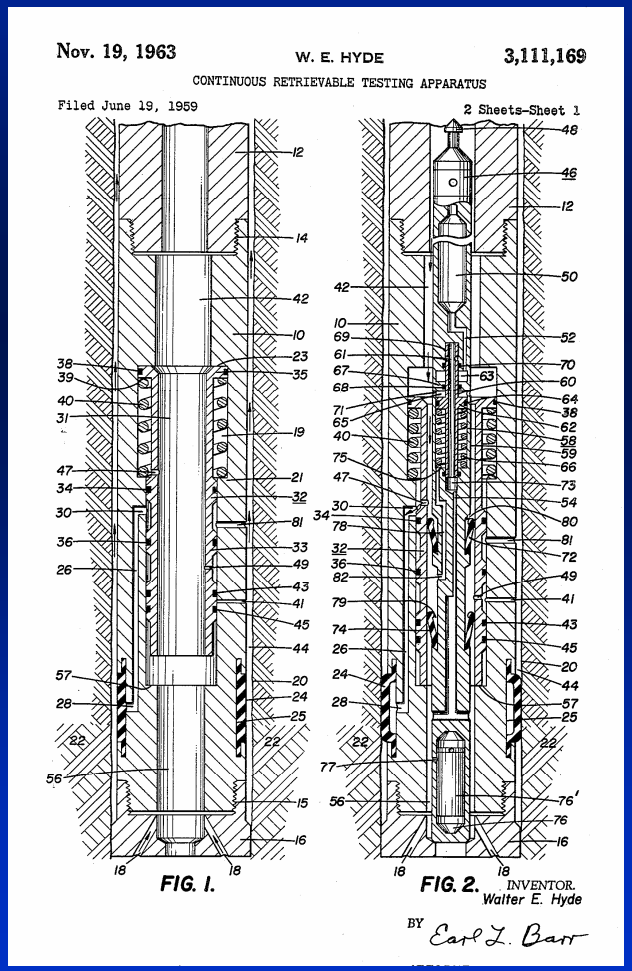


Early Formation Testers

Chambers 1947

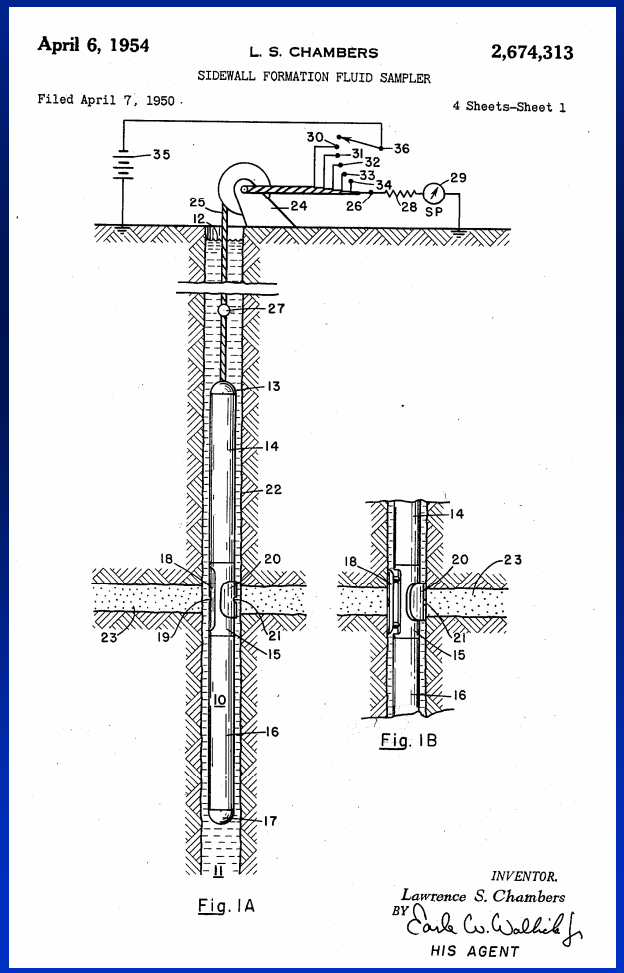


Hyde 1963



Early Formation Testers

Chambers 1954

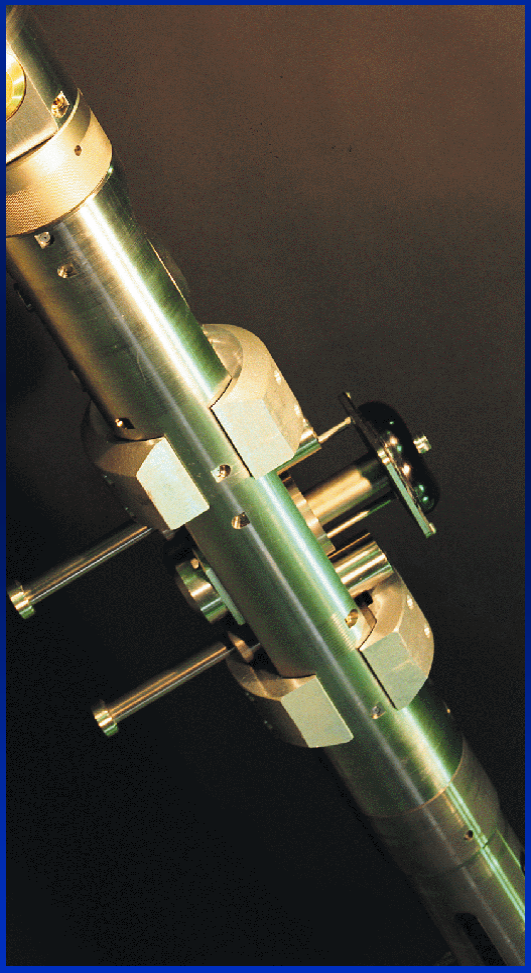


Hyde 1963

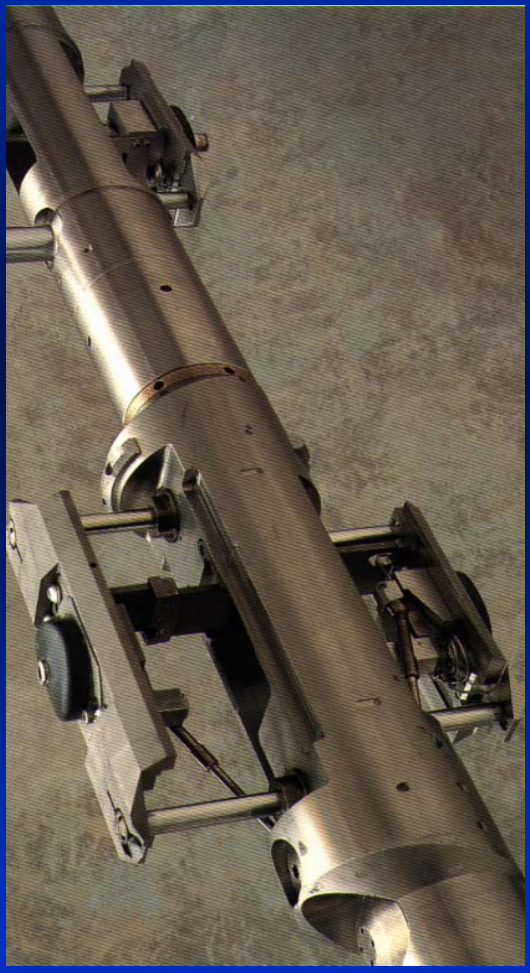
Wireline Testers

RFT 1974

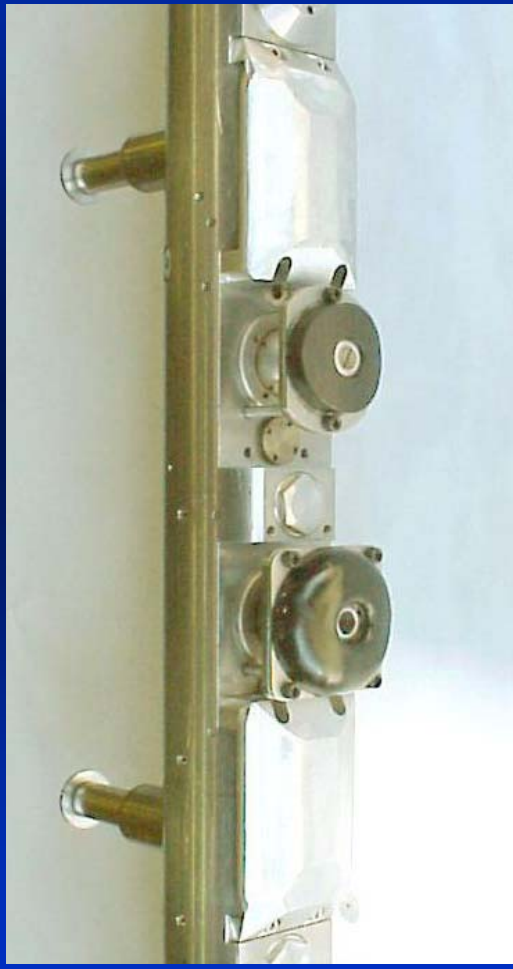
SFTT 1986



MDT 1989



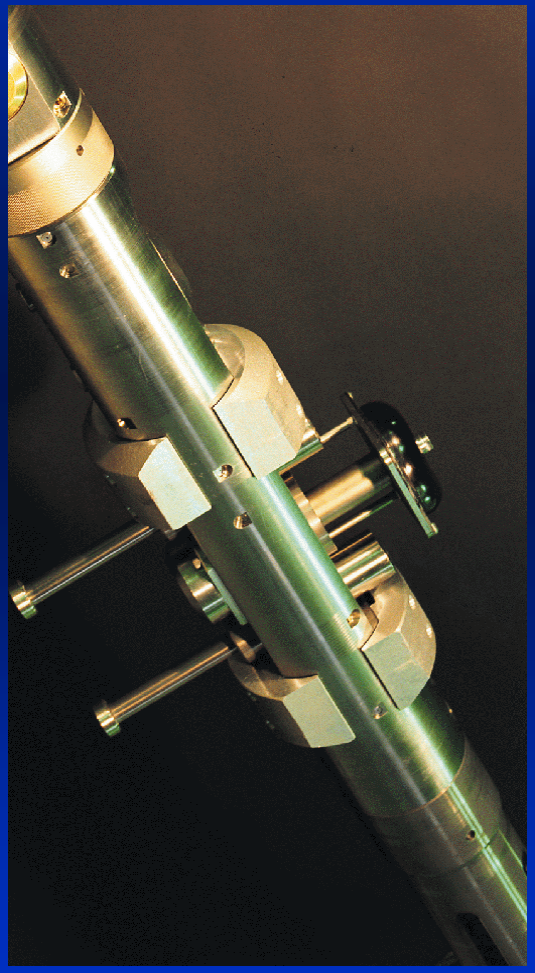
RDT 1998



Wireline Testers

RFT 1974

SFTT 1986



Focused Probe

Oval Probe

Formation Testing While Drilling
FTWD Sensors

DFT
Pathfinder
2001

GeoTap
Halliburton
2002

TestTrack
Baker INTEQ
2003

StethoScope
Schlumberger
2005

Probe Based Testers FTWD Sensors

- ✓ Proven Pad/Probe design
- ✓ Bidirectional communications
- ✓ 0.01 psi Quartz Gauge Precision
- ✓ 1 – 3 drawdowns per set
- ✓ 5000 - 7000 psi drawdown
- ✓ 0.5 – 50 cc drawdown volumes
- ✓ 0.1 – 8 cc/sec selectable rates
- ✓ 100+ pressure tests per trip
- ✓ 7 - 15 Minutes, Typical Test Time
- ✓ 4 ¾”, 6 ¾”, 8” and 9 ½”
  Tool sizes currently available

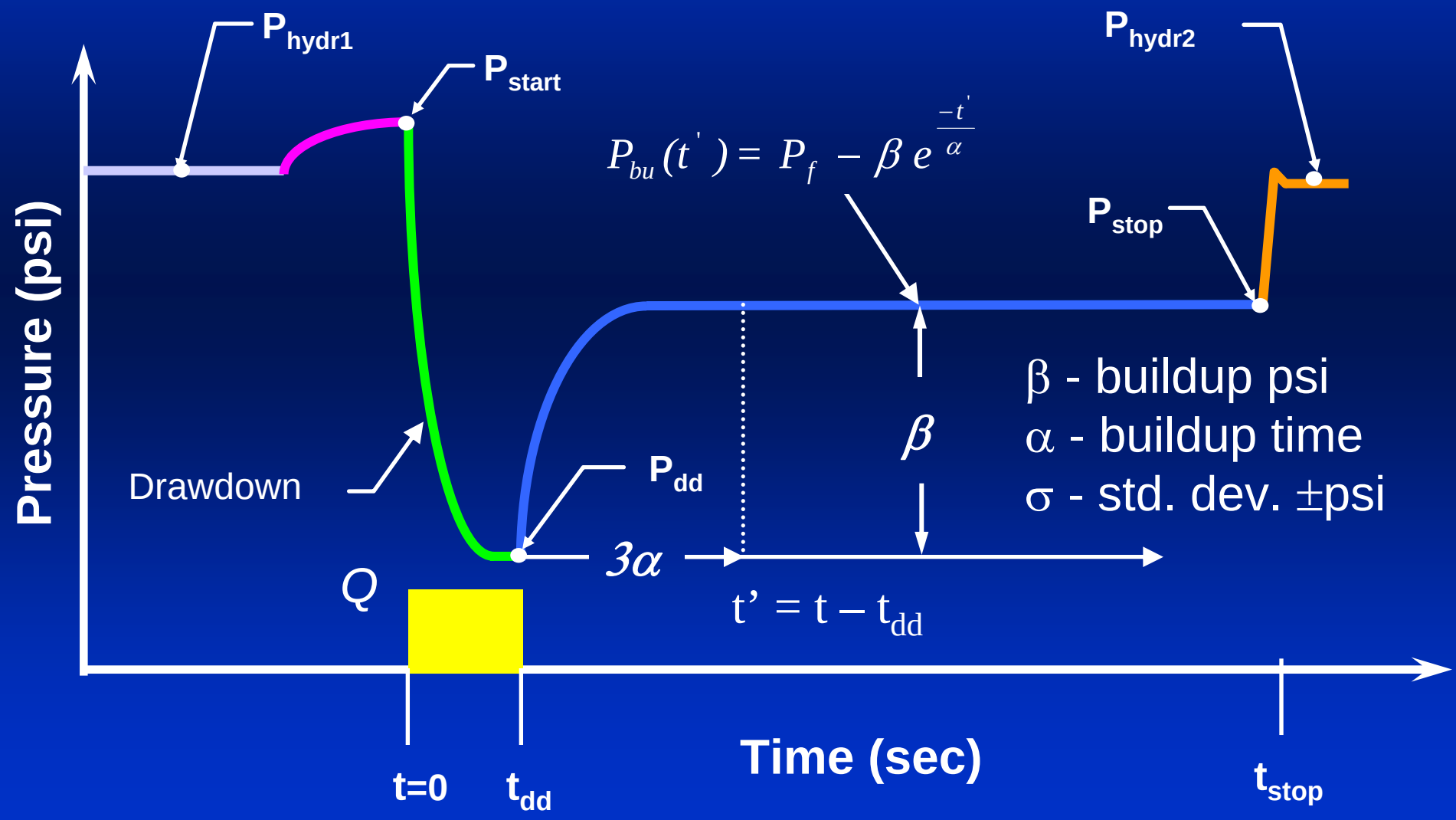
Advantages of FTWD

- Less invasion – formation damage
- Reduced sticking – no fishing
- Faster testing – less rig time
- While drilling data – pressures & gradients
- Geo Steering – horizontal drilling
- Well control – mud optimization

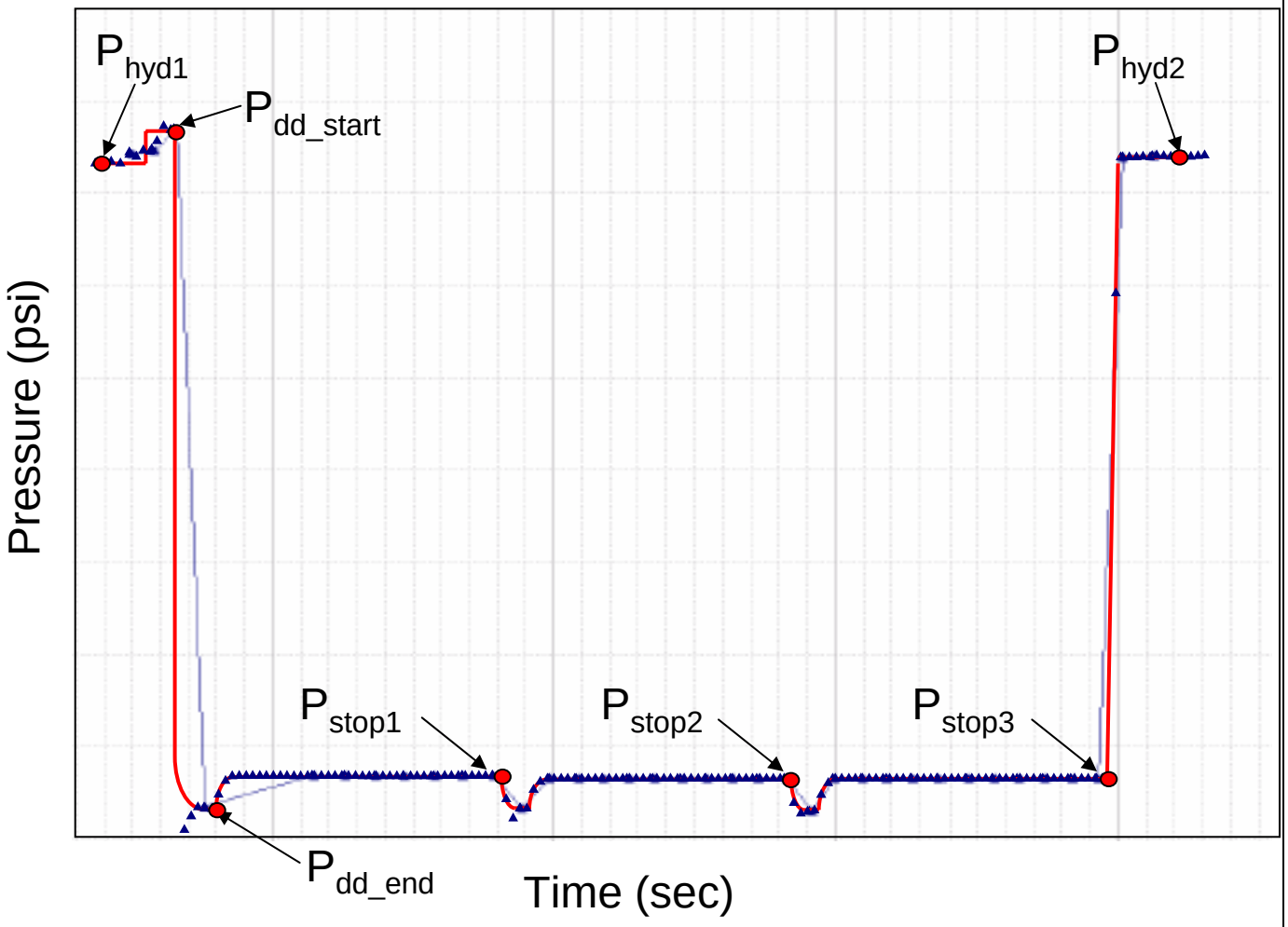
Challenges for FTWD

- High accuracy real-time formation pressures
- Verify pressure test quality in Real-time
- ECD & dynamic invasion effect pressure?
- FTWD pressures repeatable & reliable?
- FTWD pressures & gradients compare with WL?

FTWD Real-time Data Transmission Pressures & Quality Factors



Real-Time Data Modes & Summary



Test Summary

MD	12,452
TVD	7,683

Pressures:

P_{stop1}	3,521.1
P_{stop2}	3,521.4
P_{stop3}	3,522.2
P_{hyd1}	6,432
P_{hyd2}	6,445
P_{dd_start}	6,509
P_{dd_end}	3,421

Quality Factors:

β (psi)	98.0
α (sec)	1.0
σ ($\pm$psi)	0.2

Results:
Good Stable Test
Mobility 148md/cp

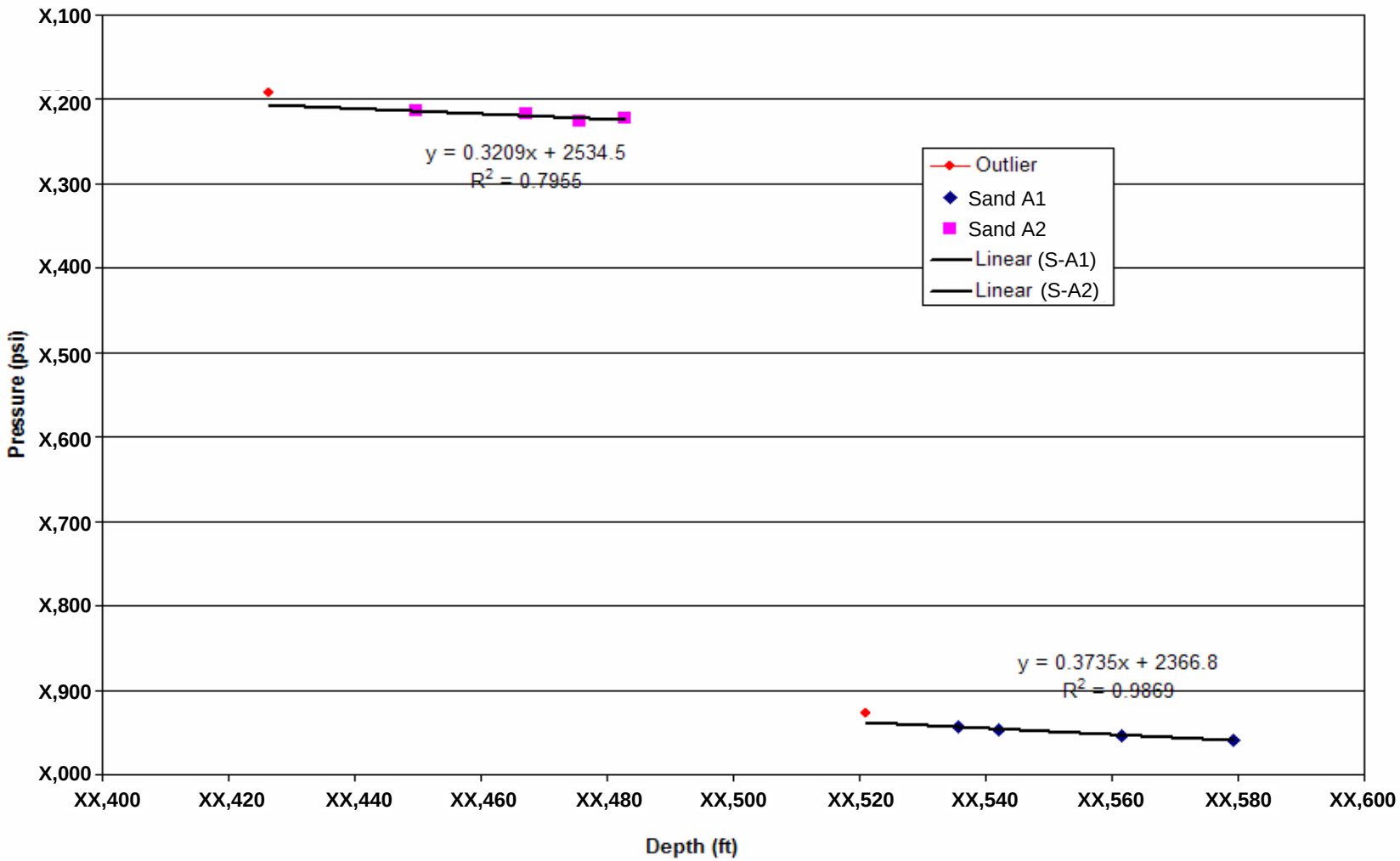
Real-Time Data Summary

FTWD Engineers	Messaoud Djefel	Date	8/20/2005	HCIM SW Ver		68.18		Flow line vol	35 cc	FTWD to Bit (m)	31.5

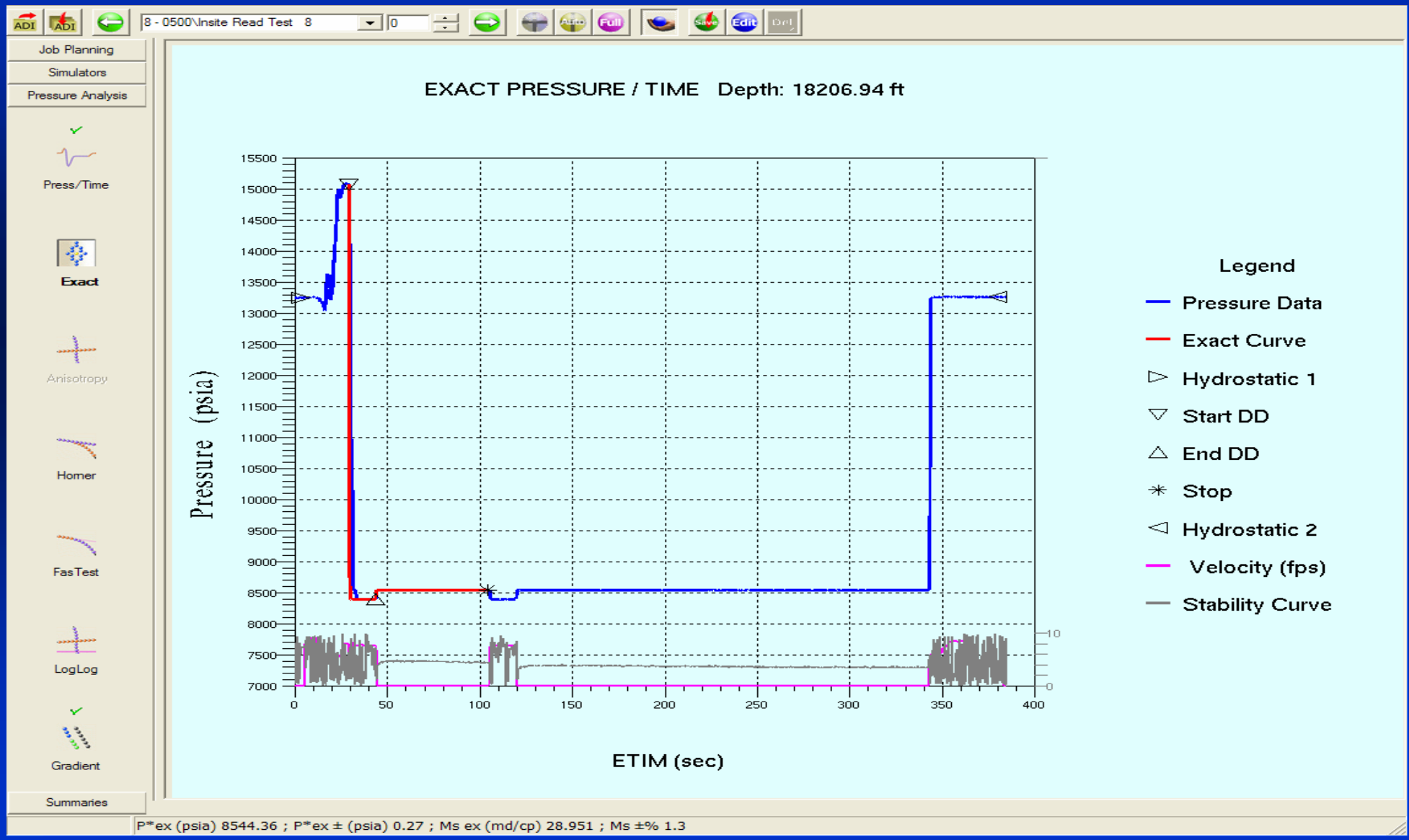
FTWD Real-Time Report

Sample No #	Bit Depth ft	FTWD MD ft	FTWD TVD ft	Date	Time	Hyd 1 psi	Hyd 2 psi	Start DD Pres psi	DD Time Sec	End DD Pres spi	End DD Time Sec	Stop Pres psi	Alpha	Beta	Std. Dev.	Survey Temp deg F	FTWD TF	Comments
Sand – A1																		
1	XX185.96	XX081.42	XX426.39	XX/XX/XX	3:47 AM	XX317.08	XX331.63	XX333.08	16.00	XX597.08	224.00	XX793.00	0.00	128.00	0.06	172	-18.65	Good Stable Test - Good RT to Rec Match
2	XX212.47	XX107.93	XX449.71	XX/XX/XX	4:59 AM	XX273.58	XX273.58	XX289.58	16.00	XX649.58	224.00	XX814.00	0.50	0.00	0.06	172.00	-15.72	Good Stable Test - Good RT to Rec Match
3	XX232.54	XX128.00	XX467.13	XX/XX/XX	7:17 AM	XX273.00	XX288.00	XX289.00	15.00	XX697.00	224.00	XX817.00	0.00	85.33	0.06	172.00	148.00	Good Stable Test - Good RT to Rec Match
4	XX241.43	XX136.89	XX475.54	XX/XX/XX	7:45 AM	XX244.67	XX230.22	XX260.67	15.20	XX708.67	224.00	XX825.00	0.00	106.67	0.06	172.00	154.00	Good Stable Test - Good RT to Rec Match
5	XX249.49	XX144.95	XX482.79	XX/XX/XX	8:25 AM	XX215.81	XX215.81	XX159.81	16.00	XX703.81	224.00	XX823.00	0.00	106.67	0.06	172.00	154.00	Good Stable Test - Good RT to Rec Match
Sand – A2																		
6	XX274.00	XX170.00	XX503.67	XX/XX/XX	10:20 AM	XX273.00	XX259.00	XX289.00	15.00	XX313.00	224.00	XX466.00	0.00	106.67	0.06	172.00	-9.87	Good Stable Test - Good RT to Rec Match
7	XX294.46	XX189.92	XX520.92	XX/XX/XX	10:40 AM	XX230.22	XX230.22	XX246.22	15.20	XX358.22	224.00	XX528.00	0.00	106.67	0.06	168.00	-1.09	Good Stable Test - Good RT to Rec Match
8	XX311.52	XX206.98	XX535.68	XX/XX/XX	11:47 AM	XX259.12	XX273.58	XX275.12	15.00	XX403.12	224.00	XX543.00	0.00	128.00	0.06	168.00	154.03	Good Stable Test - Good RT to Rec Match
9	XX311.52	XX214.46	XX542.14	XX/XX/XX	4:01 PM	XX288.00	XX288.08	XX288.08	15.00	XX503.33	224.00	XX546.00	0.00	42.67	0.06	165.00	95.50	Good Stable Test - Good RT to Rec Match
10	XX311.52	XX236.93	XX561.54	XX/XX/XX	5:44 PM	XX302.57	XX346.17	XX318.57	15.20	XX310.57	224.00	XX554.00	0.00	192.00	0.06	165.00	-53.77	Good Stable Test - Good RT to Rec Match
11	XX311.52	XX257.49	XX579.27	XX/XX/XX	7:17 PM	XX360.73	XX375.30	XX376.73	15.20	XX368.73	224.00	XX559.00	0.00	106.67	0.06	165.00	-15.72	Good Stable Test - Good RT to Rec Match
Sand - B																		
12	XX311.52	XX983.00	XX342.71	XX/XX/XX	11:09 AM	XX158.00	XX158.00	XX158.00	15.00	XX610.67	224.00	XX696.00	127.50	85.33	2.06	168.00	145.00	Somewhat Stable Test
13	XX311.52	XX108.00	XX449.66	XX/XX/XX	11:43 AM	XX360.00	XX346.00	XX346.00	15.00	XX679.00	224.00	XX680.00	0.50	1.00	7.56	168.00	161.00	Unstable test - Bad RT to Rec Matc

Real-Time Data & Gradients



Post Processing Downloaded Data



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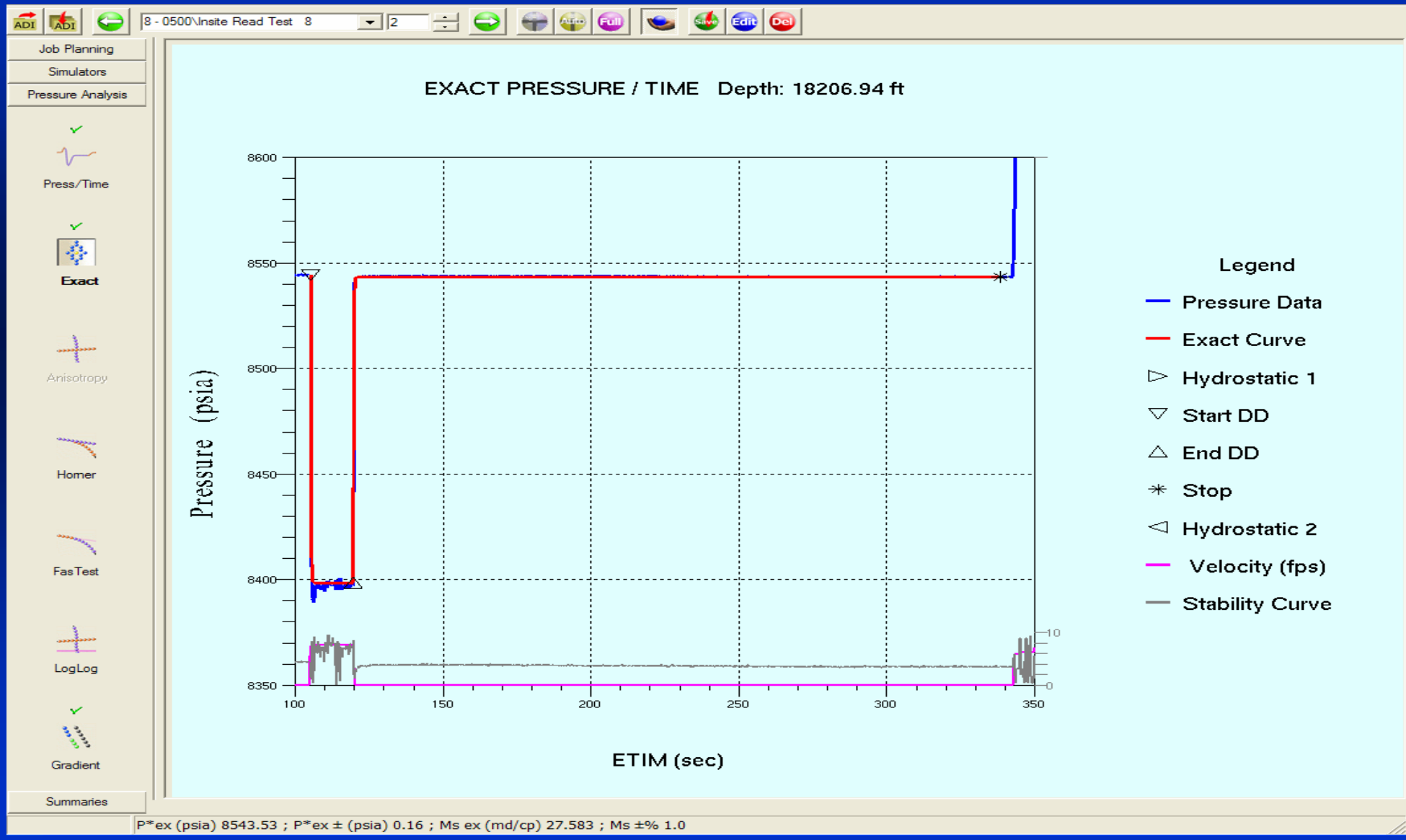
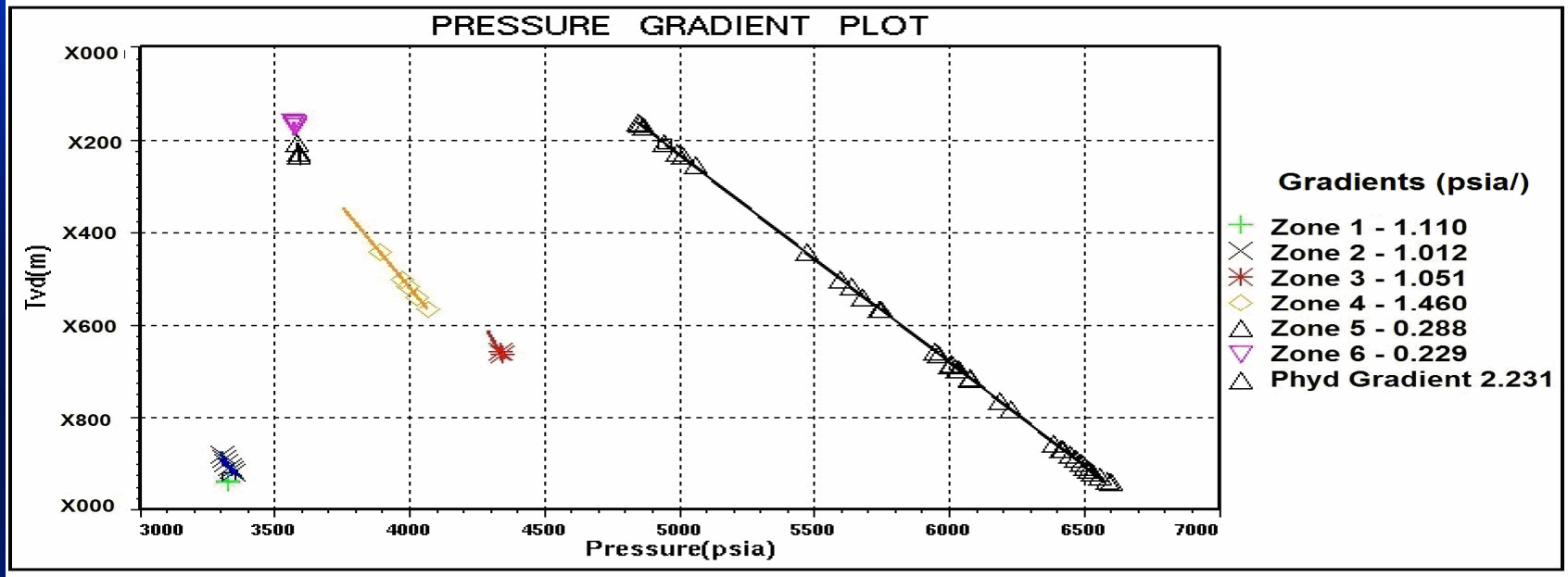


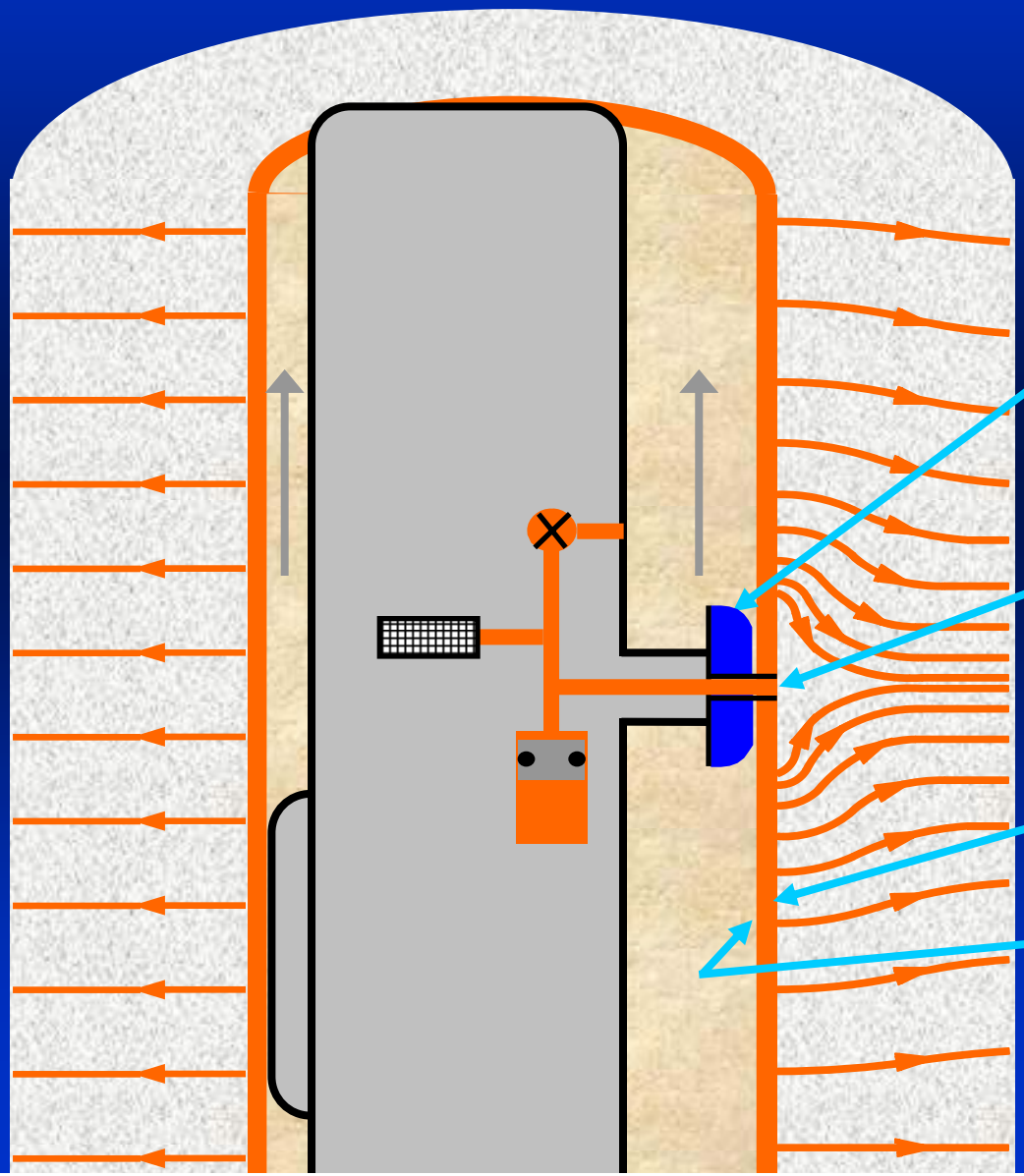
Pressure Gradients



Gradient Group	Gradient psia/m	Equivalent Fluid Density #/gal	g/cc
Zone 1	1.1113	6.5138	0.7805
Zone 2	1.0117	5.9302	0.7106
Zone 3	1.0510	6.1604	0.7382
Zone 4	1.4602	8.5591	1.0256
Zone 5	0.2885	1.6908	0.2026
Zone 6	0.2293	1.3439	0.1610

Disclaimer: All equivalent fluid densities are calculated from TVD pressure gradients.

Dynamic Wellbore Conditions



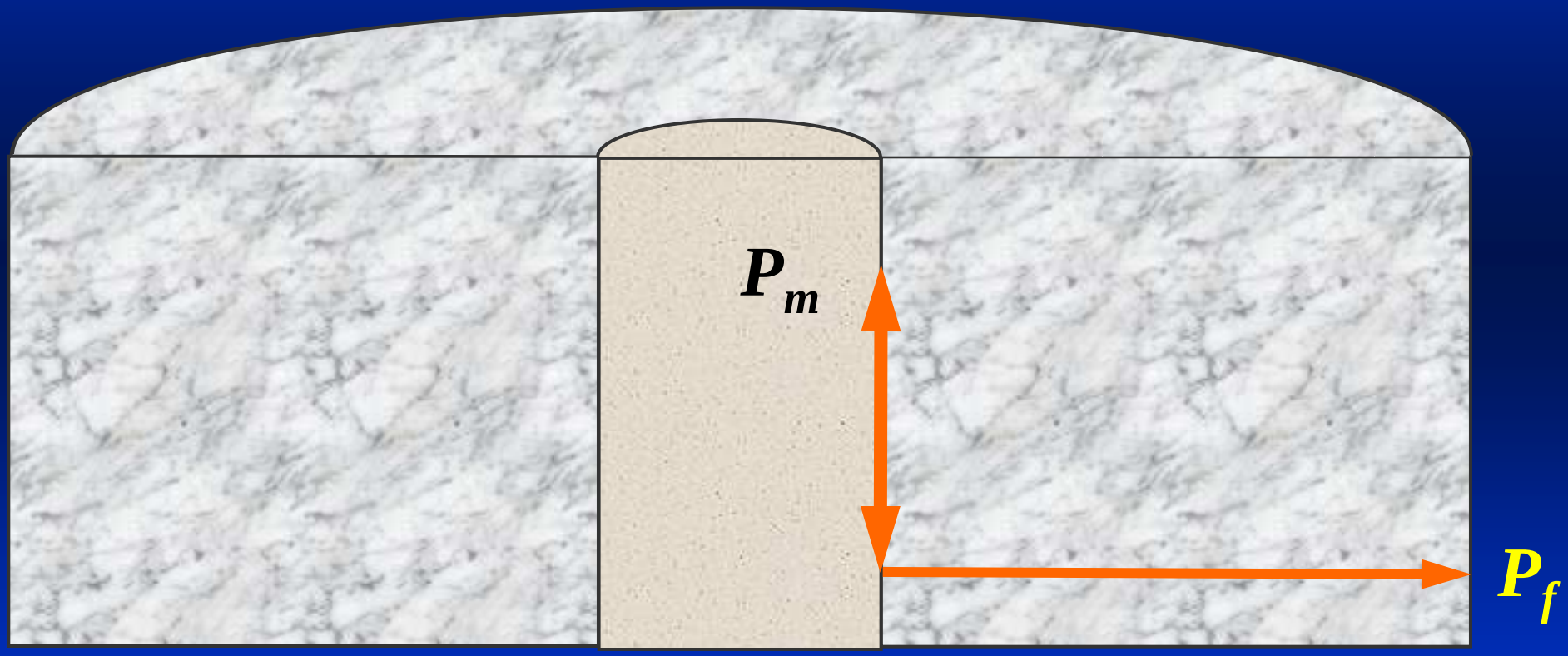
Packer element directs mud filtrate flow around probe

$P_{bu} \approx P_{ss}$ sandface pressure

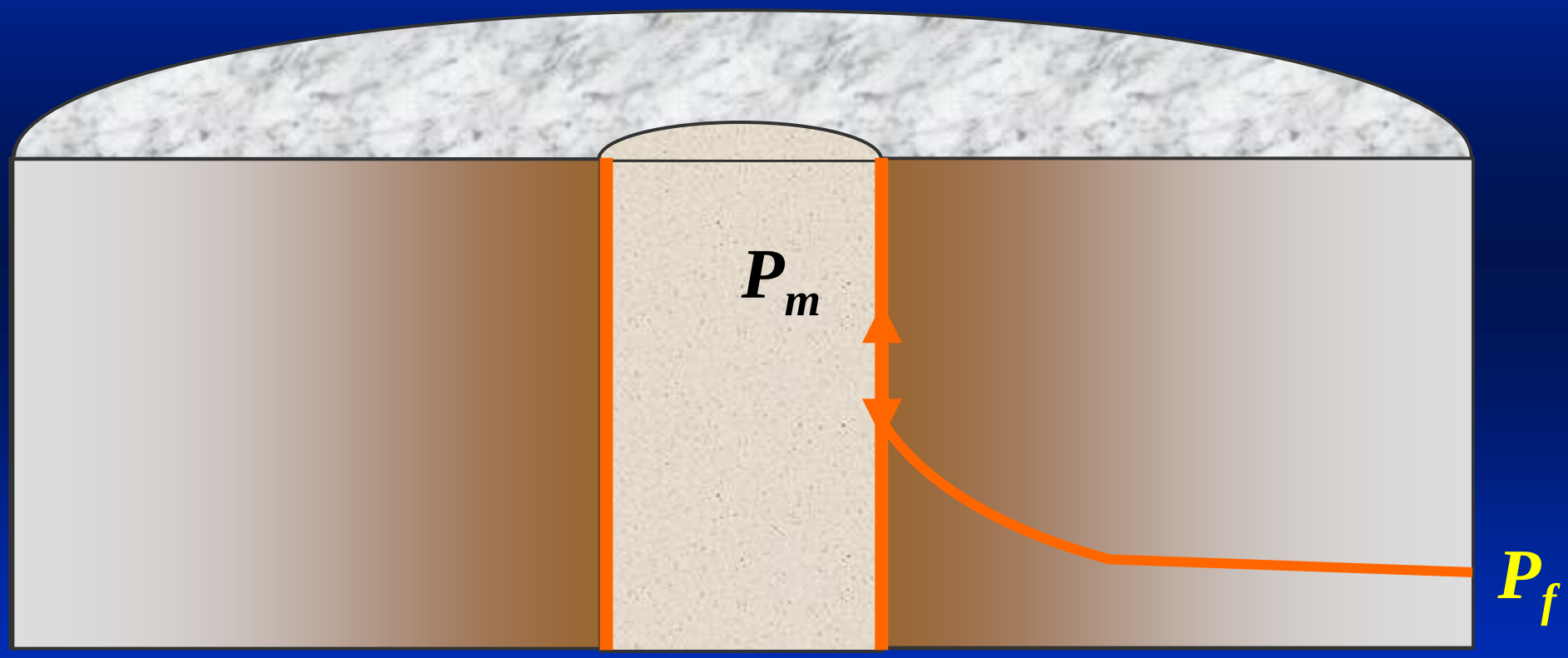
P_{ss} - actual sandface supercharge pressure

P_{mh} - mud hydrostatic pressure

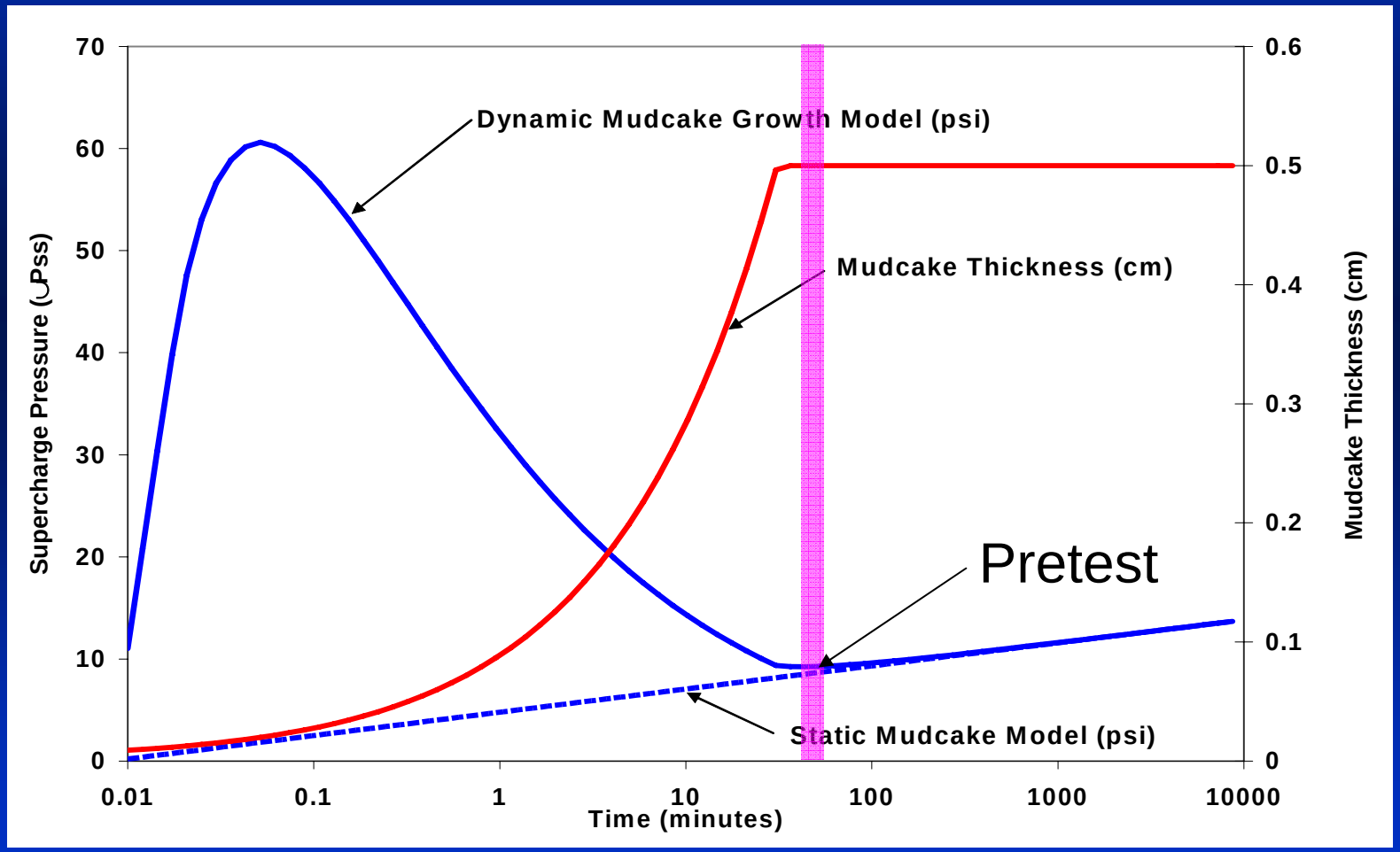
Dynamic Drilling Environment Models From 2005 SPE and SPWLA Papers



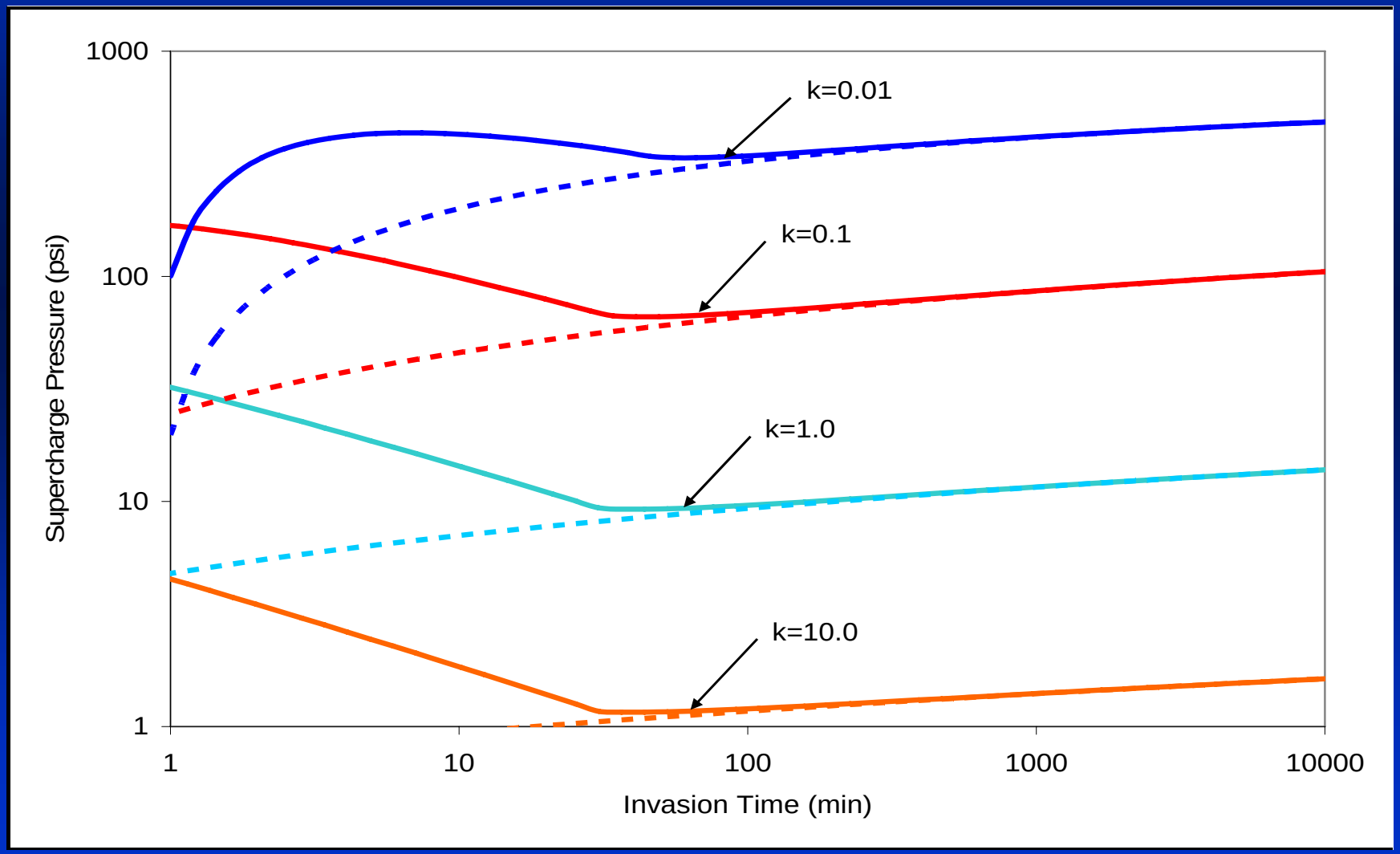
Dynamic Drilling Environment Models From 2005 SPE and SPWLA Papers



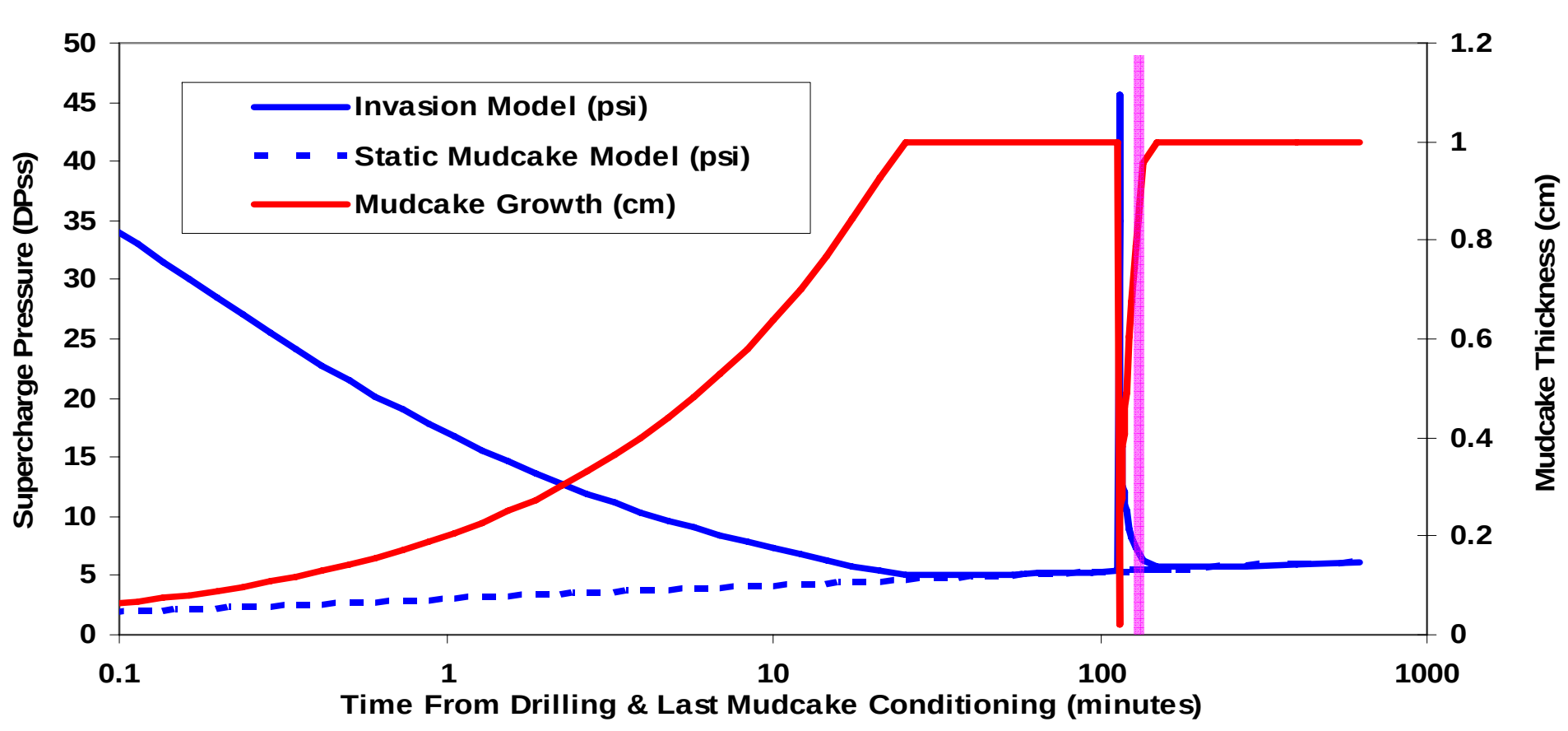
Supercharge Simulation (1 md/cp)



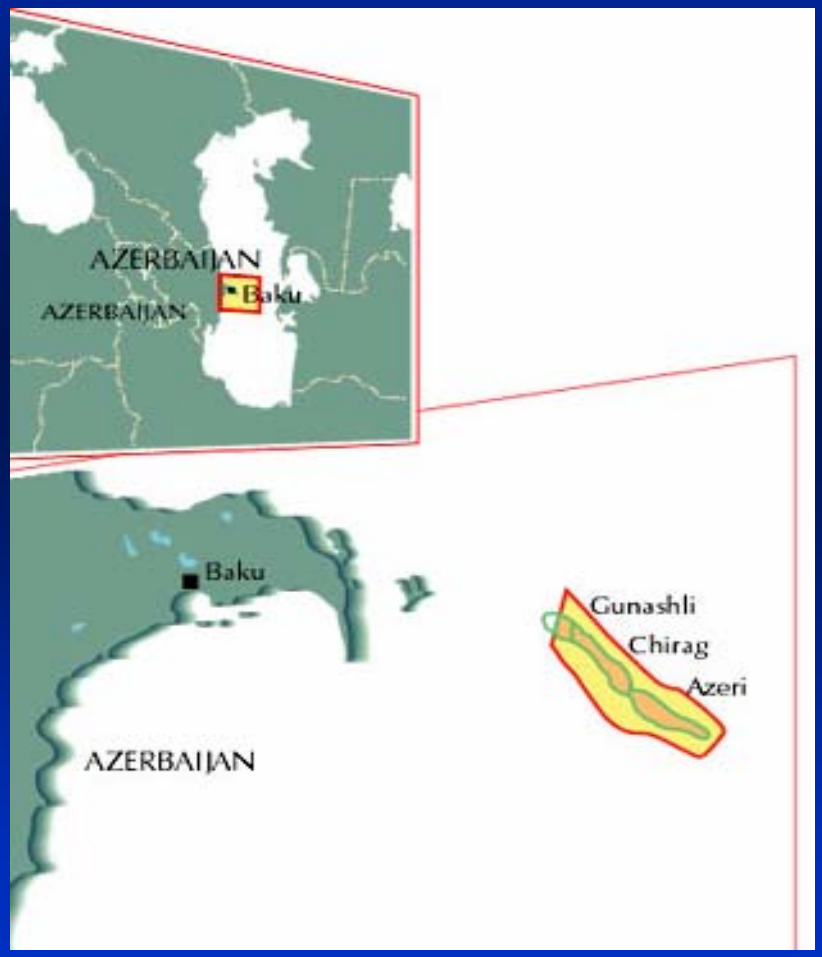
Supercharge Sensitivity to Permeability
1000 psi Overbalance



Supercharge Events – Pipe Rotations
1000 psi Overbalance 10 md/cp



FTWD Experience in Caspian Development (SPE 96719 Joseph Finneran, Clive Green, Haavard Reed, BP)

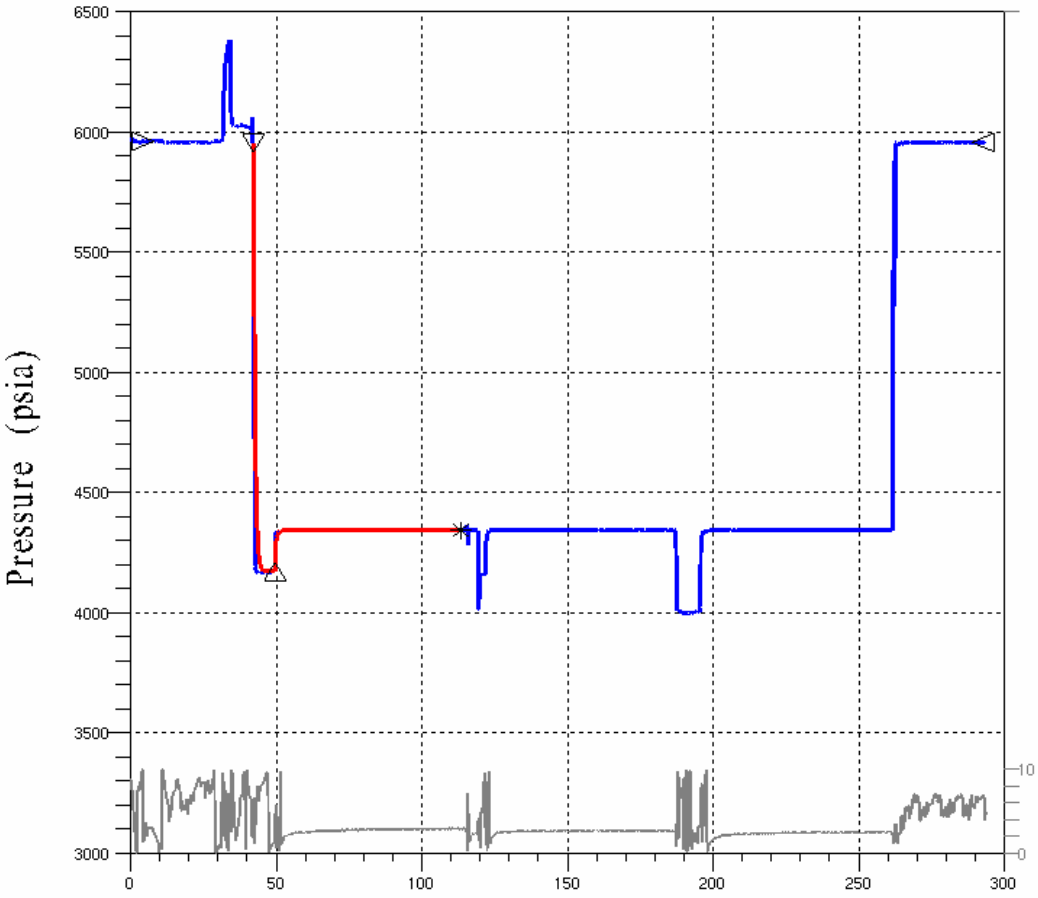


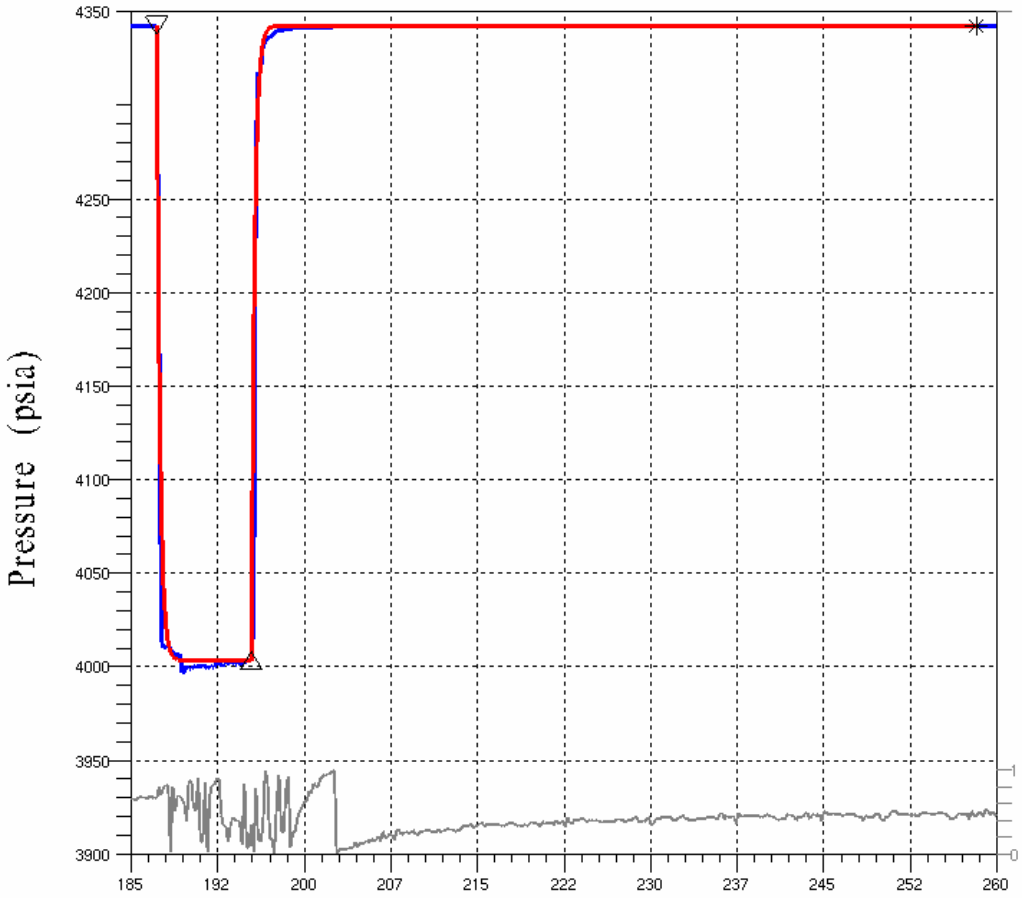
FTWD Experience in Caspian Development (SPE 96719 Joseph Finneran, Clive Green, Haavard Reed, BP)

Table 2--GeoTap history, Caspian Region

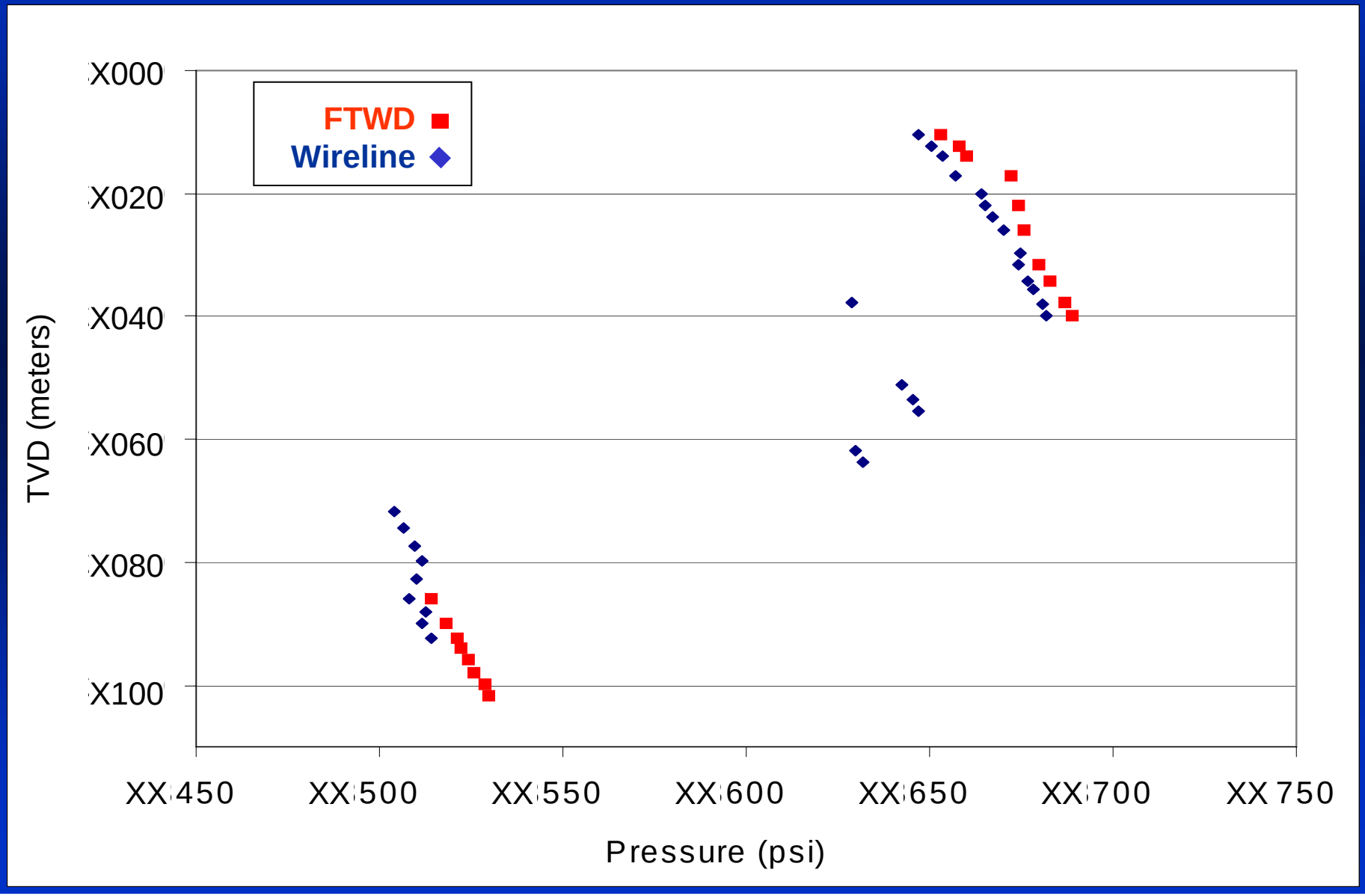
Well	Tool Size (in.)	Hole Size (in.)	Date	Good Tests	Tight Tests	No Seal	Total Tests	Success Rate (%)
1	6 ¾	8 ½	Dec-03	19	0	0	19	100
2	6 ¾	8 ½	Jun-04	16	0	0	16	100
3	8	12 ¼	Oct-04	28	3	4	35	89
4	6 ¾	8 ½	Nov-04	31	0	0	31	100
5	6 ¾	8 ½	Dec-04	28	1	0	29	100
6	6 ¾	8 ½	Apr-05	34	4	3	41	93
7	8	12 ¼	Apr-05	22	8	8	38	79
8	6 ¾	8 ½	May-05	20	0	0	20	100
9	6 ¾	8 ½	Jun-05	18	0	0	18	100
10	6 ¾	8 ½	Jun-05	23	1	0	24	100
		Total		239	17	15	271	95

Stable Pressure Test
Low Supercharge Effect

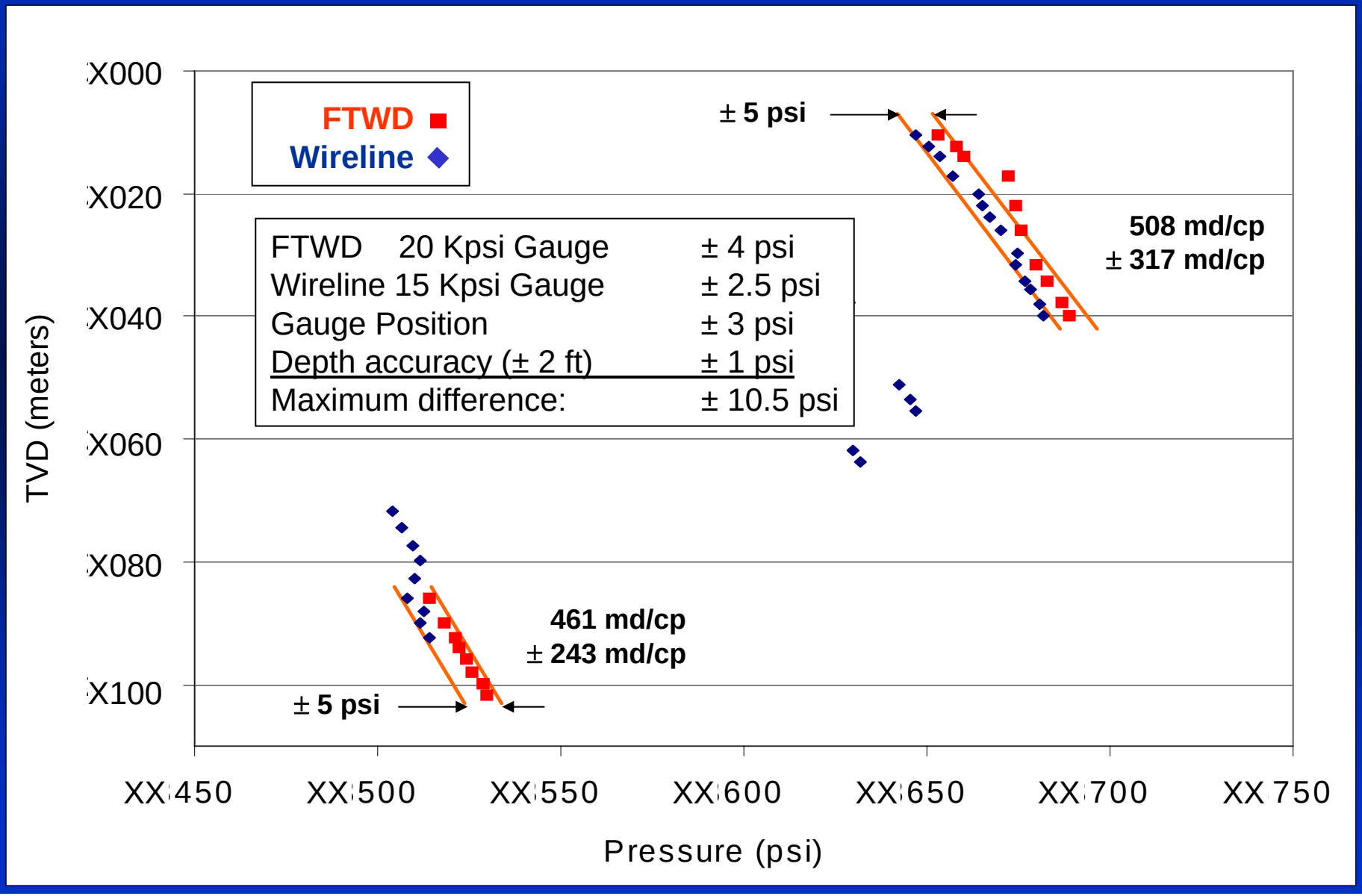




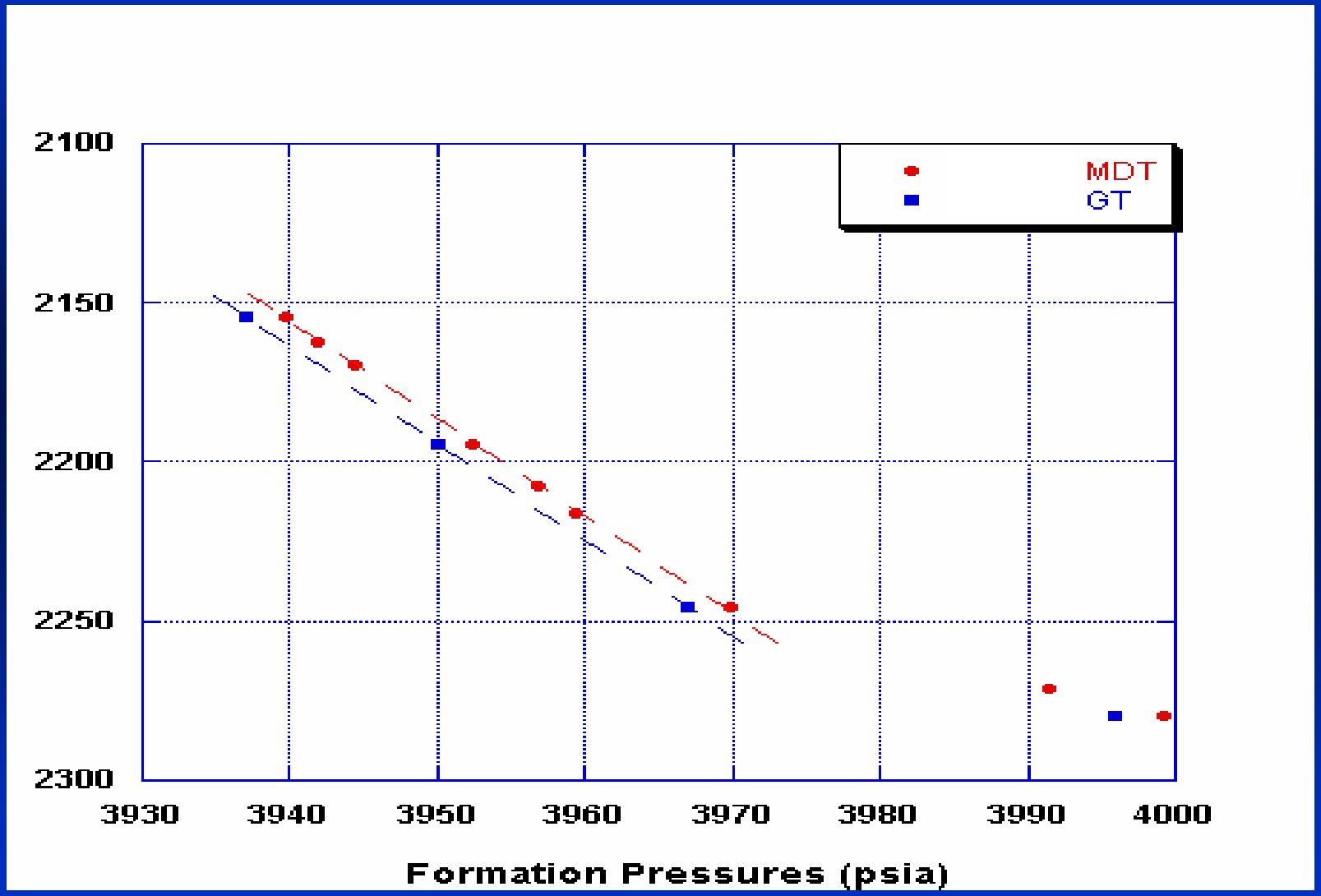
FTWD and Wireline Pressures



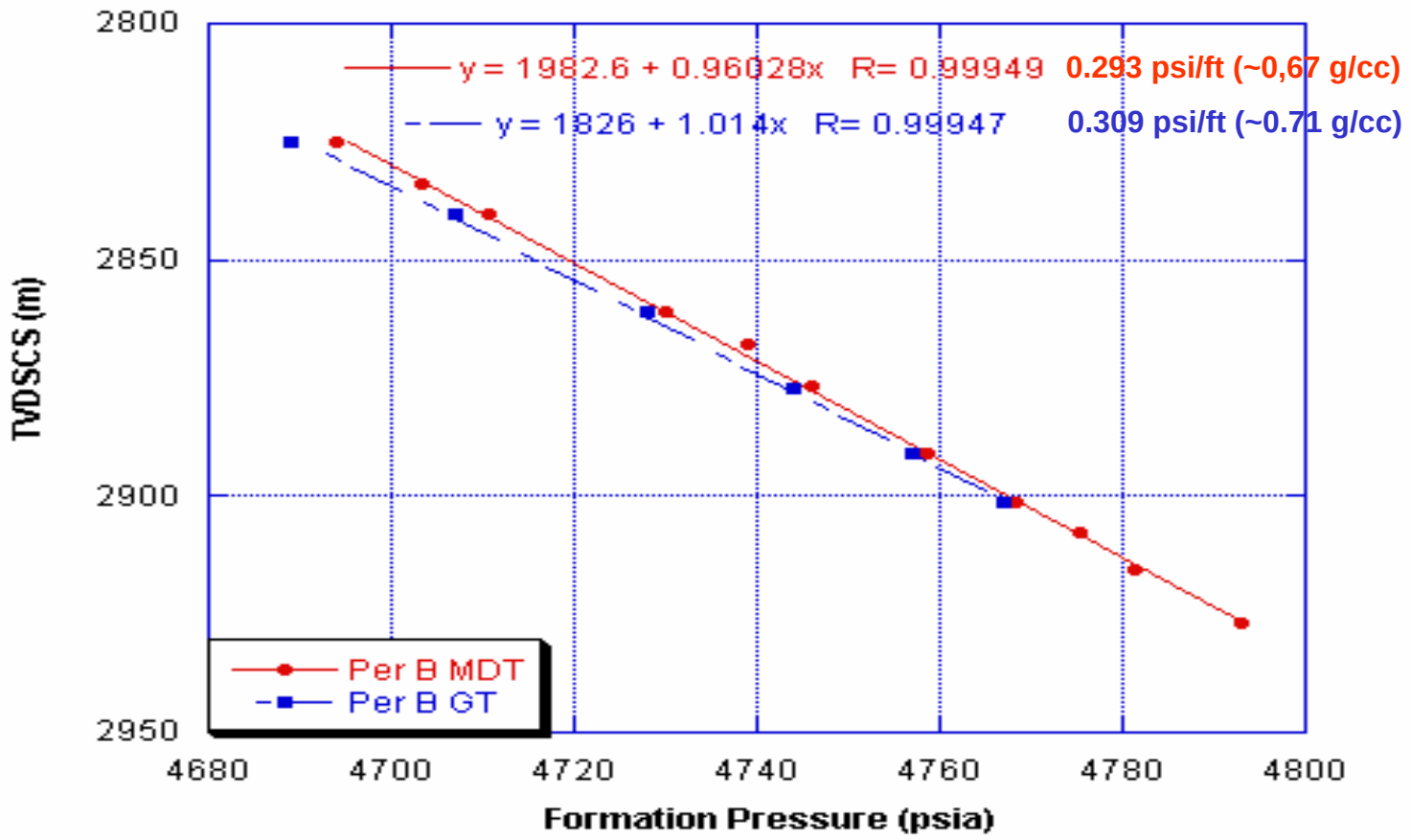
FTWD and Wireline Pressures



FTWD and Wireline Pressure Gradients

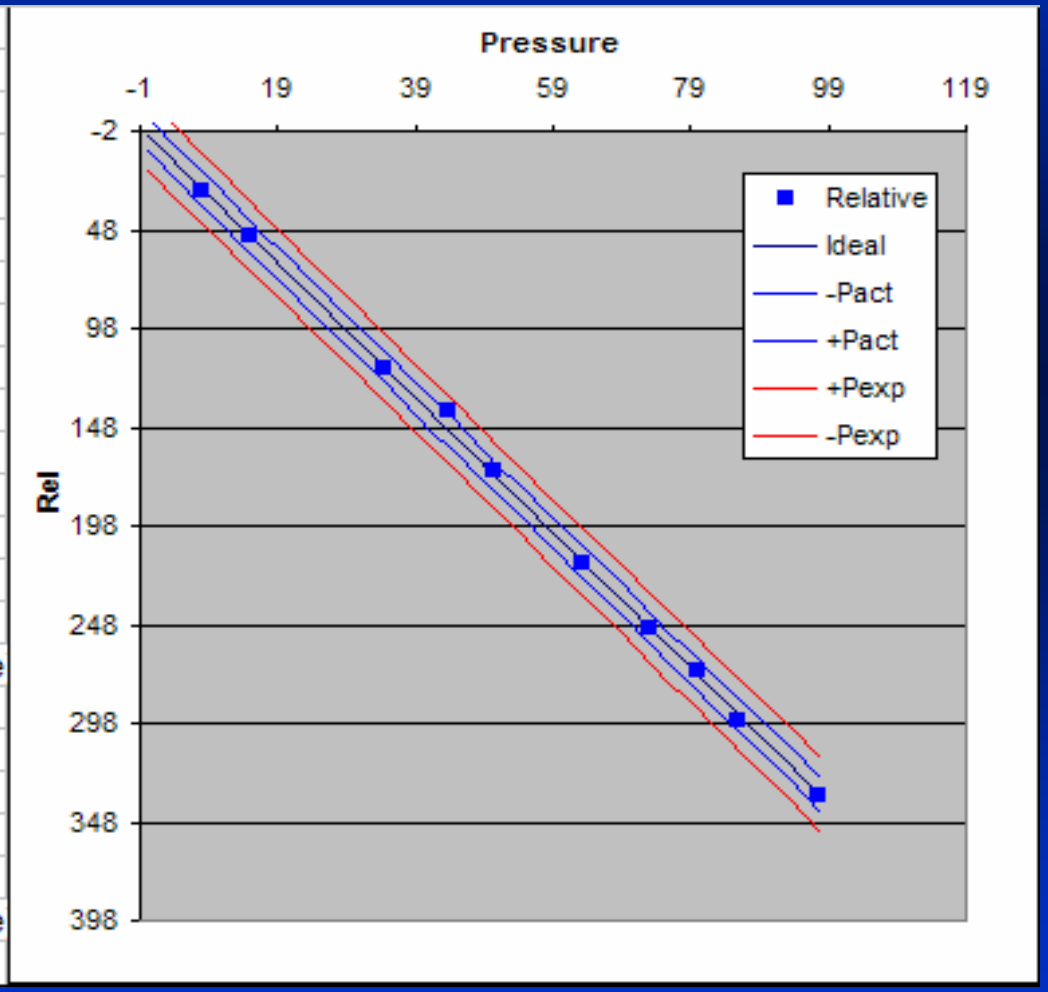


FTWD and Wireline Pressure Gradients



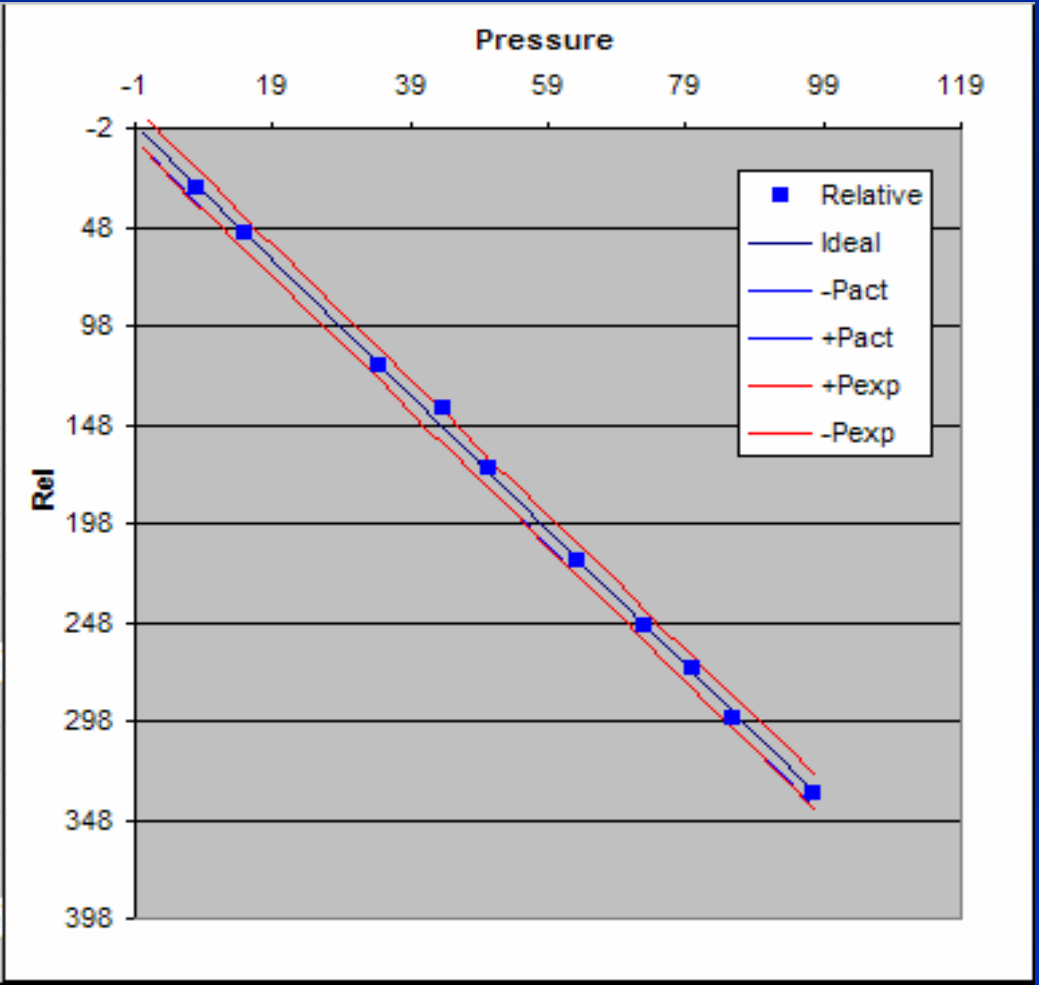
Wireline Gradient Statistics

Inputs	Units	Description
0.5	± psi	Press repeatability, 95% Confidence
5.0%	± %	Depth repeatability, 95% Confidence
16.74	± ft	Depth repeatability, 95% Confidence
334.8097	ft	Interval vertical length
11	#	Number of pressure test points
0.293	psi/ft	Gradient
Results		
33.48	ft	Average Point spacing
909	#	Number of tests analyzed
Expected Deviations (95% Confidence)		
0.014	± psi/ft	Gradient max dev
4.7%	± %	Gradient max dev
0.306	psi/ft	max Gradient
0.279	psi/ft	min Gradient
+/- Pexp	Expected	point scatter range (95% Confidence
Actual Pressure Deviations (95% Confidence)		
0.006	± psi/ft	Gradient max dev
2.1%	± %	Gradient max dev
0.299	psi/ft	max Gradient
0.287	psi/ft	min Gradient
+/- Pact	Actual	point scatter range (95% Confidence
Gradient Analysis Input Data		



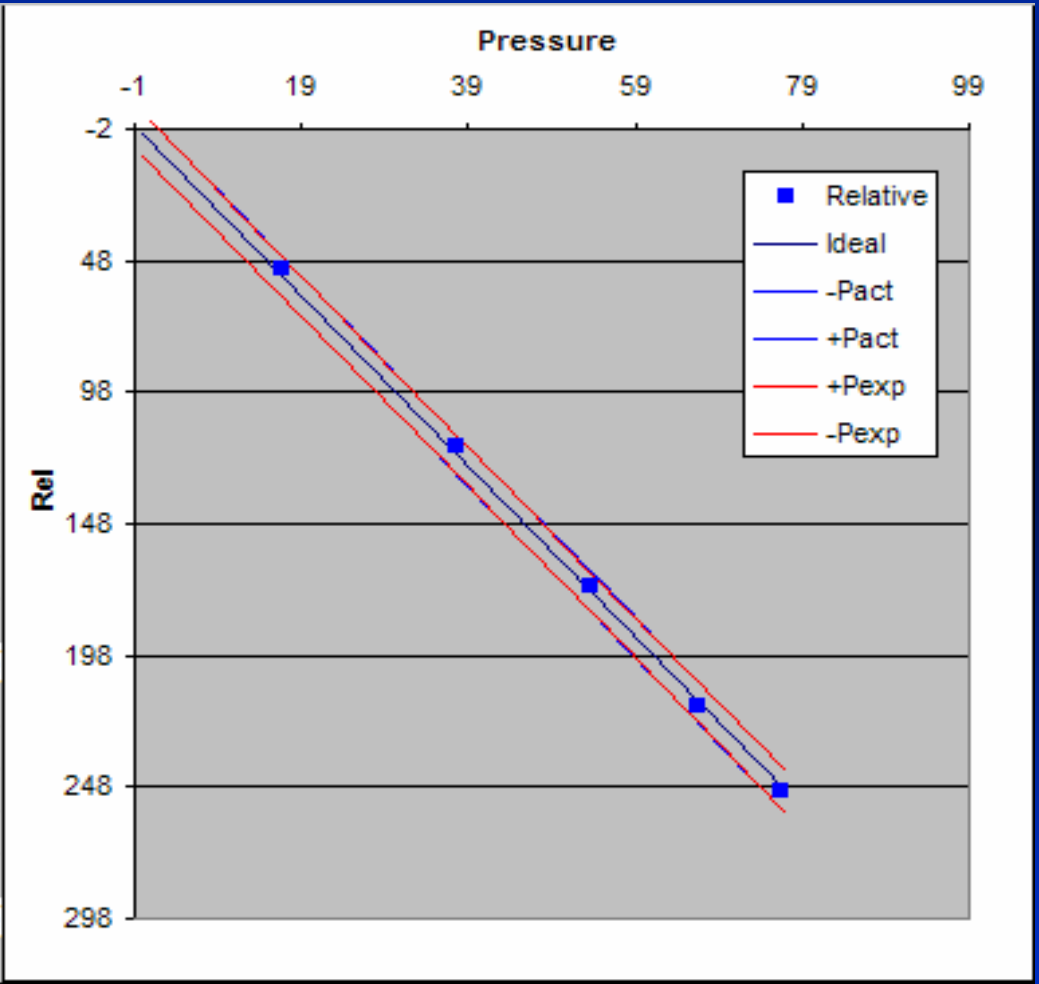
Wireline Gradient Statistics

Inputs	Units	Description
0.5	± psi	Press repeatability, 95% Confidence
2.3%	± %	Depth repeatability, 95% Confidence
7.70	± ft	Depth repeatability, 95% Confidence
334.8097	ft	Interval vertical length
11	#	Number of pressure test points
0.293	psi/ft	Gradient
Results		
33.48	ft	Average Point spacing
909	#	Number of tests analyzed
Expected Deviations (95% Confidence)		
0.007	± psi/ft	Gradient max dev
2.3%	± %	Gradient max dev
0.299	psi/ft	max Gradient
0.286	psi/ft	min Gradient
+/- Pexp	**Expected**	point scatter range (95% Confidence
Actual Pressure Deviations (95% Confidence)		
0.006	± psi/ft	Gradient max dev
2.1%	± %	Gradient max dev
0.299	psi/ft	max Gradient
0.287	psi/ft	min Gradient
+/- Pact	Actual	point scatter range (95% Confidence
Gradient Analysis Input Data		



FTWD Gradient Statistics

Inputs	Units	Description
0.5	± psi	Press repeatability, 95% Confidence
2.8%	± %	Depth repeatability, 95% Confidence
7.00	± ft	Depth repeatability, 95% Confidence
250	ft	Interval vertical length
6	#	Number of pressure test points
0.309	psi/ft	Gradient
Results		
50.00	ft	Average Point spacing
1666	#	Number of tests analyzed
Expected Deviations (95% Confidence)		
0.011	± psi/ft	Gradient max dev
3.4%	± %	Gradient max dev
0.320	psi/ft	max Gradient
0.299	psi/ft	min Gradient
+/- Pexp	**Expected**	point scatter range (95% Confidence
Actual Pressure Deviations (95% Confidence)		
0.010	± psi/ft	Gradient max dev
3.2%	± %	Gradient max dev
0.319	psi/ft	max Gradient
0.299	psi/ft	min Gradient
+/- Pact	Actual	point scatter range (95% Confidence
Gradient Analysis Input Data		

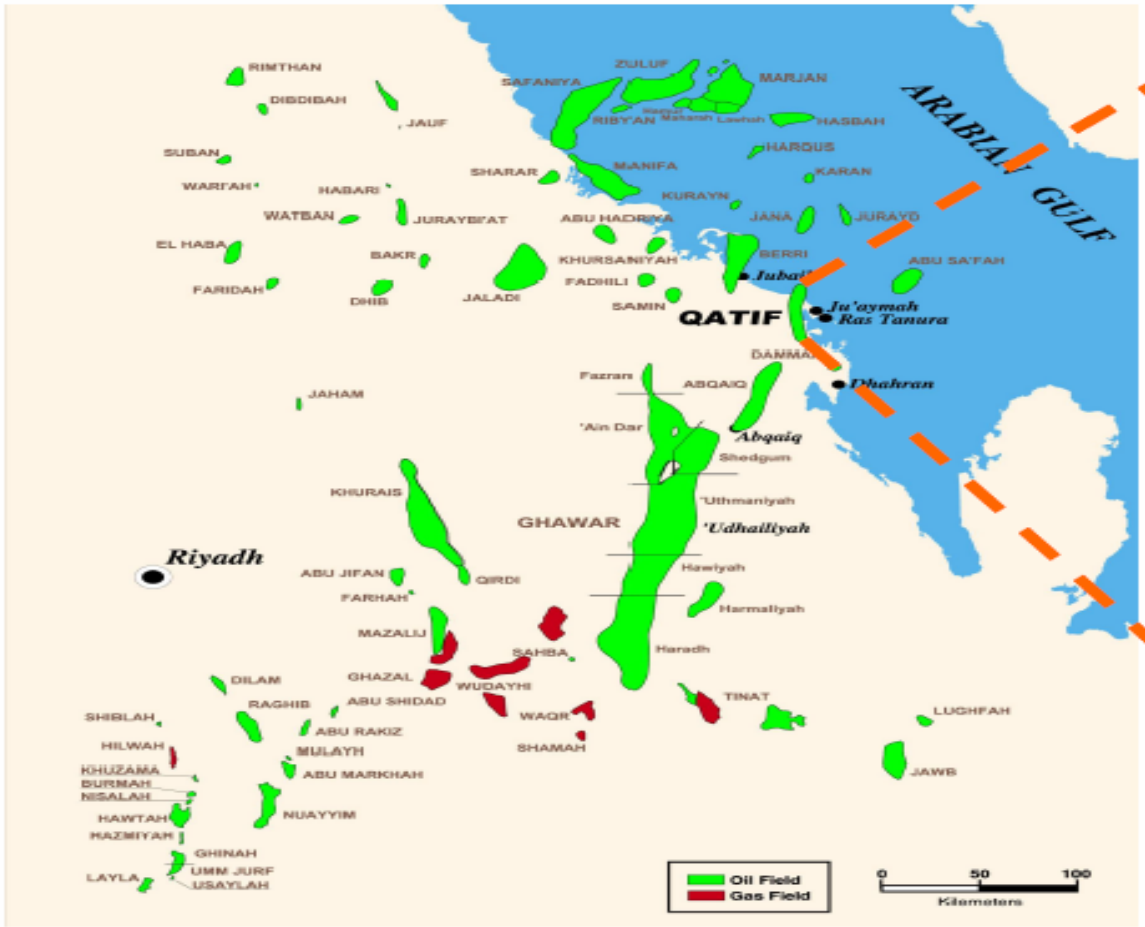


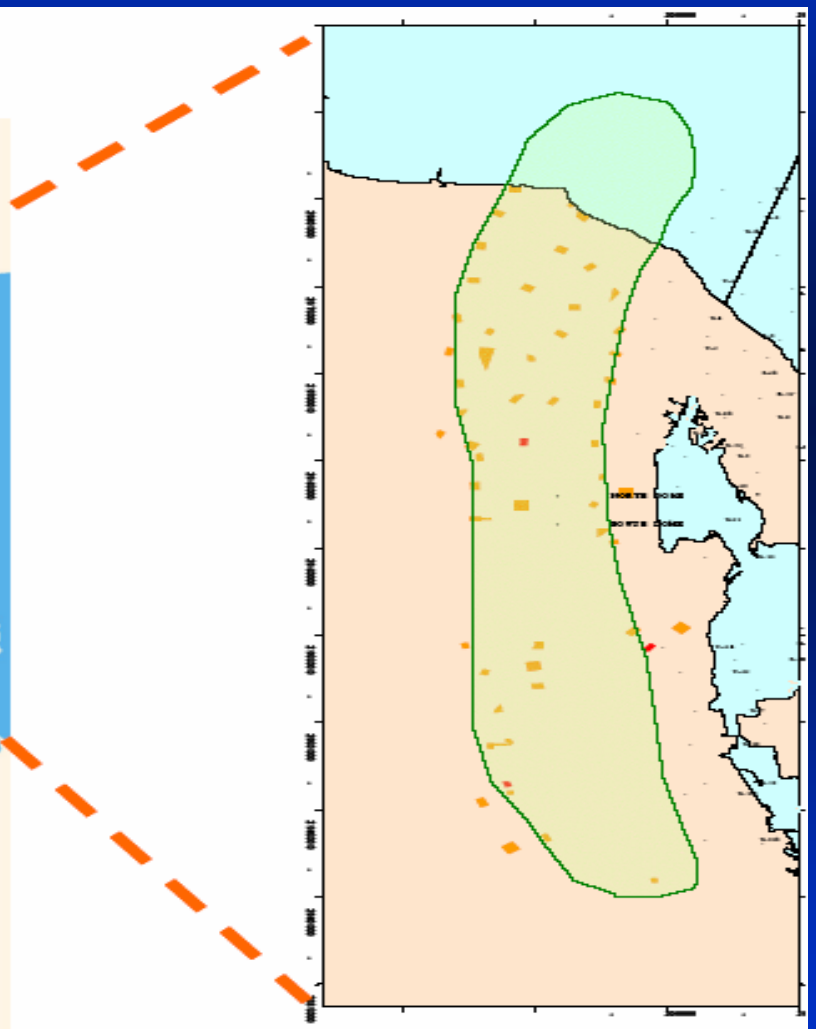
FTWD vs. Wireline Gradients

Wireline Gradients									
		Interval TVD ft			Gradient	Gradient	Gradient	Depth	Depth
Gauge	Analysis	min	max	ft	psi/ft	± psi/ft	± %	± ft	± %
QP1	QP1-1 Main	8515.95	8559.76	43.81	0.262	0.008	3.21%	1.45	3.31%
QP1	QP1-2 Sidetrack	8794.00	8862.39	68.39	0.268	0.005	1.99%	1.65	2.41%
QP2	QP2-3 Main	8516.27	8658.89	142.62	0.282	0.002	0.75%	1.3	0.91%
QP2	QP2-2 Sidetrack	8792.79	8843.77	50.98	0.272	0.007	2.76%	1.6	3.14%
QP3	QP3-1 Main	8517.58	8561.36	43.78	0.260	0.007	2.67%	1.25	2.86%
QP3	QP3-2 Sidetrack	8796.10	8860.86	64.76	0.273	0.006	2.33%	1.9	2.93%
SP1	SP1-1 Main	8517.58	8561.36	43.78	0.262	0.008	3.20%	1.4	3.20%
SP1	SP1-2 Sidetrack	8796.100	8864.490	68.39	0.273	0.004	2.37%	1.250	1.83%
	Averages				0.269	0.006	2.41%		2.57%

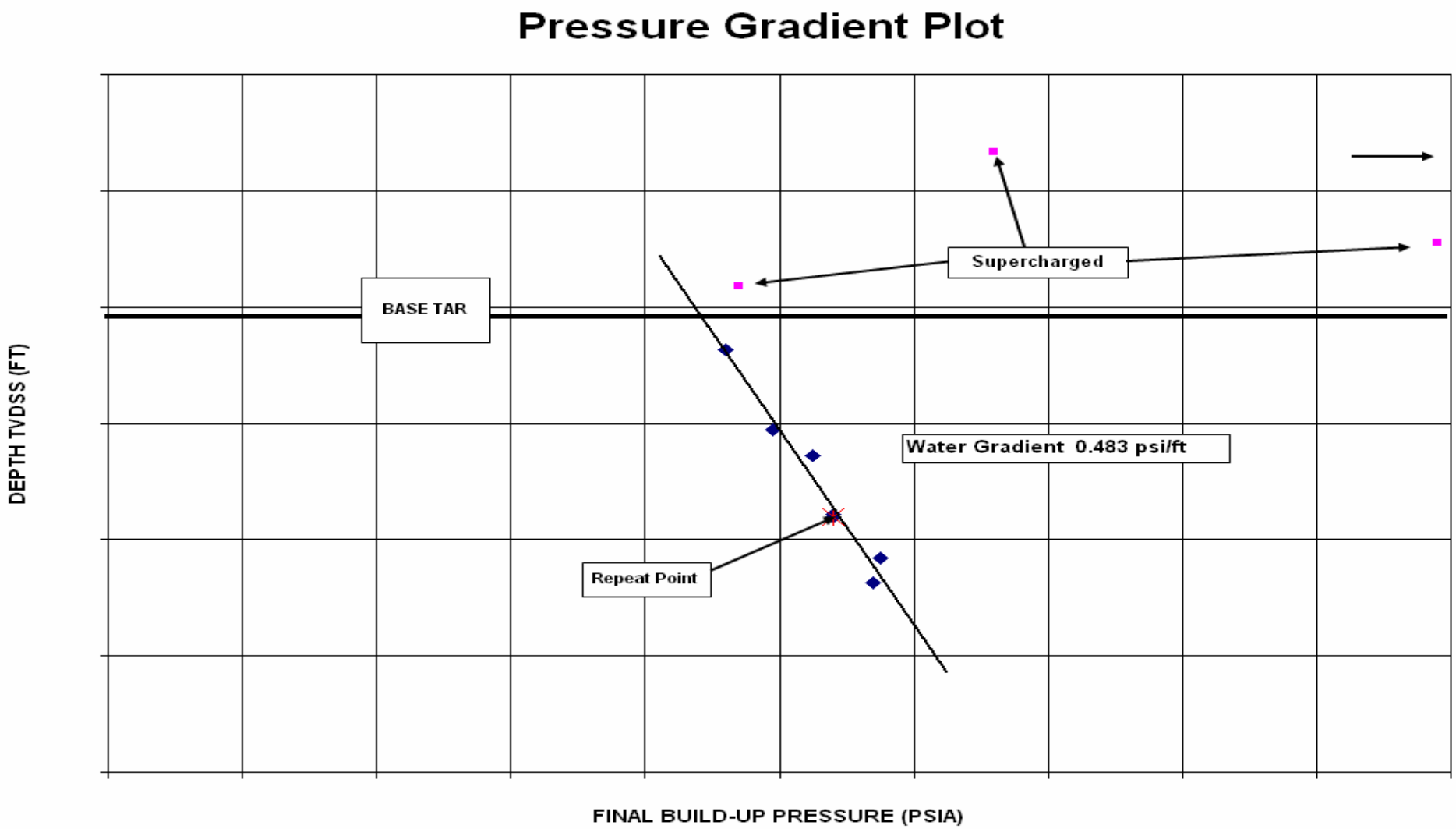
FTWD Vs. Wireline									
		Interval TVD ft			Gradient	Gradient	Gradient	Depth	Depth
Gauge	Analysis	min	max	ft	psi/ft	± psi/ft	± %	± ft	± %
QG	GeoTap	9340.55	9590.55	250.00	0.309	0.010	3.18%	7.3	2.92%
QG	MDT	9340.55	9675.36	334.81	0.293	0.006	2.08%	7.8	2.33%
	Averages					0.008	2.63%		2.62%

Qatif Field
Eastern Province of Saudi Arabia

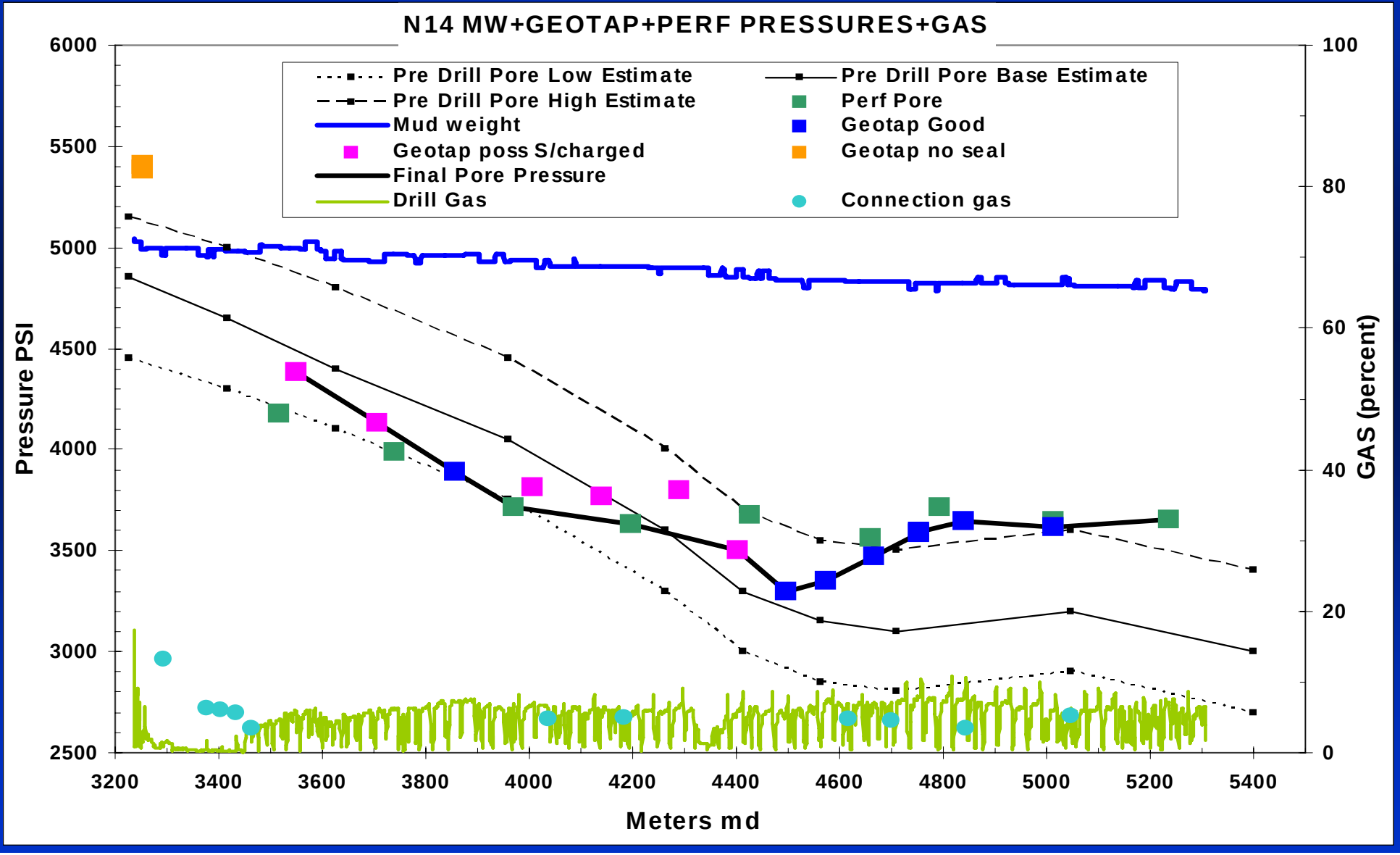




Using Supercharge to ID Tar

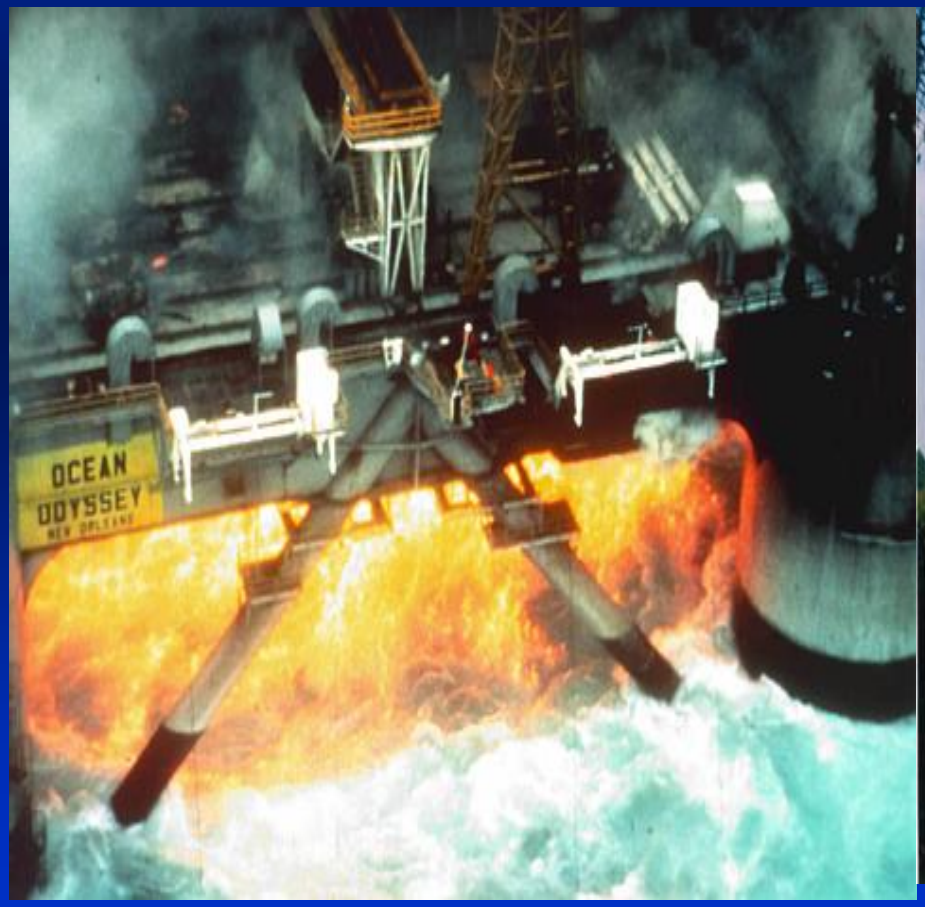


Optimizing Drilling & Completions (SPE/IADC 92712 - 25 February 2005)



Drilling Challenges
Well Control and Optimization

FTWD offers additional opportunities for well control, optimized drilling and completions that wireline can't.



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Optimize Drilling Using Remote Real-Time Monitoring

At the Wellsite

Wellsite Engineer monitors drilling, collects data, LWD, mud, updates prediction and sends information to Pore Pressure Team.

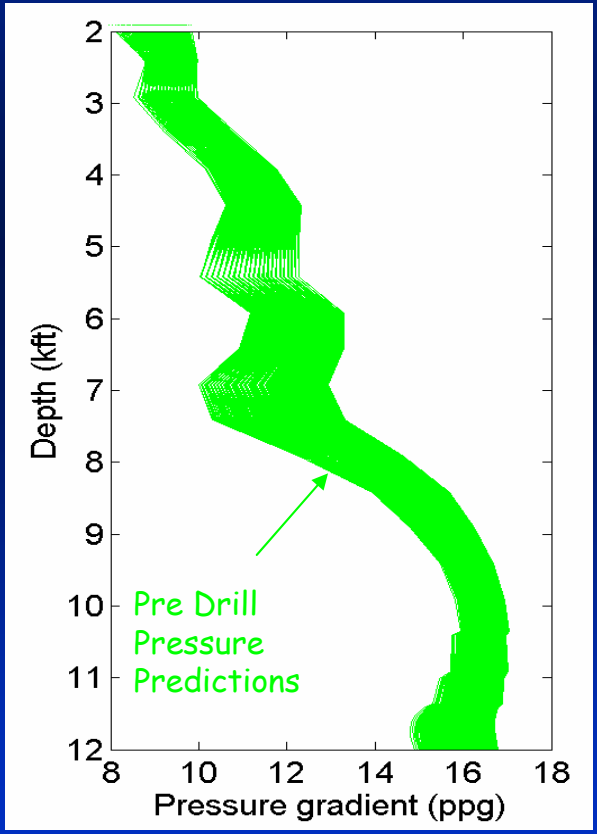
LWD

Resistivity While Drilling

MWD

FPWD

Sonic While Drilling



At the Remote Support Center

Pore Pressure Team receives information from the Wellsite Engineer , updates the pore pressure prediction, and sends results to the rig.

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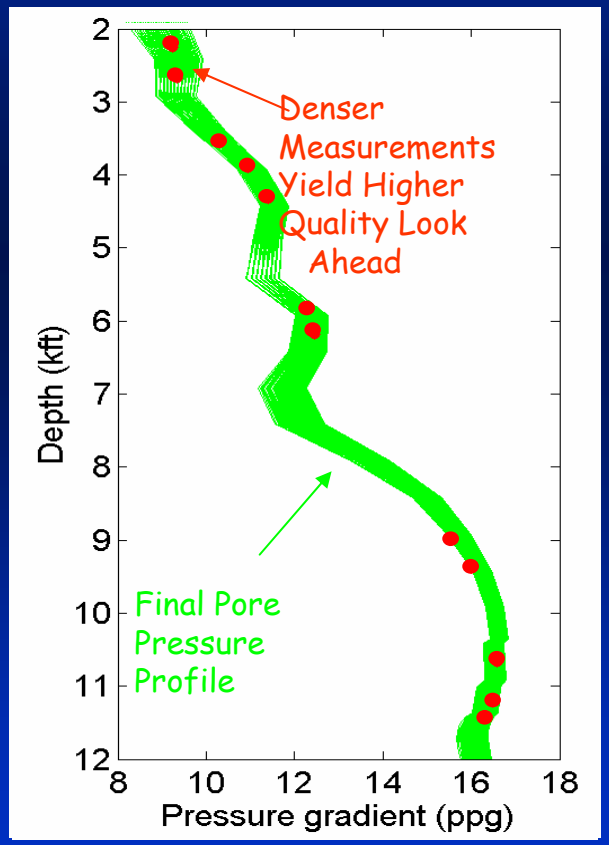

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Well Economics

Value to Client

6 NPT Days Eliminated	$900k
Wireline Delayed Until EOW	$150k
Eliminated 5” Casing	$500k
Slimhole Drilling Costs Savings	>$500k
Less Additional LWD Costs	(360k)
Savings to client	>$1.7M

Drilling well for less cost without intermediate casing

FTWD Summary

- Introduced in 2001-2003
- Initially used where WFT could not test
- Has replaced WFT for pressures in many cases
- Pressures and gradients are equivalent to WFT
- In conditions where WFT perform well FTWD pressures and gradients are comparable
- Concerns still exist about pressure stability
- Drilling applications now driving adaptation
- Will sampling be next?