A Methodology for Evaluating Economic Refracturing Candidates and Optimizing Refracture Treatments*

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Refracturing Background

Numerous well performance studies:
- Significant reserves remain in existing well bores.
- Infill wells can be marginally economic in a low gas price environment.
- Refracturing can be an economical alternative to new well drilling to access these reserves.

Conclusions

- If remaining producible gas reserves can be accessed with refracs the economics can be attractive even at low gas prices
- The candidate selection and treatment execution steps are relatively straightforward and use off-the-shelf hardware and software
- The techniques have the potential to significantly improve the success rate and economics of refracture treatments

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Robert Barba

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AAPG New Ways to Look at Old Data

November 8, 2010

Refracturing Background

- Numerous well performance studies:
  - Significant reserves remain in existing wellbores
  - Infill wells can be marginally economic in a low gas price environment
  - Refracturing can be an economical alternative to new well drilling to access these reserves

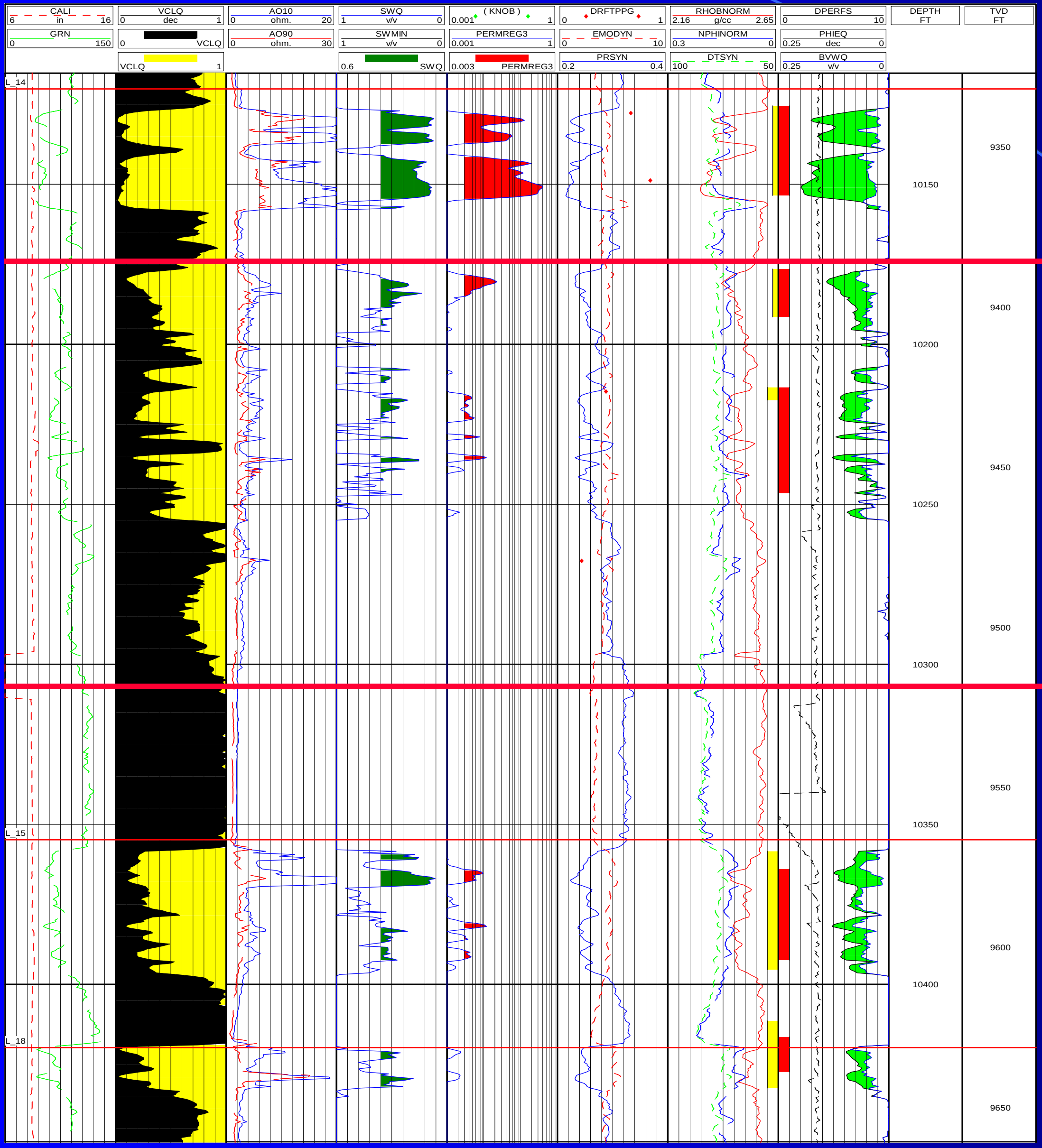
Why Are the Hydrocarbons Still There?

- Many opportunities are the result of assuming fracs are “reserve-seeking missiles”
- It is common knowledge that fracs “work”
- “How fracs work” is not as well understood

Refrac Opportunities

- Wells with:
  - Multiple perforation clusters in single frac stages
  - Poor fluid selection
    - Water-based fluids in sub-irreducible reservoirs susceptible to capillary phase trapping
    - High-viscosity fluids where complexity needed
  - Poor proppant selection
  - Inadequate proppant volumes

Multiple Perf Clusters Single Stage



PLT	Effective Frac Length
452 MCFD	0 ft (+5 skin)
136 MCFD	1 ft (0 skin)
135 MCFD	420 ft

20 acre offset upper zone
6 MMCFD

Multiple vs Single Perf Clusters

Multiple Perf Clusters

Apparent Frac Length

Single Perf Cluster

254 ft **264 ft**

1 ft

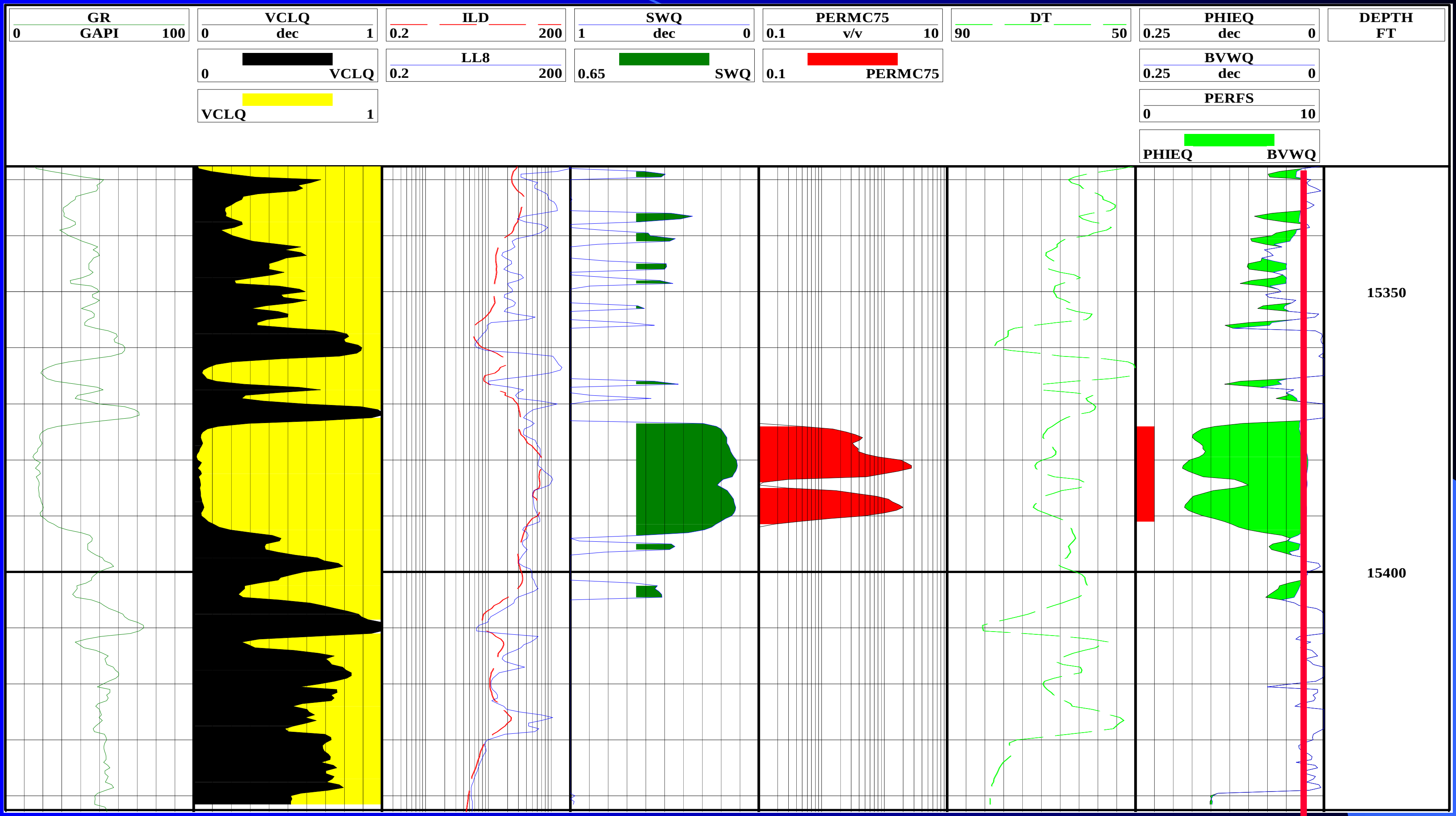
Refrac candidates

1 ft

One cluster in multiple batch performs identical to single cluster
Remaining zones skin removal

SPE 90483

Sub-Irreducible BVW

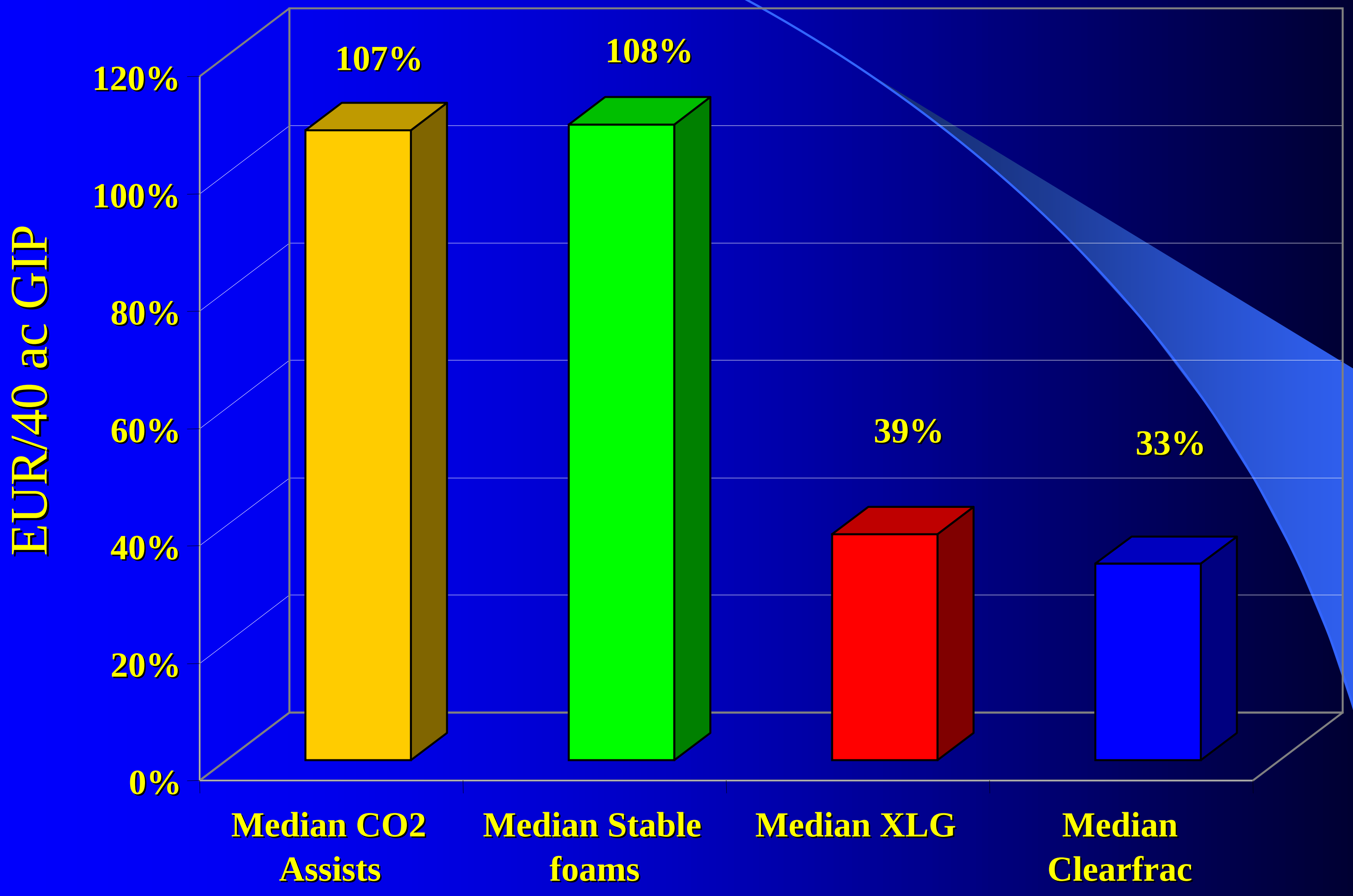


Morrow SE New Mexico

Highly susceptible to capillary phase trapping

BVW 2.5%
BVI 5%

Sub-Irreducible Sw Frac Performance



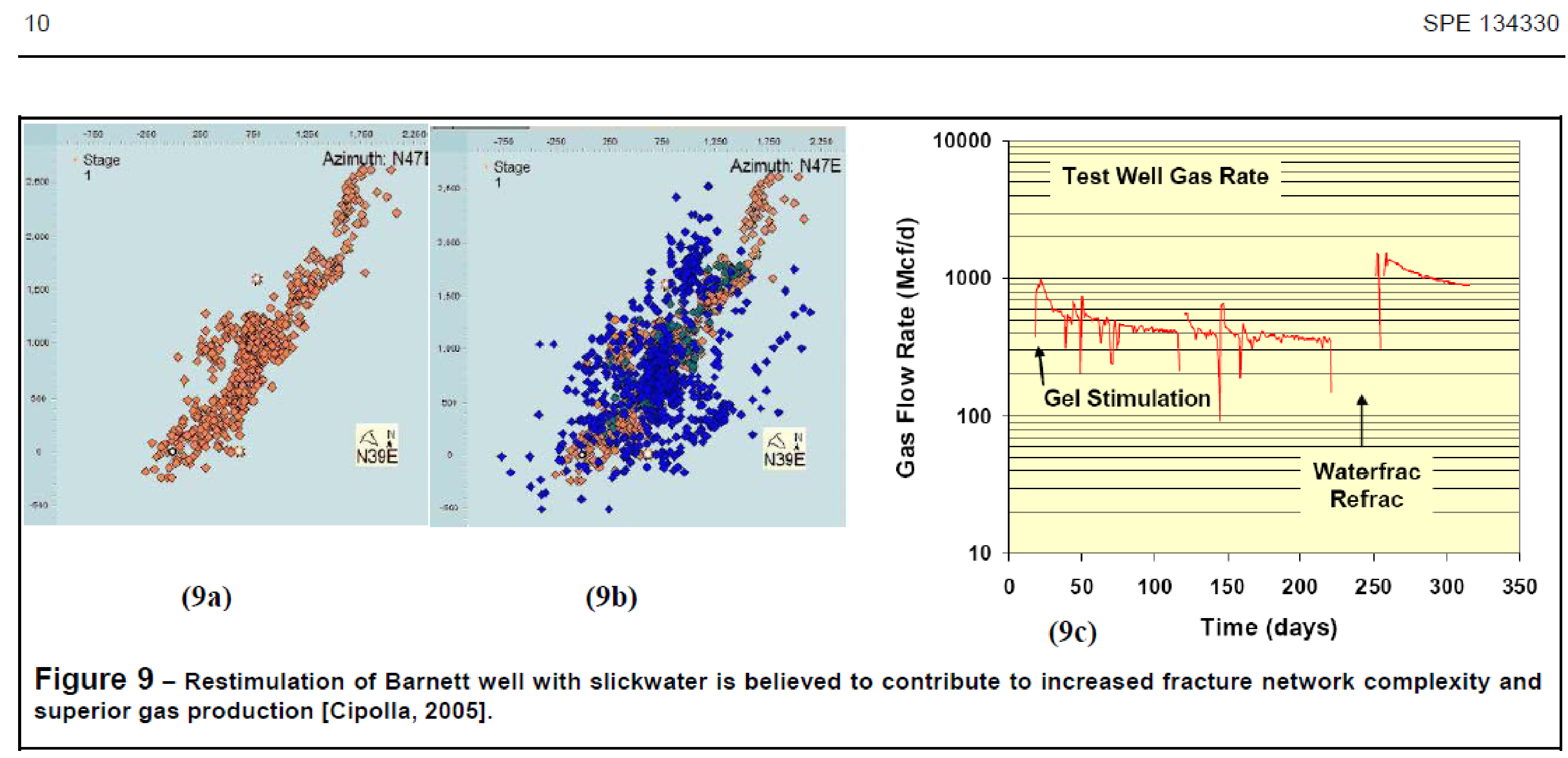
Sub-Irreducible Sw Field Papers

SPE	Year	Fluid	Remarks
11574	1983	LG	Halliburton
11575	1983	Foams	Halliburton
18963	1989	XLG	200 Wells (Cornell)
37429	1997	XLG	GRI AST (Aud)
37433	1997	Foams	500 wells (Halliburton/Enron)
56725	1999	XLG	GRI AST (Aud)
67206	2001	XLG	Morrow Schlumberger
67212	2001	Foams	322 wells and offsets-Morrow (BJ)
	Total		
	1	LG	
	4	XL	
	3	Foams	

All of the above studies used production results only

Not normalized to formation permeability and pressure

Fluid Selection



10 SPE 134330

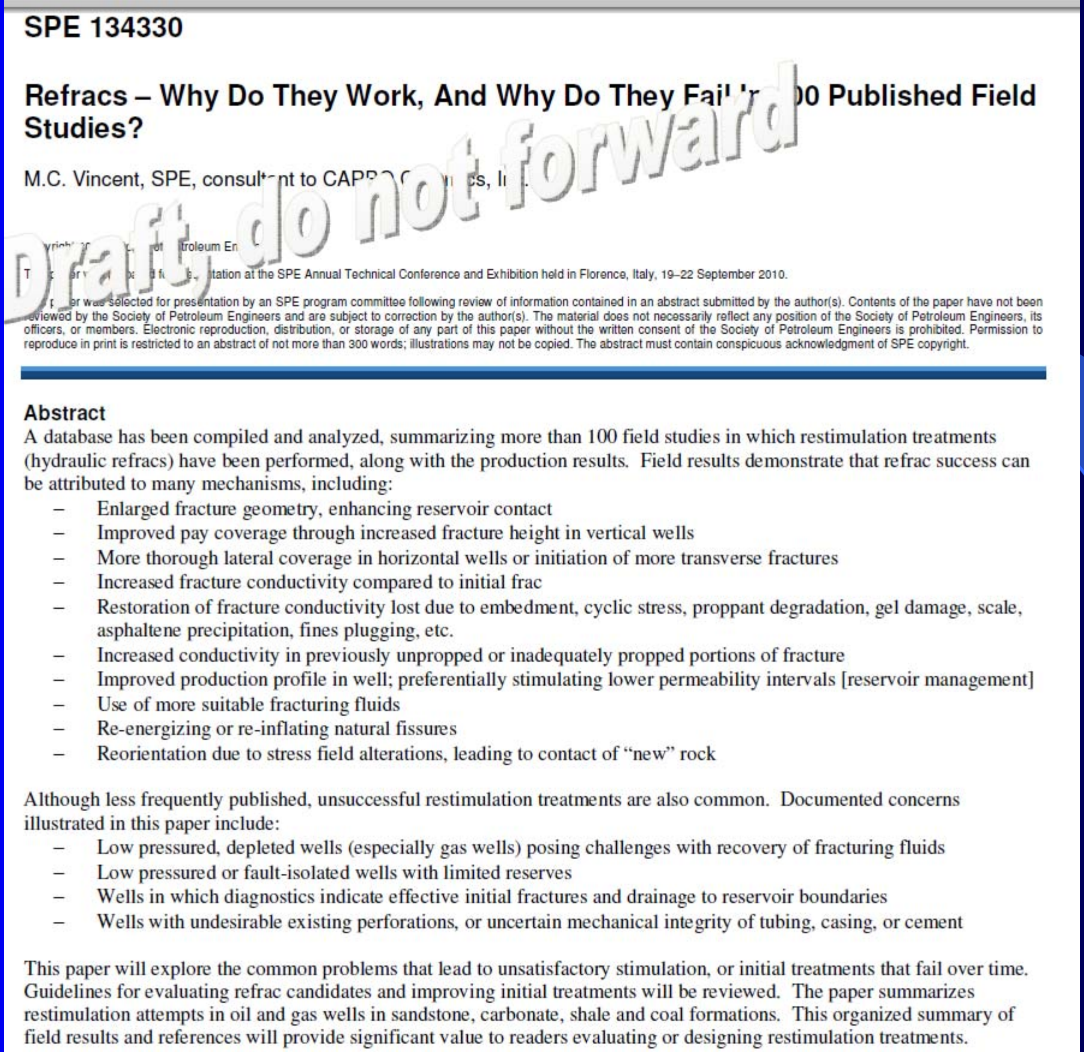
(9a) (9b) (9c)

Figure 9 – Restimulation of Barnett well with slickwater is believed to contribute to increased fracture network complexity and superior gas production [Cipolla, 2005].

Slickwater refrac of Barnett vertical well originally fracced with crosslinked system

Original paper SPE 108817

Poor Proppant Types and Volumes



SPE 134330

Refracs – Why Do They Work, And Why Do They Fai[illegible] [illegible]0 Published Field Studies?

M.C. Vincent, SPE, consult[illegible]nt to CAP[illegible] [illegible]s, I[illegible]

Abstract

A database has been compiled and analyzed, summarizing more than 100 field studies in which restimulation treatments (hydraulic refracs) have been performed, along with the production results. Field results demonstrate that refrac success can be attributed to many mechanisms, including:

- Enlarged fracture geometry, enhancing reservoir contact
- Improved pay coverage through increased fracture height in vertical wells
- More thorough lateral coverage in horizontal wells or initiation of more transverse fractures
- Increased fracture conductivity compared to initial frac
- Restoration of fracture conductivity lost due to embedment, cyclic stress, proppant degradation, gel damage, scale, asphaltene precipitation, fines plugging, etc.
- Increased conductivity in previously unpropped or inadequately propped portions of fracture
- Improved production profile in well; preferentially stimulating lower permeability intervals [reservoir management]
- Use of more suitable fracturing fluids
- Re-energizing or re-inflating natural fissures
- Reorientation due to stress field alterations, leading to contact of "new" rock

Although less frequently published, unsuccessful restimulation treatments are also common. Documented concerns illustrated in this paper include:

- Low pressured, depleted wells (especially gas wells) posing challenges with recovery of fracturing fluids
- Low pressured or fault-isolated wells with limited reserves
- Wells in which diagnostics indicate effective initial fractures and drainage to reservoir boundaries
- Wells with undesirable existing perforations, or uncertain mechanical integrity of tubing, casing, or cement

This paper will explore the common problems that lead to unsatisfactory stimulation, or initial treatments that fail over time. Guidelines for evaluating refrac candidates and improving initial treatments will be reviewed. The paper summarizes restimulation attempts in oil and gas wells in sandstone, carbonate, shale and coal formations. This organized summary of field results and references will provide significant value to readers evaluating or designing restimulation treatments.

Recent paper (Florence Sept 2010) good update on worldwide refracs
Over 100 case studies detailed in paper

Refrac Optimization Process Flow Chart

Evaluate Candidate Well and Zone Performance

Pressure Test Each Zone

Isolate Economic Zones and Refrac

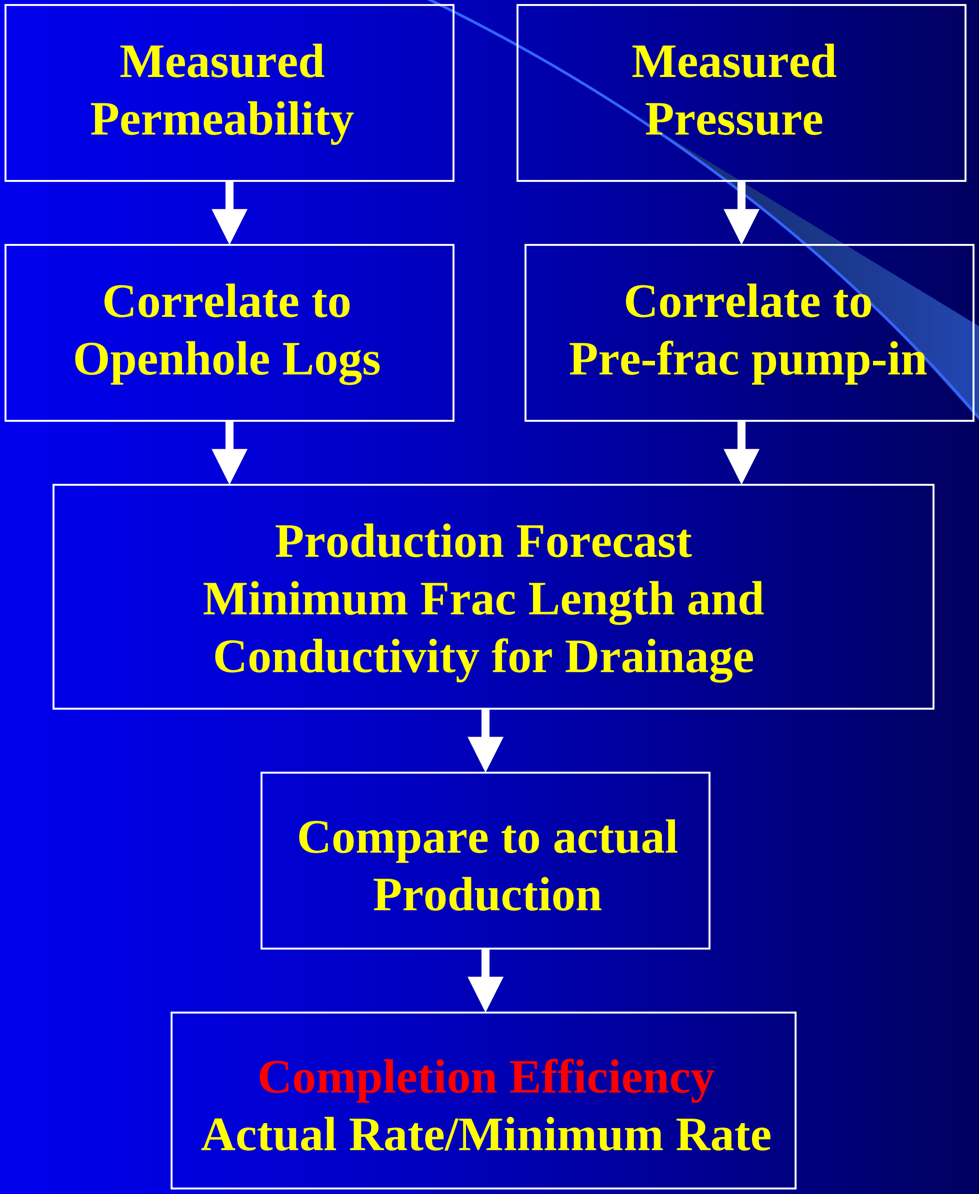
Why Poor Initial Well Performance?

- Low permeability-thickness?
- Low reservoir pressure?
- An inefficient stimulation?
- All of the above?

Performance Analysis Techniques

1. Completion Efficiency
2. Apparent frac length
3. Recovery factor
4. Production analysis

CE Process Flow Chart



Measured Permeability

Measured Pressure

Correlate to Openhole Logs

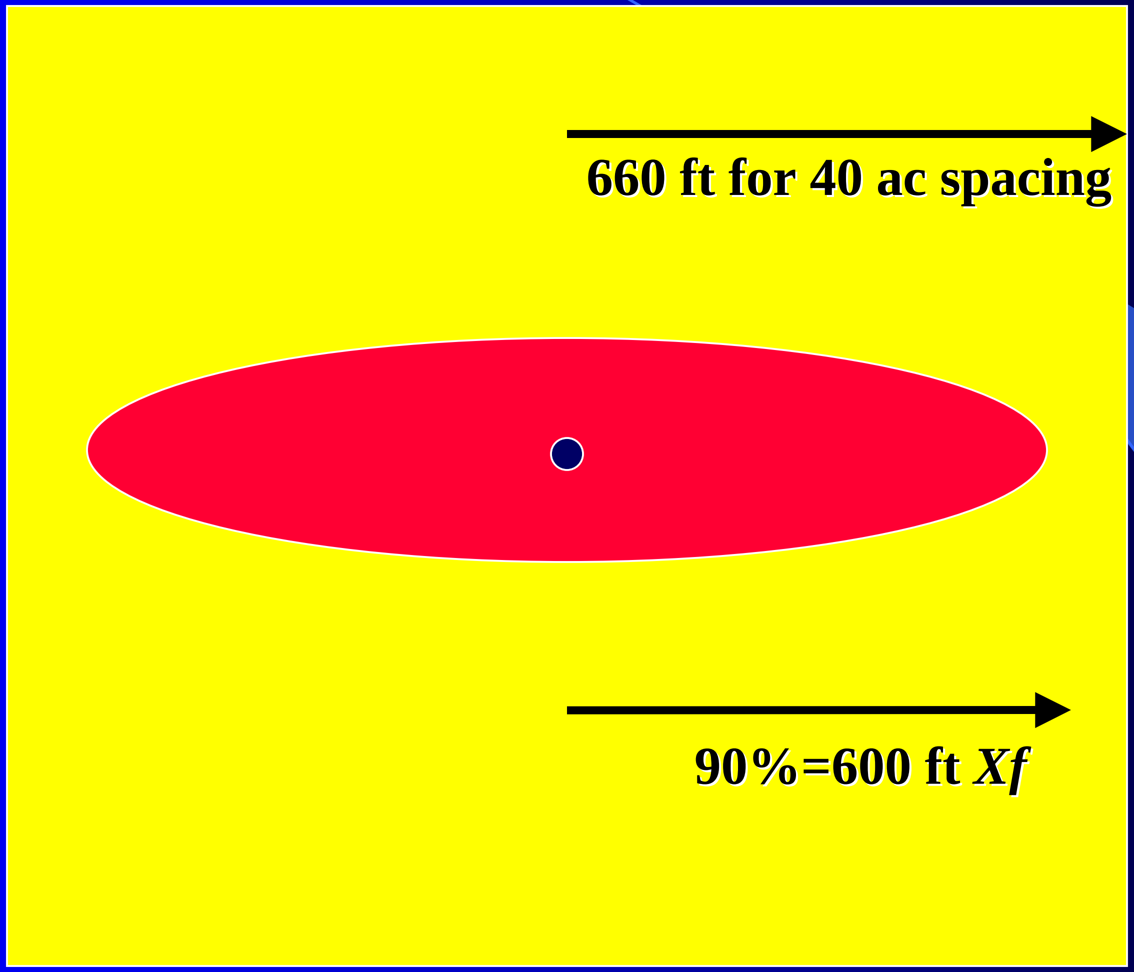
Correlate to Pre-frac pump-in

Production Forecast
Minimum Frac Length and
Conductivity for Drainage

Compare to actual Production

Completion Efficiency
Actual Rate/Minimum Rate

Completion Efficiency Concept

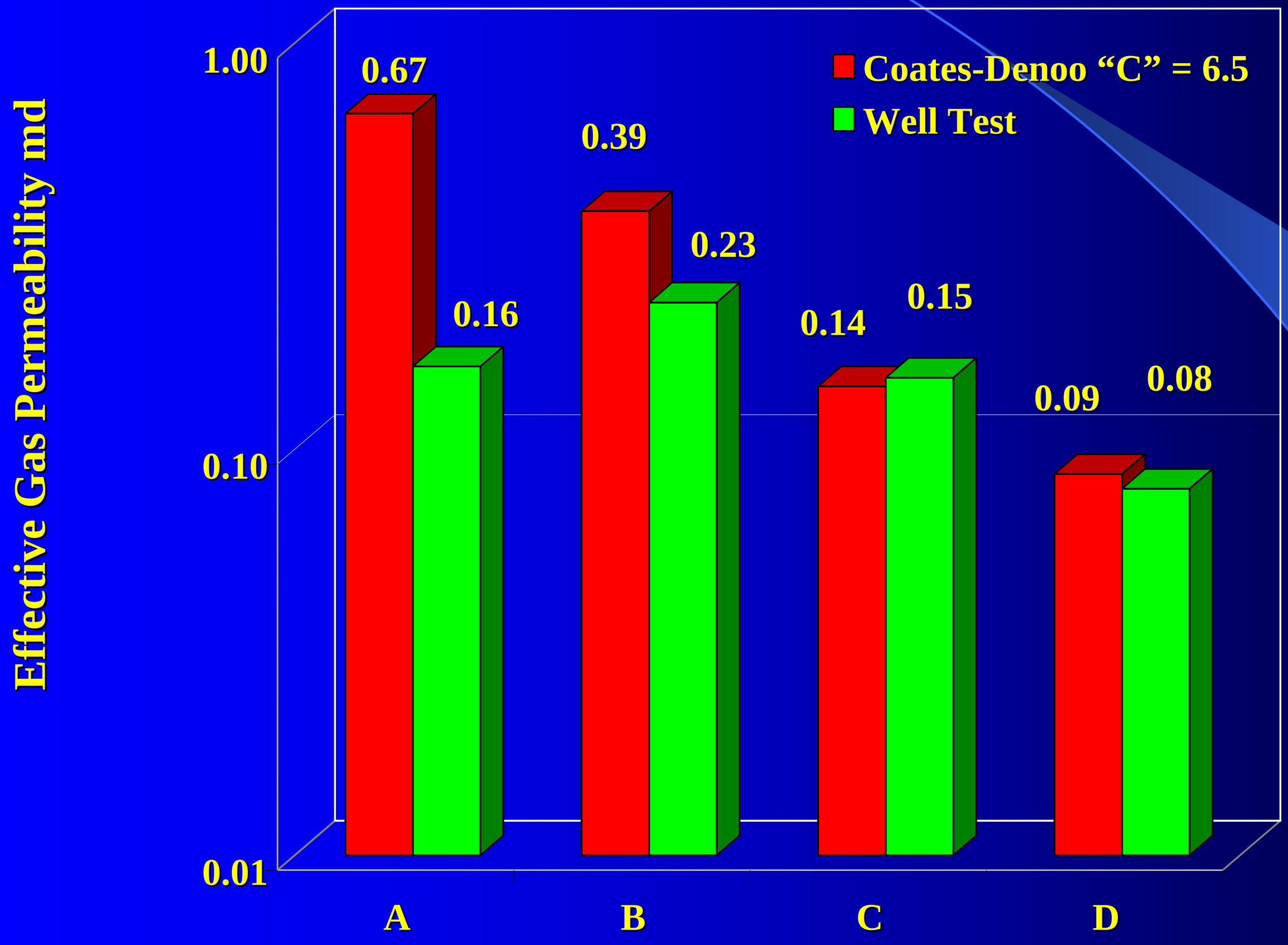


CE 100% if actual rate = rate with 600 ft infinite conductivity frac
Absolute minimum-elliptical drainage not square

CE Model Permeability Calibration

- Field *kh* from pressure transient test or flow test
- *Kh* using Coates-Denoo model:
  - $Kh = \Sigma[(C * \Phi^2 * (\Phi - B_{vw})/B_{vw}))^2]$
  - Vary "C" until *kh*=field *kh*
  - Used worldwide with excellent results

CE Model Perm vs Well Test



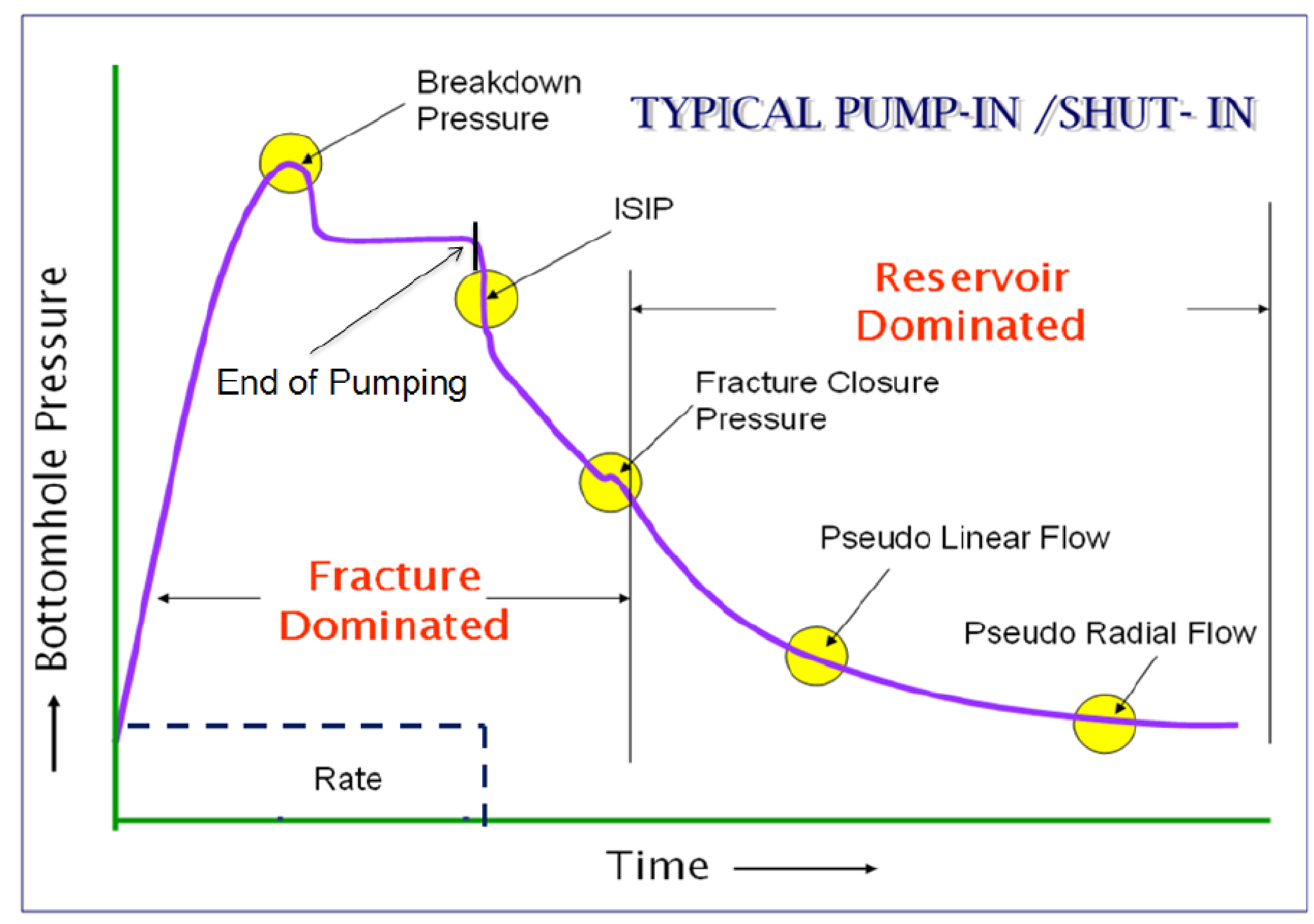
Well A was a multiple zone well test

SPE 90483

CE Model Pressure Calibration

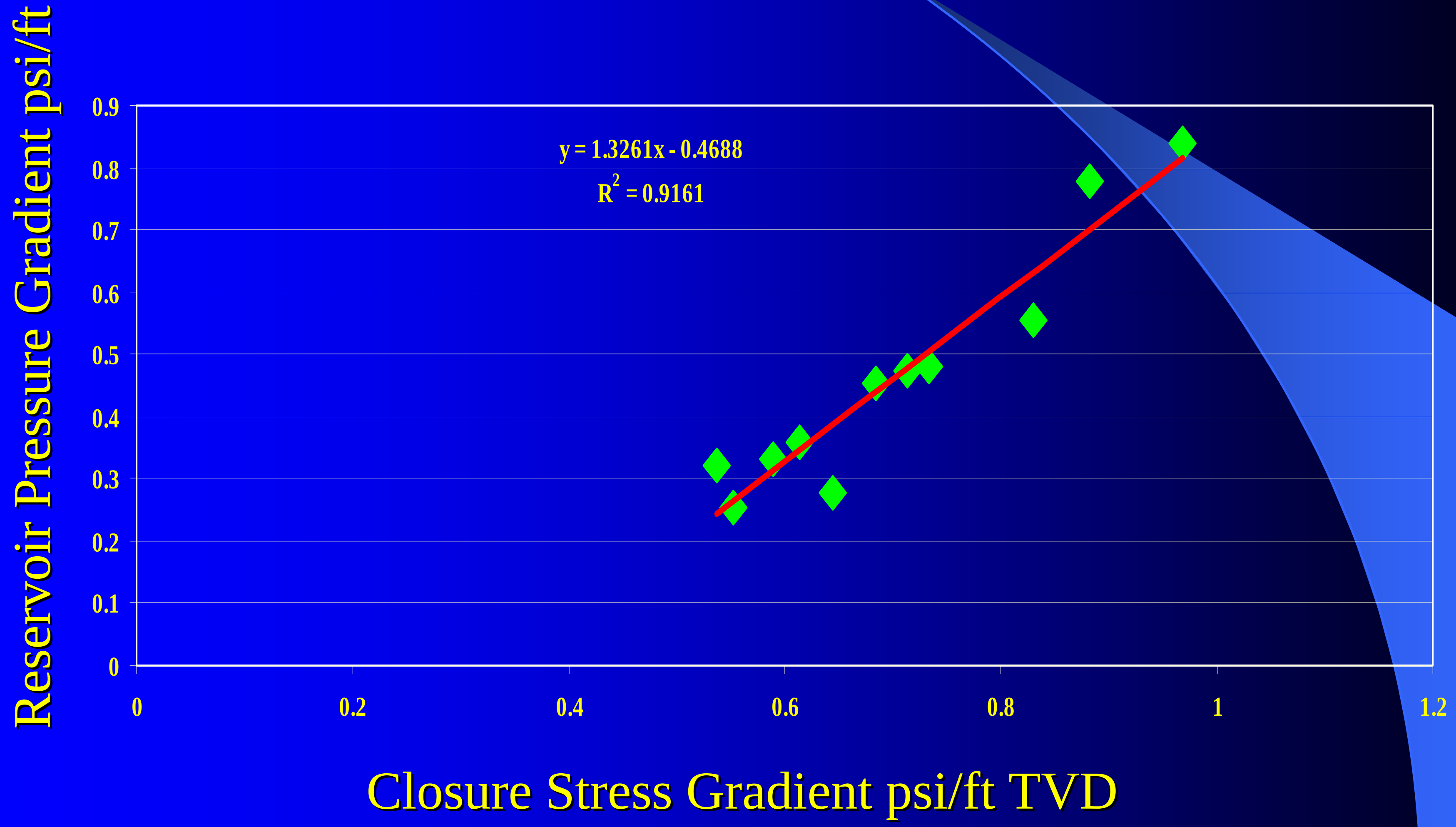
- Measured reservoir pressure vs pre-frac pump in test closure and/or ISIP
- Use pre-frac pump-in test results to estimate pressure at time of completion

DFIT Pressure Profile



Small volume pumped enough to initiate a fracture

Measured Reservoir Pressure vs Closure Pressure



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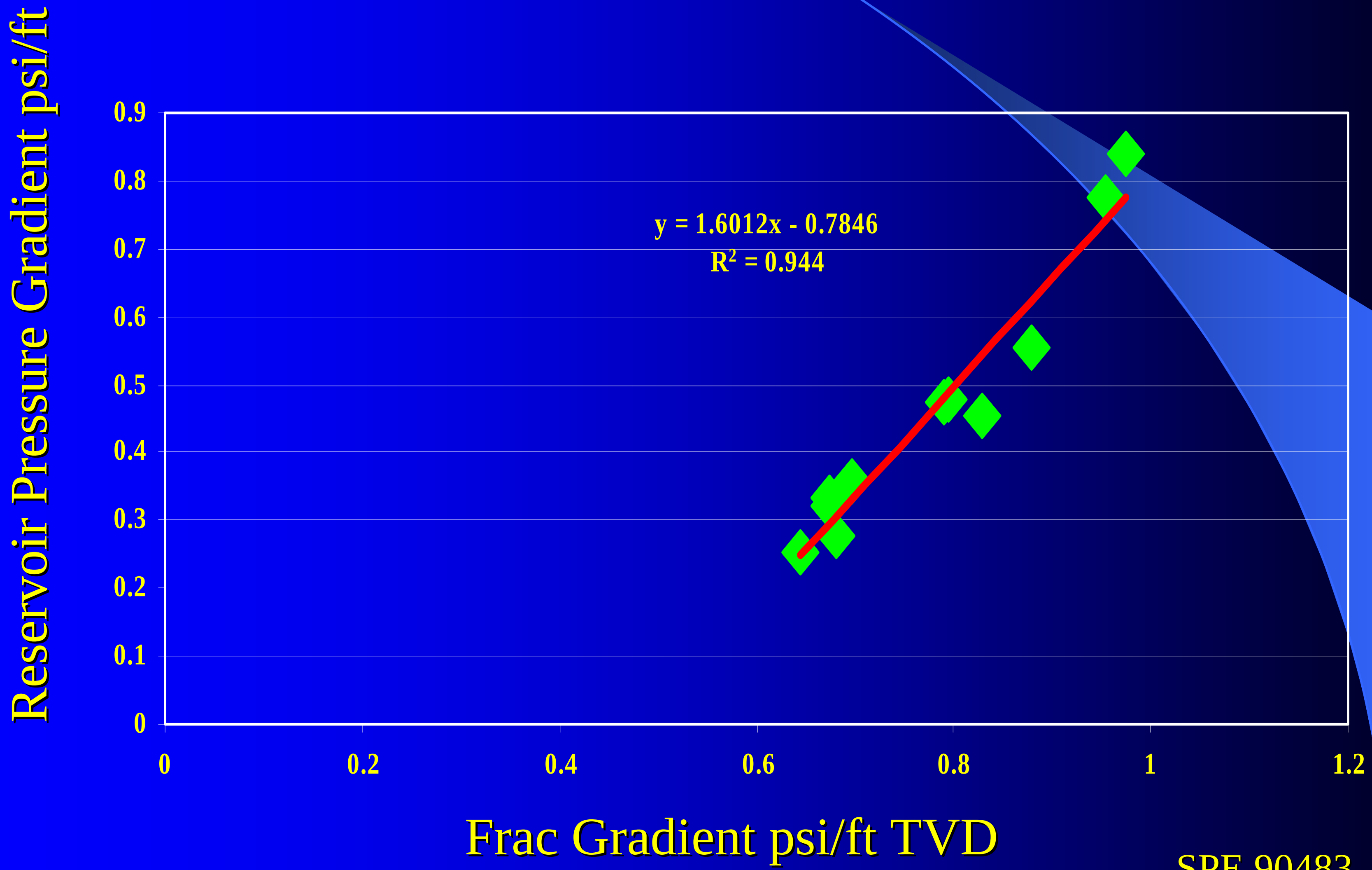
Measured Reservoir Pressure vs Frac Gradient



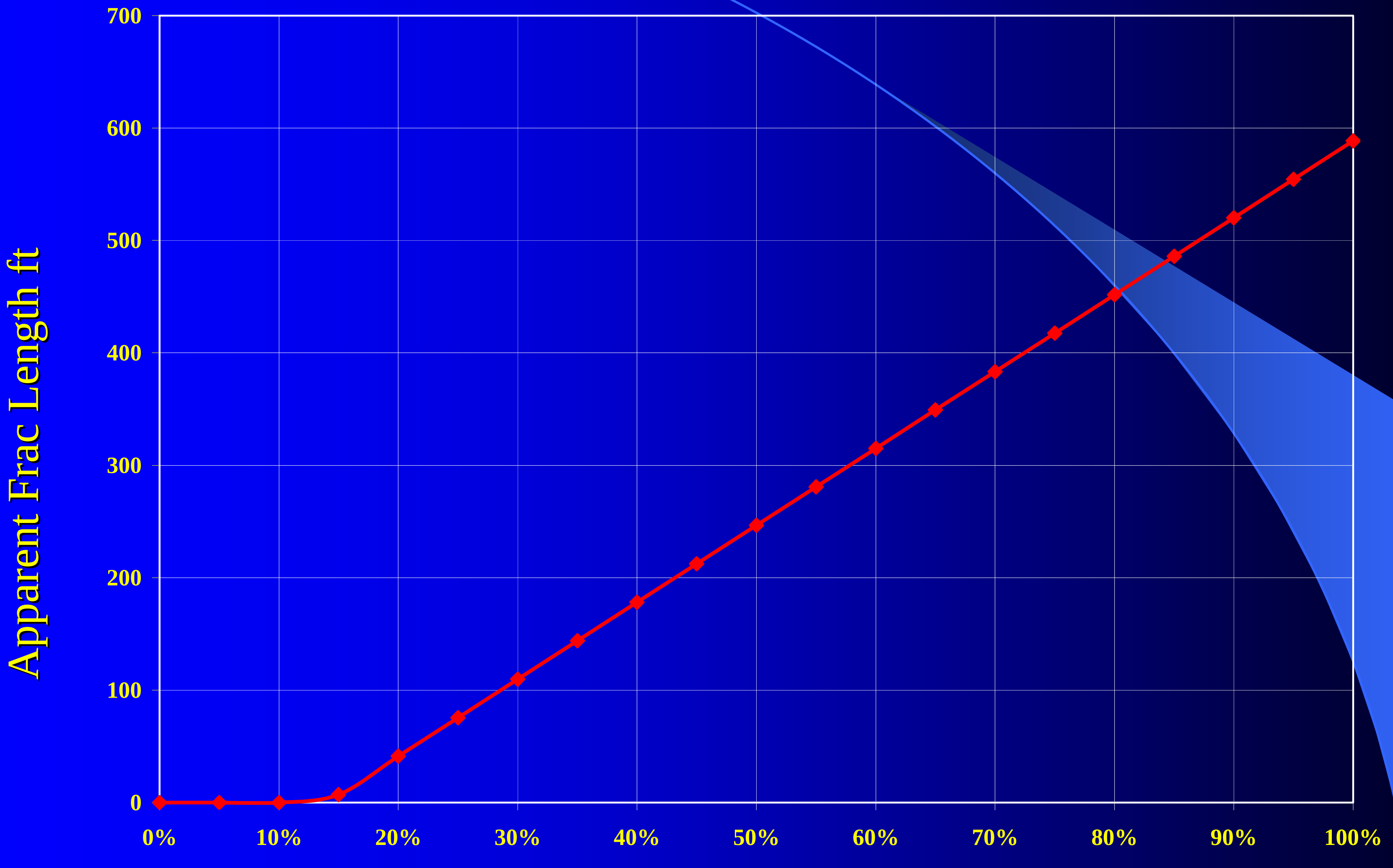
SPE 90483

2. Apparent Frac Length

- Vary X_f until model=actual rate
- Assume infinite conductivity
- Not true X_f -conductivity rarely infinite
- Qualitative frac efficiency index to compare relative performance

SPE 90483 and others

CE vs Apparent Frac Length



Completion Efficiency

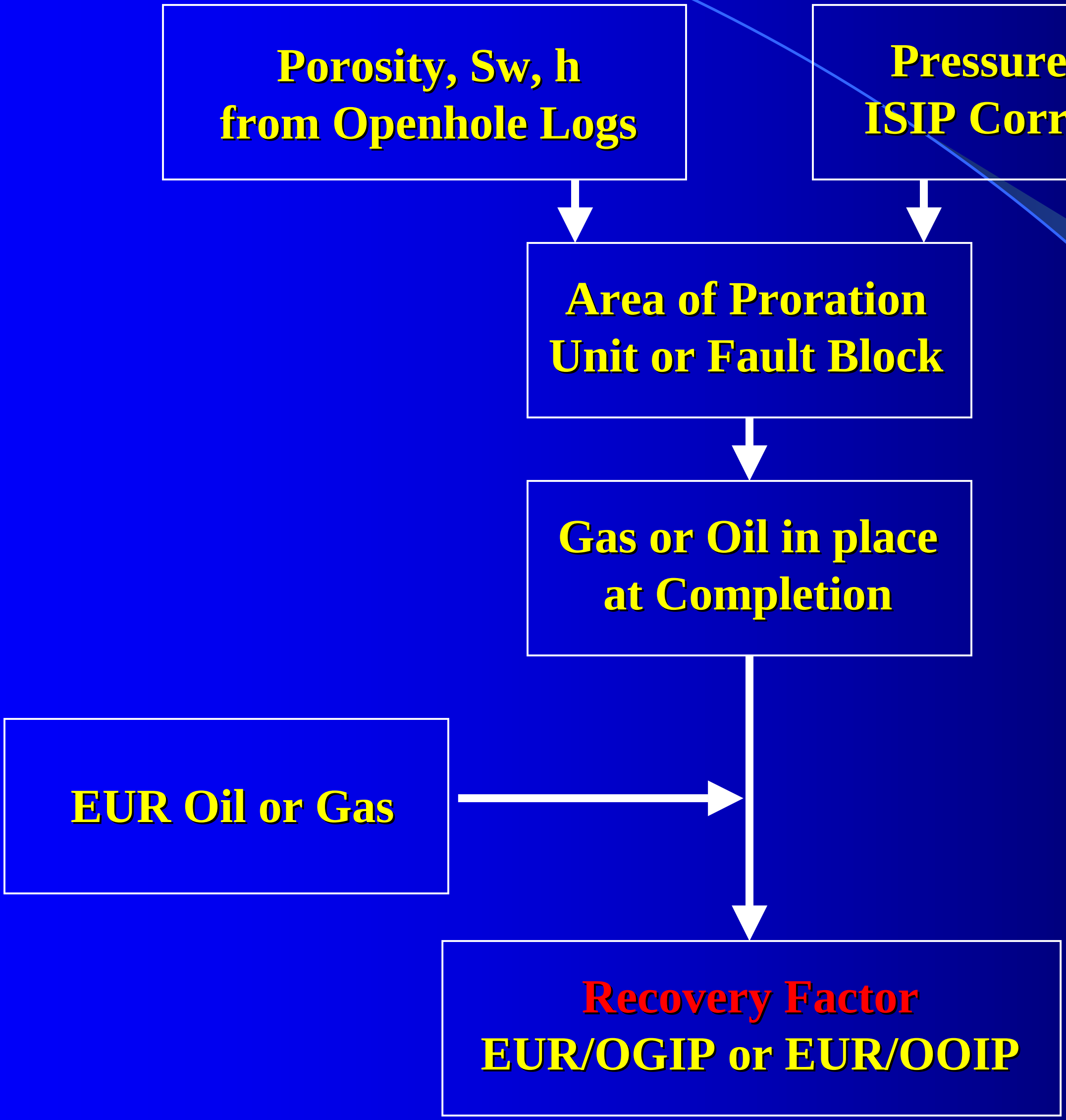
40 acre spacing 600 ft *Xf* minimum/200 mdft conductivity

3. Recovery Factor (RF)

- Estimate ultimate recovery from:
  - Decline curve
  - Rate vs cum production
  - Rate/transient
  - P/Z
- Estimate GIP for proration unit/fault block
- RF=EUR/GIP or EUR/OIP

SPE 90483 and others

Recovery Factor Flow Chart



Porosity, Sw, h
from Openhole Logs

Pressure from
ISIP Correlation

Area of Proration
Unit or Fault Block

Gas or Oil in place
at Completion

EUR Oil or Gas

Recovery Factor
EUR/OGIP or EUR/OOIP

4. Production Analysis

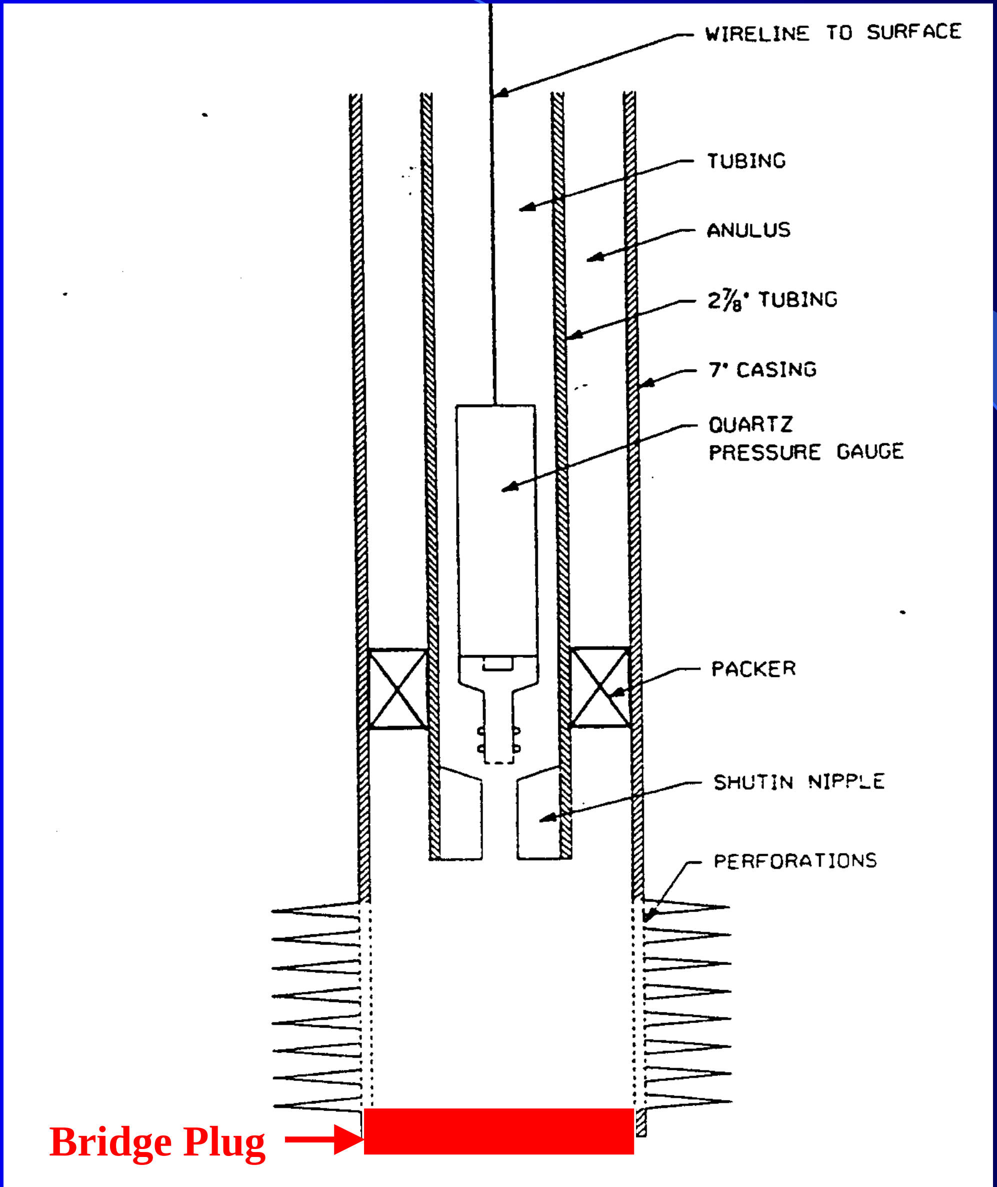
- RPI or rate-transient analysis
- Good for well performance and EURs
- Multiple zone performance-limited
- Results typically consistent with CE and RF
- Linear flow analysis useful for gas shales

SPE 37409 (Crafton 1997) (RPI)
Fetkovich (1980) (rate-transient type curve analysis)

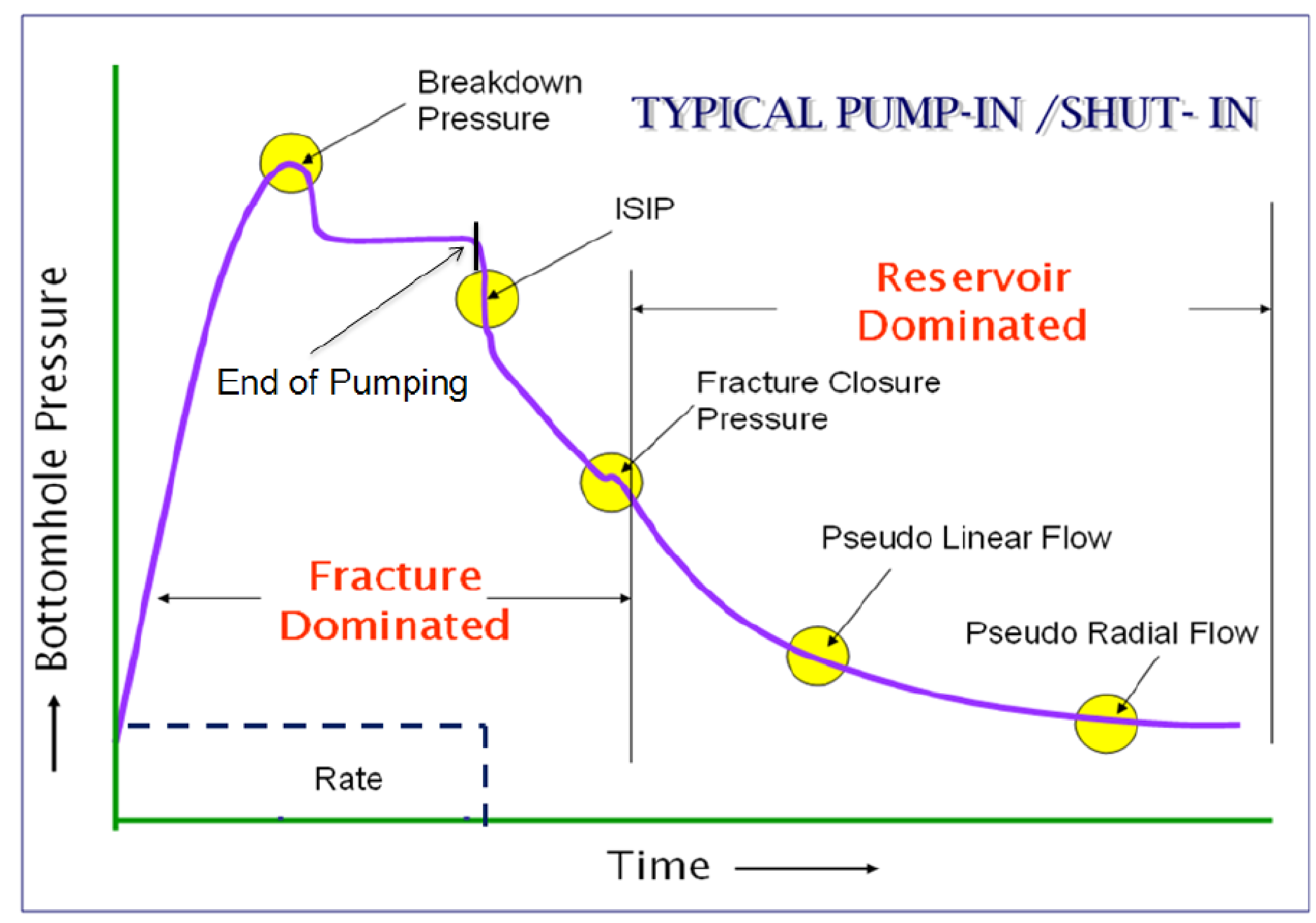
Key Refrac Candidate Issues

- What zones contain the remaining producible hydrocarbons?
  - How are the hydrocarbons distributed?
    - Petrophysical analysis combined with PLT
  - What is the current reservoir pressure in each zone?
    - Where did the primary fracture go?
    - What is left in the secondary zones?

Zonal Pressure Testing Hardware



Injection Testing Pressure Response

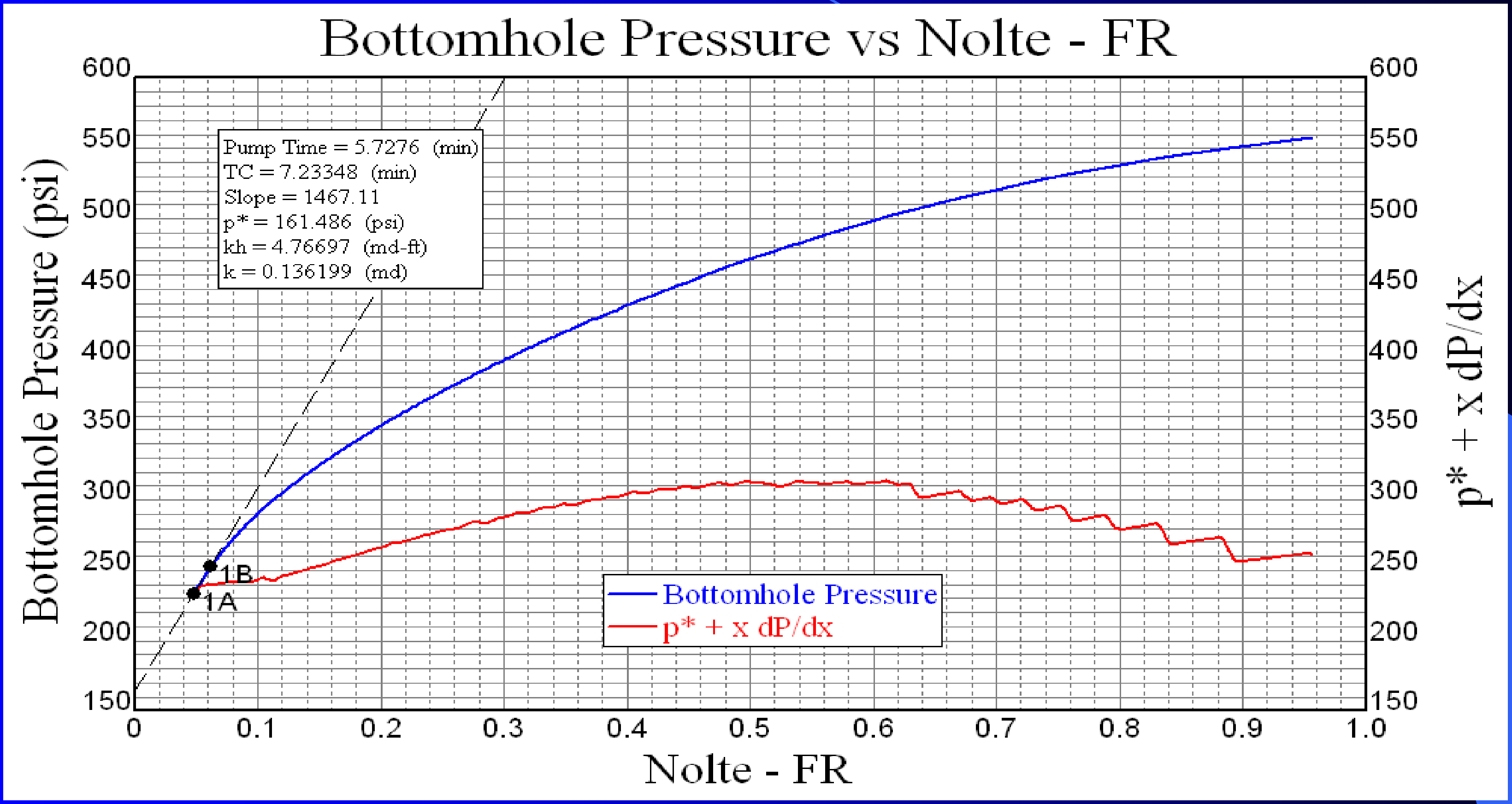


QC data with log-log plot to determine radial flow
Small volume pump-ins do not require type curve analysis

Zonal Pressure Testing

- Existing perforated intervals can be straddled with assembly and pressures obtained from static buildup and/or injection/falloff testing (DFIT or diagnostic fracture injection test)
- Over 60 tests successfully executed to date using hardware described
- System displayed used surface readout and downhole shut-in
- Can use memory gauges

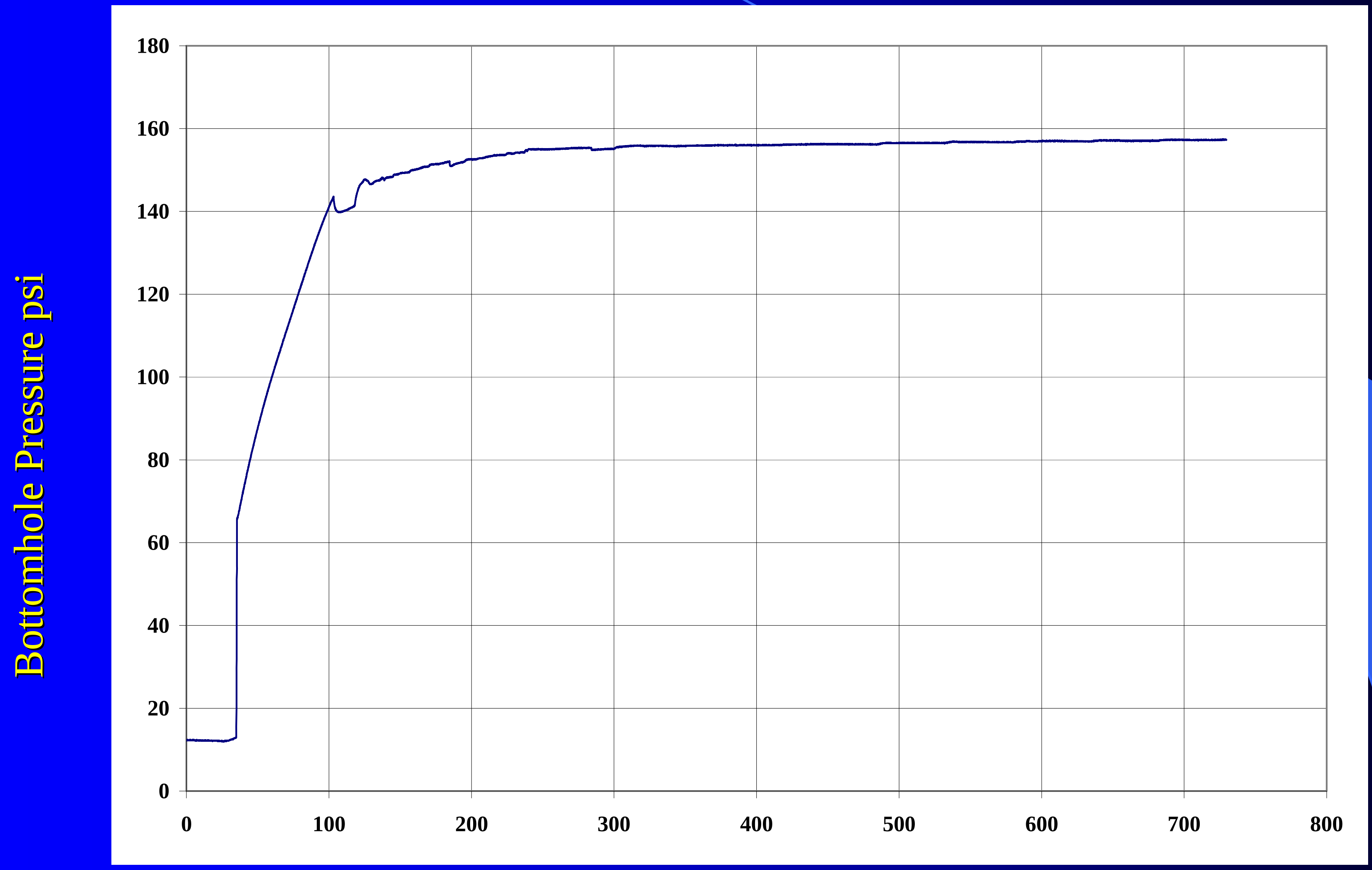
Zonal Pressure Testing Example



Pump Time = 5.7276 (min)
TC = 7.23348 (min)
Slope = 1467.11
p* = 161.486 (psi)
kh = 4.76697 (md-ft)
k = 0.136199 (md)

QC data with log-log plot to determine radial flow
Small volume pump-ins do not require type curve analysis

Zonal Pressure Testing Example



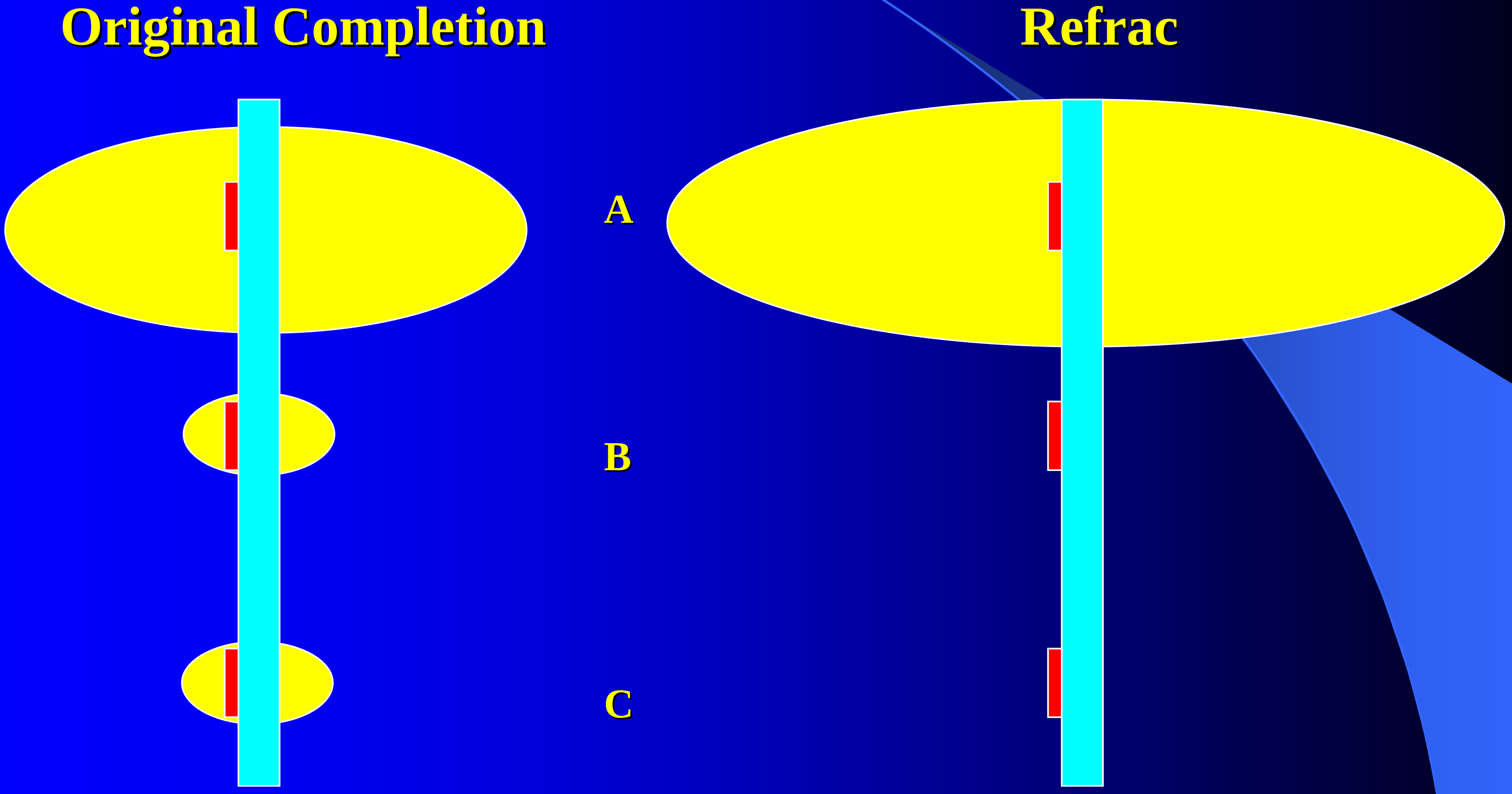
Time (Seconds)

Static buildup pressure using downhole shut-in-gives minimum pressure

Key Refrac Candidate Issues

- How do you access the remaining producible reserves with a refrac?
  - Frac all existing perfs together?
    - “Eastwood” frac
  - How do you frac below existing perfs?

Multiple Zone Scenario

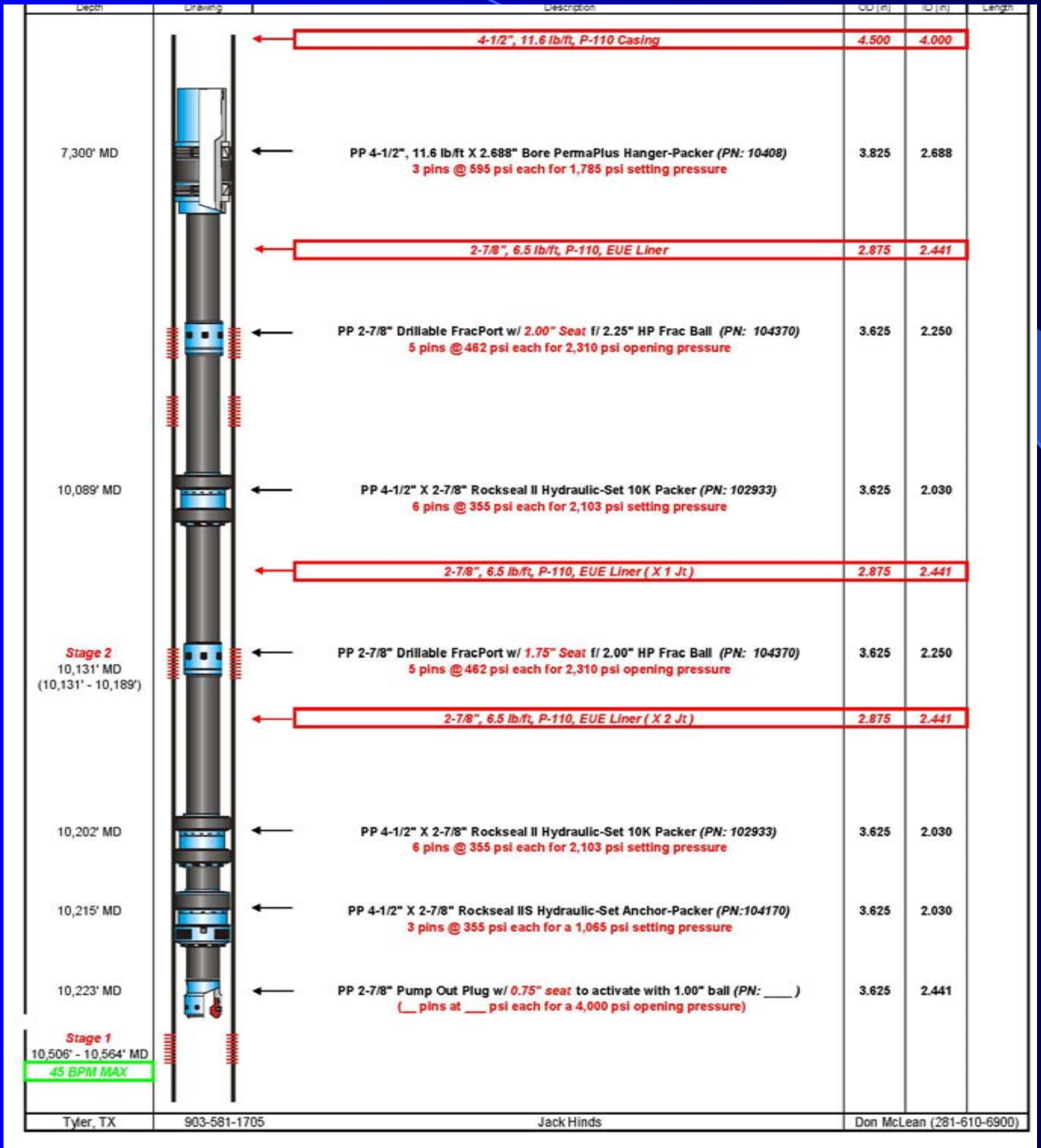


“Eastwood” frac goes where gas was

Refrac Options Below Existing Perfs

- Packer and bridge plug
    - Get proppant above packer-often problematic
- Coiled tubing
    - Limited to treatment down tubing
- Metal liners
- Casing patches (Pengo/Owen)
- Openhole swell packers
- Openhole mechanical packers (preferred)

Mechanical Packer Example



Depth	Drawing	Description	OD (in)	ID (in)	Length
		4-1/2", 11.6 lb/ft, P-110 Casing	*4.500*	*4.000*	
7,300' MD		**PP 4-1/2", 11.6 lb/ft X 2.688" Bore PermaPlus Hanger-Packer *(PN: 10408)*** **3 pins @ 595 psi each for 1,785 psi setting pressure**	3.825	2.688	
		2-7/8", 6.5 lb/ft, P-110, EUE Liner	*2.875*	*2.441*	
		PP 2-7/8" Drillable FracPort w/ *2.00" Seat* f/ 2.25" HP Frac Ball *(PN: 104370)* **5 pins @ 462 psi each for 2,310 psi opening pressure**	3.625	2.250	
10,089' MD		**PP 4-1/2" X 2-7/8" Rockseal II Hydraulic-Set 10K Packer *(PN: 102933)*** **6 pins @ 355 psi each for 2,103 psi setting pressure**	3.625	2.030	
		2-7/8", 6.5 lb/ft, P-110, EUE Liner (X 1 Jt)	*2.875*	*2.441*	
Stage 2 10,131' MD (10,131' - 10,189')		**PP 2-7/8" Drillable FracPort w/ *1.75" Seat* f/ 2.00" HP Frac Ball *(PN: 104370)*** **5 pins @ 462 psi each for 2,310 psi opening pressure**	3.625	2.250	
		2-7/8", 6.5 lb/ft, P-110, EUE Liner (X 2 Jt)	*2.875*	*2.441*	
10,202' MD		**PP 4-1/2" X 2-7/8" Rockseal II Hydraulic-Set 10K Packer *(PN: 102933)*** **6 pins @ 355 psi each for 2,103 psi setting pressure**	3.625	2.030	
10,215' MD		**PP 4-1/2" X 2-7/8" Rockseal IIS Hydraulic-Set Anchor-Packer *(PN:104170)*** **3 pins @ 355 psi each for a 1,065 psi setting pressure**	3.625	2.030	
10,223' MD		**PP 2-7/8" Pump Out Plug w/ *0.75" seat* to activate with 1.00" ball *(PN: ____)*** **(__ pins at ___ psi each for a 4,000 psi opening pressure)**	3.625	2.441	
Stage 1 10,506' - 10,564' MD *45 BPM MAX*					
Tyler, TX	903-581-1705	Jack Hinds	Don McLean (281-610-6900)		

Mechanical Packer Vertical Well Refracs as of Q2 2009 (2 Vendors)

Location	Formation	Size of Tools	# Stages	Type of Stim. System	FracPort/FracJet Information
Lipscomb County TX	Cleveland Sand	4-1/2" x 2-7/8"	4	StackFrac	Drillable FracPorts
Lipscomb County TX	Cleveland Sand	4-1/2" x 2-7/8"	5	StackFrac	Drillable FracPorts
Lipscomb County TX	Cleveland Sand	4-1/2" x 2-7/8"	5	StackFrac	Drillable FracPorts
Hemphill County, TX	Granite Wash	5-1/2" x 3-1/2"	2	StackFrac	Drillable FracPorts
Lipscomb County TX	Cleveland Sand	4-1/2" x 2-7/8"	4	StackFrac	Drillable FracPorts
Lipscomb County TX	Cleveland Sand	4-1/2" x 2-7/8"	4	StackFrac	Drillable FracPorts
Sublette County, WY	Frontier Sandstone	4-1/2" x 2-7/8"	2	StackFrac	Drillable FracPorts
Lipscomb County TX	Cleveland Sand	4-1/2" x 2-7/8"	4	StackFrac	Drillable FracPorts
Lipscomb County TX	Cleveland Sand	4-1/2" x 2-7/8"	5	StackFrac	Drillable FracPorts
Lipscomb County TX	Cleveland Sand	4-1/2" x 2-7/8"	5	StackFrac	Drillable FracPorts
Van Buren County, AR	Fayetteville Shale	5-1/2" x 3-1/2"	7	StackFrac	Drillable FracPorts
Rusk County, TX	Cotton Valley	5-1/2" x 3-1/2"	6	StackFrac	Drillable FracPorts
Rusk County, TX	James Lime	5-1/2" x 3-1/2"	6	Stack Frac	Drillable FracPorts
Rusk County, TX	James Lime	5-1/2" x 3-1/2"	7	StackFrac	Drillable FracPorts
Cherokee County, TX	James Lime	5-1/2" x 3-1/2"	3	StackFrac	Drillable FracPorts
Rusk County, TX	James Lime	5 1/2" X 3 1/2"	4	Stack Frac	Drillable FracPorts
Lincoln Parish, LA	Cotton Valley	7-5/8" X 4-1/2"	5	StackFrac	Drillable FracPorts
Panola County, TX	Cotton Valley	4-1/2" x 2-7/8"	3	StackFrac	Drillable FracPorts
Rusk County, TX	Cotton Valley	5-1/2" x 3-1/2"	6	StackFrac	Drillable FracPorts
Upshur County, TX	James Lime	4-1/2" x 2-7/8"	1	Stack Frac	Drillable FracPorts
Rusk County, TX	James Lime	4-1/2" x 2-7/8"	6	StackFrac	Drillable FracPorts
Sublette County, WY	Pinedale	4-1/2" x 2-7/8"	3	StackFrac	Drillable FracPorts

Formation	Casing	Size of System OD - ID	Thread	Number of Sections	Number of Packers	Success	Equipment
Barnett Shale	5.5" 17#	435-281	3 1/2" 8RD	4	4	YES	Ball Actuated Frac-Sleeves, and Open-Hole Packers between Zones
Cotton Valley	5-1/2"17#	435-281	3 1/2" EUE 8RD	3	4	YES	Ball Actuated Frac-Sleeves, and Open-Hole Packers between Zones
Cotton Valley	4-1/2" 15.10#	365-237	2 7/8" BTS-6	2	4	YES	Mechanical Sliding-Sleeves, and Open-Hole Packers between Zones
Cotton Valley	4-1/2" 15.10#	365-237	2 7/8" BTS-6	3	4	YES	Mechanical Sliding-Sleeves, and Open-Hole Packers between Zones
Lobo	4-1/2" 13.50#	365-237	2 7/8" 8 RD	2	4	YES	Ball Actuated Frac-Sleeves, and Open-Hole Packers between Zones
Cotton Valley	4-1/2" 11.6#	365-237	2 7/8" EUE 8RD	4	4	YES	Ball Actuated Frac-Sleeves, and Open-Hole Packers between Zones
Lower Vicksburg	5" 23.2	365-237	2 7/8" LTC	2	1	YES	Ball Actuated Frac-Sleeves, and Open-Hole Packers between Zones

Conclusions

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Conclusions

- If remaining producible gas reserves can be accessed with refracs the economics can be attractive even at low gas prices
- The candidate selection and treatment execution steps are relatively straightforward and use off-the-shelf hardware and software
- The techniques have the potential to significantly improve the success rate and economics of refracture treatments