Can Refracs be a useful tool in a depressed price environment?

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Permian Basin Study Group
Houston, Tx- May 24, 2016

Why Refrac

- Capturing Loss Pay
- New Technology
- Production Expectations
- Protect wells from frac hits
- Frac hit recovery
- Remedial tool kit
- Refracturing Works

Brief History

- SPE 134330 –summary of 143 published reports of the outcome of refrac attempts: Mike Vincent
- SPE 136757 –evaluation of 100 Bakken refracs: Mike Vincent
- SPE 179148 -Lessons Learned From Refracturing Wells: Using Data to Develop an Engineered Approach; Baker Hughes
- Reducing ReFrac Risk/SEC & ReFracs/Candidate Selection: Bob Barba: May 26th, Houston Garden Inn, http://www.theenergyforum.com/refrac_study0516/main.asp

Devon ReFrac Program

- Devon Energy, Barnett Refrac Program, 1,000 vertical data wells
- Working laboratory in the Barnett
- Finer grade sand and more diversion
- Mechanical diversion techniques working better
- By the end of 2015, Devon will have restimulated 60% of its existing vertical Barnett wells.

Devon Energy Press Release & conference call 8/5/15

http://seekingalpha.com/article/3552056-devon-energy-restimulating-barnett-wells-protect-production-base?

How do they work

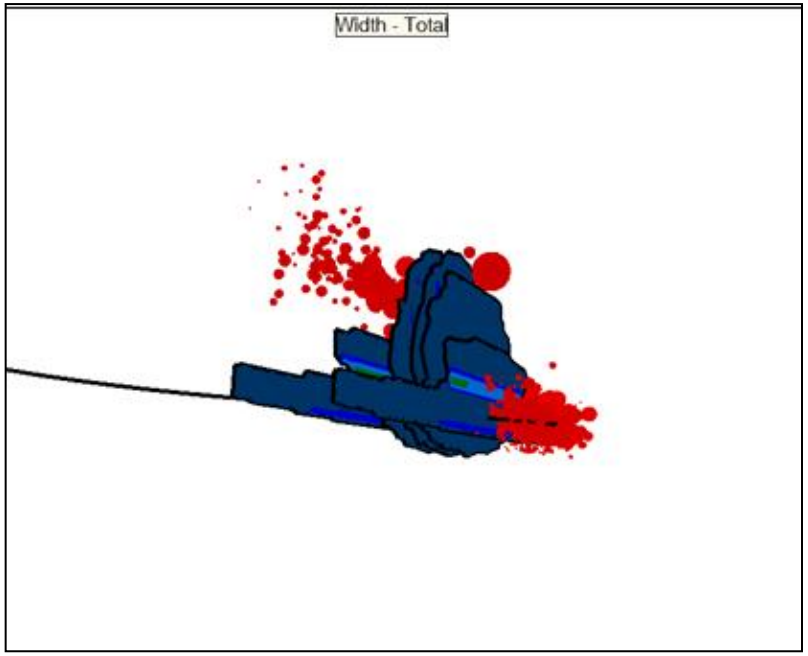
- Increase fracture area
- Improvements in pay coverage through increased fracture height in vertical wells
- Better lateral coverage in horizontal wells or initiation of more transverse fractures and natural fractures
- Increased fracture conductivity compared to initial frac
- Restoration of fracture conductivity
- Water imbibition - Soaking
- Improve wellbore-to-frac connection/conductivity
- Reorientation / Altered stress
- Use of more suitable frac fluids
- Re-energizing natural fissures or fractures
- Other mechanisms

Refracturing Considerations

- Each candidate must be evaluated on a well by well basis to help ensure economic success.
- The original hydraulic fracturing treatment and reservoir assumptions must be evaluated prior to any refrac program to understand the cost benefit.
- In some cases it may be a good idea to embark on a refracturing program to help protect wells from ensuing frac hit from adjacent wells. This will help prevent fracture damage from possible offset well frac hits and aid in frac growth in the child well.
- Each refrac program may have a unique set of circumstances that will determine the proper approach
- Data surveillance is the key to success

Eagle Ford Fracture Complexity

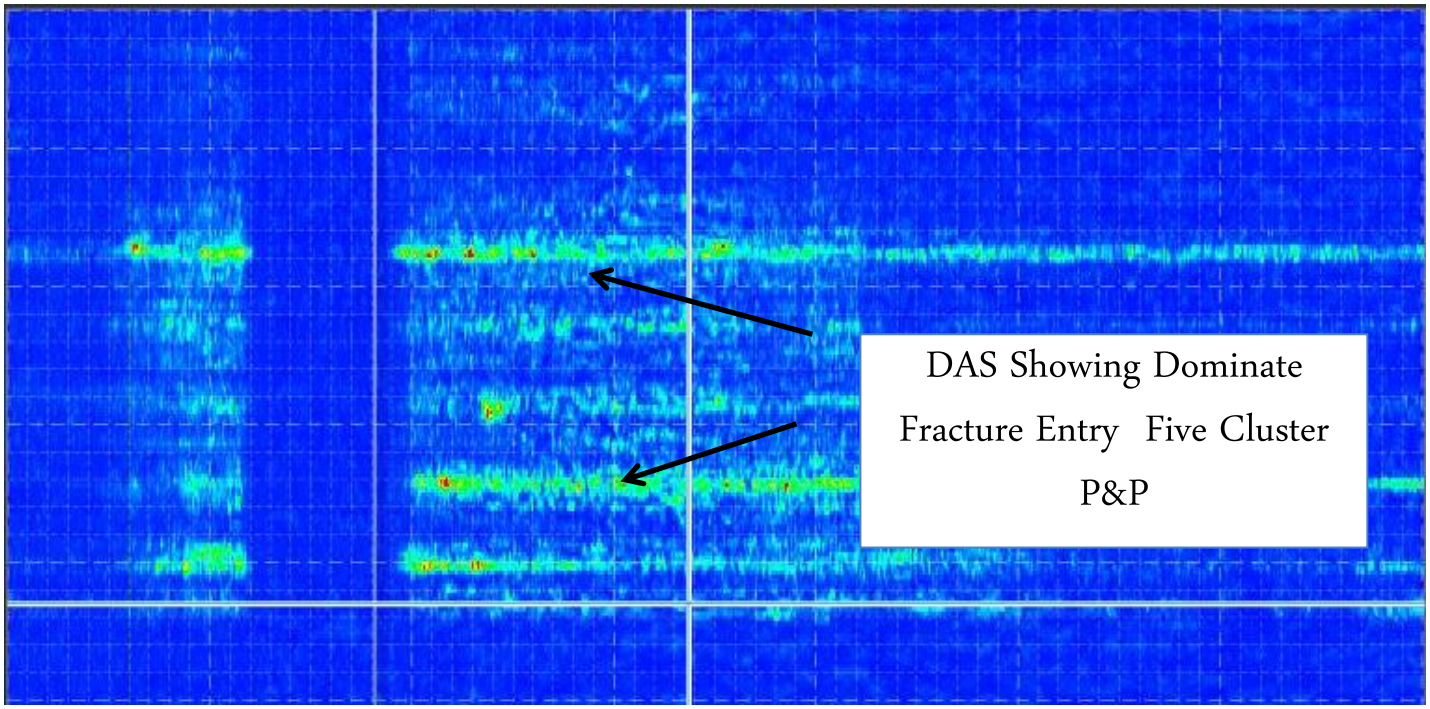
Why Re-Frac



Original plug and perf operation 30% effective at best

Re-fracturing Horizontal Shale Wells ...SPE HFTC 168607-MS and April 2014 JPT

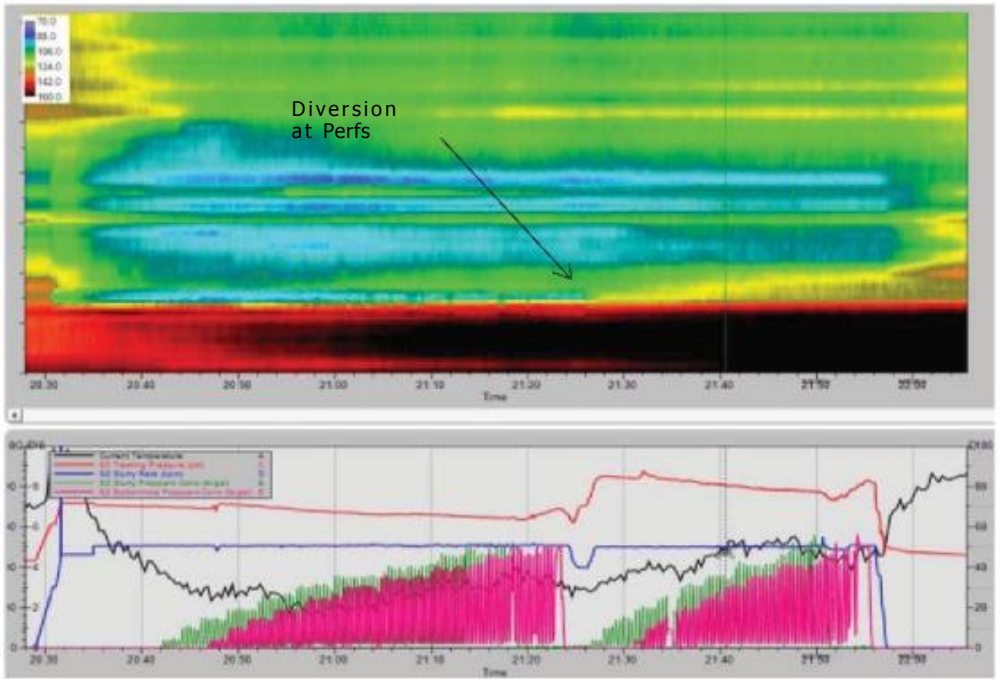
Why Re-Frac

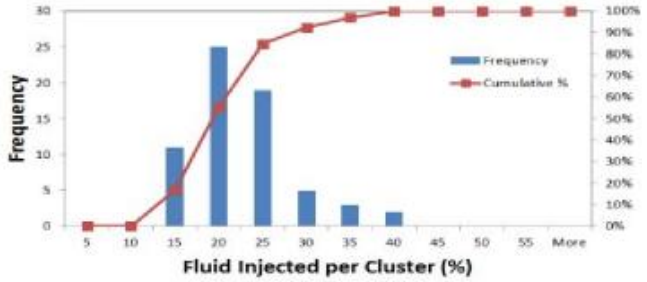


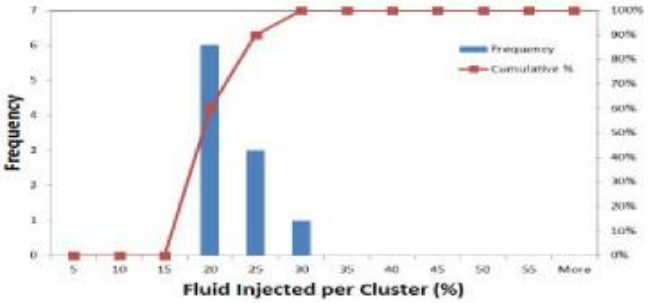
Fiber optic DAS validation of the model

An Integrated Dataset …URTec 178667– July 2015

Why Re-Frac



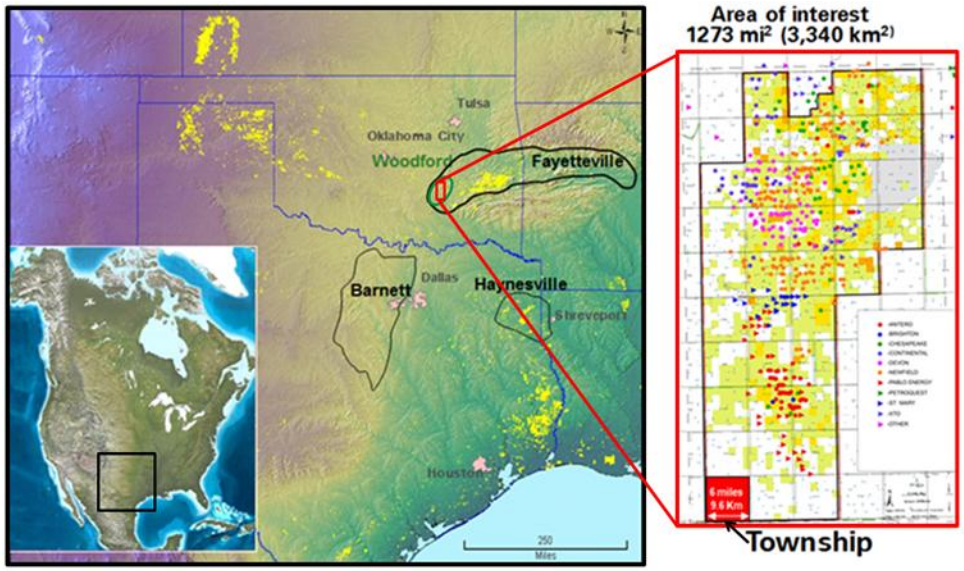


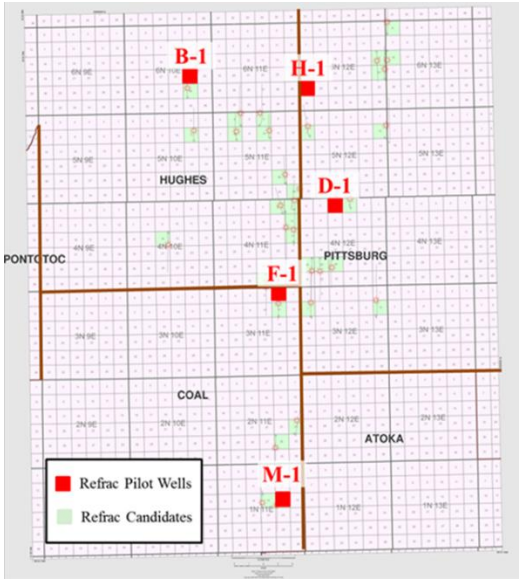


Because it works

URTec 217506 – July 2015

Woodford Refac Example

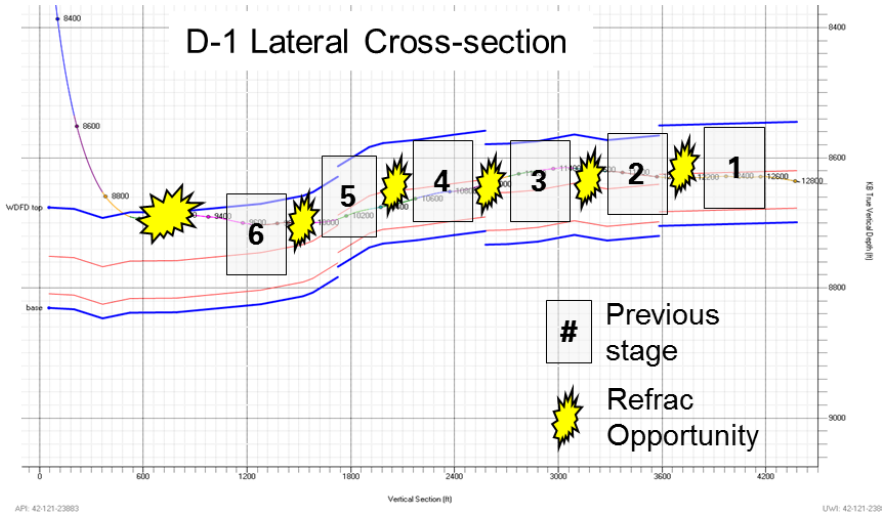




Re-fracturing Operations

- Five well pilot projects executed between January and August 2013.
  - Re-fracturing project increased gas production and reserves
- Nine additional wells have been re-fractured since the pilot.
  - Seven additional wells were re-fractured in 1Q 2014.
- Majority of initial rates were in-line with predictions, except for wells with operational issues.

Re-Frac Target Example



Opportunities

- Wide Frac Stage spacing.
  - Old applied average 505 ft.
  - Post re-Frac average 300 ft.
- Un-perforated pay at heel.
- Ineffective fracture stages from original completion.

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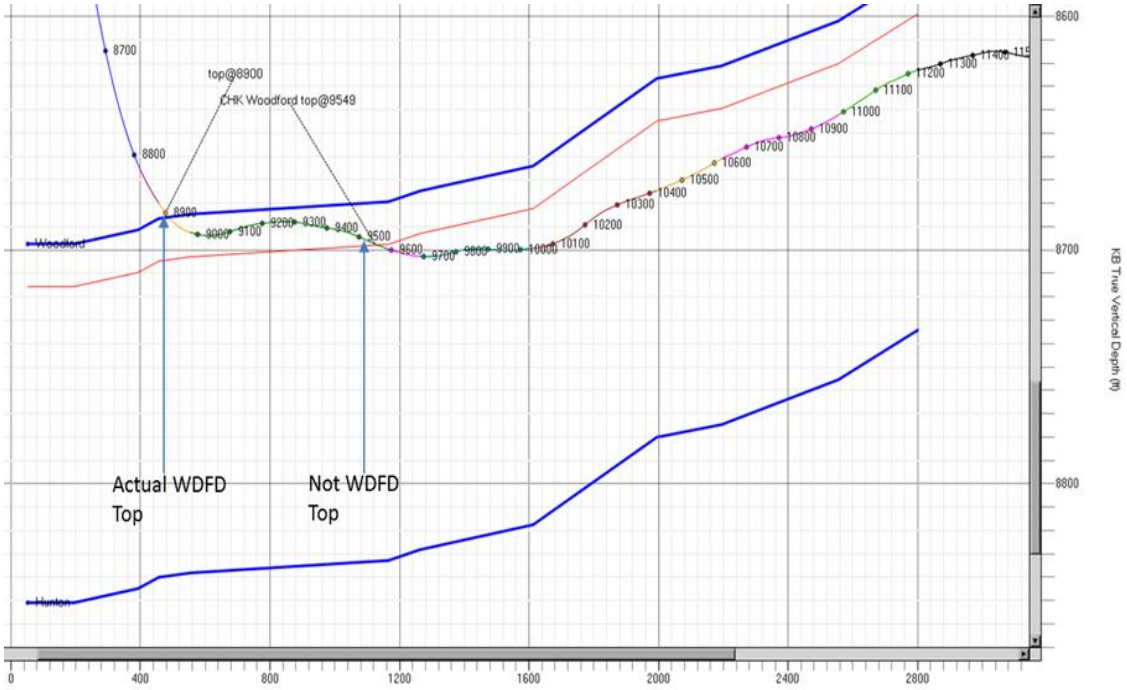
The Target (Bypassed Pay)

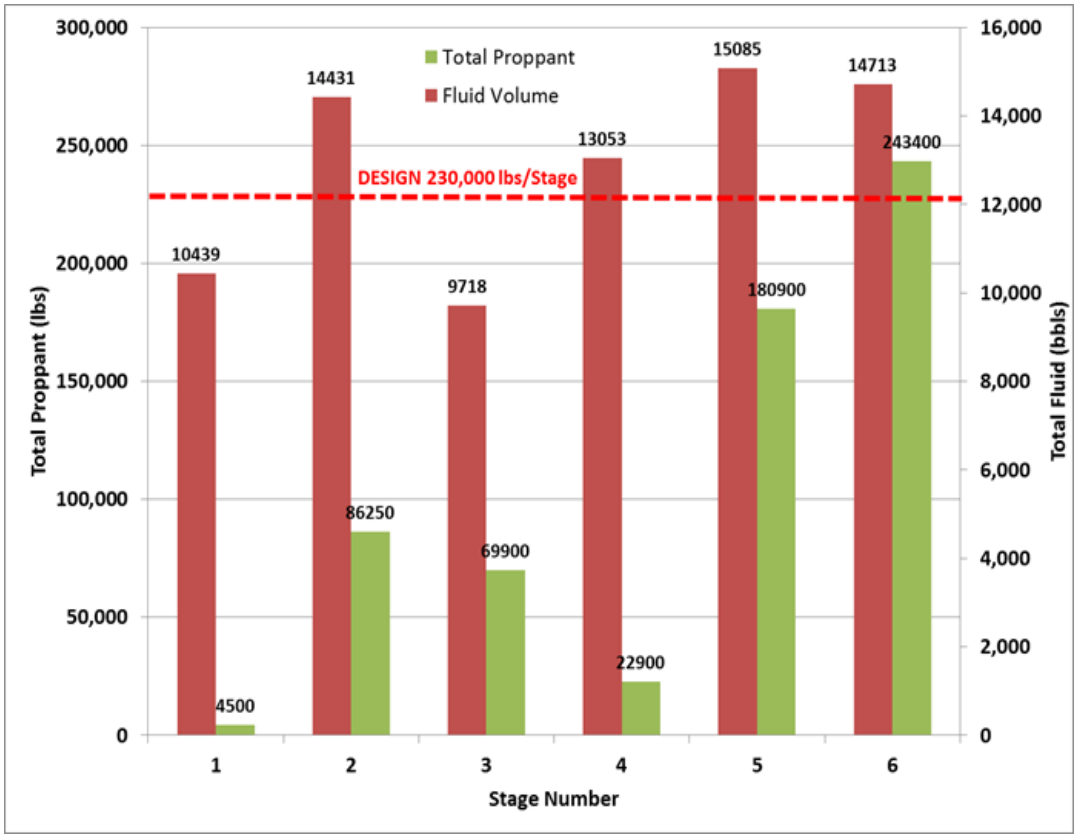


Top of Woodford Definition Changed

- Un-perforated pay at heel

The Target (Fracture Efficiency)

Woodford F-1 Well Original Fracture Treatment Summary

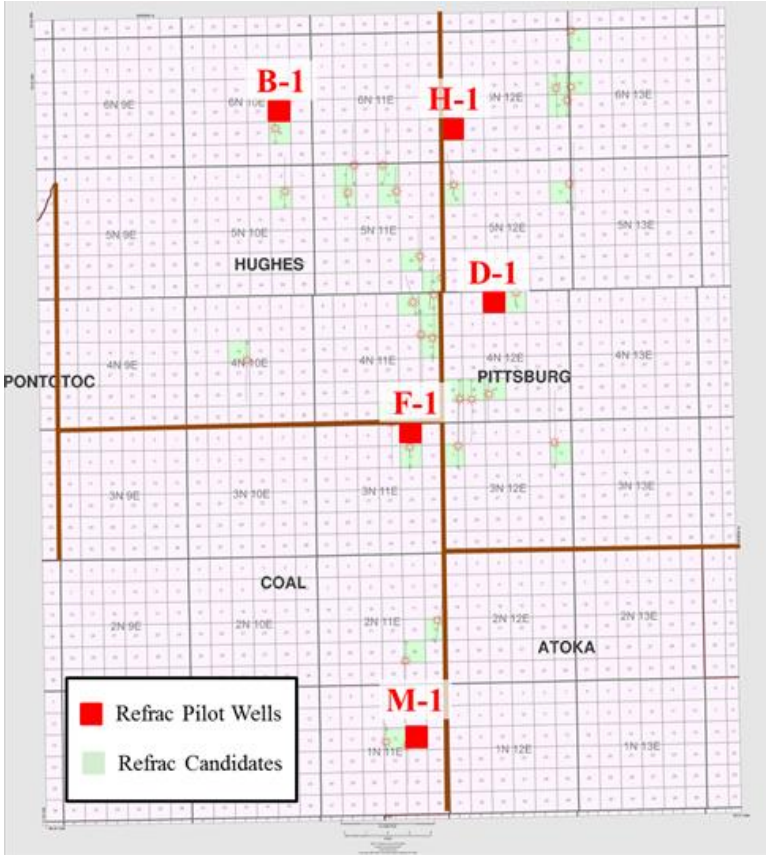


- Ineffective fracture stages were placed during the original completion.
- Other reservoirs may have different reasons for re-frac opportunities.

Candidate Selection Example

- EUR Predictions
- Thick Pay Intervals
- Reservoir pressure
- Stage spacing > 500 ft/stage (Under-perforated lateral).
- Original Proppant Placement (Completion Design)
- Under-performing wells
- Water production and availability
- Well integrity
- Offset well interference

Five Well Pilot Program



- D-1: Wide stage spacing, pay at heel
- F-1: Remediate Frac-hit
- H-1: Shallow, in North Area
- M-1: Deep, good rock quality
- B-1: Large un-perforated pay interval

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Five Well Pilot Program

Candidate Selection Data for Woodford Re-fracture Pilot Wells

Pilot Well	Single Well in Section	Frac Stage Spacing (ft.)	Original Stage Count (No.)	Effective Stage Count (No.)	Additional Pay (ft.)	Lateral Length (ft.)	Depth to Top of Woodford TVDSS (ft.)	Cumulative Production (Bscf) 4Q12	Net Pay (ft.)	Original Pressure (psi)	Pre-Re Gas Rate (mscf/d)	Pre-Refrac Water Rate (bwpd)	Best Rock Area (Y/N)
D-1	Y	525	6	4	738	3.135	8,696	1.73	151	4,348	550	4	Y
F-1	N	524	6	2	212	3,143	8,474	1.72	172	4,237	300	0	Y
H-1	Y	673	5	3	944	3,367	6,839	0.40	147	3,420	100	31	N
M-1	Y	496	6	4	0	2,973	10,600	2.27	174	5,300	700	10	Y
B-1	Y	892	2	1	2,910	3,801	5,455	0.38	164	2,728	150	5	N

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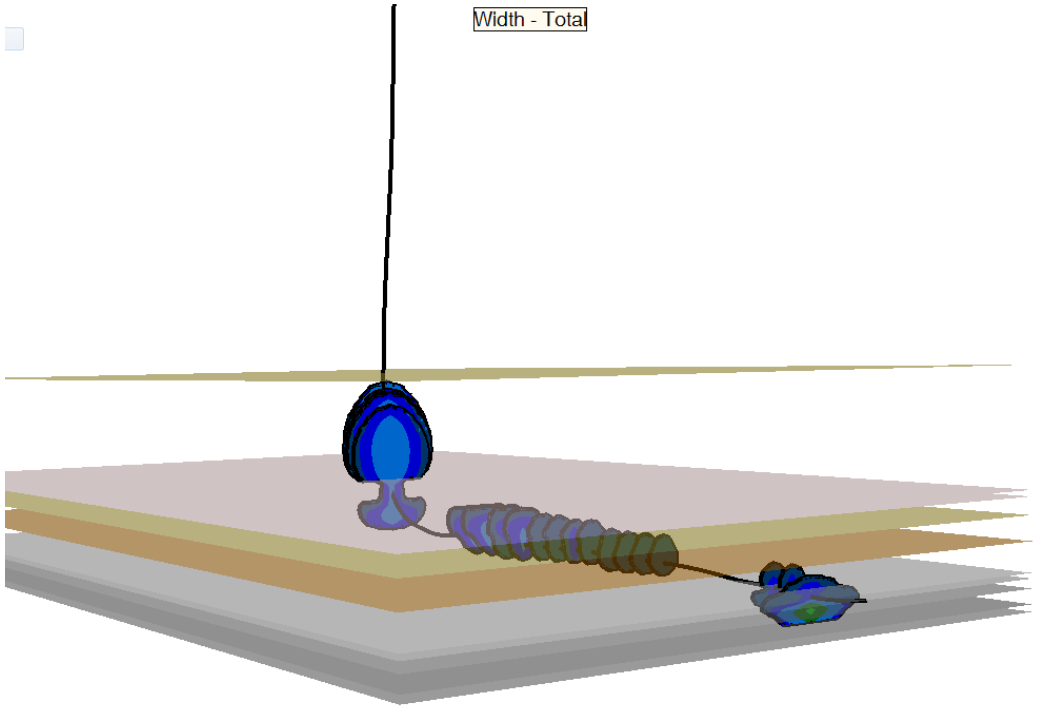
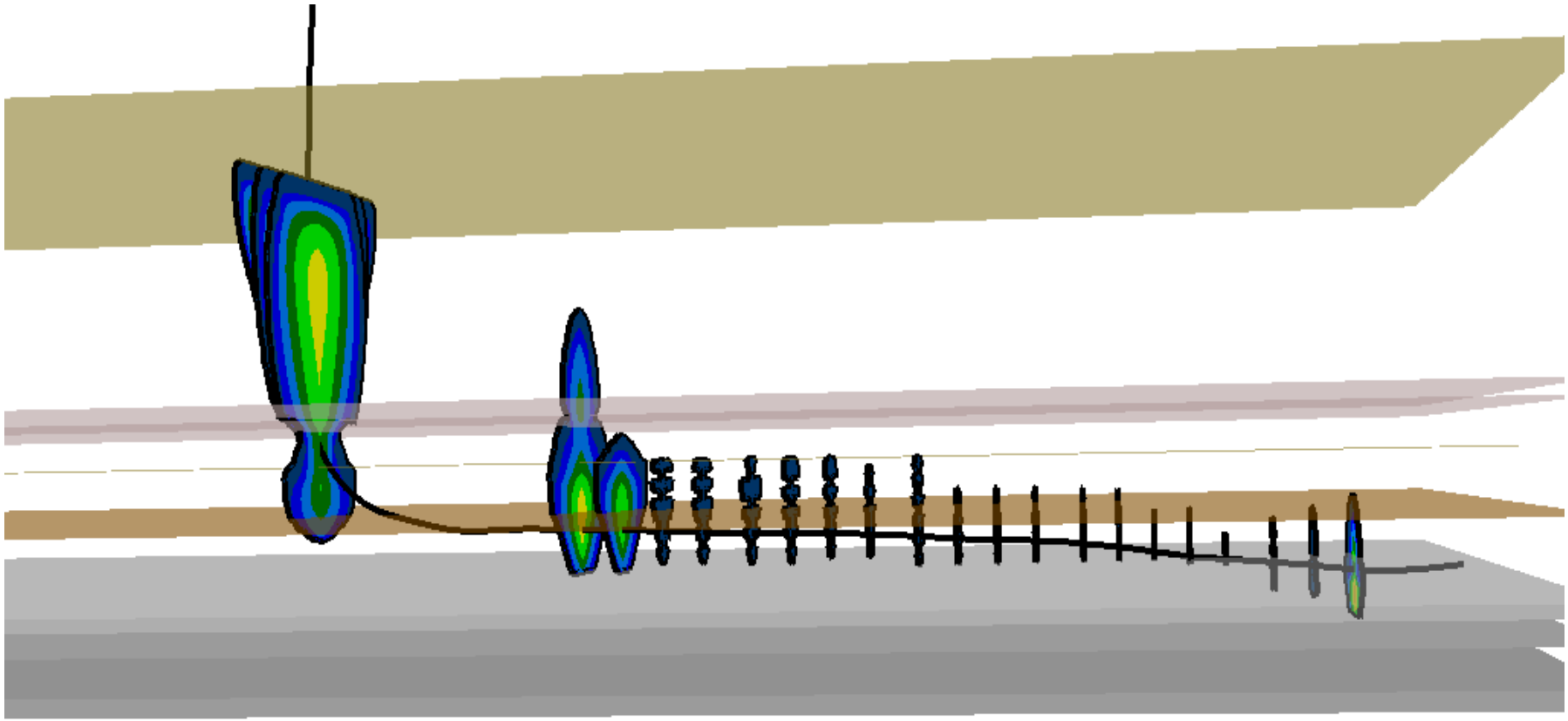
3D Frac Simulation Original Perforations

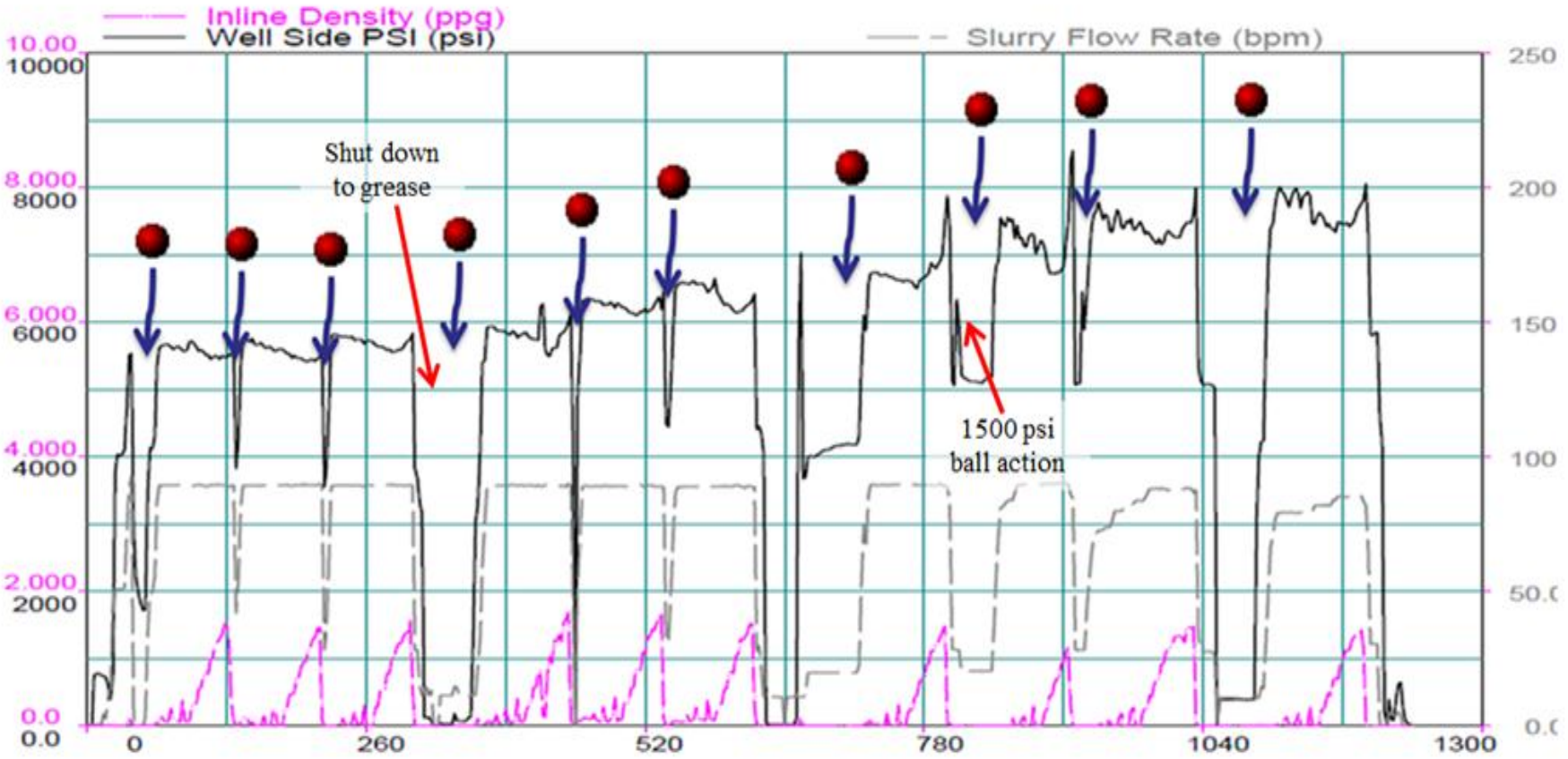


3D Frac Simulation Add Perforations



Re-Fracture Process

Pump Rate vs. Time Chart with Ball Drops ( ) for the Woodford H-1 Well



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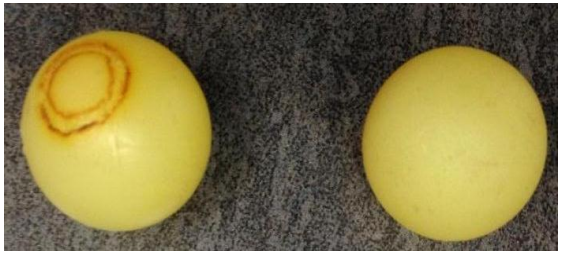
Diversion Agents

Rubber coated nylon balls

Bio-degradable balls



Biodegradable
Polymer Diverting Agent
(8 / 40 / 100 mesh)

To accelerate breaking the polymer diversion agent (if needed), pump a well lateral volume of 5% sodium hydroxide in heated water and let soak on the perforations for 6 hours.

Degradable Diverters - Balls or Granular

- Polylactide Resin (PLA) lactic-acid.
- Biocide (SRB's) THPS (microbes like PLA).
  - (Tetrakis Hydroxymethyl Phosphonium Sulfate) .
  - 50 to 100ppm or .05 to 1 gpt (check vendor).
- Diverter loading per stage.
  - # of balls = perf efficiency x (total # perfs)/(total # stages).
  - Lb of particle agent = 4 lb/perf x perf efficiency x (total # perfs) / (total # stages)
- New diverting materials
  - Poly-Pods : Adaptive Frac Diverter

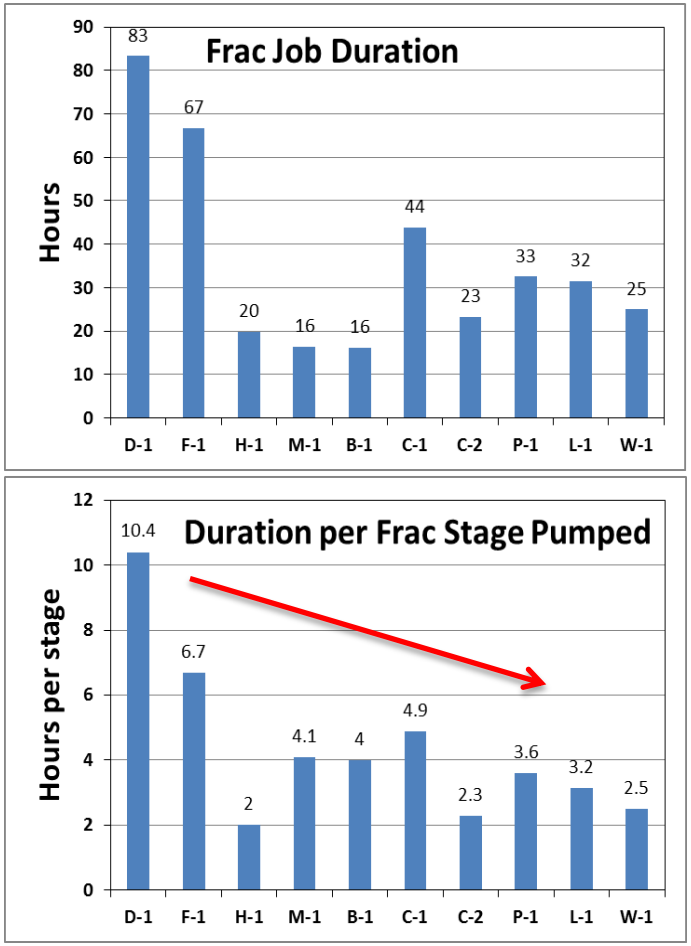
Mixed Results from Diverter Systems

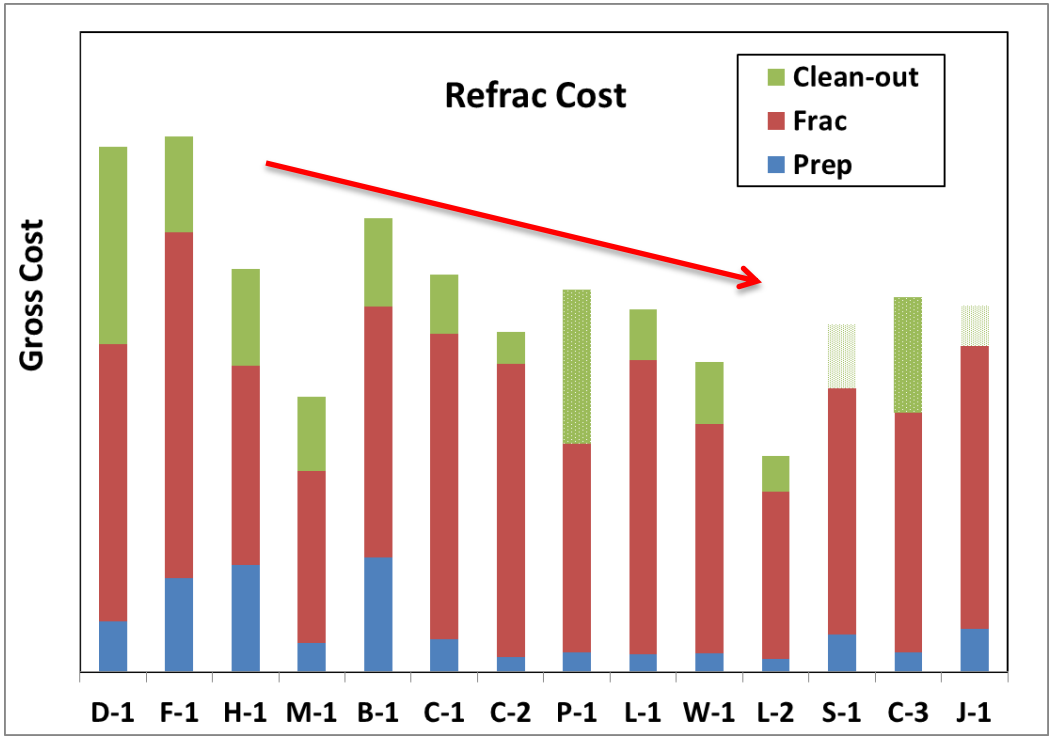
- Microseismic data has indicated in some cases that diverting systems can be detrimental (HFTS)
  - Laredo Petroleum, Core Lab, Pinnacle
- Fiber optic data has indicated diverters are shutting down smaller fractures and allowing dominate fracture to continue to take the majority of the fluid
- Diverter systems equivalent or outperformed mechanical isolation in some areas

Re-Fracture Operational Problems

- Planning for potential screen outs
- Flow back or CT if possible
- Plan for higher than expected wellhead treating pressures
- CT sticking during post job clean out operations
- Verify casing integrity
- Equipment malfunctions
- Adequate on-site water supply
- Contractor equipment maintenance

Re-Fracture Operational Performance





Job duration and the total refrac treatment cost demonstrate continuous improvement.

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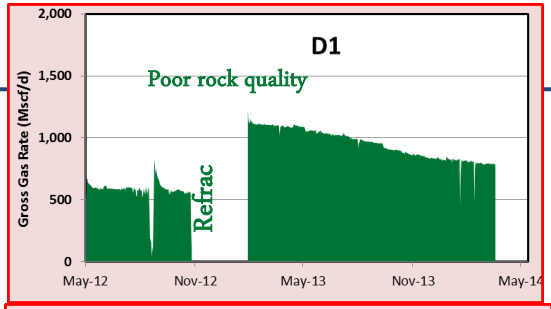
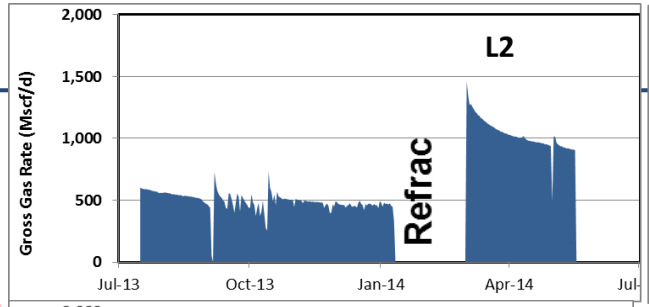
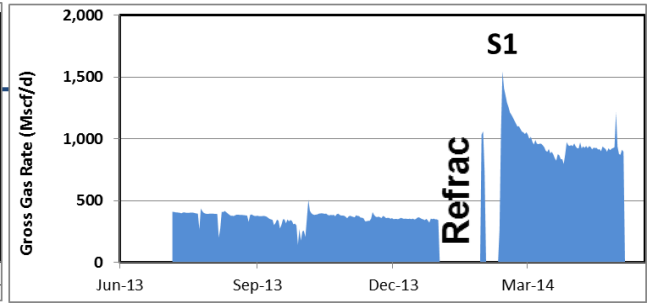
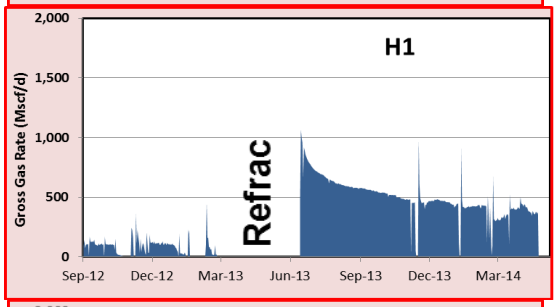
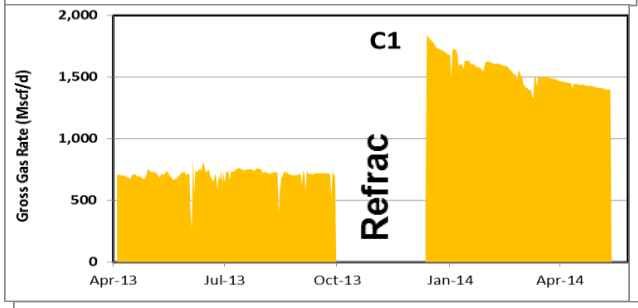
Refrac Results



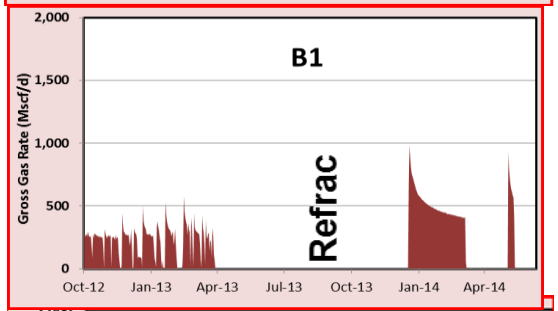


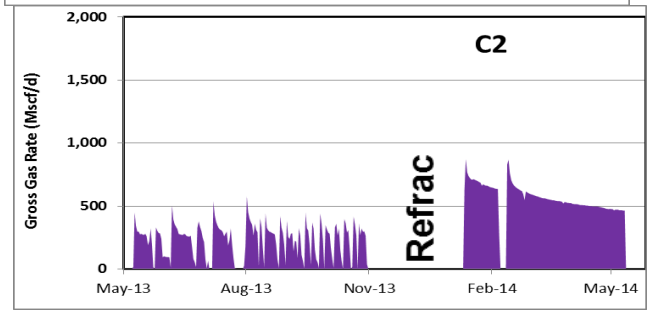


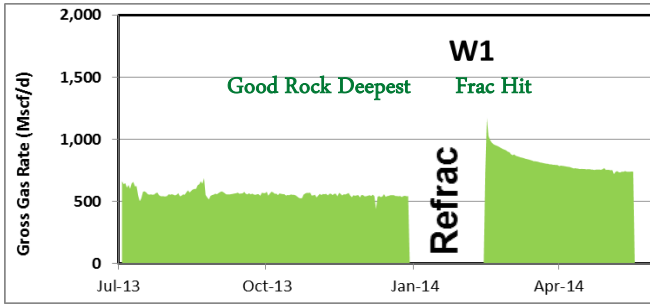


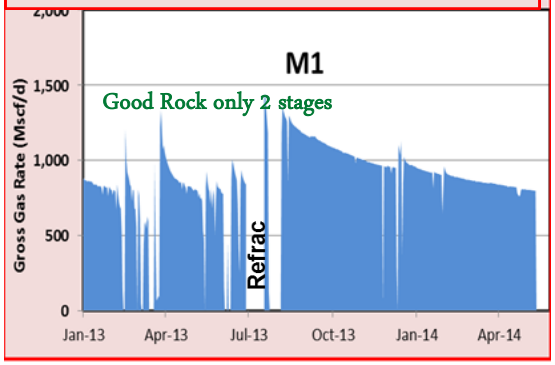


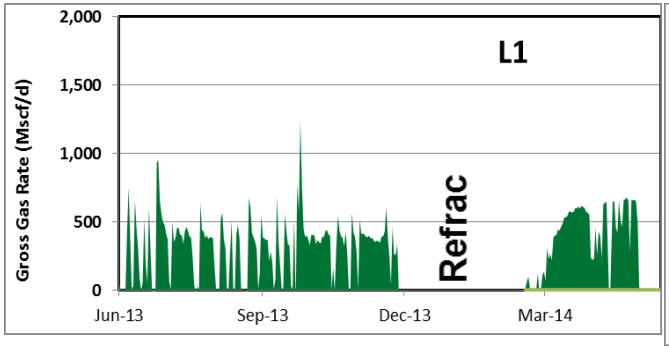
Red background = pilot wells

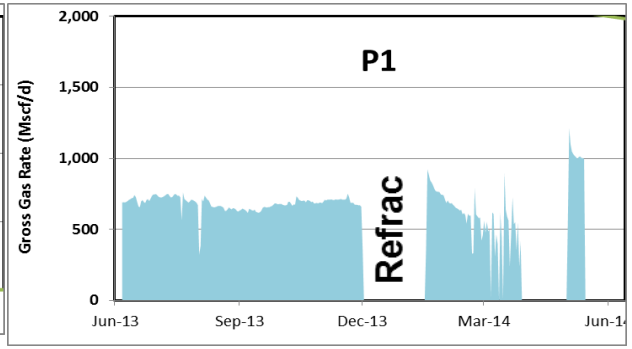




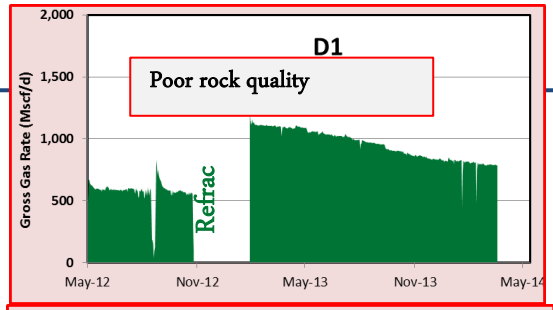


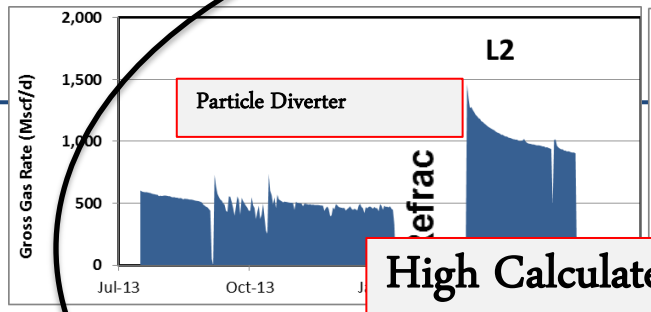


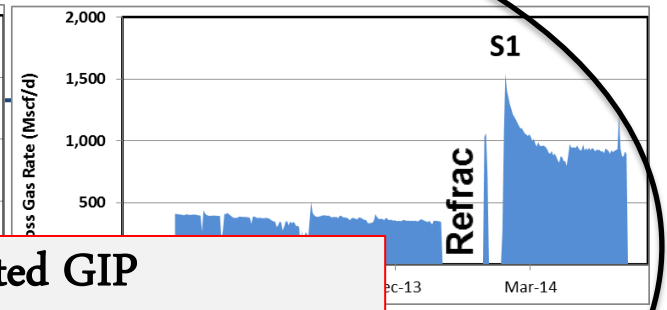




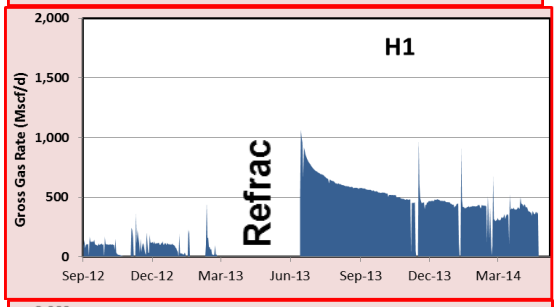
Refrac Results

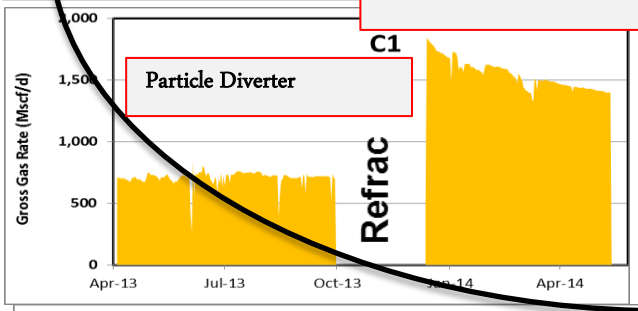




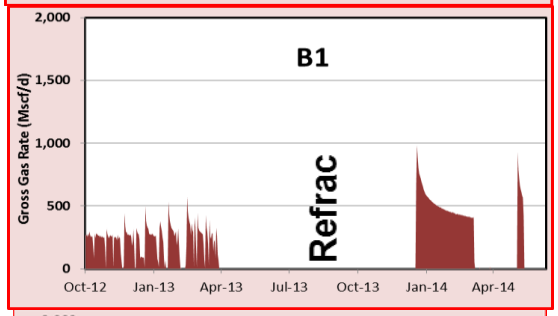


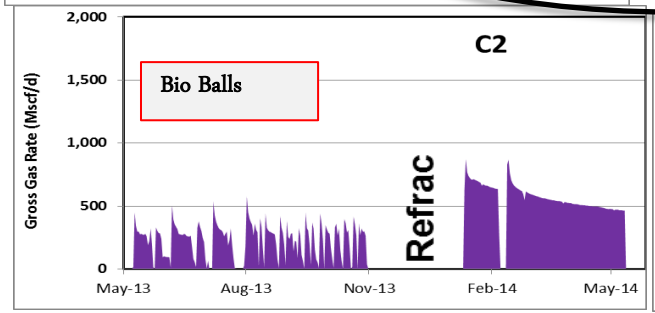
High Calculated GIP

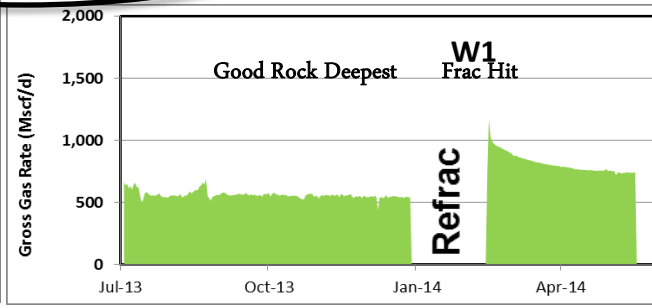


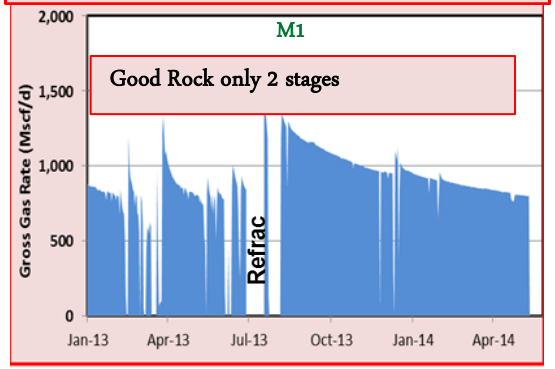


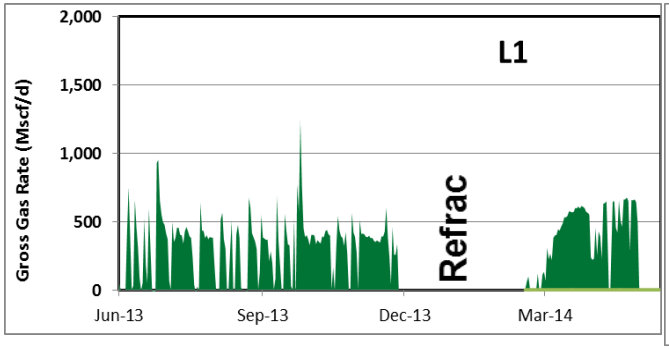
Red background = pilot wells
Used Ball Diversion

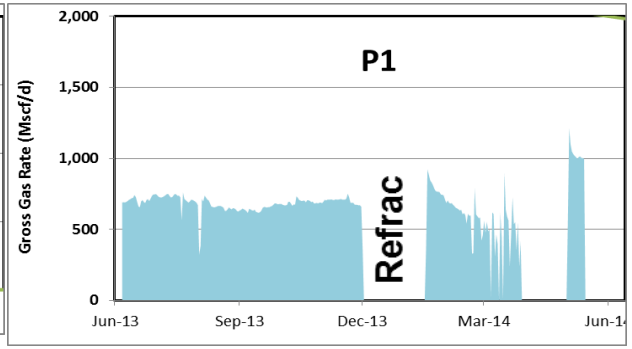








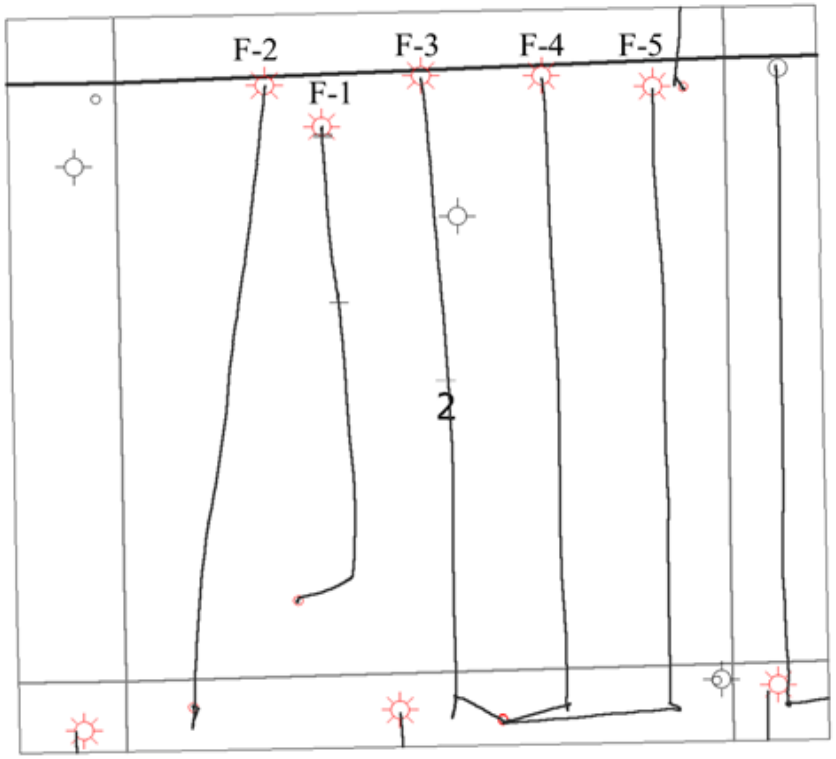




Diverter Summary

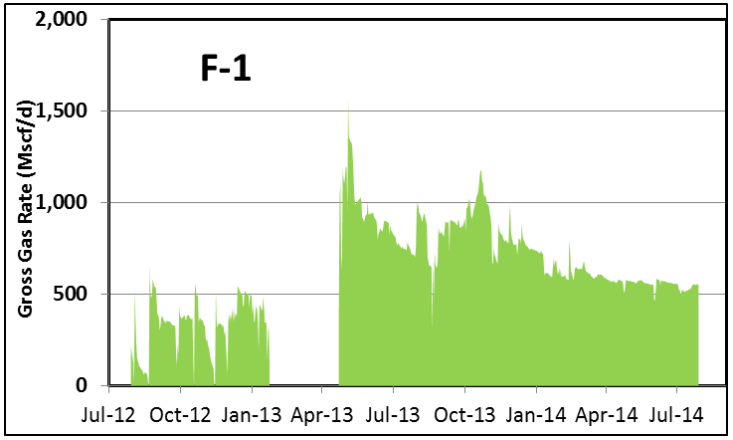
D1	- 290 rubber balls
F1	- 462 bio-balls
H1	- 360 bio-balls
M1	- 285 bio-balls
B1	- 75 bio-balls
C1	- 1,300 lbs of bio-diverter
C2	- 346 bio-balls
P1	- 1,815 lbs of bio-diverter
L1	- 1,500 lbs of bio-diverter
W1	- 1,900 lbs of bio-diverter
LLN	- 850 lbs of bio-diverter
S2	- 353 lbs of bio-diverter
C2b	- 900 lbs of bio-diverter
J1	- 525 lbs of bio-diverter

Re-Fracs Compensate for Frac-Hits



F-1 Well and Adjacent New Wells.

- The F-1 well had been producing for 5 years.
- Adjacent new wells were drilled and fractured in early 2013.
- The F-1 well was re-fractured along with the fracturing on the new wells.
- All five wells were then brought on production at about the same time.



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Key Learnings from Woodford Re-Fracs

Subsurface Considerations:

- Re-fracturing can protect an older well from Frac hits by adjacent wells.
- Wells with high GIP and better rock quality make the best refrac candidates.
- Depletion may result in communication between wells over large distances.

Project Management:

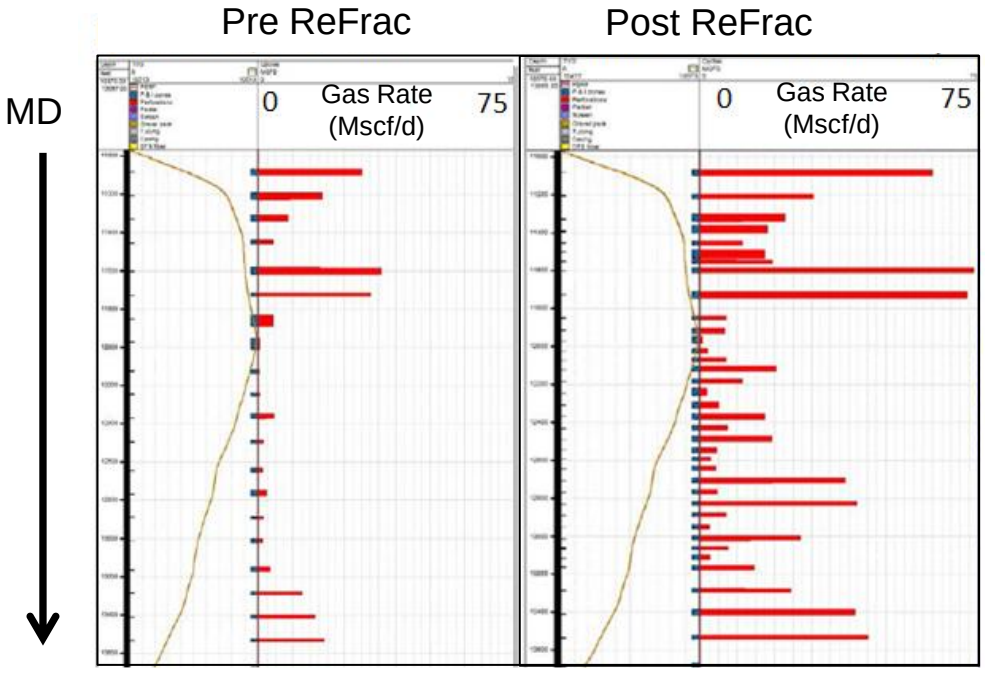
- Allow learnings to be incorporated into the program.
- Plan should consider impact of legacy wells

Operational Issues:

- Linear gel significantly lowers surface treating pressures.
- Design to encounter treating pressures at the original treating pressure.
- Perform post frac clean-out operations with a work-over rig if possible
- Coiled tubing can pose additional risk of stuck pipe.
- Resin-coated tail-in sand reduced clean-out time.

Key Learnings from Surveillance Data

- From the wells with RA tracer and PLTs (all fractured with balls).
  - Tracer concentrated at the heel, indicating ball diversion was not as widespread as desired.
  - Tracer is detected at multiple perforation clusters spread across ~ 2/3 of the well, indicating some level of ball diversion occurred.
  - Majority of production from F1 PLT is from the heel of the well.
  - M-1 PLT showed an improvement in the production profile.



B-1 Tracer Log Summary

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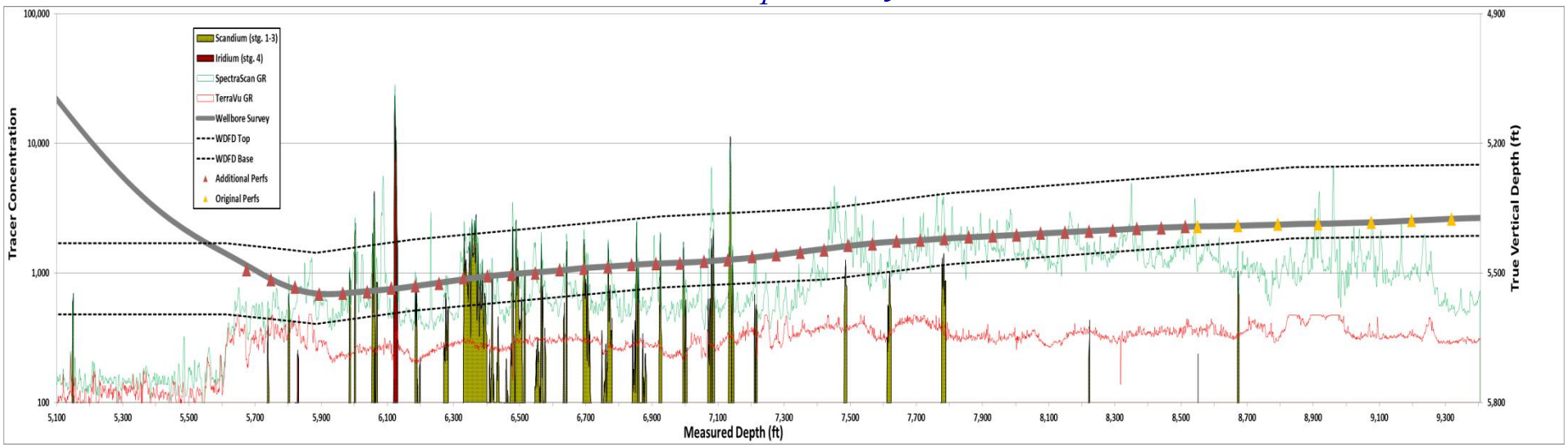
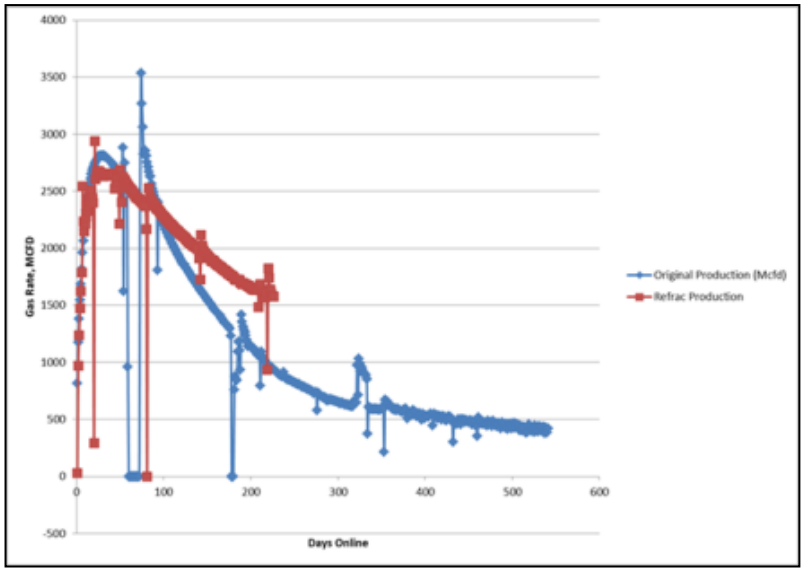


- Spectral gamma ray logged 3,219’ of this 3,257’ lateral (to 9,404’ MD; PBTD is 9,441’)
- Most of the tracer is concentrated at the heel, indicating that ball diversion and proppant placement was not as widespread as desired.
- Iridium (stage 4) is concentrated in just one set of perforations.
- Tracer is detected at multiple perforation clusters spread across ~ 3/4 of the heel section, indicating some level of limited ball diversion occurred.

Shale Re-Frac Example

- Dry gas well, underperforming well compared to offsets / neighbors.
- Original stimulation used low volume crosslinked fracs (4600 bbl/stg).
- Well refrac'ed with high volume slickwater hybrid (9500 bbl/stg).



Lateral Length = 4,850'

305' stage spacing:, cluster spacing: 61'

5 Clusters/ stage, 4 shots per cluster

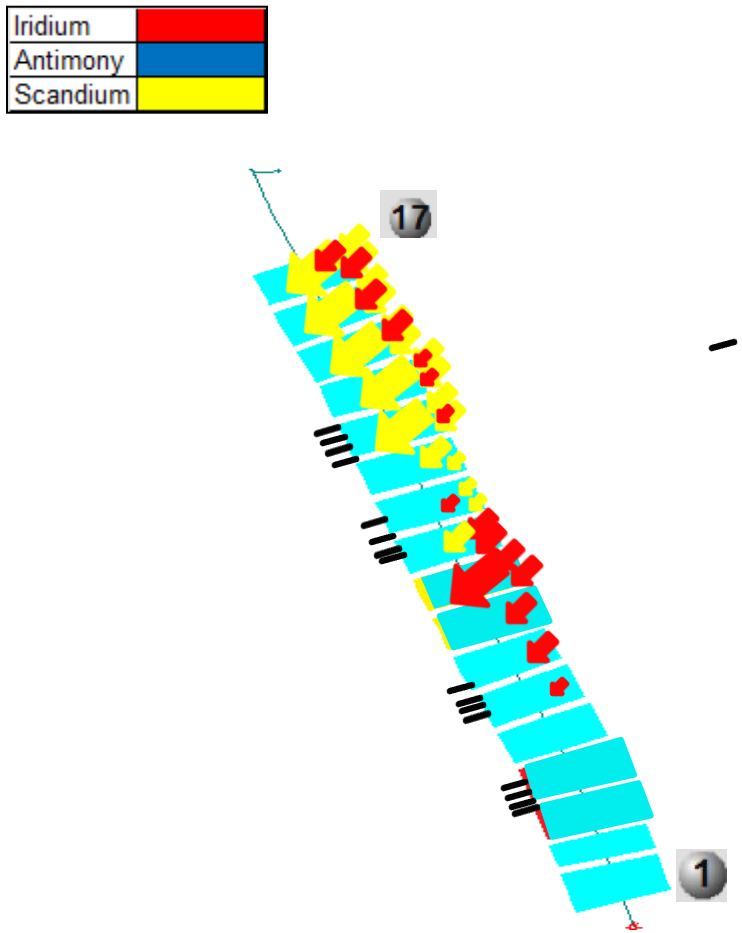
<u>Refrac</u>

Cluster perforations added for refrac

15 stages separated by slugs of degradable diversion agent

New perforations, improved hydraulic fracturing design and fluid system.

RA Proppant Results From ReFrac



16 new perforation clusters

- The majority of the treatment went in the heel
- 2/3rds of the lateral received some treatment
- Full later did not receive treatment

RA Tracer log indicates re-frac mainly treated the heel section of the well.

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Lessons Learned

- Adjust treatment volumes based on offset depletion
- Model offset depletion
- Perforate new pay
- Diversion mater may work against you
- Chance for improved flow-back (imibition)
- Microseismic can give you a better picture of created fracture area and lateral coverage
- Data driven decisions

Things to look for

- GTI HFTS
- Bounding Well Refracs (Dick Leonard)
- Offset Refracs
- Managed pad drilling and completion
- Stack Pay
- SimOpps

Additional References

- Re-fracturing Horizontal Shale Well: Case History of a Woodford Shale Pilot Project, Hydraulic Fracturing Journal, October 2014 Volume 1-Number 4, pg76; Sam French - BP
- URTec:217506: An Integrated Dataset Centered Around Distributed Fiber Optic Monitoring – Key to the Successful Implementation of a Geo-Engineered Completion Optimization Program in the Eagle Ford Shale; Stephan Cadwallader, Jeff Wampler: BP America
- Hydraulic Fracturing Journal : October 2014 Volume 1-Number 4 page 76
- ATCE 2015 SPE-174979-MS - Refracs - Diagnostics Provide a Second Chance to Get it Right ; Dick Leonard, Bubby Woodroof : Core Lab
- Refracs: Why Do They Work, and Why Do They Fail in 100 Published Field Studies? Mike Vincent SPE 134330 & 136757

Recognition

- Stephan Cadwallader
  - Sr. Reservoir Engineer, Formerly BP Lower 48.
- Sam French, Presenting-Author (HFT 2014)
  - Sr. Reservoir Engineer, BP Lower 48.
- Martin Rylance.
  - Engineering Manager Frac & Stim and Sr. Advisor, BP GWO
- Bob Barba
  - Integrated Energy Services
- Mike Vince
  - Insight Consulting
- SPE