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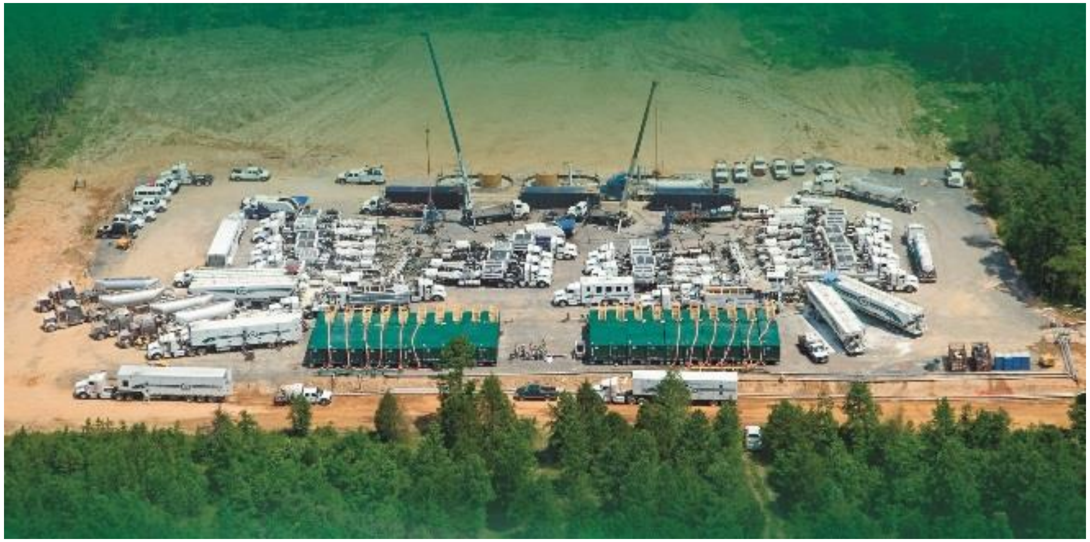
# REDEFINING REFRACS

## What Is, What Isn't, & What Might Be…




Eric G. Schmelzl

VP Strategic Business

NCS Multistage

# OUTLINE

- Refrac Activity & Challenges
- Refrac Diagnostics
- The IDEAL Refrac
- Hypothesis:

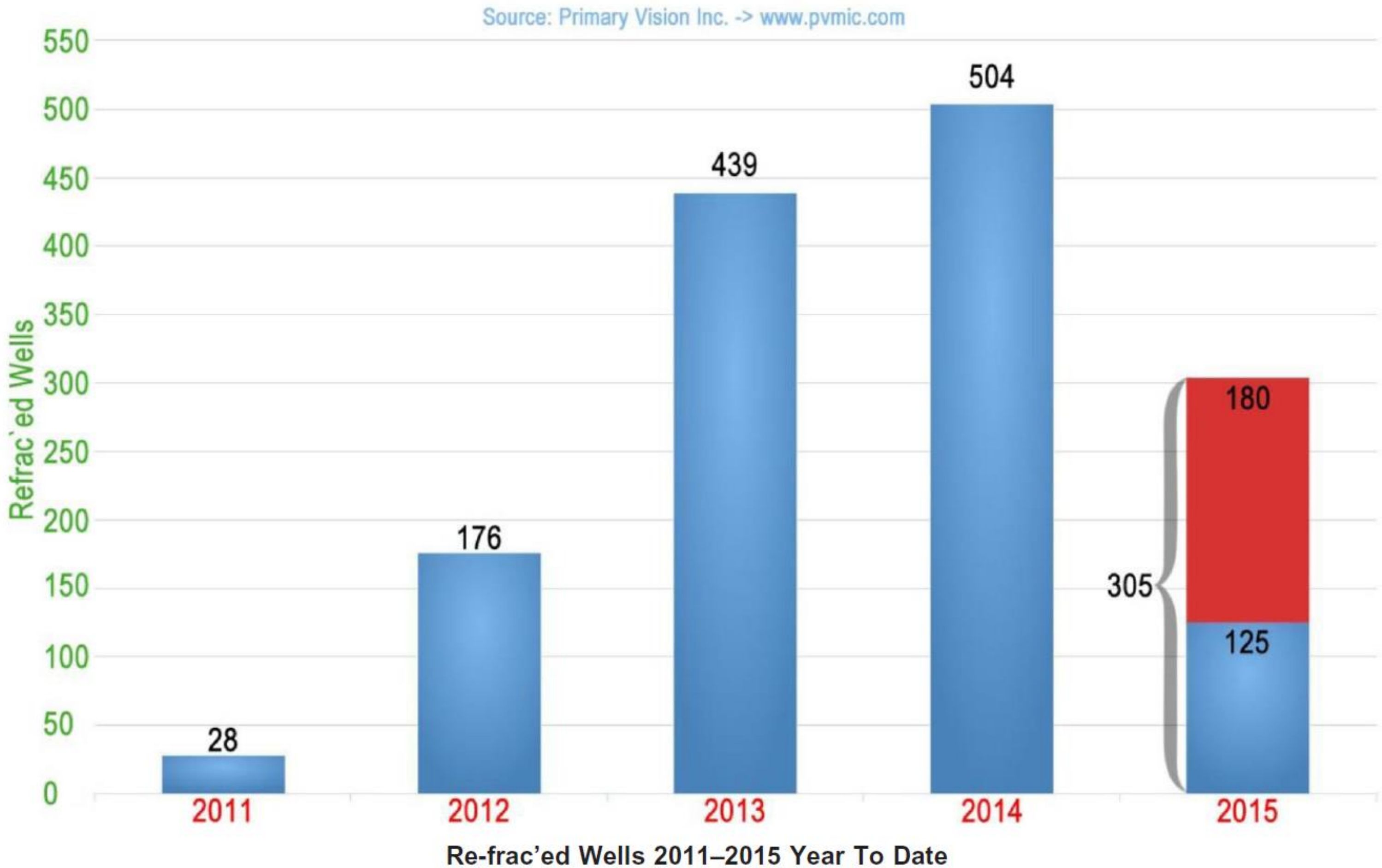
  New Tools

  \+ New Options

  = New Results?

*Hydraulic fracturing operations in the Montney Canada. Calfrac Well Services Photo.*

# REFRACS STILL HAPPEN….

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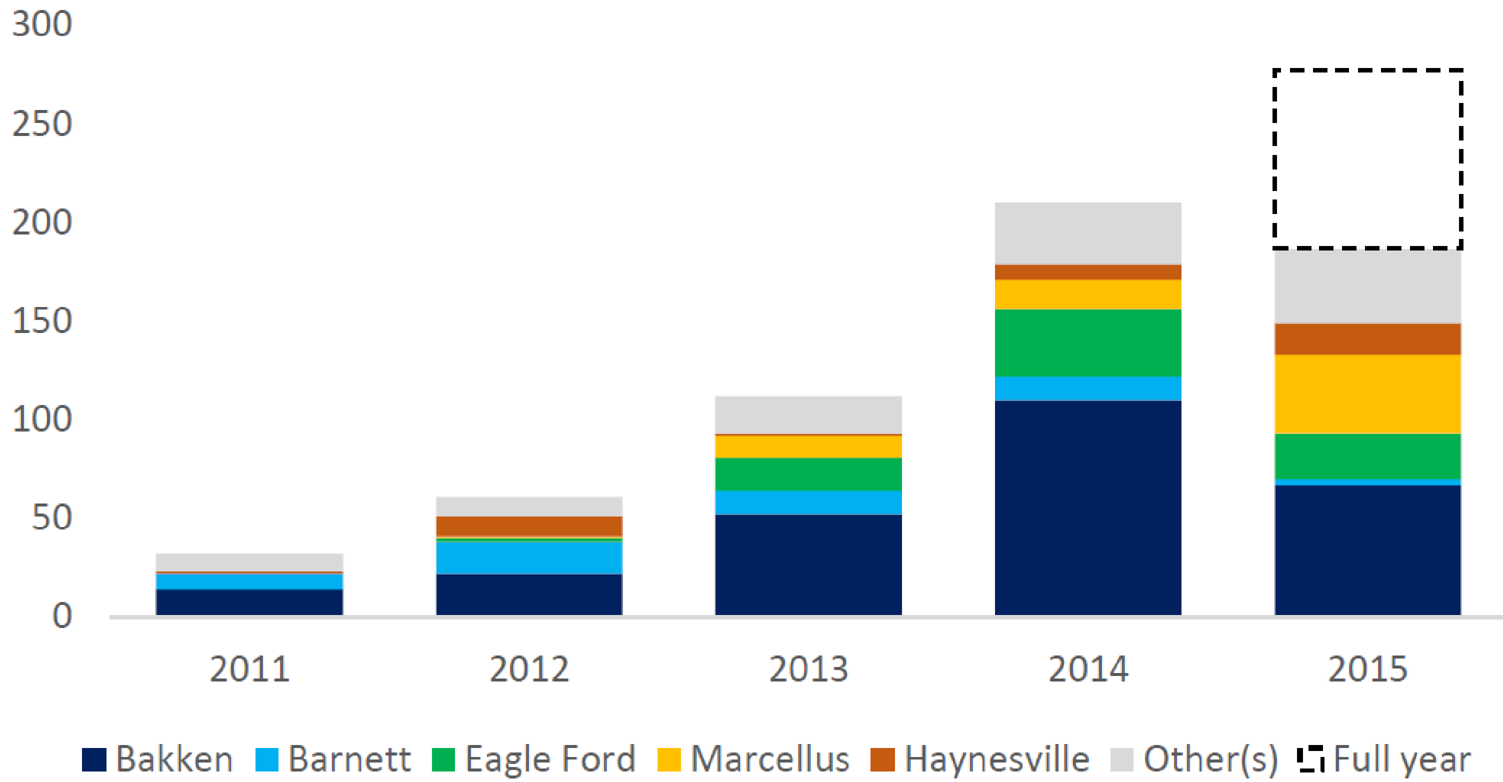
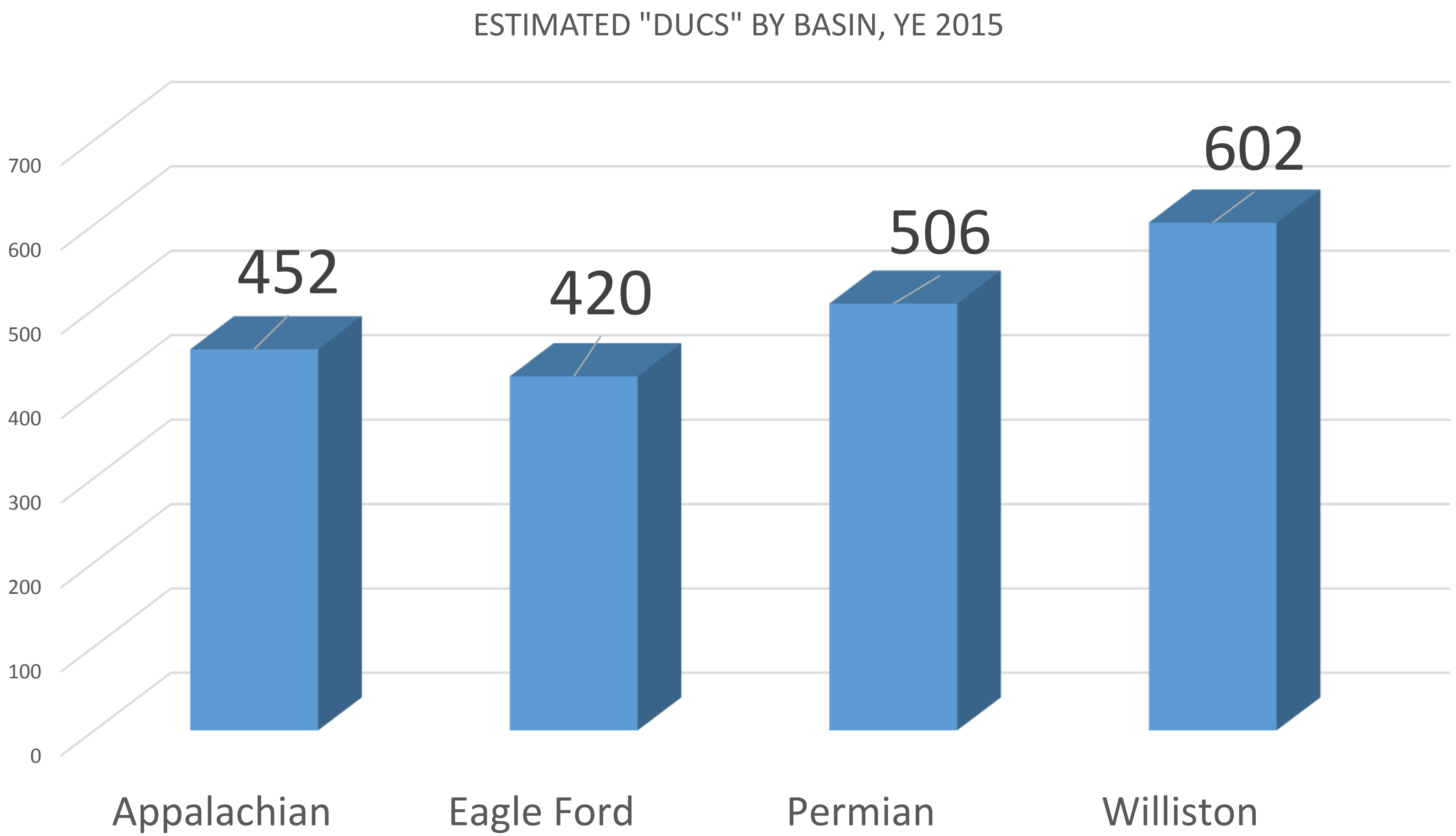
# WHERE DO WE REFRAC?




*Number of refractured horizontal wells by play, as of August 2015. Source: Rystad Energy NASWellData and Rystad Energy analysis.*

# DUC's vs. REFRACS




Data From Navport Analytics

# One Days Headlines, April 2016….

- ***Breaking:*** Goodrich Eyes Bankruptcy After Lackluster Offering

- Chaparral Warns of Bankruptcy; $1.6B in Debt

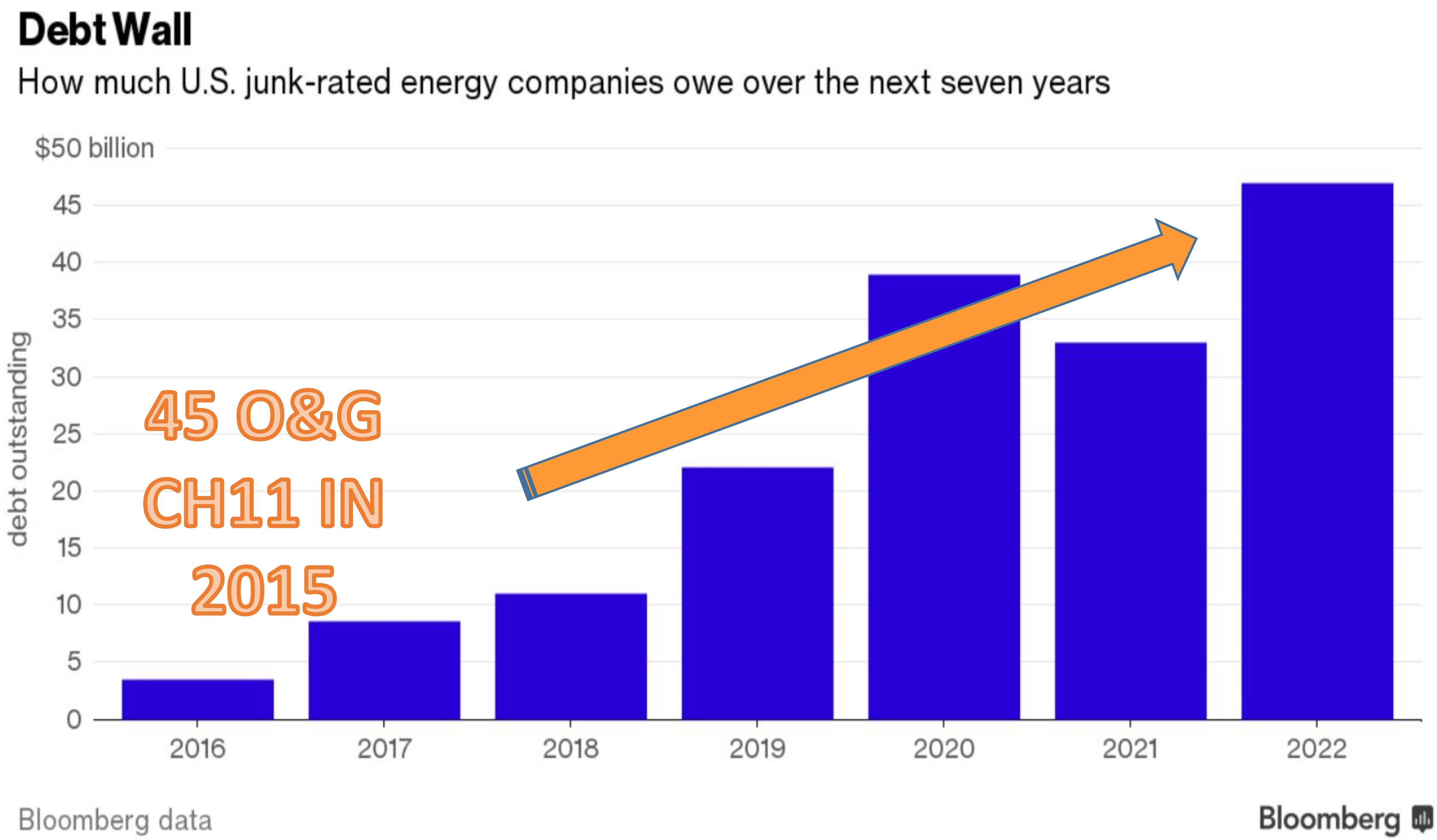
- Midstates Saddled with $1.9 Billion in Debt; Heading for Bankruptcy

- Southcross Parent Files Chapter 11 Bankruptcy

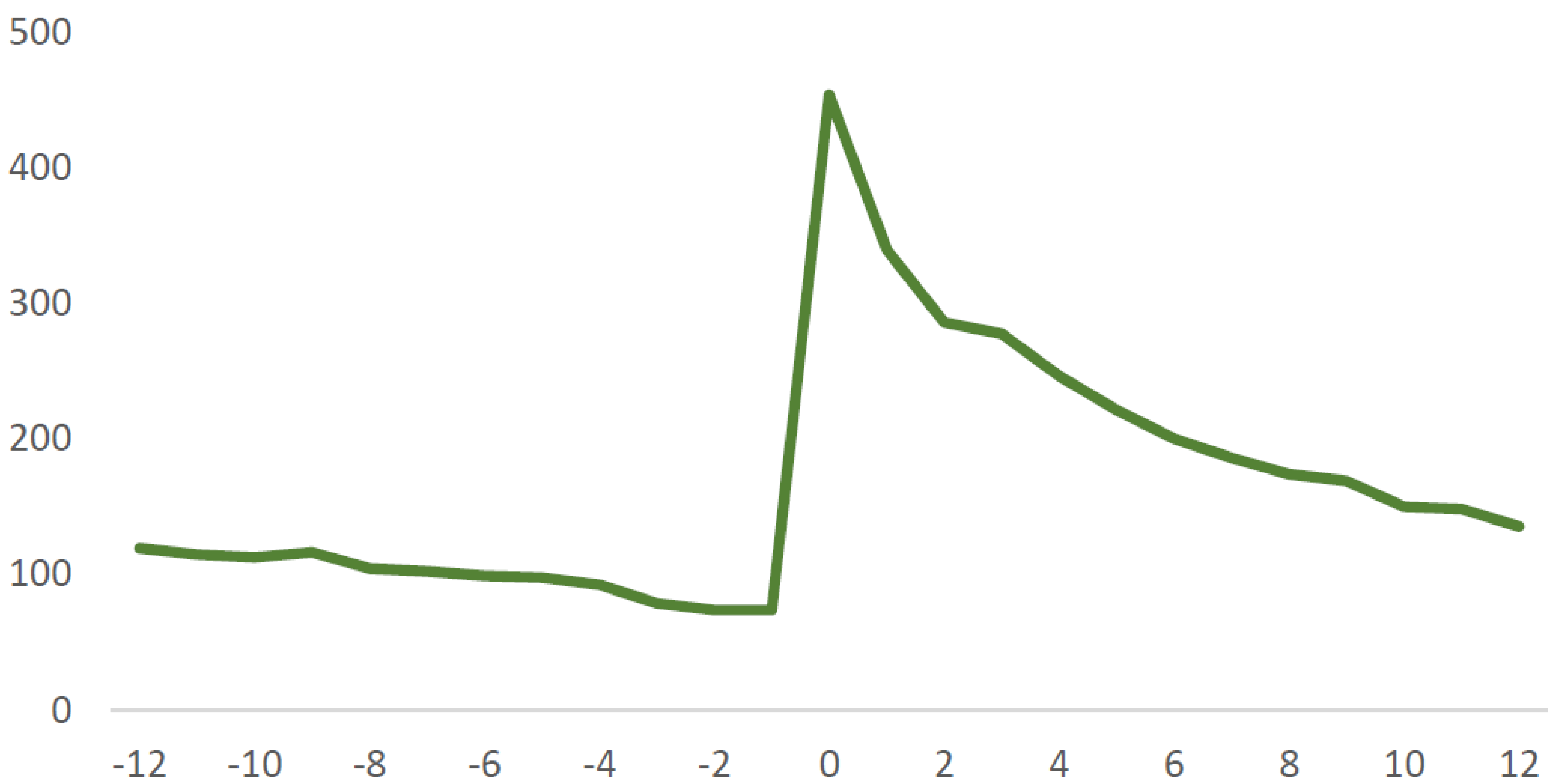
- W&T Offshore Credit Line Cut 60%; Heading for Bankruptcy

- Bakken E&P Black Ridge Talks Restructuring Plans

# LOWER FOR LOOOONGER ?



# *WHY REFRAC?*




*Average daily production (boe/d) for Bakken wells refracked in 2014 and 2015.*

*Rystad Energy NASWellData and Rystad Energy analysis.*

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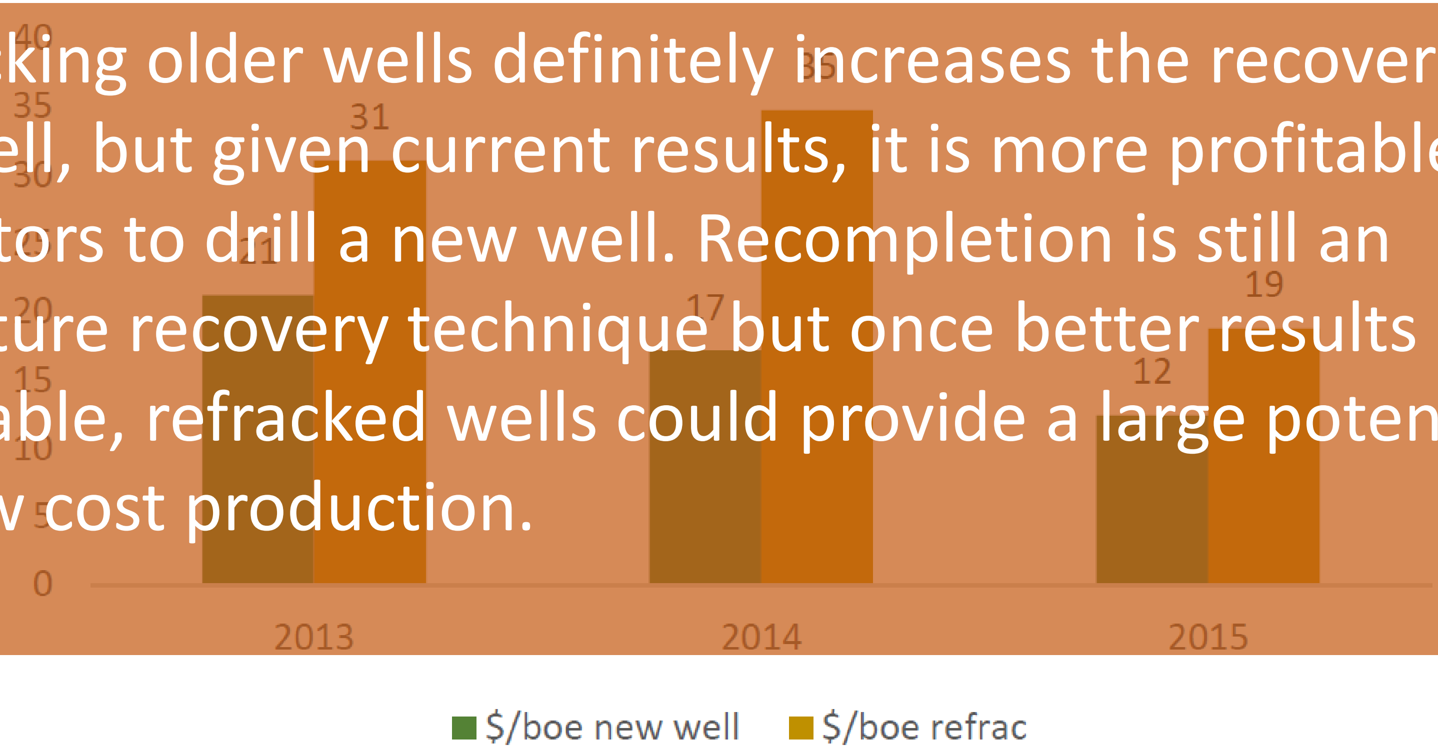
# WHY REFRAC?

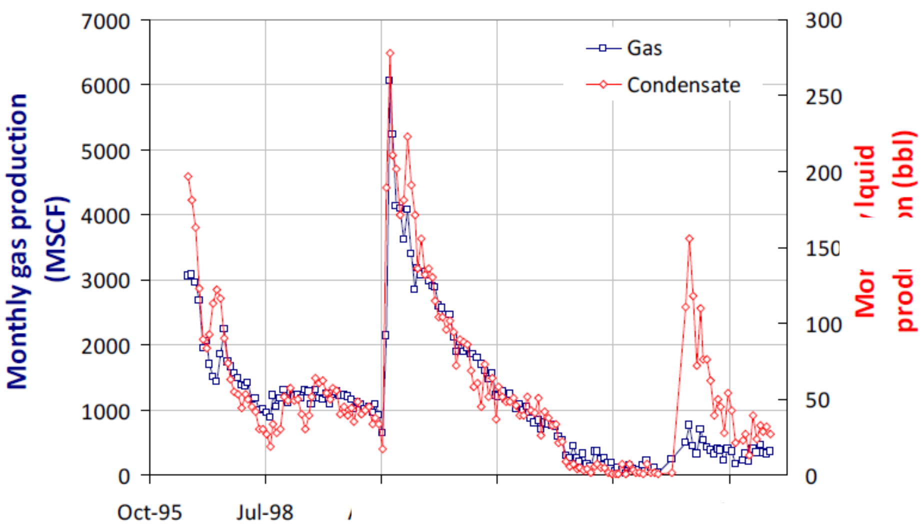
Refracking older wells definitely increases the recovery of the well, but given current results, it is more profitable for operators to drill a new well. Recompletion is still an immature recovery technique but once better results are replicable, refracked wells could provide a large potential for low cost production.



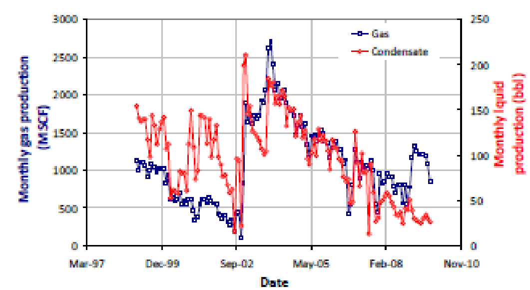

*Development cost per boe for Bakken wells compared to refrack wells in each year.*

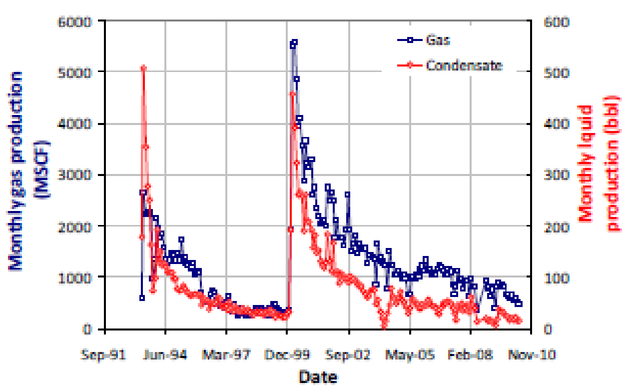
*Rystad Energy NASWellData and Rystad Energy analysis.*

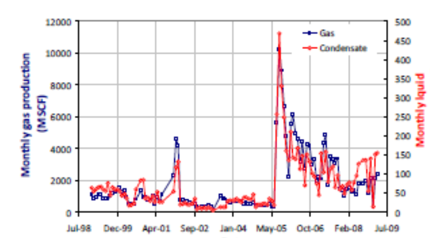
# *SUCCESSFUL REFRACS*




1. Increase EUR &/or
2. Provide Rate Acceleration




Ref: RPSEA Report
M. Sharma

# *REFRACS CAN*

1. RESTORE FRACTURE CONDUCTIVITY
   (Re-Touch “Old” Rock)
2. FRAC NEW ROCK
   - ADD FRAC STAGES (Reduce Stage Spacing)
   - Diversion & Reorientation
3. APPLY NEW FRAC LEARNINGS
   (Fluids, Proppants, Chemistry etc)
4. PROVIDE FRAC-HIT “PROTECTION”
5. PRESERVE CAPITAL

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# DATA, STUDIES, SUMMARIES & COMMONALITIES

**Refracs: Why Do They Work, and Why Do They Fail in 100 Published Field Studies?**

Vincent, Mike C., Insight Consulting

134330-MS SPE Conference Paper - 2010

**Restimulation of Unconventional Reservoirs: When are Refracs Beneficial?**

Vincent, Mike C., Insight Consulting

136757-MS SPE Conference Paper - 2010

**Lessons Learned: Refracs from 1980 to Present**

Grieser, Bill, Halliburton
Calvin, James, Halliburton
Dulin, James, formerly Halliburton

179152-MS SPE Conference Paper - 2016

**A Case History of Refracs in the Oak Hill (Cotton Valley) Field**

Hunter, J.C., Graham Resources Inc.

14655-MS SPE Conference Paper - 1986

**Stress Field Change Due to Reservoir Depletion and Its Impact on Refrac Treatment Design and SRV in Unconventional Reservoirs**

Han, Jiahang, Baker Hughes
Hurt, Robert, Baker Hughes
Sookprasong, Andy, Baker Hughes

178496-MS SPE Conference Paper - 2015

**Surface Tiltmeter Mapping Shows Hydraulic Fracture Reorientation in the Codell Formation, Wattenberg Field, Colorado**

Wolhart, Stephen Lee, Pinnacle Technologies
McIntosh, Gregory Edward, Kerr-McGee Rocky Mountain Corp.
Zoll, Michael Bruce, Noble Energy Inc.
Weijers, Leen, Pinnacle Technologies

110034-MS SPE Conference Paper - 2007

**A Commercial Evaluation of Refracturing Horizontal Shale Wells**

Indras, P., Wood Mackenzie
Blankenship, C., Wood Mackenzie

174951-MS SPE Conference Paper - 2015

# EXTENSIVE REFRAC LITERATURE



**References noted in paper text (additional references in Appendix)**


Asadi, M. et al, 2002: Monitoring Fracturing Fluid Flowback with Chemical Tracers: A Field Case Study. SPE 77750 presented at the 2002 Annual Technical Conference, San Antonio TX, Sept 29-Oct 2.
Bagzis, J.M., 1989: Refracturing pays off in the Rangely field. World Oi
Barba, R.E. 2009: A Novel Approach to Identifying Refracturing Candid Reservoirs. SPE 125008 presented at the SPE Annual Technical Meet
Benedict, D.S. and Miskimins, J.L. 2009: Analysis of Reserve Recovery Lenticular Reservoirs. SPE 119355 presented at the 2009 Hydraulic F
Besler, M.R. et al, 2007: Improving Well Productivity and Profitability i Stimulating, and Operating Horizontal Wells. Paper SPE 110679 pres 11-14.
Besler, M.R. 2008: Re-fracturing: Is Too Little Prevention Requiring the Conference, Minot ND, April 27-29.
Branch, G.A. and Drennan, K.M. 1991: Refracture Stimulations in the N the Production Operations Symposium, Oklahoma City, April 7-9.
Britt, L.K., et al 2006: Water-Fracs: We Do Need Proppant After All. SI Conference, San Antonio, Sept 24-27.
Brown, K.G. et al 2003: Assessment of Remediation Treatments in Und Annual Technical Conference, Denver, Oct 5-8.
Cipolla, C.L. 2005: The Truth about Hydraulic Fracturing – It's More C 2005-2006, SPE 108817.
Cipolla, C.L. et al. 2008: The Relationship between Fracture Complexity 115769 presented at the SPE Annual Technical Conference, Denver,
Cipolla, C.L., Lolon, E., and Dzubin, B., 2009: Evaluating Stimulation E 124843 presented at the 2009 Annual Technical Conference, New
Clawson, T. 2003: Production Enhancement in a Low Pressure CBM Re Conference, Denver, April 16, 2003.
Cobb, S.L. and Farrell, J.J. 1986: Evaluation of Long-Term Proppant St Petroleum Engineering, Beijing, Mar 17-20.
Conway, M.W. et al 1985: Expanding Recoverable Reserves Through R Conference, Las Vegas, NV, Sept. 22-25.
Coulter, G.R. and Menzie, D.E. 1973: The Design of Refrac Treatments presented at the SPE/AIME Rocky Mountain Regional Meeting, Casp
Coulter, G. R. et al, 2004: Water Fracs and Sand Quantity: A Barnett Sh Technical Conference, Houston, Sept. 26-29.
Craig, D.P. 2006: Analytical Modeling of a Fracture-Injection/Falloff Se Test. Dissertation, Texas A&M, May 2006.
Craig, D.P. and Odegard, C.E. 2008: Identifying Bypassed and Ineffecti from Multiple Layers: Mesaverde Case History. SPE 114777 presente Feb 10-12.
Craig, D.P. 2010: Shale Pressure Diagnostics: Pre-frac Reservoir Evalua Shale Completion Strategies Workshop, April 22, 2010. Discussion a
Cramer, D.D. 1995: The Evolution of Hydraulic Fracturing in the Almor Conference, Dallas, Oct 22-25.
Cramer, D.D. 2008: Stimulating Unconventional Reservoirs: Lessons Le 114172 presented at the Unconventional Reservoirs Conference, Keys
Crow, W.L., 1977: Mini Massive Frac – A Stimulation Technique for L at the 1977 AIME Eastern Regional Meeting, Pittsburgh, Oct 27-28.
Crowell, R.F. and Jennings, A.R. Jr. 1978: A Diagnostic Technique for I the Annual Fall Conference, Houston, Oct 1-3.
Dozier, G. et al. 2003: Refracturing Works. *Oilfield Review* Autumn 200
Dunek, K.L. et al, 2009: Far-Field Volumetric Distribution of Fracturing Formation. SPE paper 115826 presented at the Rocky Mountain Tech
Durrani, A.J et al, 1994: The Rejuvenation of 30-Year Old McAllen Ran Management. SPE paper 24872, *JPT*, Dec 1994.
Eberhard, M. and Mullen, M. 2003:The Effect of Completion Methodol 2003) 145.
Eberhard, M. 2008: Review of Current Bakken Practices, MT and ND. Minot ND, April 27-29.
Elbel, J.L. and Mack, M.G. 1993: Refracturing: Observations and Theor Symposium, Oklahoma City, OK, Mar 21-23.
Ely, J.W. et al, 2000: Restimulation Program Finds Success in Enhancin Technical Conference, Dallas, Oct 1-4.





Emrich, C. et al, 2001: Codell Restimulations Evolve to 200% Rate of Return. SPE 67211 presented at the 2001 Production Operations Symposium, Oklahoma City, Mar 24-27.
Ennis, B.K. 1989: Case History of Restimulations in Western Oklahoma. SPE 18861 presented at the 1989 SPE Production Operations Symposium, Oklahoma City, Mar. 13-14.
Esphahanian, C. and Storhaug, D.G 1997: A Statistical Approach to Pay Identification in the Tight, Fractured, Heterogeneous Reservoirs of the Piceance Basin, paper SPE 38366 presented at the 1997 Rocky Mountain Regional Meeting, Casper, Wyoming, 18-21 May.
Fetkovich, M.J. et al. 1990: Depletion Performance of Layered Reser
Fisher, K., Robinson, B.M., and Voneiff, G.W., 1995: A Comprehen Tracer Engineered Stimulation Procedures. SPE paper 30794 prese Dallas, Texas, 22-25 October.
Flores, D.Q. and Indriati, S. 2009: Finding Additional Resources in a Campaign in Vicksburg Basin, South Texas. SPE abstract 125260 Antonio, TX June 15-17.
Fleming, M.E. et al. 1992: Successful Refracturing in the North West Oil and Gas Recovery Conference, Midland, March 18-20.
Garland, T.M et al. 1957: Effects of Hydraulic Fracturing Upon Oil F USBM, RI 5371.
Gil, I.R. et al 2007: "Super Height Growth" – Strange Surface Pressu Fracturing Technology Conference, College Station, TX, Jan 29-3
Ghauri, W.K. 1980: Results of Well Stimulation by Hydraulic Fractu
Gottschling, J.C. et al 1985: Nitrogen Gas and Sand: A New Techniq 1985.
Green, D., et al 2006: Hydraulic Fracturing of Miocene and Oligocen presented at the Asia Pacific Oil & Gas Conference, Adelaide, AU
GRI Gas Research Institute, 1996: Assessment of Technological Bar Wells, Final Report. GRI 96/0267, July 1996.
Gutor, C. et al 2003: New Life for Old Wells – A Case study of the E Tubing and Snubbing Techniques. SPE 81730 presented at the SP
Hahn, G. 1986: How Long will it Prop? Drilling, the Wellsite Public
Handren, P. and Palisch, T. 2007: Successful Hybrid Slickwater Frac Technical Conference, Anaheim, Nov 11-14.
Harper, T. R., et al 1985: Fracturing Without Proppant. SPE paper 13 Symposium, Denver, March 19-22.
Hecker, M.T., Houston, M.E, and Dumas, J.D. 1995: Improved Com Emitting Tracers. SPE paper 30651 presented at the 1995 Annual
Hejl, K.A. 1992: High-Rate Refracturing: Optimization and Perform Mountain Regional Meeting, Casper, May 18-21.
Holditch, S.A. and Ely J, 1972: Successful Deep Well Stimulation U the 1972 SPE Annual Fall Meeting, San Antonio, October 8-11.
Howard, G.C. and Fast, C.R. 1970: *Monograph 2 – Hydraulic Fractu*
Hower, T.L. and Decker, M.K. 1992: Identifying Recompletion Cand Continent Gas Symposium, Amarillo, TX, April 13-14.
Huckabee, P. et al 2005: Field Results: Effect of Proppant Strength a presented at the SPE Annual Technical Conference, Dallas, Oct 9-
Hunter, J.C. 1986: A Case History of Refracs in the Oak Hill (Cotton Meeting, Tyler, TX, April 21-22.
Husen, A.A. et al. 2003: Hydraulic Fracturing the Best Producer - A Conference, Bahrain, April 5-8.
Jeu, S.J. et al 1988: Exploitation of Deeply Buried Coalbed Methane Basin, Colorado, and San Juan Basin, New Mexico. SPE paper 18 2-5.
JPT Online, March 2006: Techbits: Refracturing in Low-Permeabilit entitled "Refracturing in the Fruitland Coal" presented at ATW, S
Kohlhaas, C.A. 1982: Field Study – Steinle Ranch, an Intermediate I SPE 10875 presented at the 1982 Rocky Mountain Regional Meeti
Lambert, S.W., Trevits, M.A. 1980: The Feasibility of No-proppant Coalbed. US DOE Report of Investigation, April, 1980.
Lantz, T. et al, 2007: Refracture Treatments Proving Successful in H 108117 presented at the 2007 Rocky Mountain Oil and Gas Sympo
Lehman, L.V. et al. 1998: Desorption Enhancement in Fracture-Stim 2998 Eastern Regional Conference, Pittsburgh, Nov 9-11.
Leonard, D. 2009: Refracturing of Barnett. Presentation at PNR Ener
Leshchyshyn, T. et al. 1999: Technical and Economic Rationalizatio Water-Based Fracture Fluids. Petroleum Society paper 99-60 prese Alberta, June 14-18.





Li, P., Song, Z. and Wu, Z. 2006: Study on Reorientation Mechanism of Refracturing in Ordos Basin - A Case Study: Chang 6 Formation, Yanchang Group, Triassic System in Wangyao Section of Ansai Oil Field. SPE paper 104260 presented at the 2006 International Oil & Gas Conference , Beijing, December 5-7.
Liu, H., et al, 2008: Evaluation of Refracture Reorientation in Both Laboratory and Field Scales. SPE 112445 presented at the 2008 International Symposium on Formation Damage Control, Lafayette, February 13-15.
MacDonald, R.J. et al. 2002: Comparing Production Responses from Devonian Shale and Berea Wells Stimulated with Nitrogen Foam and Proppant vs. Nitrogen Only, Pike Co., Kentucky. SPE paper 77464 presented at the 2002 Annual Technical Conference, Sep 29 – Oct 2.
MacDonald, R.J. et al. 2005: A Rapid and Efficient Method to Identify Underperforming Stripper Gas and Oil Wells. SPE 95511 presented at the Annual Technical Conference, Dallas, Oct 9-12.
Marsh, J. et al. 2000: Economic Fracturing of Bypassed Pay: A Direct Comparison of Conventional and Coiled Tubing Placement Techniques. SPE 60313 presented at the Rocky Mountain Regional/Low Perm Reservoirs Symposium, Denver, Mar 12-15.
McCabe, M.A. et al. 1999: Investigation of a New Fracturing Fluid and Conductivity Enhancement Technology on Coalbed Methane Production. SPE paper 52193 presented at the 1999 Mid-Continent Operations Symposium, Oklahoma City, Mar 28-31.
McDaniel, B.W. 1986: Conductivity Testing of Proppants at High Temperature and Stress. SPE Paper 15067 presented at the 56th California Regional Meeting, Oakland, April 2-4.
McDaniel, B.W. 1990: Hydraulic Fracturing Techniques Used for Stimulation of Coalbed Methane Wells. SPE paper 21292 presented at the 1990 Eastern Regional Meeting, Columbus OH, Oct 31-Nov 2.
Miller, J.D. et al. 2004: Fracturing Fluid Viscosity Profiles Determine Well Productivity in a Remedially Stimulated Tight Gas Reservoir. SPE paper 90194 presented at the Annual Technical Conference, Houston, Sep. 26-29.
Mohaghegh, S. et al. 2002: Identification of Successful Practices in Hydraulic Fracturing Using Intelligent Data Mining Tool; Application to the Codell Formation in the DJ-Basin. SPE 77597 presented at the Annual Technical Conference, San Antonio, TX, Sep 29-Oct 2.
Montgomery, C.T. and Steanson, R.E. 1984: Proppant Selection – The Key to Successful Fracture Stimulation. SPE paper 12616 presented at the Deep Drilling and Production Symposium, Amarillo, TX April 1-3.
Moschovidis, Z. et al, 2000: The Mounds Drill-Cuttings Injection Field Experiment: Final Results and Conclusions. SPE paper 59115 presented at the IADC/SPE Drilling Conference, New Orleans, Feb 23-35.
Pagano, T.A. 2006: Rock Properties, Deliverability Mechanism influence Codell Restimulation. OGJ July 10, 2006. 44-47.
Palisch, T. et al. 2008: Slickwater Fracturing – Food for Thought. SPE paper 115766 presented at the A Denver, Sept 21-24.
Palmer, I.D. 1992: Review of Coalbed Methane Well Stimulation. SPE 22395 presented at the 1992 I Engineering, Beijing, China, March 24-27.
Palmer, I.D. 1993: Induced Stresses Due to Propped Hydraulic Fracture in Coalbed Methane Wells. SI Mountain Regional Low Perm Symposium, Denver, Apr 12-14.
Parrot, D.I. and Long, M.G. 1979: A Case History of Massive Hydraulic Refracturing in the Tight Mu presented at the Symposium on Low-Permeability Gas Reservoirs, Denver, May 20-22.
Pauls, R.W. et al 1985: Successful Stimulation of the Olmos Formation Using Oil-Base Fluids and Hig 13817 presented at the Production Operations Symposium, Oklahoma City, Mar 10-12.
Popa, A.S. et al 2003: Identification of Contaminated Data in Hydraulic Fracturing Databases: Applica DJ Basin. SPE 83446 presented at the SPE Western Regional/AAPG Pacific Section Meeting, Long
Pospisil, G. et al 1992: Results of a Large-Scale Refracture Stimulation Program, Kuparuk River Unit, at the 1992 SPE Annual Technical Conference and Exhibition, Washington, D.C., Oct. 4-7.
Reese, J.L. et al 1994: Selecting Economic Refracturing Candidates. SPE paper 28490 presented at the Orleans, Sept 25-28.
Reeves, S.R. et al 1999: Restimulation of Tight Gas Sand Wells in the Rocky Mountain Region. SPE Mountain Regional Meeting, Gillette, WY, May 15-18.
Reeves, S.R. et al 2000: Benchmarking of Restimulation Candidate Selection Techniques in Layered, Reservoir Simulation. SPE 63096 presented at the Annual Technical Conference, Dallas, Oct 1-4.
Rieb, B.A. and Leshchyshyn, T. T. 2005: Production Success of Proppant Stimulation on Horseshoe C 96864 presented at the 2005 Annual Technical Conference, Dallas, Oct 9-12.
Rieb, B. 2006: Proppants Raise the Curve for Coalbed Methane Production. World Oil, Aug 2006.
Roussel, N.P. and Sharma, M.M. 2010: Quantifying Transient Effects in Altered-Stress Refracturing o presented at the 2009 Hydraulic Fracturing Technology Conference, The Woodlands, TX, Jan 19-21
Roussel, N.P. and Sharma, M.M. 2010: Optimizing Fracture Spacing and Sequencing in Horizontal W at the 2010 International Symposium Formation Damage, Lafayette, LA, Feb 10-12.
Rodvelt, G. et al. 2001: Multiseam Coal Stimulation Using Coiled-Tubing Fracturing and a Unique Bo paper 72380 presented at the 2001 Eastern Regional Meeting, Canton, OH, Oct. 17-19.
Rushing, J.A. 2003: Evaluation of a Hybrid Water-Frac Stimulation Technology in the Bossier Tight C at the Annual Technical Conference, Denver, Oct. 5-8.
Sallee, W.L and Rugg, F.E. 1953: Artificial Formation Fracturing in Southern Oklahoma and North Ce 1953) 37, No 11, 2539-2550.
Saucier, R.J. 1988: A Field Development Program in Hydraulic Fracture Stimulation. SPE 18257 pres Conference, Houston, Oct 2-5.
Sencenbaugh, R.N, et al. 2001: Restimulating Tight Gas Sand: Case Study of the Codell Formation. SI Rocky Mountain Petroleum Technology Conference, Keystone, CO, May 21-23.
Shaefer, M. 2006: Awakening an Old Field – A Case Study of a Refracturing Program in the Greater C presented at the Annual Technical Conference, San Antonio, Texas, Sept 24-27.





Shaefer, M.T. and Lytle, D.M. 2001: Fracturing Fluid Evolution Plays a Major Role in Codell Refracturing Success. SPE paper 71044 presented at the Rocky Mountain Petroleum Technology Conference, Keystone, CO, May 21-23.
Shah, S.N. et al. 2010: Fracture Orientation and Proppant Selection for Optimizing Production in Horizontal Wells. SPE paper 128612 presented at the SPE Oil and Gas India Conference, Mumbai, Jan 20-22.
Shelley, R.F. 1999: Artificial Neural Networks Identify Restimulation Candidates in the Red Oak Field. SPE paper 52190 presented at the Mid-Continent Operations Symposium, Oklahoma City, Mar 28-31.
Siebrits, E. et al. 2000: Refracture Reorientation Enhances Gas Production in Barnett Shale Tight Gas Wells. SPE 63030 presented at the Annual Technical Conference, Dallas, Oct 1-4.
Smith, C.F. and Murphy, D.L. 1974: Field Evaluation of Gas Well Stimulation Methods – Sutton County, Texas. SPE 4800 presented at the Permian Basin Oil Recovery Conference, Midland, TX, Mar 11-12.
Stim-Lab Proppant Conductivity and Fluid Damage Consortia, 2007-2009. Duncan, OK.
Stutz, H.L. et al. 2002: Calibrating Coal Bed Methane Fracture Geometry in the Helper Utah Field Using Treatment Well Tiltmeters. SPE paper 77443 presented at the 2002 Annual Technical Conference, San Antonio, Sep 29-Oct 2.
Surjaatmadja, J. 2007: The Mythical Second Fracture and Its Optimal Placement for Maximizing Production. SPE 106046 presented at the 2007 Europec/EAGE Annual Conference, London, June 11-14.
Tucker, R.L. 1979: Practical Pressure Analysis in Evaluation of Proppant Selection for the Low-Permeability, Highly Geopressured Reservoirs of the McAllen Ranch (Vicksburg) Field. SPE paper 7925 presented at the Symposium on Low Permeability Gas Reservoirs, May 20-22.
Tuffs, B. 2009: Mannville CBM in Central Alberta. CSUG 11th Annual Unconventional Gas Conference, Nov 18-20.
Vincent, M.C. 2002: Proving It – A Review of 80 Published Field Studies Demonstrating the Importance of Increased Fracture Conductivity. SPE paper 77675 presented at the 2002 Annual Technical Conference, San Antonio, Sep 29-Oct 2.
Vincent, M.C. et al 2007: Field Trial Design and Analyses of Production Data from a Tight Gas Reservoir: Detailed Production Comparisons form the Pinedale Anticline. SPE paper 106151 presented at the 2007 Hydraulic Fracturing Technology Conference, College Station, TX Jan 29-31.
Vincent, M.C. 2009: Examining our Assumptions – Have Oversimplifications Jeopardized Our Ability to Design Optimal Fracture Treatments? Paper SPE 119143 presented at the 2009 Hydraulic Fracturing Technology Conference, The Woodlands, Jan 19-21.
Wang, S.G., et al, 2007: Case Studies of Propped Refracture Reorientation in the Daqing Oil Field. SPE 106140 presented at the 2007 Hydraulic Fracturing Technology Conference, College Station, January 29-31.
Warpinski, N.R. and Branagan, P.T.. 1989: Altered Stress Fracturing. *JPT* Sept 1989 990-997.
Waters, G. et al. 2009: Utilization of Real Time Microseismic Monitoring and Hydraulic Fracture Diversion Technology in the Completion of Barnett Shale Horizontal Wells. OTC 20268 presented at the Offshore Technology Conference, Houston May 4-7.
Wolhart, S. et al. 2007: Surface Tiltmeter Mapping Shows Hydraulic Fracture Reorientation in the Codell Formation, Wattenberg Field, Colorado. SPE paper 110034 presented at the Annual Technical Conference, Anaheim, Nov. 11-14.
Wong, S.W. et al. 2000: Fresh Water Injection Stimulation in a Deep Tight Oil Reservoir. SPE paper 62618 presented at the 2000 SPE/AAPG Western Regional Meeting, Long Beach CA June 19-23.
Wright, C.A. and Conant, R.A. 1994: Reorientation of Propped Refracture Treatments. SPE paper 28078 presented at the 1994 SPE/ISRM Rock Mechanics Conference, Delft, The Netherlands, Aug 29-31.
Wright, C.A., Conant, R.A. et al. 1995: Hydraulic Fracture Orientation and Production/Injection Induced Reservoir Stress Changes in Diatomite Waterfloods. SPE paper 29625 presented at the Western Reional Meeting Mar 8-10.
Wright, C.A. and Conant, R.A. 1995: Hydraulic Fracture Reorientation in Primary and Secondary Recovery from Low-Permeability Reservoirs. SPE paper 30484 presented at the Annual Technical Conference, Oct 22-25.
Wright, C.A. and Stewart, D.W. et al. 1994: Reorientation of Propped Refracture Treatments in the Lost Hills Field. SPE paper 27896 presented at the 1994 Western Regional Meeting, Long Beach, CA, Mar. 23-25.
Yao, F, et al. 2007: Reorientation Refracturing Case Study. SPE paper 106595 presented at the Production and Operations Symposium, Oklahoma City, Mar 31 – Apr 3.


FROM SPE 134330

"The efforts of many researchers have already cast much darkness on the subject, and it is likely that if they continue, we will soon know nothing about it at all."

Mark Twain

# SOME "TYPICAL" OBSERVATIONS

- "Initial completions exhibit inconsistent proppant coverage across the perforated interval." – SPE-174979, Leonard, Moore, Woodruff, Senters

- Wells employing (refrac) diversion techniques … are not consistently contacting new rock.  - SPE 174979

- " The biggest challenge in re-stimulating old wells is how to handle the existing perforations."  - SPE 174979

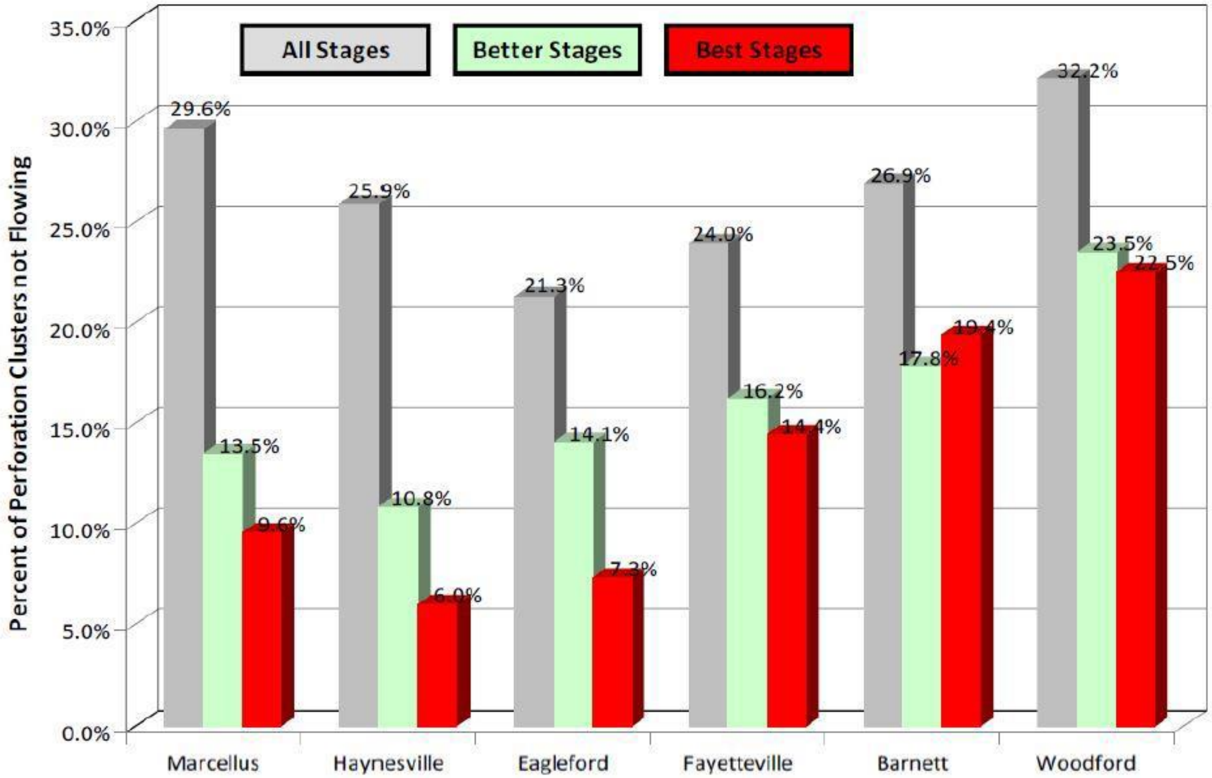
- "…the variation in (refrac) outcomes is too wide for refracturing to be adopted on a large scale today." – SPE 174951, Indras, Blankenship

- "… Can we design wells that can be easily isolated and refractured?" – SPE 136757, M. Vincent

# WHAT TO CONSIDER

- WELL CONFIGURATION & HYDRAULIC ISOLATION
  - Balls/Perfs/Ports/Baffles/Plugs
- WELL INTEGRITY
  - Casing Size, Weight, Erosion, Corrosion, Cement Integrity, External Packers, Casing Deformation etc.
- Existing Fractures
  - Conductivity, Location, Dimensions, Inter-well Communication
- Remaining Resource (Recovery Factor)
  - Where Is It & How Do We Target It

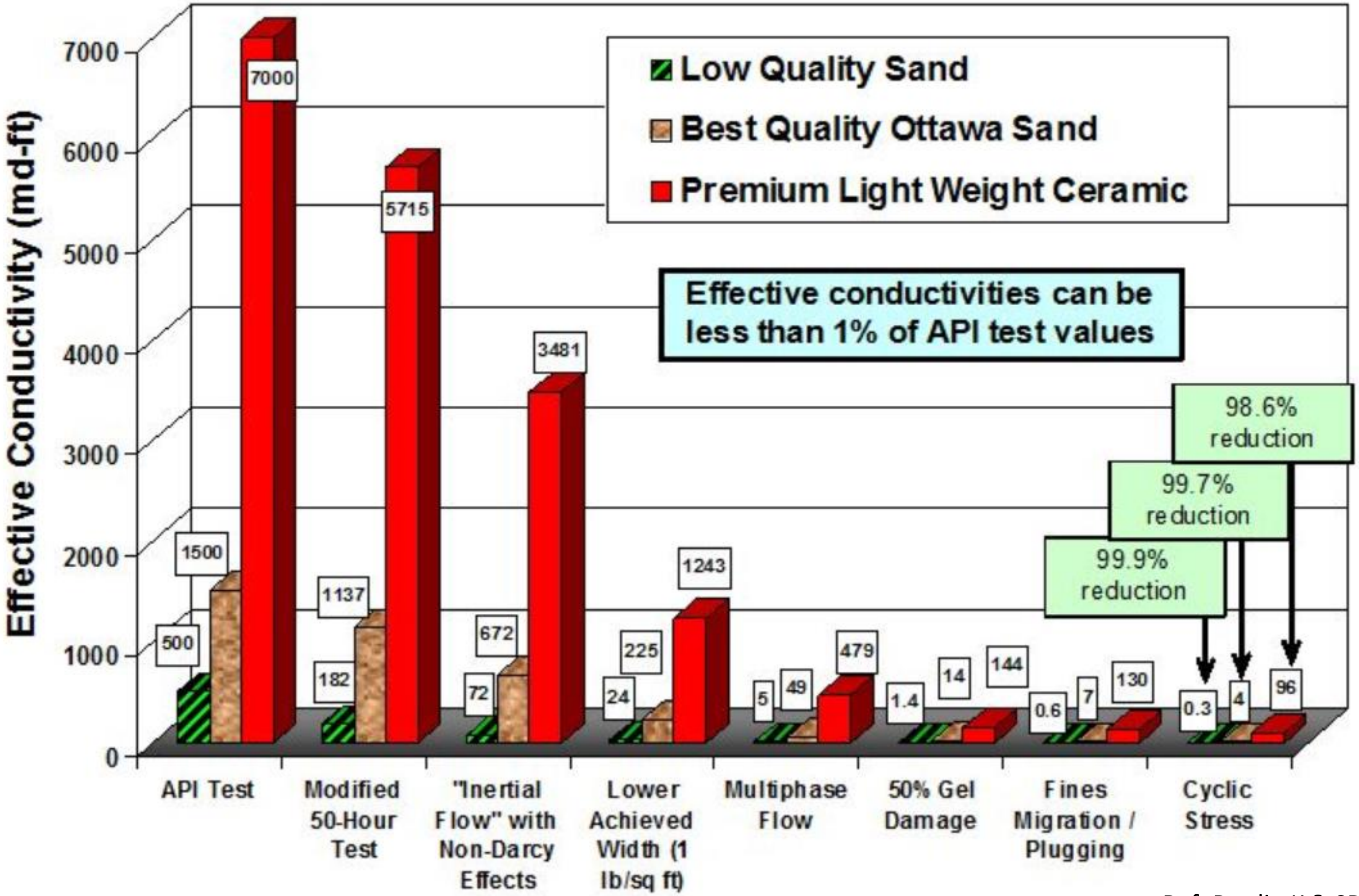
# PERF CLUSTER PERFORMANCE




SPE 155485

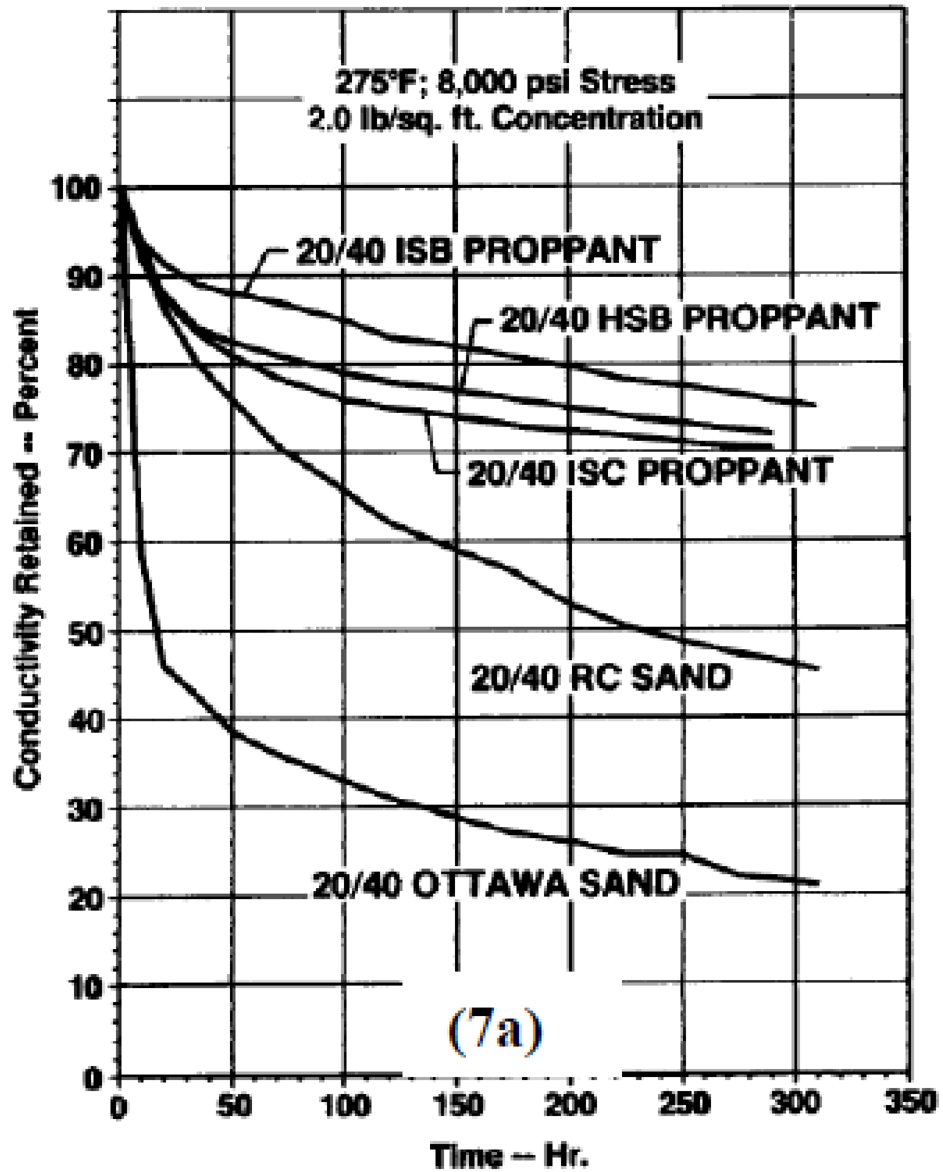
**Percentage of all perforation clusters that are not producing. Gray bars include all fracture stages. Green is for stages producing from 110% to 150% above the average rate. The red bars are for stages producing greater than 150% the average rate (Miller et al. 2011).**

# Realistic Conductivity Reductions




Ref: PredictK & SPE 106301

# HOURS, NOT MONTHS




McDaniel 1986

# OPPORTUNITIES

….. 40% to 60% of stages produce little or no hydrocarbons, while 30% of the stages represent 80% of a well’s entire production. Baker Hughes estimates that ineffective stages have come at an annual cost upward of USD 40 billion.

Trent Jacobs, JPT

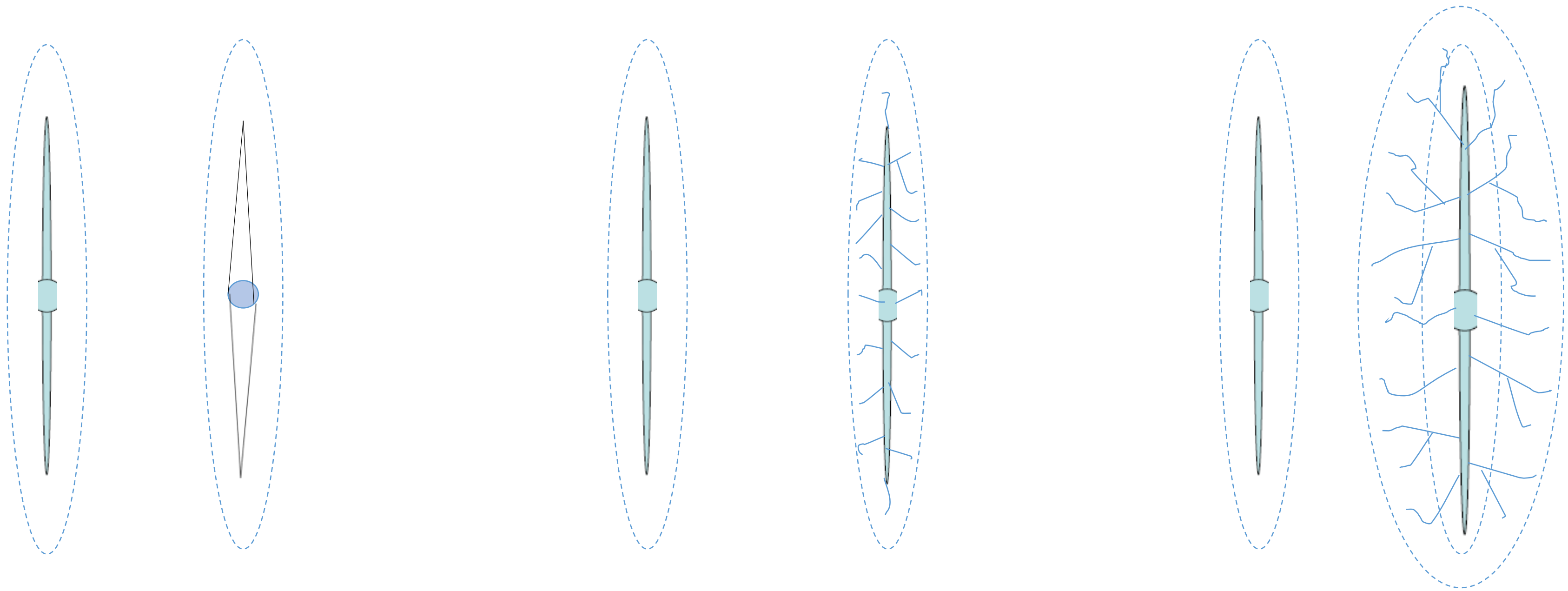
# Why Refracture

The simple reason to refracture a well is to boost production. But to do that, operators need to pinpoint the problems they seek to remedy and then design the proper refracture treatment.

- Address proppant embedment or rock creep.
- Implement new completion learnings.
- Contact virgin rock by adding perforations, diversion, or reorientation.
- Reorient existing fractures to new areas of the reservoir.
- Replace crushed or low-conductivity proppant.
- Bypass damage caused by salt deposition, scale, or fines plugging.
- Fix stages where proppant was overflushed or flowed back into the wellbore.
- Improve the durability of initial proppant.
- Repressurize an existing well before offset drilling and completions.
- Re-energize natural fractures or rearrange existing proppant pack.
- Deliver production chemicals such as emulsion breakers and scale inhibitors.

Reference: JPT April 2015 – Trent Jabobs' Interview with Mike Vincent

# Measuring Refrac Performance

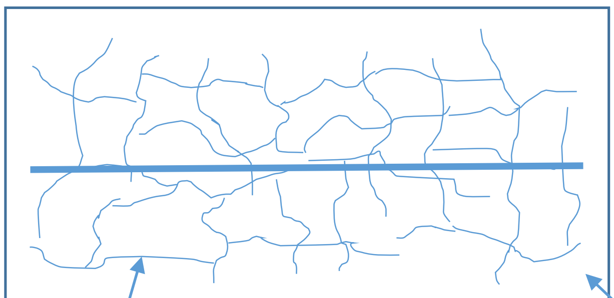


| Restore or Improve Apparent Conductivity | Increase Fracture Area | Increase Stimulated Reservoir Volume |
|---|---|---|
| $k_f w$ | A | OGIP or OOIP |

# RTA Modelling & The Concept of Effective Permeability

## Physical Description

Fractured reservoir with matrix permeability



$k_{matrix}$

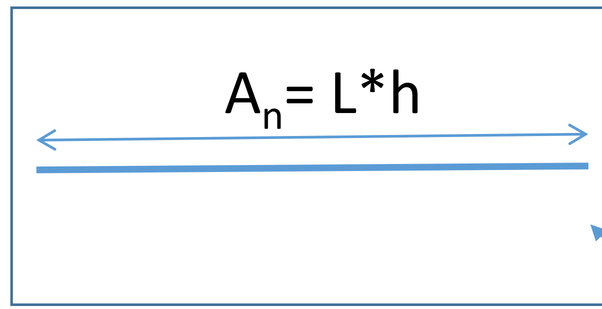
A = total connected fracture area

Sum of all connected $x_f h_f$

=

## Functional Model

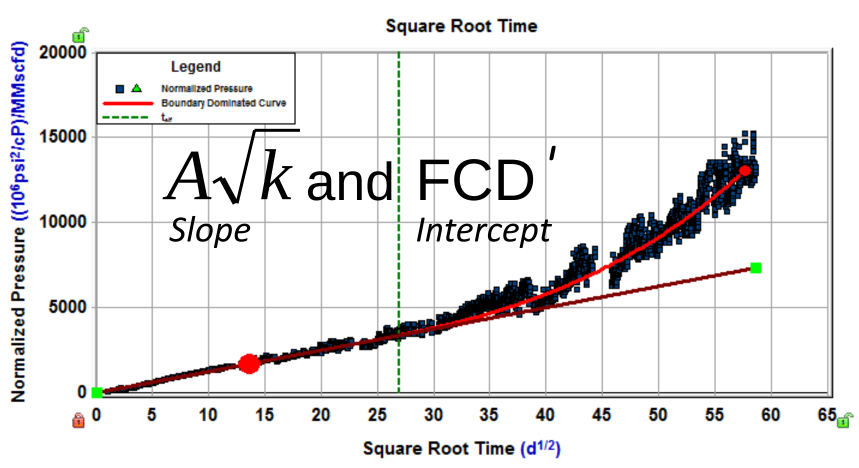
Unfractured reservoir with equivalent permeability

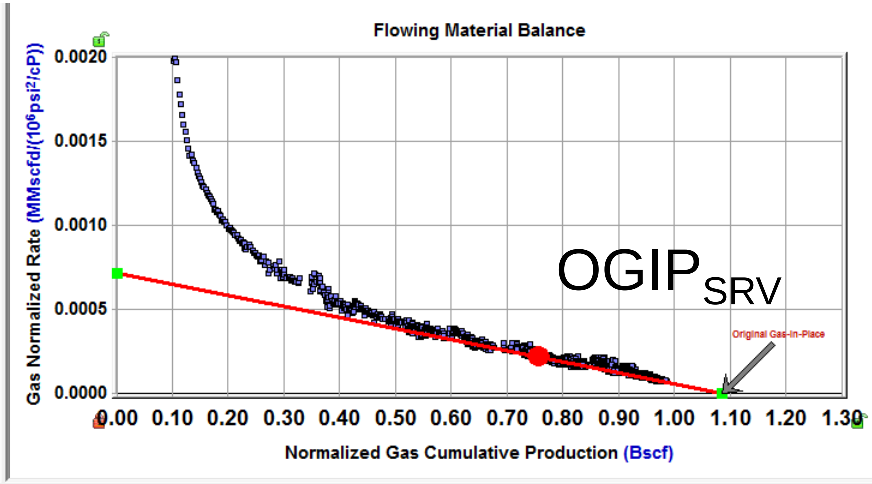


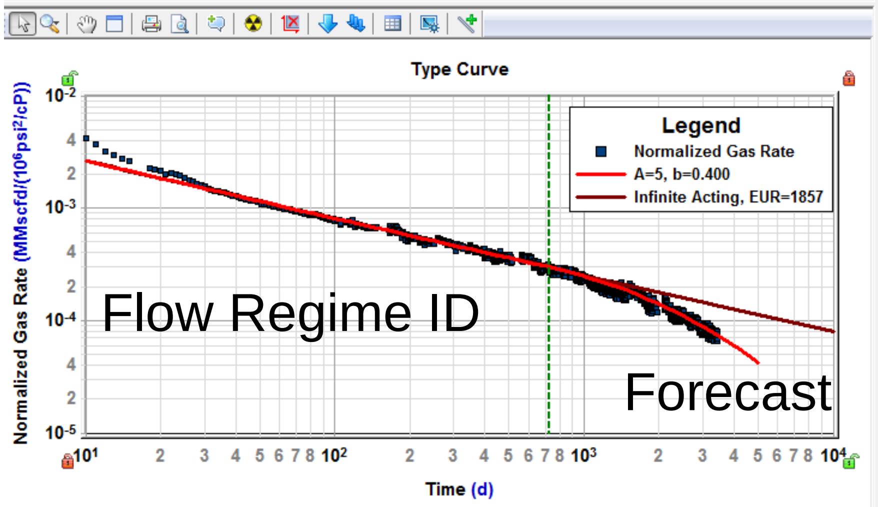

$k_{eff}$

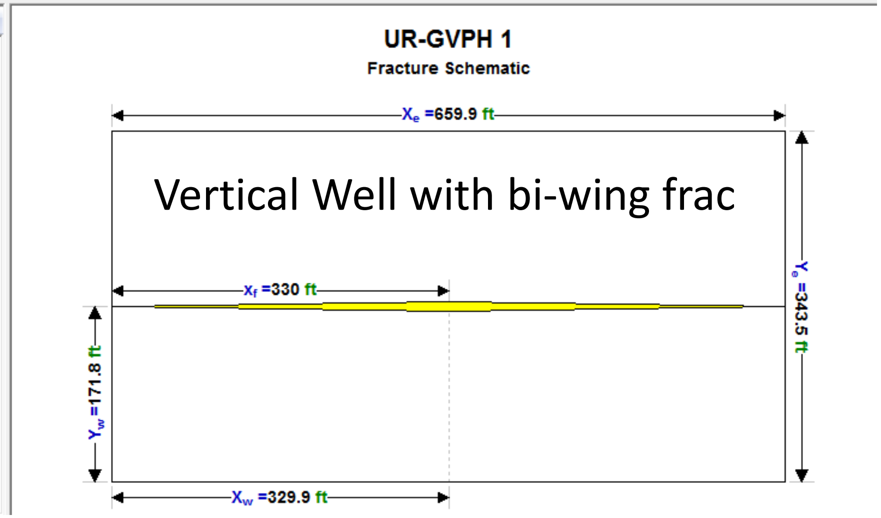
$$k_{eff} = \left[ \frac{A\sqrt{k_{matrix}}}{A_n} \right]^2$$

# RTA Methodology



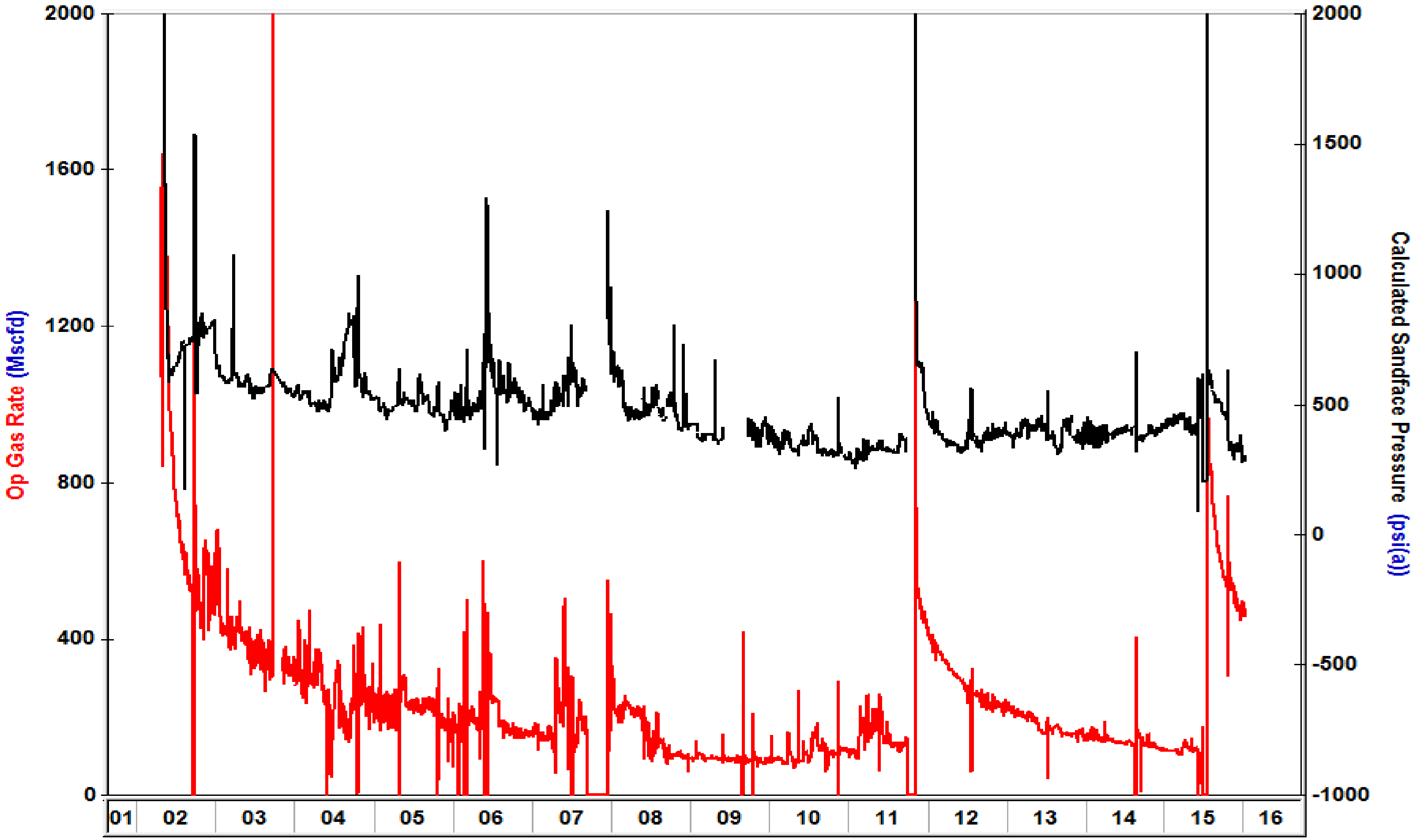



# Barnett Well Case Studies

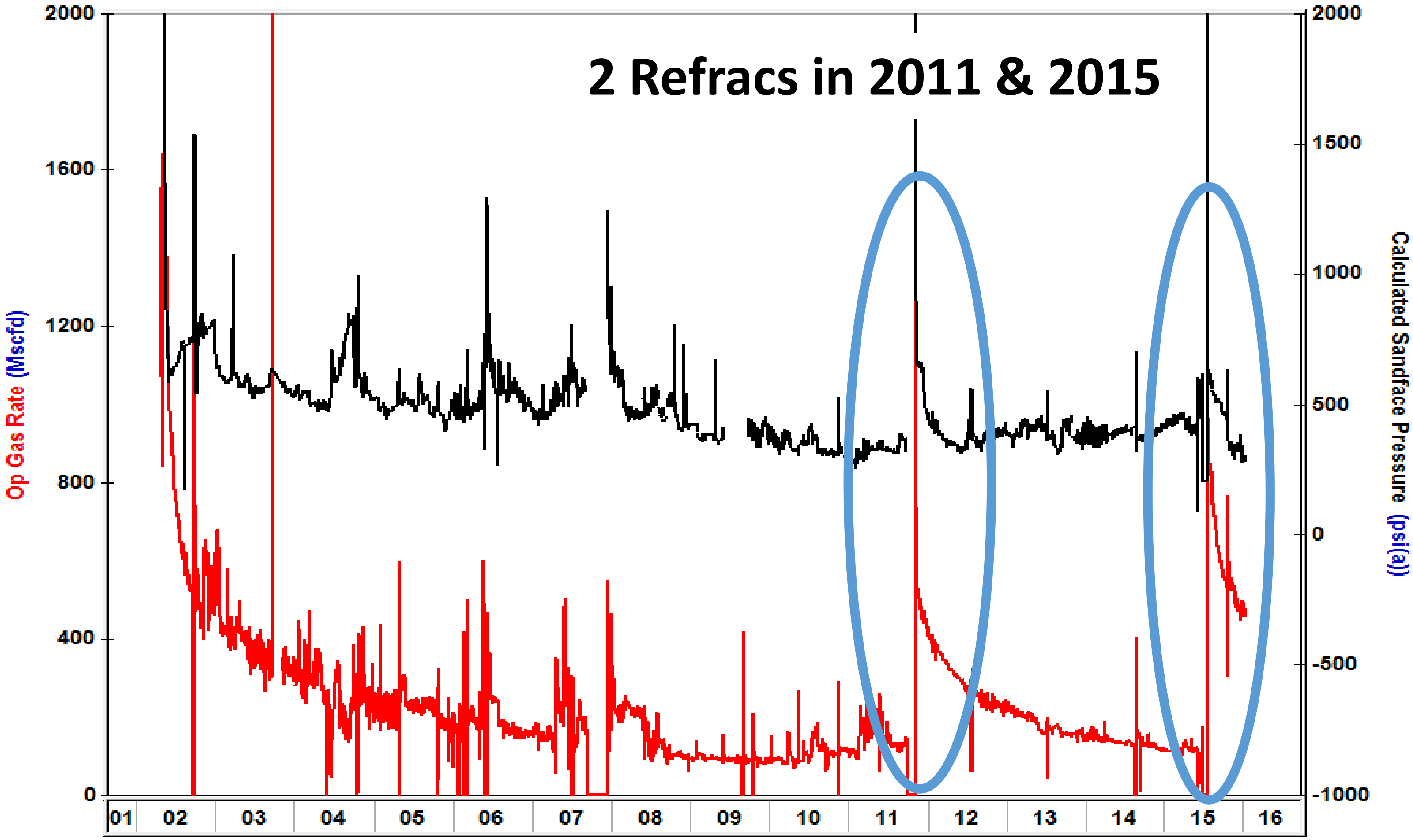
1) Vertical Well with 2 Refracs

2) Horizontal Well with 1 Refrac

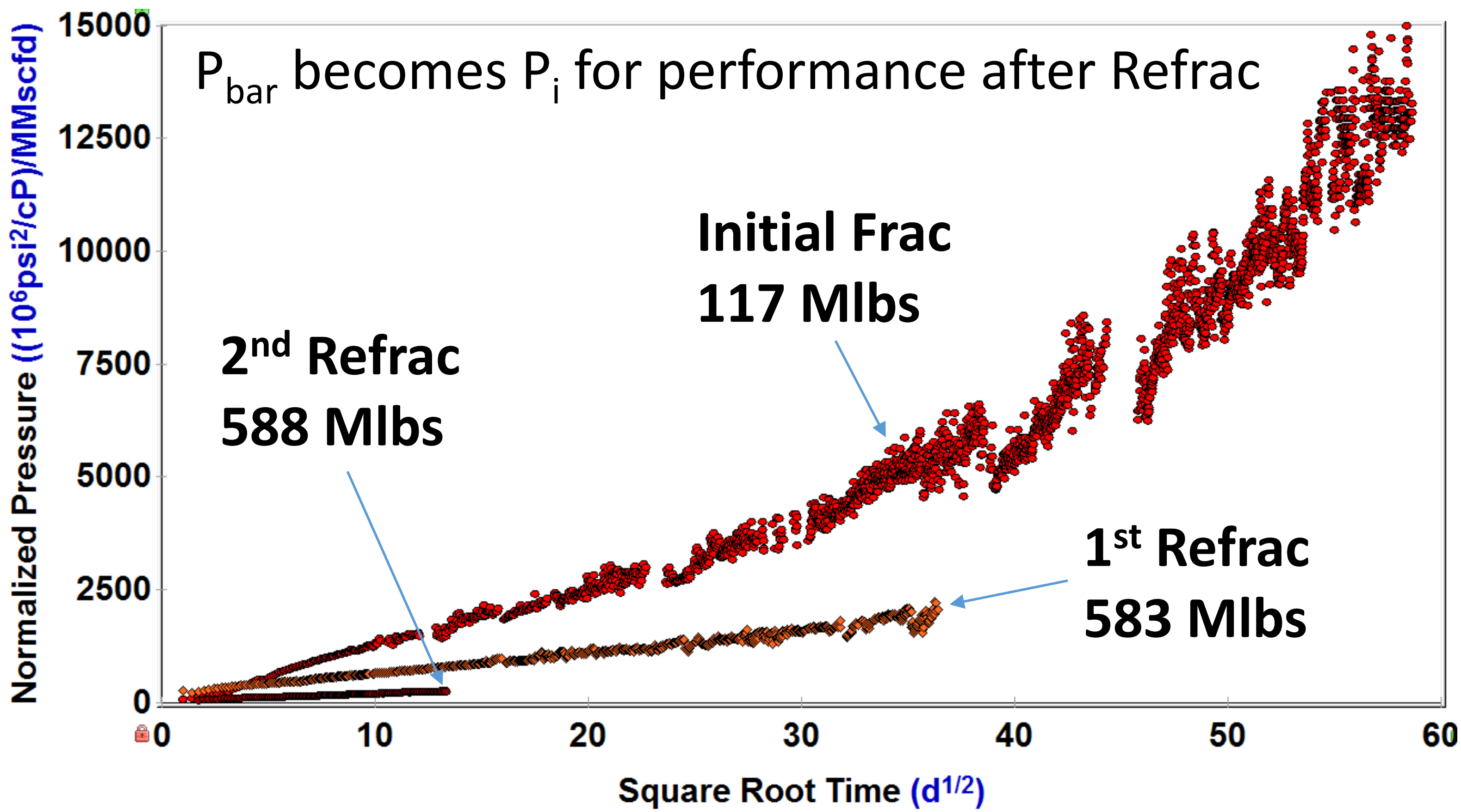
# Barnett Field Example 1 – Vertical Well



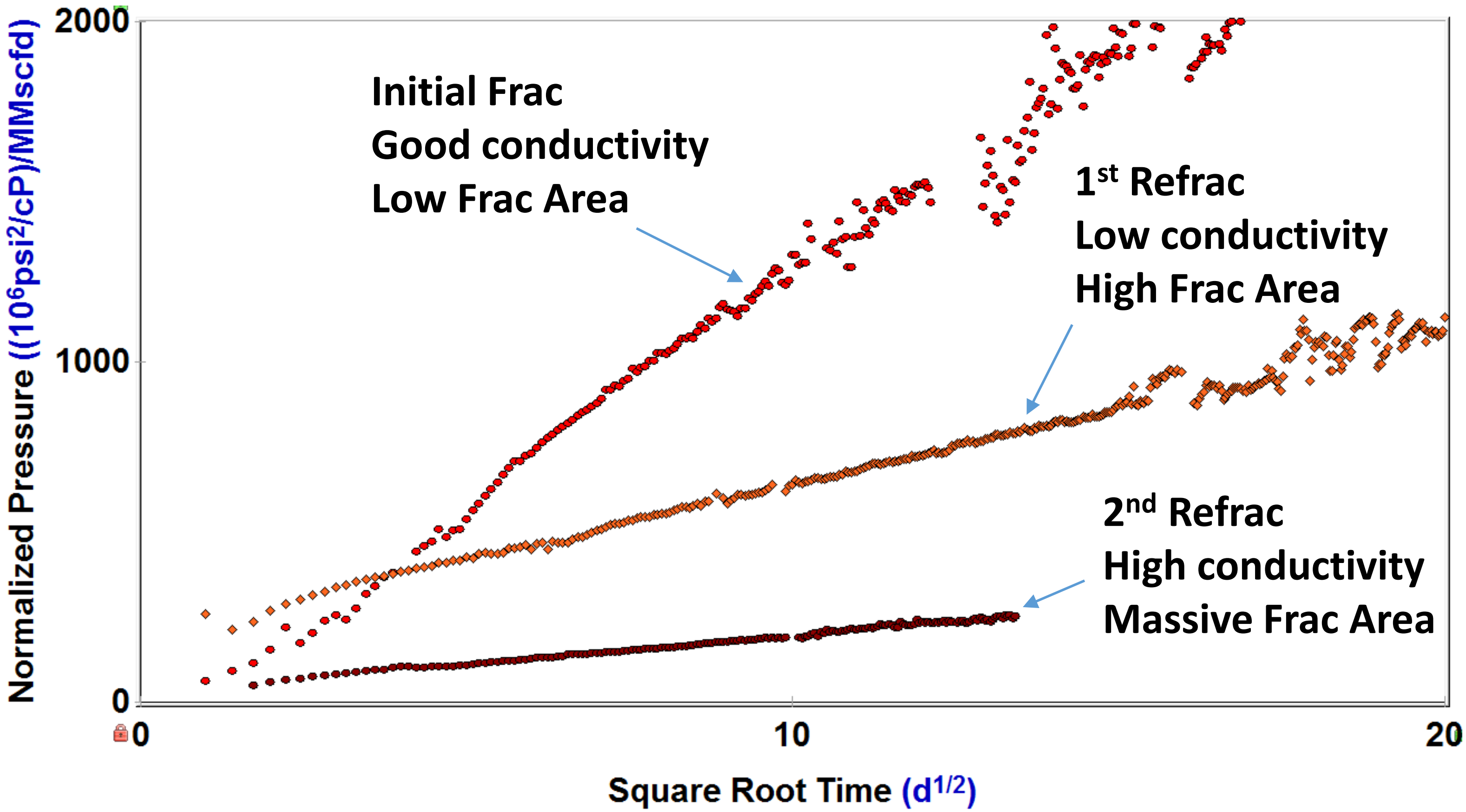
# Barnett Field Example 1 – Vertical Well



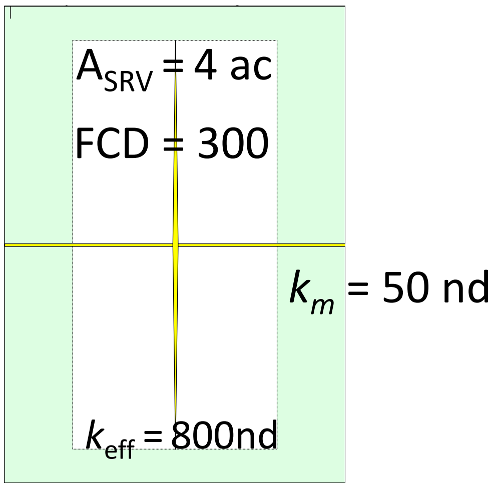
# Ex. 1 - Reinitializing with Sqrt Time Plot



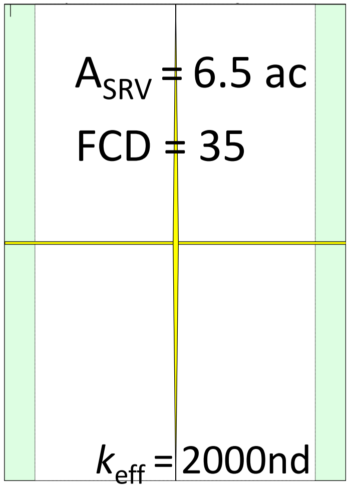
# Ex. 1 - Reinitializing with Sqrt Time Plot



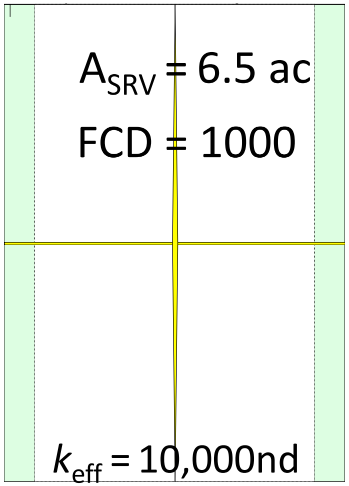
# Example 1 – Performance Modeling



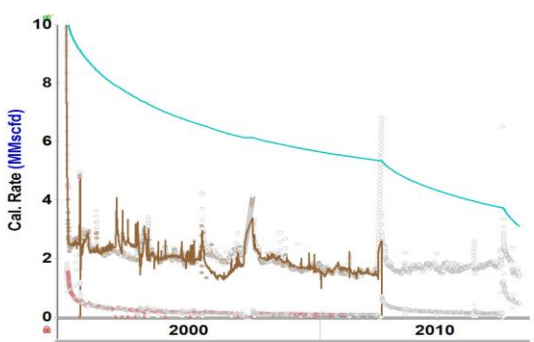

Initial Completion

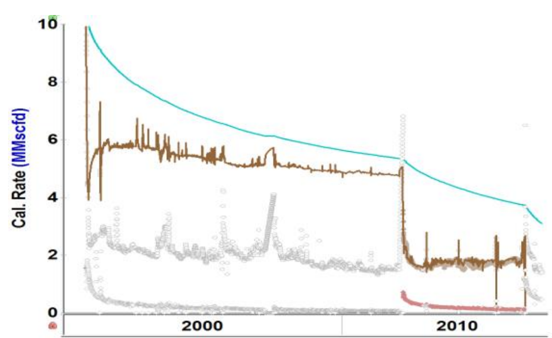


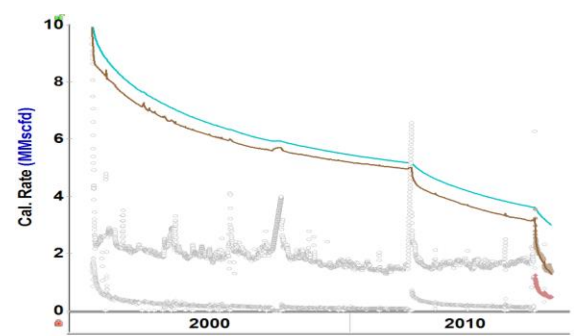

1st Refrac




2nd Refrac

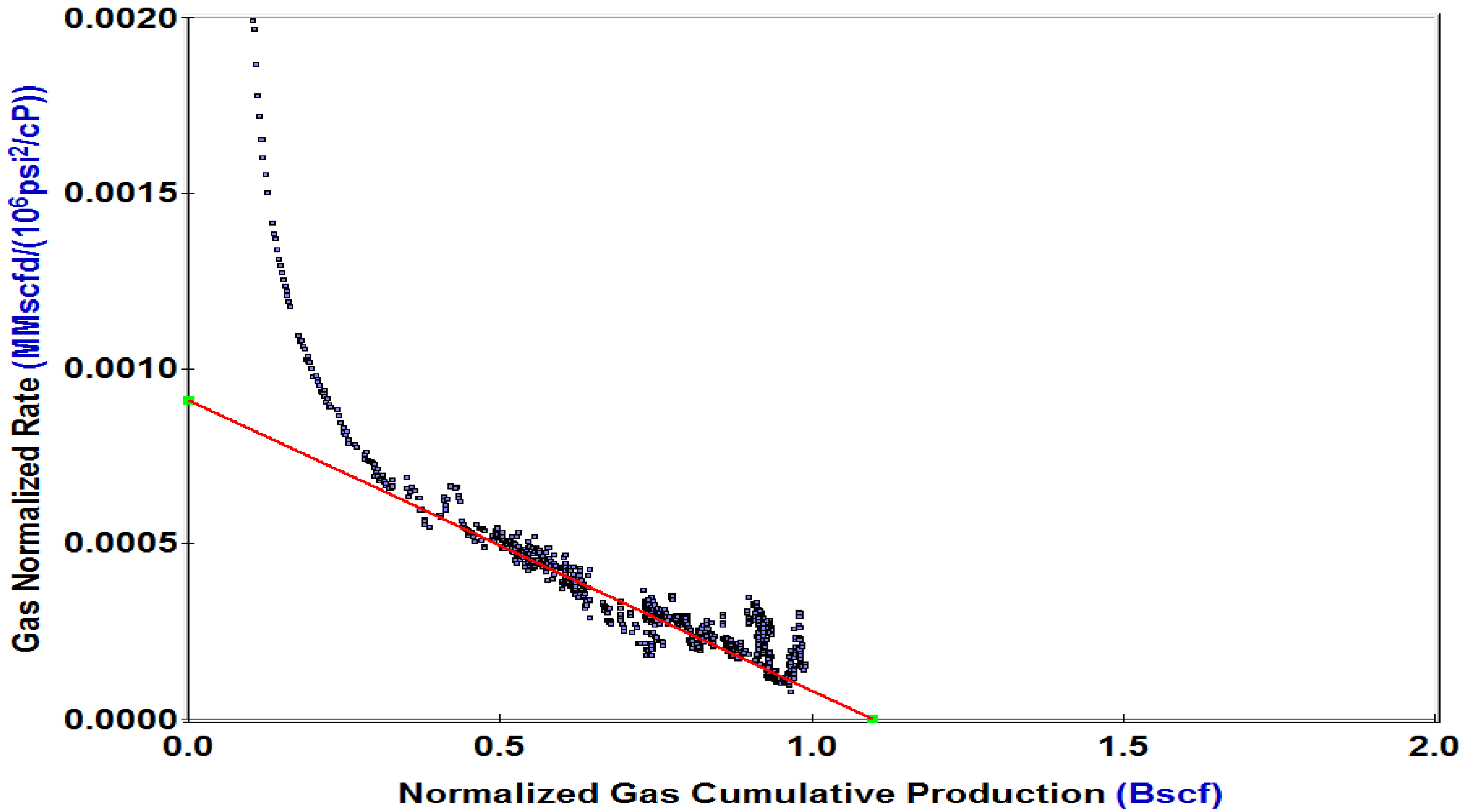


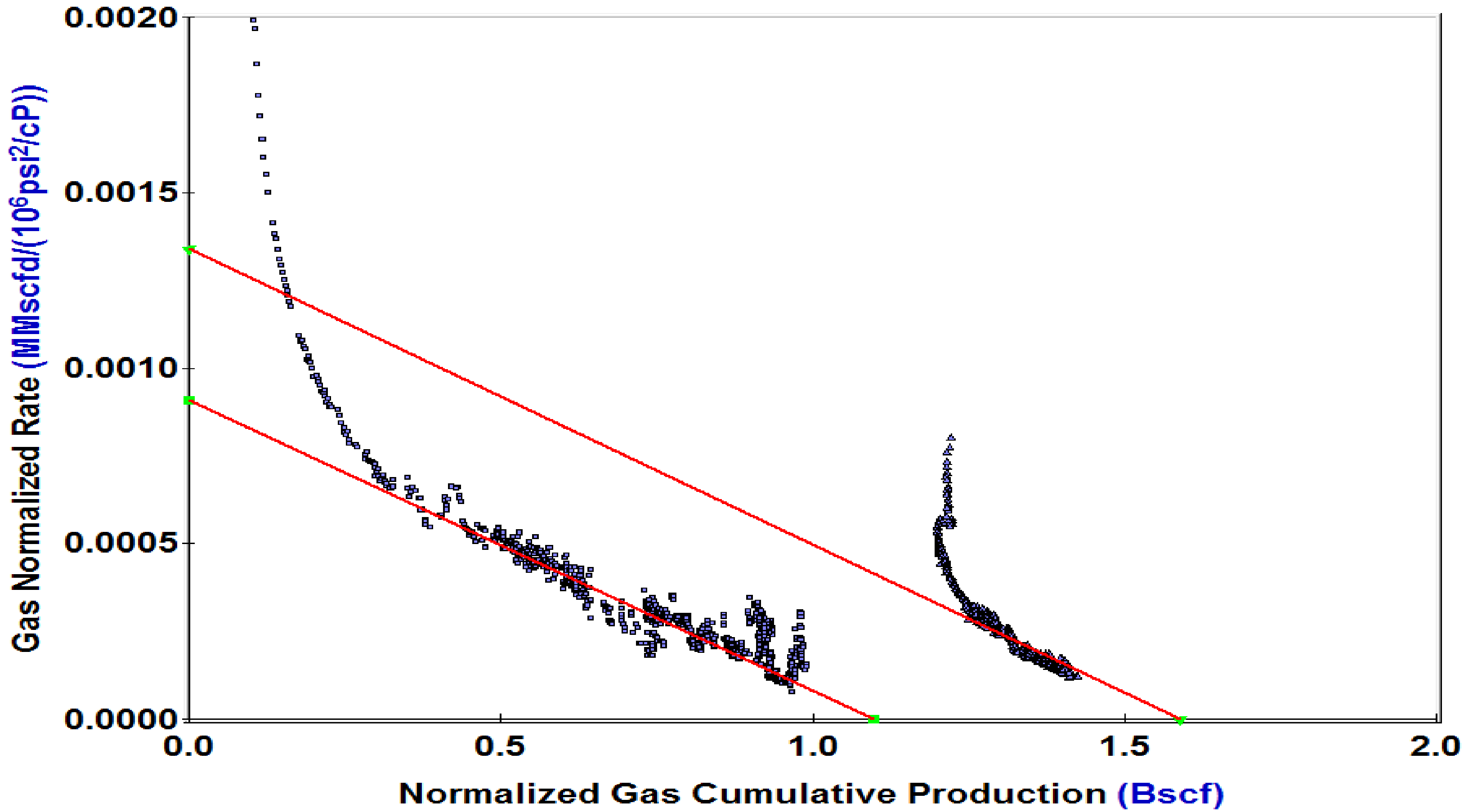




History matching bottomhole flowing pressure

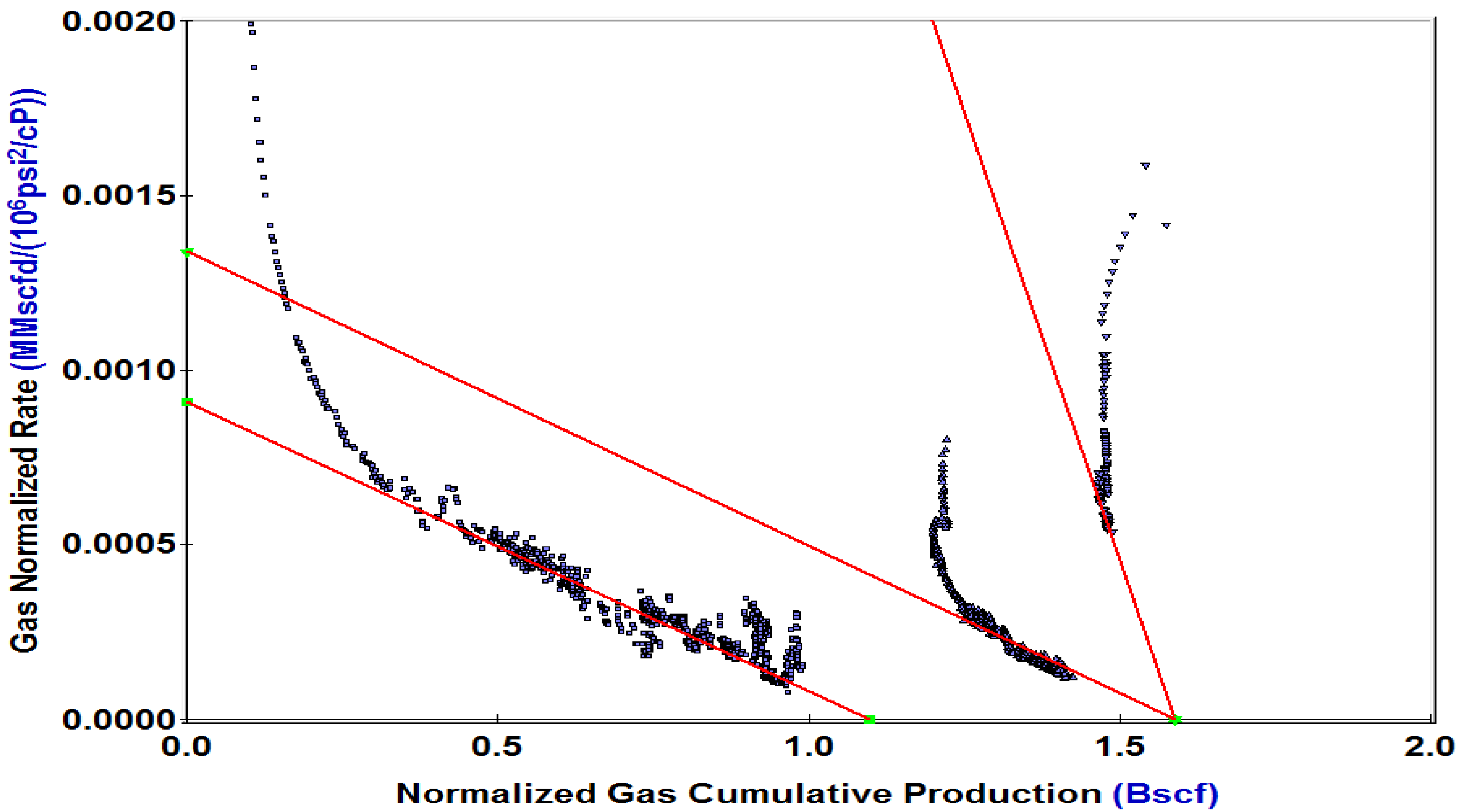
# Example 1 - FMB Analysis



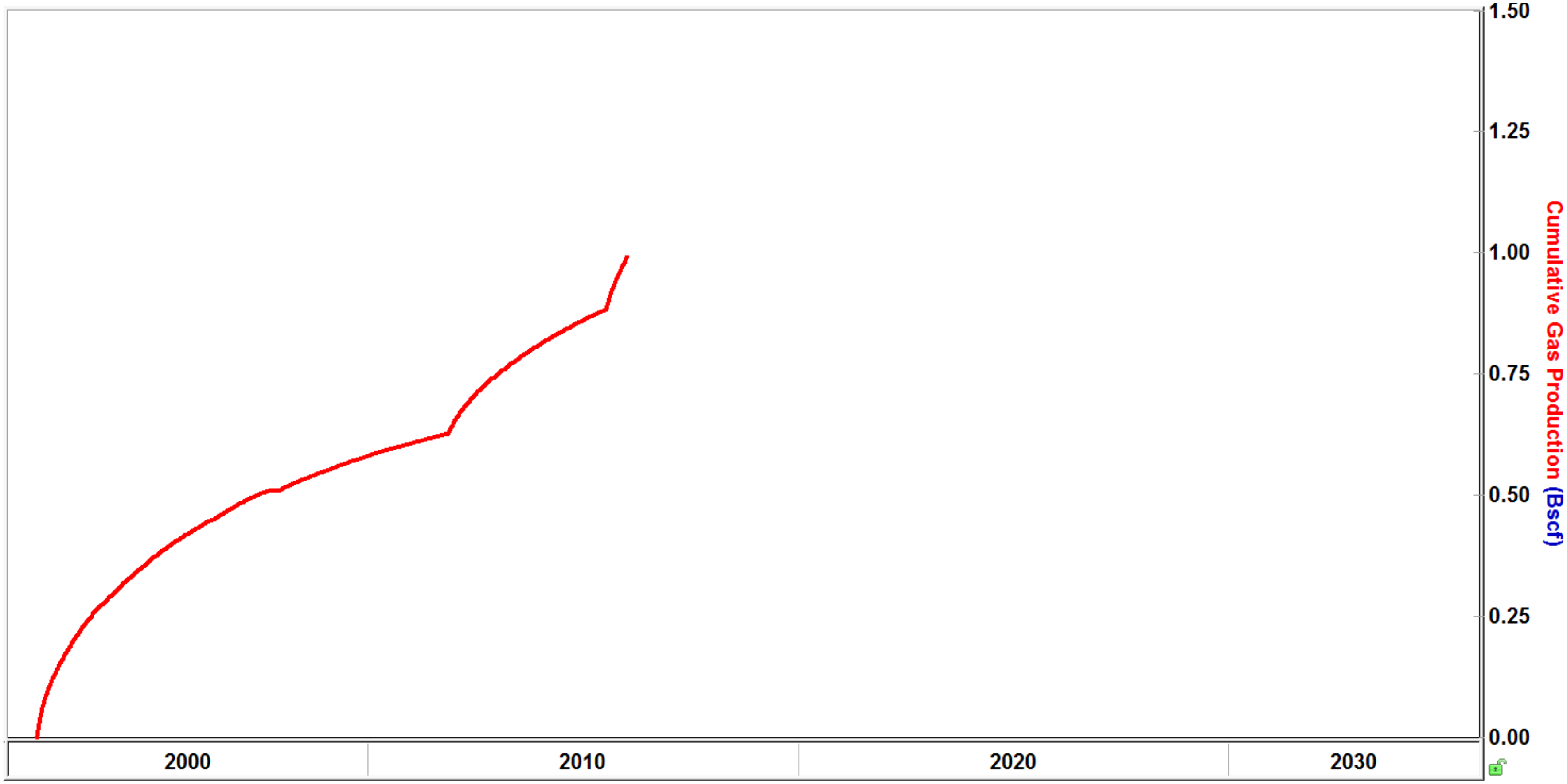
# Example 1 - FMB Analysis



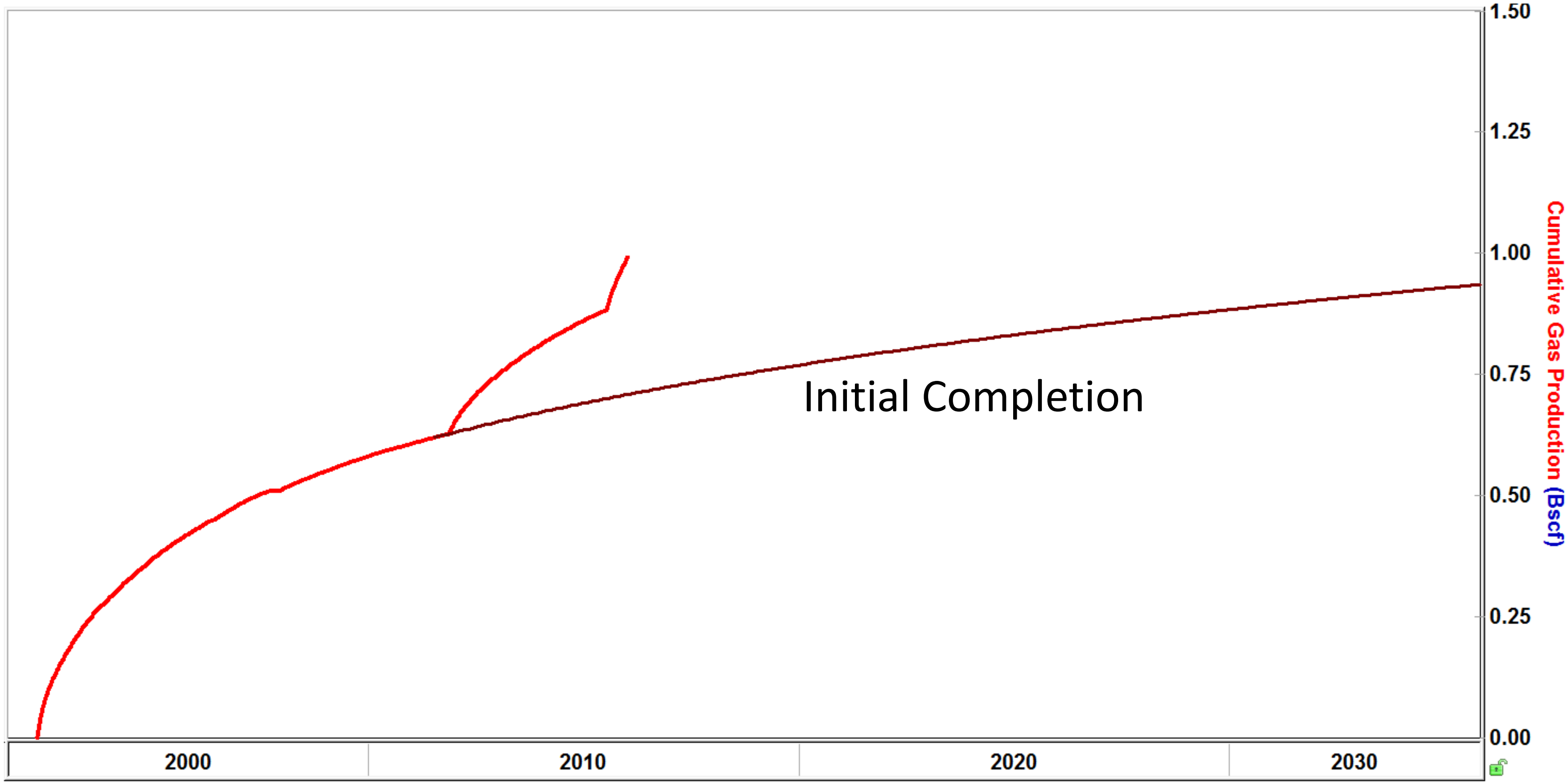
# Example 1 - FMB Analysis



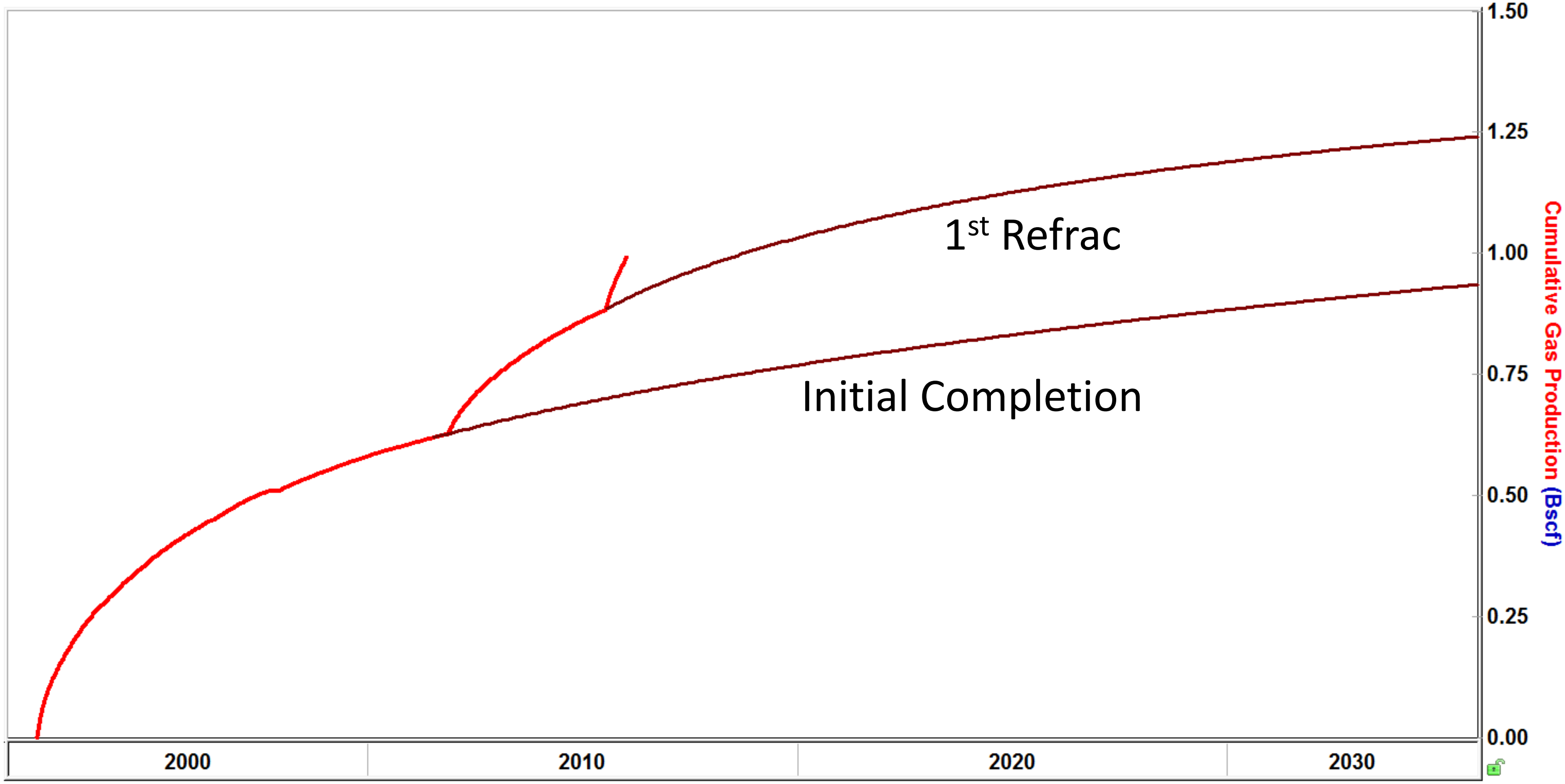
# Example 1 - Cum vs. Time (Forecasting)



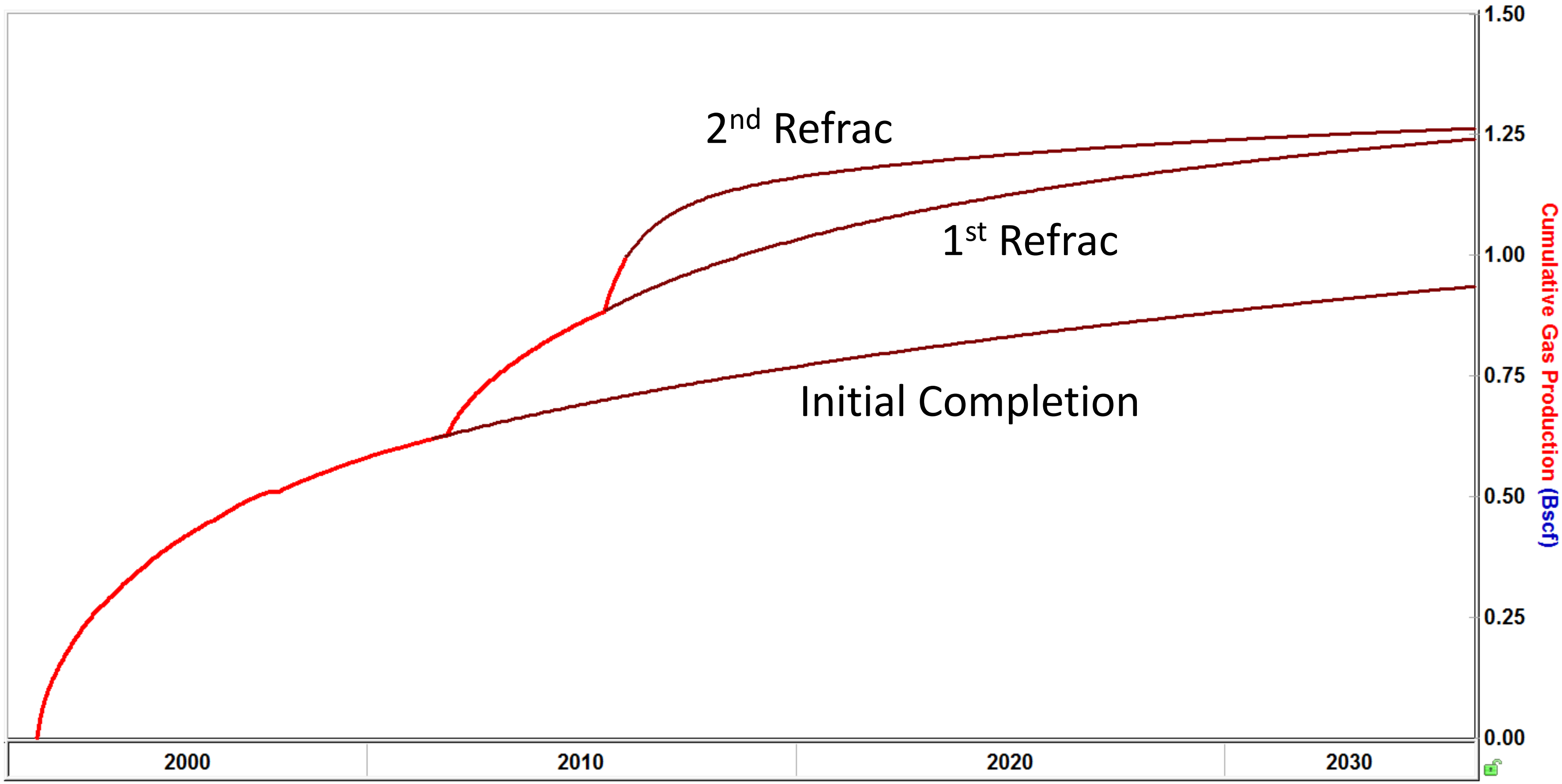
# Example 1 - Cum vs. Time (Forecasting)



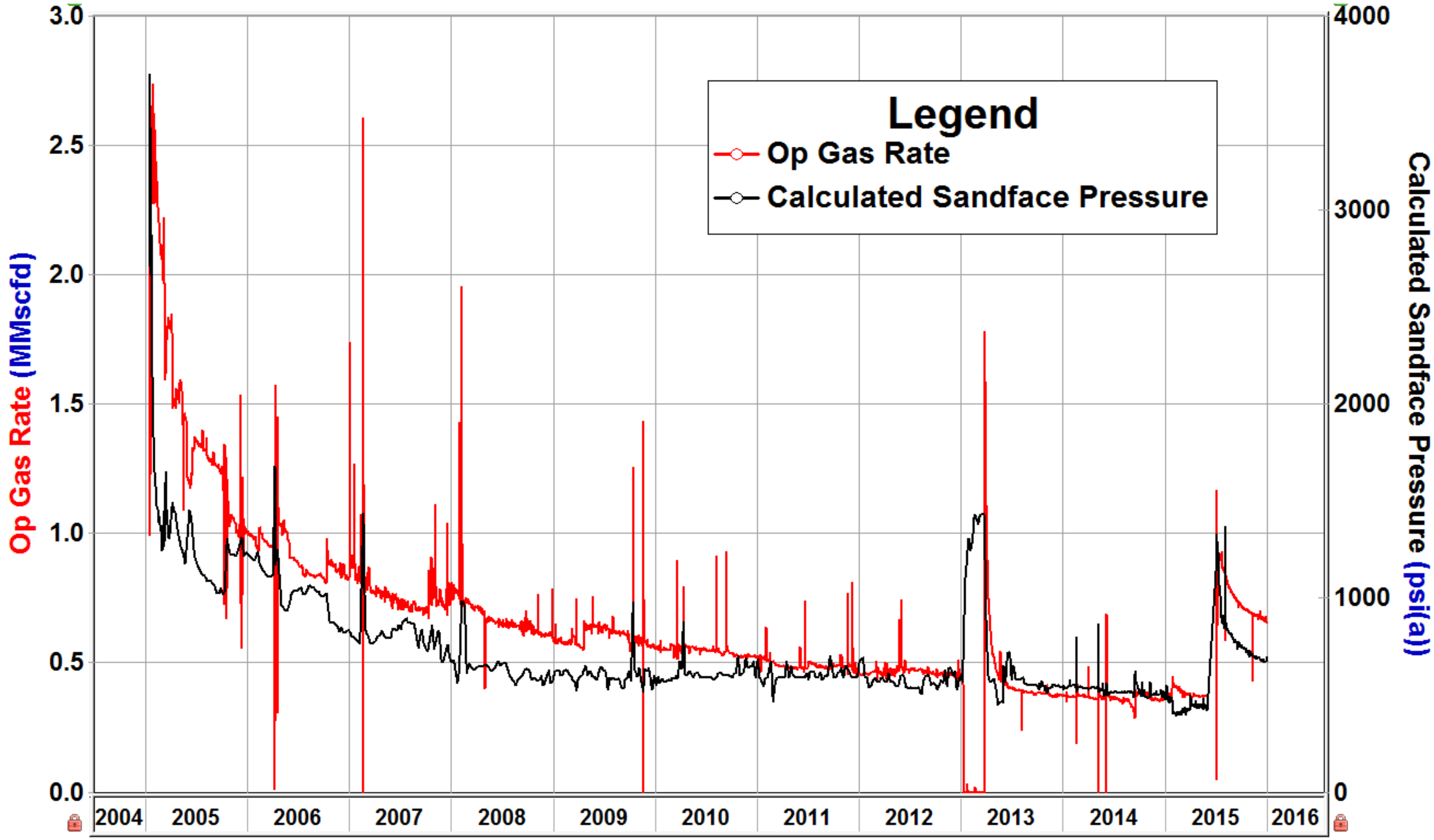
# Example 1 - Cum vs. Time (Forecasting)



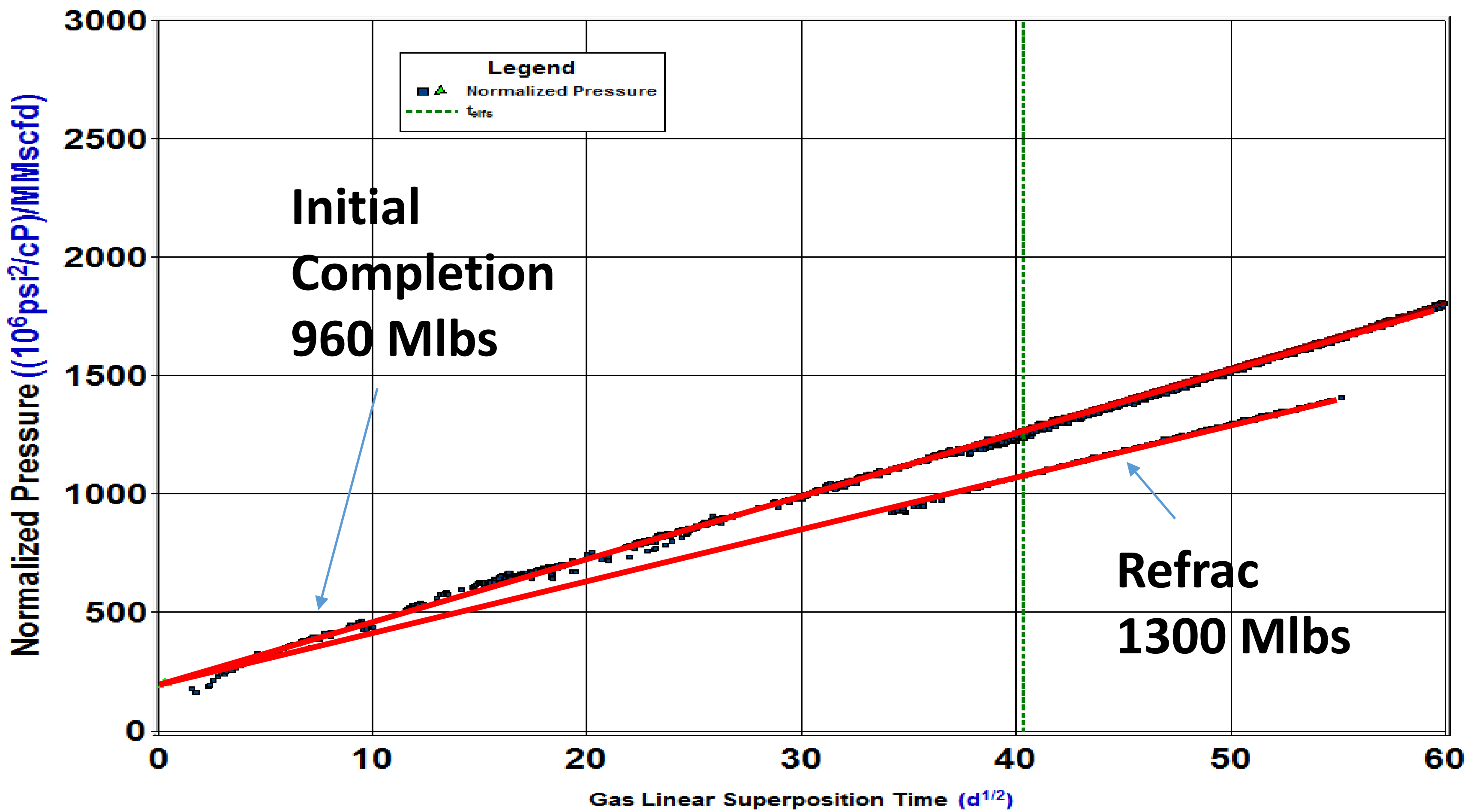
# Example 1 - Cum vs. Time (Forecasting)



# Barnett Field Example 2 – Horizontal Well

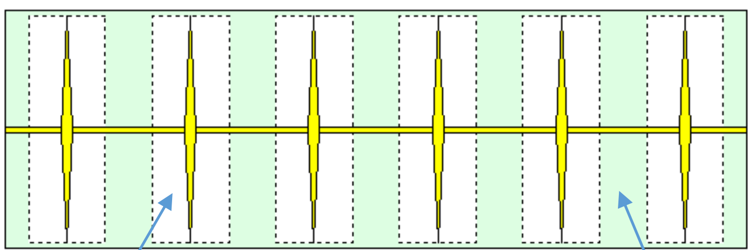


# Ex. 2 – Linear Superposition Time Analysis



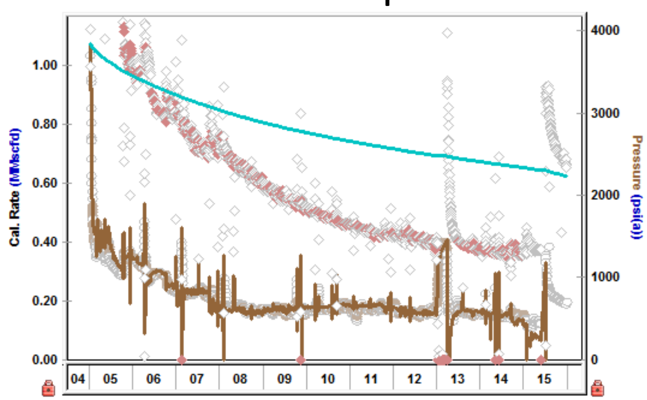
# Example 2 – Performance Modeling

$A_{SRV}$ = 27 ac $A_d$ = 46 ac

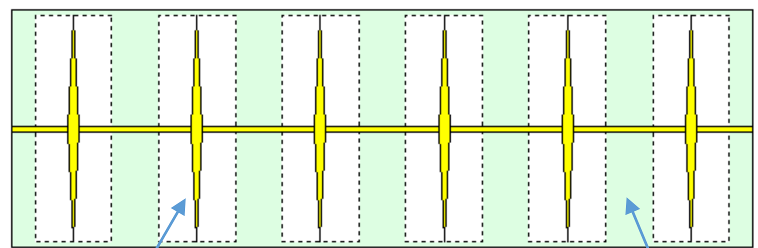


$k_{eff}$ = **216nd** $k_m$ = 50nd

Initial Completion

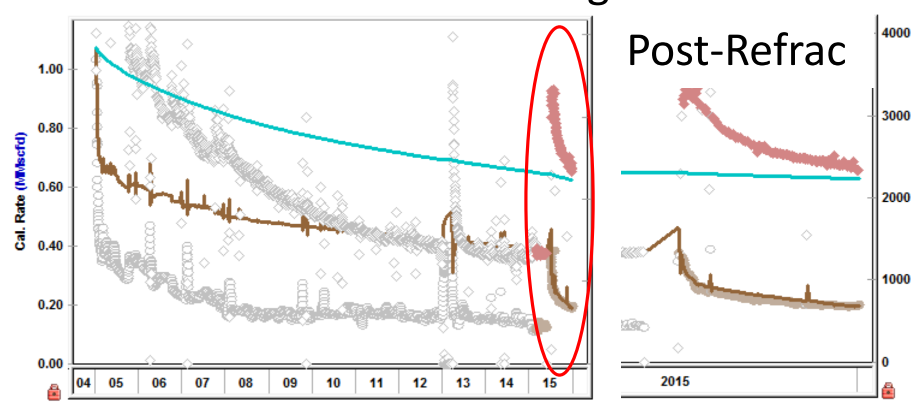



$A_{SRV}$ = 27 ac $A_d$ = 46 ac

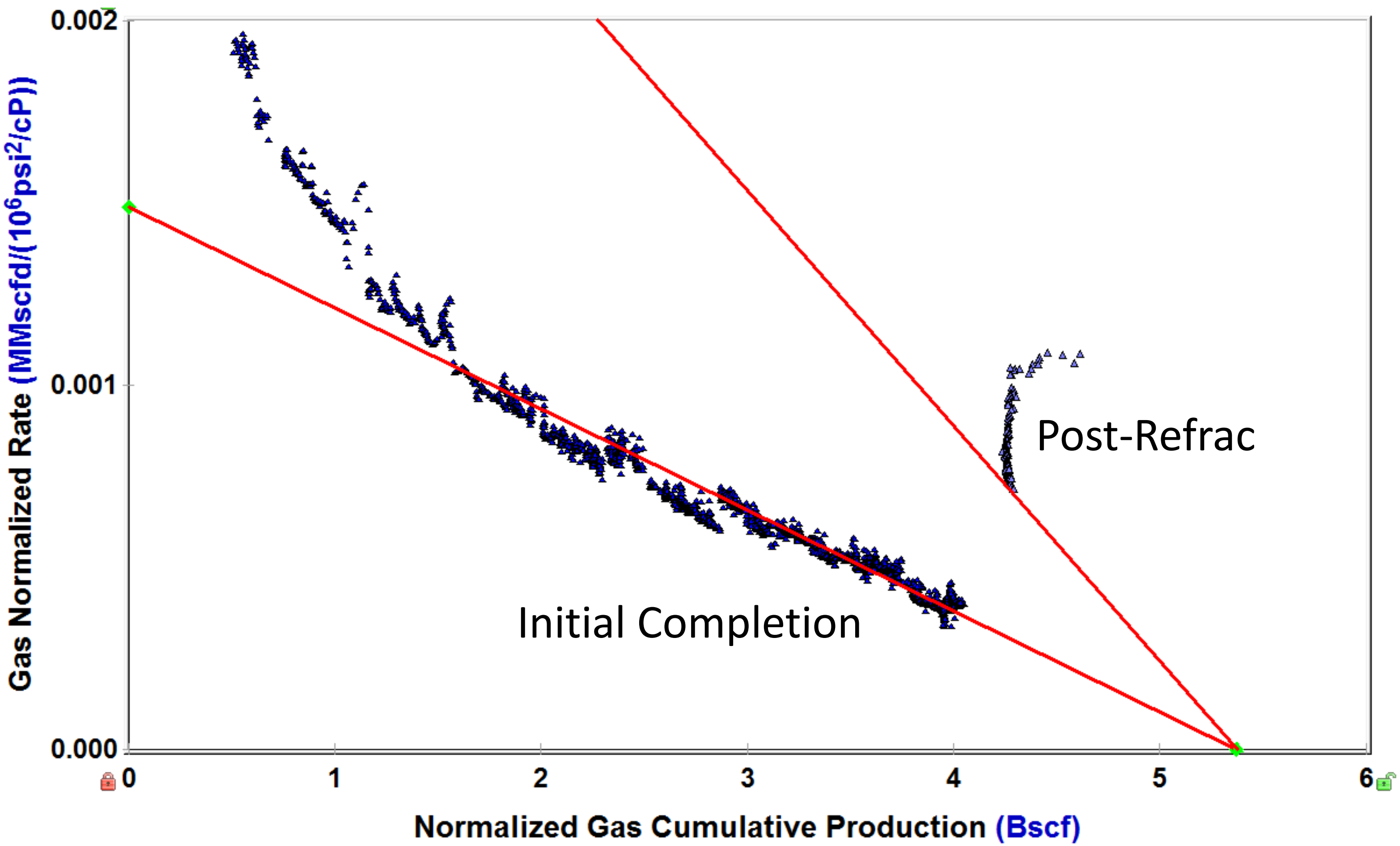


$k_{eff}$ = **400nd** $k_m$ = 50nd

Same SRV following Refrac!



# Example 2 - FMB Analysis



# MUCH NEEDED ANSWERS

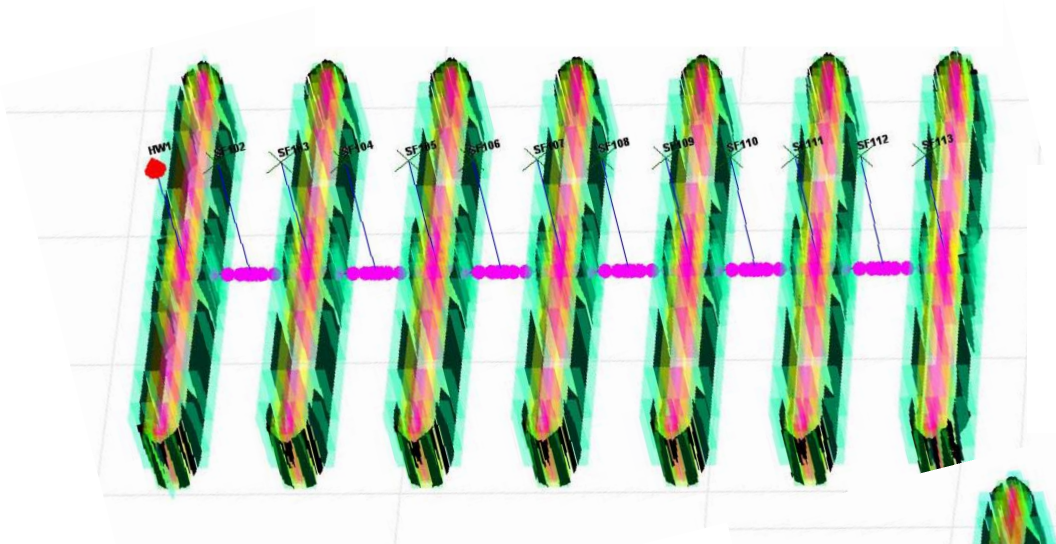
- While production data analysis cannot tell us the specifics of fracture geometry, it <u>can</u> tell us if a refrac has accomplished the following:

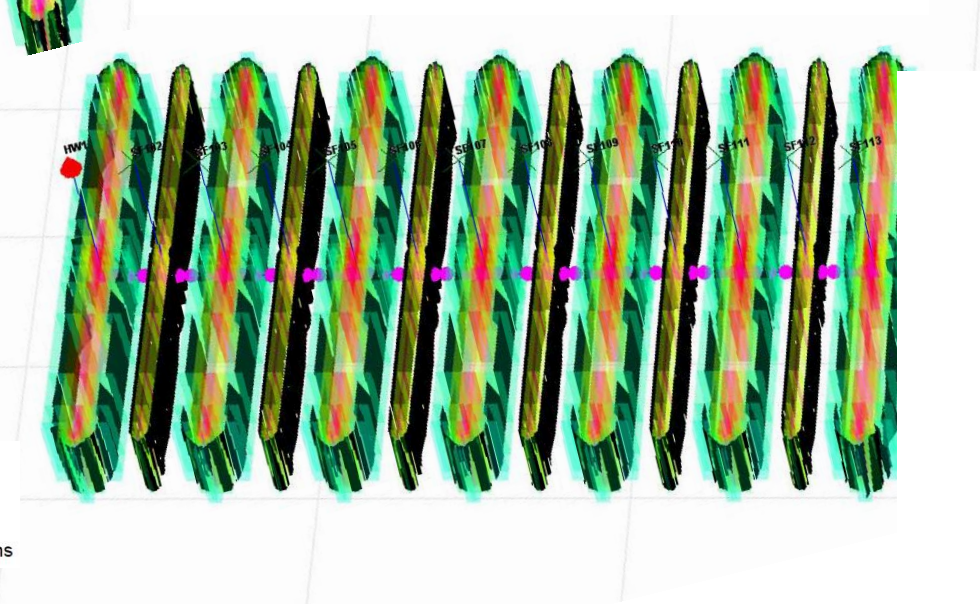
  1- Increased SRV

  2- Increased fracture area (*effective permeability*) within SRV

  3- Changed fracture conductivity

# The Goal; Frac Placement Control

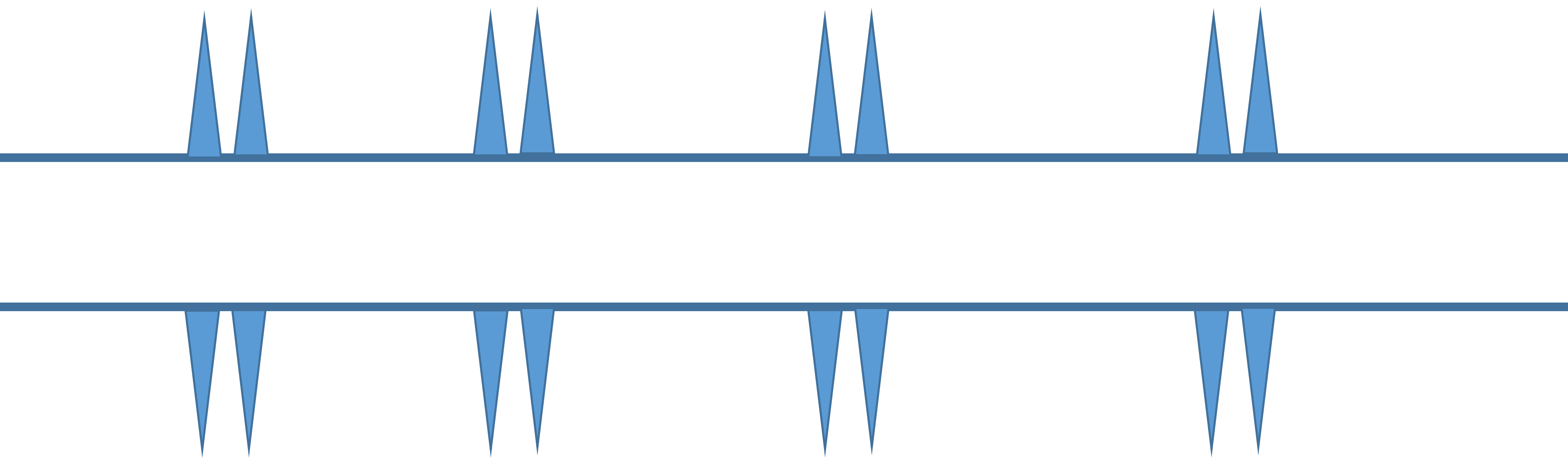


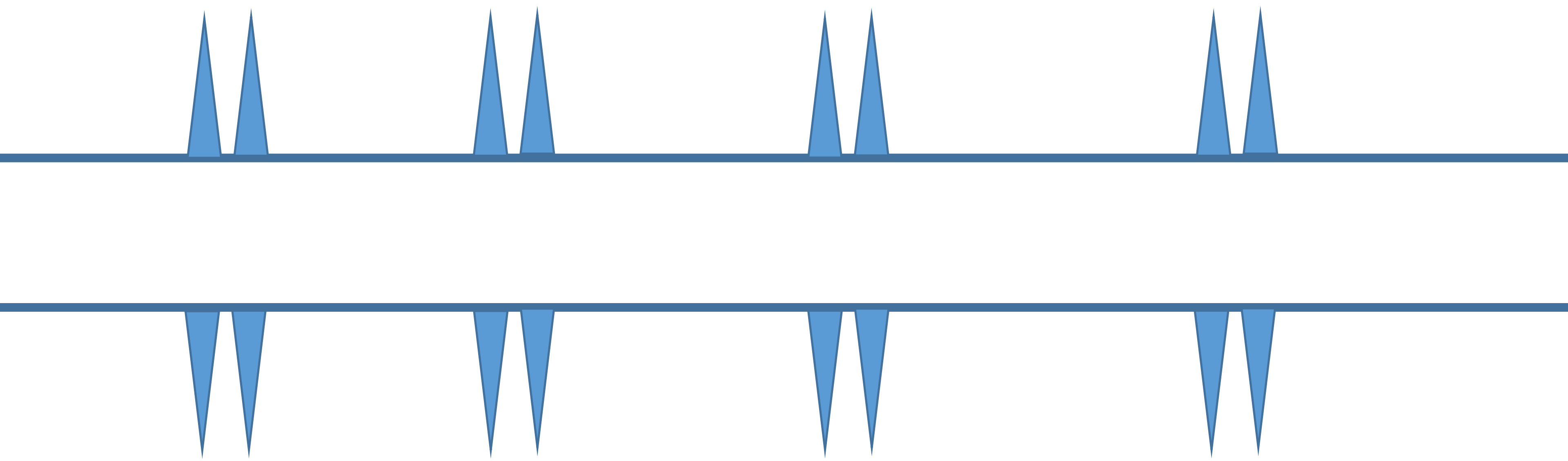

**SPE 154669**

**Barnett Shale Horizontal Restimulations: A Case Study of 13 Wells**
Mark Craig, SPE, and Steve Wendte, SPE, Devon Energy Corp; Jim Buchwalter, SPE, Gemini Solutions

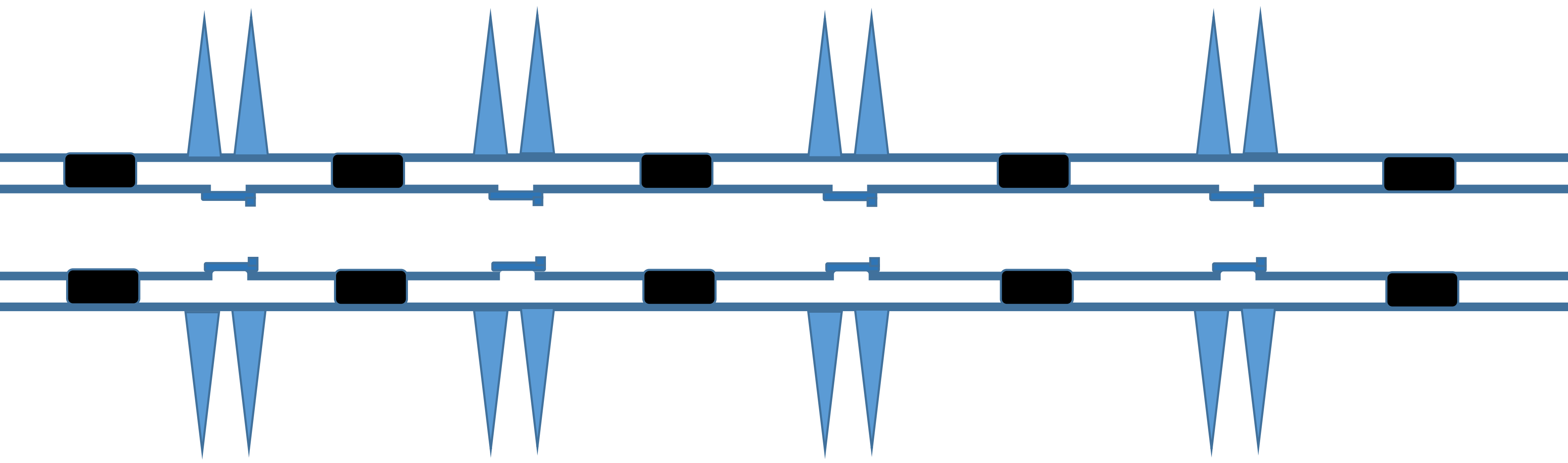
# Mechanical ReFrac Systems



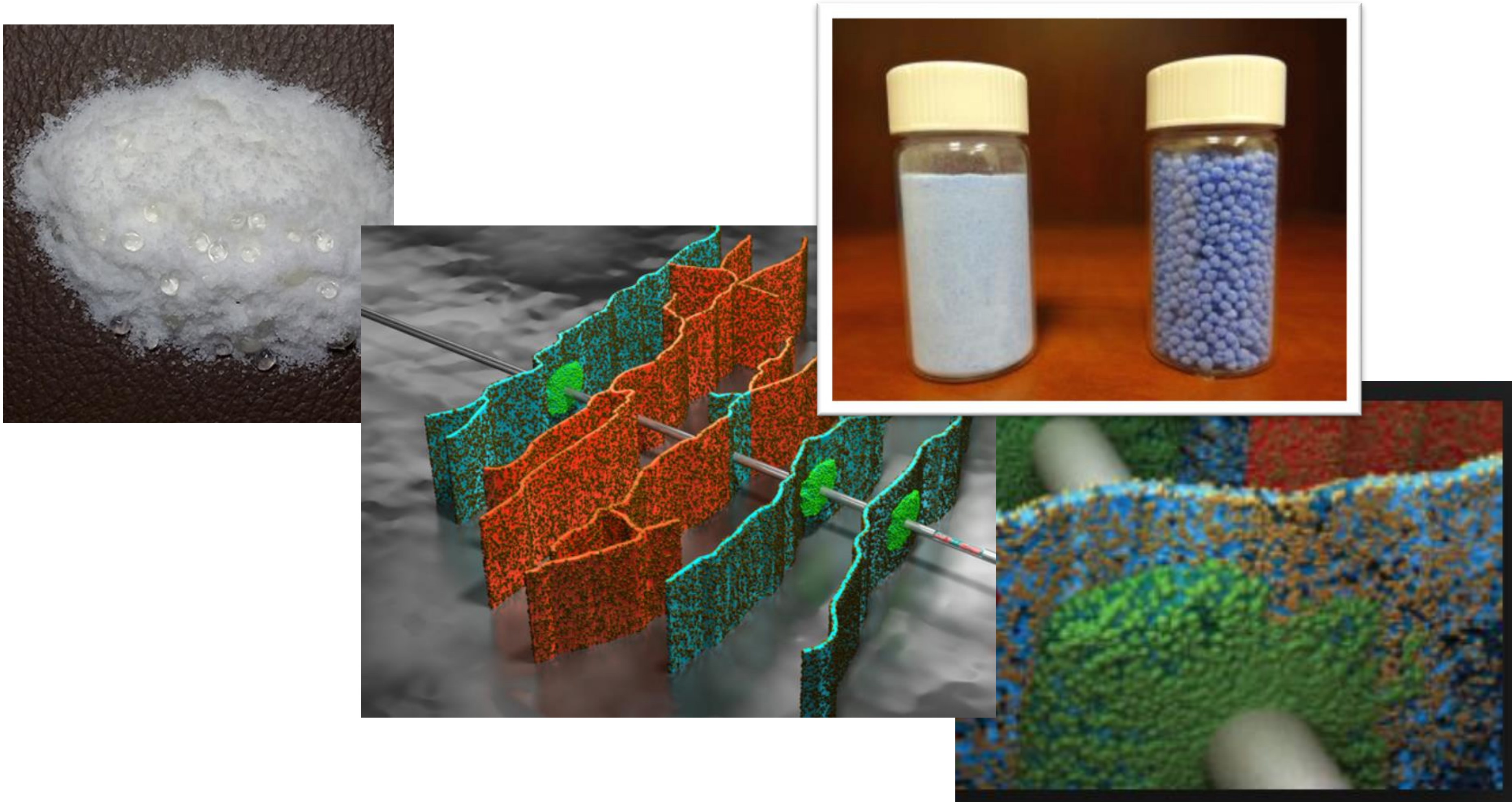
# Mechanical ReFrac Systems



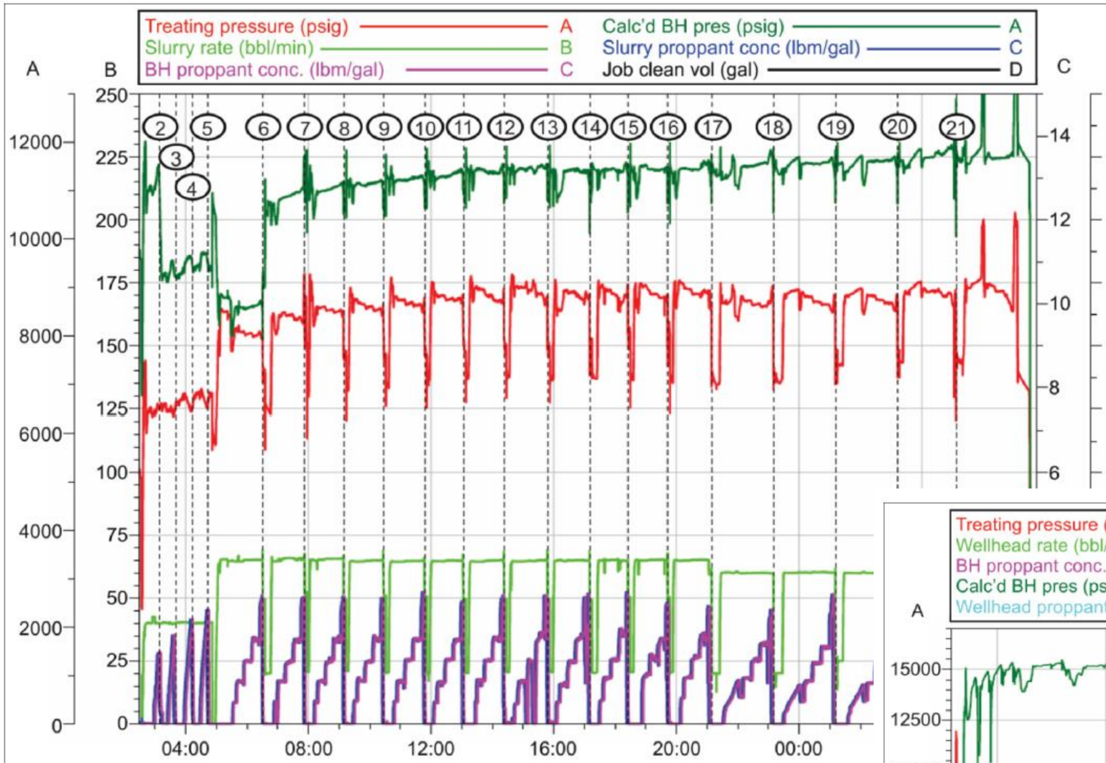
# Mechanical ReFrac Systems

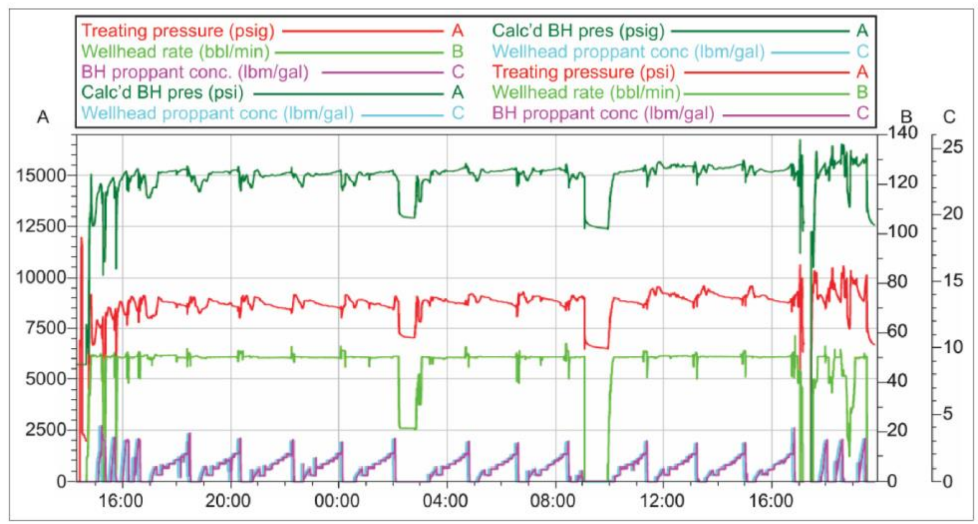


# DEFAULT TO DIVERSION



# CONTROL OF FRAC PLACEMENT?




**SPE-177306-MS**

**Refracturing Design for Underperforming Unconventional Horizontal Reservoirs**

J. T. Krenger, J. Fraser, and A. J. Gibson, Devon Energy; A. Whitsett, J. Melcher, and S. Persac, Halliburton

# WHAT MIGHT AN "IDEAL" REFRAC LOOK LIKE ??

- FLUID & PROPPANT PLACEMENT CONTROL
- REDUCED RISK OF WELL BASHING
- REFRAC EXISTING STAGES
- CAPACITY TO ADD NEW STAGES
- MULTIPLE REFRACS OVER WELL LIFE
- LOWEST OPERATIONAL RISK
- PRODUCTION MANAGEMENT
- MAXIMUM SRV

# WHAT MIGHT AN "IDEAL" REFRAC LOOK LIKE ??

- FLUID & PROPPANT PLACEMENT CONTROL PINPOINT
- REDUCED RISK OF WELL BASHING
- REFRAC EXISTING STAGES
- CAPACITY TO ADD NEW STAGES
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- LOWEST OPERATIONAL RISK
- PRODUCTION MANAGEMENT
- MAXIMUM SRV

# WHAT MIGHT AN "IDEAL" REFRAC LOOK LIKE ??

- FLUID & PROPPANT PLACEMENT CONTROL PINPOINT
- REDUCED RISK OF WELL BASHING DISCRETE STAGES
- REFRAC EXISTING STAGES
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- REDUCED RISK OF WELL BASHING DISCRETE STAGES
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- CAPACITY TO ADD NEW STAGES PRE-INSTALLED, OR ADD
- MULTIPLE REFRACS OVER WELL LIFE FULL ID RETAINED
- LOWEST OPERATIONAL RISK
- PRODUCTION MANAGEMENT
- MAXIMUM SRV

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- LOWEST OPERATIONAL RISK SCREENOUT MITIGATION
- PRODUCTION MANAGEMENT SELECTIVE PRODUCTION
- MAXIMUM SRV

# WHAT MIGHT AN "IDEAL" REFRAC LOOK LIKE ??

- FLUID & PROPPANT PLACEMENT CONTROL — PINPOINT
- REDUCED RISK OF WELL BASHING — DISCRETE STAGES
- REFRAC EXISTING STAGES — RELIABLE STAGE ISOLATION
- CAPACITY TO ADD NEW STAGES — PRE-INSTALLED, OR ADD
- MULTIPLE REFRACS OVER WELL LIFE — FULL ID RETAINED
- LOWEST OPERATIONAL RISK — SCREENOUT MITIGATION
- PRODUCTION MANAGEMENT — SELECTIVE PRODUCTION
- MAXIMUM SRV — FRAC DESIGN OPTIMIZATION

# START WITH THE END IN MIND:

# START WITH THE END IN MIND:
# ***RE-CLOSABLE FRAC SLEEVES***

# START WITH THE END IN MIND: ***RE-CLOSABLE FRAC SLEEVES***

- MEETS ALL "IDEAL" CRITERION
- NEEDS FIELD TRIALS IN REFRAC APPLICATIONS
- A POTENTIAL STEP-CHANGE IMPROVEMENT
  - Proppant Distribution
  - Refrac Capabilities

# TO DATE: ONE WELL ONLY…

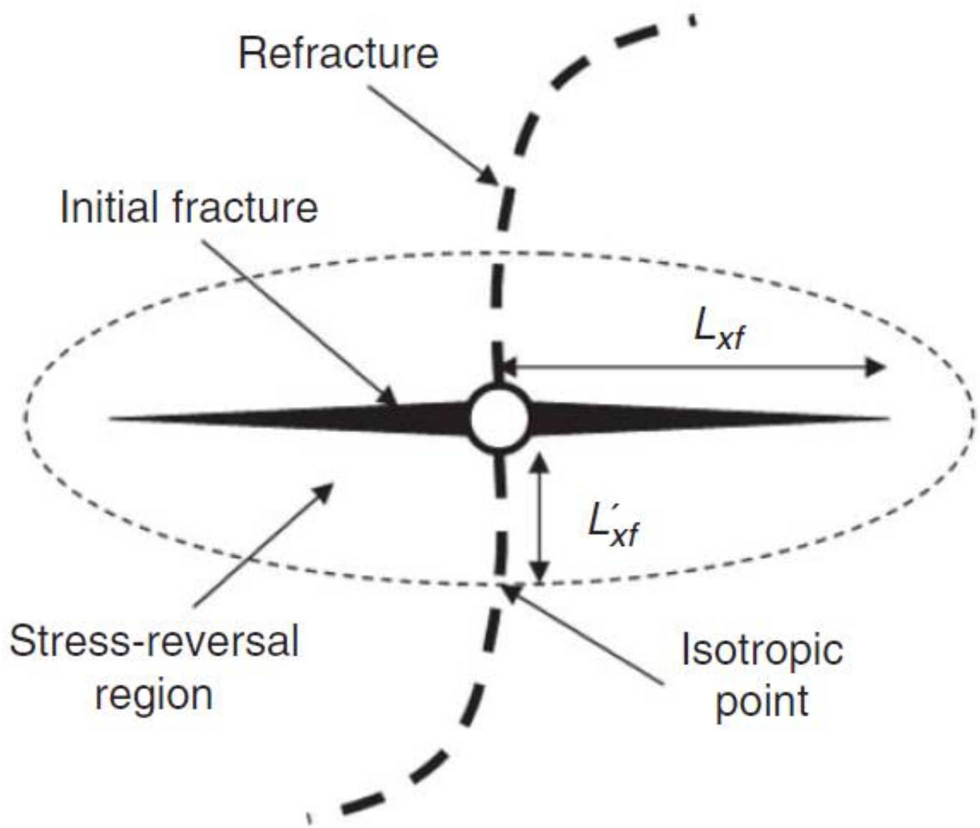
1. SLEEVES OPENED & ACIDIZED (Individually)
2. PRODUCED FOR SEVERAL WEEKS
3. SLEEVES CLOSED
4. SLEEVES FRACTURED INDIVIDUALLY
5. WELL PLACED ON PRODUCTION

# WHAT MIGHT AN "IDEAL" REFRAC LOOK LIKE ??

- FLUID & PROPPANT PLACEMENT CONTROL PINPOINT
- REDUCED RISK OF WELL BASHING DISCRETE STAGES
- REFRAC EXISTING STAGES RELIABLE STAGE ISOLATION
- CAPACITY TO ADD NEW STAGES PRE-INSTALLED, OR ADD
- MULTIPLE REFRACS OVER WELL LIFE FULL ID RETAINED
- LOWEST OPERATIONAL RISK SCREENOUT MITIGATION
- PRODUCTION MANAGEMENT SELECTIVE PRODUCTION
- MAXIMUM SRV FRAC DESIGN OPTIMIZATION

… ? INDUCED COMPLEXITY ?

# Vertical Well Frac Re-Orientation




Ebel & Mack 1993
SPE 134491, Sharma & Roussel

MULTISTAGE UNLIMITED NCS

# ZIPPERFRACS & MODIFIED ZIPPERFRACS

SPE 159786

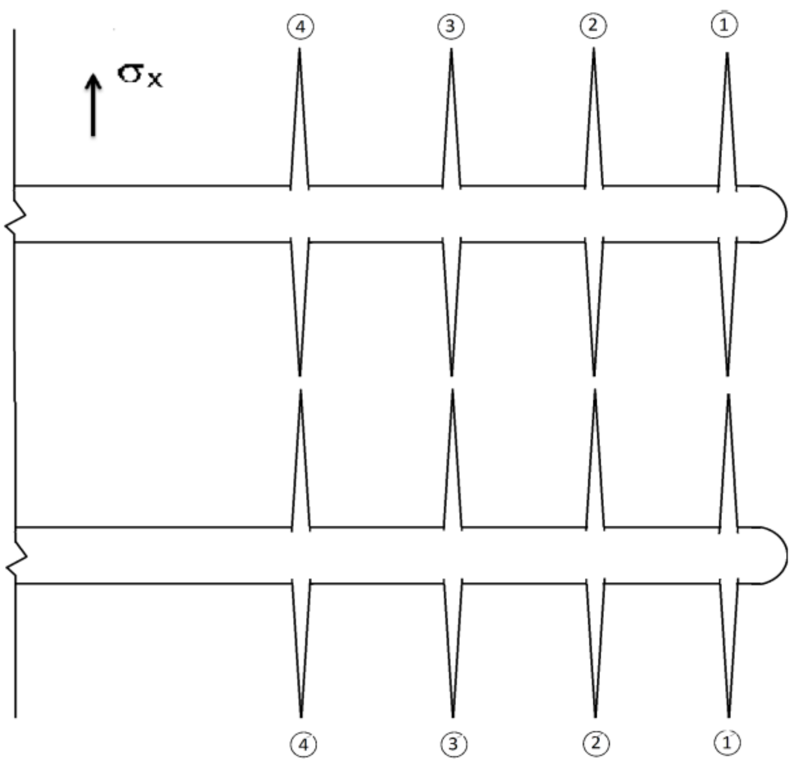



Fig. 15—Fracture placement in zipper-frac design

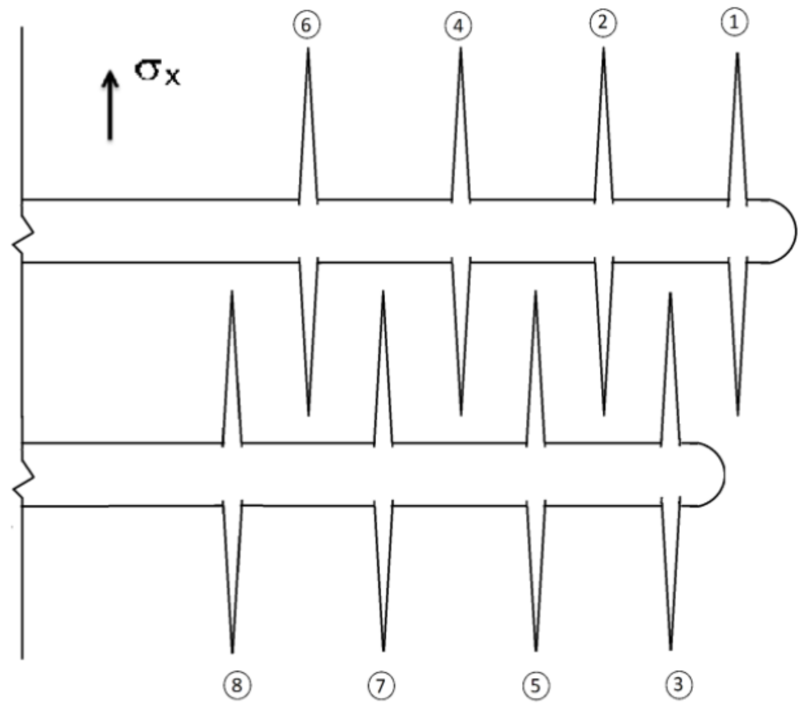
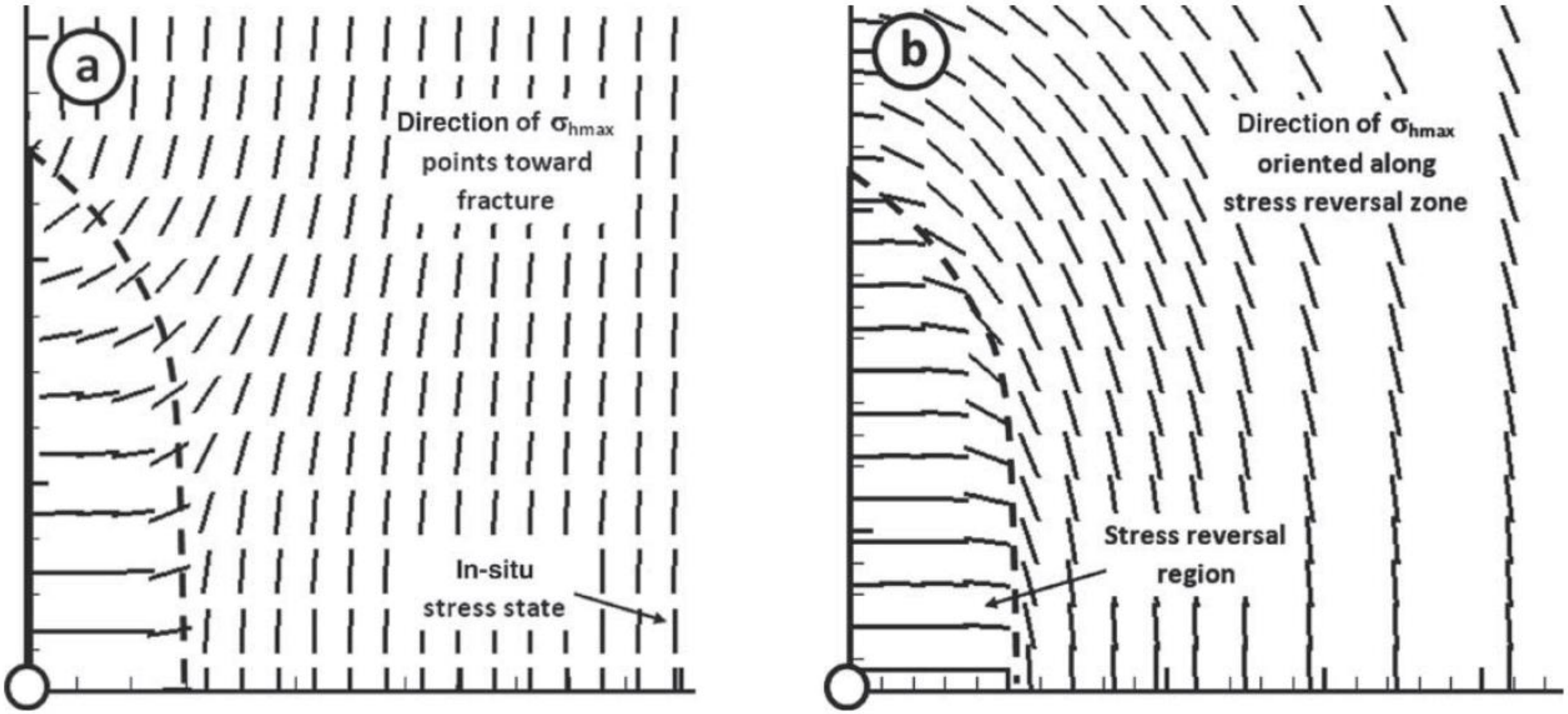


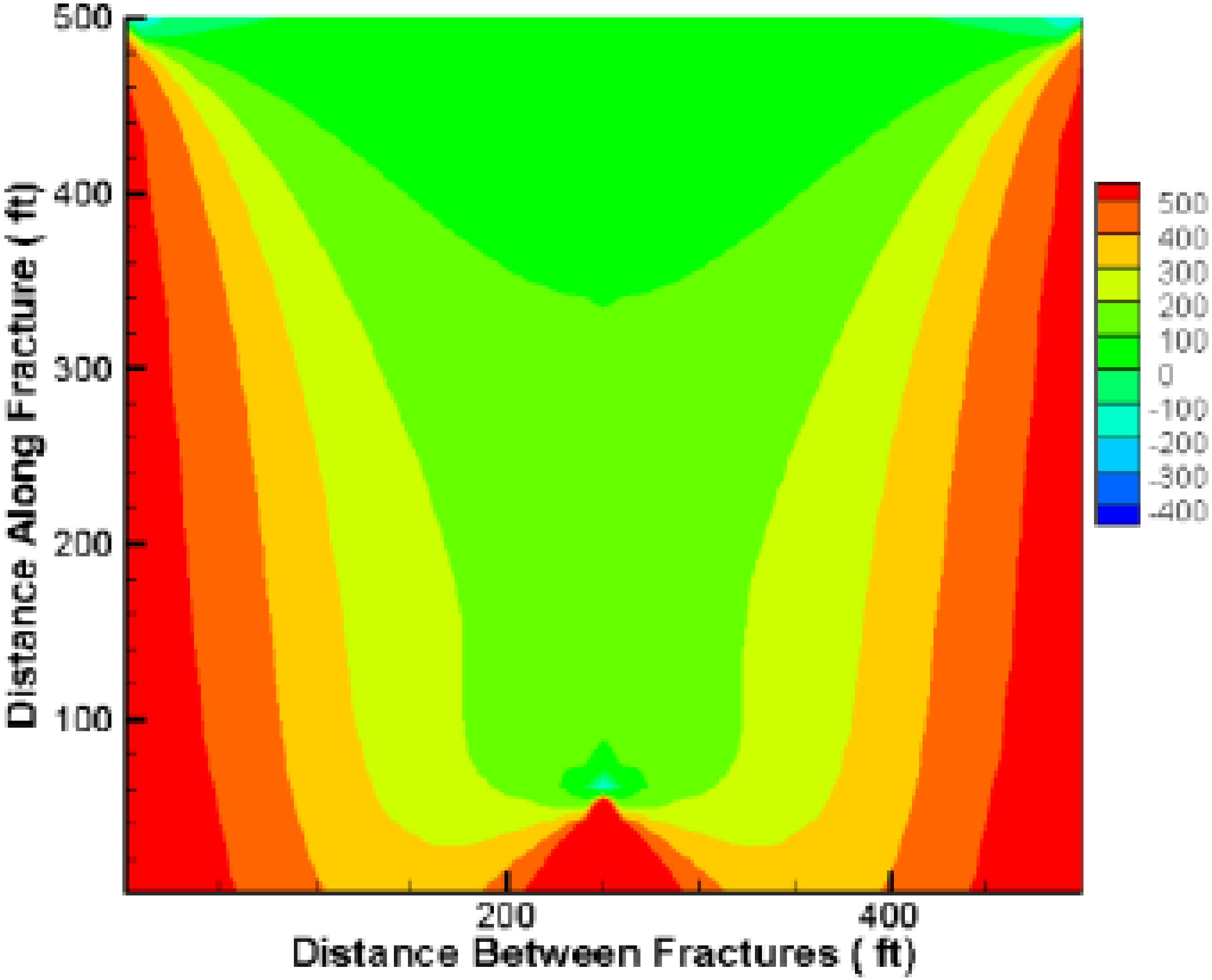

Fig. 16—Fracture placement in MZF design

# Poroelastic & Mechanical Stress Effects

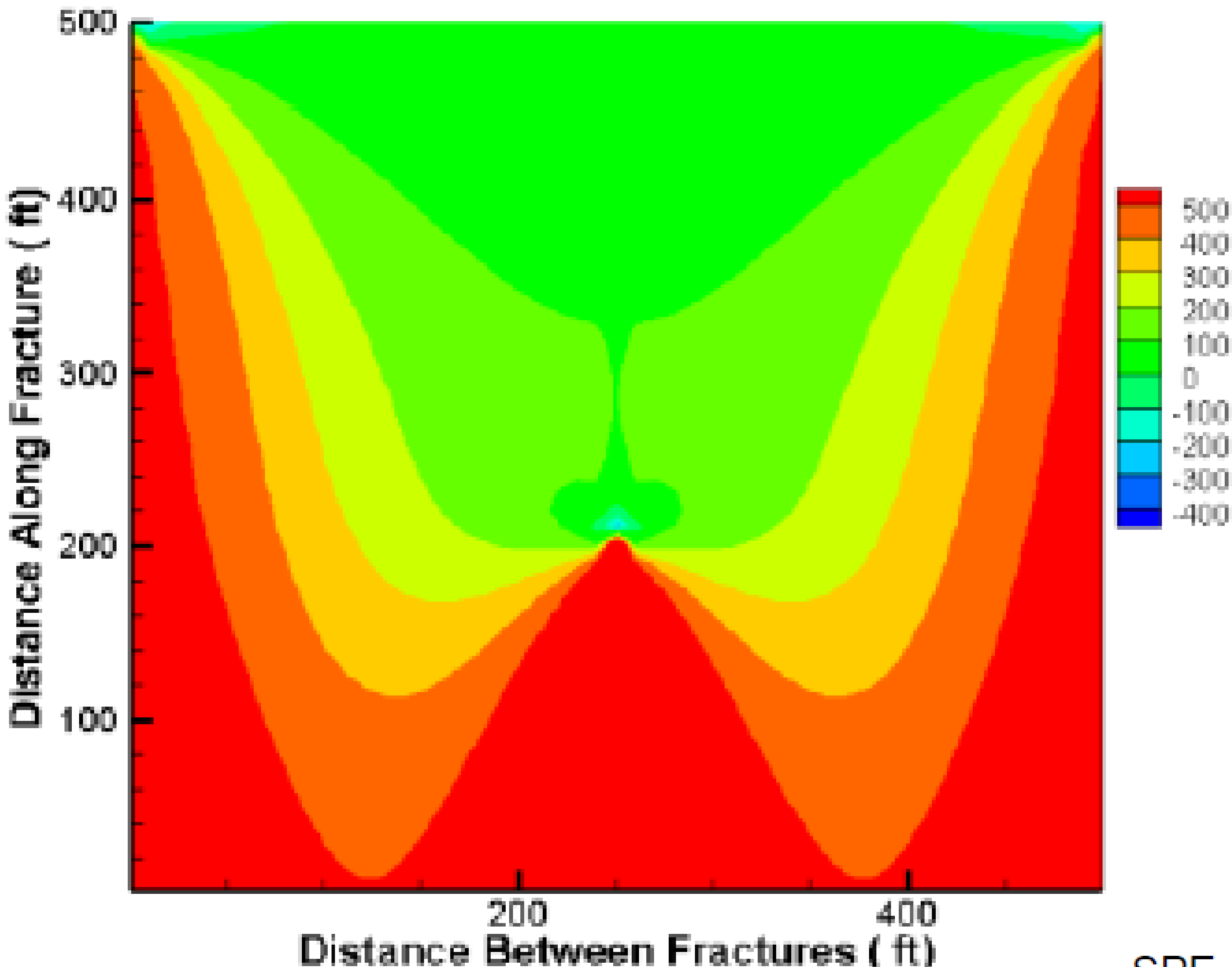



Comparison of stress reorientation resulting from (a) mechanical effects and (b) poroelastic effects (direction of maximum horizontal stress).

SPE 134491, Sharma & Roussel


500
400
300
200
100
Distance Along Fracture ( ft)
200
400
Distance Between Fractures ( ft)
500
400
300
200
100
0
-100
-200
-300
-400

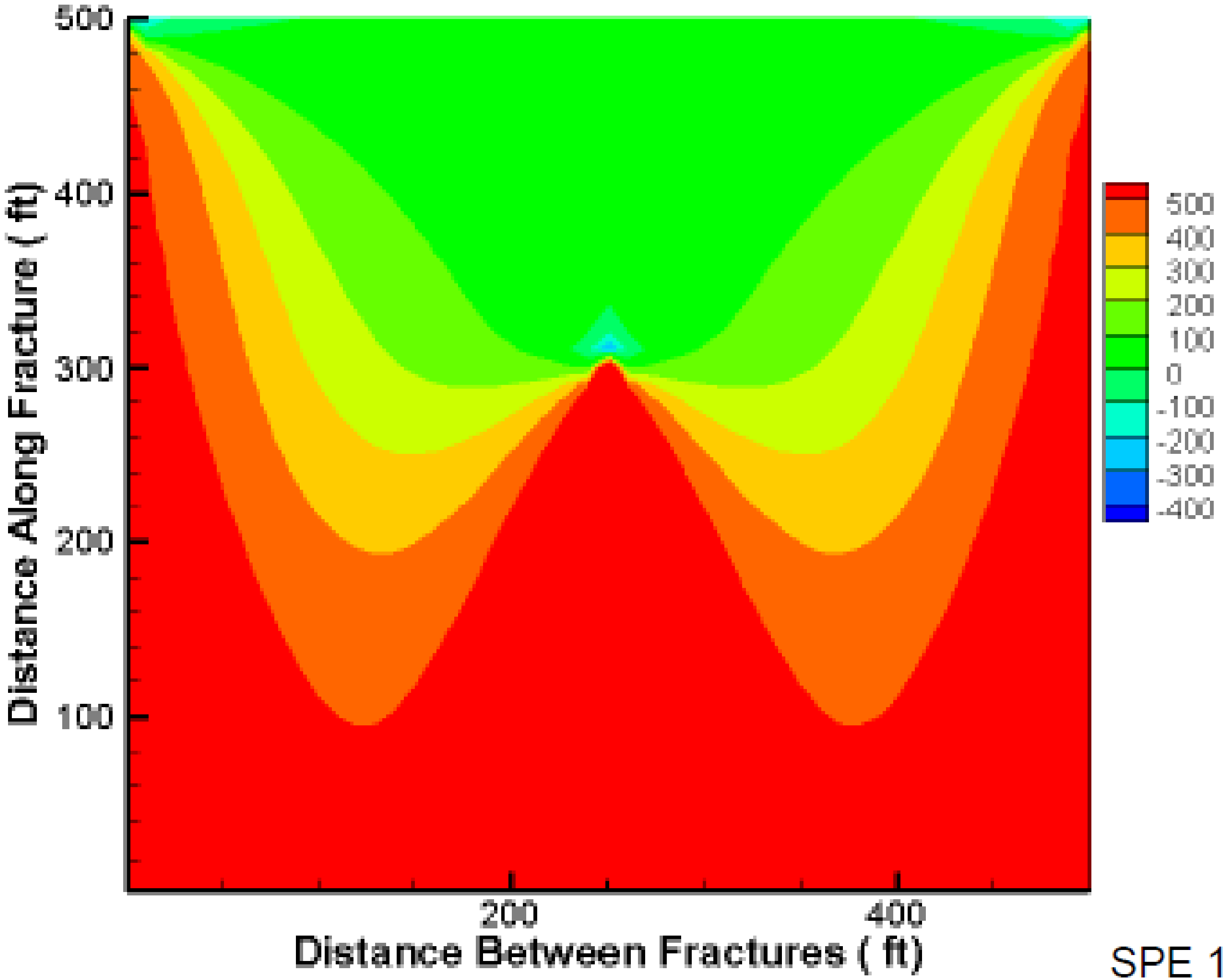
SPE 159786


500
400
300
200
100
Distance Along Fracture ( ft)
200
400
Distance Between Fractures ( ft)
500
400
300
200
100
0
-100
-200
-300
-400

SPE 159786

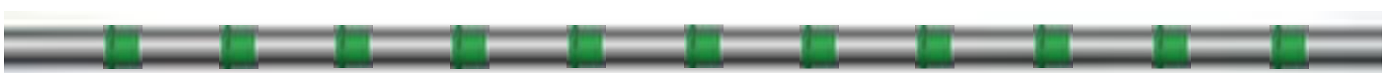
MULTISTAGE UNLIMITED

NCS




SPE 159786

# FRACTURE INTERFERENCE
## Initial Completion



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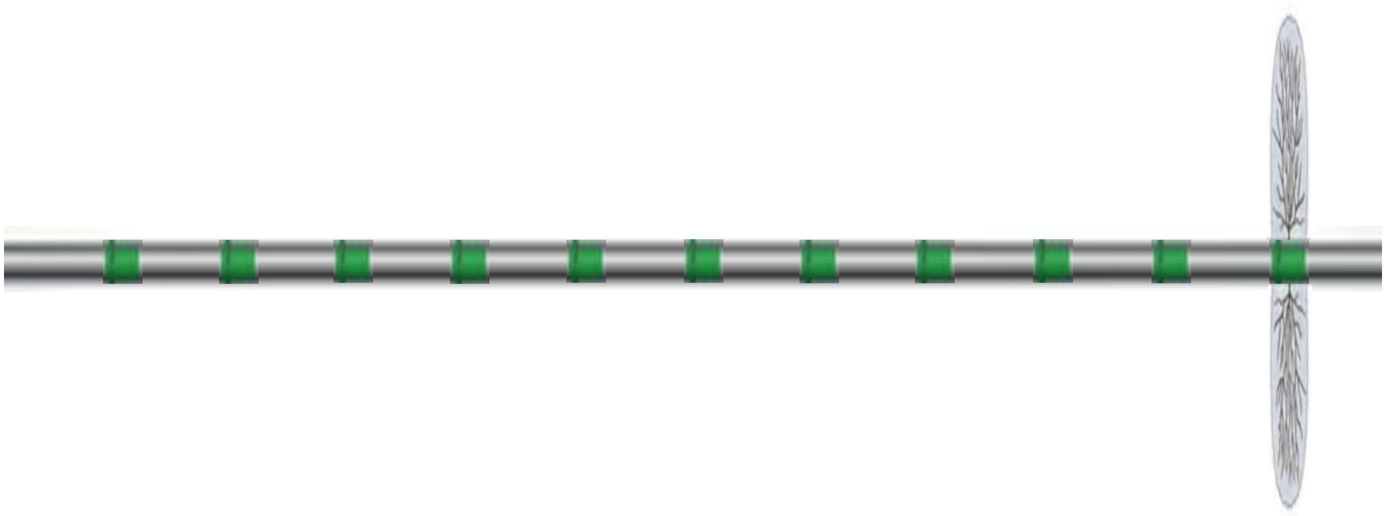

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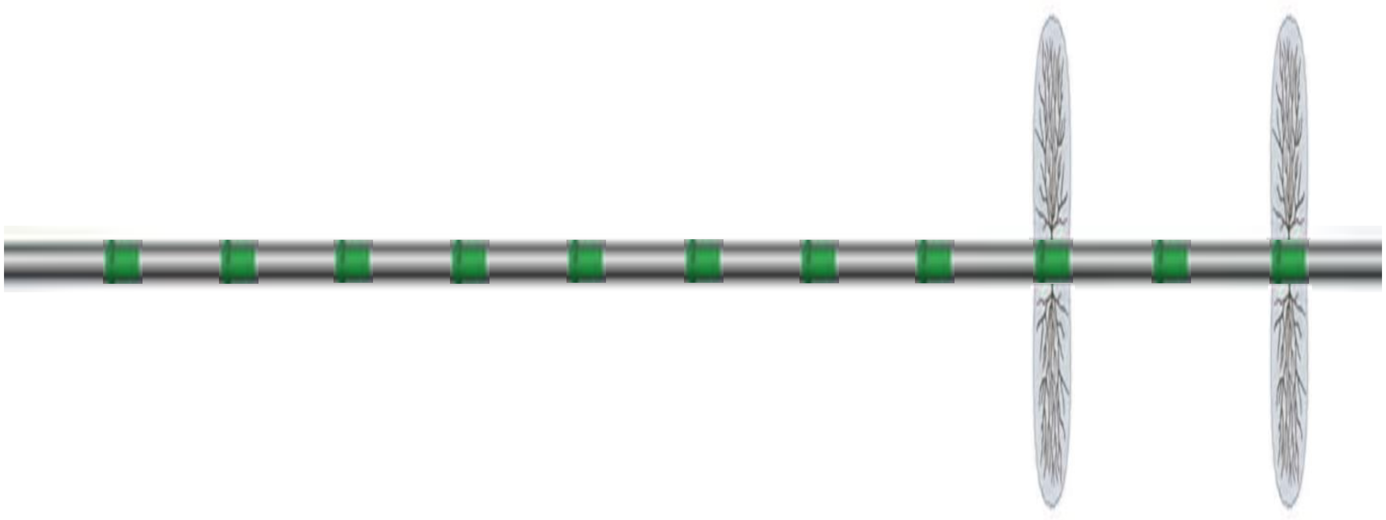

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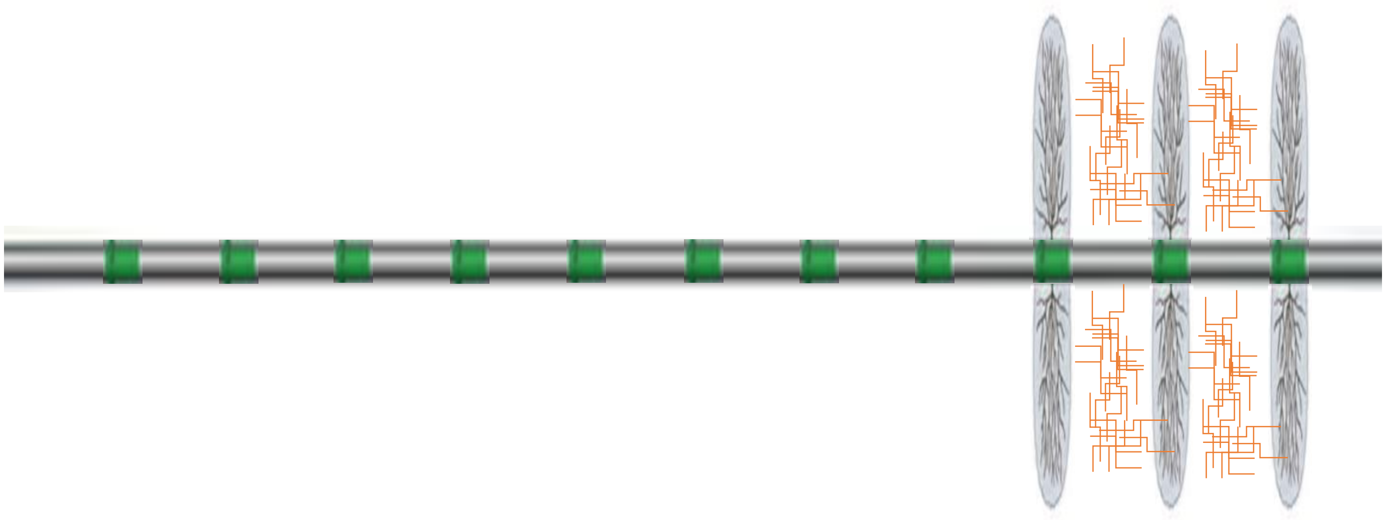

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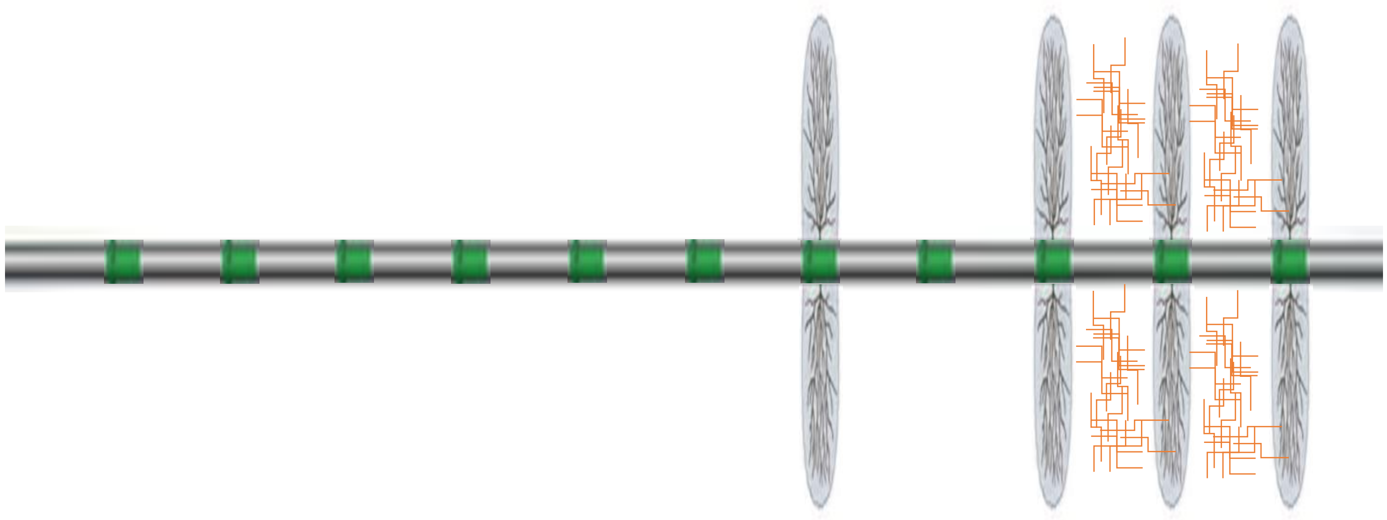

MULTISTAGE UNLIMITED

NCS

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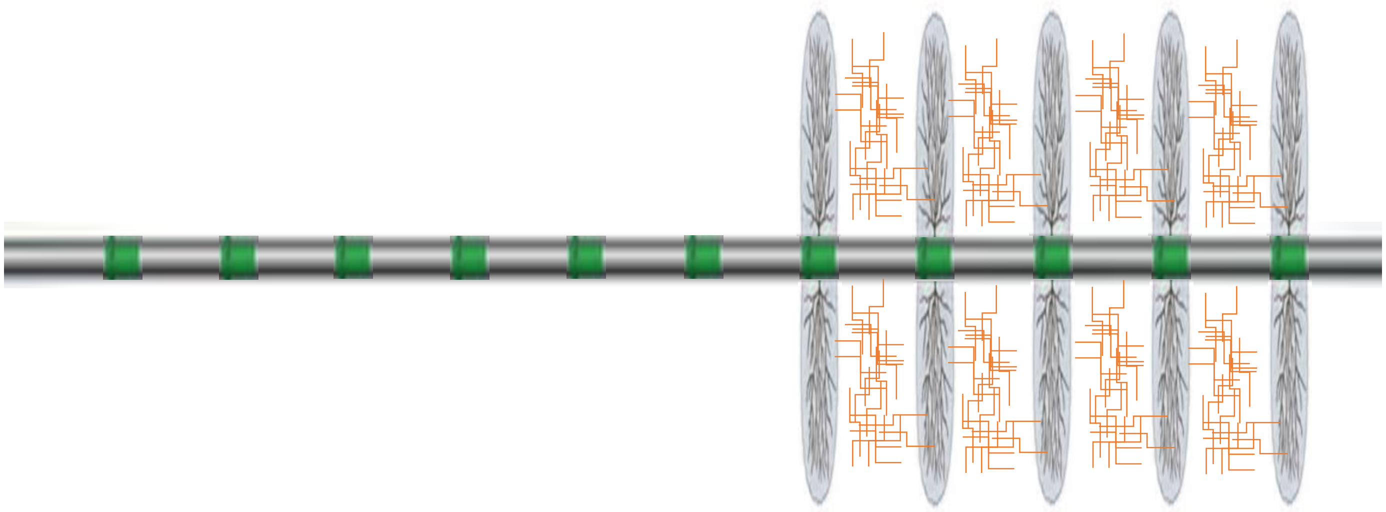

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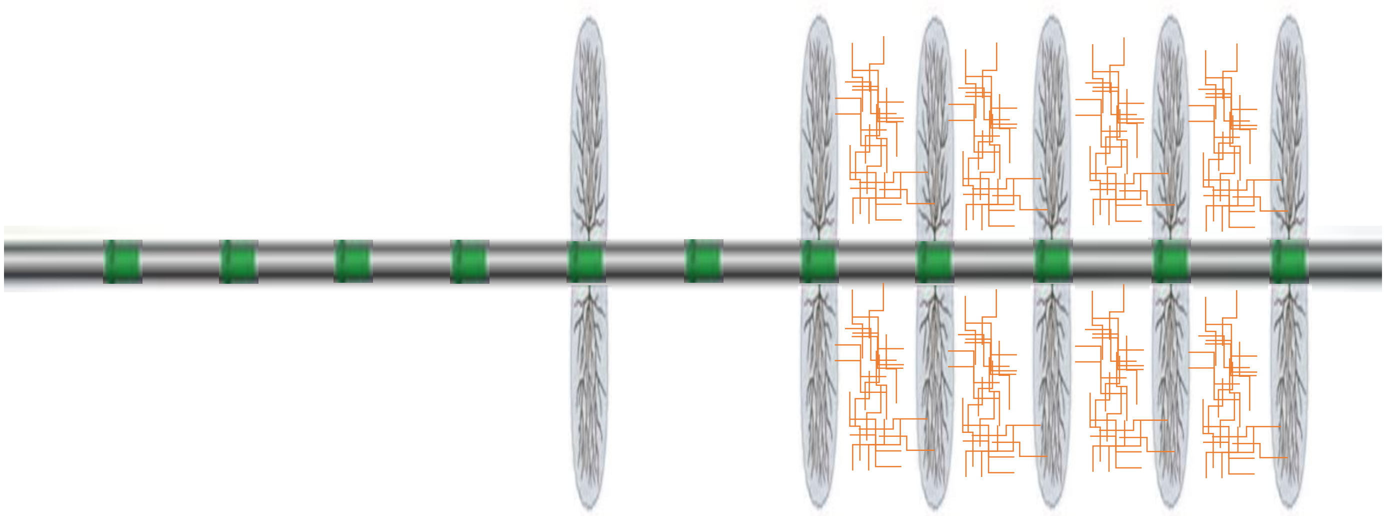

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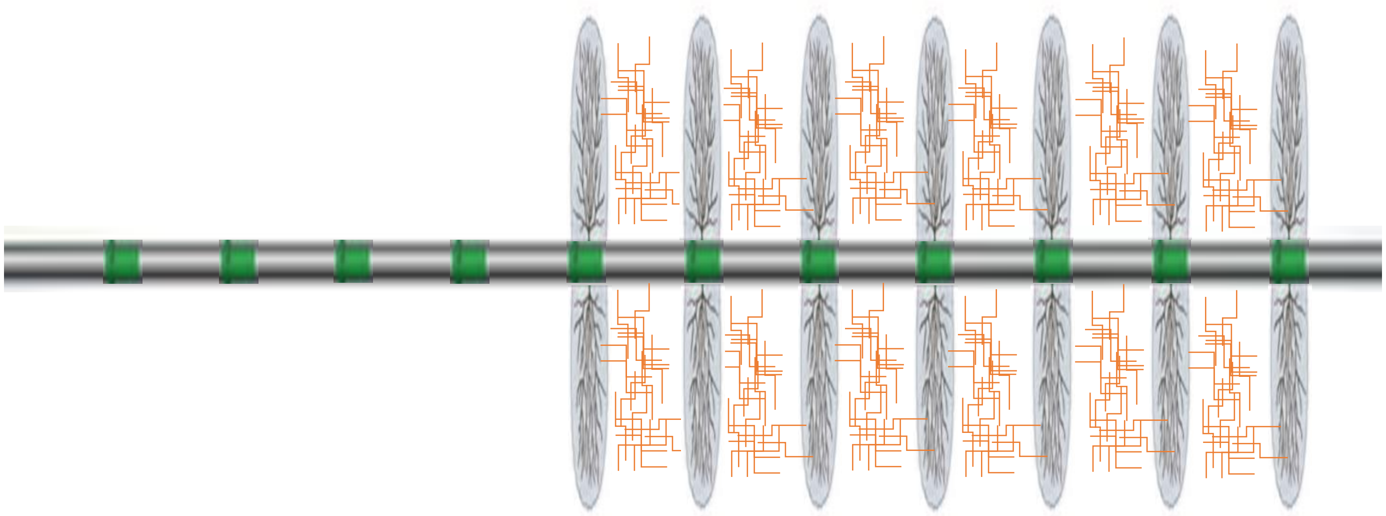

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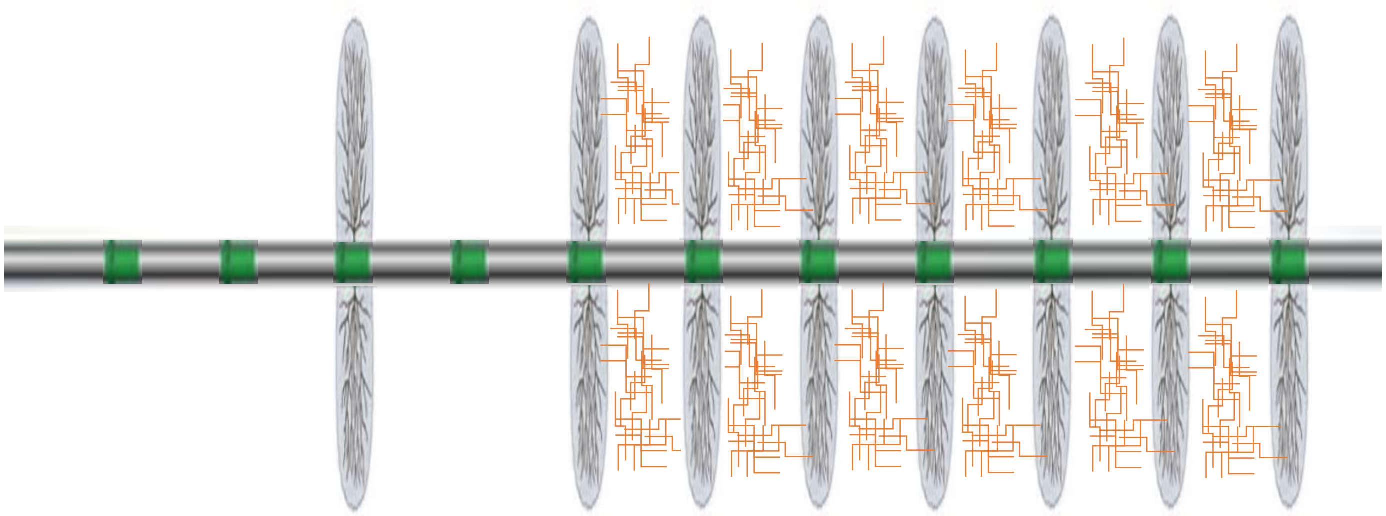

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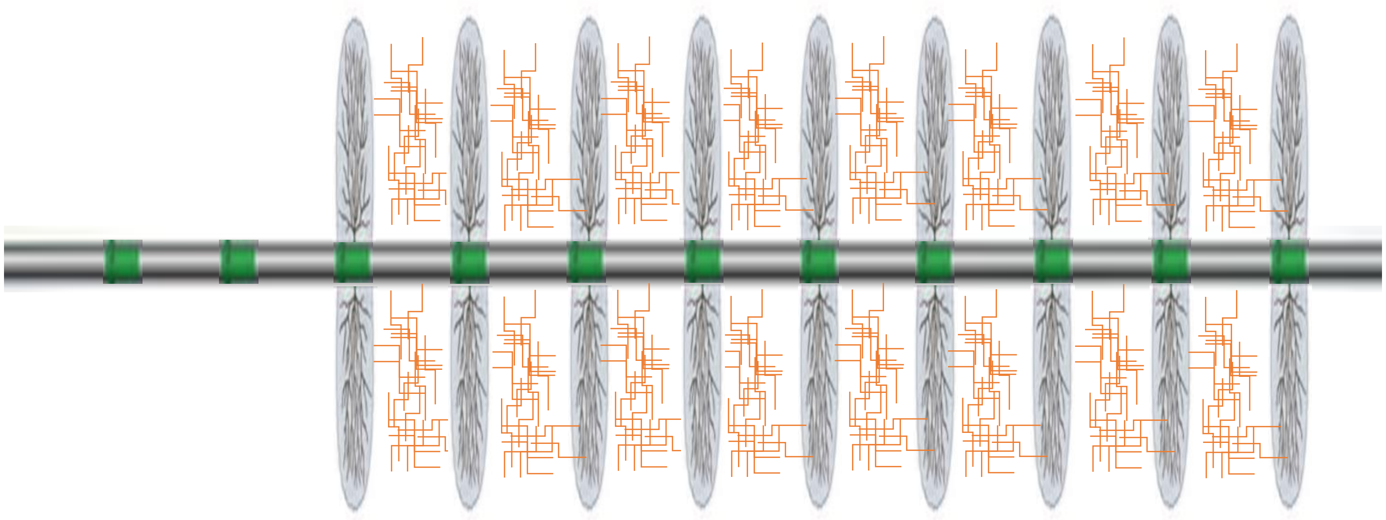

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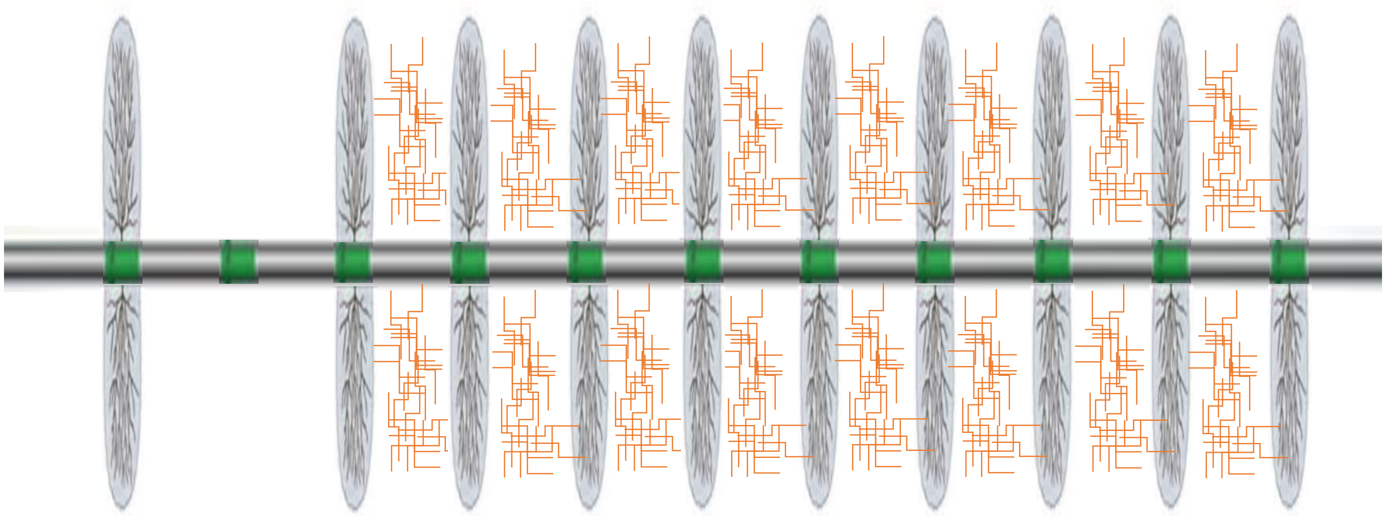

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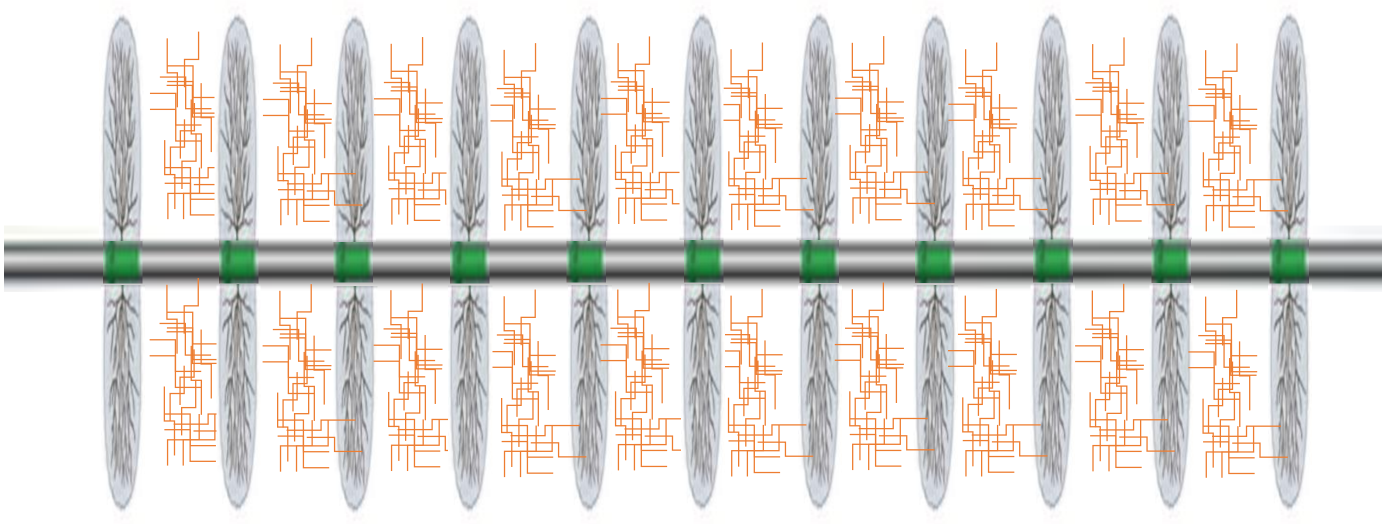
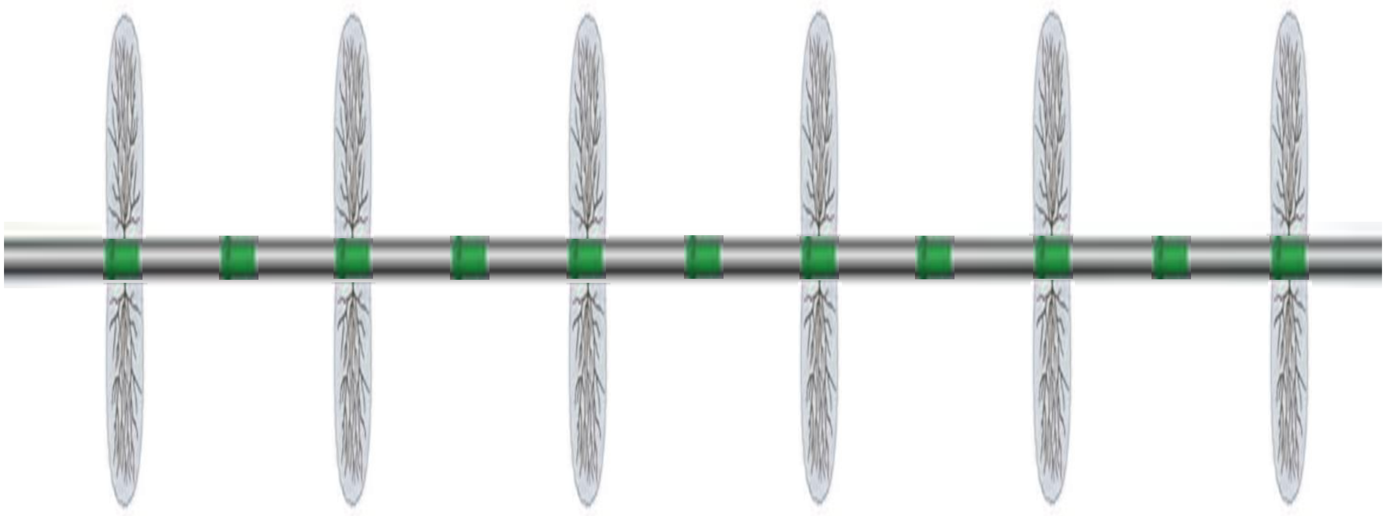


# FRACTURE INTERFERENCE

## Refrac / Recompletion



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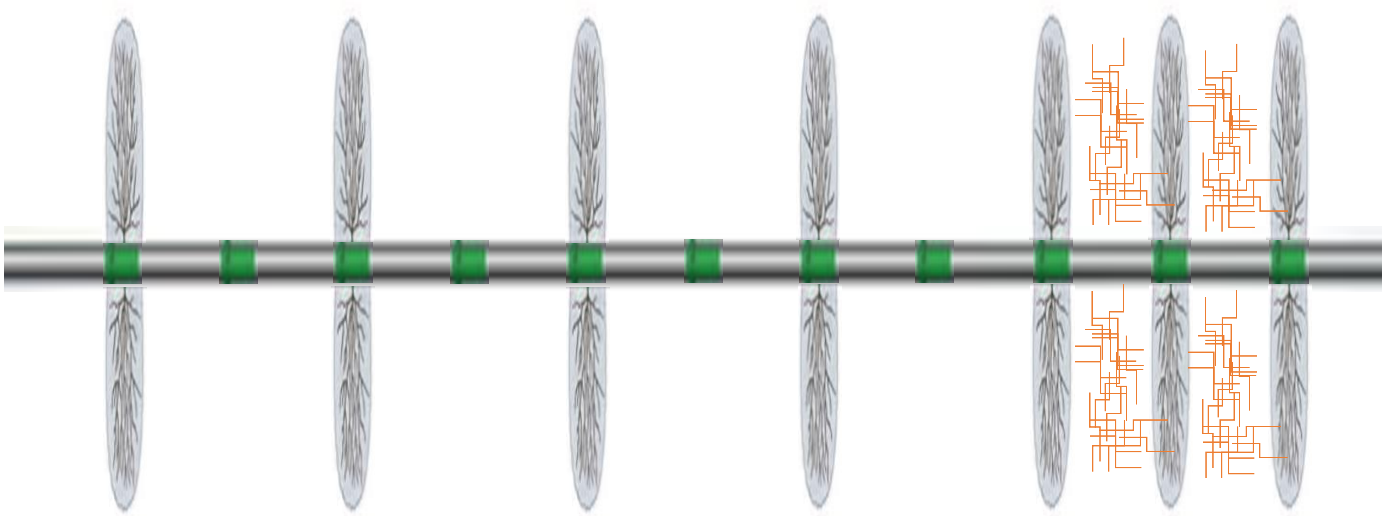

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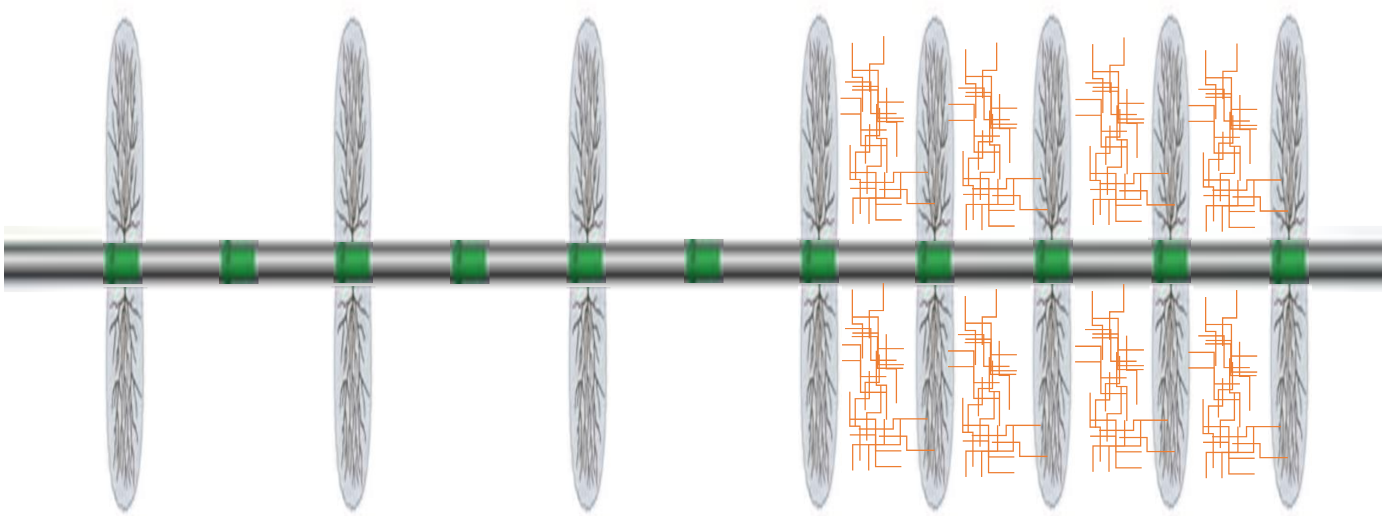

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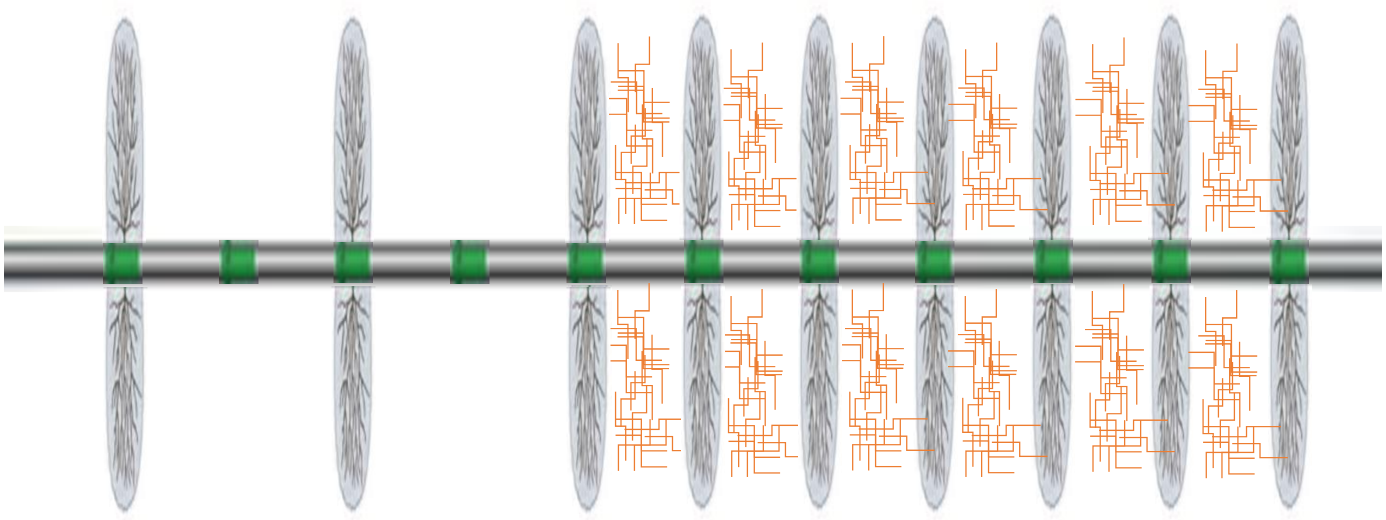

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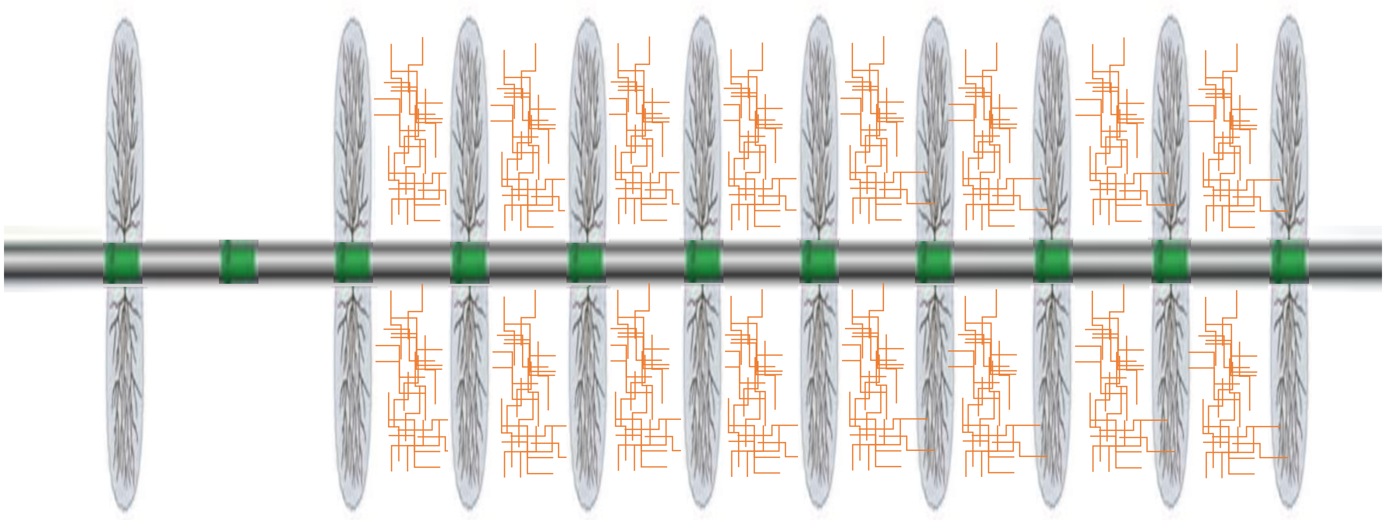

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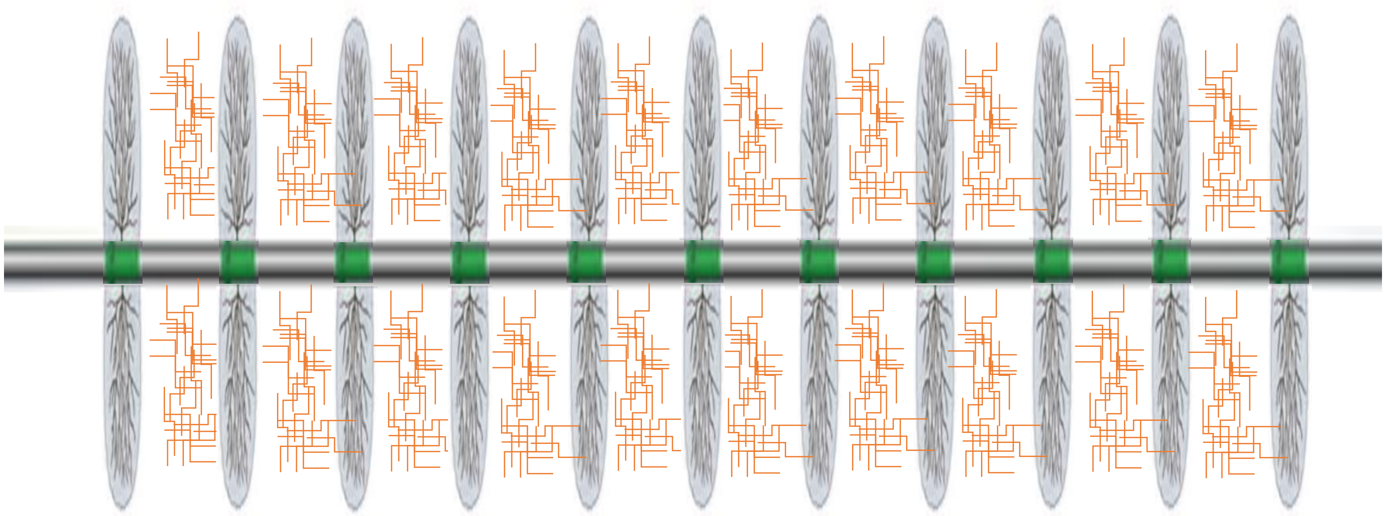
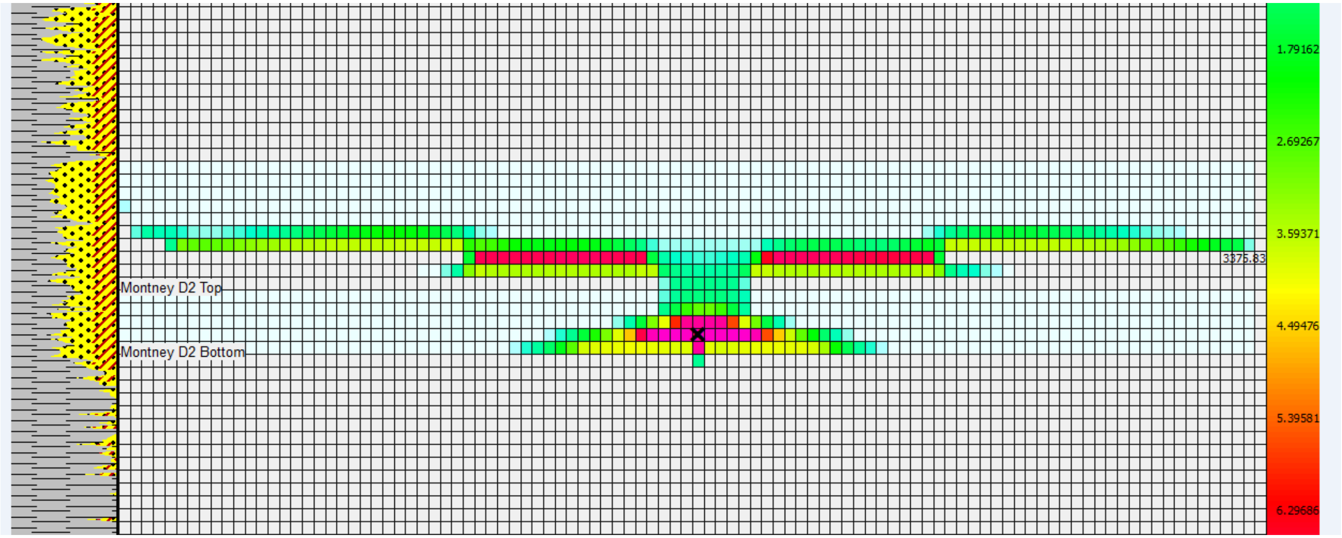
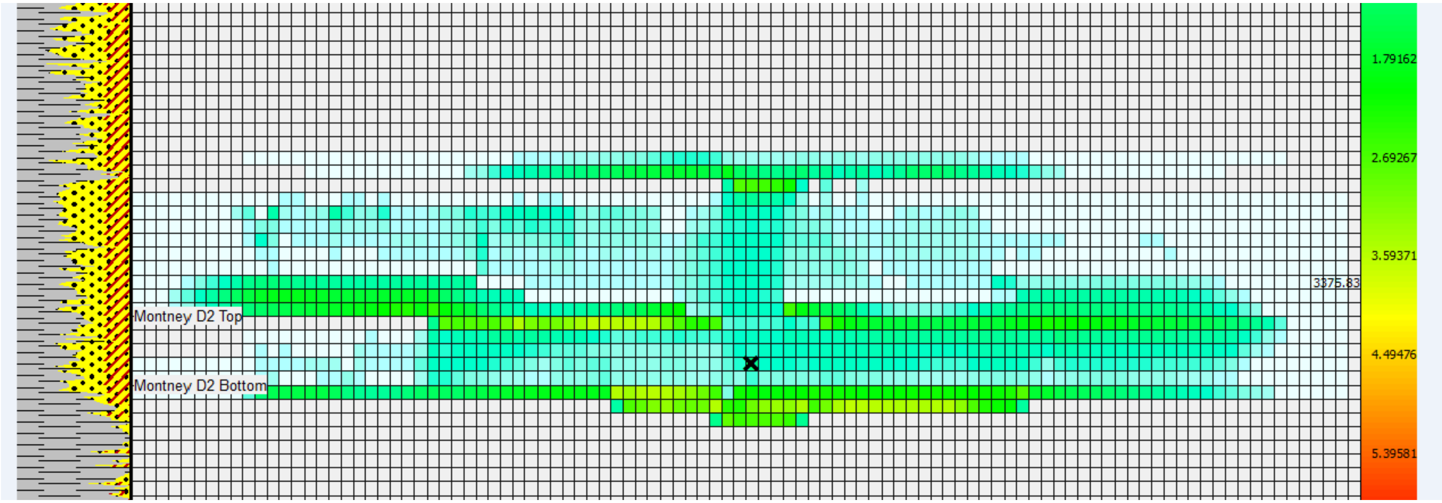
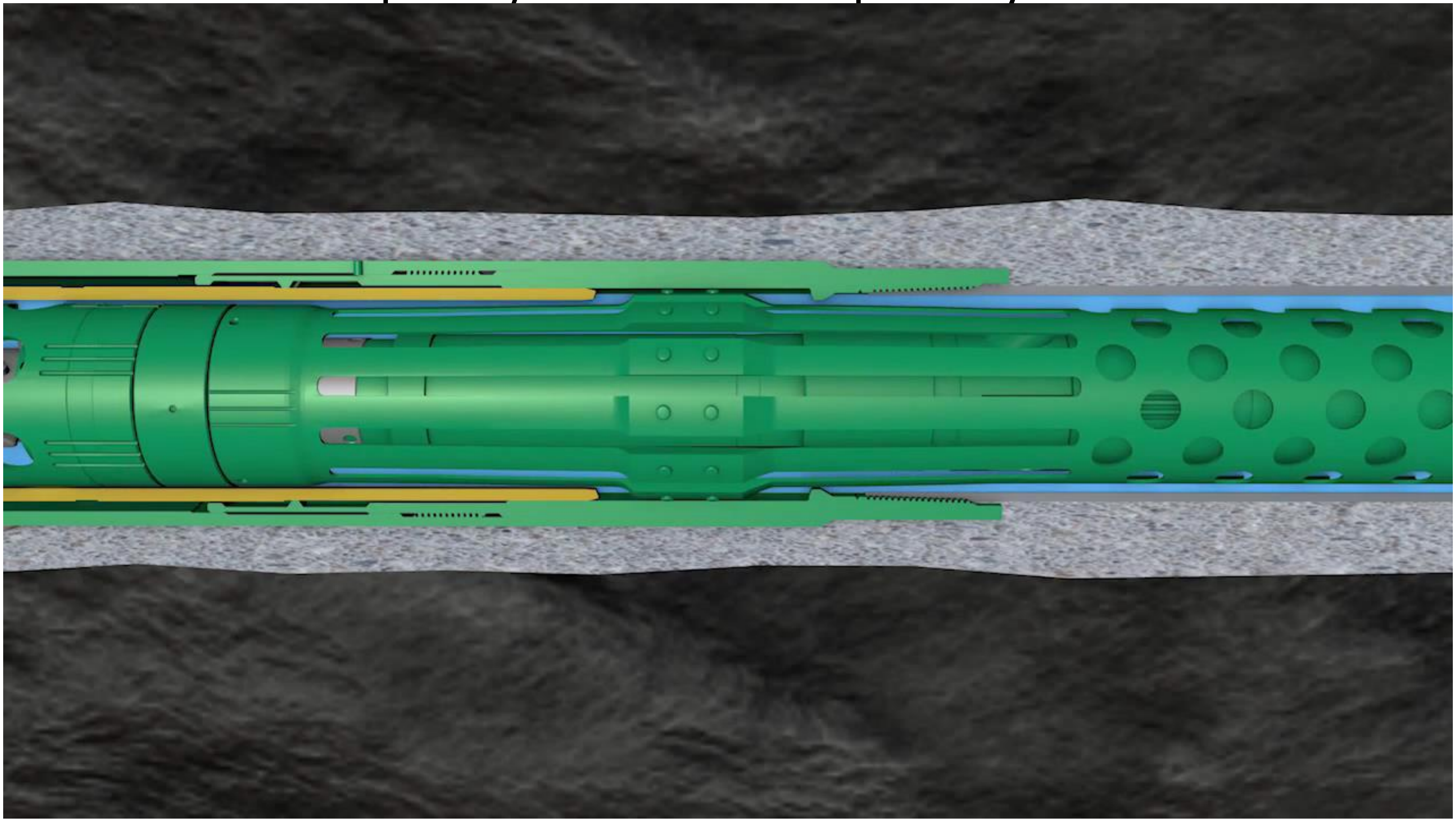


# OUT OF SEQUENCE FRACS WILL HAVE DIFFERENT GEOMETRY & PROP DISTRIBUTIONS

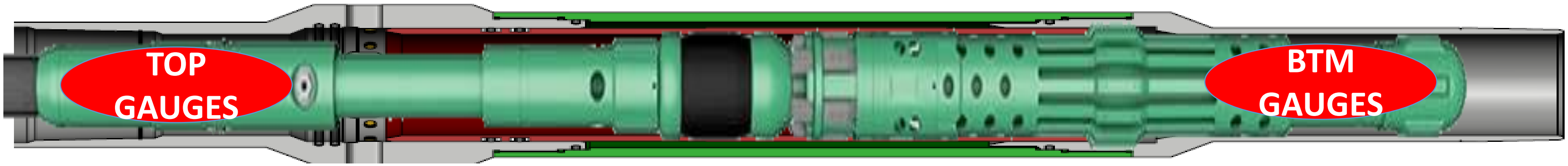


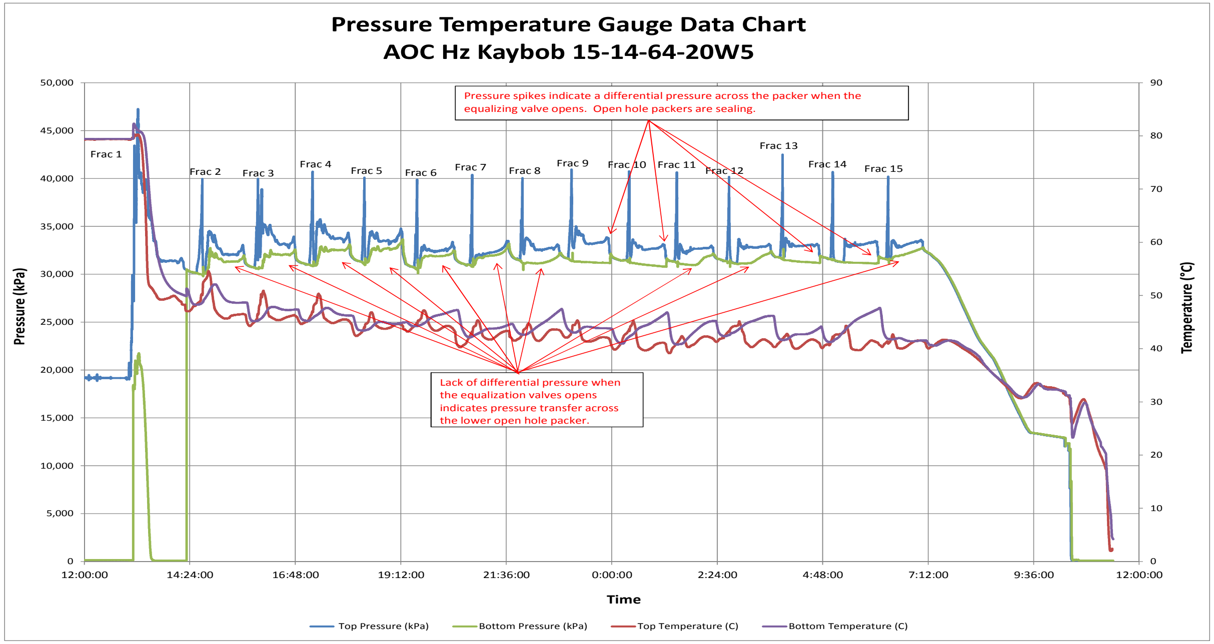



# Open / Close Simplicity

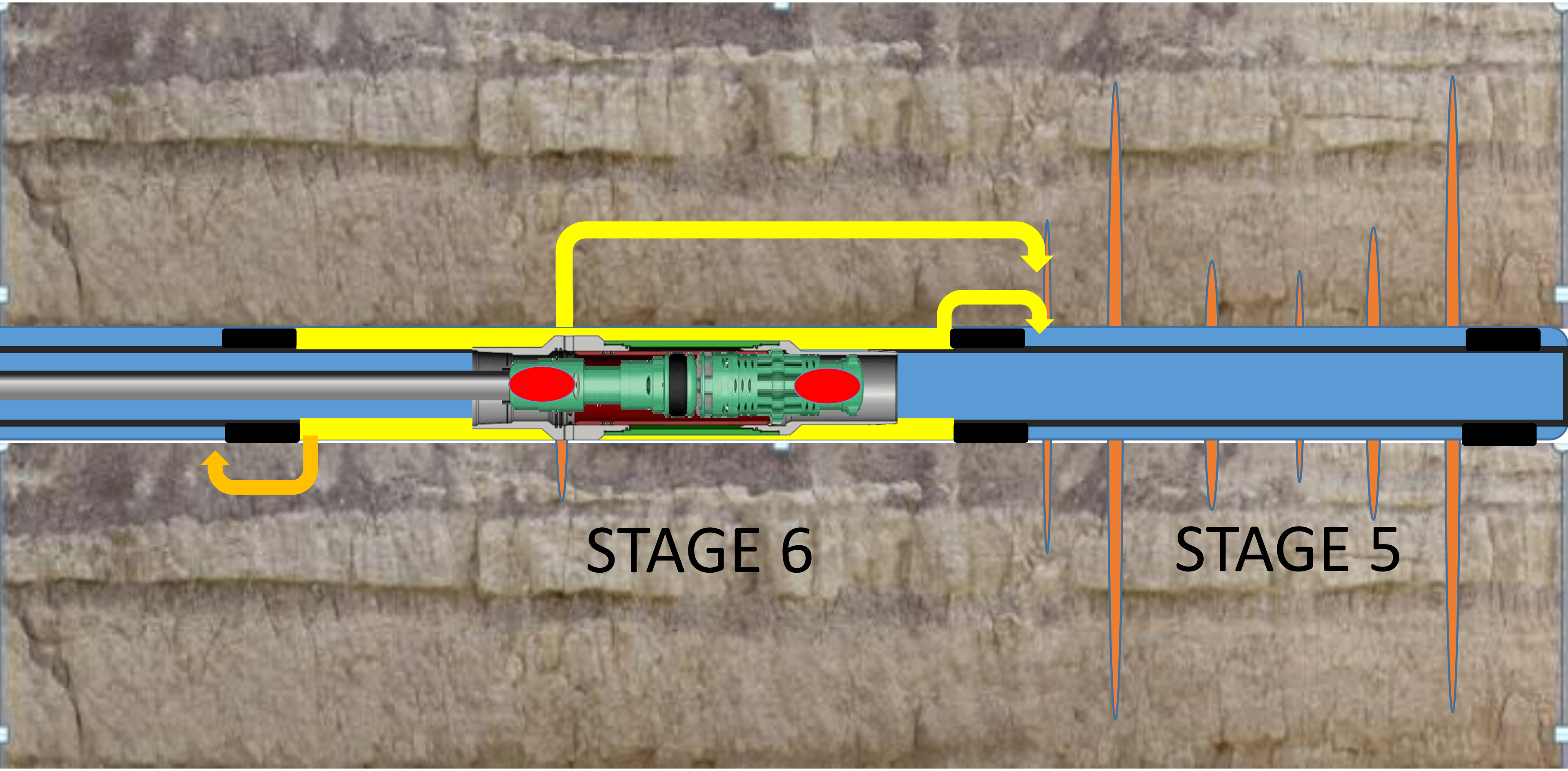


# CTU Deployment Offers Downhole Information

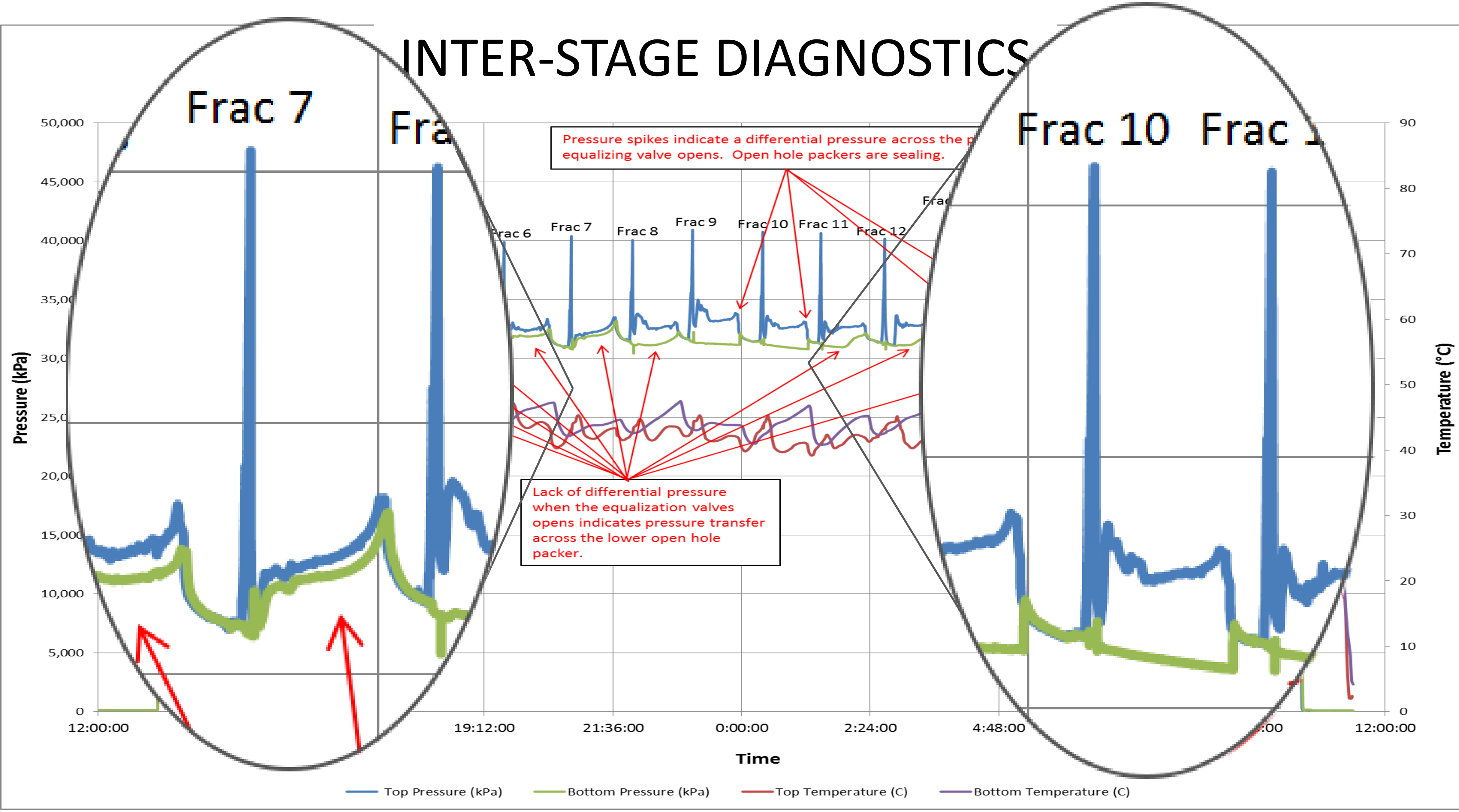


# BH GAUGE DATA – WHAT DOES IT MEAN?



# INTER-STAGE DIAGNOSTICS




**Communication** **No Communication**

# In Conclusion

- Initial Completion Designs Play A Significant Role In The Potential For Refrac Optimization & The Potential For Refrac Success
- Production Analysis (RTA) Can Help To Identify The Source (SRV, $K_{eff}$, FCD) Of Production Rate and EUR Improvements Realized Through Refrac Operations
- Discreet Fracture Placement & Frac Sequencing Is Now Operationally Viable, And May Provide Otherwise Unattainable Fracture Enhancements