Leading Successful Refracturing Campaign in Permian Basin

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Agenda

- Refrac definition and history
- Key components of refracturing project
- Role of refracs in Mature Fields
- What makes refracs unsuccessful?
- Steps to be taken to succeed
- Well candidates review process
- Importance of well integrity & diversion
- Case histories with production results
- Conclusions & recommendations

What is Refrac?

Refrac: is the second sand fracturing attempt to restore or improve well productivity

Historical Overview:

- 1953 the first Refrac job
- 1954 the first application of diverter in frac jobs
- 1961 Emphasis on higher sand concertation (>1 lb/gal)
- 1970 Importance of fluid viscosity to fracturing width
- Active refracturing in 1950's and 1970's (35% of all jobs)
- *Nowadays in US market 500-750 refrac jobs/year* (<1% of all jobs)
- Numerous success stories……reported refrac economic success rate 70-80%

So….why do we have less refracturing Jobs?

Key Components of Refracturing Project

Environment

- External Stakeholders
- Refracs History
- Advances in Technology
- HC Prices

Project

- Team Structure
- Allocated Budget
- Perceived Risk
- Project Cost

- What is our current refrac inventory?
- When is the best time to refrac?
- What are the technical limitations?
- What are the cost and associated risks?
- What would be the economic benefits?

Reservoir

- **Remaining Reserves**
- **Time & Depletion**
- Existing Pay
- Reservoir Pressure
- Bypassed Pay
- Geomechanics

Fracture

- **Fracture Architecture**
- Geometry
- Conductivity

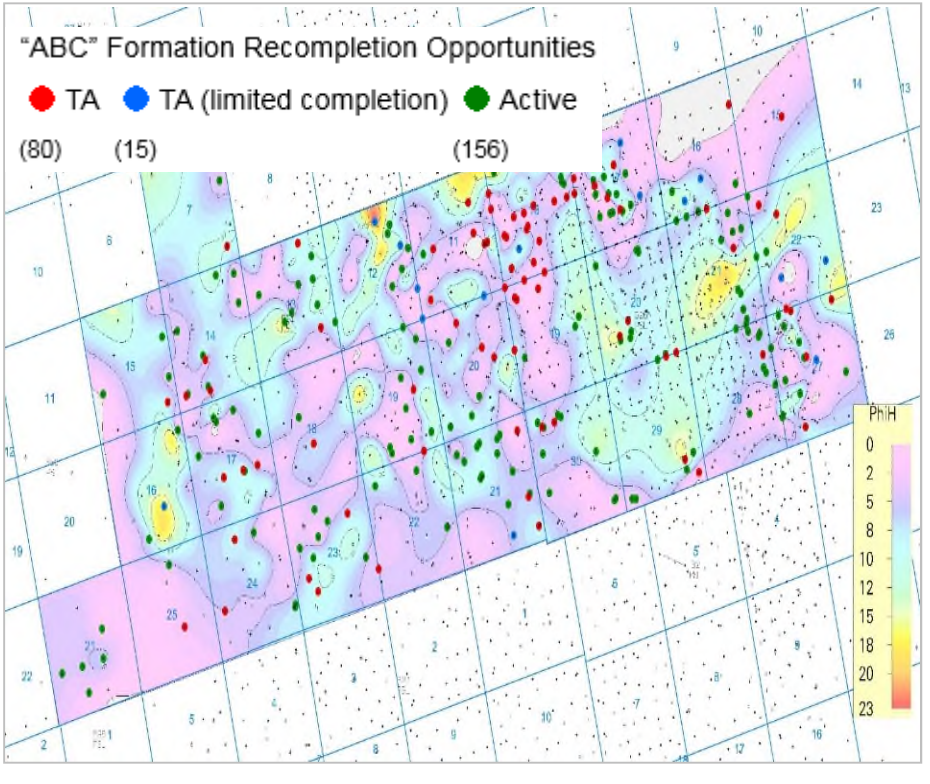
Wellbore

- **Placement & Diversion**
- **Well Integrity**
- Perforation
- Cement Integrity
- Isolation & Breakdown
- Casing Integrity

Role of Refracs in Mature Fields

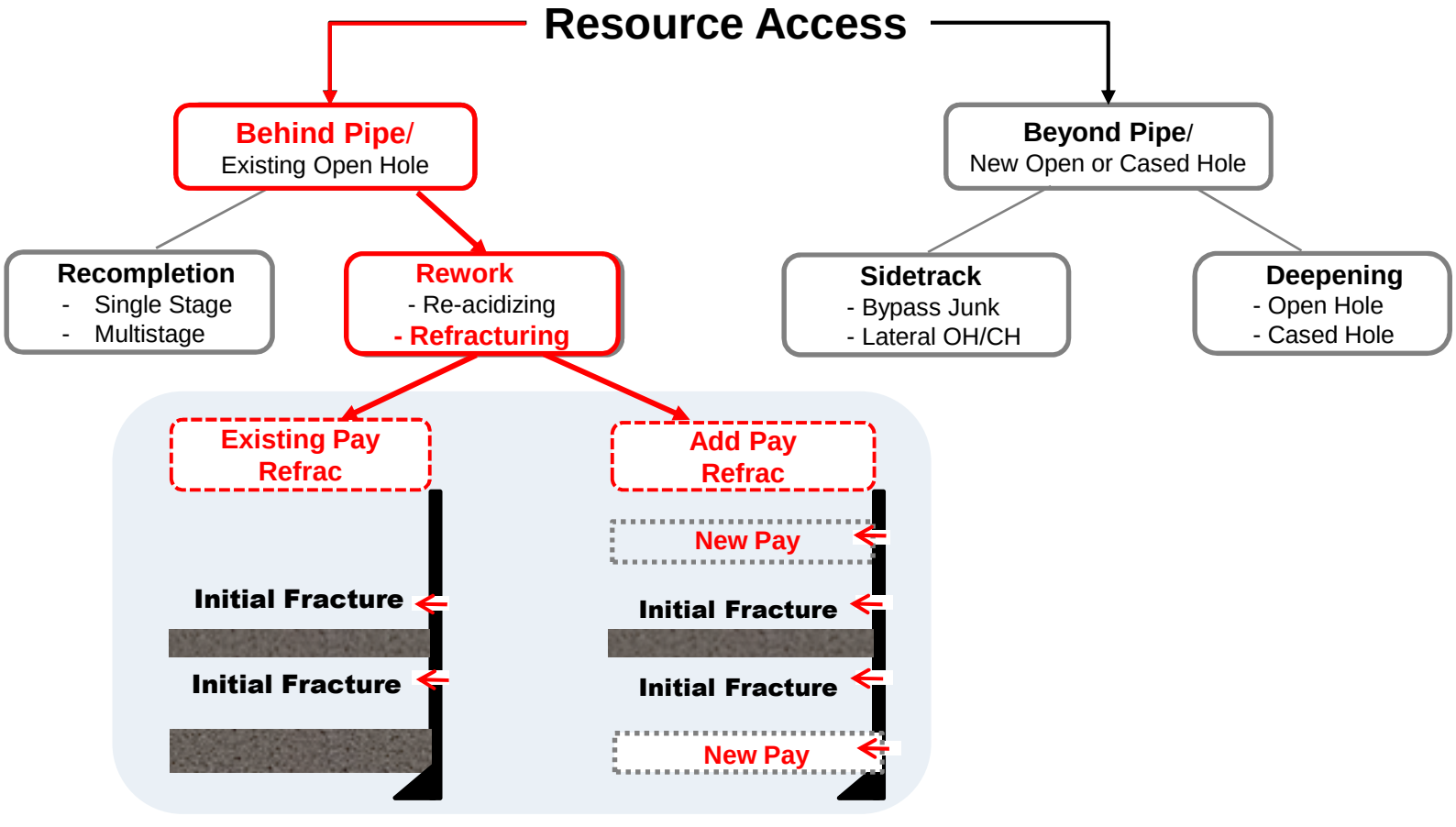
- Reduced drilling activity
- Focus on “protecting the base production”
- Increased inactive well count
- Tighter regulatory requirements
- Reduced uphole recompletion inventory
- Original fracs are degrading
- Accelerated speed of P&A
- Stimulation service cost reduction by 43%
- Cementing service cost reduction by 24%
- Is this a right time for restimulation program?

Phi-H Map per Zone of Interest



~30% of pay bypassed or/and unstimulated*

Resource Access Through Existing Wellbore



Observations: **What Makes Refracs Unsuccessful?**

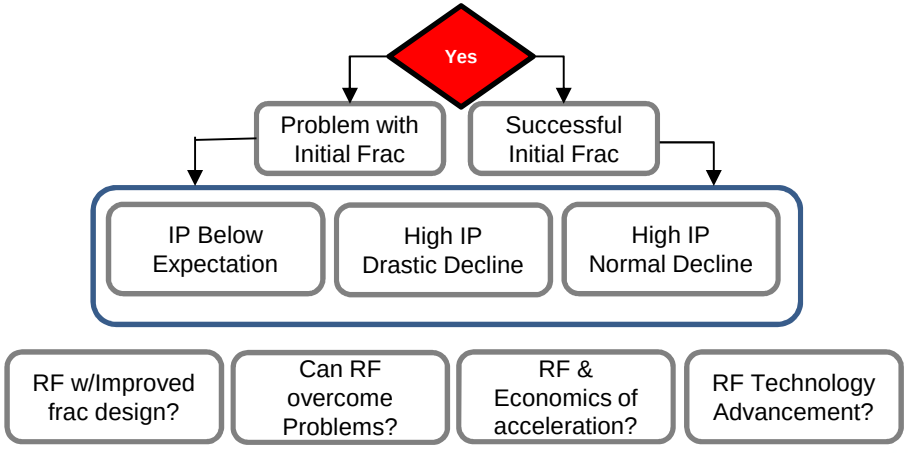
- Poor rock quality- both technically and economically challenging
- Low reservoir pressure due to depletion
- Poor diversion = bypassed pay
- Refracturing wells converted to water injection (limited success)
- Short effective fracture half-length in relation to well spacing
- Refracs with low sand concentration
- Assumption of infinite conductivity fracture (few fractures)
- Failure to assess or/and address well integrity risks
- Refracturing wells with flow assurance problems
- Other failures mechanisms

Steps to be taken to succeed

1. Evaluation of remaining reserves (flow unit approach)
2. Estimation of fracture damage/ reservoir properties and pressure
3. Detailed analysis of initial stimulation treatments
4. Comprehensive Well Integrity Management program
5. Diversion strategy (limited entry, ball sealers, mechanical isolations)
6. Perforation acid breakdown strategy – tagging acid, step-rate tests
7. Minifrac – diagnostic fracture Injection/falloff tests
8. Field supervisor training – net pressure trends, minifrac supervision
9. After fracture diagnostic logs
10. Minimization of cross-flow (delayed commingling, accelerated pump-off)
11. Flow assurance strategy per formation

Well Candidates Screening:

Does well has sufficient reserves?



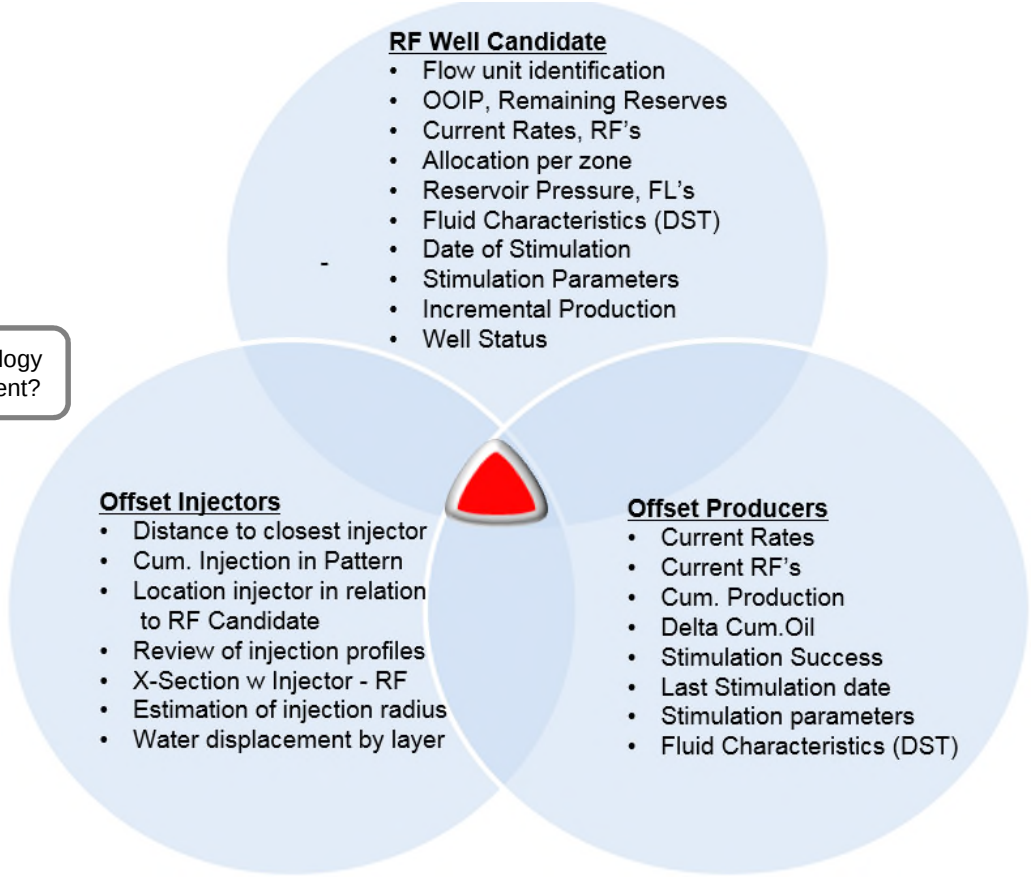
I. Identification of refrac candidates

II. Prioritization of refrac candidates

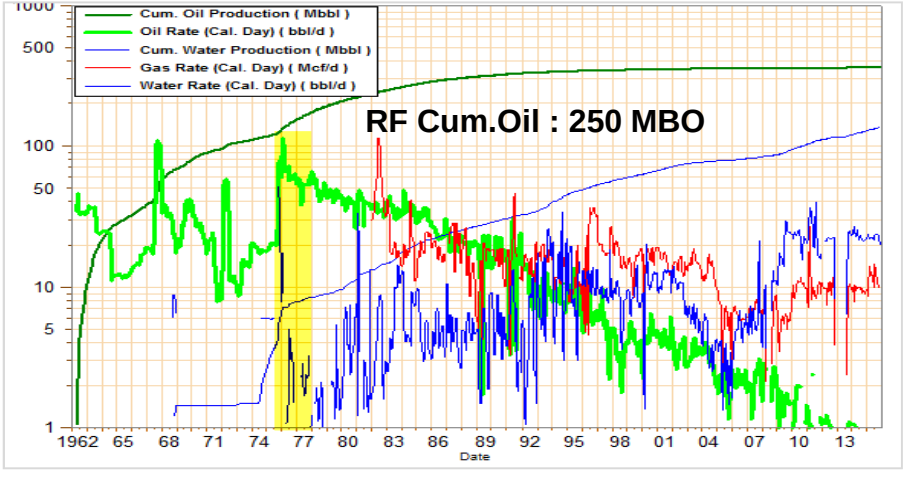
III. Design and successful implementation

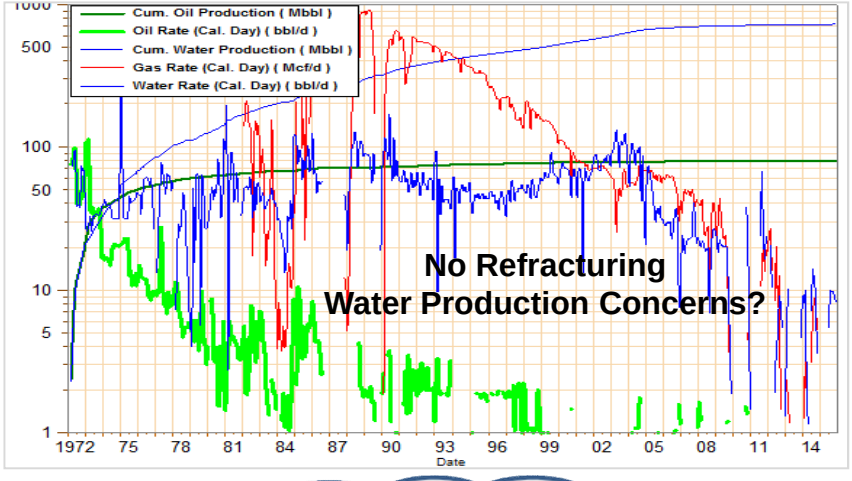
IV. Post restimulation evaluation

High Level Refrac Candidates Identification



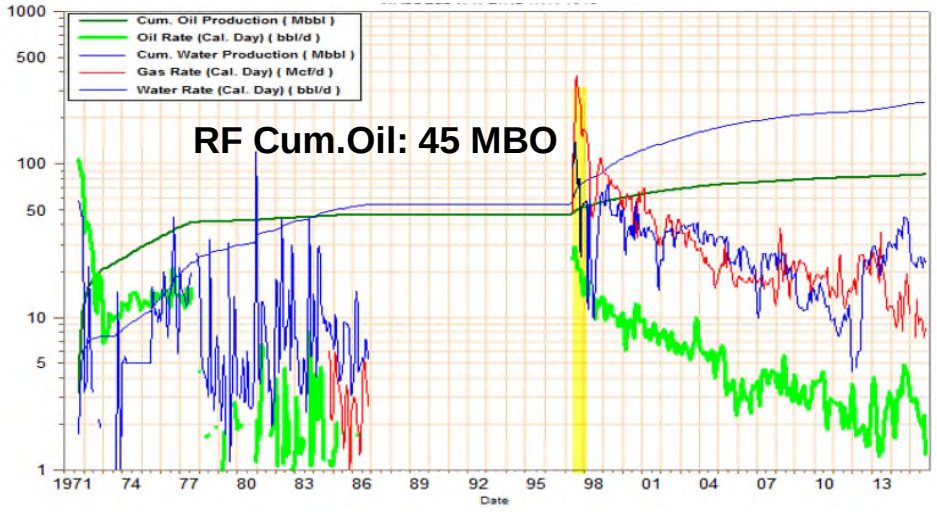
30 years of Refracturing Inventory?

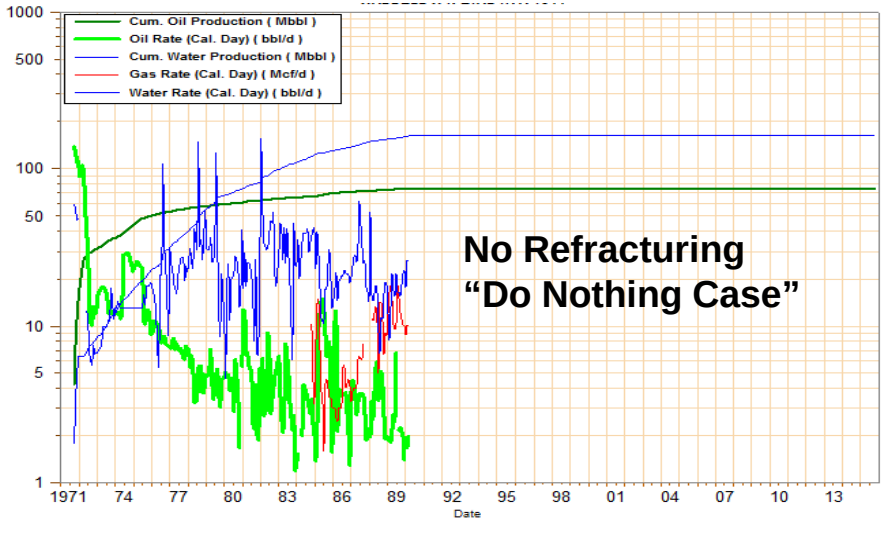




- Review and analyze historical data
- Numerous inactive wells w/ low primary recovery factors
- Wells with small volume low conductivity fracs
- Limited entry or cluster perforations with bypassed pay
- <u>Original completion in higher pay quality</u>

40 years of Re-fracturing Inventory?



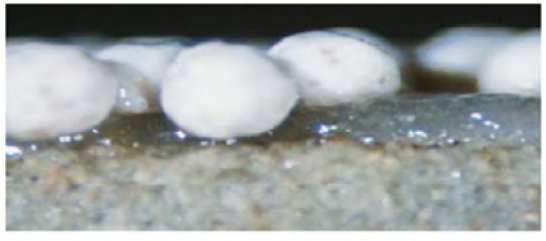


- Reperforation practices
- Notched completions
- Refrac with add pay most successful
- Low rate (<20bpm) treatments
- Height confinement in deeper zones >3600ft

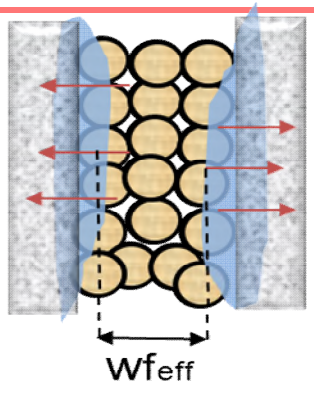
San Andres Fracture Parameters in 1970's:

- Effective Fracture Length(ft)…… ……50-70
- Fracture Height(ft)……200
- Maximum Frac Width(in)……0.15
- 20/40 mesh average.Dia(in)……0.027
- 10/20 mesh average.Dia(in)……0.061

Degradation of Fracture Conductivity Over Time



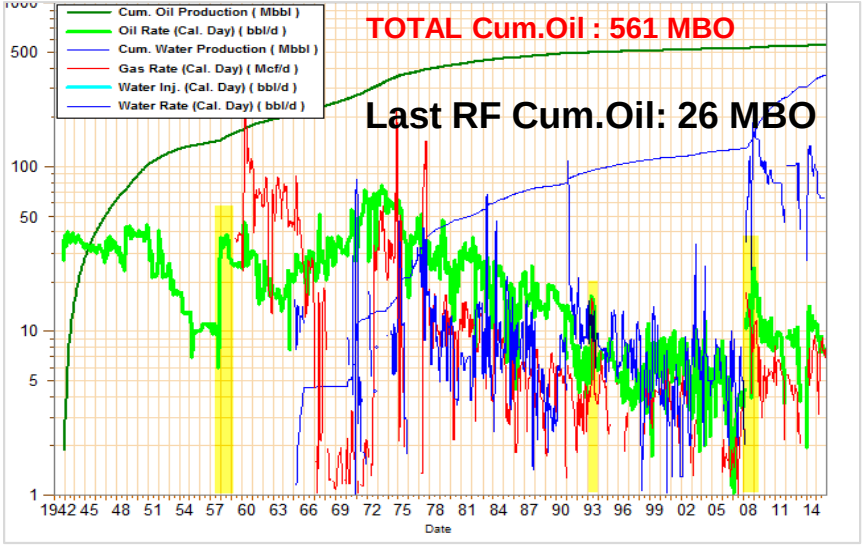
Gel filter cake (Conway and Abney, 2003)

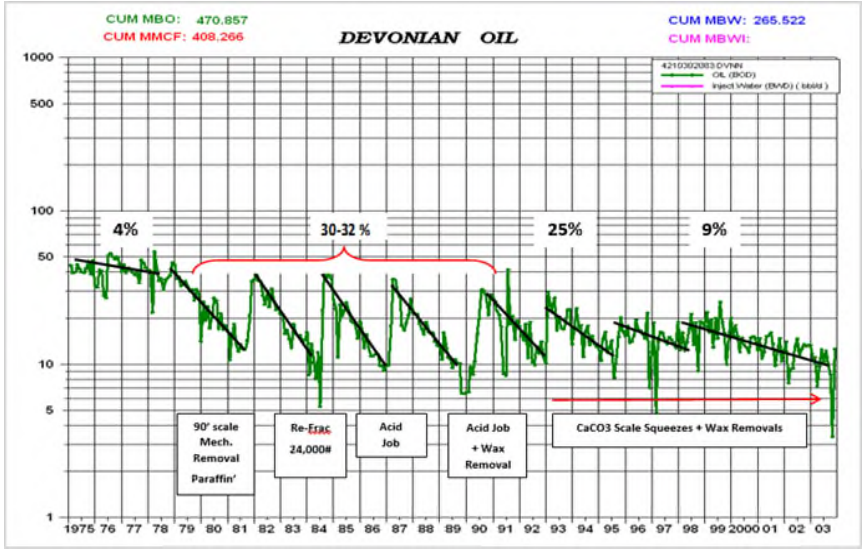


- Filter cake occupies up to 30% of fracture width
- Retained matrix permeability may decrease from up 20%
- Filter cake viscosity can be up to 20,000 cp
- Irregular particles → loss of frac width (old fracs)
- Stress cycling over life-time, depletion, increase in Pc
- In sub-monolayer pack grains carrying more closure stress

$$C_{fD} = \frac{k_f w}{k x_f}$$

Various Types of RF's & Restimulation in Conventional Reservoirs

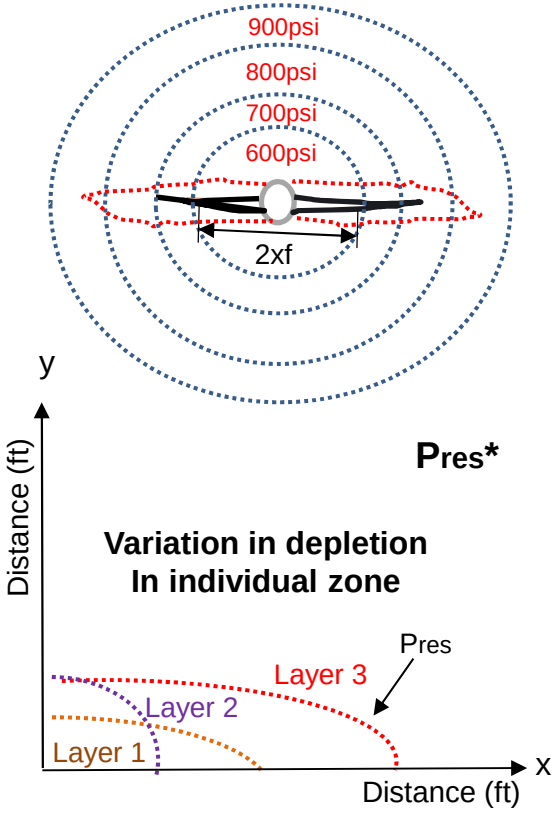




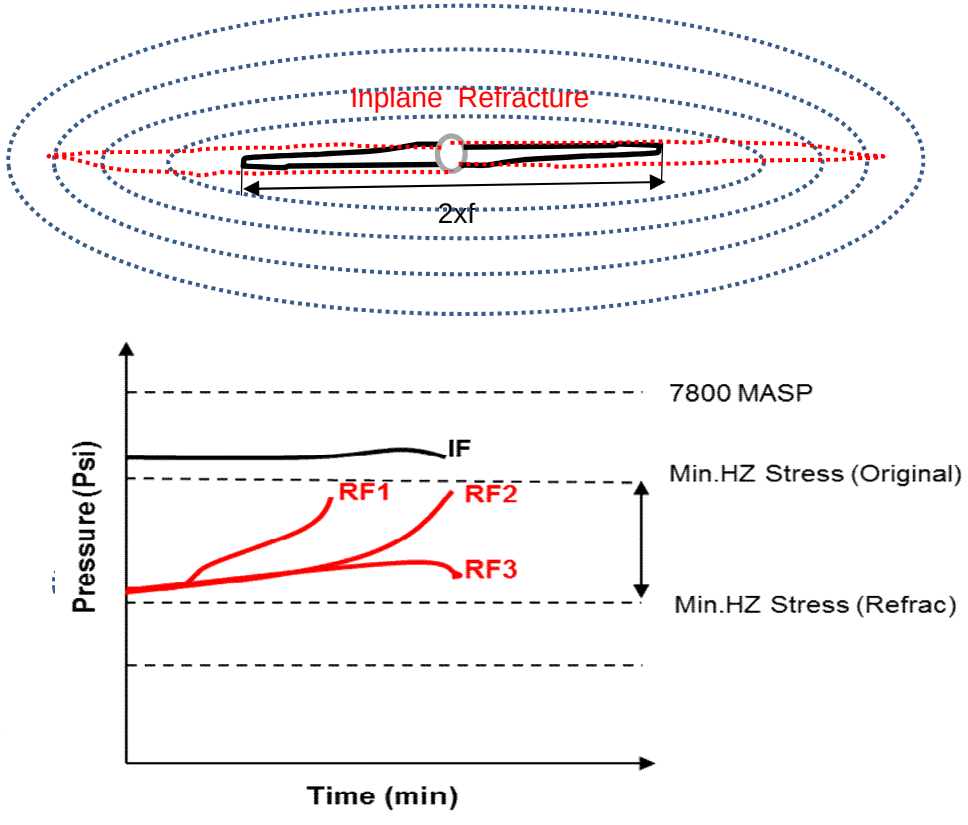
- Some cases with (4) refrac treatments
- Flow assurance issues might undermine refrac success
- Rock salt used for frac diversion
- 1 gal/1lbm rules for the treatment sizing throughout 60s' and 70's
- Most of the refracs successful none of the refracs optimum!

Defining Refracturing Mechanisms

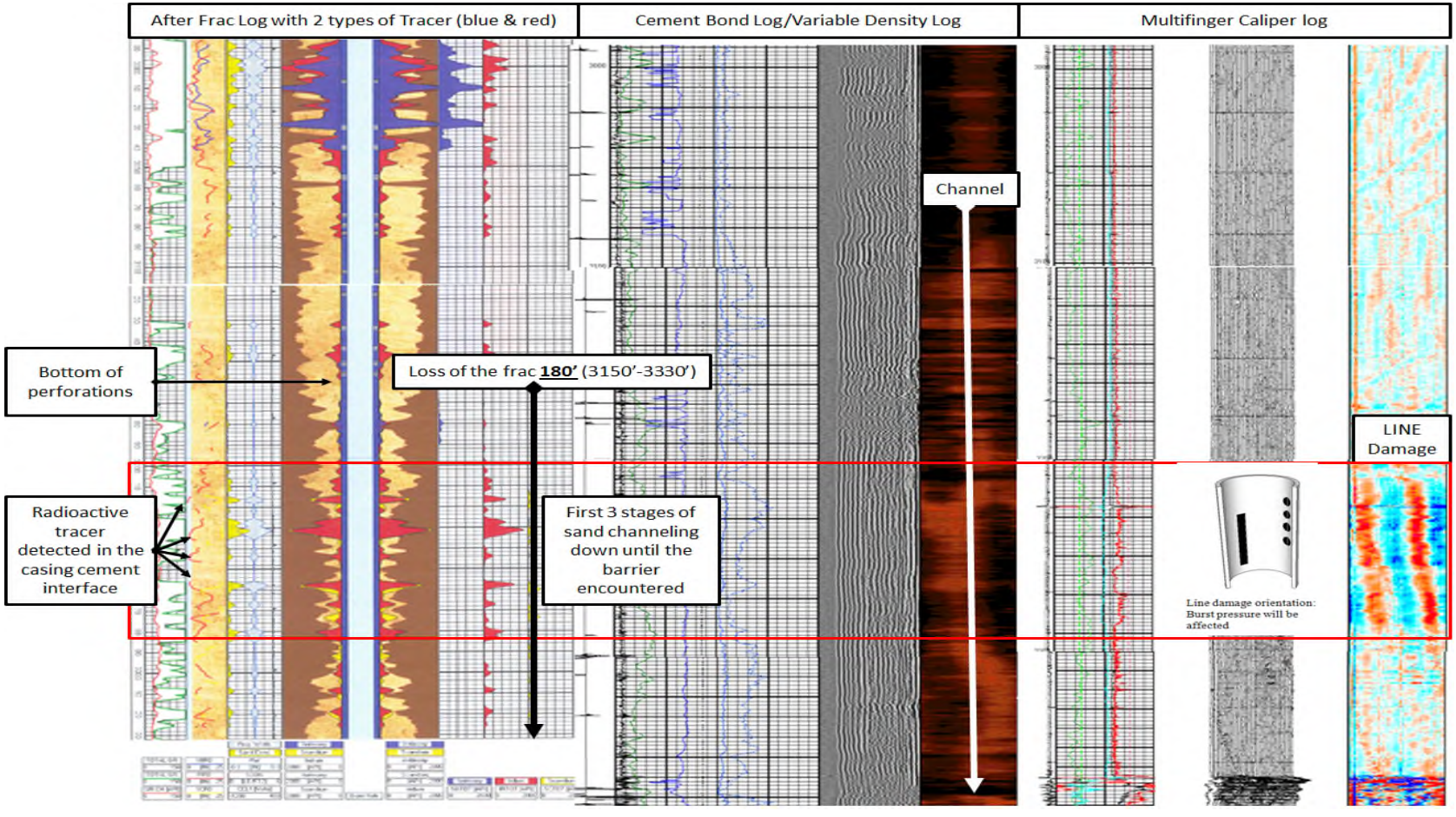
A. Conductivity & Surface Area



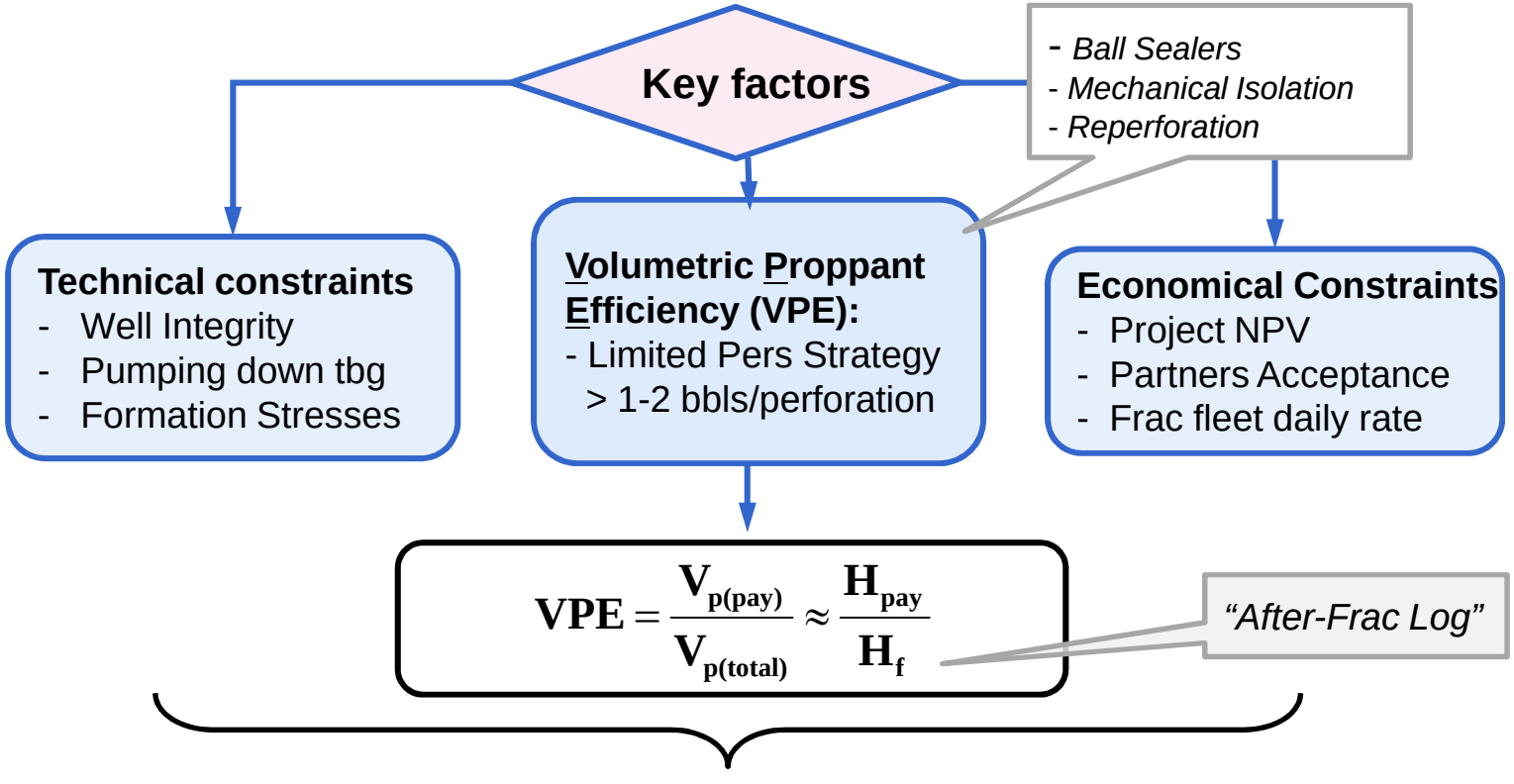
B. Fracture Length Extension



Importance of Well Integrity in Refrac Placement

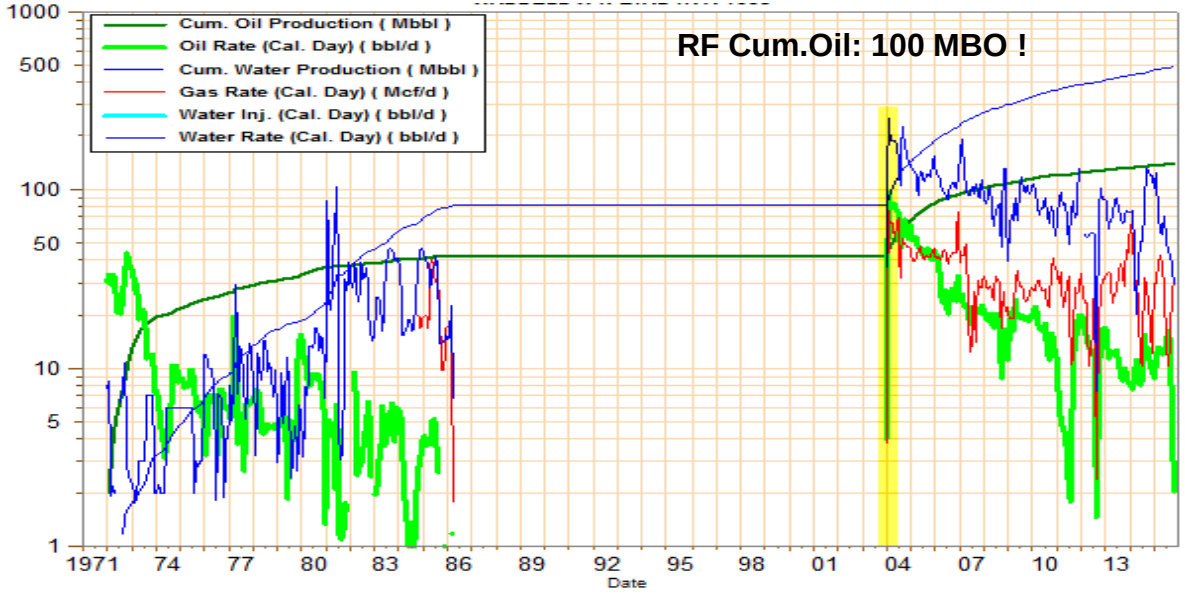


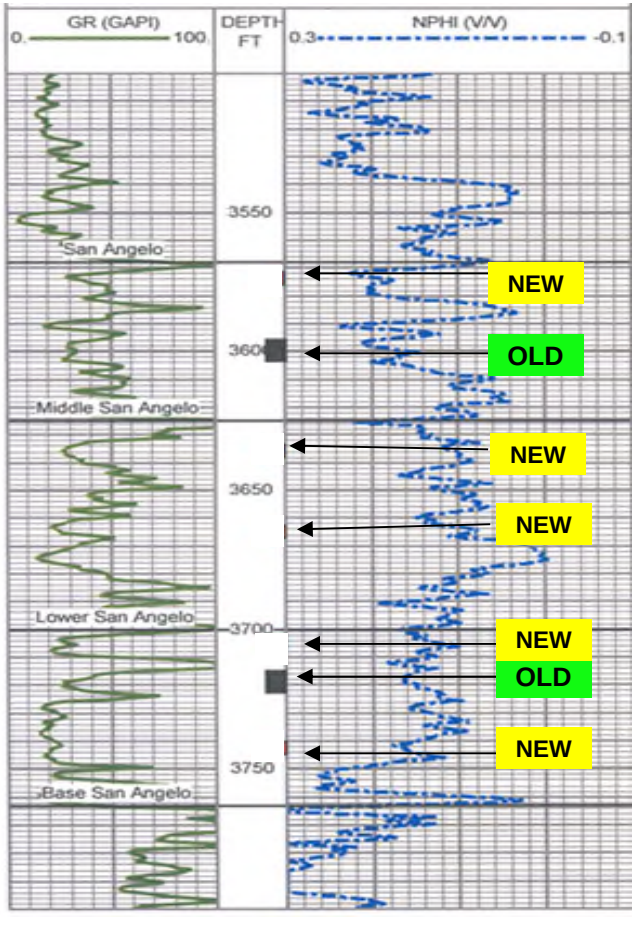
Diversion Strategy



Volumetric Proppant Efficiency is Controlled by Net Pressure in the Fracture & Diversion Efficiency.

Glorieta APF & Refrac Treatment (limited entry example)



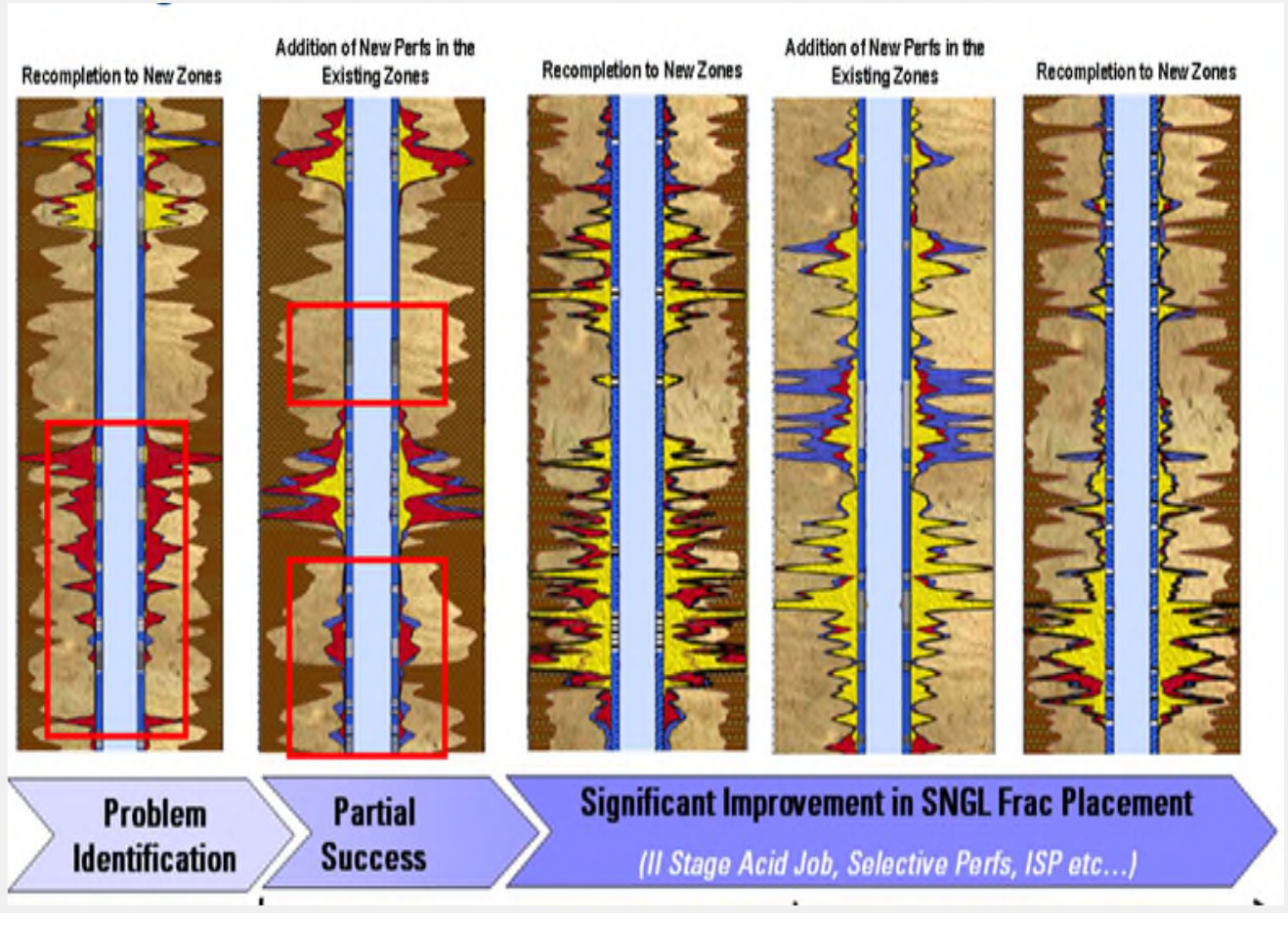


Year	Treatment History	Comments
1971	Perf: (2) 5ft intervals. Acid & Frac in 2 stages 30klb 20/40 & 10/20 at 1.5ppa	Good quality zone, limited entry. Good placement w/ isolation. Small low conductivity frac.
2004	APF Glorrieta 70K X-Link, 30klb bs 16/30 5 ppa	APF. Longer and more conductive frac (bigger sand, higher concentration).

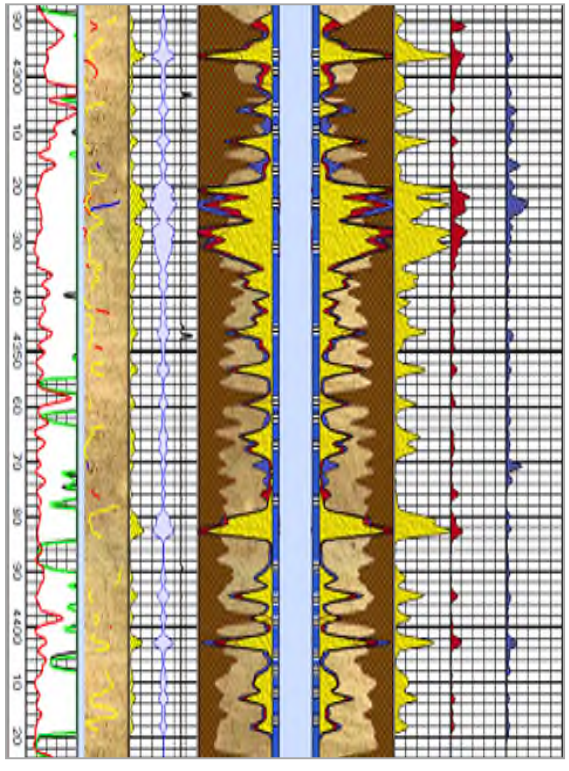
Improving Diversion Efficiency w/ After-Frac Logs (Glorieta Case)

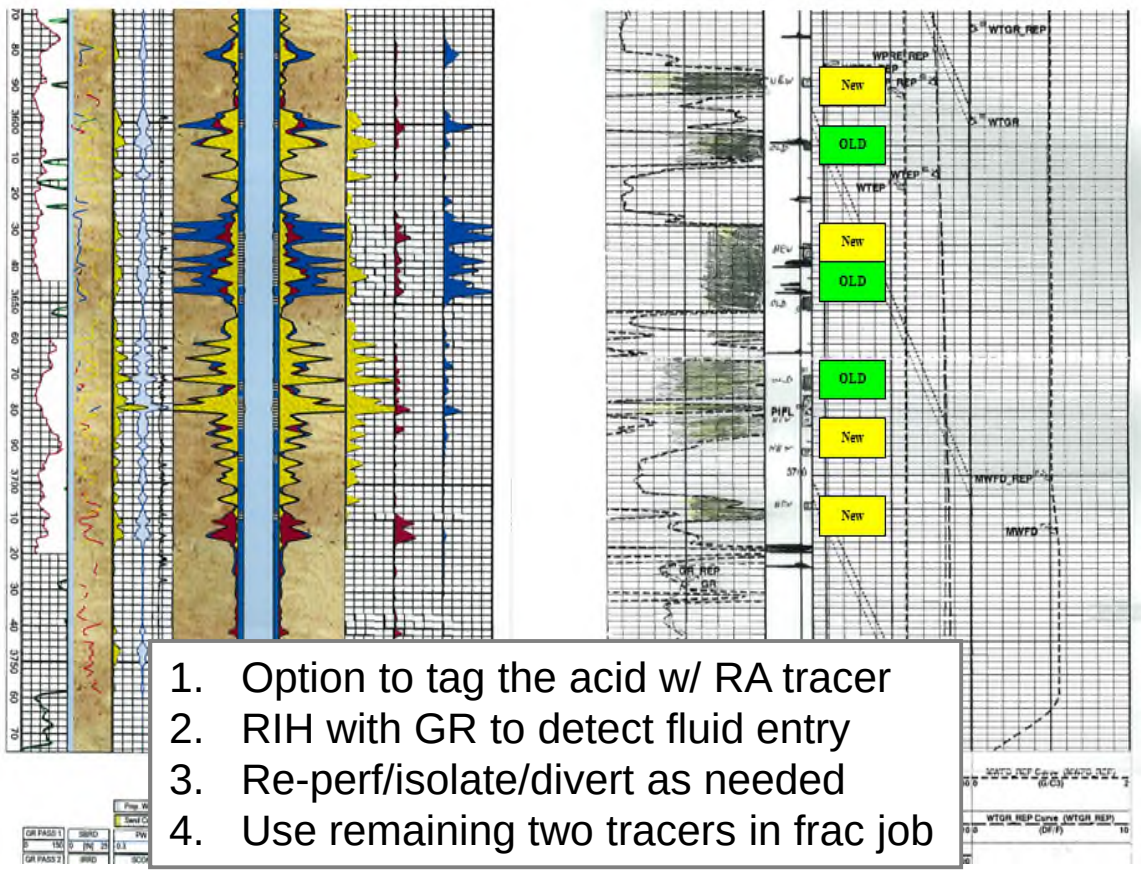
Qualitative Log Analysis

Zone Height (ft)
Total Stimulated per stage
Stimulation by zone
Non pay zone with stimulation
Stimulated Net Pay
Sand Volume (lbm)
Total Pumped in Stage
Lost/Placed to Other Zone
Lost/Placed to Non-Pay Zone
Volume of Sand placed in the Net Pay zone
Efficiency of the placement per zone



TUBB & Glorieta APF & RF Treatments (multiple perfs example)



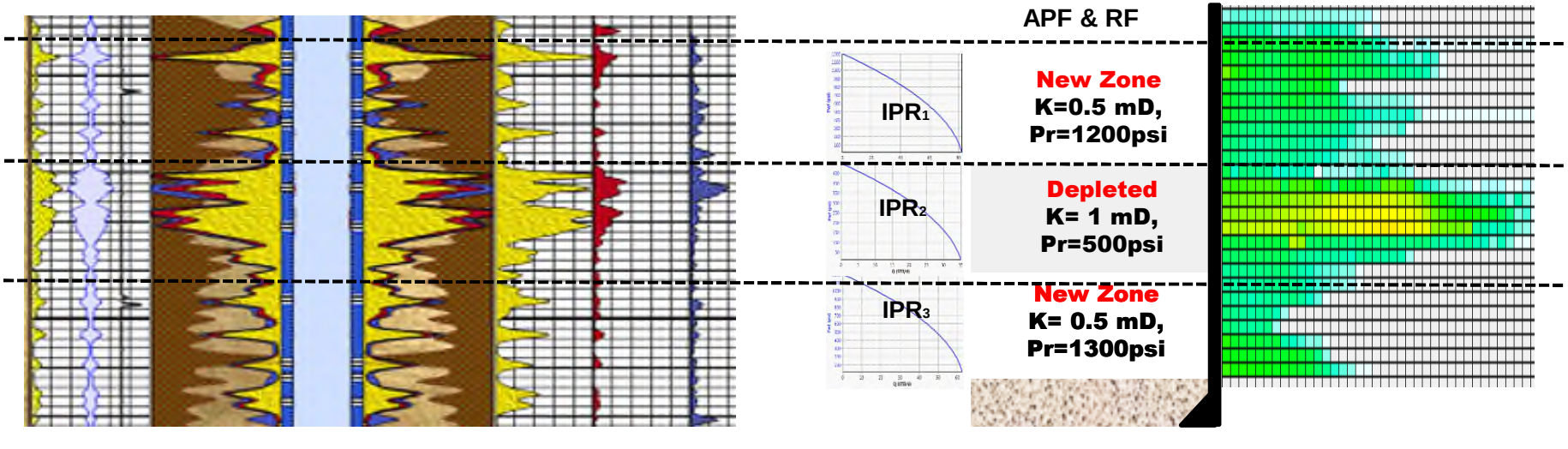


1. Option to tag the acid w/ RA tracer
2. RIH with GR to detect fluid entry
3. Re-perf/isolate/divert as needed
4. Use remaining two tracers in frac job

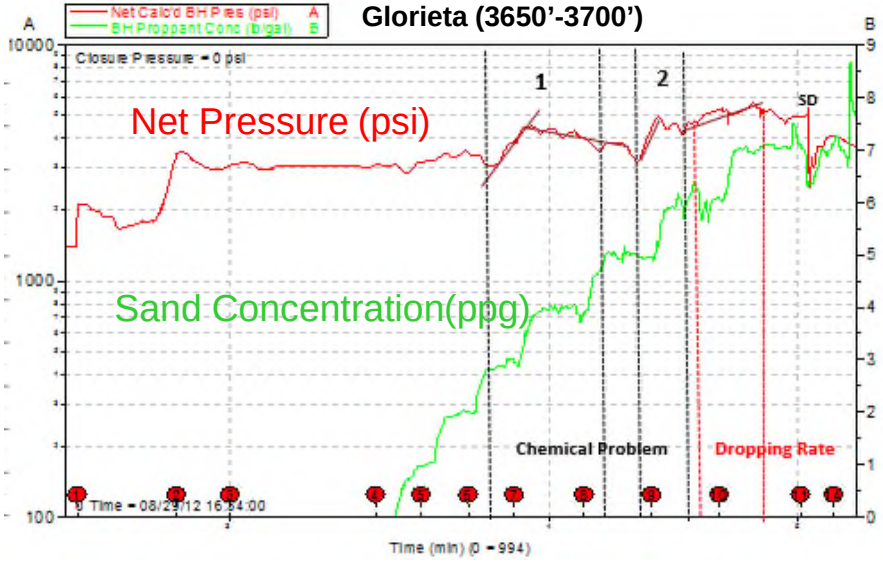
Frac Placement & Well Performance in Add Pay Refracs

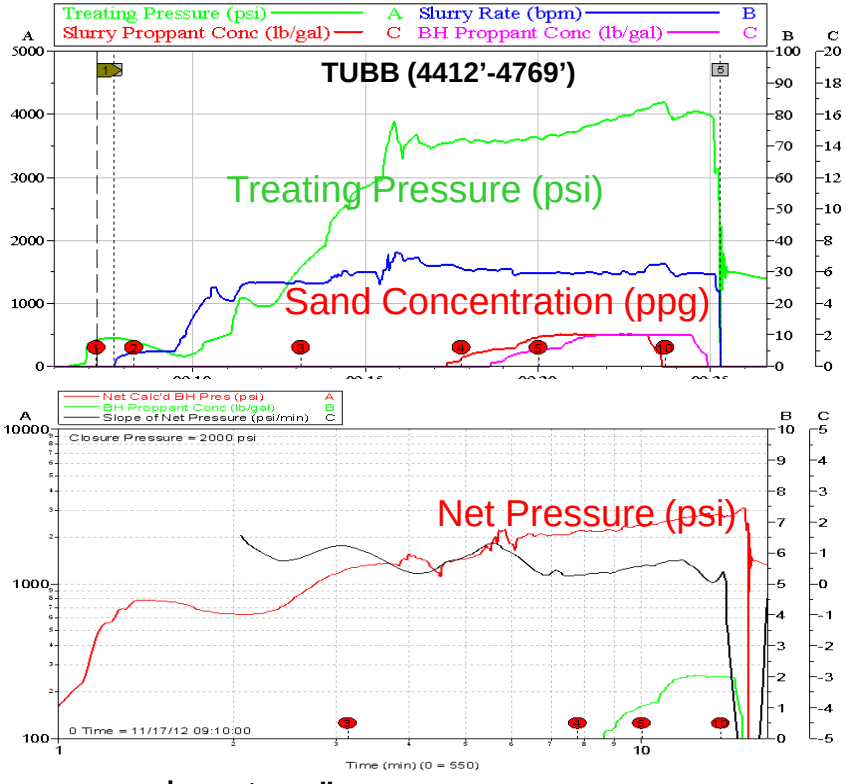
- With depletion reduction in HZ stress, Increase in refrac width
- Higher refracture proppant concentration/conductivity
- Significant length extension in Initial frac (target ~50-65% of drainage radius)
- Risk of cross-flow limiting contribution of depleted layer

! **Plan for early pump-off or delayed commingling**



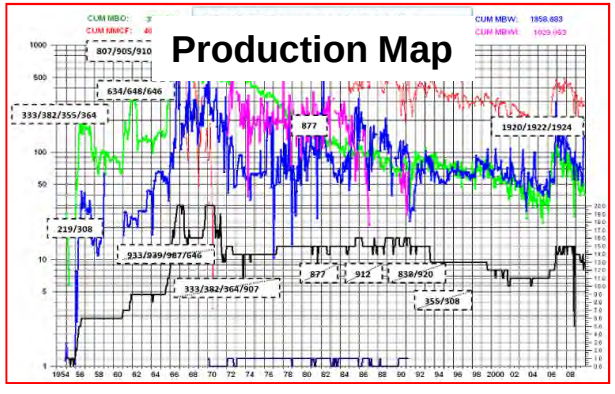
Importance of Pressure Signature in Refracs

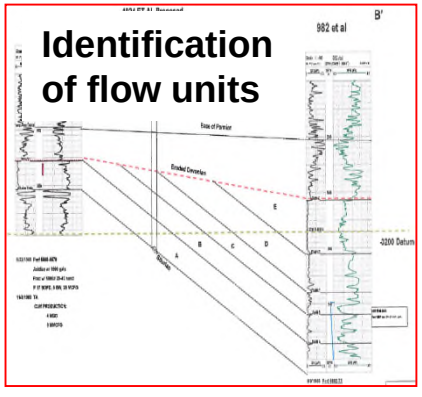


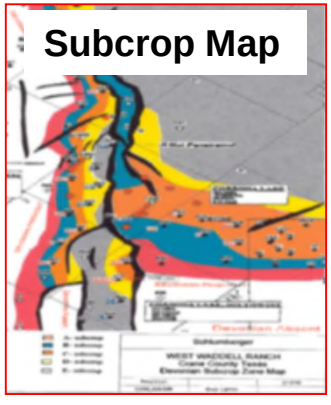


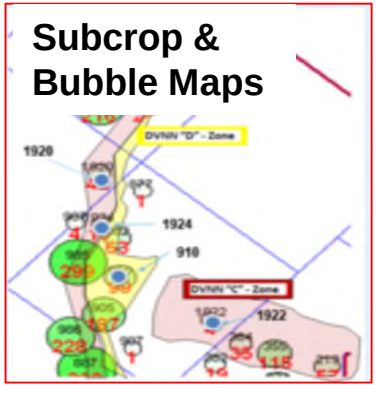
! - Gradual sand ramp up (0.5 ppg)
- Train wellsite supervisors to interpret "Net pressure signature"
- Mini-frac tests followed by PAD and proppant schedule adjustments

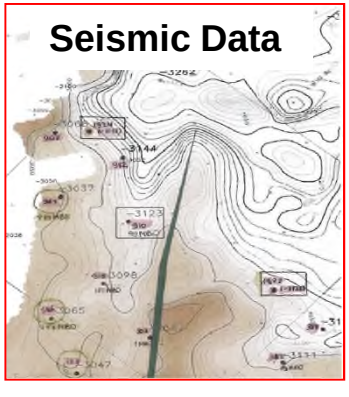
Devonian Case Study – Three Refracs in Chert Reservoir

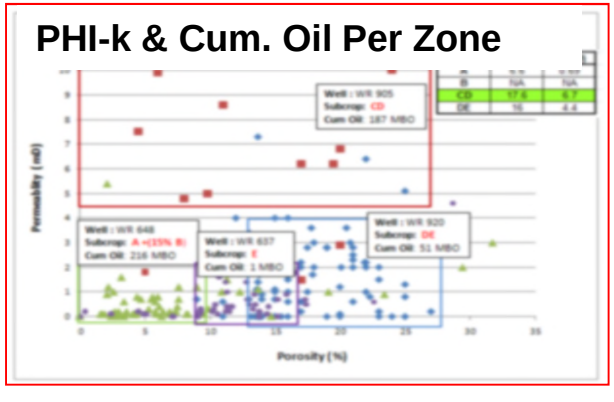




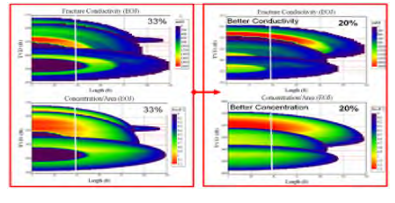


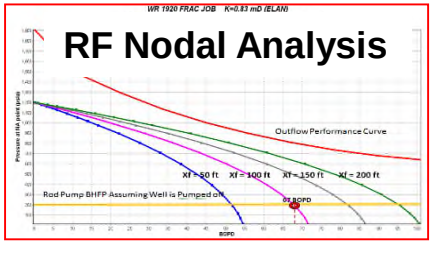


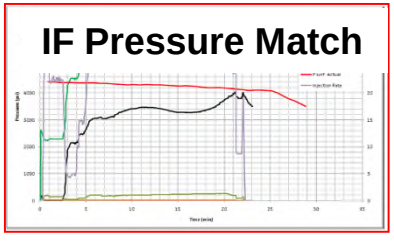




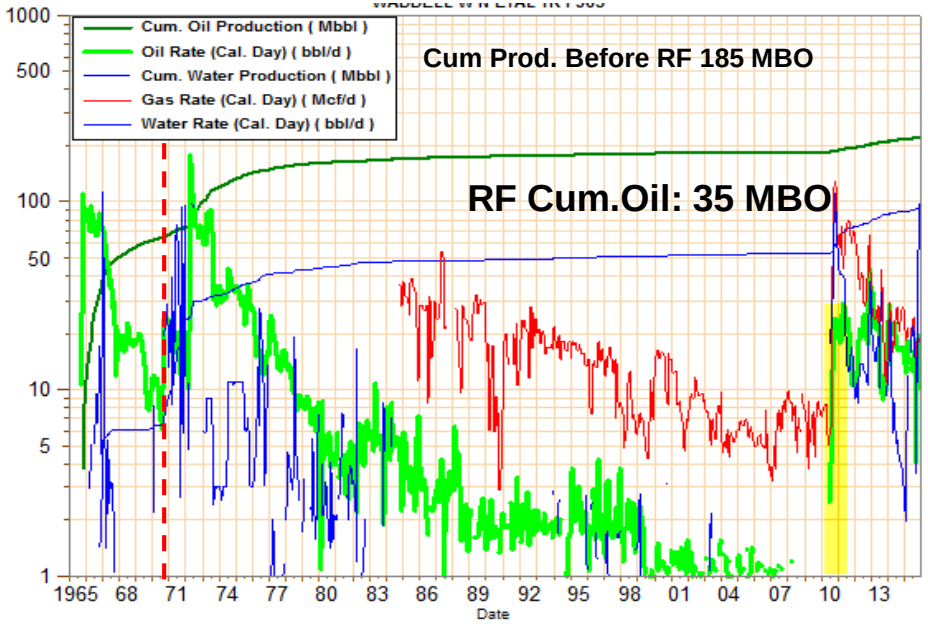
Cummulative Oil Production (MBO)									
	ABCD	AB	A	B	BC	CDE	CD	DE	E
	193	224	4	25	466	1	186	1	58
		19		137	294		92	51	51
				146	298				
				35	227				
				84	308				
					57				
Average	193	121.5	4	85.4	275	1	139	26	54.5

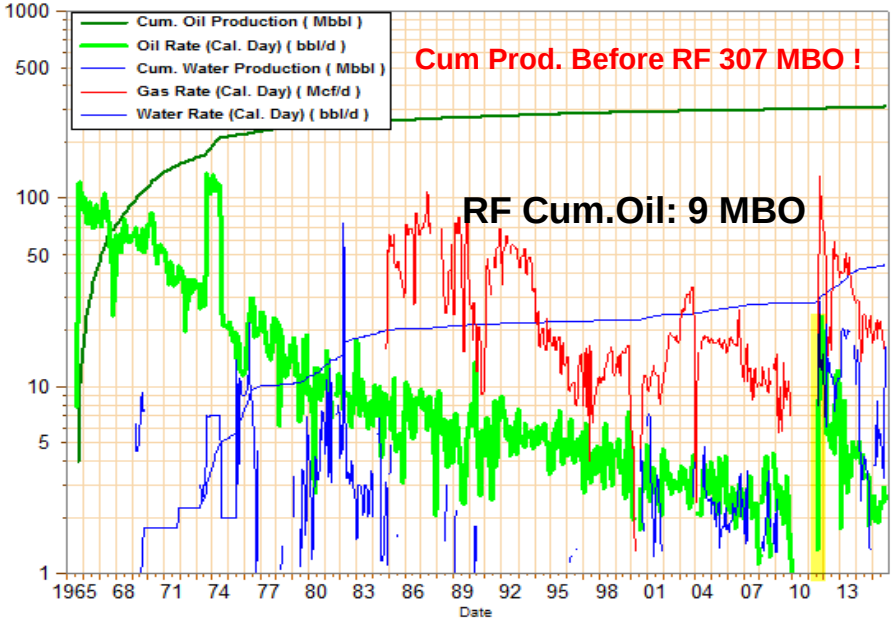






Refracturing in Devonian Chart

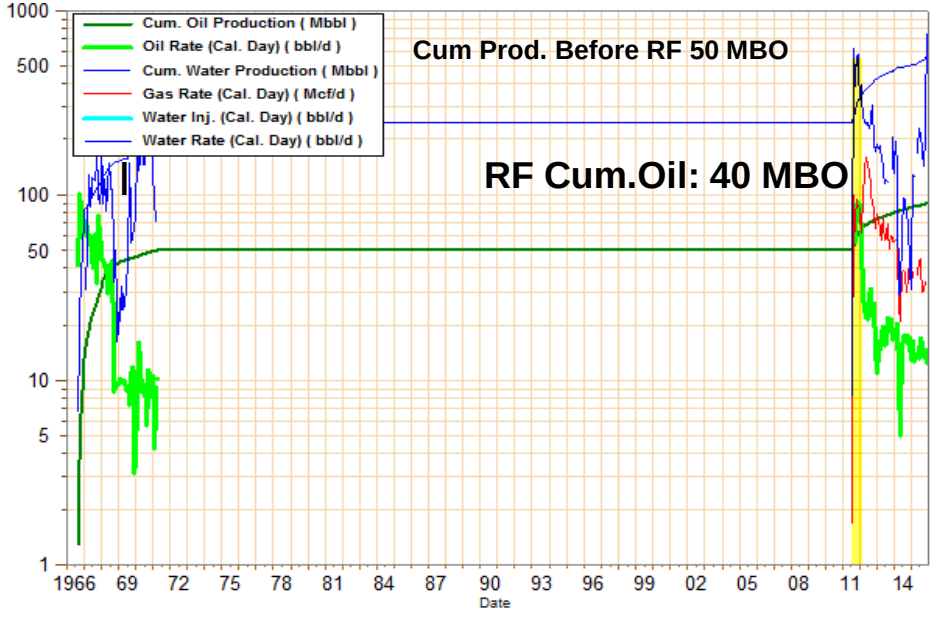




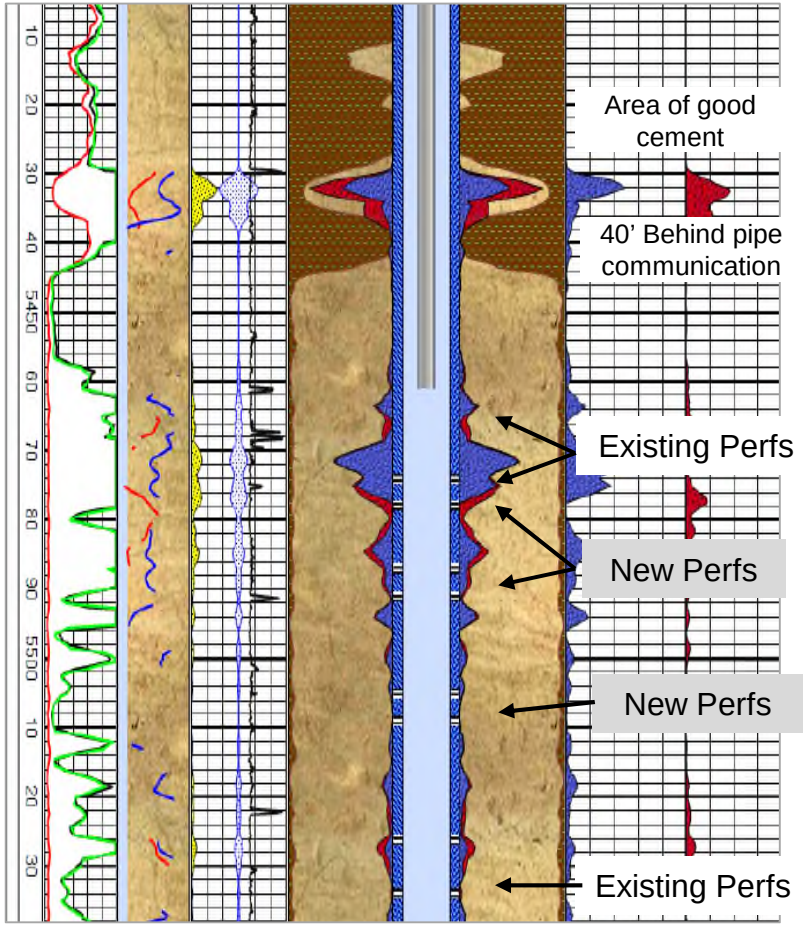
- 2 weeks PTA, high kh, leaking fault
- Low reservoir pressure (500psi)
- Benefits of fracture extension confirmed
- Great frac placement from RA Tracers
- Great results in spite of 45 years of production

- Shape of decline curve
- High cumulative production
- Complexity in drainage and depletion
- Overconfidence: in grate pay quality

Refracturing in Devonian Chart

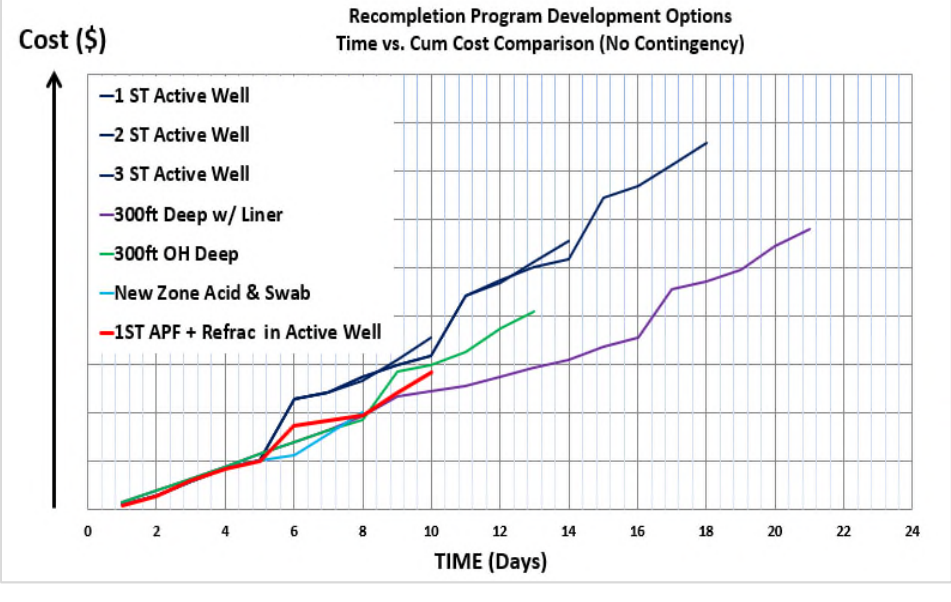


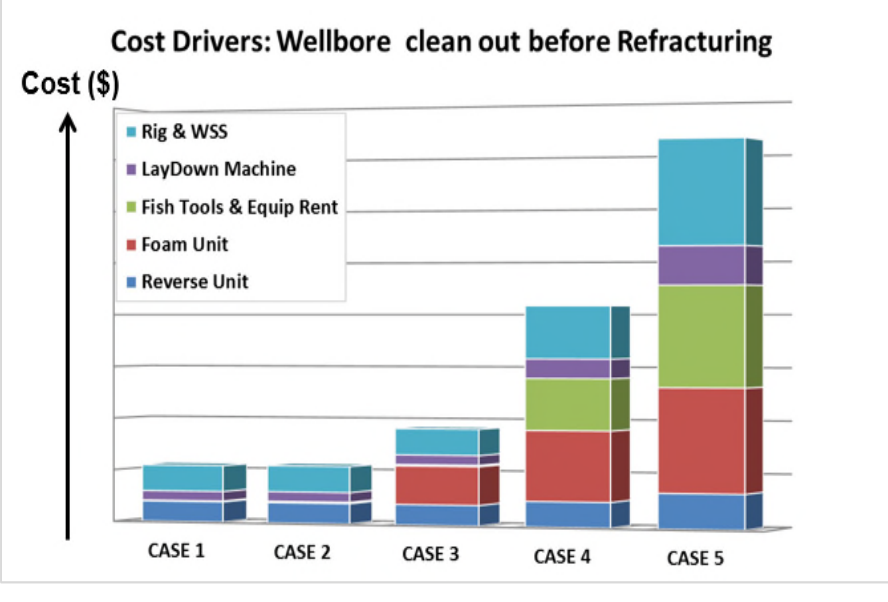
- Extension of frac length in existing pay
- Improvement in frac conductivity
- Diversion and well integrity challenges
- Economic success



Project Cost Drivers

- Refrac is comparable to 1ST frac jobs
- Project time:10 to12 days
- Plan for well integrity and after-frac logs
- Reduced facility cost and risks in active wells
- Significant reduction in well service cost
- Proper contingency planning is critical
- Clean out time drives the project cost
- Two wells = two frac jobs per day





Conclusions & Recommendations

- Refracturing programs needs to be part of Permian basin development portfolio
- Good time to allocate resources and focus on refrac inventory
- Add pay -refracs are the most challenging and rewarding !
- Diagnostic tests needed for well candidates verification
- Well integrity management is critical in all stages of project lifecycle
- Diversion efficiency was maximized with selective acidizing strategy
- Value of Information was realized with after-frac logs
- Good wells with “poor fracs” are the best candidates

! Refracuting projects are technically attainable and economical

Acknowledgements / Thank You / Questions

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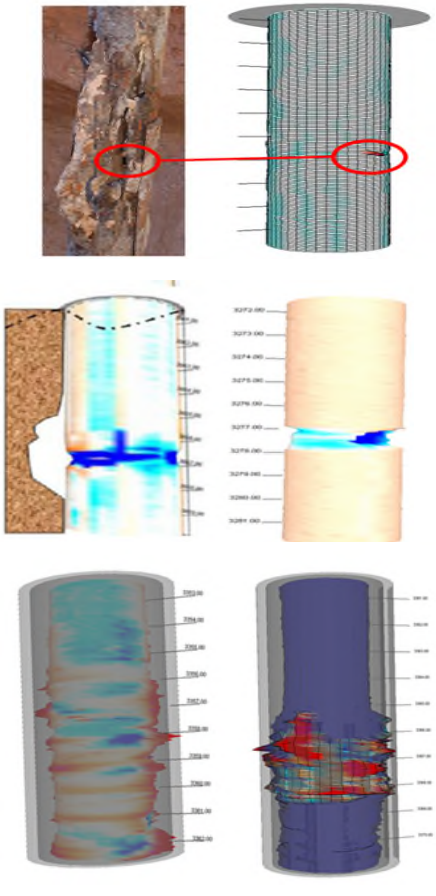
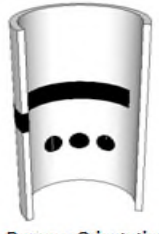
Casing Integrity Classification & Risk Profile

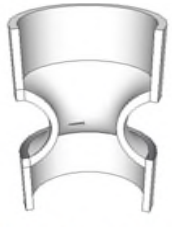


Hole: Penetration between 68 - 100% nominal wall thickness

Line Damage Orientation: Burst pressure will be affected



Ring Damage Orientation: Collapse pressure and tensile strength will be affected



Casing Collapse: Narrowing of casing ID

Possible Hole: Penetration between 43 - 68% nominal wall thickness

Ring Damage: >65% circumference, height < 1 pipe ID

Notch: Mechanical formation notching blade tool

Line Damage: <20% of circumference, height > 5 pipe ID

Isolated Damage: <65% of circumference, height < 1 pipe ID