Understanding the Challenge – Design for Effective Stimulation

Visegrád, 20 November 2014

Jonathan Abbott, Schlumberger

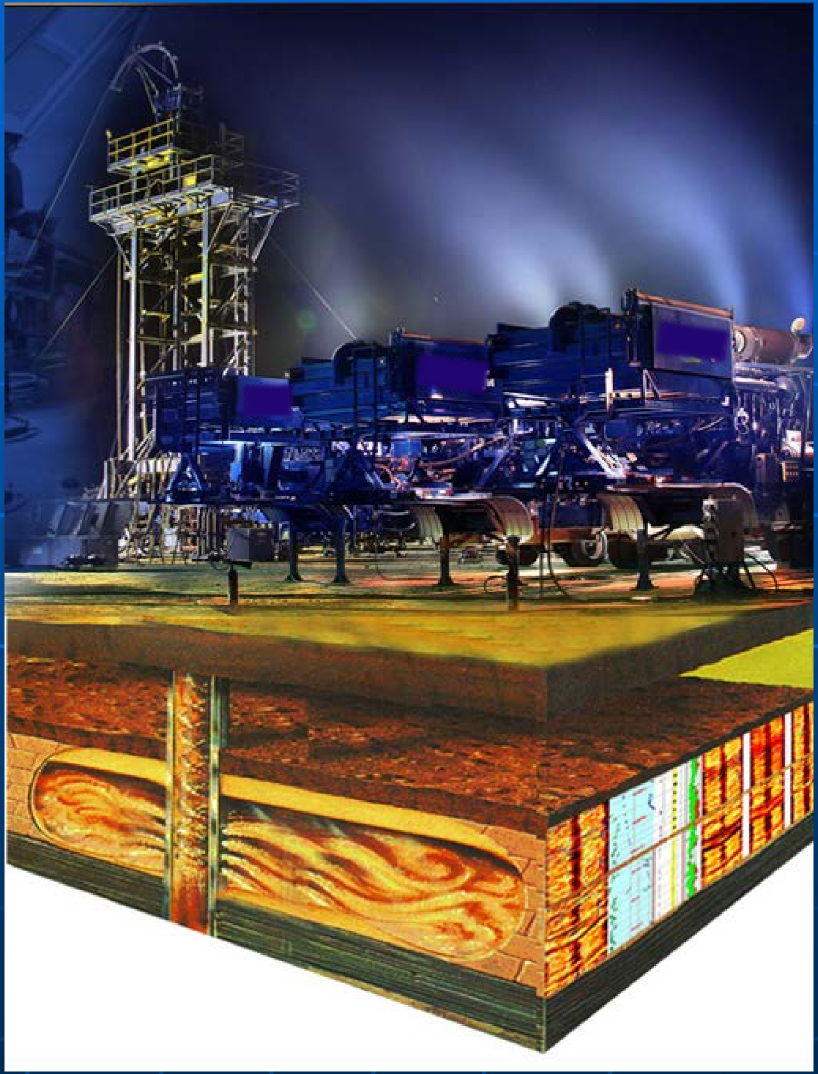
Society of Petroleum Engineers

Agenda

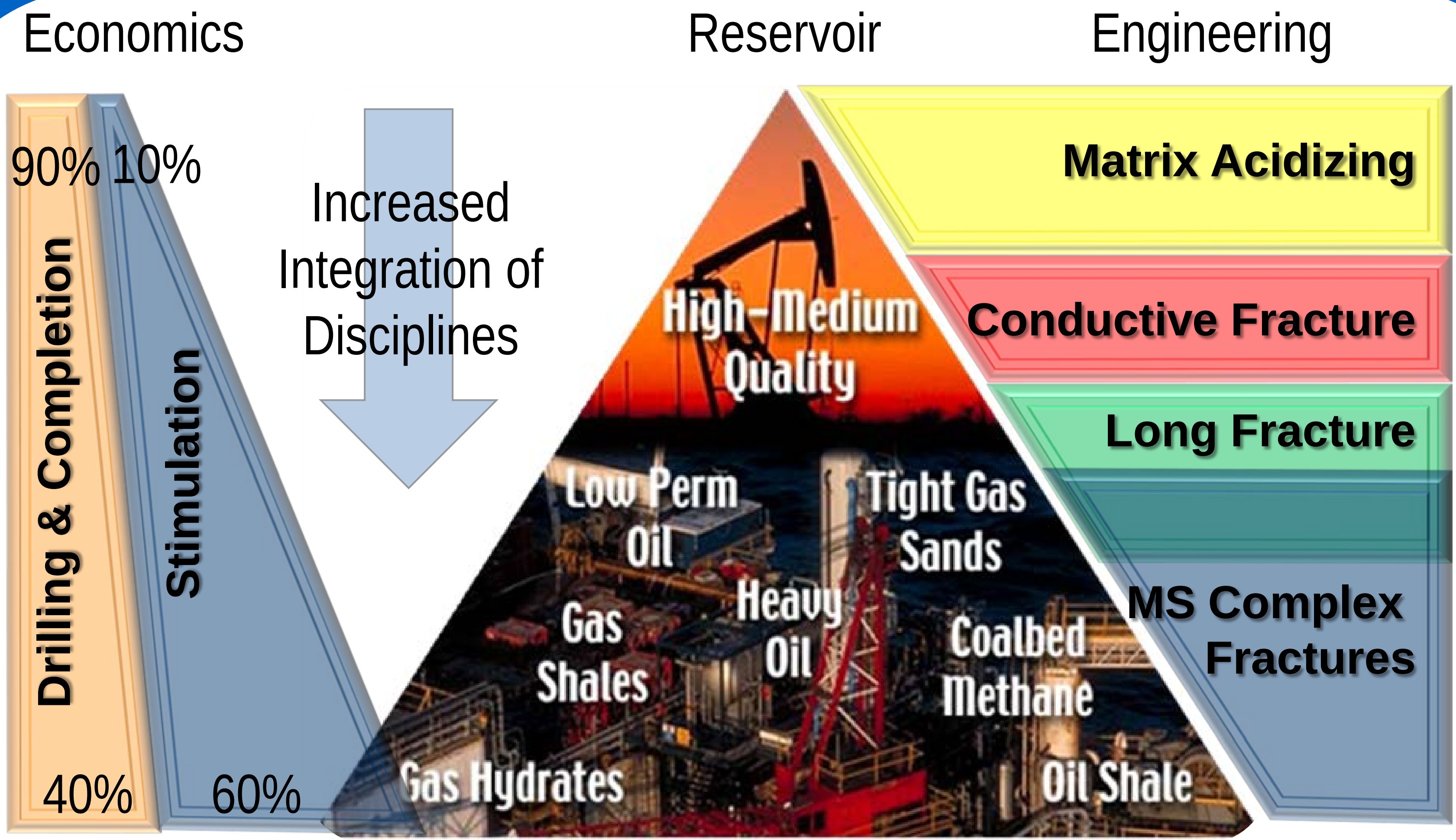
- Stimulation Challenges
- Completion Selection for the Reservoir
- Introduction to Matrix Stimulation
- Overview of Matrix Design Process
- Case Study 1: Damage Identification/Acid Design
- Case Study 2: Stimulation Placement
- Introduction to Fracturing (Focus on Acid Frac)
- Case Study 3: Acid Fracturing

Stimulation challenges …

- Maximize the NPV on well drilling and completion investment
  - Increase hydrocarbon production rate
  - Increase the reservoir economical life and reserves
- Stimulation for reservoir management
  - Efficient drainage of laminated formations
  - Delaying the onset of water production
  - Sand control
- Provide highly conductive flowpath
  - Bypass near wellbore “damage”
  - Ease in hydrocarbon drainage
- Modify flow regime deep within the formation (tens to hundreds of feet)

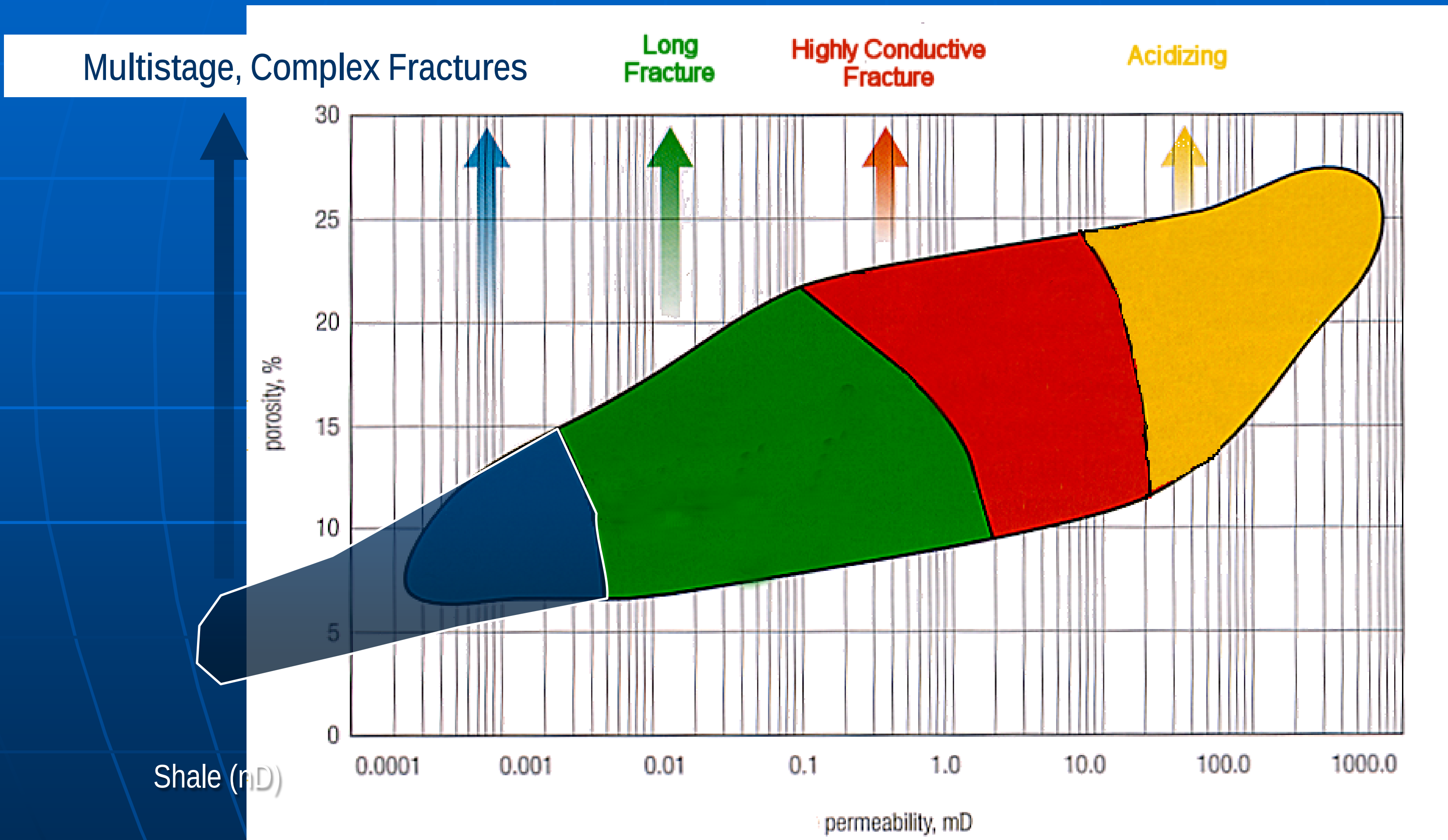


The Resource Shift



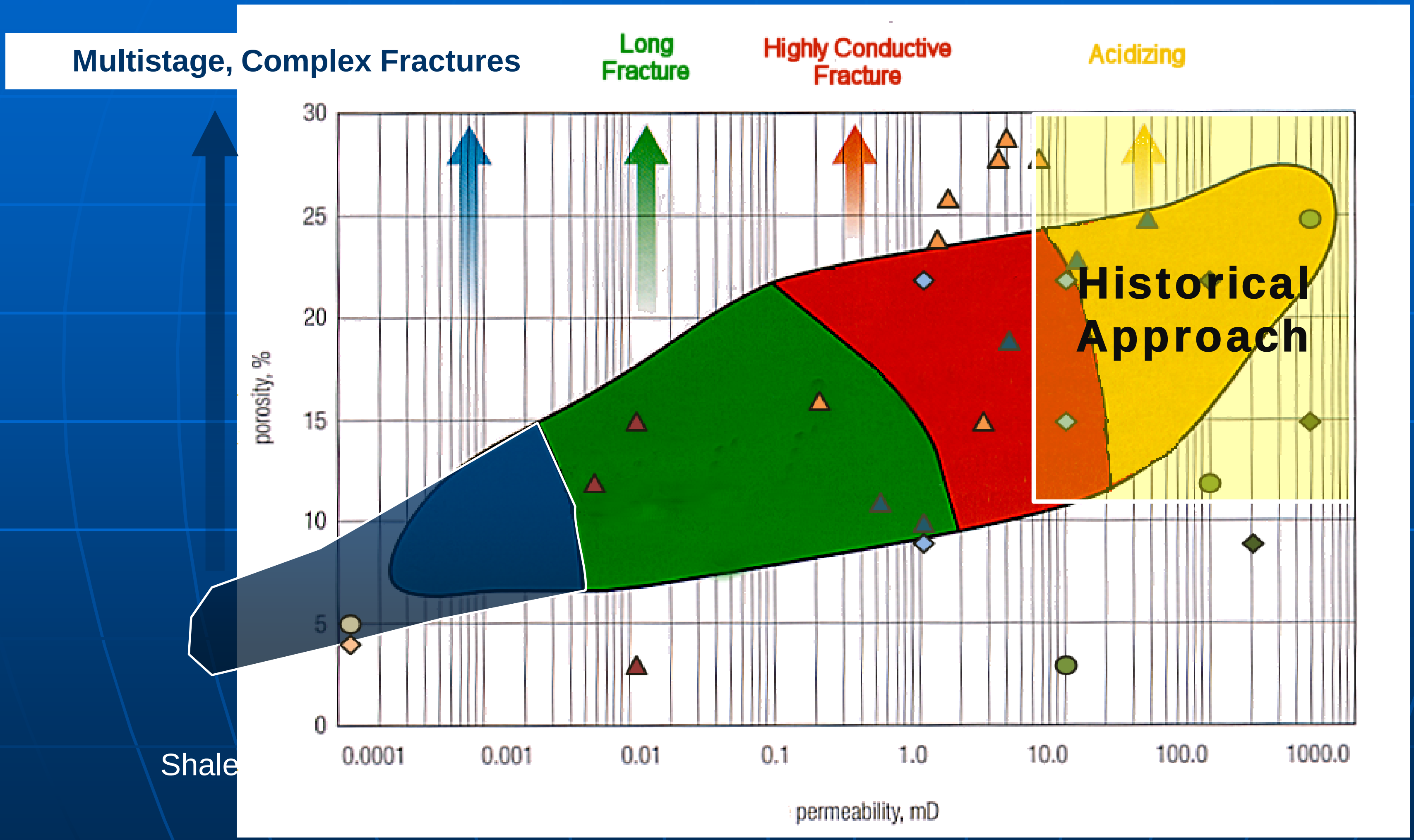
Holditch, Texas A&M

Reservoir Impact on Completion Selection



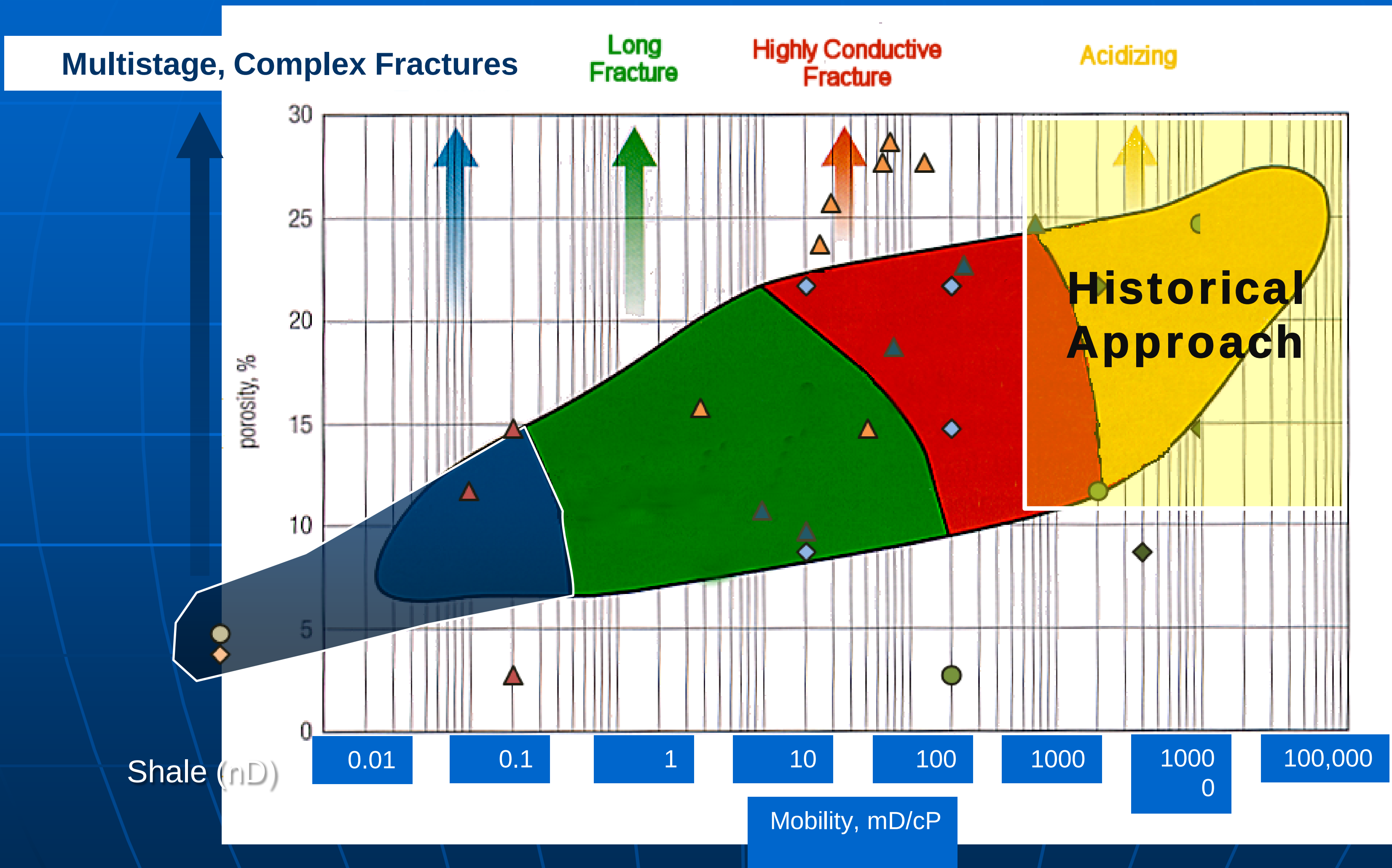
Reference. Schlumberger Oilfield Review 2002

Reservoir Impact on Completion Selection



Reference. Schlumberger Oilfield Review 2002

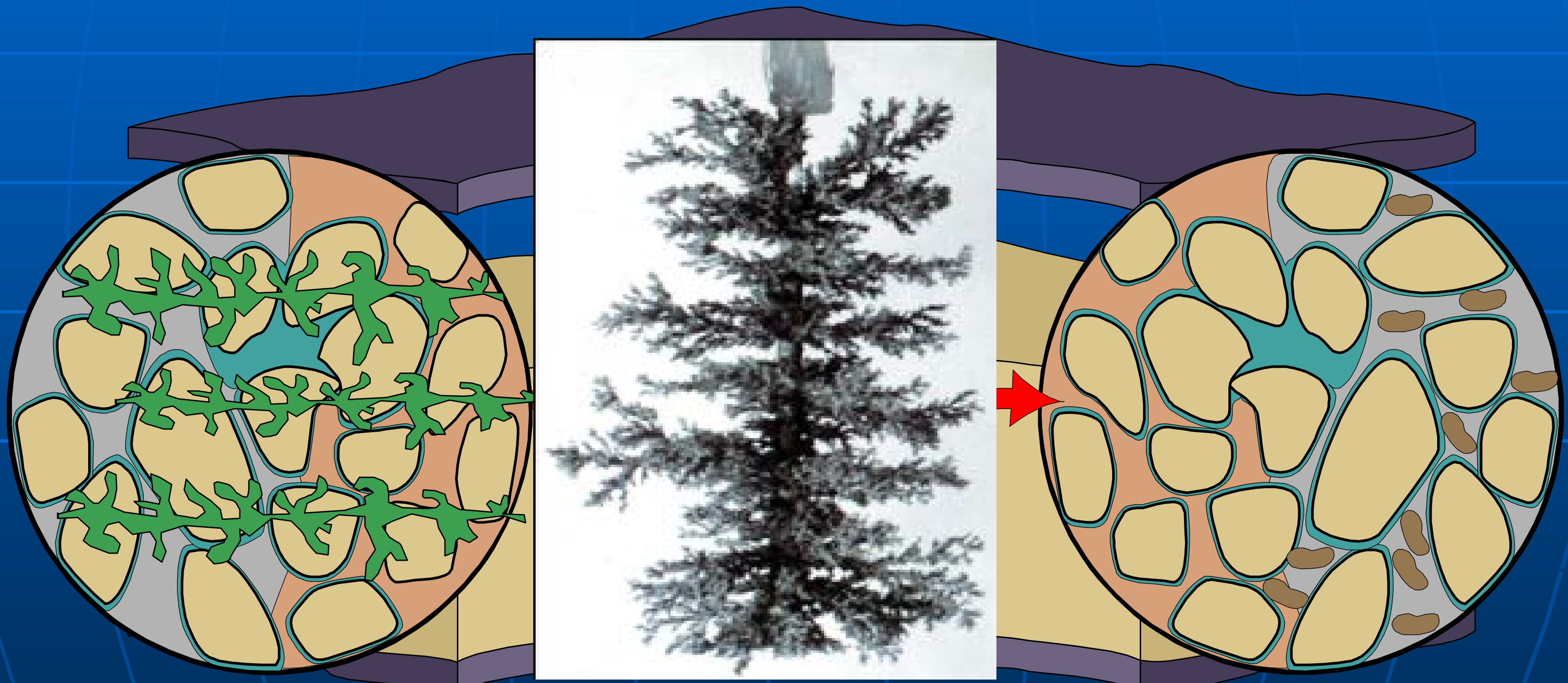
Reservoir Impact on Completion Selection



Reference. Schlumberger Oilfield Review 2002

Matrix Stimulation

- Injection of a Treatment Fluid (Acid or Chemical) to Dissolve,
  - Disperse or Bypass Near Wellbore Damage



Carbonate Treatments
Create New Flow Paths

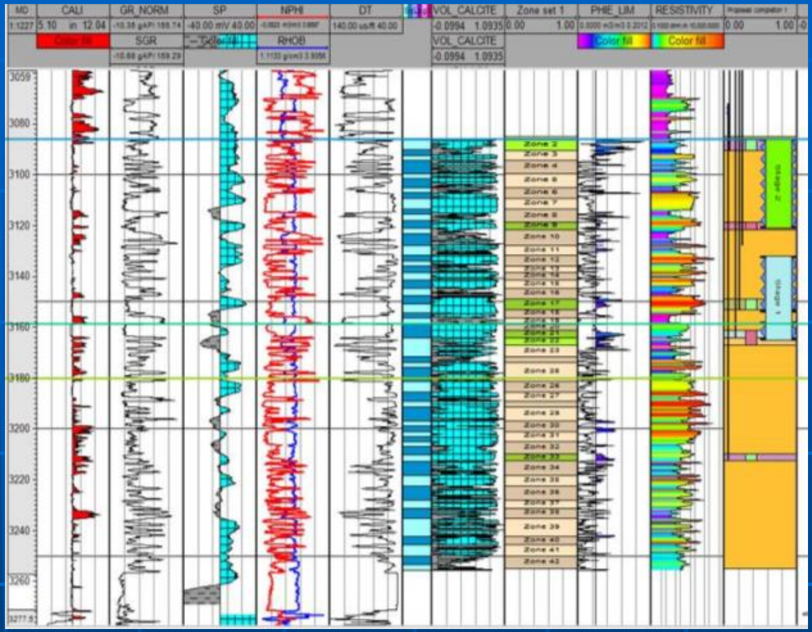
Sandstone Treatments
Remove Damaging Agent

Overview of Matrix Acidizing Design Process

- Determine if candidate is appropriate for Matrix Acidizing
- Determine the damage mechanism: Drilling/Scale – Organic/Inorganic
- Select the appropriate acid type: HCl/Emulsified/Organic/Mud Acid/Clay Acid
- Design Appropriate acid Coverage: gal/ft of formation/fluid penetration
- Ensure effective fluid placement: mechanical+chemical
- Consider pre/post treatment flushes to enhance main acid treatment and improve cleanup
- Compare designed treatment with actual results and use lessons learned for subsequent treatment.

Case Study 1: Damage Identification and Acid Design

- Well-1 and Well-2 are offset wells 150m apart
- BHST~80degC
- Lithology: Laminated Clean/Dirty Carbonate
- Low permeability, low porosity
- Low API oil gravity
- Iron species evident from core/cuttings analysis



depth (m)	carbonates				other minerals	Σ
	calcite	dolomite	ankerite	*total carbonates*	pyrite	
3060.00	47.9	0.2	6.0	***54.1***	4.8	100.0
3070.00	81.1	0.0	0.3	***81.4***	2.0	100.0
3080.00	77.3	0.0	3.4	***80.7***	2.0	100.0
3090.00	45.7	0.0	1.4	***47.1***	5.2	100.0
3100.00	94.8	0.5	1.1	***96.4***	1.1	100.0
3110.00	94.7	0.2	0.8	***95.7***	1.2	100.0
3120.00	77.0	0.0	0.9	***77.9***	2.5	100.0
3130.00	80.1	0.0	0.9	***81.0***	2.2	100.0
3140.00	97.6	0.6	1.0	***99.2***	0.4	100.0
3150.00	97.0	0.5	1.4	***98.9***	0.6	100.0
3160.00	97.2	0.1	1.9	***99.2***	0.4	100.0

Case Study 1: Design Comparison

Well-1

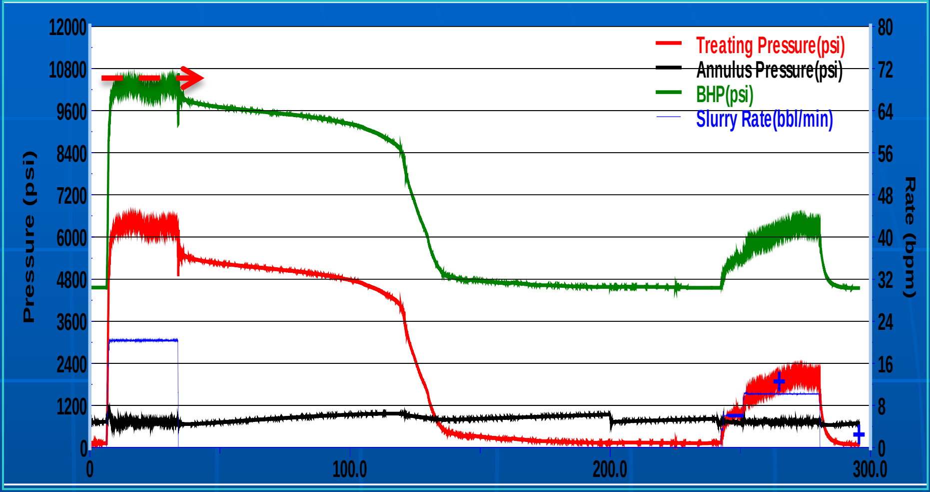
- Aggressive Acid formulation NOT designed to mitigate clay and Iron content.
- Pre-flush, Acid formulation and Post-flush NOT designed for low API oil gravity
- Potentially damaging polymer-based diverter acid applied
- Excessive fluid volumes applied for pre-job injection diagnostics

Well-2

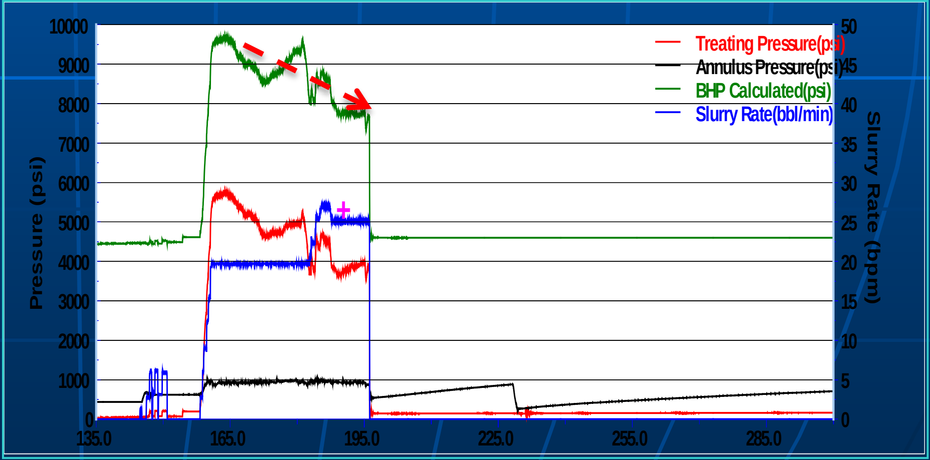
- Comprehensive analysis of formation lithology and fluids w. lab testing
- Acid formulation optimized with chelants and organic acids to prevent and suspend degradation products
- Pre-flush, Acid formulation and Post-flush designed with mutual solvent to maximize stimulation efficacy
- Polymer-based acid removed.
- Fluid volumes optimized

Case Study 1: Stimulation Results

- Well-1
  - Interval Y
  - No Effect of Acid
  - No improvement of injection



- Well-2
  - Interval Y
  - New Acid Design results in significant pressure reduction
  - Production from stage results in cancellation of additional stimulation

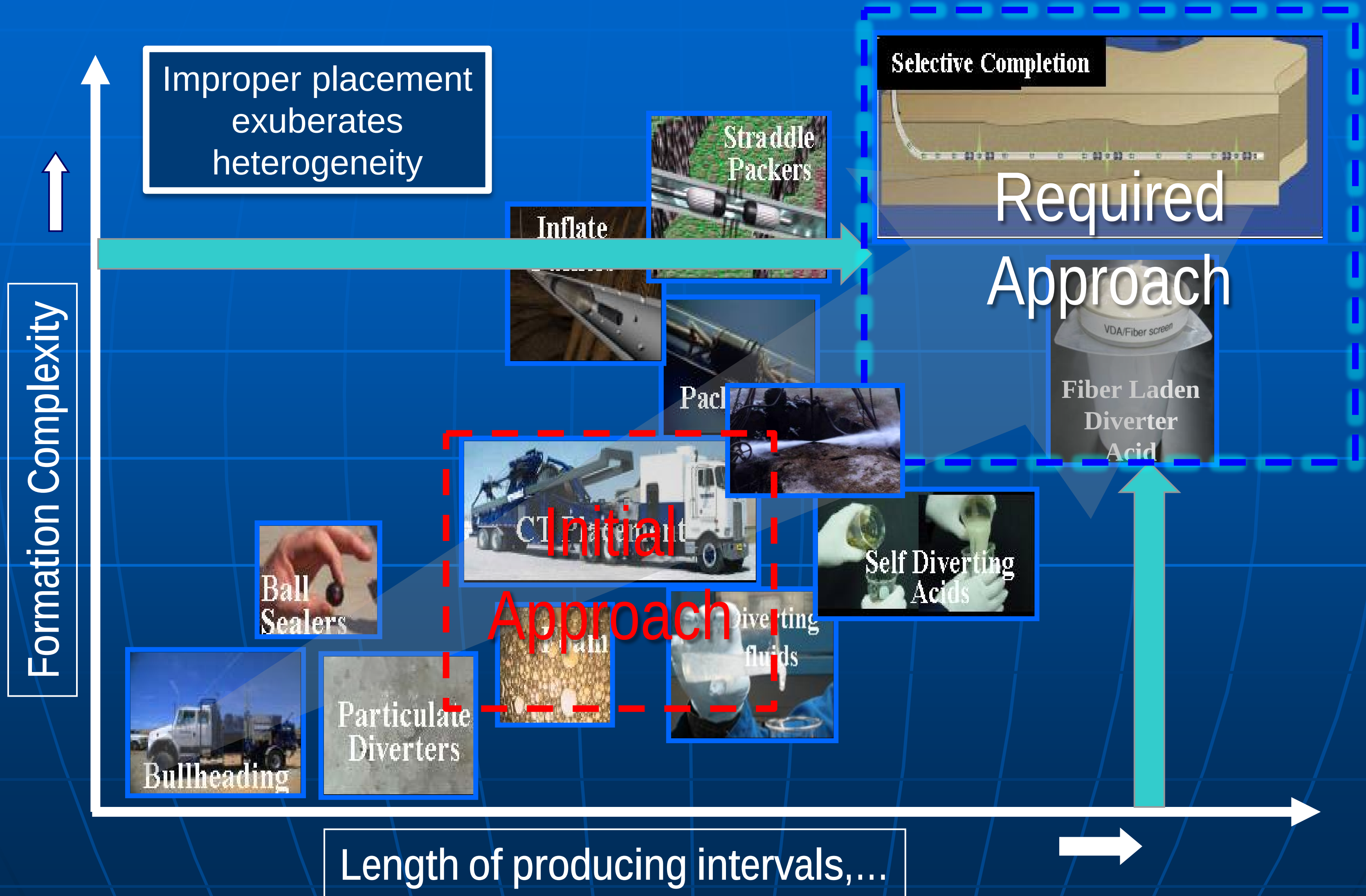


Case Study 2: Offshore Gulf

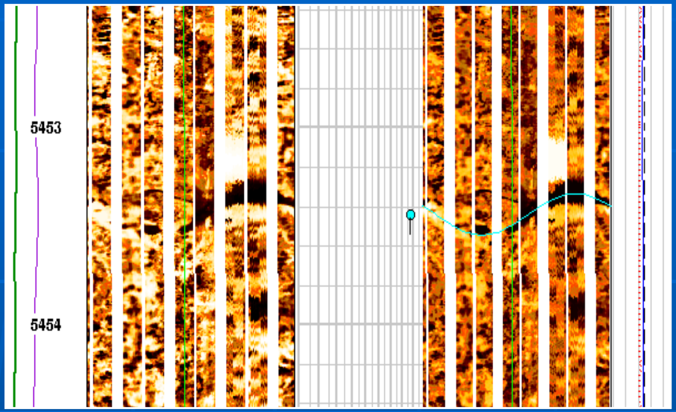
- Highly fractured, tight carbonate
- $\Phi<0.05$, $k<0.01mD$
- BHST = 290degF
- Formation Depth ~4000m
- Formation thickness ~250m
- Lateral Length ~350m

- Historical Stimulation Approach
  - CT conveyed stimulation
  - Low pump rates, low acid volumes
- New Stimulation Approach
  - Multi-Stage Completion System
  - High rate Matrix, high acid volumes
  - Fiber-laden Diverter

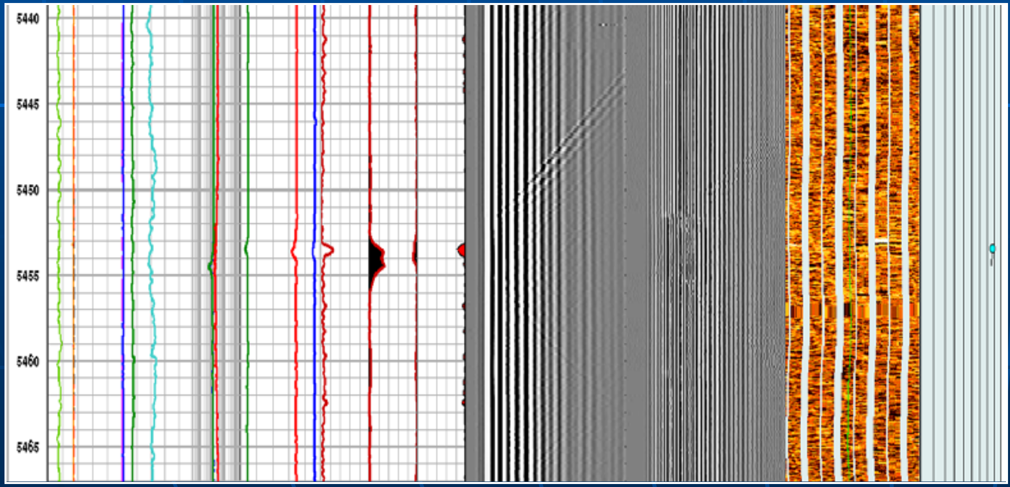
Case Study 2: Stimulation Placement



Case Study 2: Understanding Formation Complexity

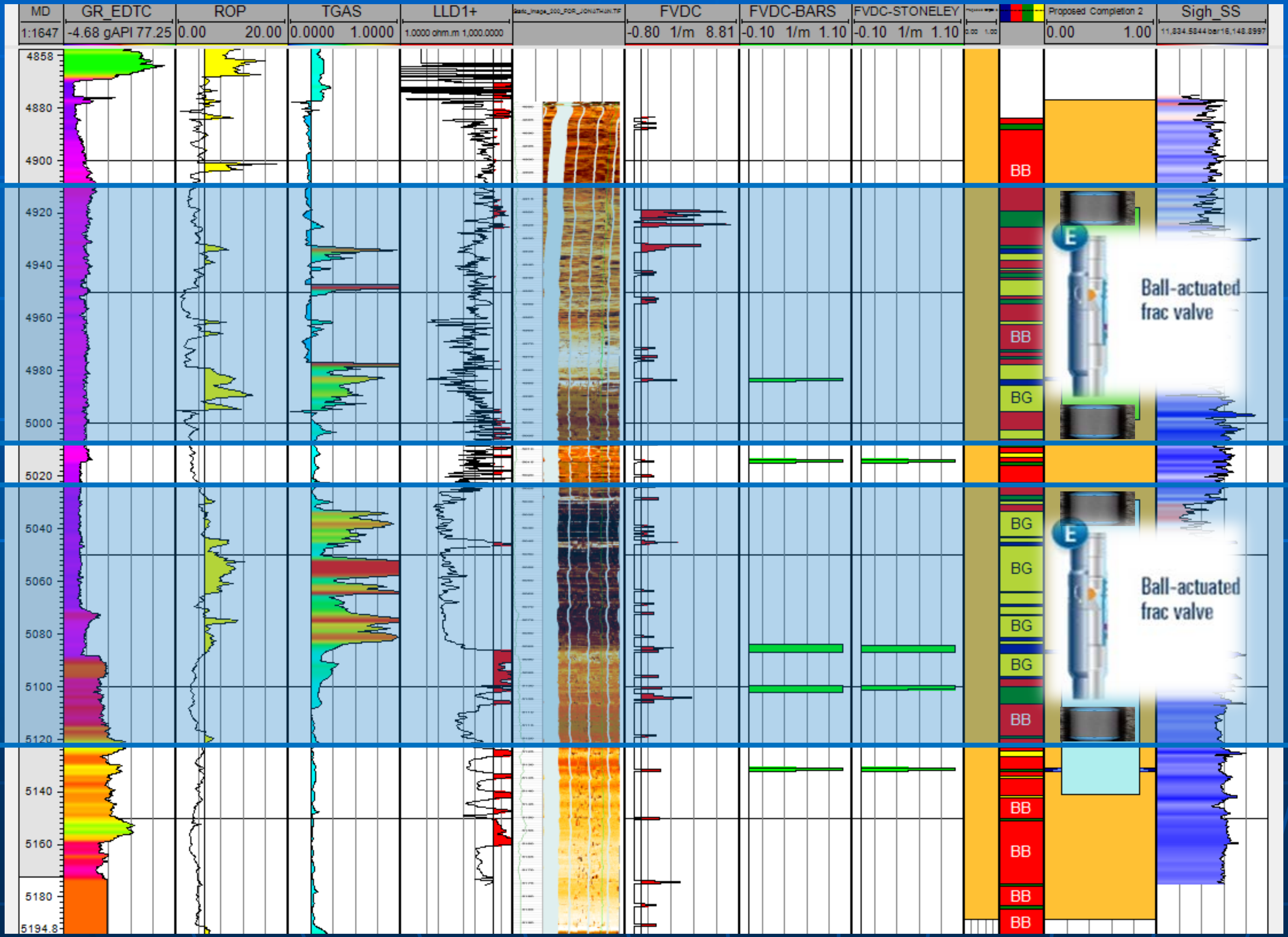


- A total of 6 fracture intervals are identified from micro formation image
- Sonic identifies as OPEN Fractures at



- Sonic borehole acoustic reflection used to identify fractures extending into the formation

Case Study 2: Completion Design

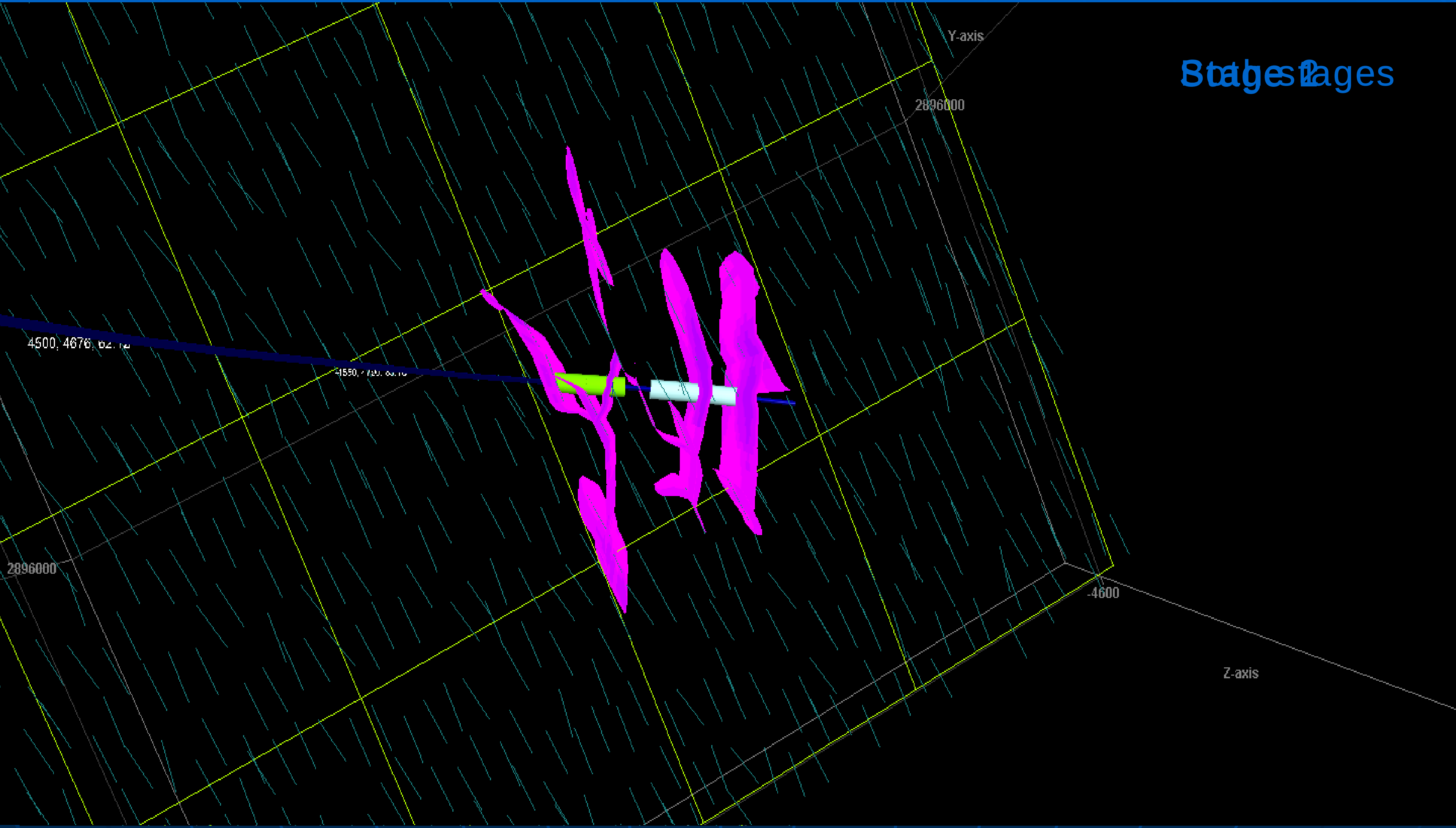


OH = 1073ft

Stg 2 – 310ft

Stg 1 – 300ft

Case Study 2: Simulated Fracture



Case Study 2: Fluid Selection

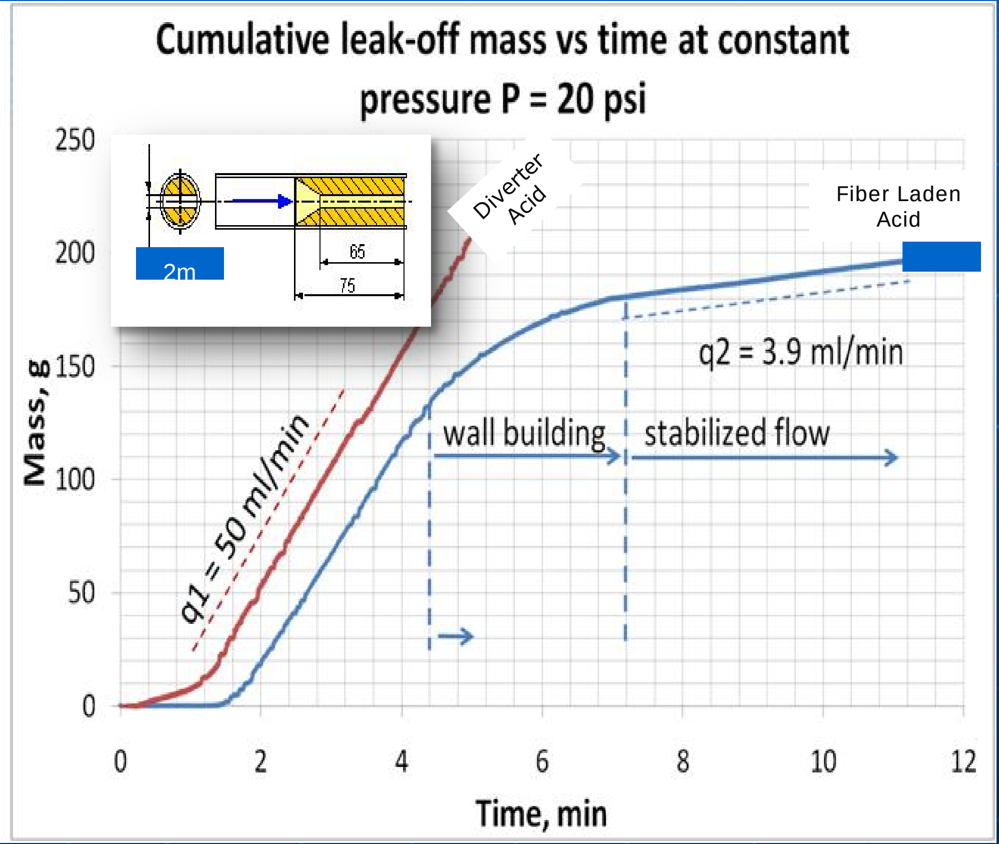
- Combination of chemical and mechanical diversion
- Promotes uniform stimulation of fractured carbonate formations

Live Diverter acid

+

Fibers

Fiber Laden Acid

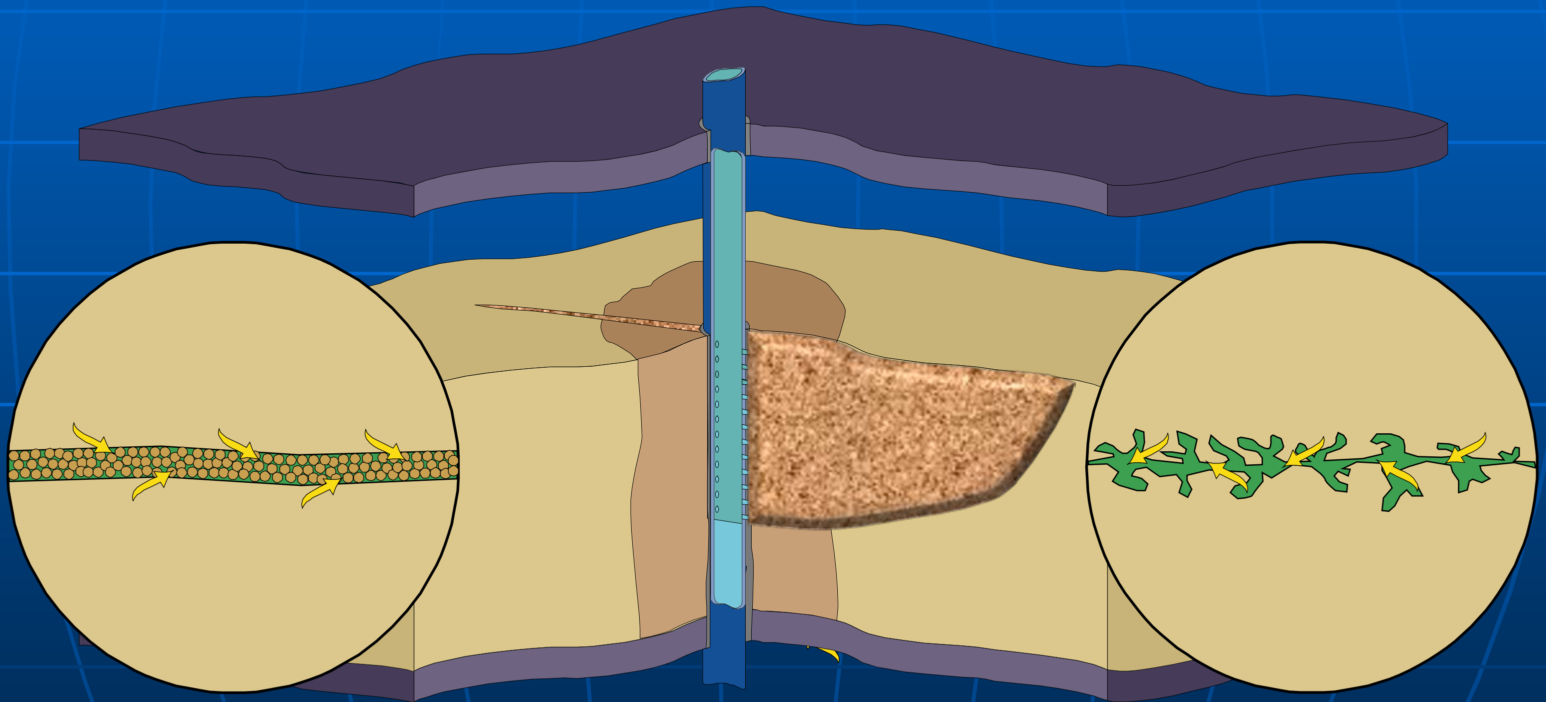


Case Study 2: Project Impact

- Well Results
  - "We are of course very pleased with these results…" - Executive Chairman
- Significant change in Field development plans
  - Restimulation of existing wells
- Production facility at max. capacity

Hydraulic Fracturing

- A Reservoir Treatment Performed to Create a High
- Conductivity Path from the Reservoir to the Wellbore

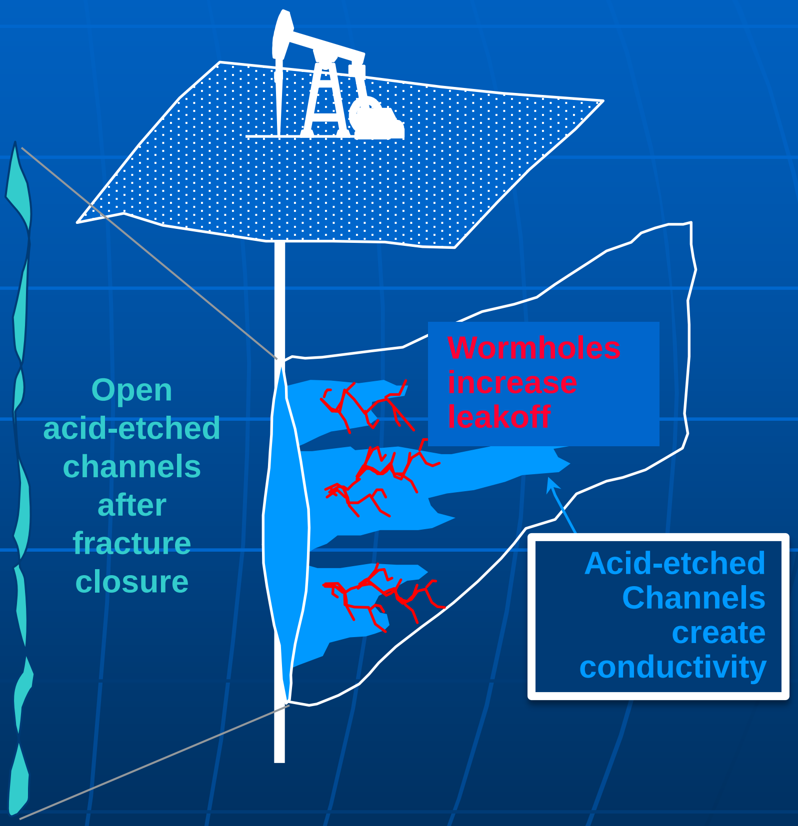


Propped Frac - Sandstones

Acid Frac - Carbonates

Acid Fracturing

- Acid is injected above fracturing pressure
  - A hydraulic fracture is created
- Acid non-uniformly dissolves and etches carbonate fracture faces
  - Highly conductive acid-etched channels remain open after fracture closes
  - No risk of screen out (risk with prop fracs)
- Length of etched fracture
  - Determined by acid type, volume, strength,
    leakoff parameters, reaction rate and injection rate
- Effectiveness determined by
  - Fracture length
  - Fracture conductivity



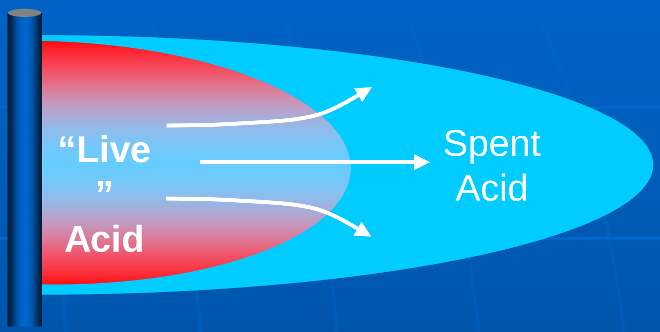
*Acid frac:
* Stochasitic, Formation dependent

General Requirements for Acid Fracturing

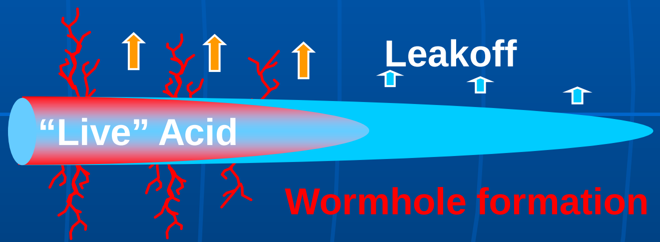
- Carbonate formations
  - Not applicable in sandstone formations
  - HCl, even HF, will not adequately etch sandstone fracture face
  - Materials (fines) released through dissolution can plug the fracture
- Cleaner Limestone and Dolomite formations
  - Dirty carbonate rocks (< 70% solubility in HCl) are poor candidates
    - Acid etched channels may be impaired
    - Release of insoluble material may plug the channel
- Competent rock
  - Conductivity can deteriorate over time
  - Soft formations unable to retain conductivity after closure
  - Chalk formations are generally not suitable:
- Connectivity vertically across interval
  - Reservoirs with horizontal sterilities (e.g., anhydrite) can compromise vertical connectivity of conductivity

Limits of Acid Fracturing

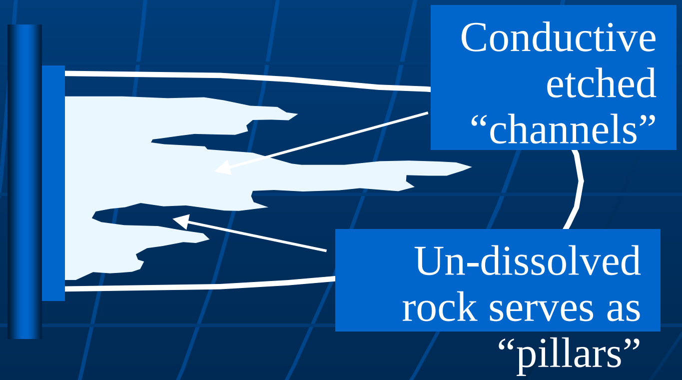
- Kinetic limit:
  - Upper limit for depth of acid penetration
  - Dependent on reaction kinetics



- Fluid loss limit:
  - Lower limit on depth of acid penetration
  - Negatively affected by wormhole formation

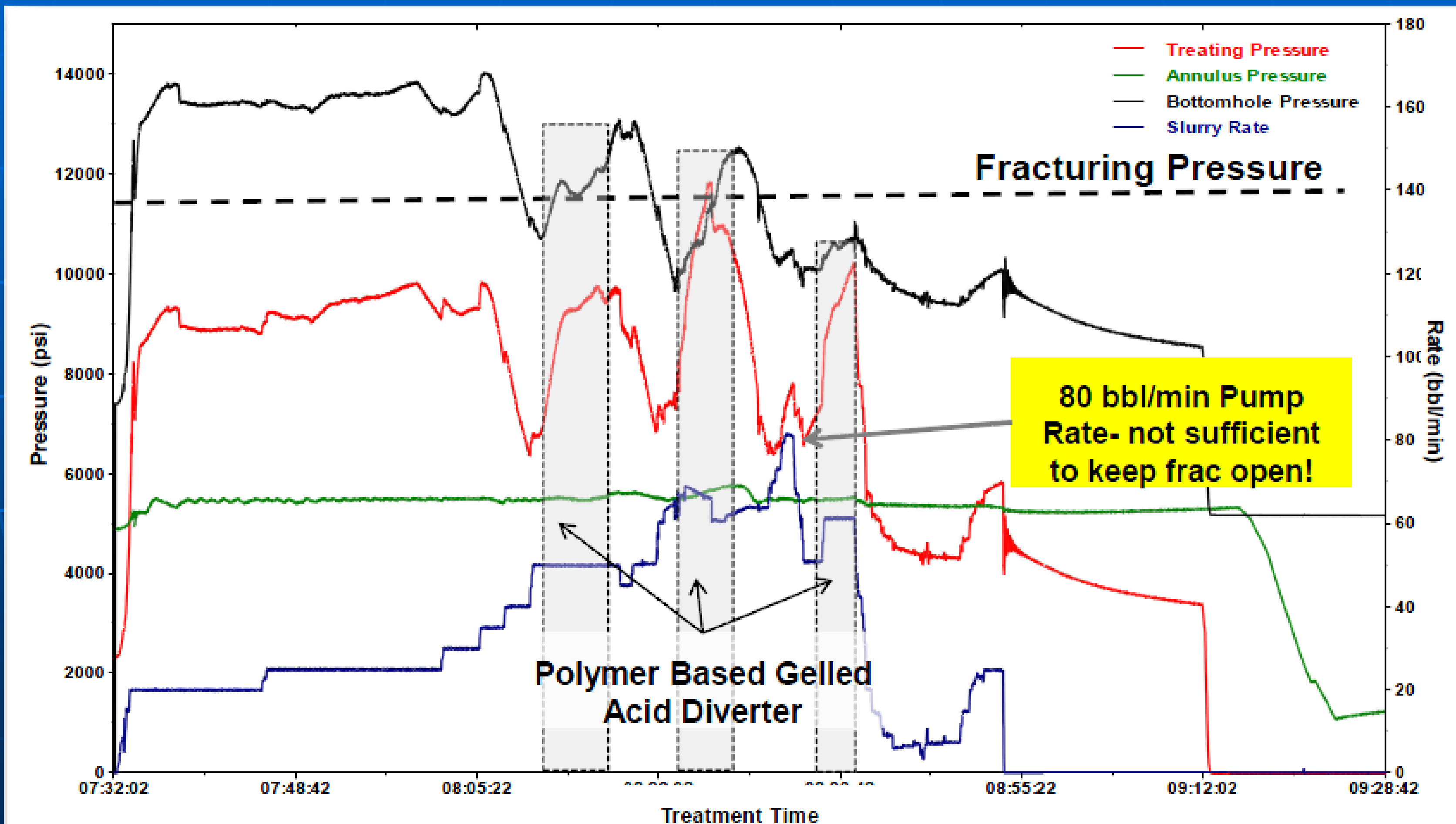


- Conditions for differential etching
  - Rock heterogeneity can create differential etching
  - Can be enhanced by viscous fingering
  - Dominated by reactivity ! (generally overlooked)



Acid Fracturing Challenges

BHP control using conventional diverter



Fiber and VES – Self Diverting Acid

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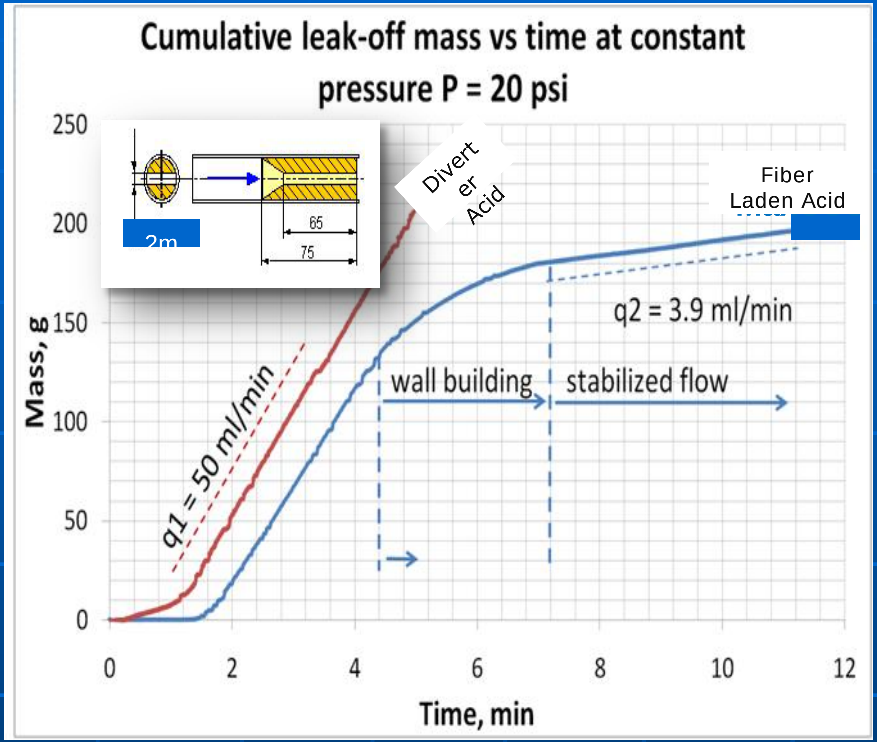
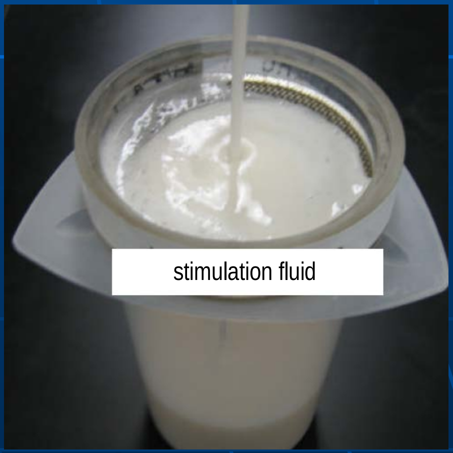
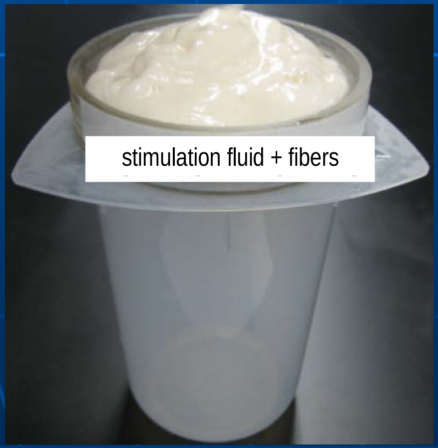




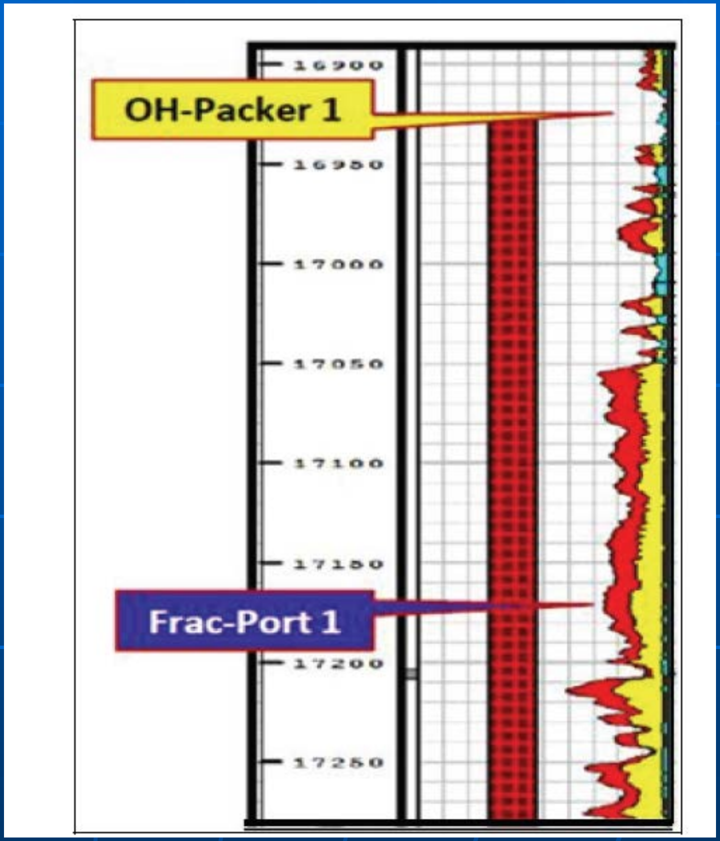


Dual leakoff control with MaxCO3 Acid:

1. Fibers bridging in natural fracture/wormhole
2. High viscosity VDA provides :
   - Larger fracture width to reduce Area/Volume and increase spending time.
   - VDA viscosity upon spending behind the fiber cake, thus decreasing spurt loss

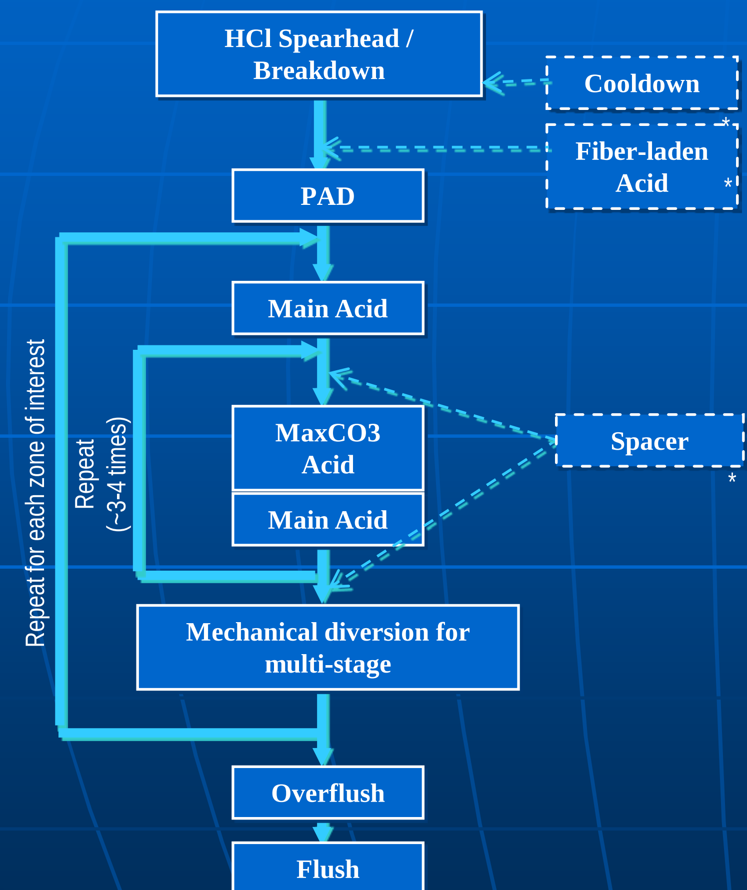
Case Study 3: Acid Fracturing with Fiber Laden Acid

- Well X
  - Open hole horizontal
  - Multi-stage completion (3 stages)
  - Stage 1: 379ft open-hole length



Full story in:
J.L. Jauregui (Saudi Aramco) et al., SPE 142512 – Successful Application of Novel Fiber Laden Self-Diverting Acid System during Fracturing Operations of Naturally Fractured Carbonates in Saudi Arabia

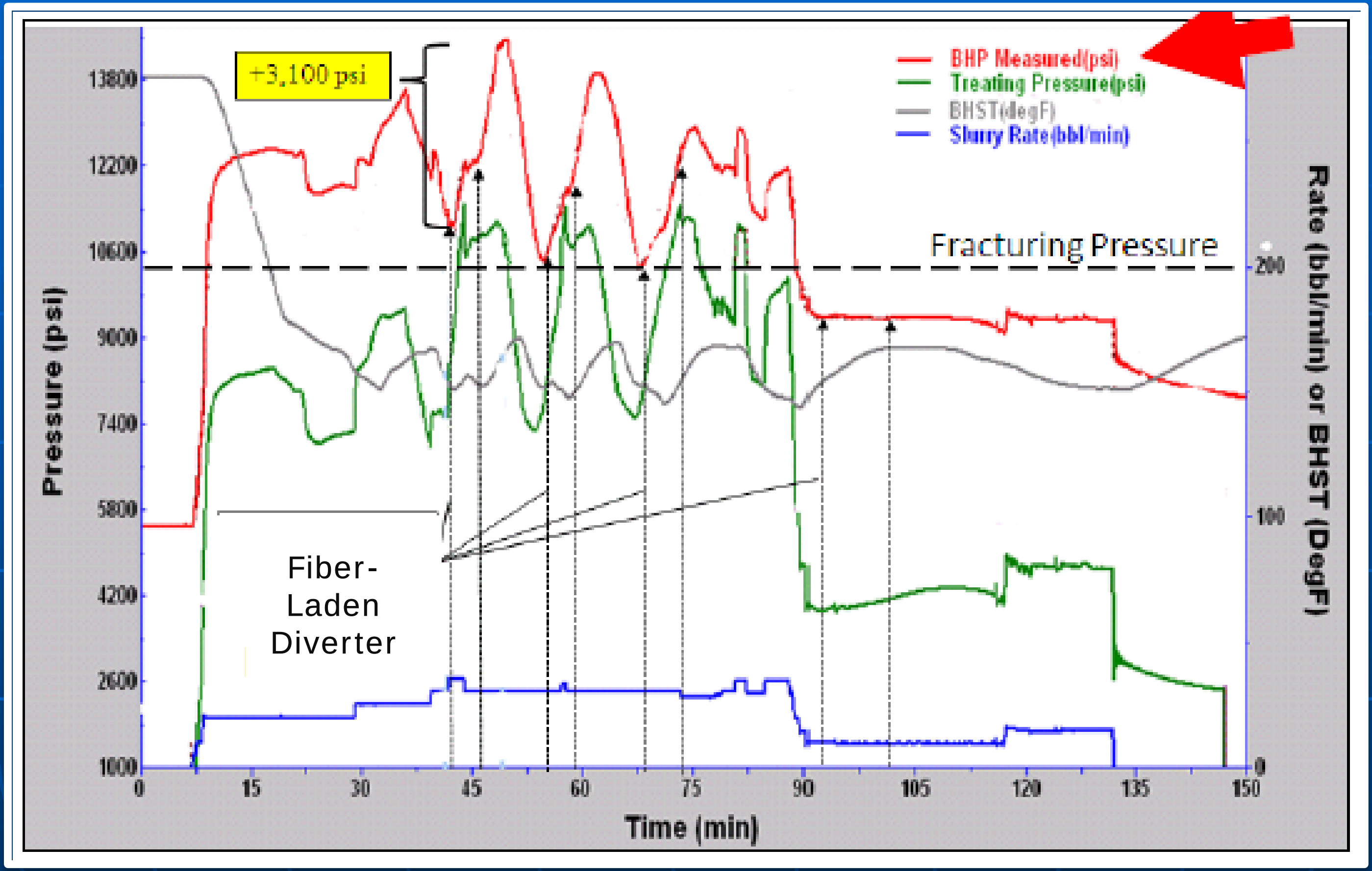
Case Study 3: Treatment Schedule



Treatment Schedule				
Stage Name	**Pump Rate (bbl/min)**	**Fluid Name**	**Stage Fluid Volume (gal)**	**Acid Conc. (%)**
Pad	25.0	CROSSLINKED 35 LB GEL	5,000	0
Acid	25.0	EMULSIFIED ACID	6,000	28
Pad	30.0	CROSSLINKED 35 LB GEL	2,500	0
Diverter 1	**30.0**	**Diverting System (75#)**	**2,000**	**15**
Pad	30.0	CROSSLINKED 35 LB GEL	5,000	0
Acid	30.0	EMULSIFIED ACID	6,000	28
Pad	30.0	CROSSLINKED 35 LB GEL	2,500	0
Diverter 2	**30.0**	**Diverting System (75#)**	**2,000**	**15**
Pad	35.0	CROSSLINKED 35 LB GEL	5,500	0
Acid	35.0	EMULSIFIED ACID	7,000	28
Pad	40.0	CROSSLINKED 35 LB GEL	2,500	0
Diverter 3	**40.0**	**Diverting System (100#)**	**2,500**	**15**
Pad	40.0	CROSSLINKED 35 LB GEL	6,000	0
Acid	40.0	EMULSIFIED ACID	9,000	28
Overflush1	40.0	Overflush	10,000	0
CFA Diverter	**10.0**	**Diverting System (100#)**	**2,500**	**15**
CFA	10.0	HCl-28_CFA	9,000	28
Overflush2	10.0	Overflush	10,000	0
Flush	10.0	Water	10,612	0

* Stages can be added if needed per treatment design

Case Study 3: Pressure plot



- Fiber Laden Acid leads to pressure increase of ~3100psi at constant injection rate
- The entire treatment remains above fracturing pressure, propagating the fracture

Case Study 3: Fiber Laden Acid vs Conventional Diverters

Conventional diverter | Conventional diverter* | Conventional diverter* | Fiber Laden Diverter | Fiber Laden Diverter

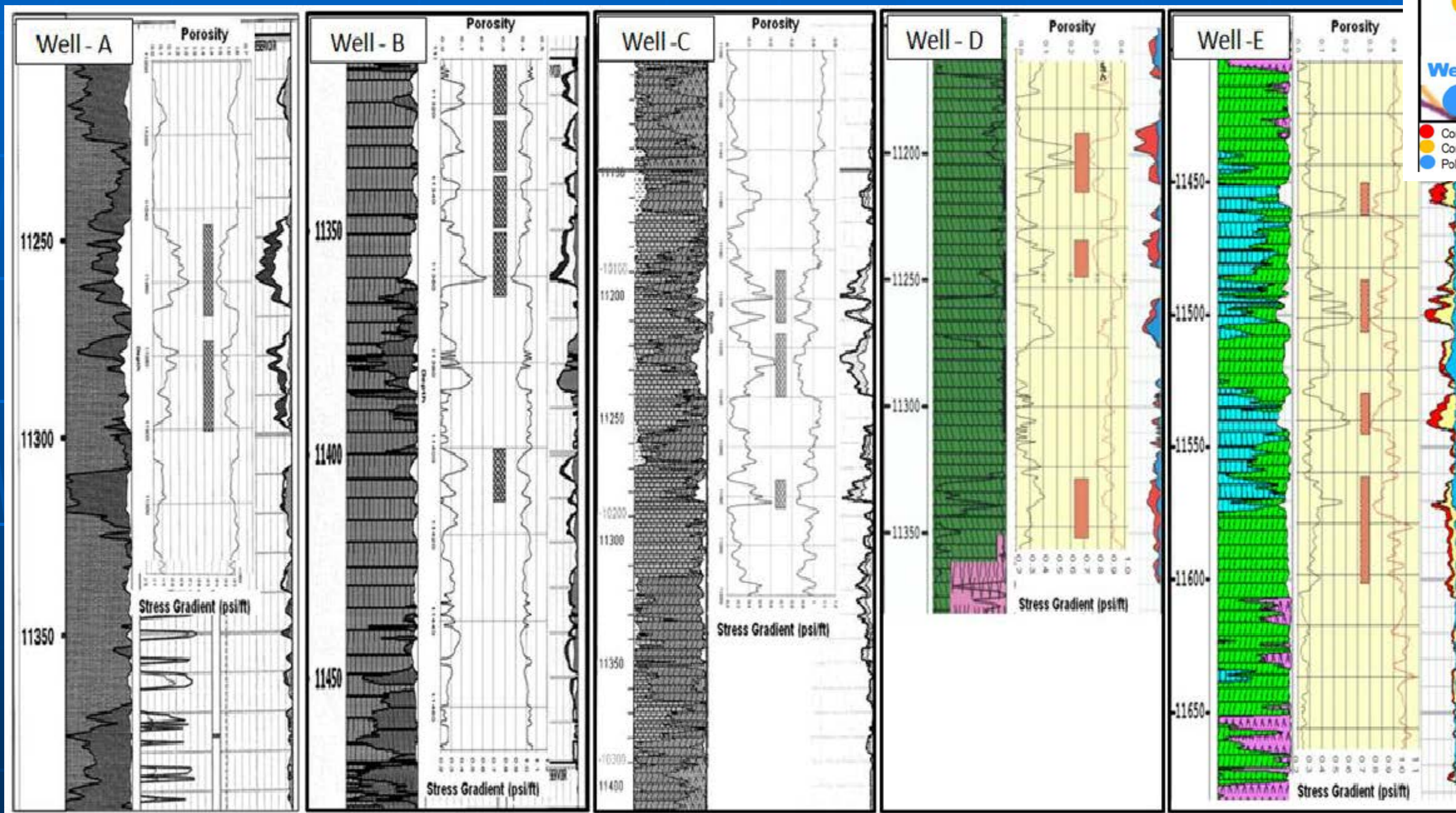
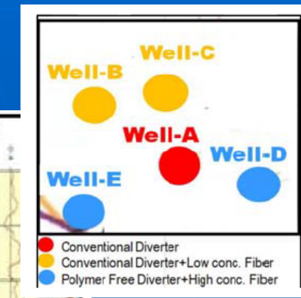
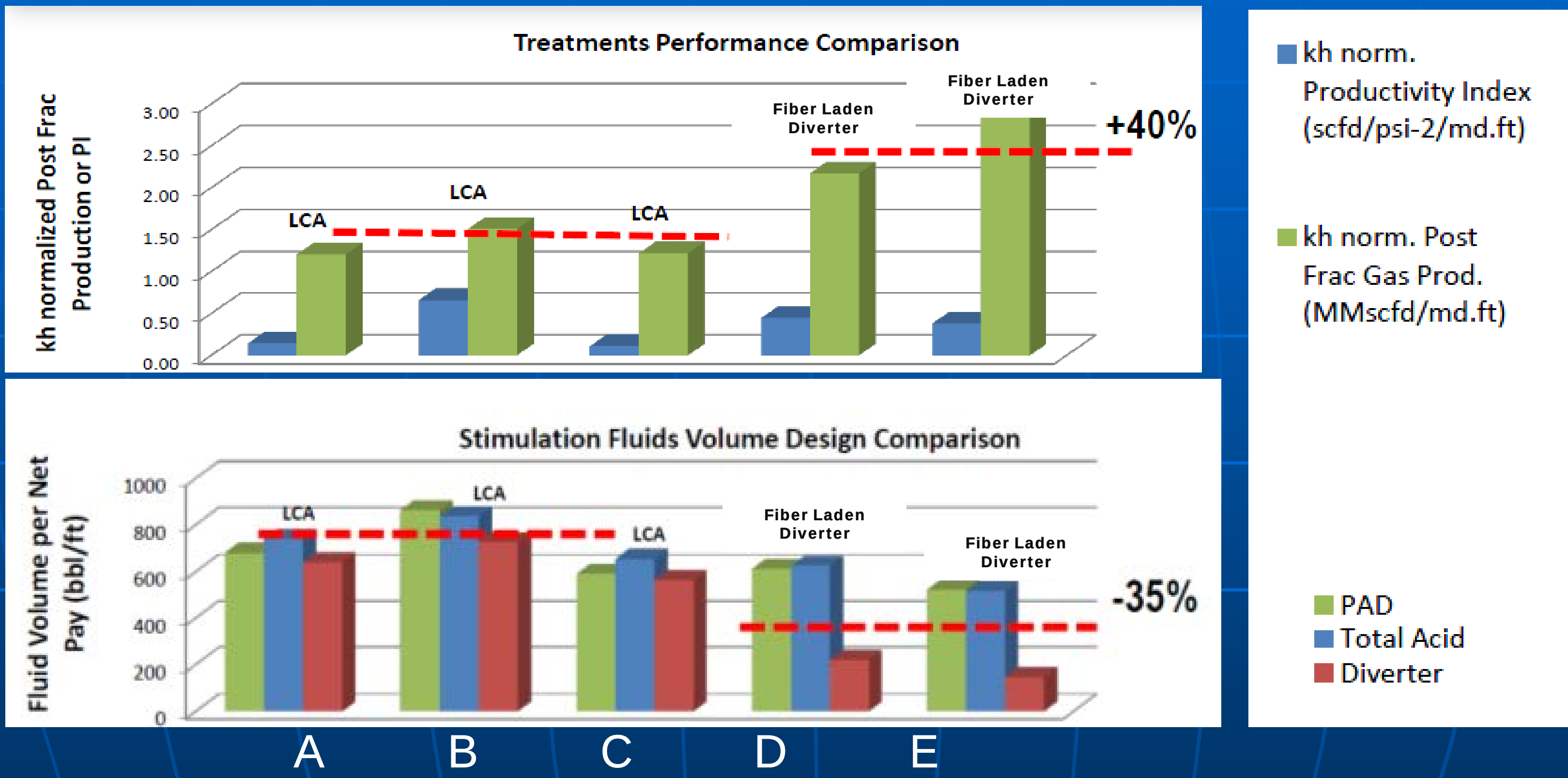


Fig. 5 — Direct offset wells mineralogy, stress gradient porosity permeability profile and perforated intervals position.



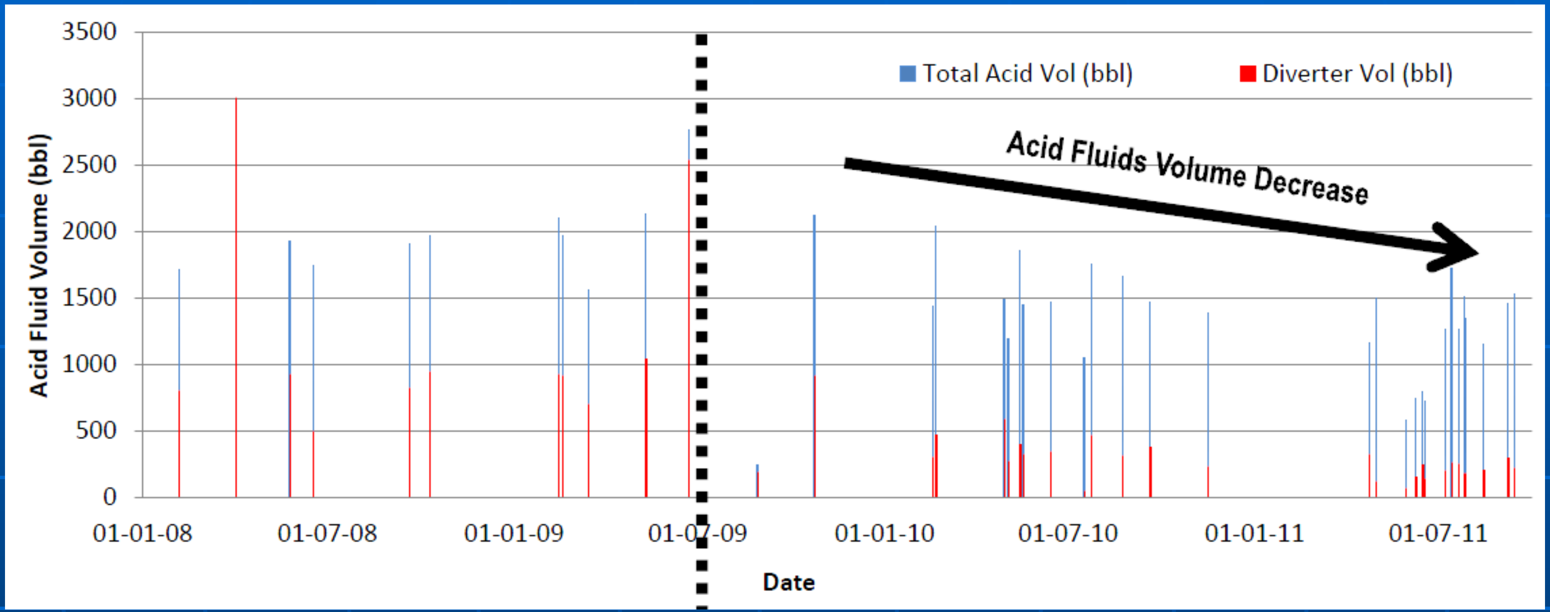
Full story in:
T. Bukovac (Schlumberger) et al., SPE 160887 –
Stimulation Strategies to Guard against Uncertainties of Carbonate Reservoirs

Case Study 3: Treatment Outcome: Comparison



- Normalized post-frac gas production has increased of 40%
- Diverter volume is now 20% of total acid volume (compared to 45% in conventional treatments)
- 445gal/ft of acid, vs 720 gal/ft in conventional treatments

Case Study 3: Reducing Job Size, Increasing Efficiency



On ~50 wells in Saudi Arabia,

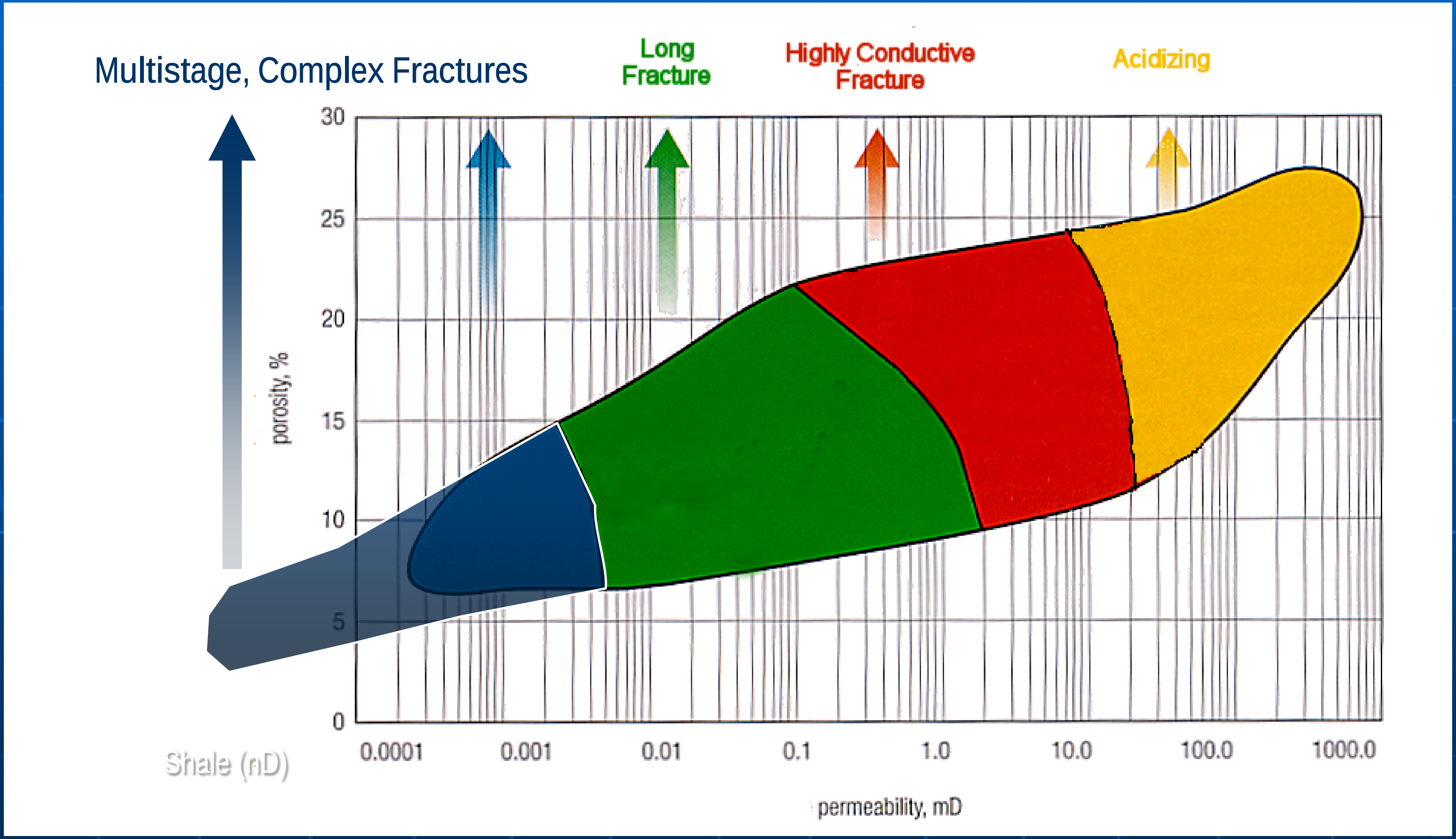
- Fiber Laden Acid enables reducing significantly the fluid volumes
- Clean-up period dropped on average from 4.7 days to 2 days

Conclusions

- Stimulation Challenges
- Completion Selection for the Reservoir
- Requirements of Effective Matrix & Acid Frac Stimulation
- Stimulation Efficacy Dependent* on:
  - Damage Identification/Acid Design
  - Stimulation Placement
  - Fluid Loss Control (Acid Fracturing)

not exclusive, other factors can impact efficacy

Questions?



Multistage, Complex Fractures
Long Fracture
Highly Conductive Fracture
Acidizing
30
25
20
15
10
5
0
porosity, %
Shale (nD)
0.0001
0.001
0.01
0.1
1.0
10.0
100.0
1000.0
permeability, mD

References:

- SPE 160887 – Stimulation Strategies to Guard against Uncertainties of Carbonate Reservoirs
- SPE 144183 – Innovative Method to Control Acid Placement During the Stimulation of Wells with High Water Cut
- SPE 142512 – Successful application of novel fiber laden self-diverting acid system during fracturing operations of naturally fractured carbonates in Saudi Arabia
- SPE 138910 - Fiber-Assisted Self-Diverting Acid Brings a New Perspective to hot, deep Carbonate Reservoir Stimulation in Mexico
- SPE 134495 - Understanding Diversion with a Novel Fiber-Laden Acid System for Matrix Acidizing of Carbonate Formations
- SPE 132003 - Field Trials of a Novel Fiber-Laden Self-Diverting Acid System for Carbonates in Saudi Arabia
- IPTC 13097 - Changing the game in the stimulation of thick carbonate gas reservoirs
- SPE 123827 - Combination of chemical diverters and degradable fibers enhances the success of stimulation in complex carbonate environments
- SPE 112419 - Successful Stimulation of Thick, Naturally Fractured Carbonate Pay Zones in Kazakhstan