REFRACTURING: WHY, WHEN AND WHEN NOT TO

GEORGE E. KING, P.E.
APACHE CORPORATION
13 NOVEMBER 2014

SPE LUNCHEON

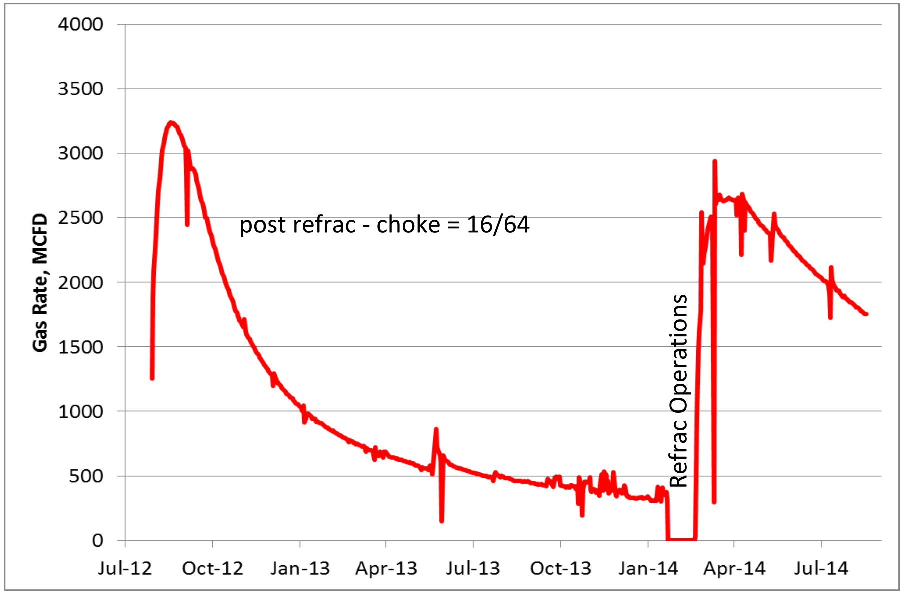
HOUSTON, TX

PARTS OF THE PRESENTATION

- Response of Refracturing
- Good and Better Targets
- Warning Flags
- What Appears to Work at this Point
  - Timing
  - Proppant
  - Diverting
  - Missed “pay” in those tight source rocks.

EAGLE FORD RE-FRACTURING – EXAMPLE FROM BP

- Dry gas well, underperforming well compared to offsets / neighbors
- Original stim used low vol X-linked fracs (4,600 bbl/stg). Refrac'ed with high volume slickwater fracs (9,500 bbl/stg).



Lateral length (perf to perf) = 4,850'

Stage spacing: 305',
Cluster spacing: 61'

5 Clusters/ stage, 4 shots per cluster, 90 degree phasing

Refrac

No perforations added for refrac

15 stages separated by slugs of biodegradable polymer diversion agent

Slide Courtesy of Sam French at BP, presented at UrTec, 2014

SOUTHERN ALBERTA SHALLOW GAS WELL REFRACS
REFRACS NOT JUST FOR SHALES

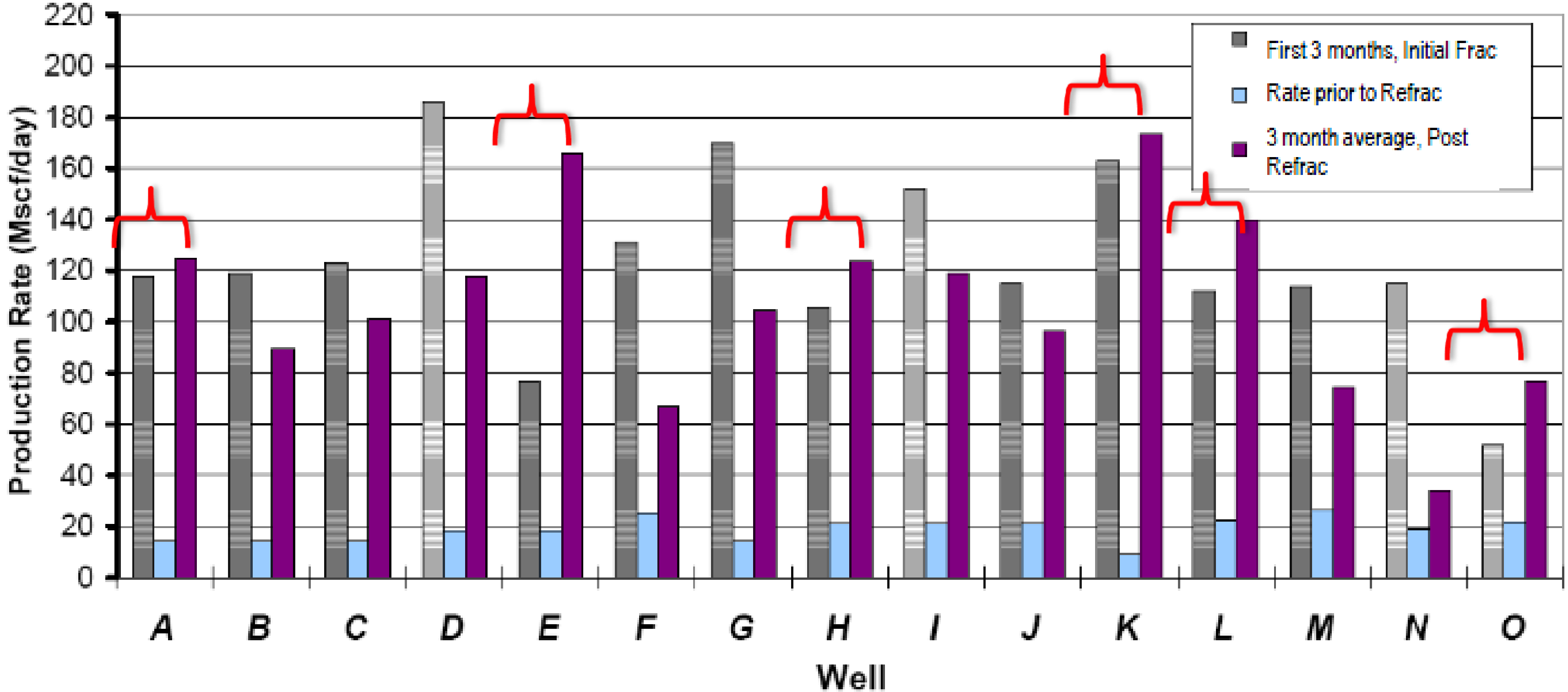


Figure 1 – Refracs consistently improved production, and frequently achieved gas rates meeting or exceeding peak production 25 to 30 years prior [adapted from Gutor 2003].

SPE 136757

Refracturing restored many wells to initial production – Is production really declining or is the flow capacity of the frac?

Performance of Refractured Barnett Shale Wells* (1999-2000 Program)

	Well Name	Date	Original Stimulation (Bcf)		After Refracture (Bcf)		Increased Recovery (Bcf)
			Cum Recovery**	EUR	Cum Recovery***	EUR	
1	Denton Creek #1	1992	0.8	1.0	2.2	2.9	1.9
2	Talley #1	1993	0.4	0.5	2.6	4.0	3.5
3	Logan #2	1991	0.4	0.6	2.2	3.3	2.7
4	Ted Morris #1	1992	0.6	0.8	2.1	3.0	2.2
5	Johnson #2	1984	0.3	0.4	1.8	2.9	2.5
	Average			0.7		3.2	2.5

**Based on analysis by Advanced Resources.*
***Cumulative gas recovery at date of refrac.*
****Cumulative gas recovery as of April 2008*

FACTORS IN SUCCESSFUL REFRACS

- **Enlarged frac geometry, reservoir contact, add contact points**
- **Improved pay coverage – increased frac height in vertical wells**
- **Increased frac conductivity or restoring frac conductivity**
- **Propping or re-propping previously unpropped fractures**
- **Fit-for-purpose fracture fluids**
- **Re-energizing / re-inflating natural fissures**
- **Frac Reorientation - field stress altered – new rock contacted**
- **Over-flushed frac jobs – repair by straddle frac & quality prop.**

Suggestion: A non-shale specific criteria was advanced by Reeves, et.al., 1999 to separate poor completions from poor geology before progressing towards a restimulation.

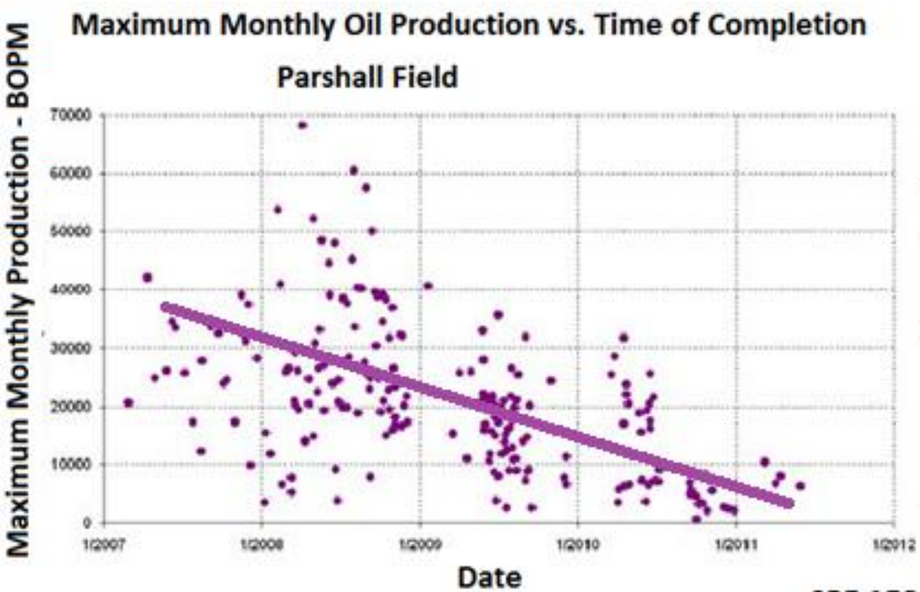
FACTORS IN FAILED REFRACS

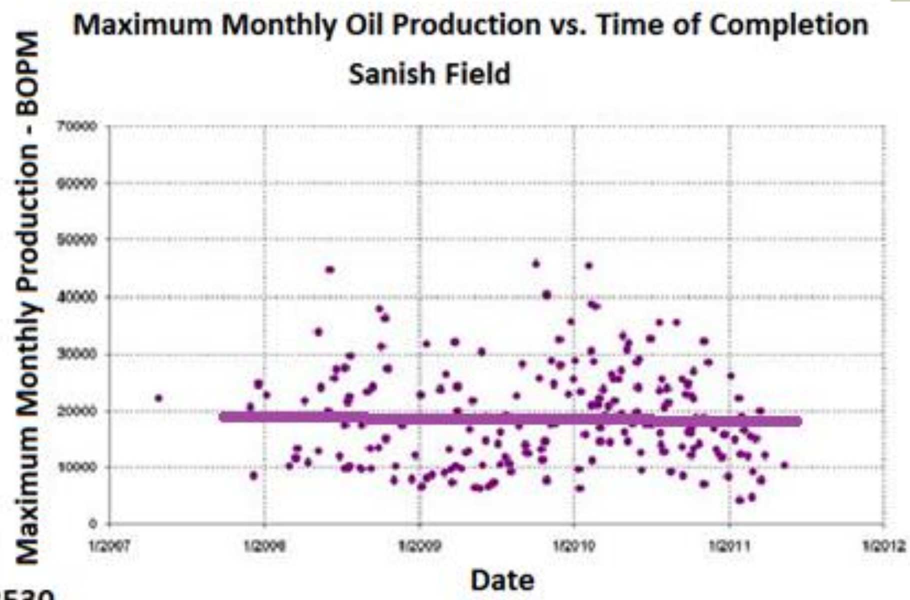
- Low pressured, depleted wells, limited reserves.
- Wells in which diagnostics indicate effective fractures & drainage to boundaries.
- Questionable mechanical integrity
- Access to better parts of formation prevented.
- Off-set wells recovered >> their “share” of reserves.

Apache

COMPARISON OF MAX MONTH PRODUCTION OF WELLS ACROSS FOUR YEARS

One field shows a steady decline in max month production with time – result of regional fractures?





SPE 152530

WHAT MAKES A GOOD REFRAC CANDIDATE? AND WHAT DOESN'T?

Good Candidate?

- Poor initial frac
- Bypassed shows
- Frac spacing >300 ft
- Less than 1000 lb/ft of prop over lateral
- Where $\sigma_H \sim \sigma_h$ & natural fracs present
- Some frac hit wells

Not so Good Candidate?

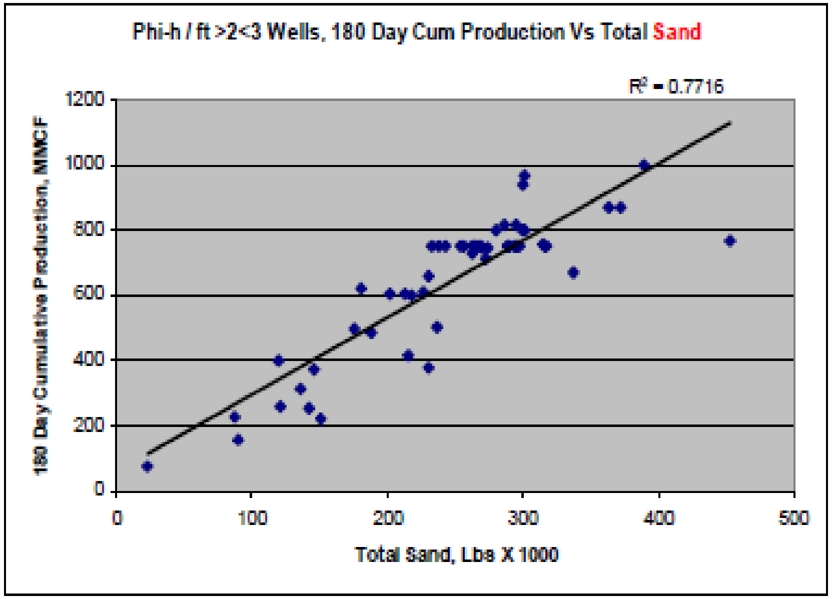
- No natural fractures
- No gas/oil shows during drilling
- High stress $\sigma_v < \sigma_H$ & $\sigma_H >> \sigma_h$
- Poorly performing in-fill wells in UCR
- Poor Integrity

Guidelines? – Yes, Absolutes? – No.

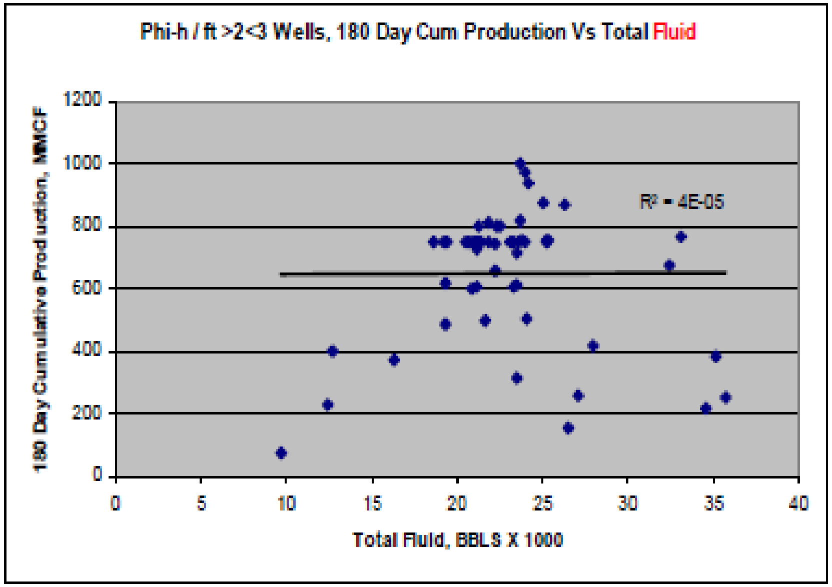
Apache

GO BACK TO FRACTURING BASICS

- Total proppant amounts can be very large & linked to well productivity – fluid volumes less important.



180 Day Cumulative Gas Production versus Total Pounds of Sand Used in Treatment for Wells with Phi-h per foot > 2 < 3



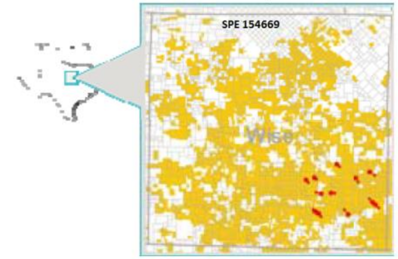
180 Day Cumulative Gas Production versus Total Barrels of Fluid Used in Treatment for Wells with Phi-h per foot > 2 < 3

Comparison of amount of sand and amount of fluid vs. 180 day cumulative production for Barnett Wells in the core area (with a lower frac barrier) with a log calculated porosity value between 2 and 3. Note that the best correlation is on the amount of sand (40/70 mesh) placed during the frac stage. Higher porosities indicated much poorer coorelations. Coulter, et. al., 2004, SPE 90891

REFRAC APPROACHES – WHAT HAS BEEN DONE? AT LEAST 8 BASIC APPROACHES

1) Cement squeeze & reperf
2) Liner patch to seal old perfs and refrac
3) Refrac old perfs (no new perfs) – w/ & w/o diverting
4) Restore proppant in near-wellbore w/ mini refrac
5) Add new perfs and refrac well with no diverters
6) Add new perfs and refrac well with diverters
7) Set plugs and refrac in stages down work string
8) Refrac specific intervals with coiled tubing

Locator Map – 13 Horizontal Well Restimulations in Wise County, Texas



RE-FRAC OF HORIZONTAL WELLS

- For 13 re-fracs, the average cost is 0.8 Bcf/well and the average cost is variable.

Summary Restimulation (Refrac) Information, Ranked on Delta Bcf Incremental Reserves

Well#	Re-Frac Yr.	Method for Refrac Control	Casing	GPI, ft	Delta Bcf	Cost, MM$
1H	2011	Squeezed & Reperfed	Cemented	3,262	**3.2**	**0.8**
2H	2008	Diversion Agent	Uncemented	3,505	**1.3**	**1.2**
3H	2010	Diversion Agent	Uncemented	2,079	**1.0**	**1.2**
4H	2011	Squeezed & Reperfed	Cemented	2,846	**1.0**	**0.6**
5H	2007	Diversion Agent	Uncemented	2,206	**0.9**	**1.0**
6H	2008	Diversion Agent	Uncemented	1,603	**0.8**	**0.8**
7H	2010	Squeezed & Reperfed	Uncemented	1,003	**0.6**	**0.4**
8H	2008	Diversion Agent & Added Perfs	Cemented	2,413	**0.6**	**1.1**
9H	2011	Squeezed & Reperfed	Uncemented	1,802	**0.5**	**0.7**
10H	2008	No Control - Just Pumped Job	Uncemented	1,204	**0.5**	**0.5**
11H	2008	Diversion Agent	Cemented	1,754	**0.4**	**0.7**
12H	2008	Diversion Agent	Uncemented	1,204	**0.4**	**0.8**
13H	2010	Expandable Casing	Uncemented	2,797	**-0.4**	**1.5**
			Average	**2,129**	0.8	0.9

GPI = Gross Perf Interval (shallowest to deepest)

SPE 154669

Initial uplift is about 0.6 MMcfd, stabilizing out to about 0.2 MMcfd in one year. Appears to be sustained – developed incremental reserves.

Of 13 Wells:

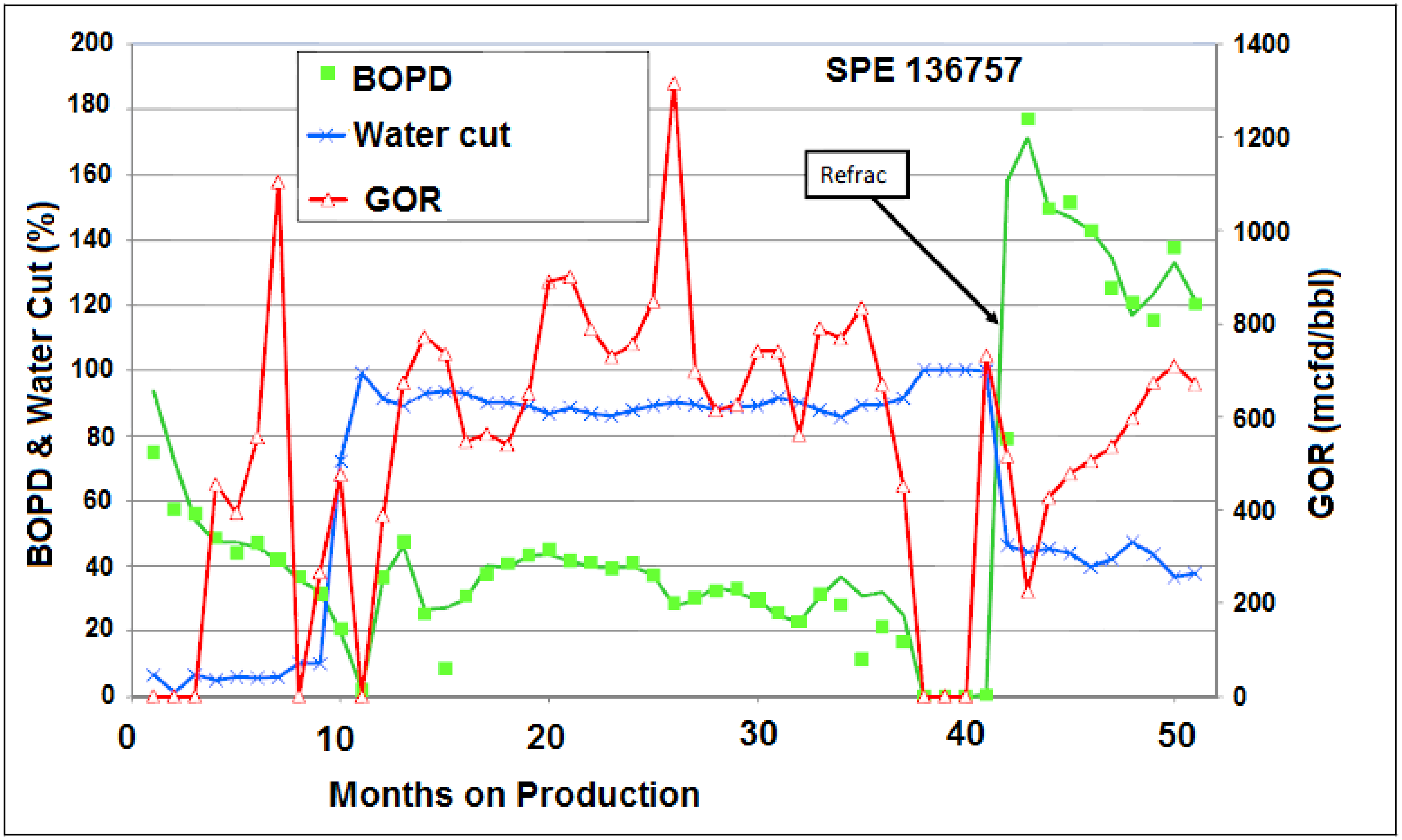
9 Had Uncemented Casing
- 5 Used Diversion Agent for Refrac Control
- 2 Used Cement Squeezes and Reperforating for Refrac Control
- 1 Had No Control. Pumped the job away in a Single Stage
- 1 Used Expandable Casing and Reperforating for Refrac Control

4 Had Cemented Casing
- 2 Used Diversion Agent for Refrac Control
- 2 Used Cement Squeezes and Reperforating for Refrac Control

TIMING

- Controls:
  - How old is the well?
  - What's the current production rate?
  - Are GOR increasing and liquids decreasing?
  - How good was the initial completion?
  - What is the oil or gas price projection?
  - What is the cost of refracs? (~25% to 40% of a new well??)

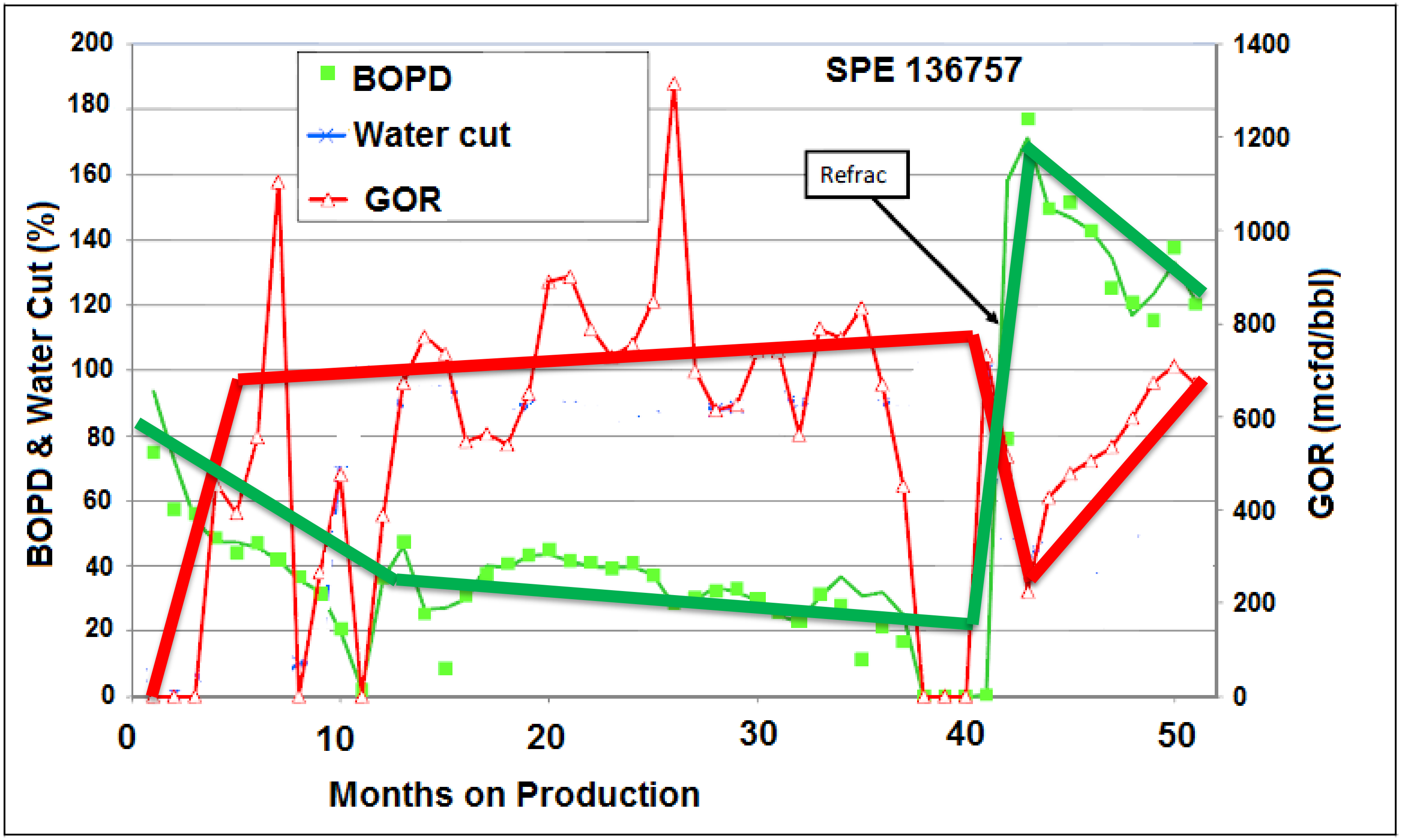
BAKKEN OIL RE-FRAC



Liquids much more difficult to flow through narrow fracs than gas – is increasing GOR and decreasing Oil a sign of unpropped fracture closure?

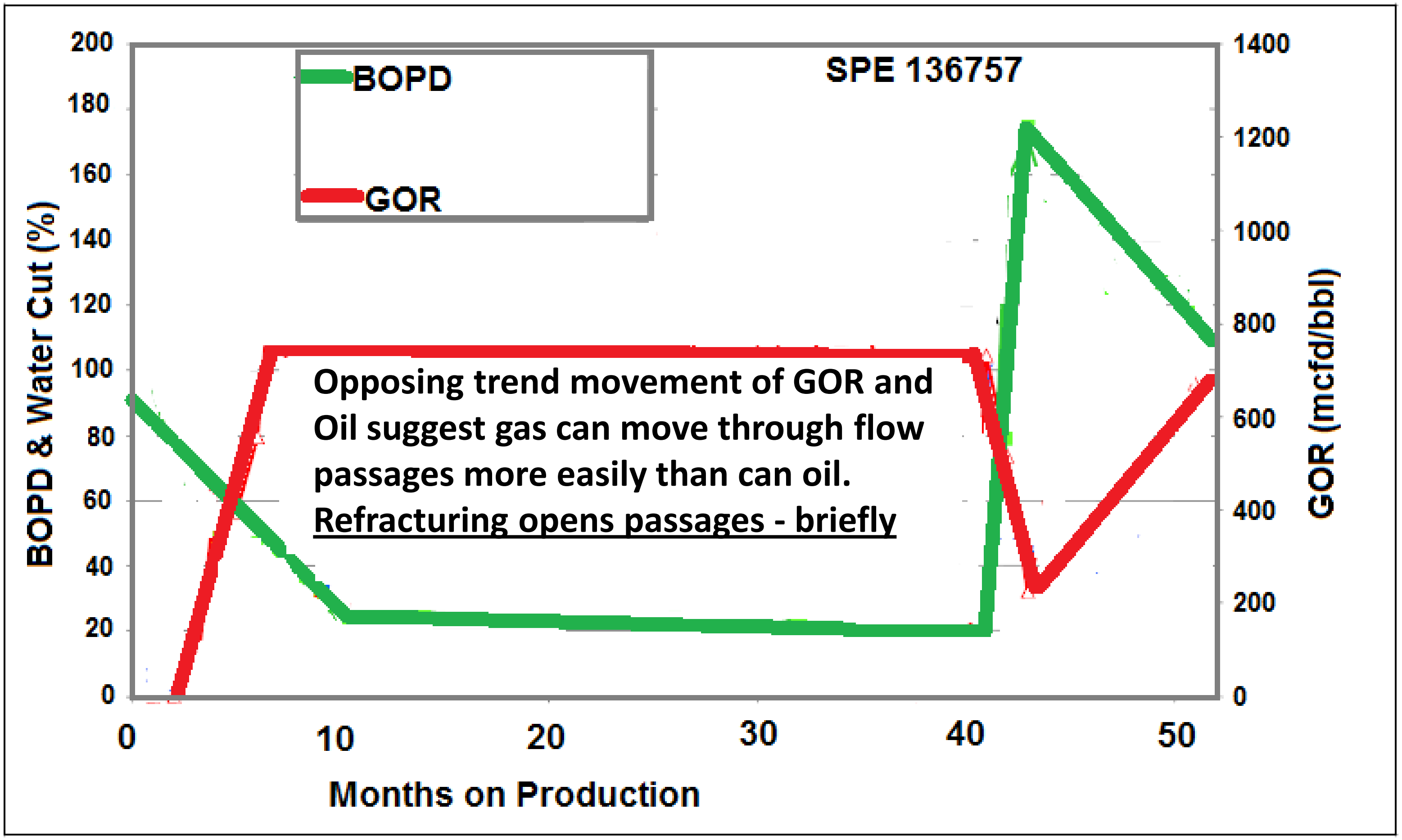
Apache

BAKKEN OIL RE-FRAC



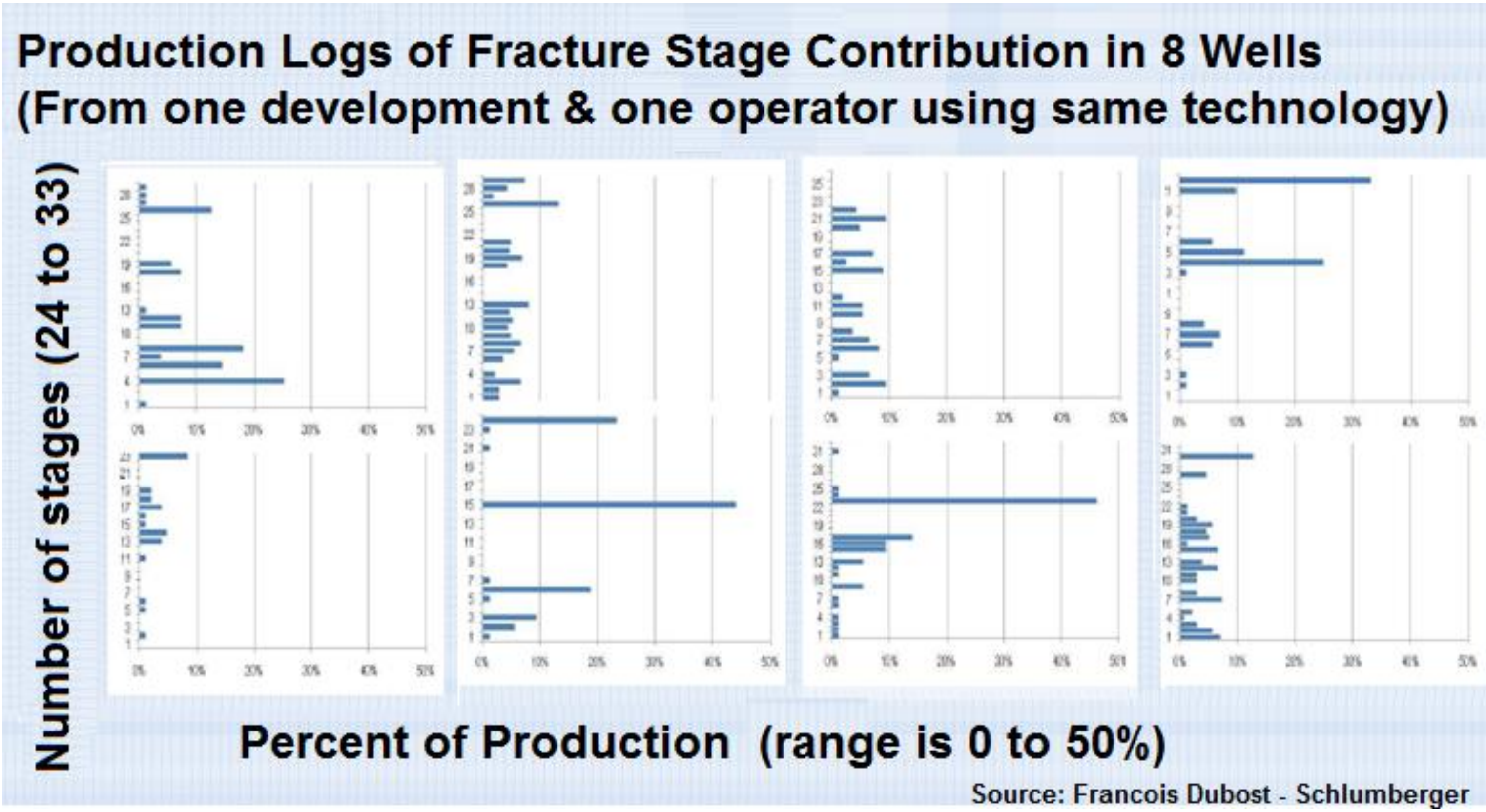
Liquids much more difficult to flow through narrow fracs than gas – is increasing GOR and decreasing Oil a sign of unpropped fracture closure?

BAKKEN OIL RE-FRAC



Liquids much more difficult to flow through narrow fracs than gas – is increasing GOR and decreasing Oil a sign of unpropped fracture closure?

DO ALL PERF CLUSTERS OR FRACS PRODUCE?

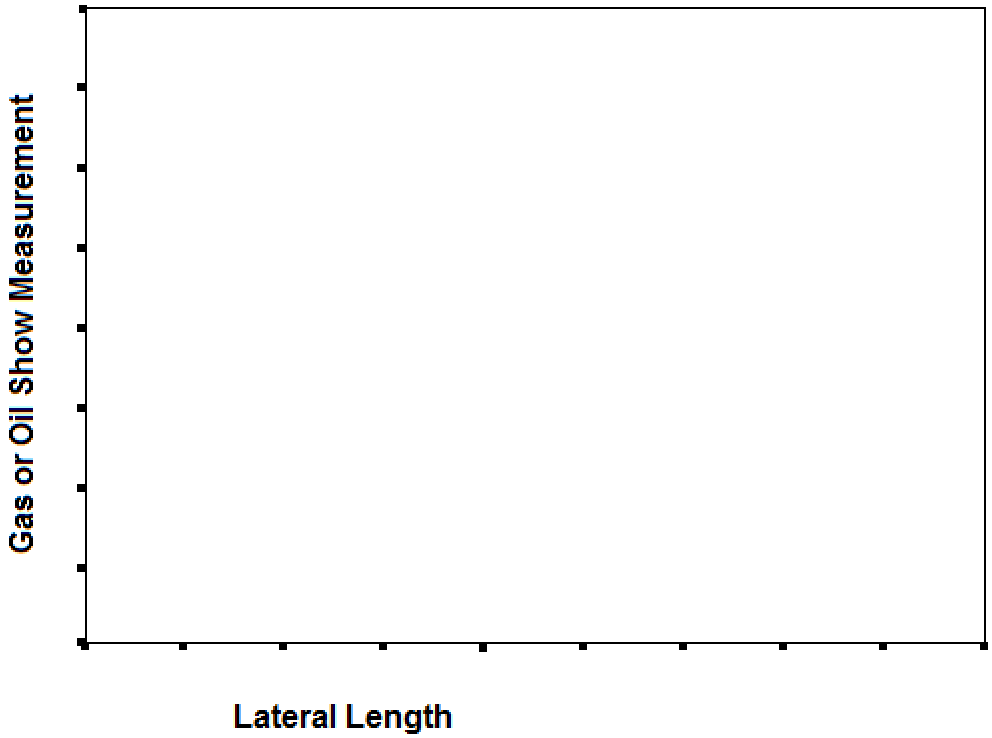


A common finding by production logs or tracers in Horizontal Multi-Fractured Wells.
- 30 to 50% of the fractures are producing 80% of the production.

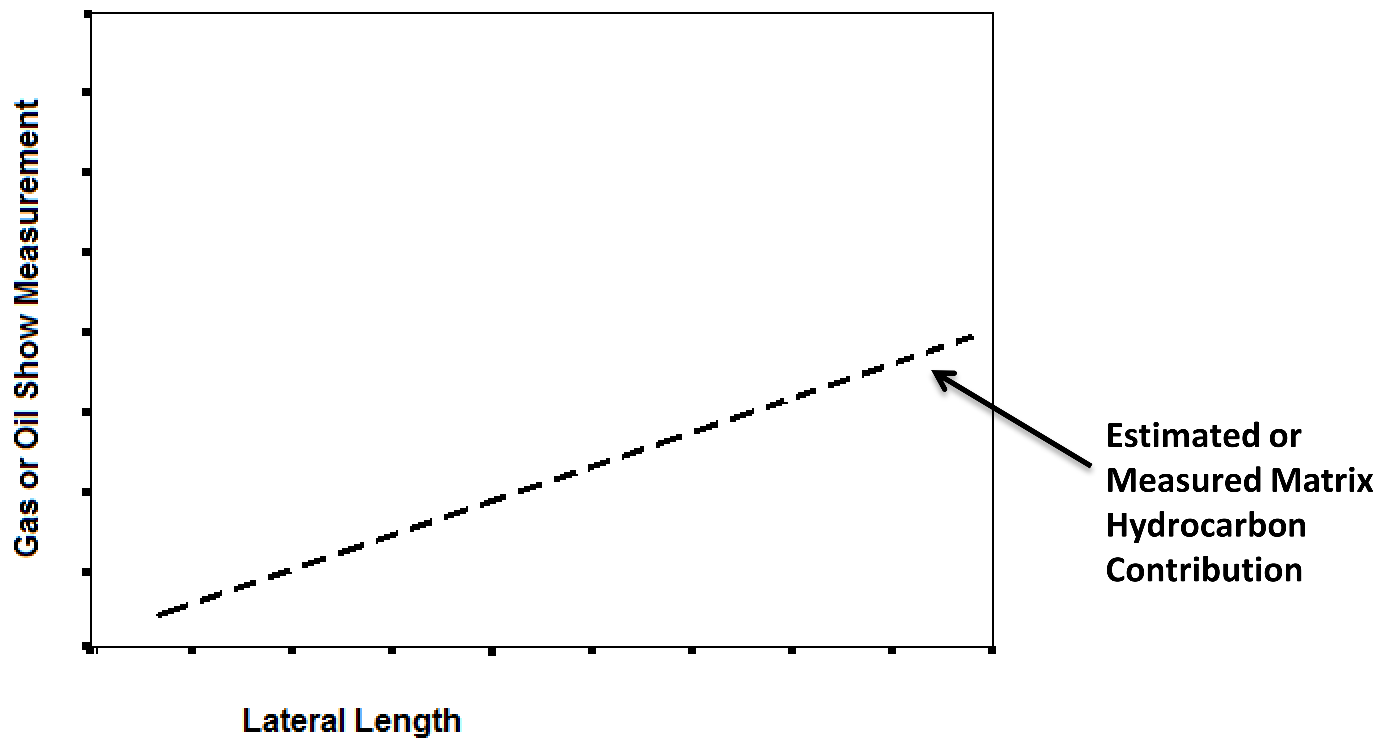
Are these underperforming fracture stimulations a refrac opportunity or a waste of money?

- **Check for over-flushed fractures**
- **Ask yourself why are you continuing to fracture in unproductive areas & wasting $.**

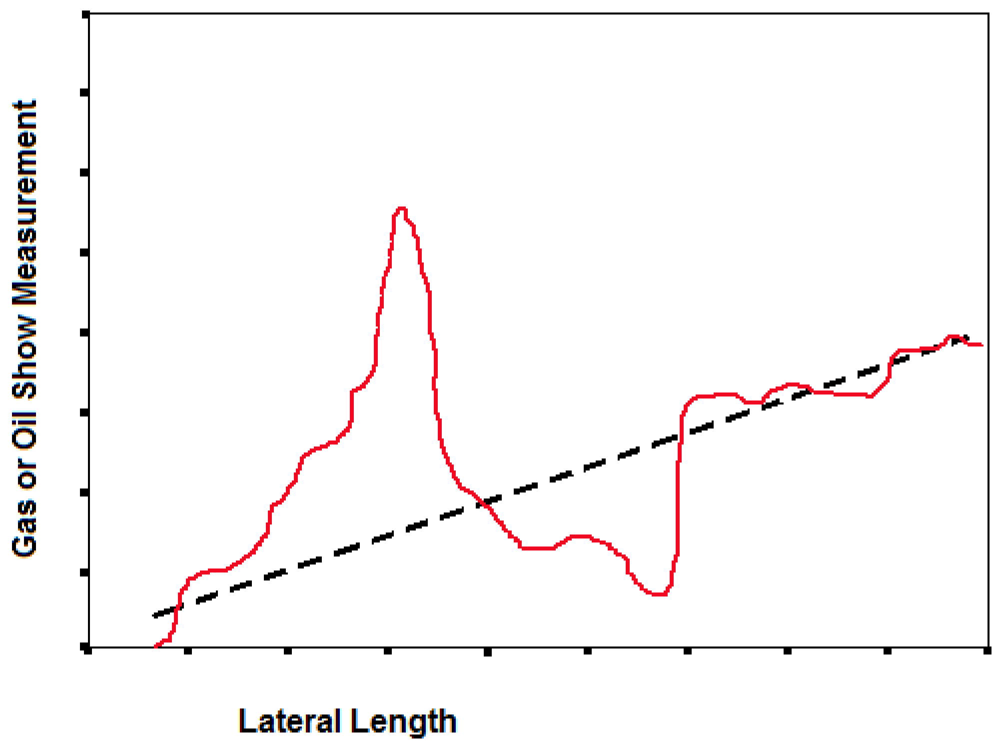
OIL & GAS SHOWS ALONG THE LATERAL



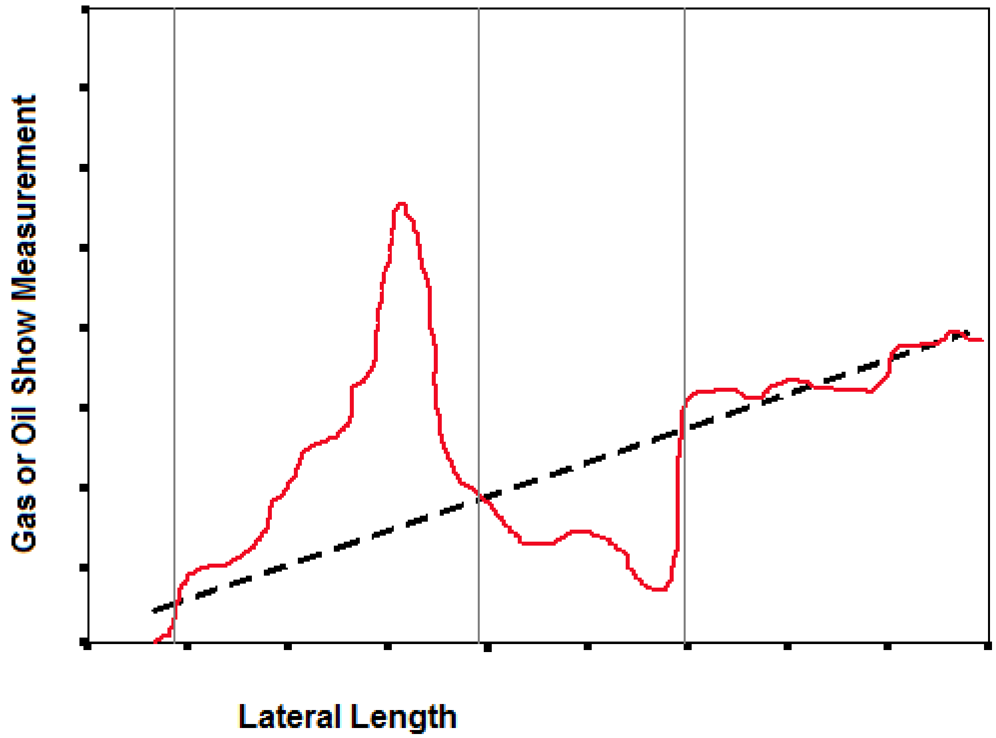
OIL & GAS SHOWS ALONG THE LATERAL



OIL & GAS SHOWS ALONG THE LATERAL

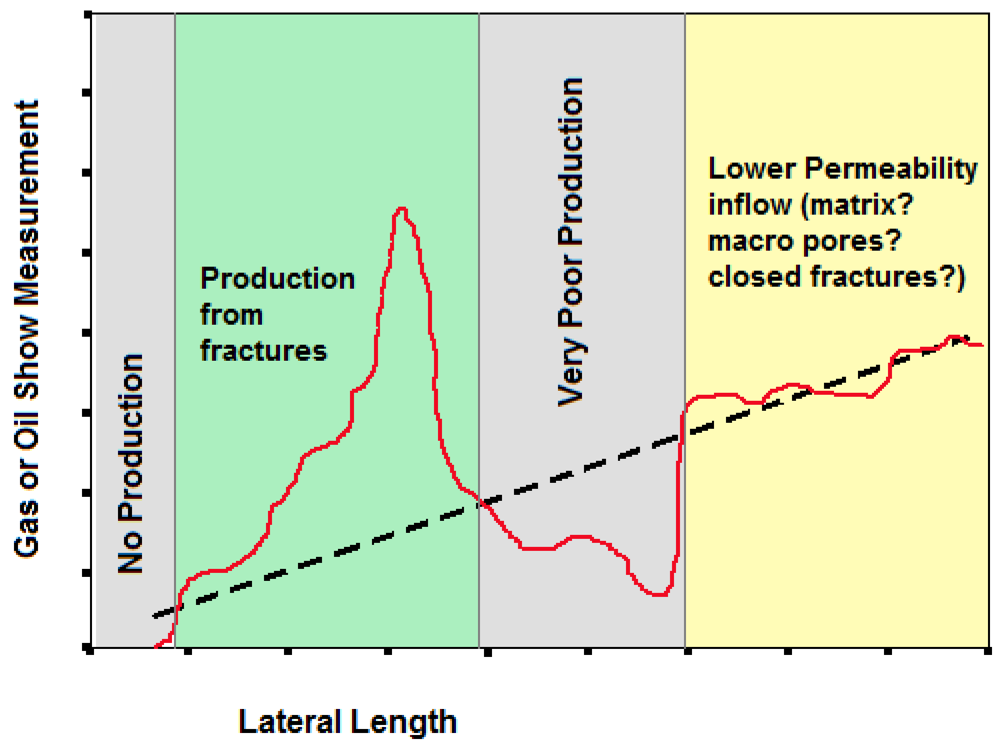


OIL & GAS SHOWS ALONG THE LATERAL



Apache

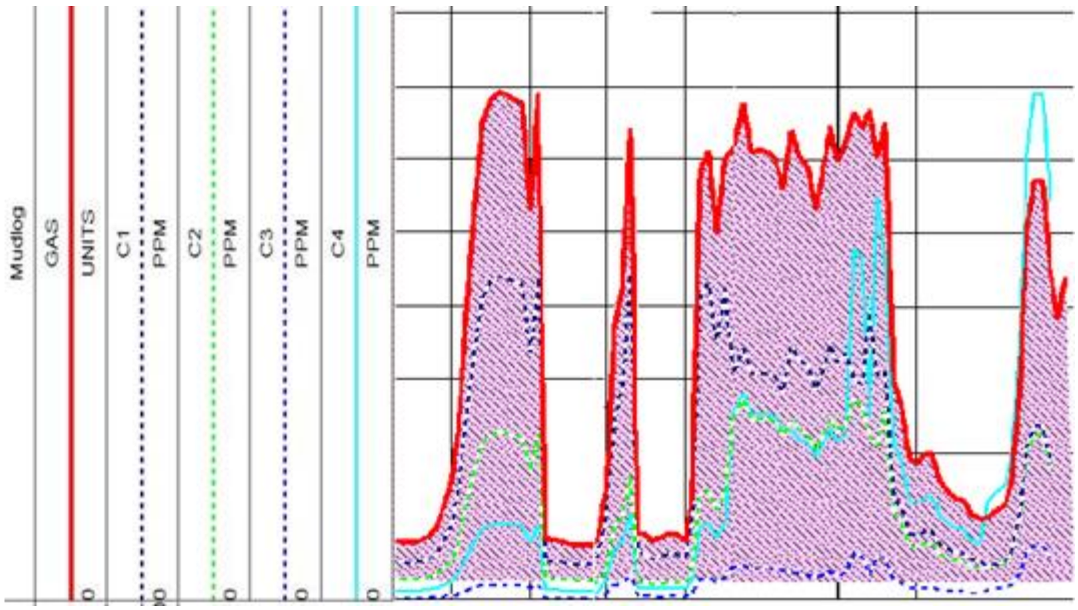
OIL & GAS SHOWS ALONG THE LATERAL



Adapted from: Berkat, et al.: "Identification and Characterization of Producing Fractures in Naturally Fractured Reservoirs Using PIWD," SPE 120687

PIWD = productivity index while drilling

LOOK AT THE COMPONENTS OF THE GAS SHOWS



- Gas Show
  - Quantity
  - Ratio of gasses
  - Corresponding GR
- Other logs (CNL, Density) to help assess TOC
- Density for Brittleness
- Resistivity for water saturation and salinity
- ROP (rate of penetration)
- Is it a hot shale or a natural fracture?

The objective is to align the perf clusters with natural fractures.

CONCLUSIONS

- Refracturing depends on:
  - Target
  - Timing
  - Method

SOME OBSERVATIONS

- Refracs often have a lower fracture gradients than found in the initial fracs. The uniaxial strain equation implies that high production that produces low pore pressure should also reduce the fracture gradient.

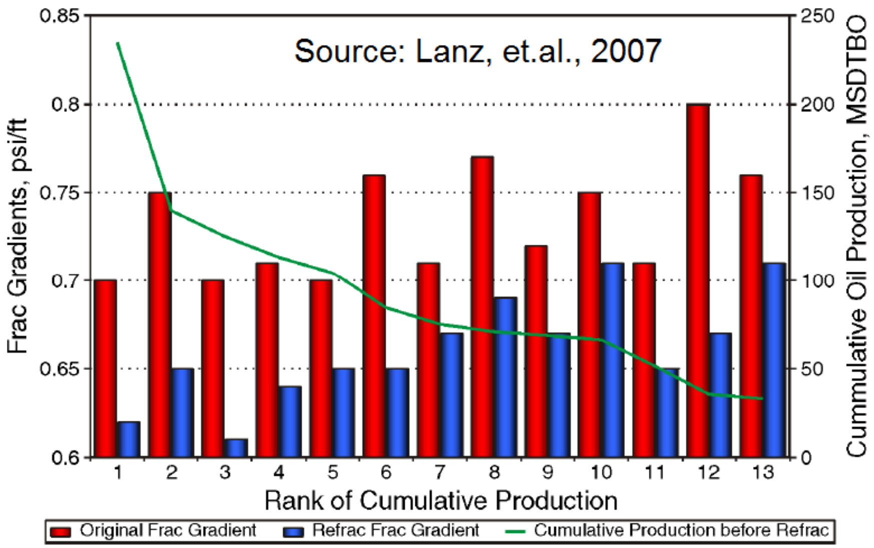


Fig. 4—Comparison of original treatment to the refracture treatment fracture gradients.

Table 2—Comparison of Original and Refracture Treatment Pressures

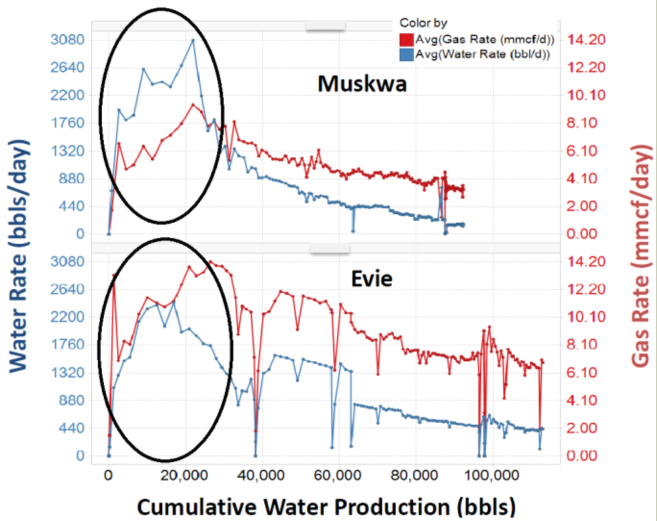
Treatment	Initial Frac Gradient, (psi/ft)	Average Initial ISIP, psi	Average Final ISIP, psi	Net Increase, psi
Original	0.73	3,011	3,816	788
Refrac	0.66	2,342	3,552	1,179

Apache

MESSAGE IN A BOTTLE (SPE 168892)

- **Produced water following hydraulic fracture stimulation frequently contains unique messages (data) from the stimulated formations.**
  - **Changes in chemistry of water reflect the architecture of the producing stimulated network.**
  - **Processes of water mixing; solid dissolution ion diffusion from matrix water to fracture water and the effect of area-to-volume ratio in leaching of ions from walls of the fracture to the injected water describe where the frac water went.**

Production Profiles

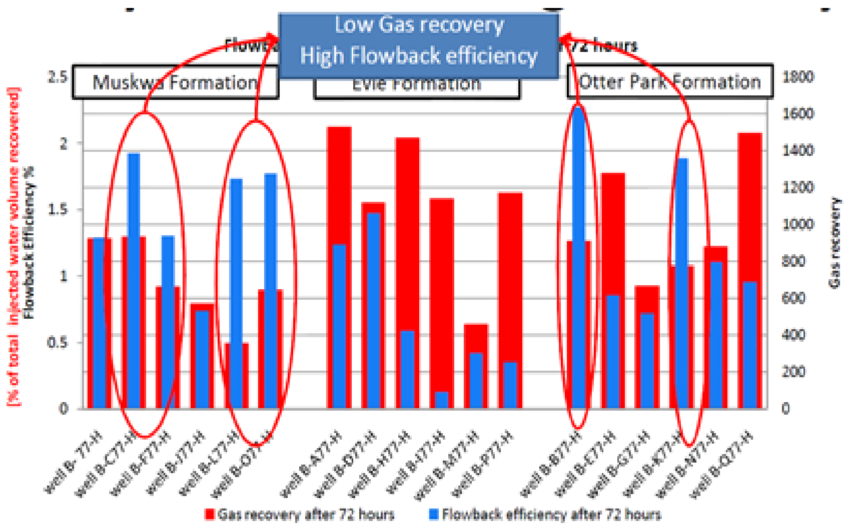


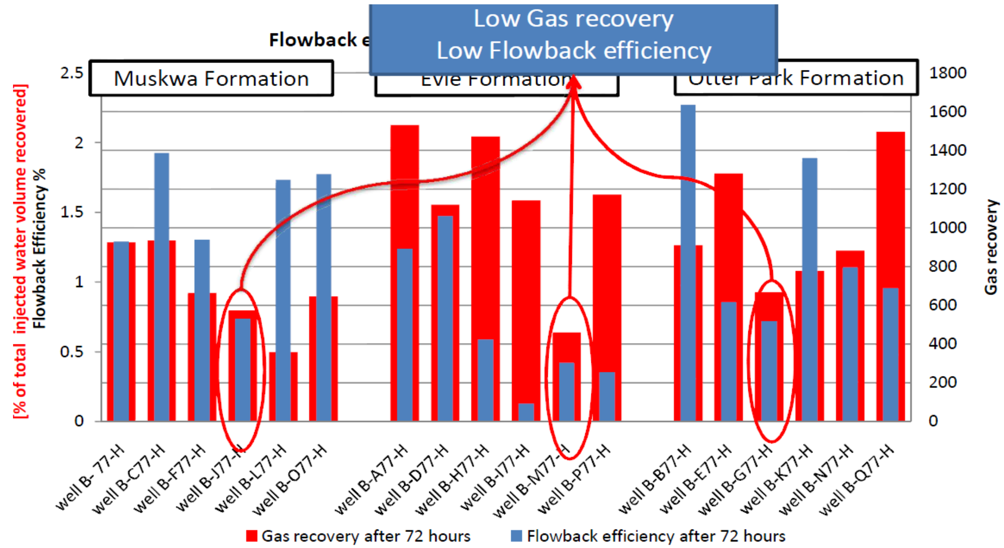
Is rapid flow easier from a planar fracture than a complex fracture?

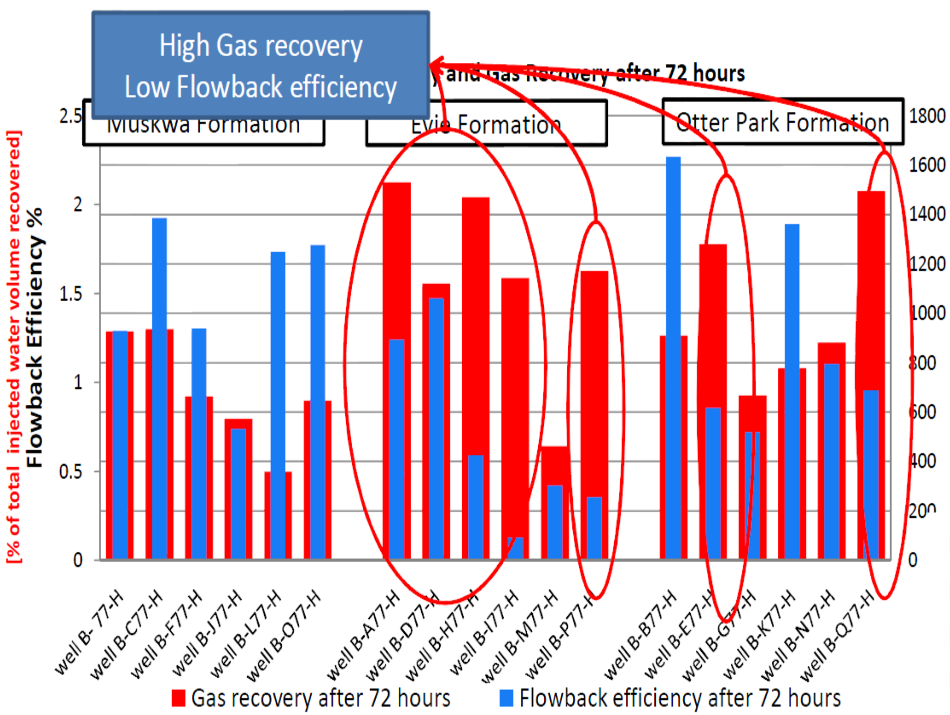
Bearinger, D.: "Message in a Bottle," (Nexen) SPE Workshop Hydraulic Fracturing Flowback, 6-7 November 2013, San Antonio, TX. & SPE 168892

Apache

Analysis of water and gas recovery







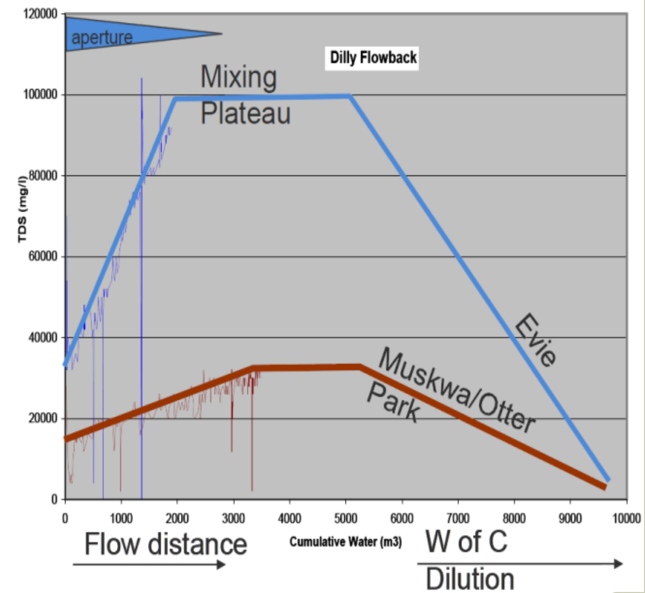
What is this telling us? If we get the highest gas recovery with lowest water recovery, should we be trying to get less <u>early</u> water recovery?

It may help with fracture type estimation & <u>early</u> is a key.

Ezulike, O.: “Flowback Analysis for Determining Load Recovery and Its Effects on Early-Time Hydrocarbon Production Rate,” (U Alberta) SPE Workshop Hydraulic Fracturing Flowback, 6-7 November 2013, San Antonio, TX. & SPE 168892

VARIANCE IN PRODUCED WATER TDS

- Time of sampling is the control
- Induced fracture water recovered first, then salinity increases as water recovered from complex (natural fractures).
- Water reaches a plateau – characteristic of stable water flow from early production.
- Salinity declines after frac flowback is exhausted, connate water decreases and condensed water increases with gas production increase.

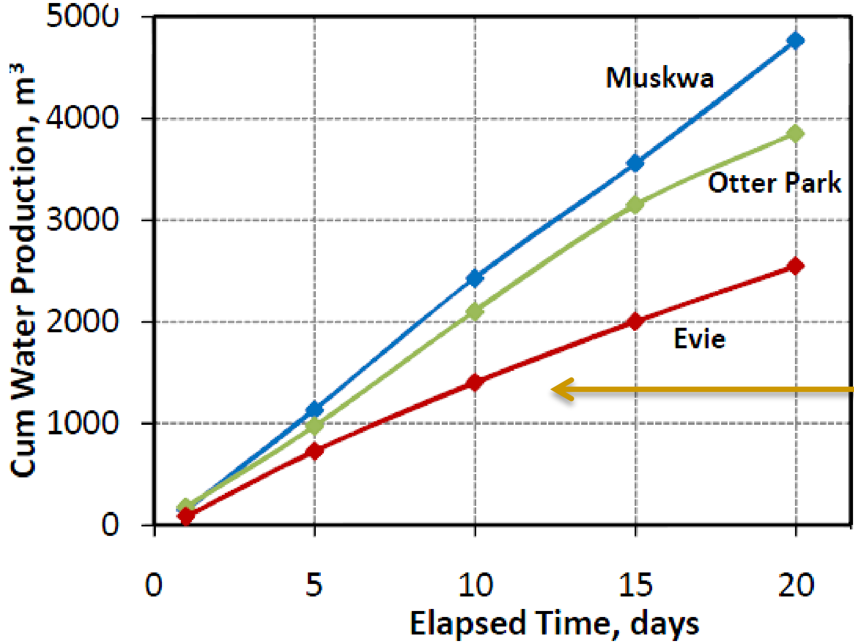


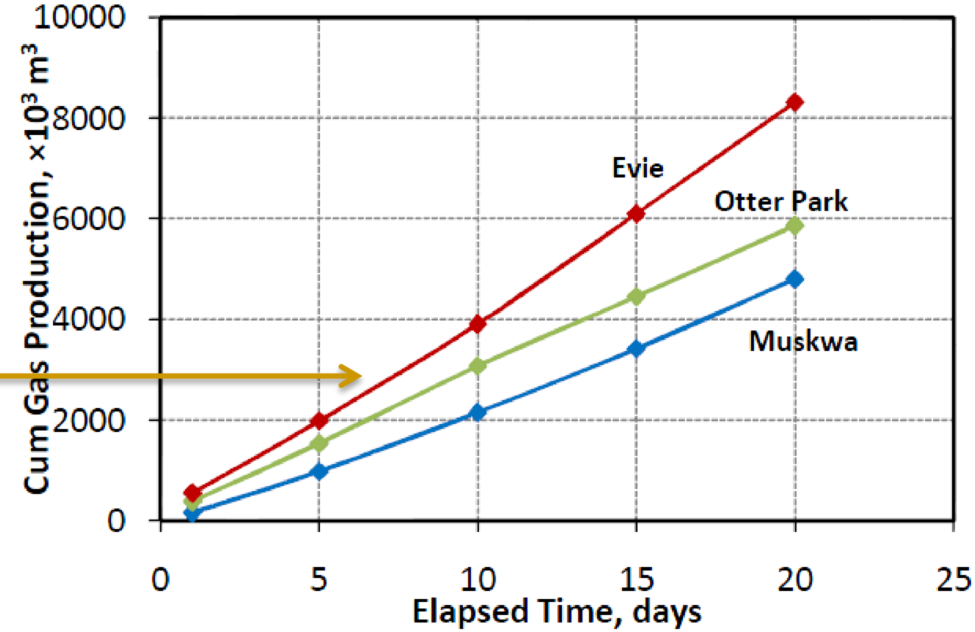
Bearinger, Doug: "Message in a Bottle," (Nexen) SPE Workshop Hydraulic Fracturing Flowback, 6-7 November 2013, San Antonio, TX.

FLOWBACK VOL. VS. GAS PRODUCTION

	Averaged Flowback Volume (m^3)					
	After 1 Day	After 5 Days	After 10 Days	After 15 Days	After 20 Days	Total over complete data available
Muskwa	150.70	1132.63	2428.88	3557.33	4762.45	4757.8 (23 days)
Evie	84.85	728.35	1402.07	2001.50	2548.12	3322.67 (28 days)
Otter Park	178.42	973.13	2100.59	3146.86	3853.24	4246.85 (23 days)

	Averaged Gas Production (Mm^3)					
	After 1 Day	After 5 Days	After 10 Days	After 15 Days	After 20 Days	Total over complete data available
Muskwa	168.99	985.89	2155.52	3419.85	4806.57	5409.70 (23 days)
Evie	549.47	1983.31	3912.10	6102.41	8320.99	12156.03 (28 days)
Otter Park	382.45	1538.07	3076.11	4457.92	5869.45	6773.32 (23 days)





Ezulike, O.: "Flowback Analysis for Determining Load Recovery and Its Effects on Early-Time Hydrocarbon Production Rate," (U Alberta) SPE Workshop Hydraulic Fracturing Flowback, 6-7 November 2013, San Antonio, TX. & SPE 168892

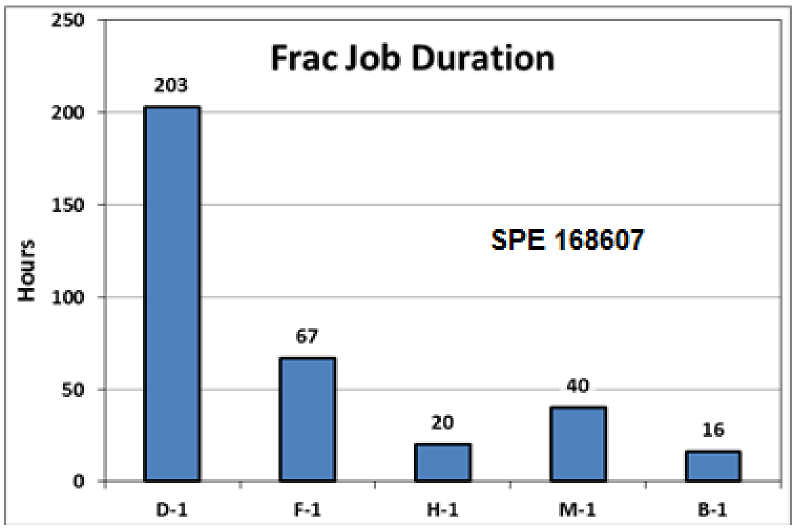
ION RATIOS IN THE PRODUCED WATER

- Sodium (Na) & potassium (K) ions appeared to move faster by diffusion than Ca & Mg ions. (ion transfer & ratio judgment)
- Formation clay & permeability may affect cation ratios.
- Slope of TDS rise related to connate water salinity and contact area of fractures & formation.
- Ion concentration & ion ratios impacted by area-to-volume ratio of fracs. Lower AVR in planar fracs & higher AVR in complex fracs.
- Waters in producing wells diluted by condensation from gas, but dilution has no effect on ion ratio.
- As load fluid recovered, salinity dropped radically as formation water production decreased & condensed water increased.

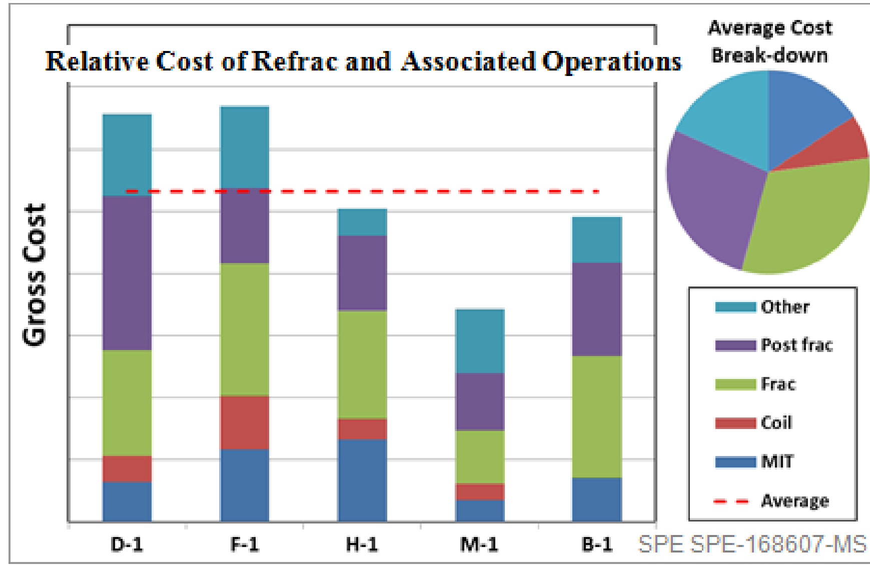
Bearinger, D.: "Message in a Bottle," SPE Workshop Hydraulic Fracturing Flowback, 6-7 November 2013, San Antonio, TX. & SPE 168892

COST & TIME BREAKDOWN OF REFRAC

- Refracs – How Successful?
- Best are older wells w/ x-link or foam initial frac
- Must have the reserves in place to be economic.



The initial two wells of the pilot program were the most expensive but costs and frac duration have come down with subsequent wells



Recent, horizontal multi-frac with many stages do not appear to be that good of a candidate?

REFRAC POPULARITY?

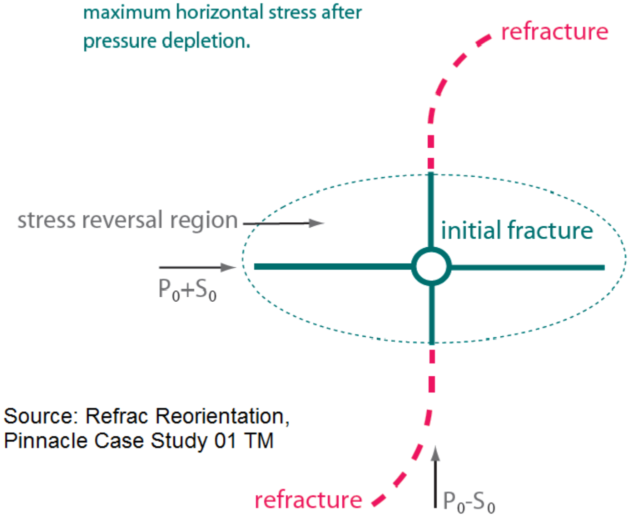
- Refracs small portion of fracturing activity
- Refracs are about 2 to 3% of fracs per year.
- Most refracs made w/o sufficient candidate analysis.
- Unconventionals appear to have the highest refrac success rate – particularly in early years of shale frac modernization (i.e., 2000 to 2008)
- Barnett refracs returned initial rate & EUR gained 0.6 bcf to 3 bcf.

Sources: Wolhart, 2002, Vincent

Apache

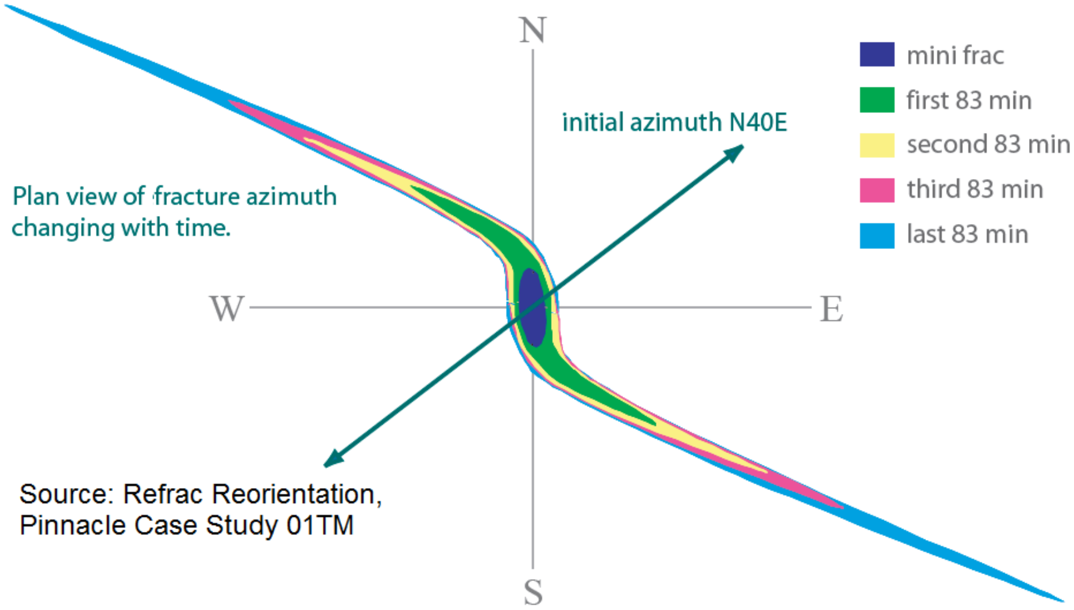
REORIENTATION EFFECTS

Stress reversal region shown above indicates elliptical area where original minimum horizontal stress becomes new maximum horizontal stress after pressure depletion.



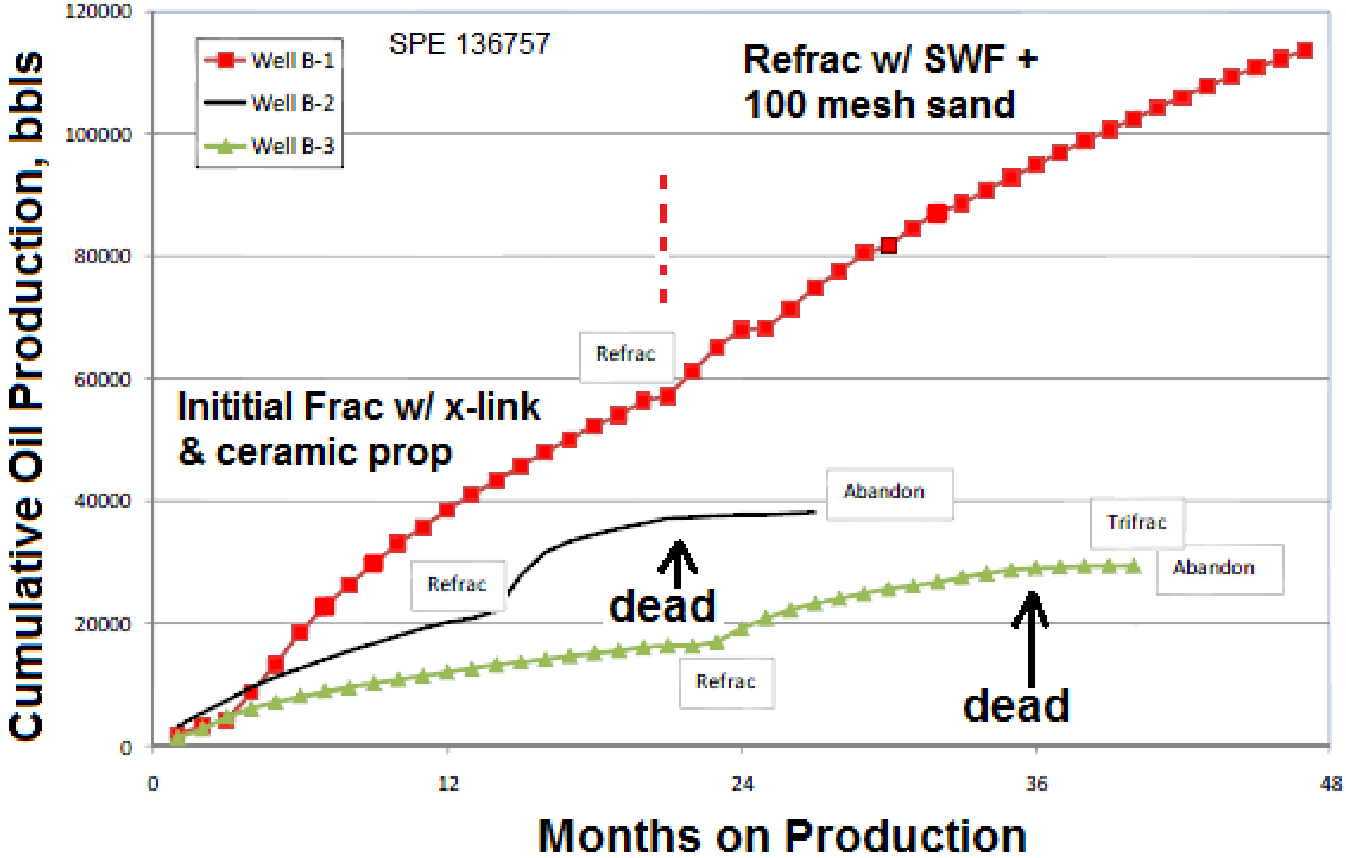
Source: Refrac Reorientation, Pinnacle Case Study 01 TM

Plan view of fracture azimuth changing with time.



Source: Refrac Reorientation, Pinnacle Case Study 01TM

NOT EVERY WELL IS A GOOD CANDIDATE

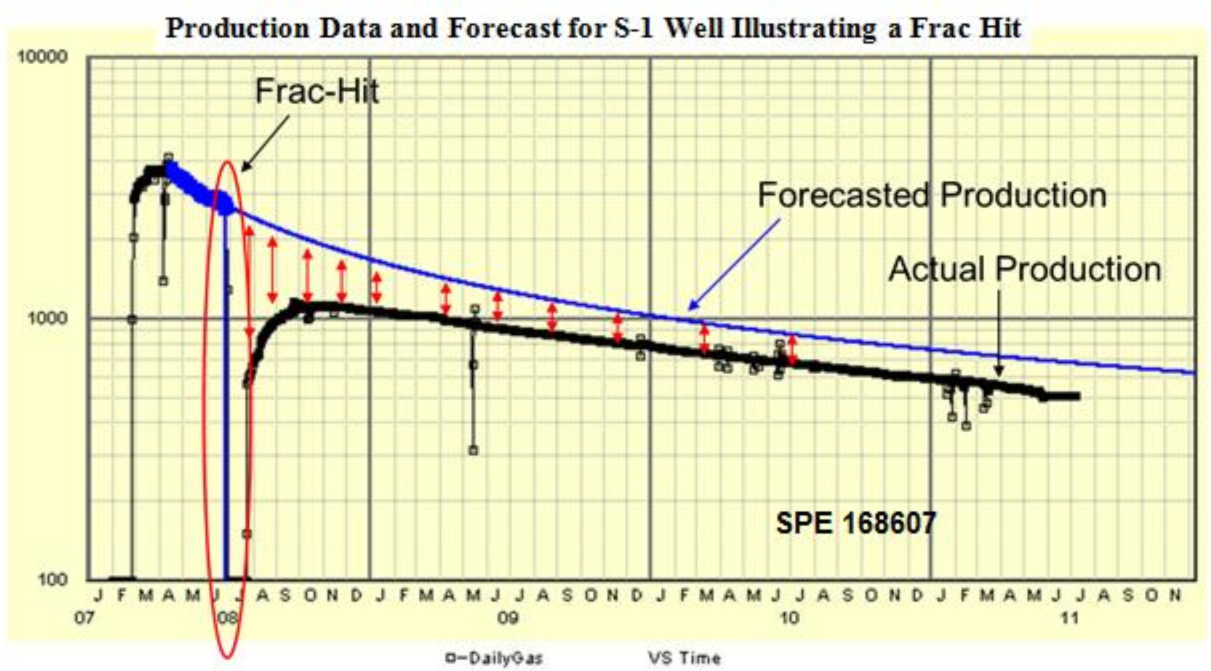


One successful refrac

Two low yield refracs

FRAC HITS

- A Frac "Hit" is a pressure or fluid incoming response from a frac treatment in an adjacent (?) well.



FRAC HITS

Planar Fractures

- Most likely hit distance => less than 1500 ft.
- Skips wells? => sometimes
- Longer hits => 4000 ft.
- Mechanical damage potential => high
- Likely production effect in "hit" well => reduced production 5% to 15%.
- Prevention => pressure up w/field gas, auto shut in.
- Design change => increase well spacing, stagger perf flusters out of frac's way.

Complex

- Most likely hit distance => about 500 ft.
- Skips wells? => frequently
- Longer hits => rare over 1000 ft.
- Mechanical damage potential => low – water loading is main issue
- Likely production effect in "hit" well => increased 10% to 50%
- Prevention => most operators don't bother, some load well.
- Design change => stagger perf clusters if less than 500 ft.

REFRACTURING TO MITIGATE FRAC HITS

- Adding rate & reserves is the main goal of refracturing.
- Some reports indicate older wells with "new" (re)fracture before new, adjacent wells were fractured, were at least partly protected.
- Wells shut in and/or loaded or pressurized also appeared to be protected.

REFERENCES

- Craig, M., Wendte, S., Buchwalter, J.: “”Barnett Shale Horizontal Restimulations: A Case Study of 13 Wells,” SPE 154669, SPE Americas Unconventional Resources Conference, Pittsburgh, PA, USA, 5-7 June 2012.
- Fredd, C.N., McConnell, S.B., Boney, C.L., England, K.W.: “Experimental Study of Fracture Conductivity for Water-Fracturing and Conventional Fracturing Applications,” SPE 74138, SPE Journal, Vol. 6, No. 03, pp 288-298.
- French, S., Rodgerson, J., Feik, C.: Re-Fracturing Horizontal Shale Wells: Case History of a Woodford Shale Pilot Project,” SPE 168607, SPE Hydraulic Fracturing Conference, 4-6 February 2014, The Woodlands, TX, USA.
- Lanz, T., Greene, D., Eberhard, M., Pershall, R.: “Refracture Treatments Proving Successful in Horizontal Bakken Wells: Richland County, Montana,” SPE Rocky Mountain Oil & Gas Technical Symposium, Denver, CO, USA, 16-18 April 2007.
- Reeves, S.R., Hill, D.G., Hopkins, C.W., Conway, M.W., Tiner, R.L., Mohaghegh, S.: “Restimulation Technology for Tight Gas Sand Wells,” SPE 56482, SPE Annual Technical Conference and Exhibition, Houston, TX, USA, 3-6 October 1999.
- Siebrits, E., J.L. Elbel, R.S. Hoover, I.R. Diyashev, L.G. Griffin, S.L. Demetrius, C.A. Wright, B.M. Davidson, N.P. Steinsberger, D.G. Hill: “Refracture Reorientation Enhances Gas Production in Barnett Shale Tight Gas Wells,” SPE 63030, SPE Annual Technical Conference and Exhibition, Dallas, TX, USA, 1-4 October 2000.
- Vincent, M.C.: “Refracs – Why Do They Work, And Why Do They Fail in 100 Published Field Studies,” SPE 134330, SPE Annual Technical Conference and Exhibition, Florence, Italy, 19-22 September 2010.
- Vincent, M.C.: Examining Our Assumptions – Have Oversimplifications Jeopardized Out Ability to Design Optimal Fracture Treatments,” SPE 119143, SPE Hydraulic Fracturing Conference, The Woodlands, TX, USA, 19-21 January 2009.
- Wolhart, S., “Hydraulic Fracturing Restimulation,” SPE Distinguished Lecturer Series. 2002.

Apache

END OF SLIDE SUPPORT PACKAGE