Measuring a Reservoir from the Inside Out Using Inplace Elastic Energy Reserves*

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Abstract

Reservoir boundaries can be measured from the interior using wave mechanics and elastic energy contributions. Capillary networks begin to form and grow from a wellbore at the time the well is opened for production. A wall of initiating capillary pressure becomes the initial boundary for the cone of influence. As this capillary network grows it adds active contributing mass to the cone of influence. As sealing boundaries are encountered, singular changes occur in the cone of influence around the wellbore that can be decoded into pieces of boundary images. With further refinement in an energy model these can be assembled into a blind map that can bear a striking resemblance to seismic images. This is an independent means for verifying reservoir size, shape and volume. It is often used as a means for calibrating seismic processing parameters. The fundamentals will be presented along with examples of "blind energy mapping." Seismic measures a reservoir from the topside down with sound waves. This is a methodology that produces images using wave mechanics from the inside out.

Measuring a Reservoir from the Inside Out Using In-place Elastic Energy Reserves

AAPG Workshop September 2009

Houston, Texas

Fred L. Goldsberry, SPEE

President, WAVEX®, Inc.

A Pressure Transient Cone of Influence is Segmented by *Capillary Shockwaves.*

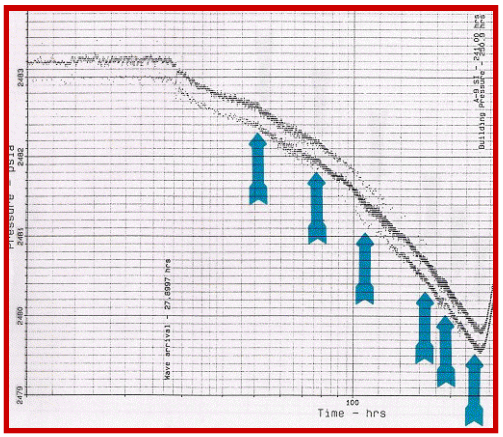
These Waves Contain Decodable Information about the Boundaries Encountered by the Cone. They are Repeatable.

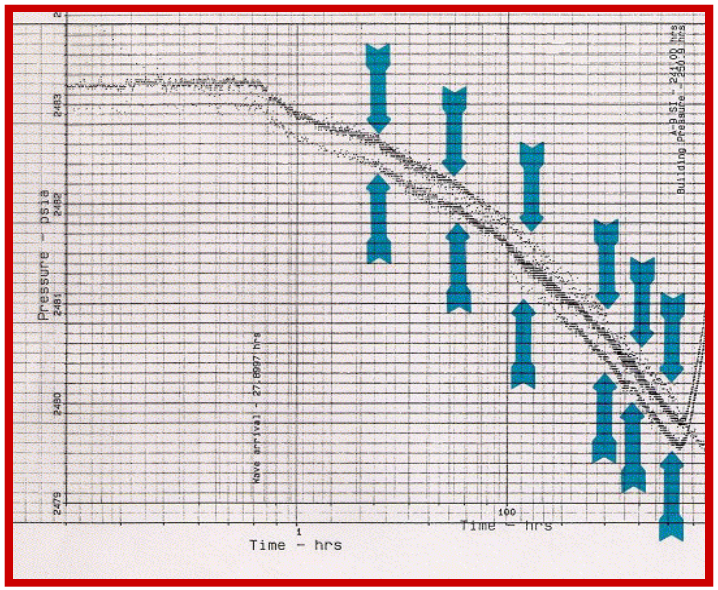
Observation Well — **2000 Feet** — **Producer**

Overlaying the Plots:

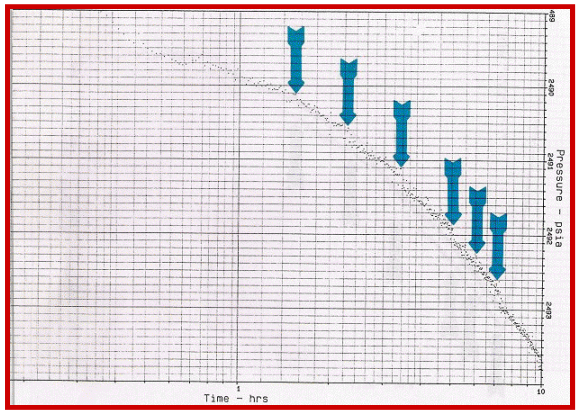
The Steps and Slopes Replicate!

Static Observation Well

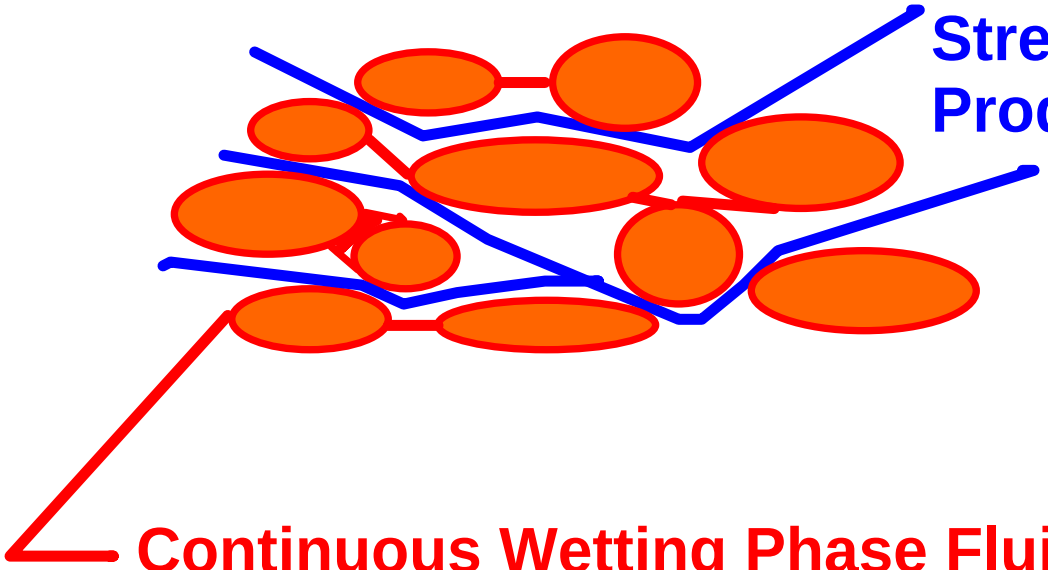




Buildup in the Producer

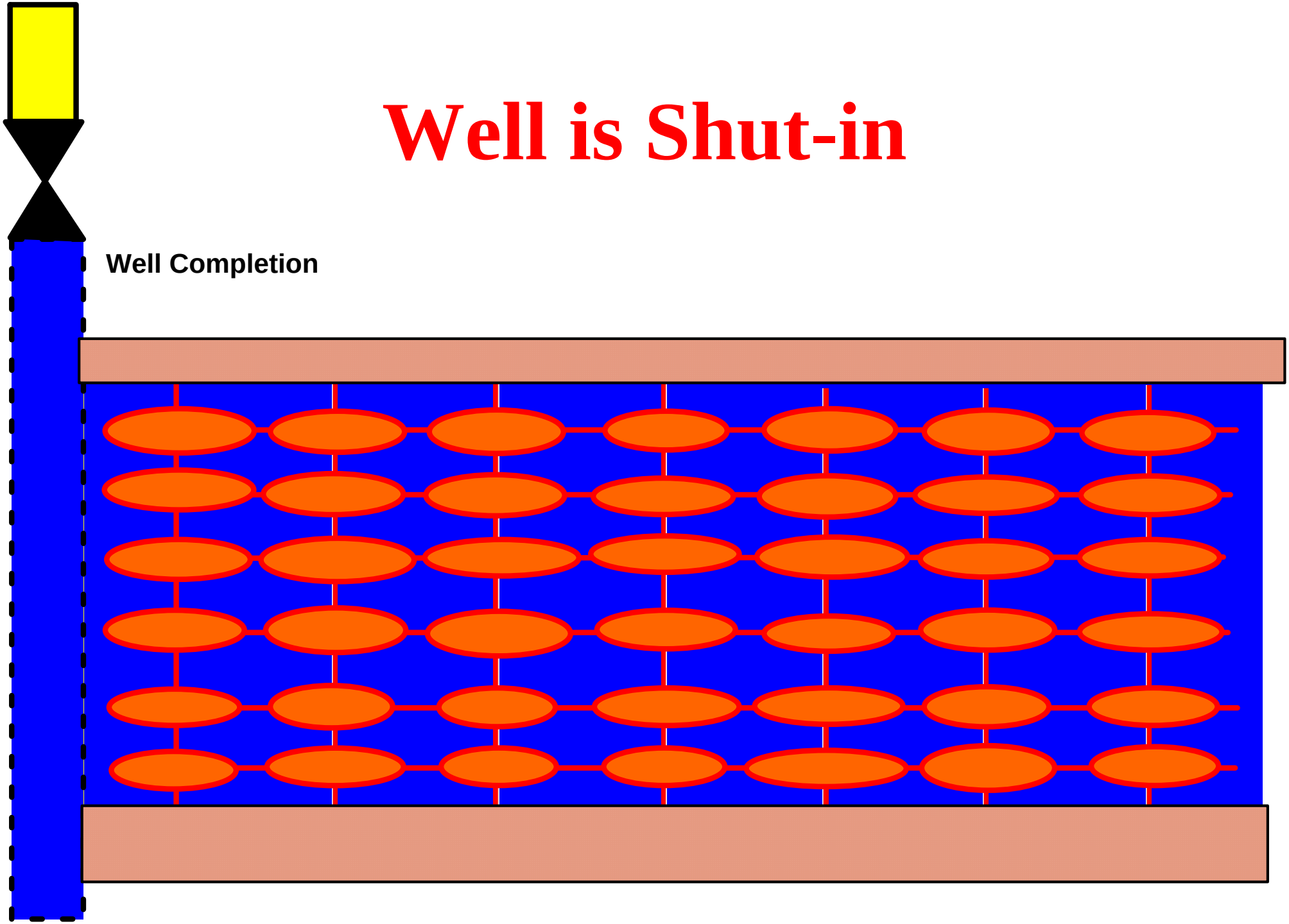


Capillary Paths Stabilize as Entry Pressure Is Overcome

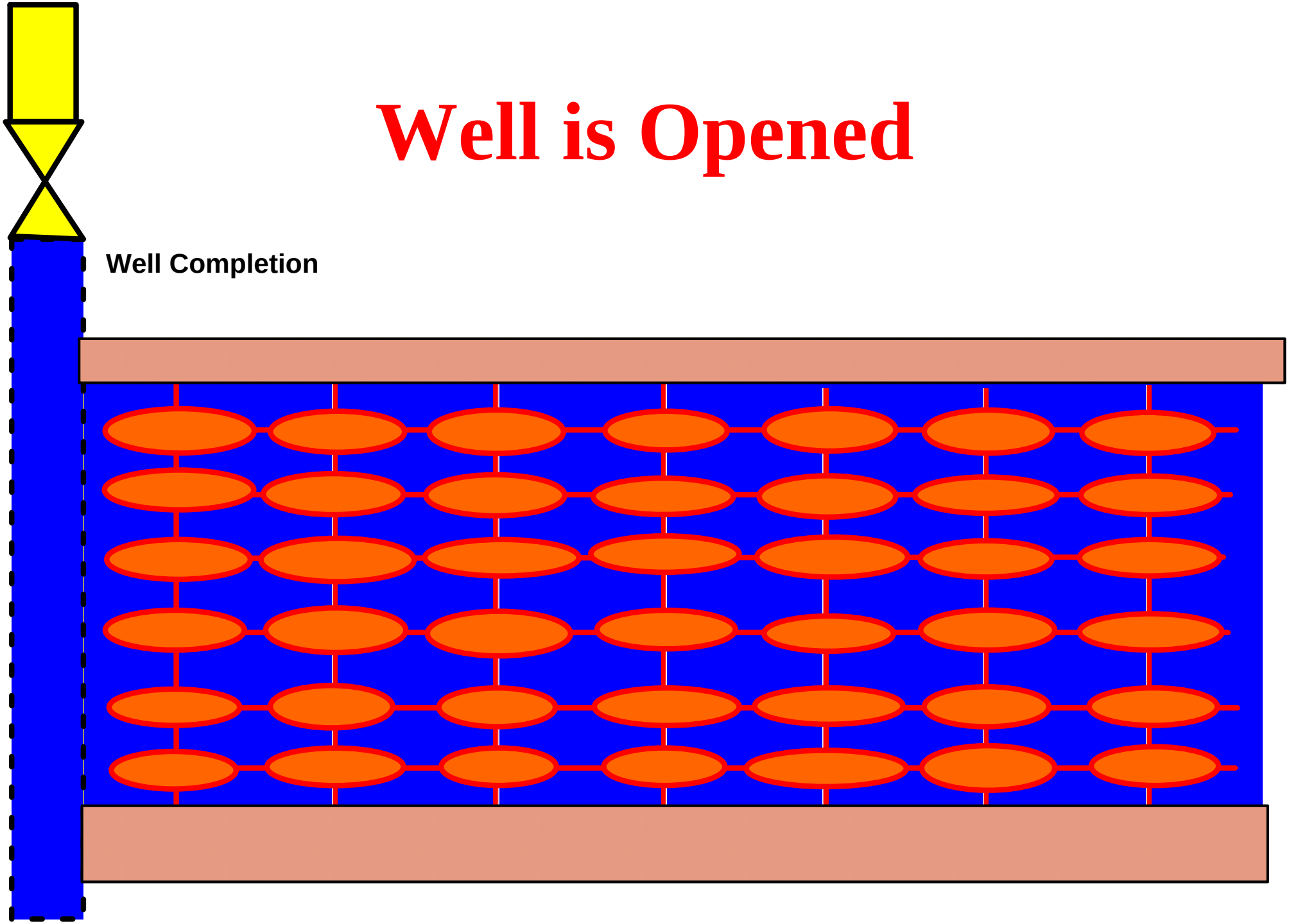


To Break the Fluid Film in Order to Allow a Change in Flow Path, Requires a Finite Initiating Differential Pressure Across any Pore Throat.

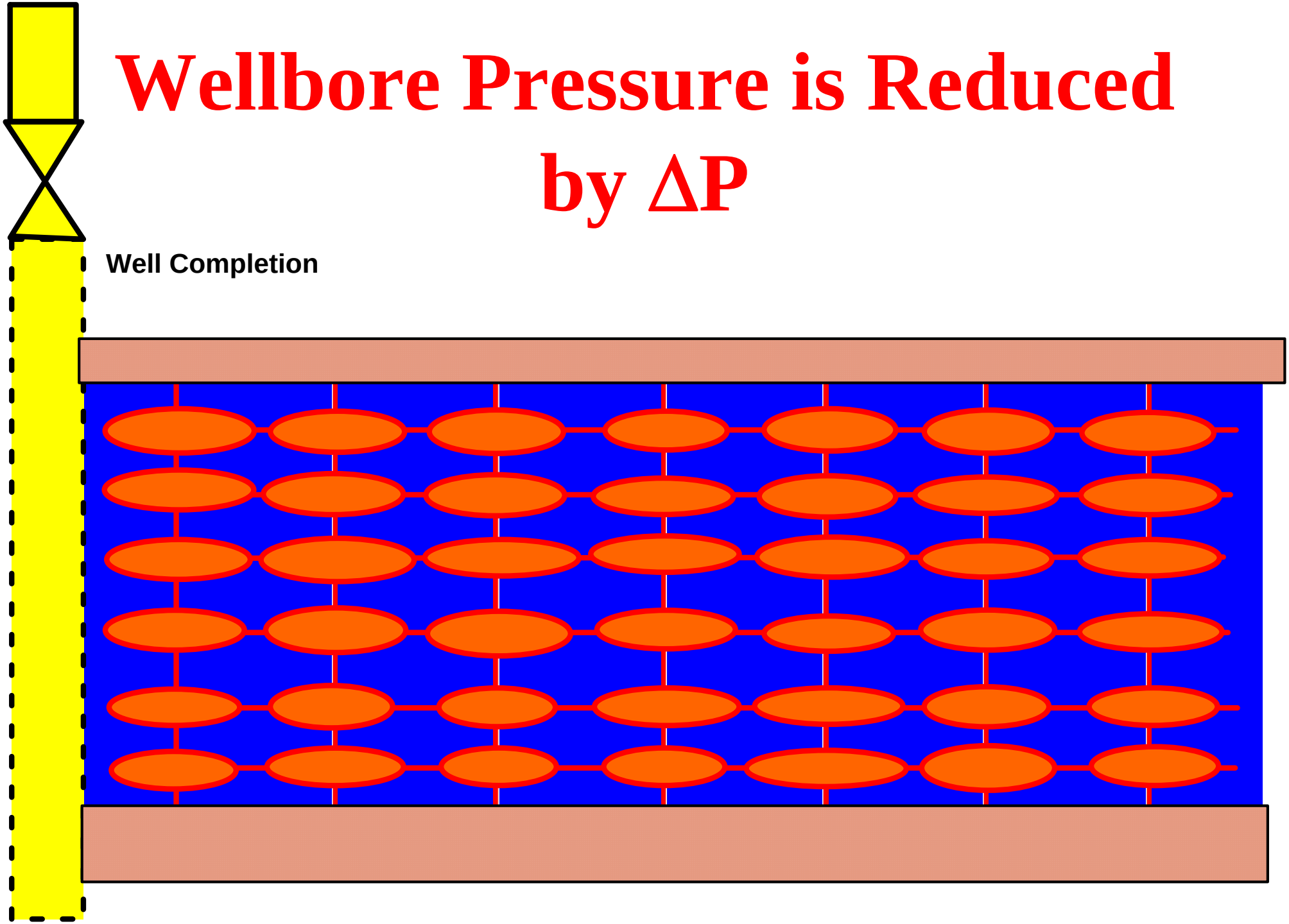
Well is Shut-in



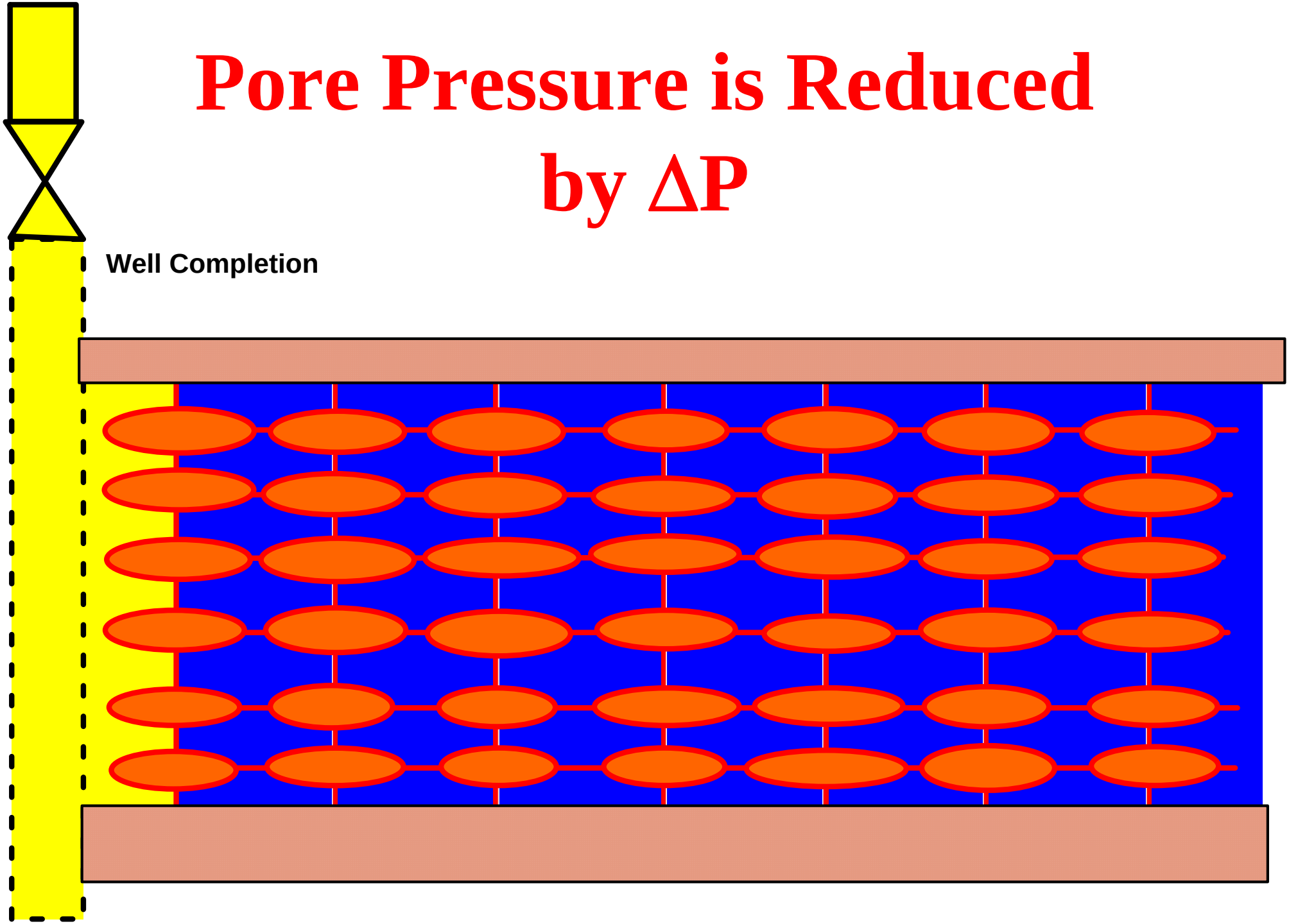
Well is Opened



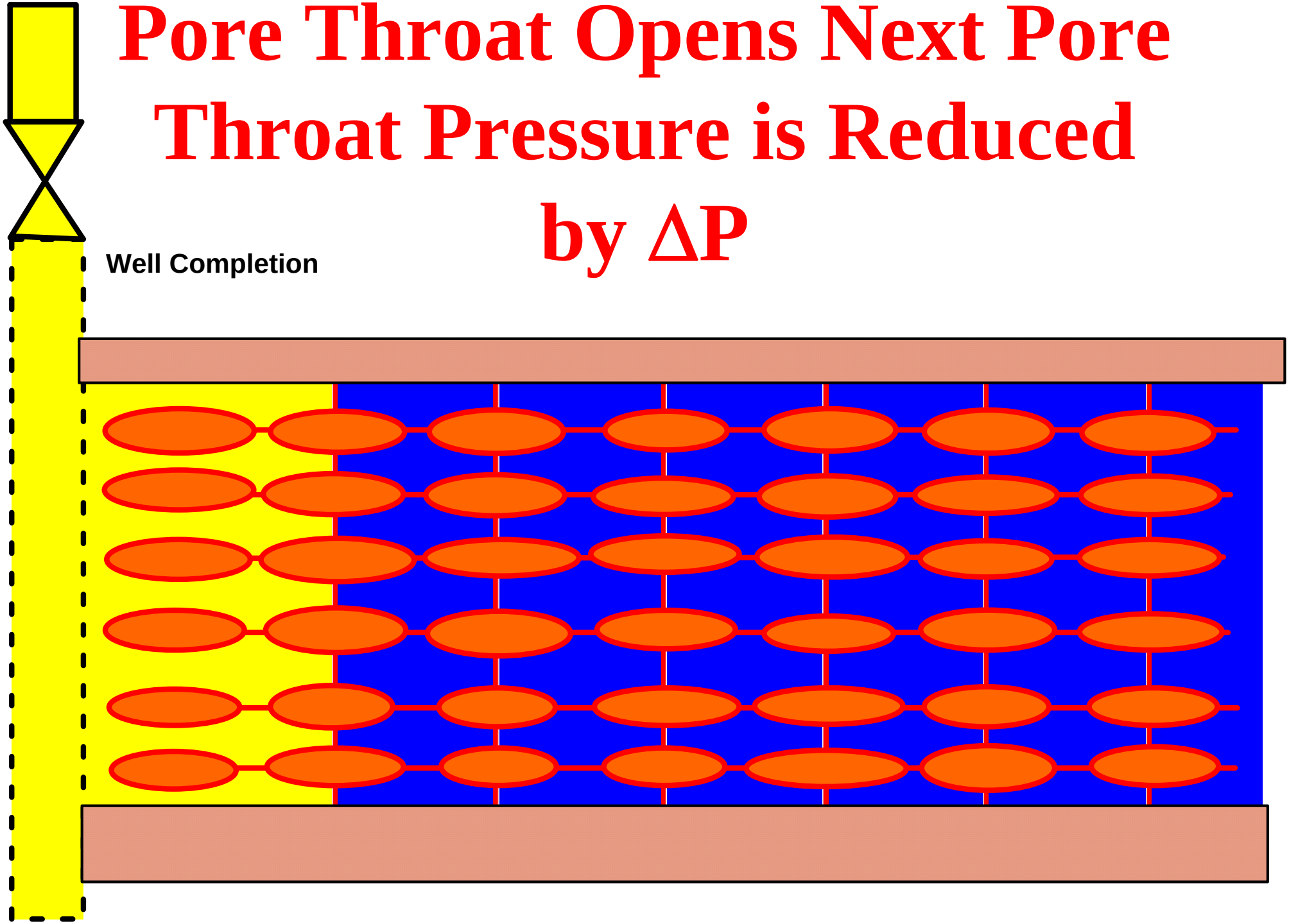
Wellbore Pressure is Reduced by ΔP



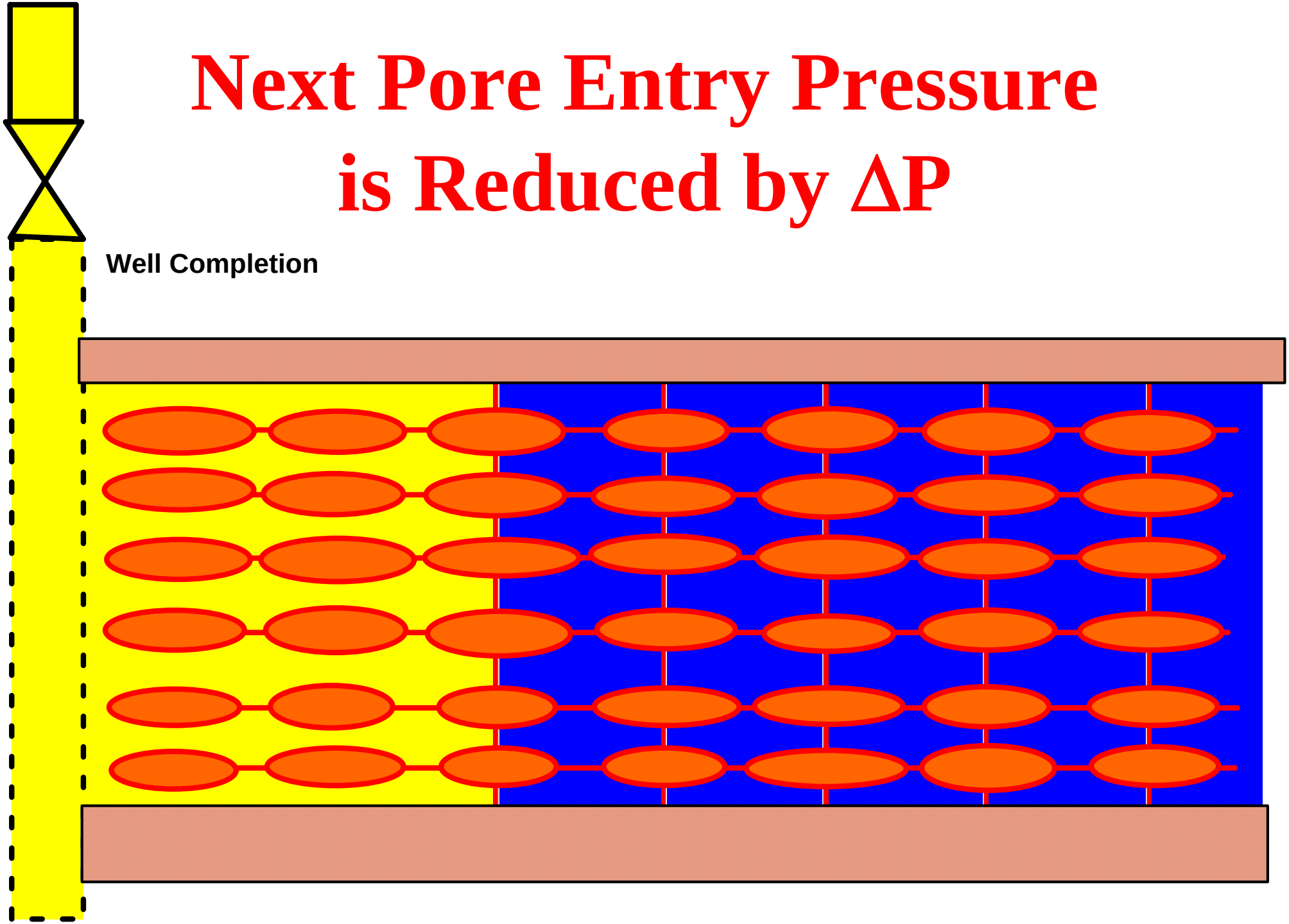
Pore Pressure is Reduced by ΔP



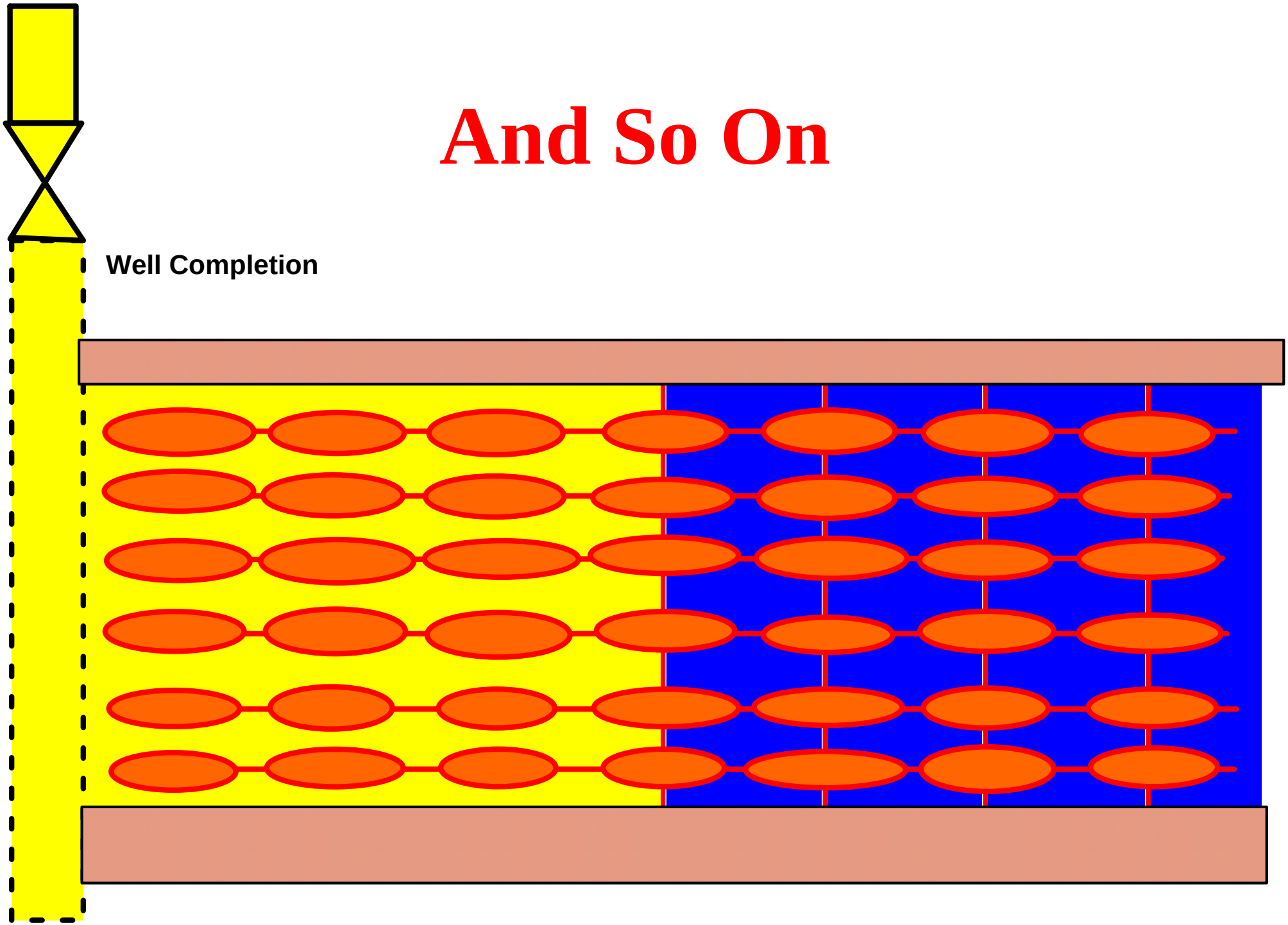
Pore Throat Opens Next Pore Throat Pressure is Reduced by ΔP



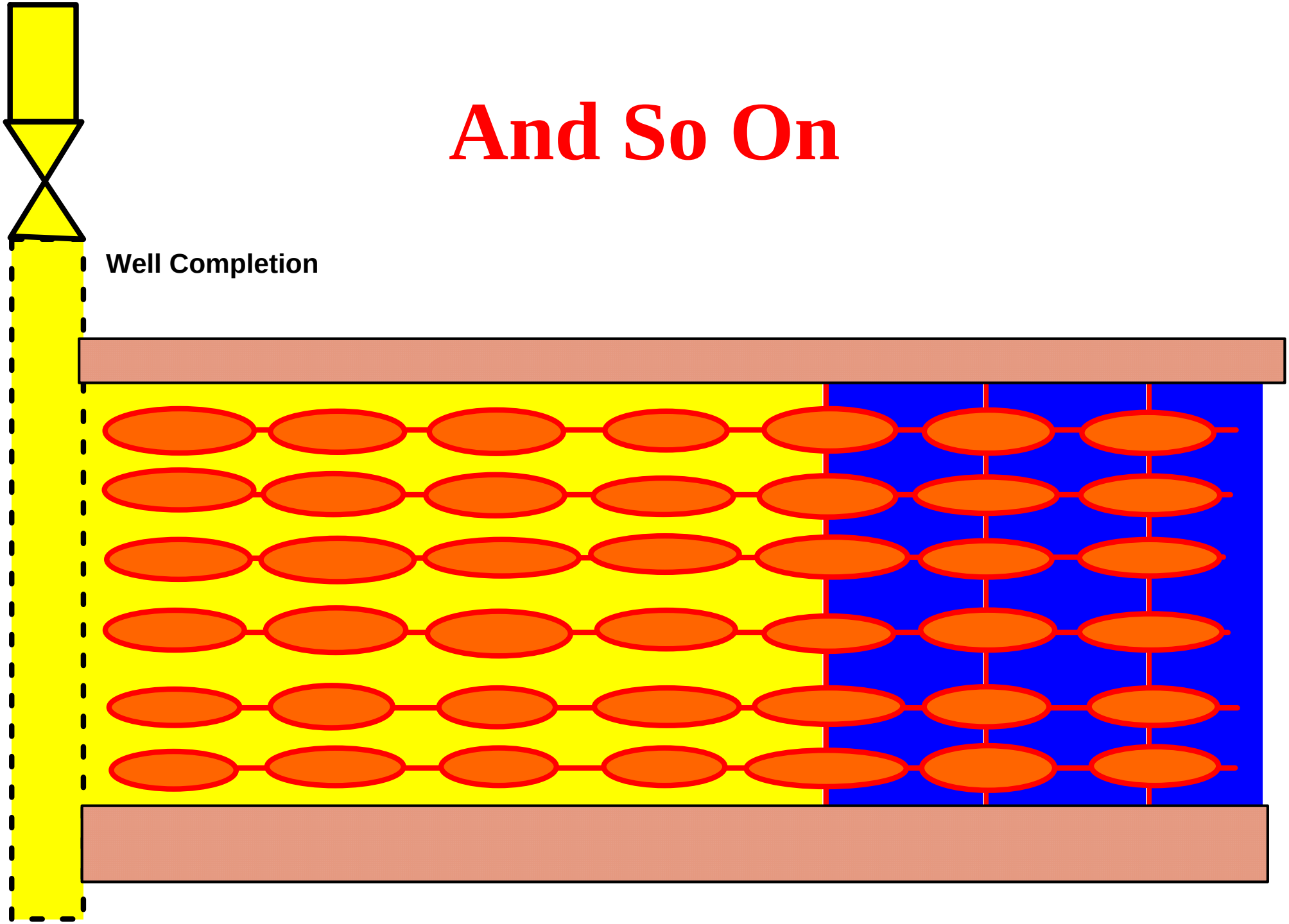
Next Pore Entry Pressure is Reduced by ΔP



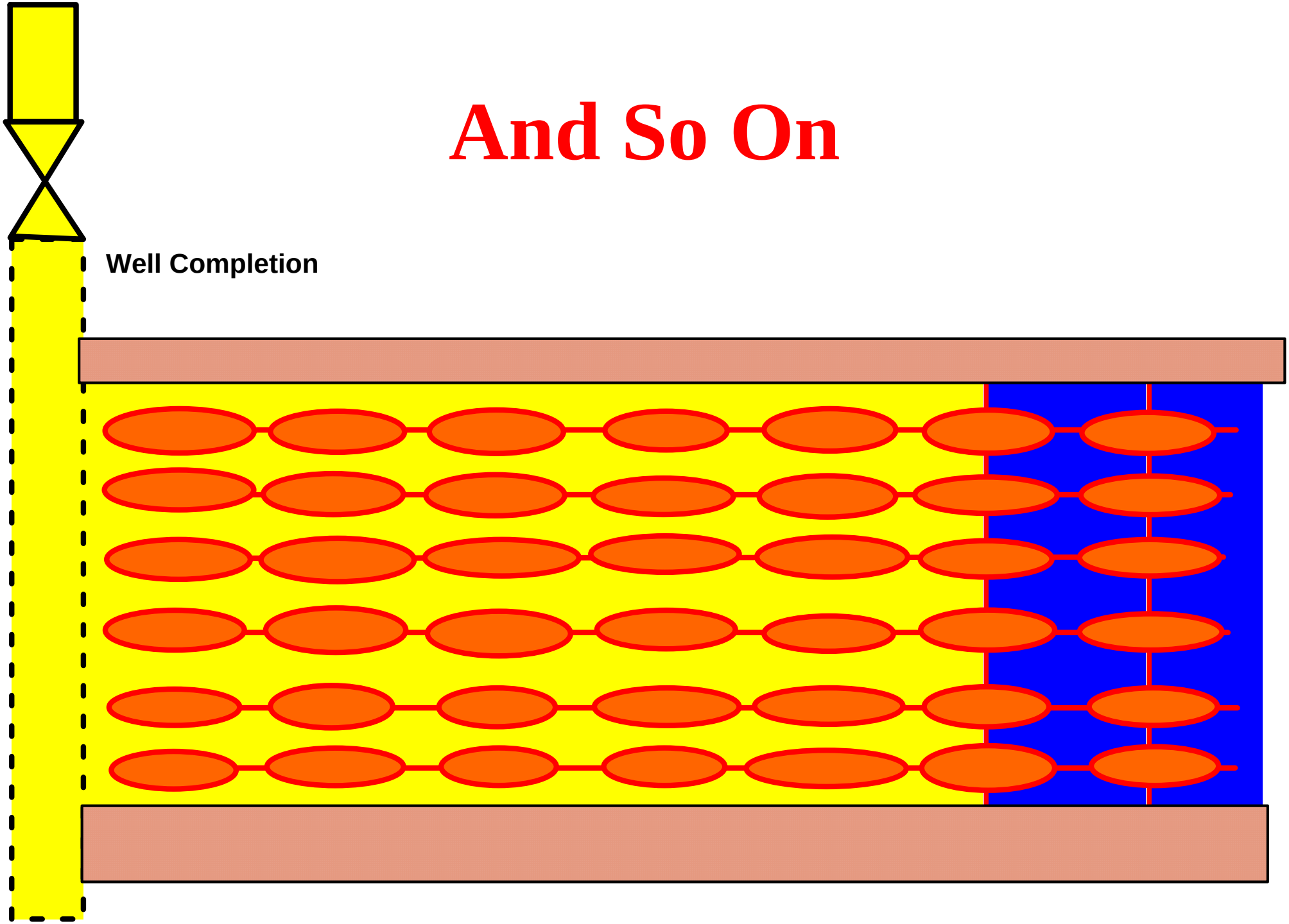
And So On



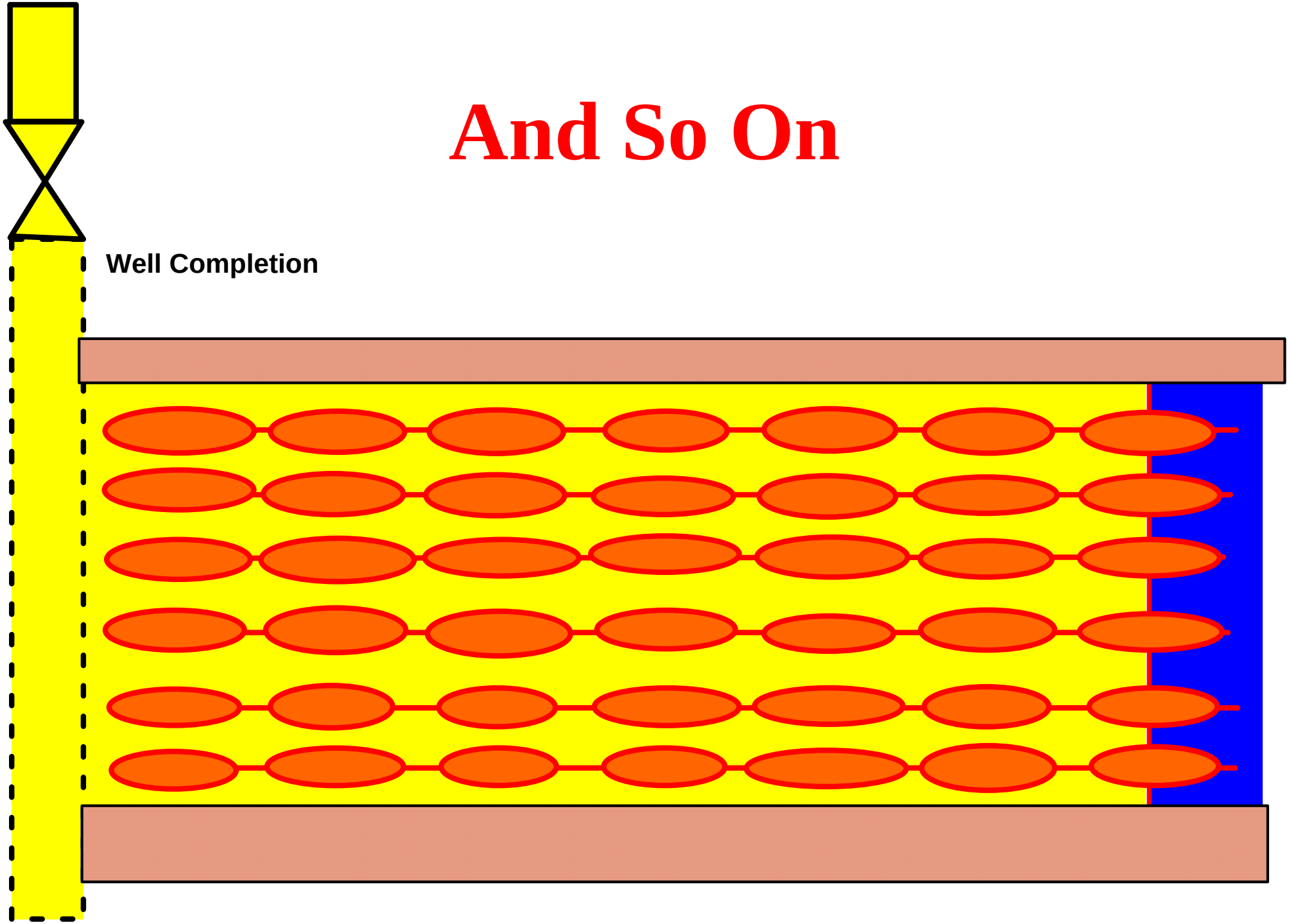
And So On



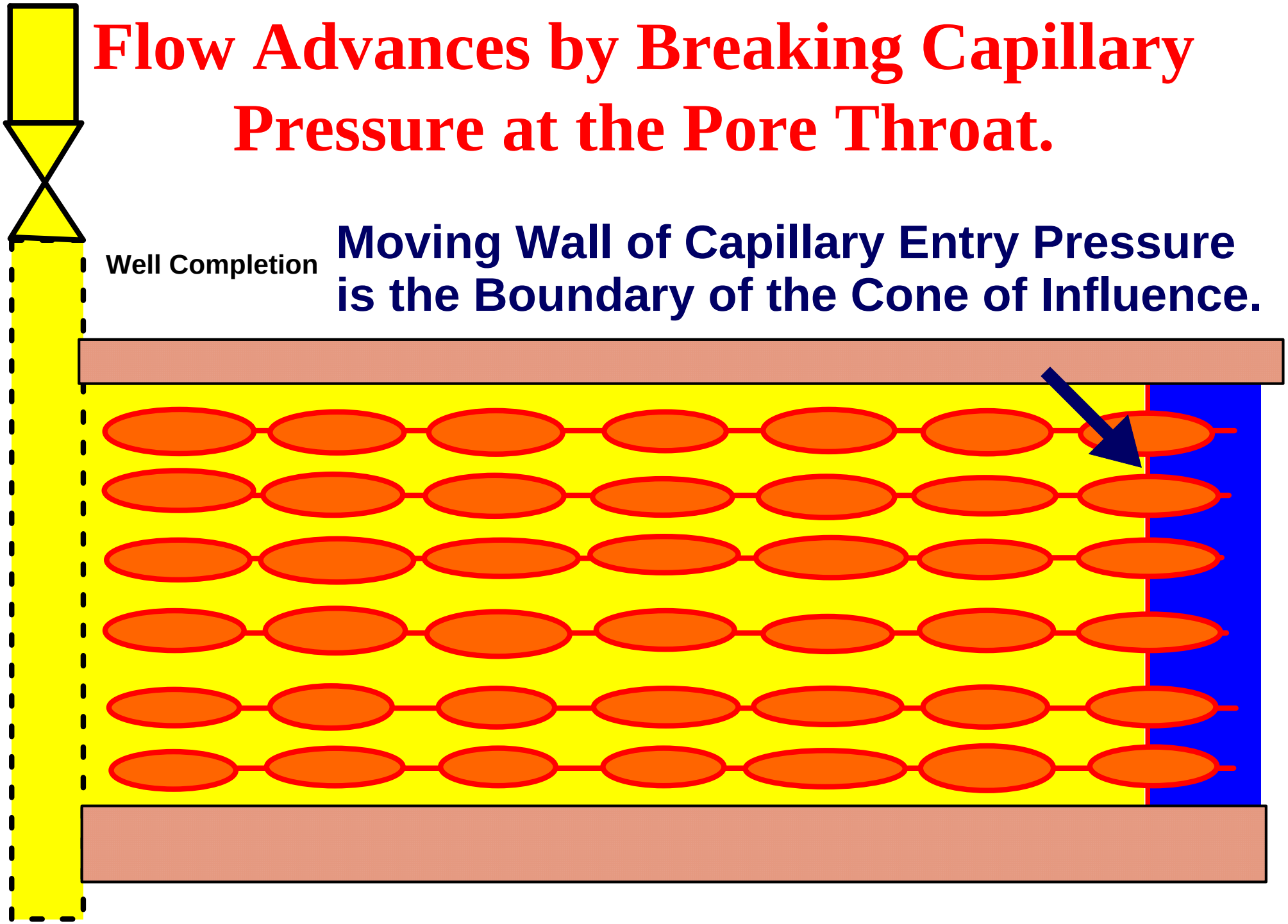
And So On



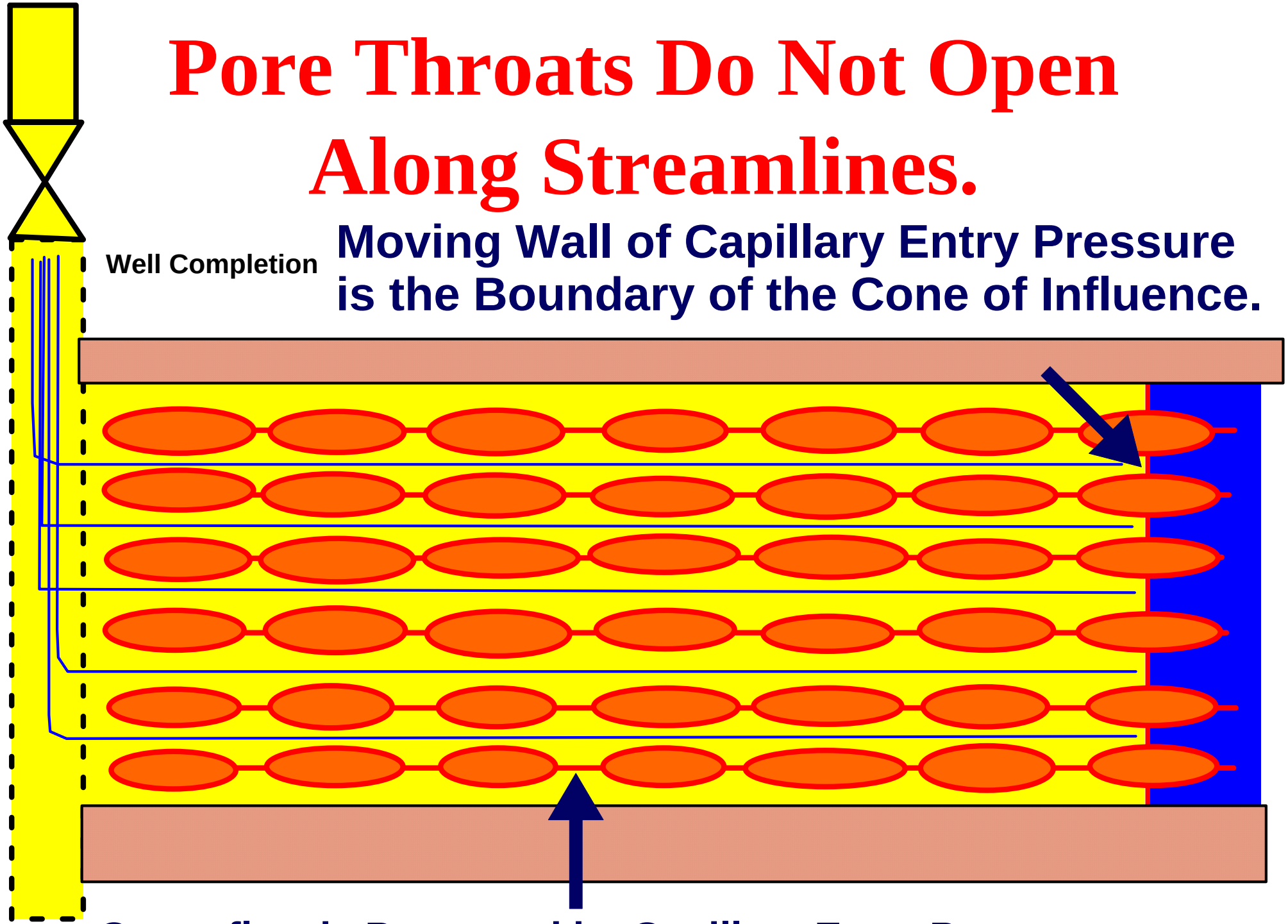
And So On



Flow Advances by Breaking Capillary Pressure at the Pore Throat.

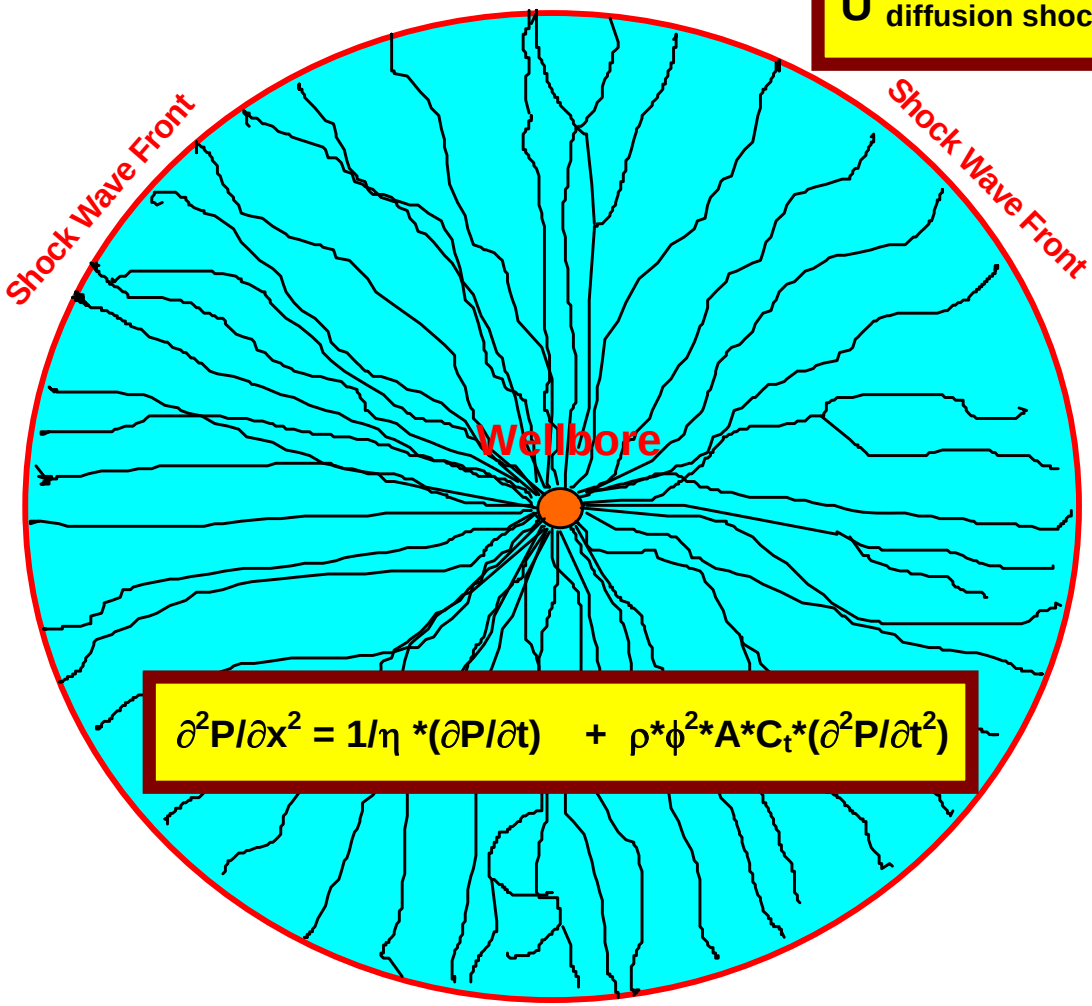


Pore Throats Do Not Open Along Streamlines.

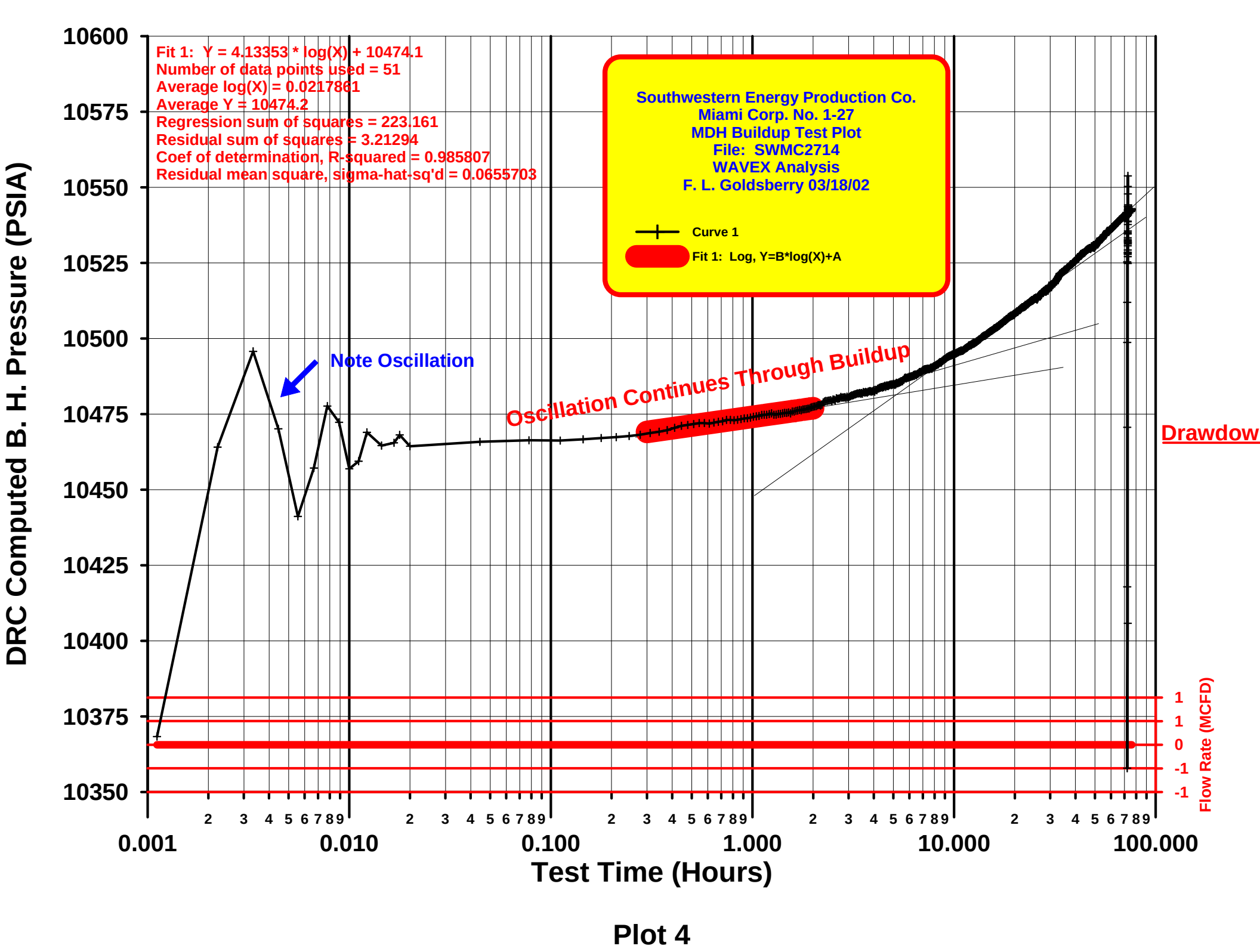


Clusters of Growing Capillaries

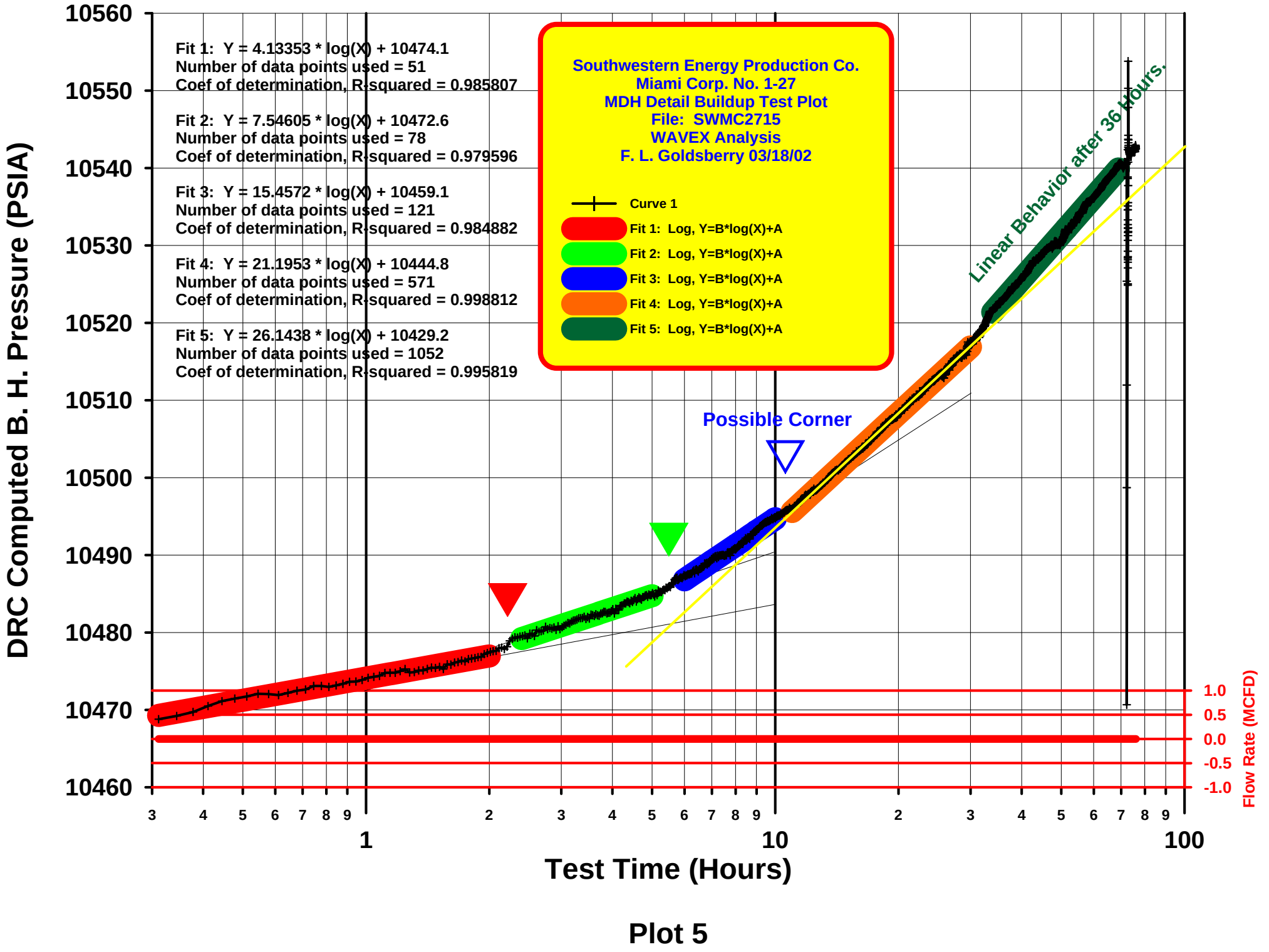
$$U_{\text{diffusion shockwave}} = (\eta/t)^{1/2}$$



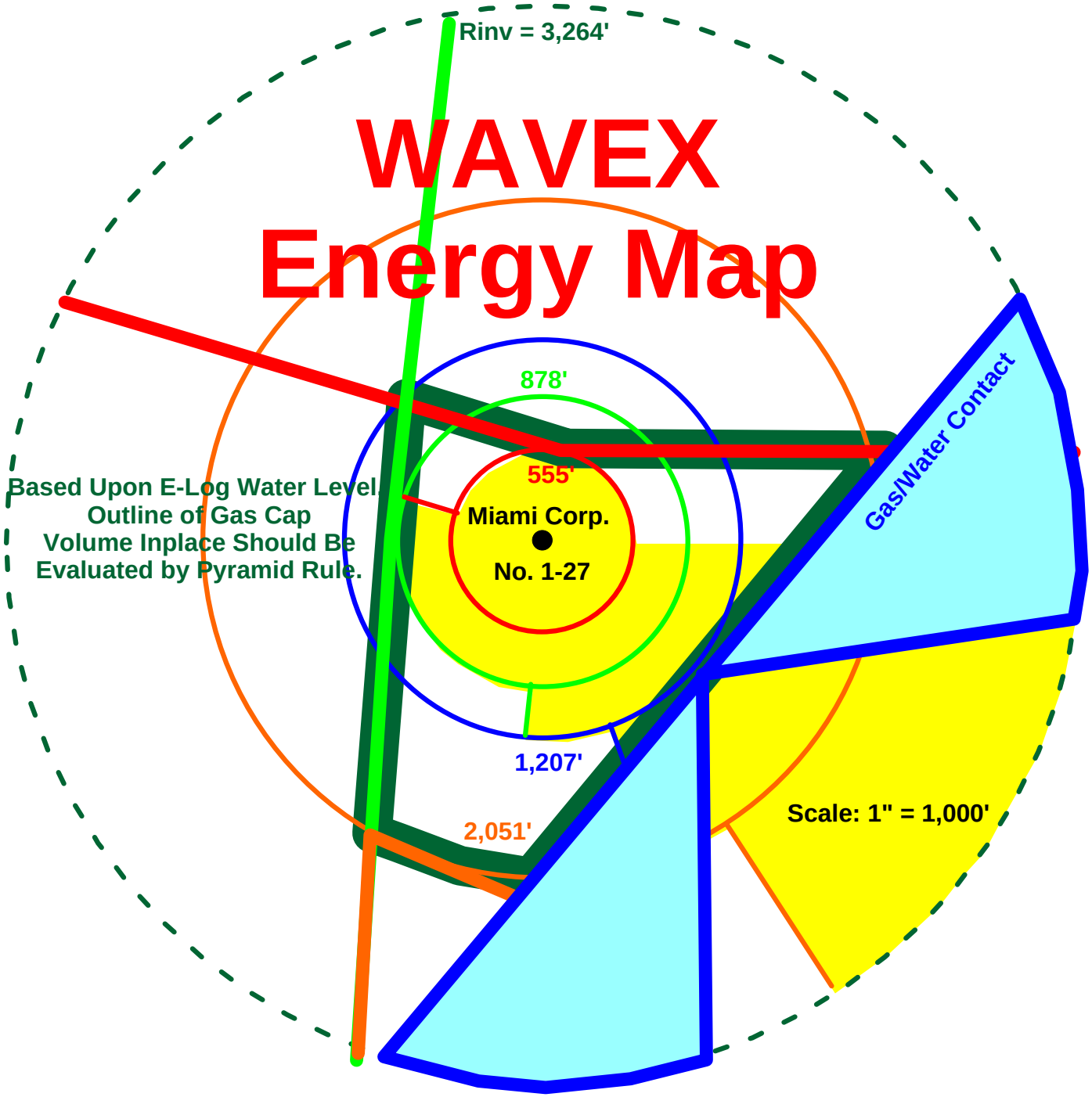
$$\partial^2 P/\partial x^2 = 1/\eta \ *(\partial P/\partial t) \quad + \quad \rho*\phi^2*A*C_t*(\partial^2 P/\partial t^2)$$


Fit 1: Y = 4.13353 * log(X) + 10474.1
Number of data points used = 51
Average log(X) = 0.0217861
Average Y = 10474.2
Regression sum of squares = 223.161
Residual sum of squares = 3.21294
Coef of determination, R-squared = 0.985807
Residual mean square, sigma-hat-sq'd = 0.0655703
Southwestern Energy Production Co.
Miami Corp. No. 1-27
MDH Buildup Test Plot
File: SWMC2714
WAVEX Analysis
F. L. Goldsberry 03/18/02
Curve 1
Fit 1: Log, Y=B*log(X)+A
Note Oscillation
Oscillation Continues Through Buildup
Drawdow
DRC Computed B. H. Pressure (PSIA)
10600
10575
10550
10525
10500
10475
10450
10425
10400
10375
10350
Flow Rate (MCFD)
1
1
0
-1
-1
0.001
0.010
0.100
1.000
10.000
100.000
Test Time (Hours)

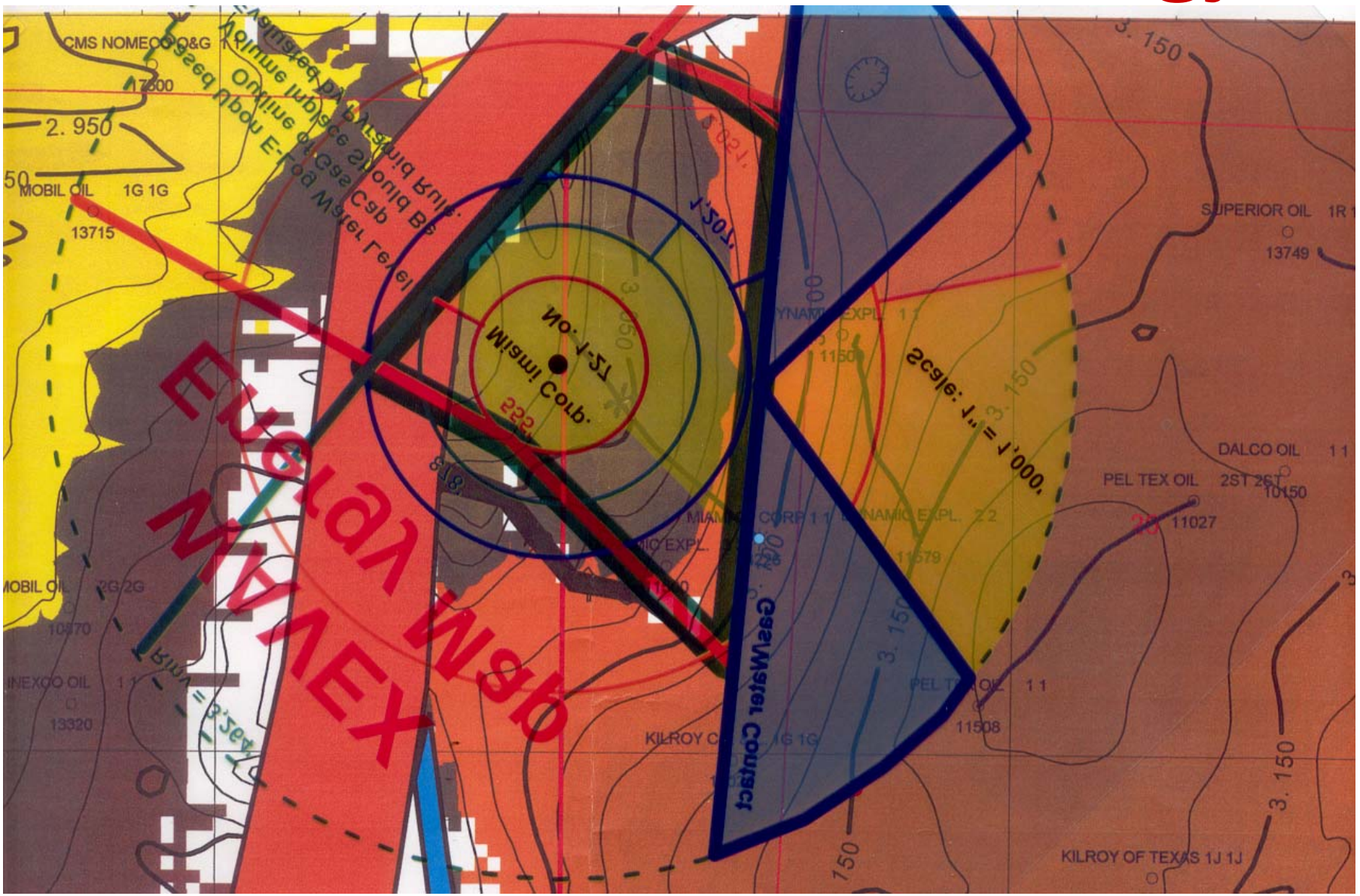
Plot 4

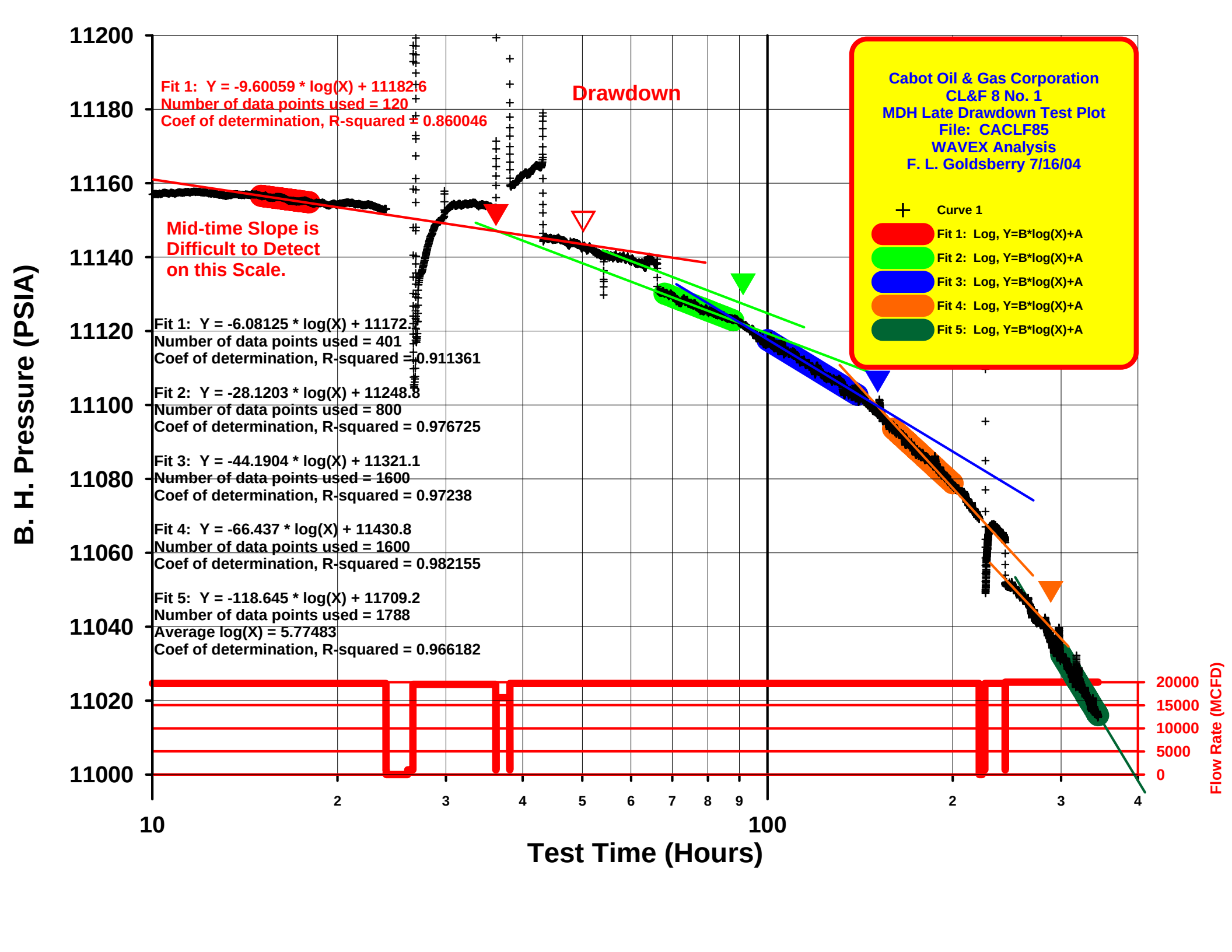

Fit 1: Y = 4.13353 * log(X) + 10474.1
Number of data points used = 51
Coef of determination, R-squared = 0.985807
Fit 2: Y = 7.54605 * log(X) + 10472.6
Number of data points used = 78
Coef of determination, R-squared = 0.979596
Fit 3: Y = 15.4572 * log(X) + 10459.1
Number of data points used = 121
Coef of determination, R-squared = 0.984882
Fit 4: Y = 21.1953 * log(X) + 10444.8
Number of data points used = 571
Coef of determination, R-squared = 0.998812
Fit 5: Y = 26.1438 * log(X) + 10429.2
Number of data points used = 1052
Coef of determination, R-squared = 0.995819
Southwestern Energy Production Co.
Miami Corp. No. 1-27
MDH Detail Buildup Test Plot
File: SWMC2715
WAVEX Analysis
F. L. Goldsberry 03/18/02
Curve 1
Fit 1: Log, Y=B*log(X)+A
Fit 2: Log, Y=B*log(X)+A
Fit 3: Log, Y=B*log(X)+A
Fit 4: Log, Y=B*log(X)+A
Fit 5: Log, Y=B*log(X)+A
Linear Behavior after 36 Hours.
Possible Corner
DRC Computed B. H. Pressure (PSIA)
10560
10550
10540
10530
10520
10510
10500
10490
10480
10470
10460
Flow Rate (MCFD)
1.0
0.5
0.0
-0.5
-1.0
3 4 5 6 7 8 9
1
2 3 4 5 6 7 8 9
10
2 3 4 5 6 7 8 9
100
Test Time (Hours)

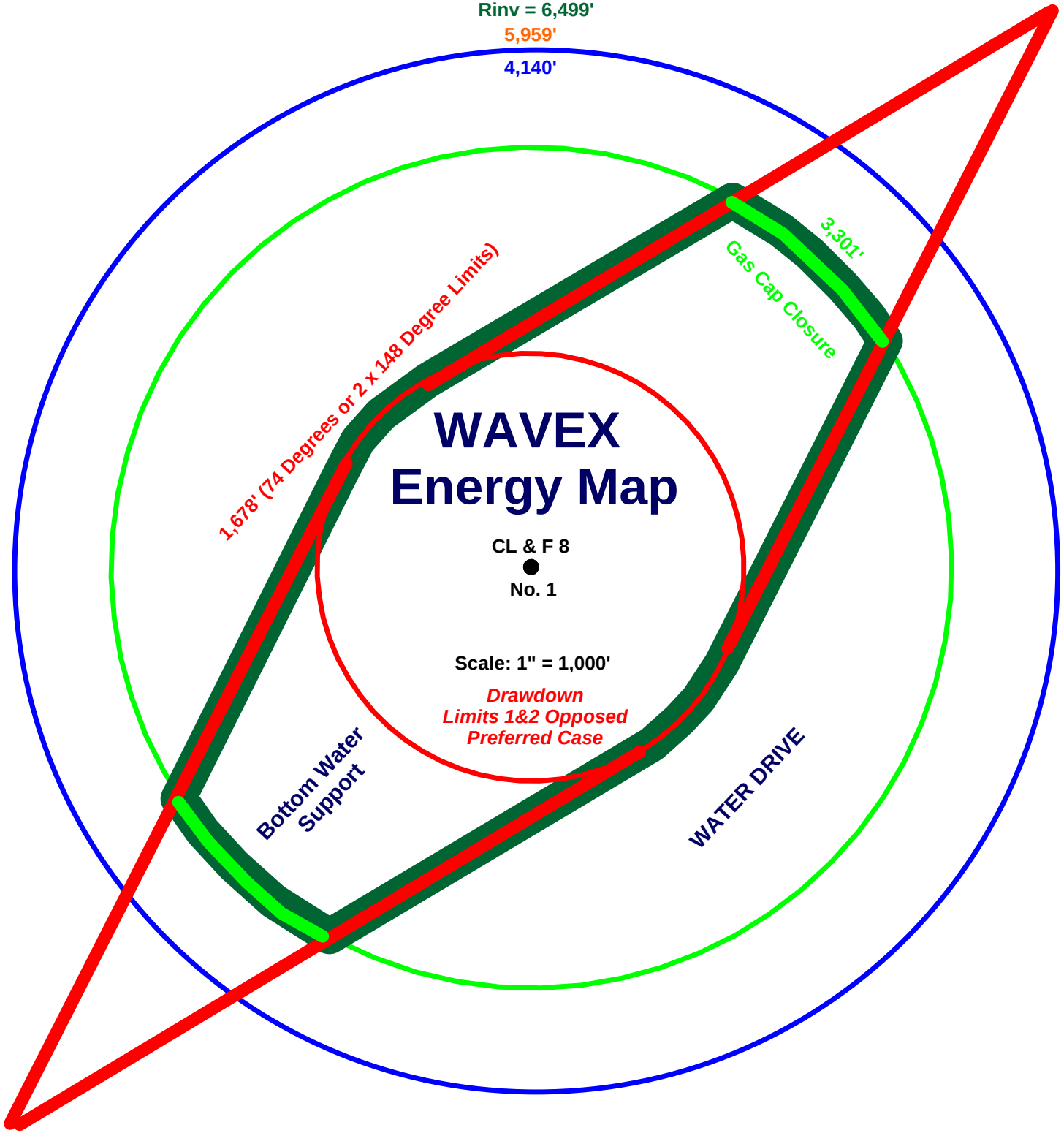
Plot 5

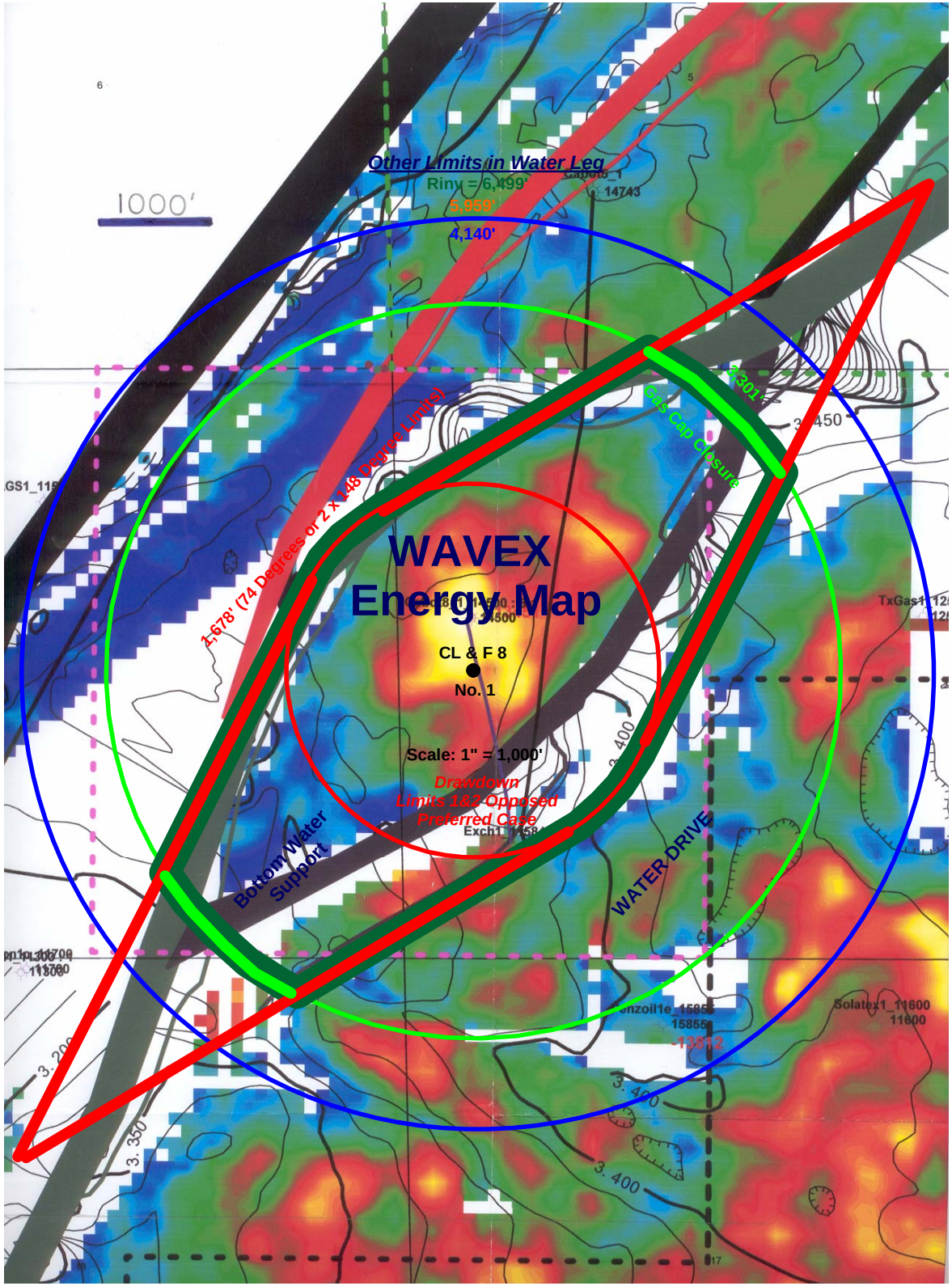

Rinv = 3,264'
WAVEX
Energy Map
878'
555'
Miami Corp.
No. 1-27
Based Upon E-Log Water Level.
Outline of Gas Cap
Volume Inplace Should Be
Evaluated by Pyramid Rule.
Gas/Water Contact
1,207'
2,051'
Scale: 1" = 1,000'

Best Blind fit Over Geology

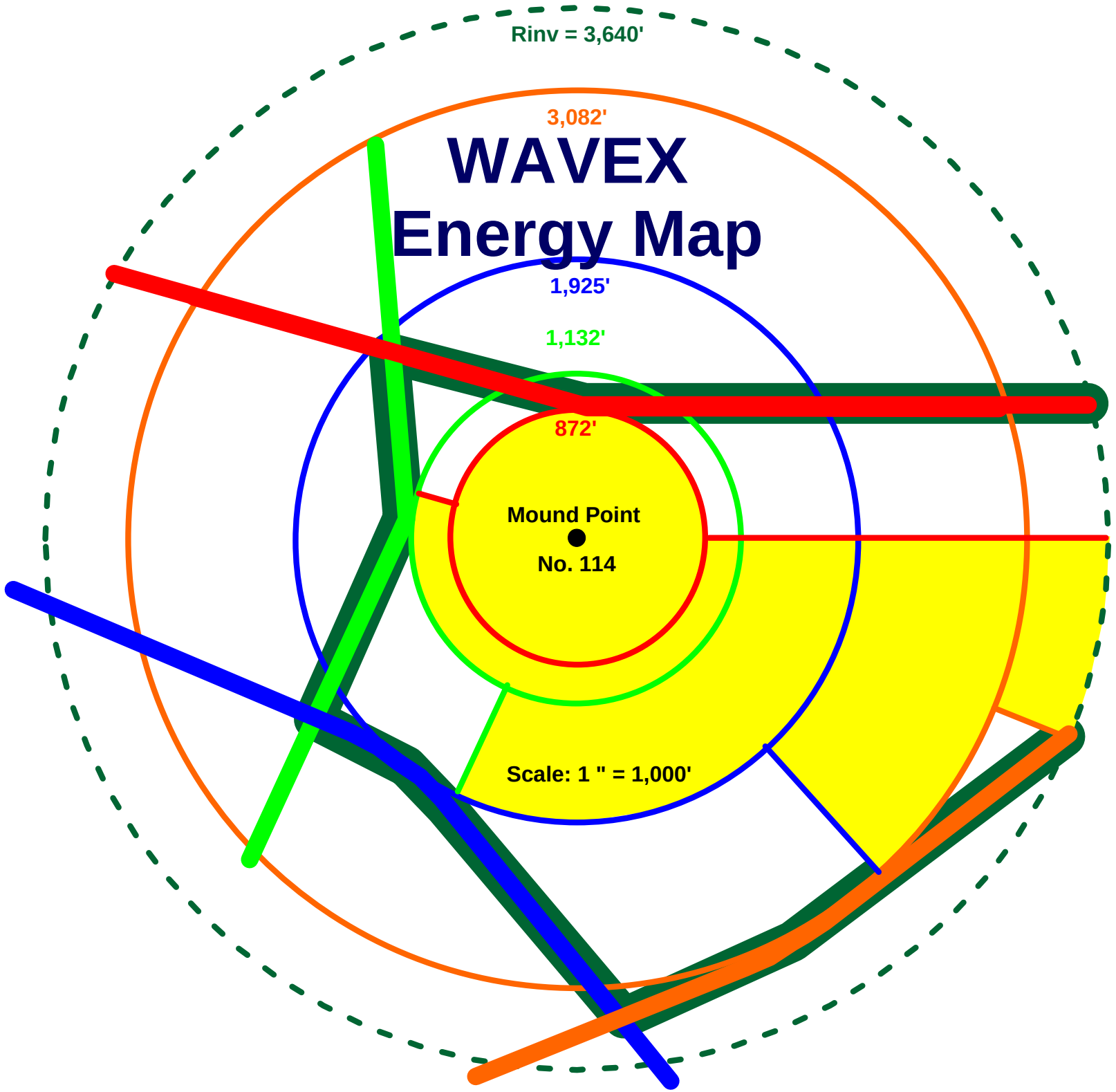


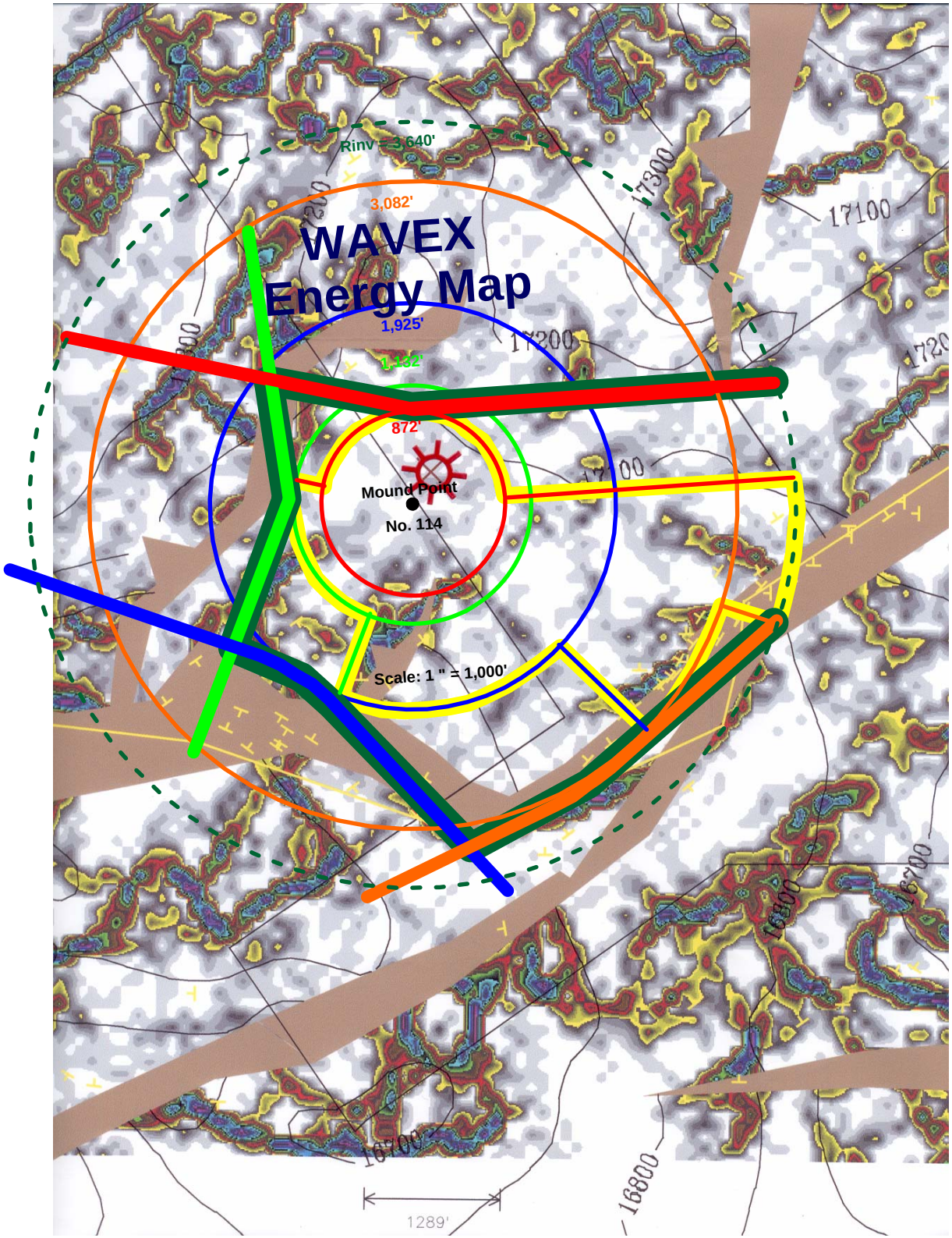

Cabot Oil & Gas Corporation
CL&F 8 No. 1
MDH Late Drawdown Test Plot
File: CACLF85
WAVEX Analysis
F. L. Goldsberry 7/16/04
Curve 1
Fit 1: Log, Y=B*log(X)+A
Fit 2: Log, Y=B*log(X)+A
Fit 3: Log, Y=B*log(X)+A
Fit 4: Log, Y=B*log(X)+A
Fit 5: Log, Y=B*log(X)+A
Drawdown
Fit 1: Y = -9.60059 * log(X) + 111821.6
Number of data points used = 120
Coef of determination, R-squared = 0.860046
Mid-time Slope is Difficult to Detect on this Scale.
Fit 1: Y = -6.08125 * log(X) + 11172.1
Number of data points used = 401
Coef of determination, R-squared = 0.911361
Fit 2: Y = -28.1203 * log(X) + 11248.8
Number of data points used = 800
Coef of determination, R-squared = 0.976725
Fit 3: Y = -44.1904 * log(X) + 11321.1
Number of data points used = 1600
Coef of determination, R-squared = 0.97238
Fit 4: Y = -66.437 * log(X) + 11430.8
Number of data points used = 1600
Coef of determination, R-squared = 0.982155
Fit 5: Y = -118.645 * log(X) + 11709.2
Number of data points used = 1788
Average log(X) = 5.77483
Coef of determination, R-squared = 0.966182
B. H. Pressure (PSIA)
11200
11180
11160
11140
11120
11100
11080
11060
11040
11020
11000
Flow Rate (MCFD)
20000
15000
10000
5000
0
10
2
3
4
5
6
7
8
9
100
2
3
4
Test Time (Hours)

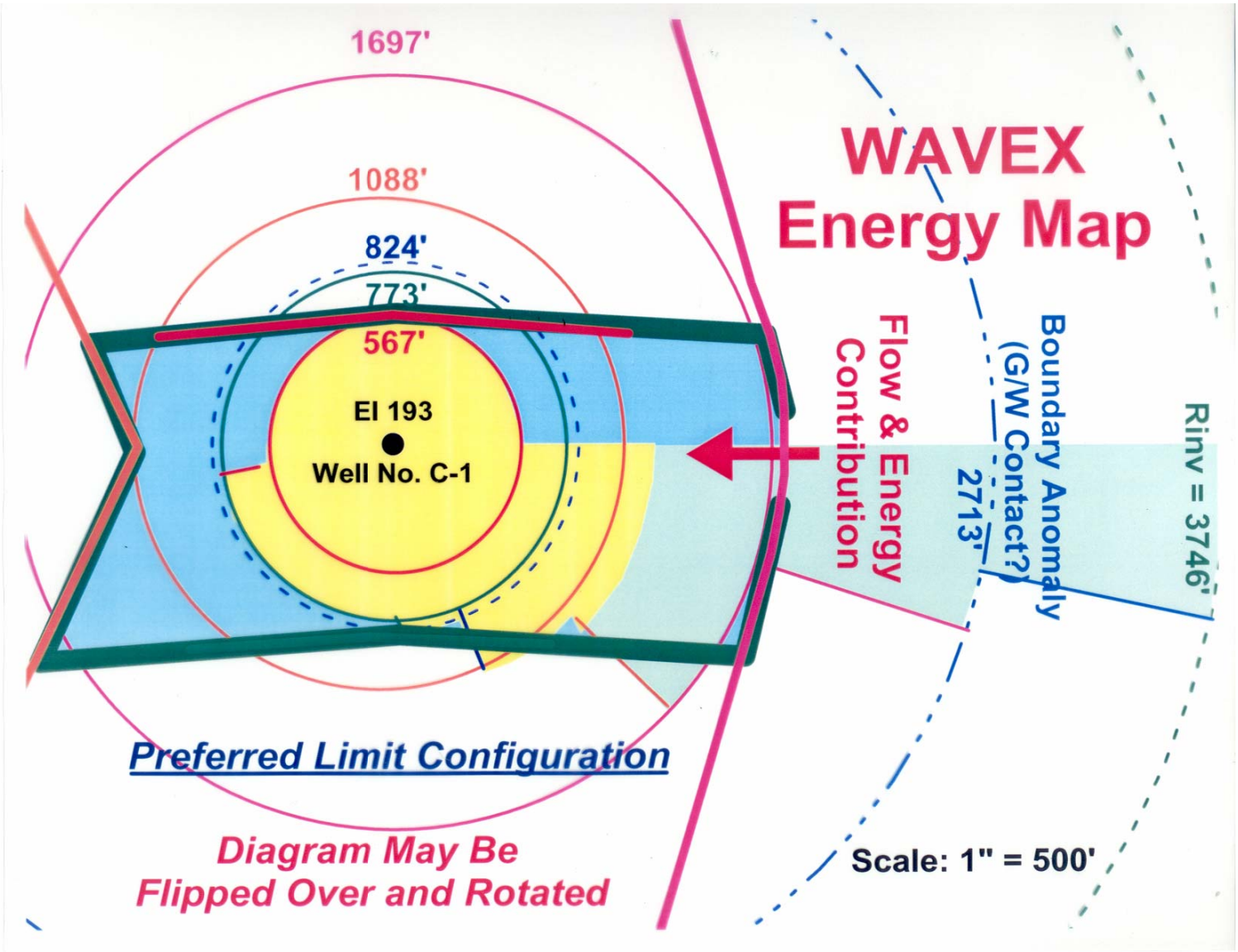

Other Limits in Water Leg
Rinv = 6,499'
5,959'
4,140'
3,301'
Gas Cap Closure
1,678' (74 Degrees or 2 x 148 Degree Limits)
WAVEX
Energy Map
CL & F 8
No. 1
Scale: 1" = 1,000'
Drawdown
Limits 1&2 Opposed
Preferred Case
Bottom Water
Support
WATER DRIVE

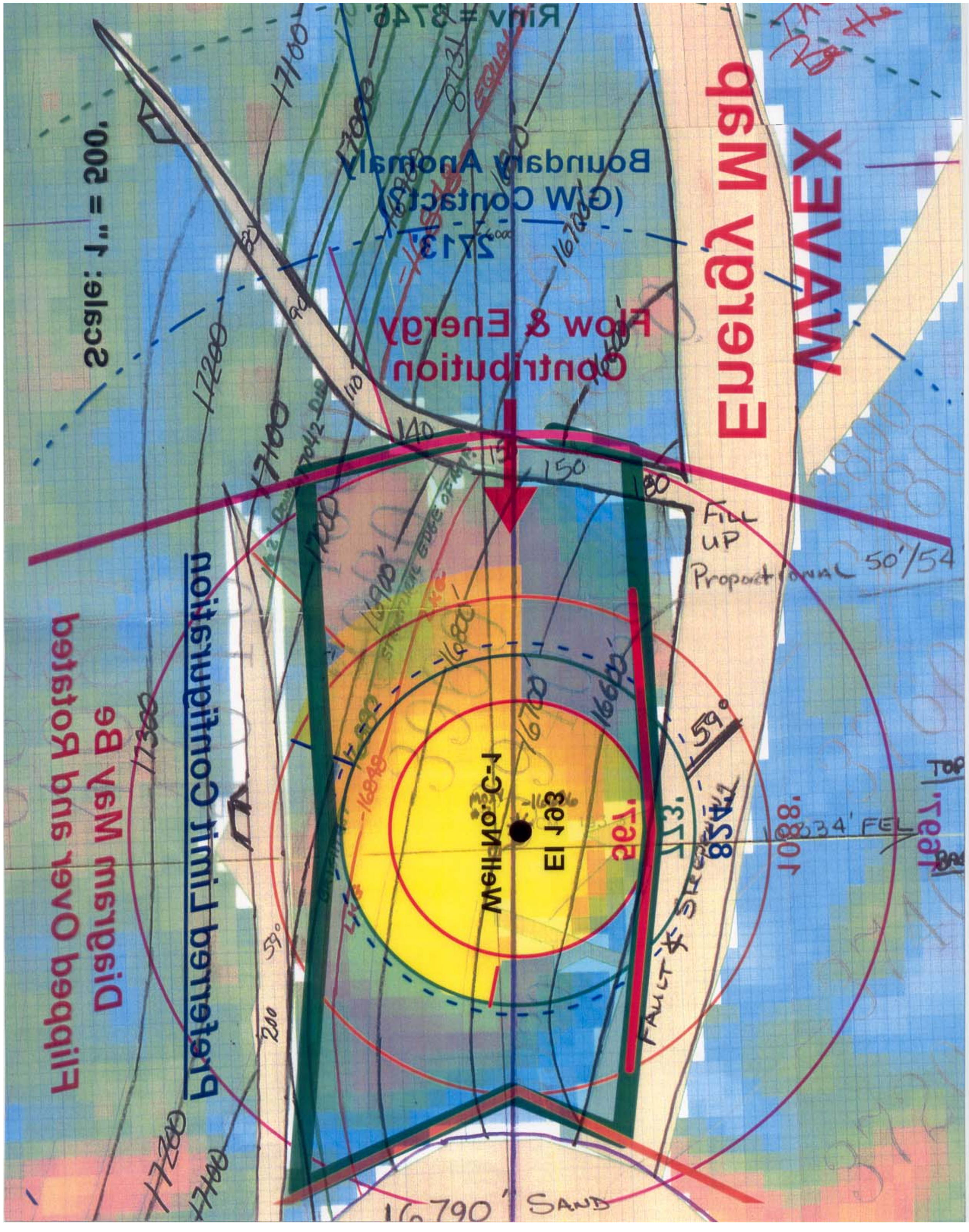

Other Limits in Water Leg
Rinv = 6,499'
5,959'
4,140'
1000'
WAVEX
Energy Map
CL & F 8
No. 1
Scale: 1" = 1,000'
Drawdown
Limits 1&2 Opposed
Preferred Case
1,678' (74 Degrees of 2 x 148 Degree Limits)
Cap Cap Closure
Bottom Water
Support
WATER DRIVE
14743
13012
3,450
3,400
3,350
3,200
Solatex1_11600
11600

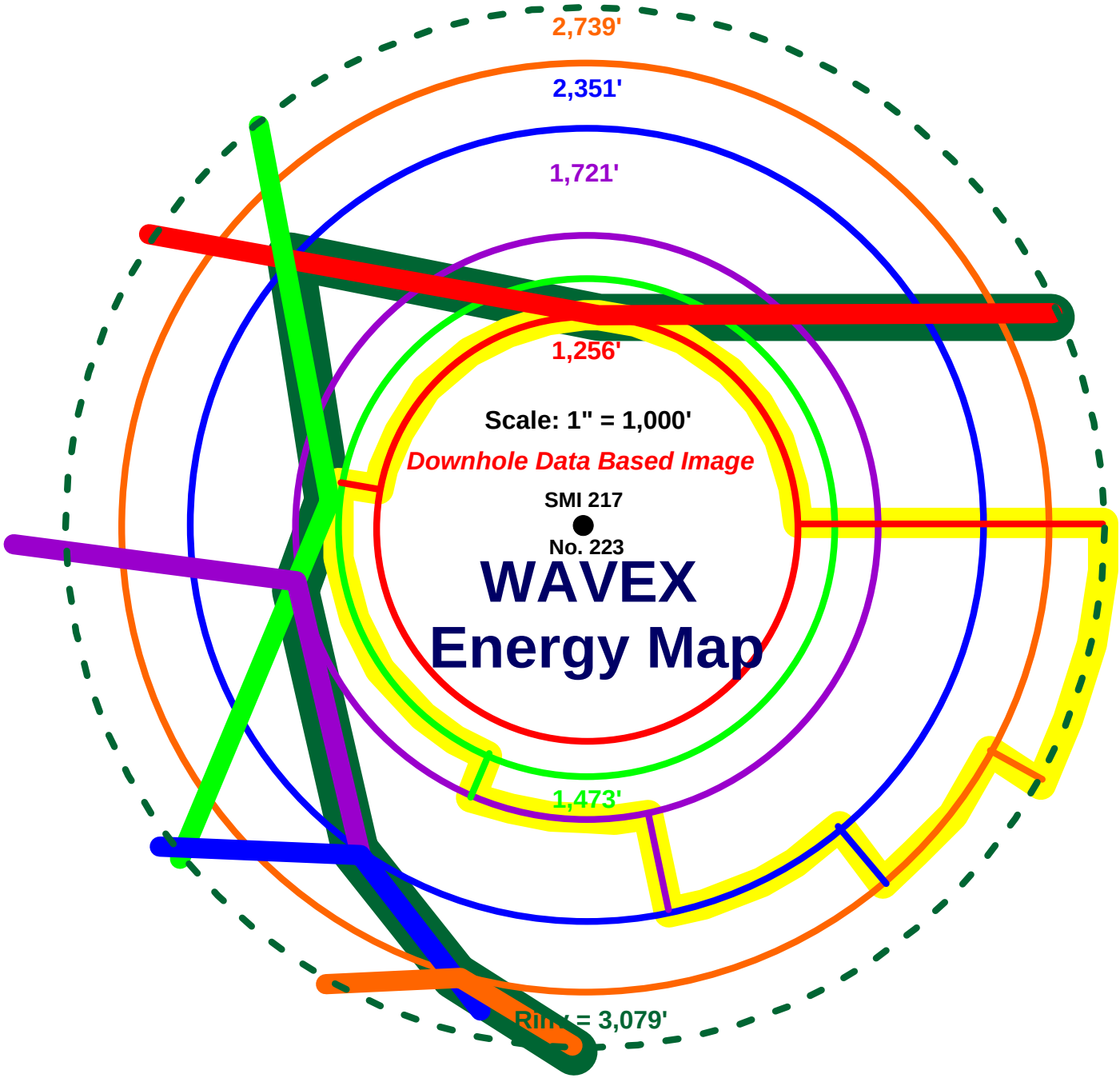
additional examples


Rinv = 3,640'
3,082'
WAVEX
Energy Map
1,925'
1,132'
872'
Mound Point
No. 114
Scale: 1 " = 1,000'


WAVEX
Energy Map
Rinv = 3,640'
3,082'
1,925'
1,132'
872'
Mound Point
No. 114
Scale: 1 " = 1,000'
1289'
17300
17100
17200
17100
16800
16700
16700
16800

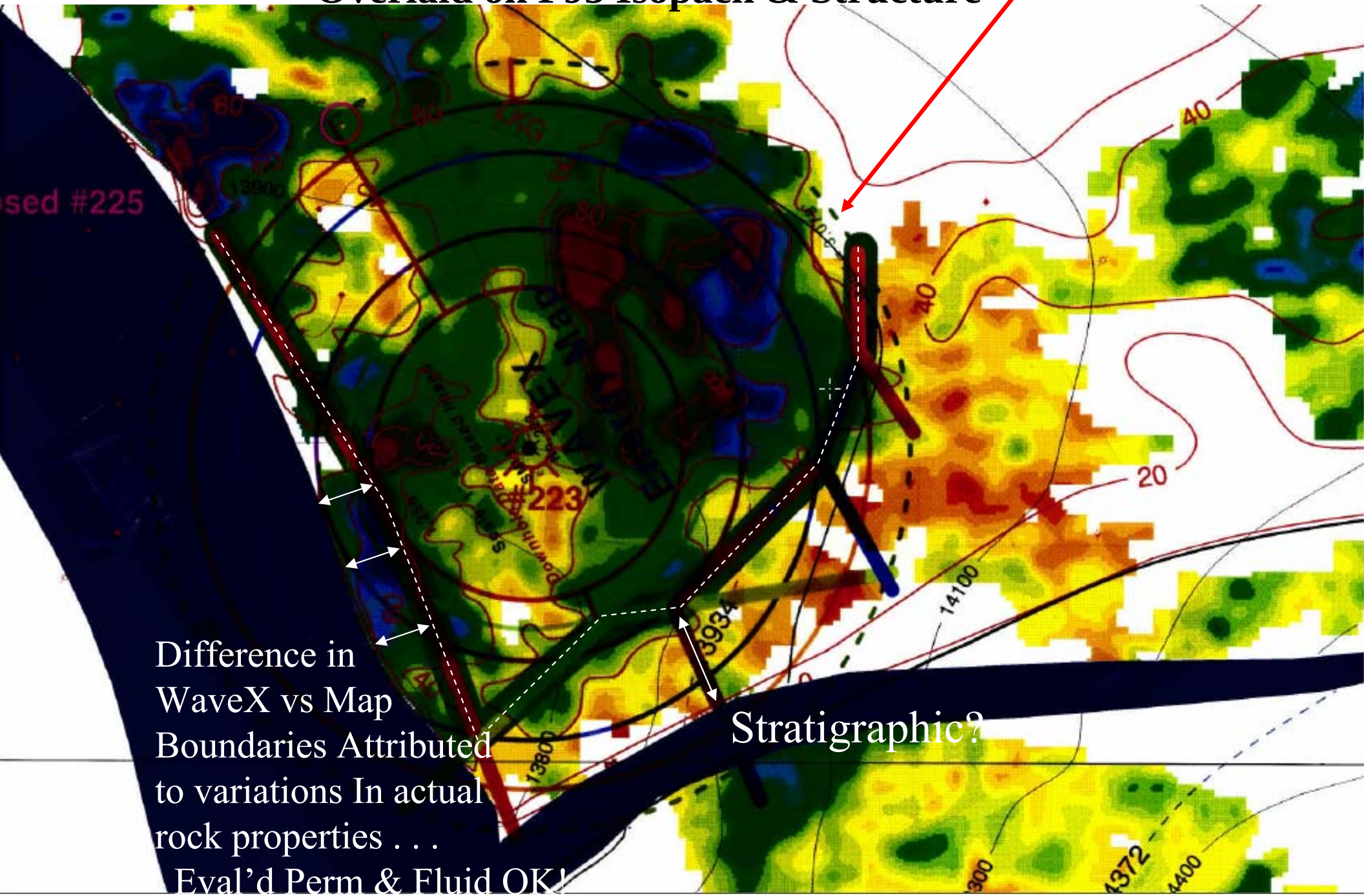

1697'
1088'
824'
773'
567'
El 193
Well No. C-1
WAVEX
Energy Map
Flow & Energy
Contribution
Boundary Anomaly
(G/W Contact?)
2713'
Rinv = 3746'
Preferred Limit Configuration
Diagram May Be
Flipped Over and Rotated
Scale: 1" = 500'

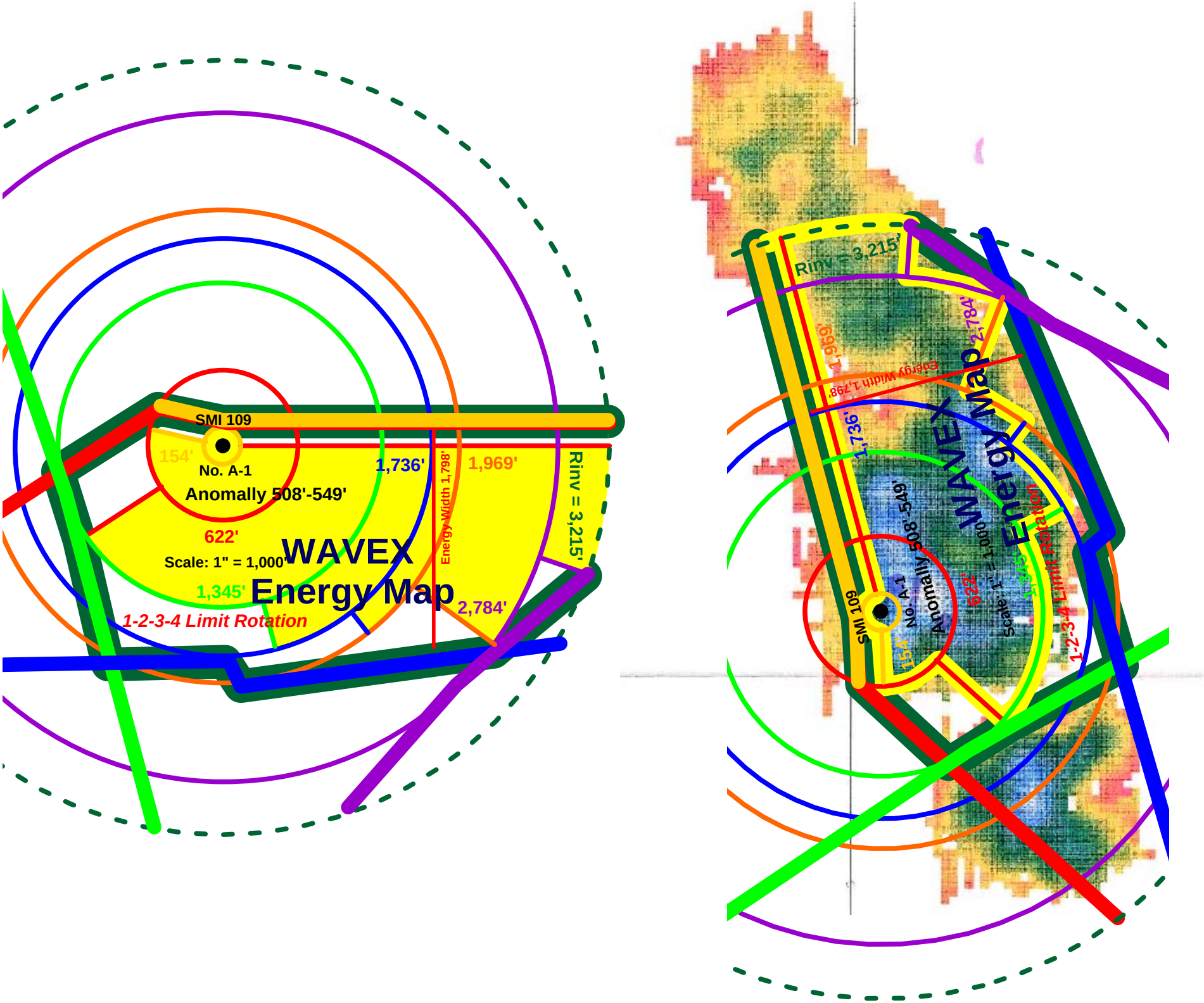

Flipped Over and Rotated
Diagram May Be
Preferred Limit Configuration
Scale: 1" = 500'
Boundary Anomaly
(G/W Contact?)
2713'
Flow & Energy
Contribution
Energy Map
MWVEX
Well No. C-1
El Jay
297'
1088'
10834' FEL
FILL
UP
Proportional 50'/54
FAULT & SEEP
16,790' SAND


2,739'
2,351'
1,721'
1,256'
Scale: 1" = 1,000'
Downhole Data Based Image
SMI 217
No. 223
WAVEX
Energy Map
1,473'
Rim = 3,079'

SMI 217 #223 Rob L-8
Mid-Offset Amplitude Extraction
Overlaid on P95 Isopach & Structure

With Overlay of WaveX Energy Map




SMI 109
154'
No. A-1
Anomally 508'-549'
622'
Scale: 1" = 1,000'
1,345'
1,736'
Energy Width 1,798'
1,969'
Rinv = 3,215'
2,784'
1-2-3-4 Limit Rotation
WAVEX
Energy Map
Rinv = 3,215'
2,784'
1,969'
Energy Width 1,798'
1,736'
SMI 109
154'
No. A-1
Anomally 508'-549'
622'
Scale: 1" = 1,000'
1,345'
1-2-3-4 Limit Rotation
WAVEX
Energy Map