R&D Programs in Unconventional Oil and Gas Reservoir Development and Production

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RESERVOIR SIMULATION GROUP

Outline

- Overview
- Shale Gas Hydraulic Fracturing Optimization
- Comments

Overview

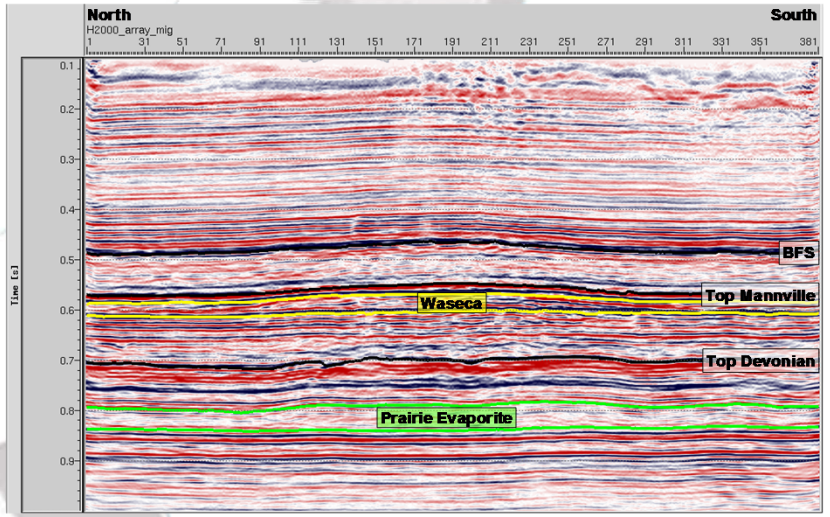
- “Sweet spots” identification and reserve evaluation
- Production evaluation and optimization
- Well drilling and completion
- Formation stimulation

8 Geo-Factors

- TOC
- R_o
- Depth
- Net thickness
- Gas content
- Mineral composition
- Petrophysical properties
- Rock mechanics

Tools

- Geology
- Geophysics
- Reservoir Engineering



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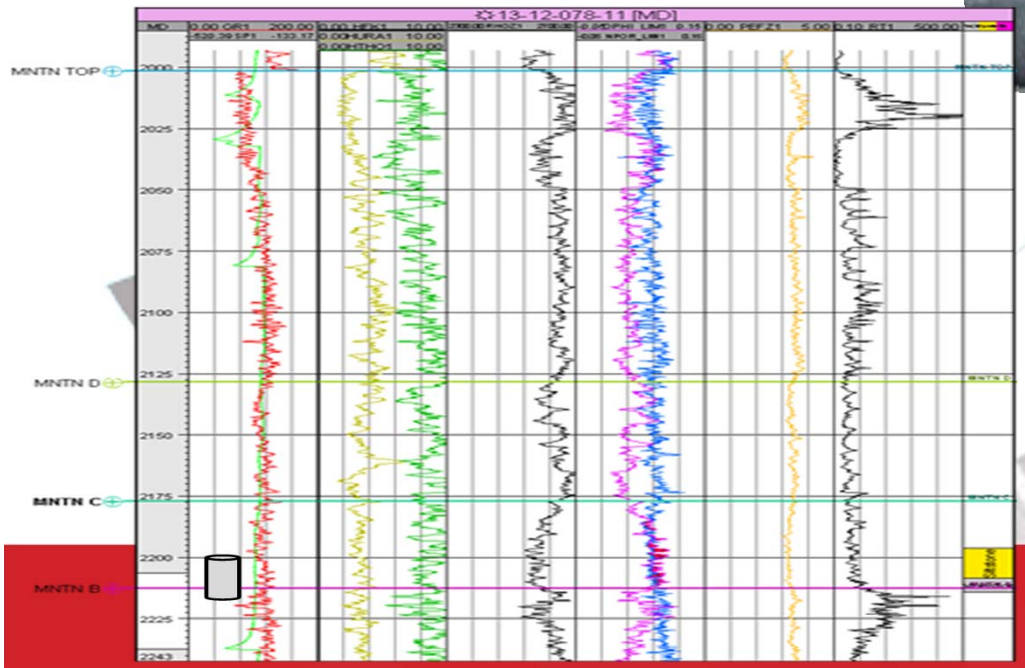
Geology

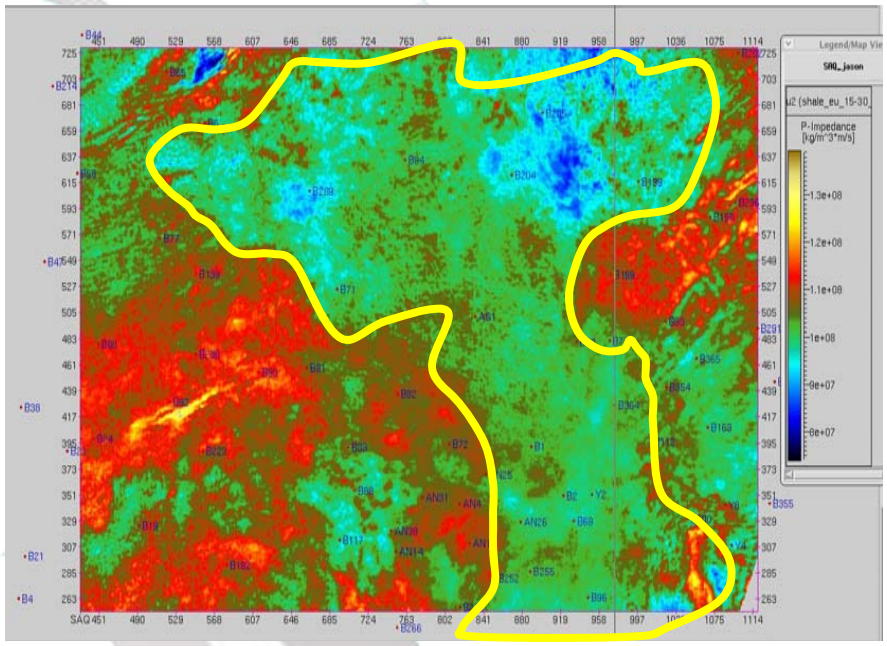
- **Core analysis**
- **Well logs**



Courtesy of Leyva, Yazdi, Murdoch

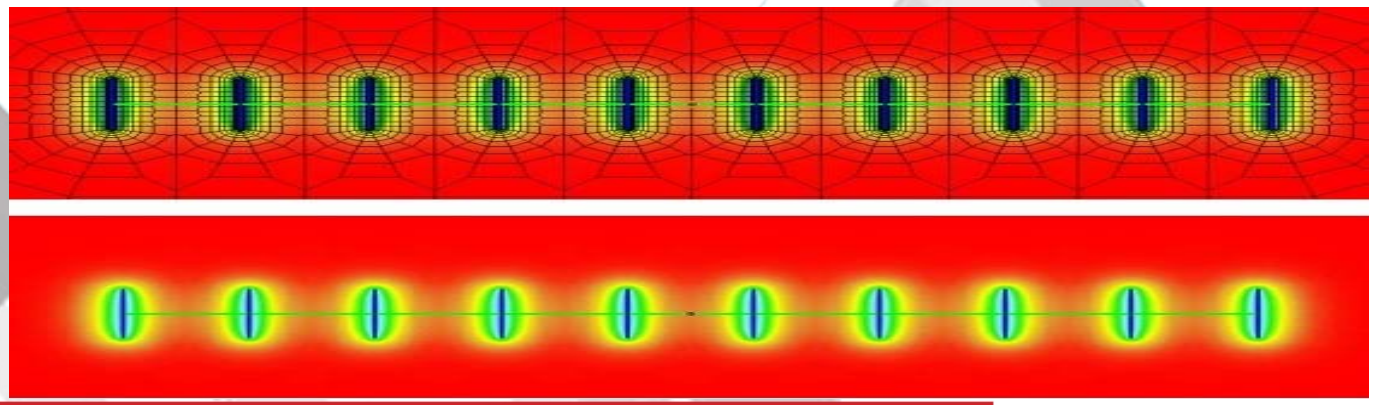
Geophysics

- AVO
- Lithology
- Specialized attributes
- Seismic inversion
- Time delay analysis
- Frequency spectrum



Reservoir Engineering

- Drilling and completion
- Formation stimulation
- Optimization



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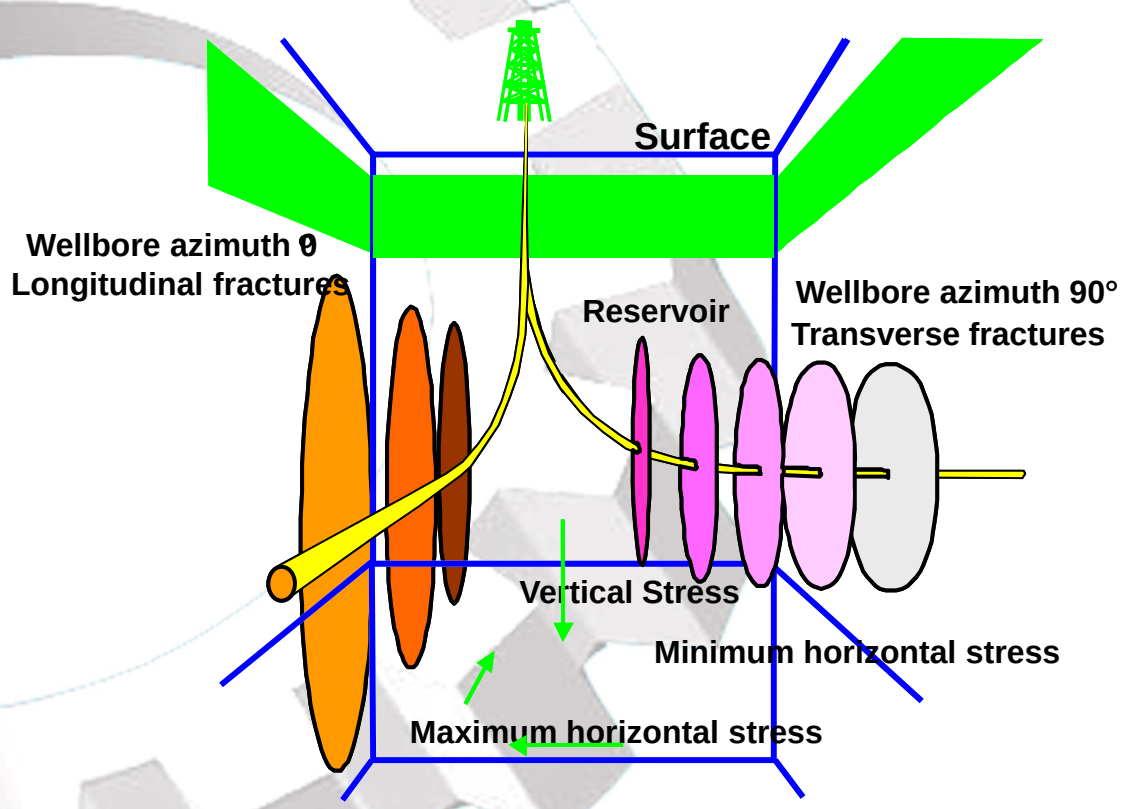
Shale Gas Hydraulic Fracturing Optimization

Objective

- Increase effective reservoir contact area by hydraulic fracture/ and complex fracture network with natural fracture.



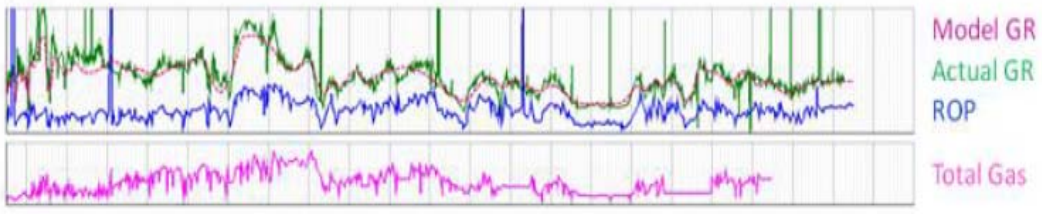
Shale Gas Stimulation Optimization Design process

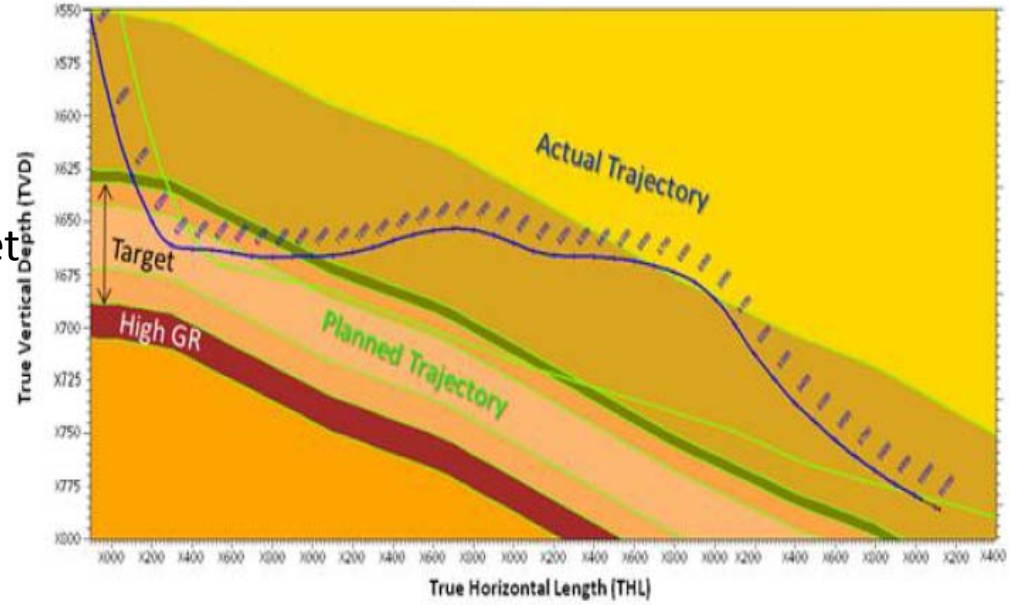
- Wellbore placement /landing point
- Horizontal wellbore lateral length
- Completion hardware and isolation techniques
- Fracture spacing and number of hydraulic fractures in one lateral
- Fracturing fluid/additives, proppant selection and pumping schedule
- Stimulated Reservoir Volume (SRV)
- Fracture monitoring and evaluation

Wellbore Placement/Landing Point

If horizontal wellbore trajectory is far off from planned trajectory:

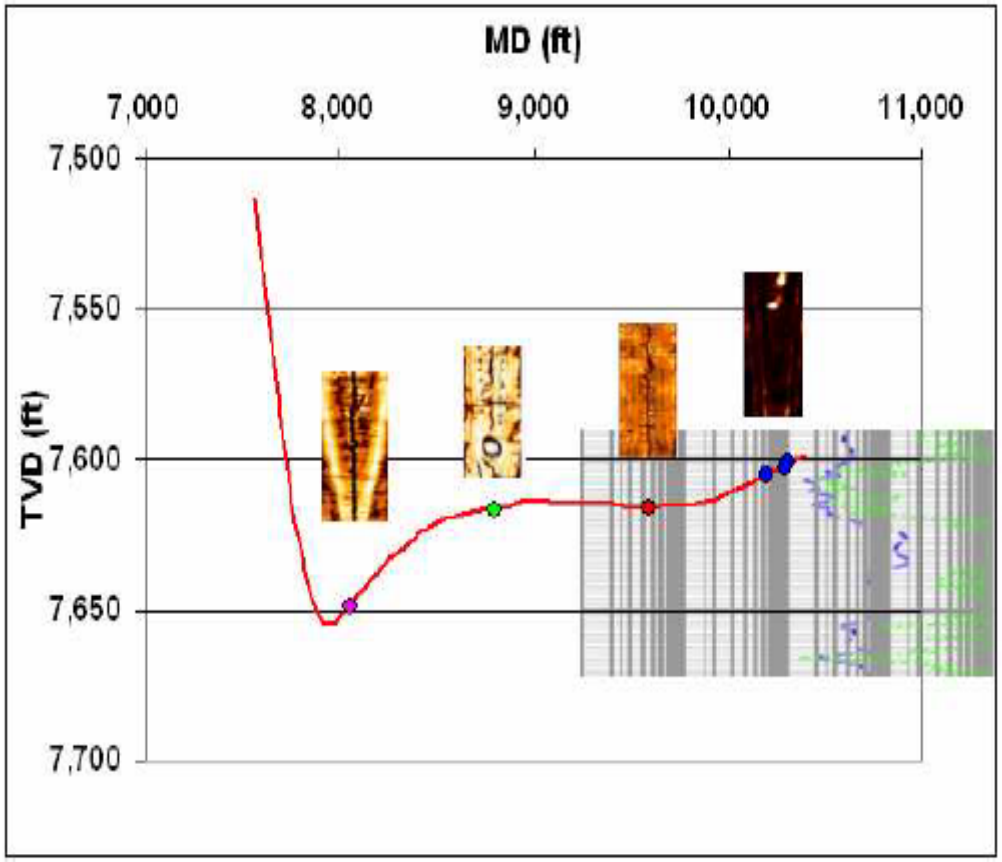
- High hydraulic fracturing breakdown pressure
- Failure of proppant placement
- Fracture geometry shift out of sweet spot
- Poor production result
- Create hazardous situation

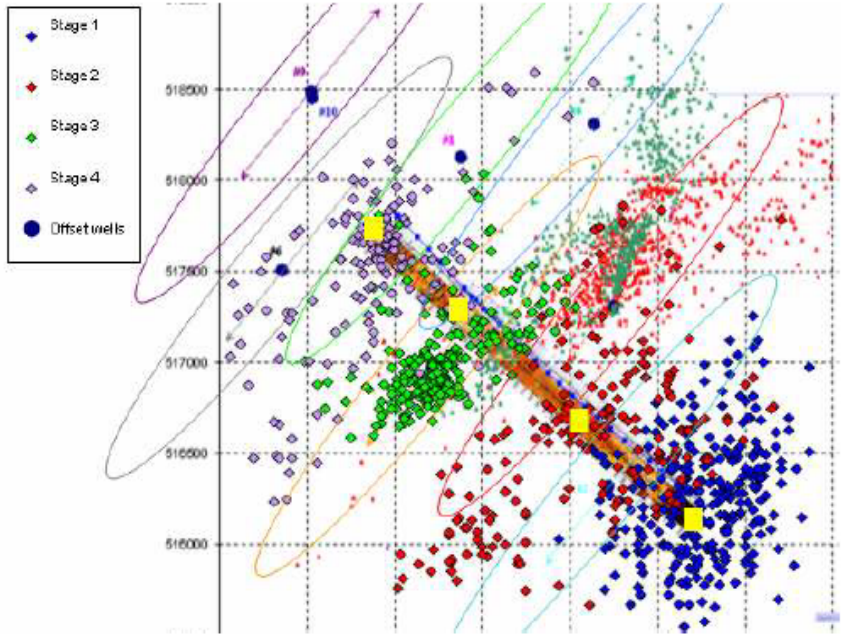




Model Vertically Exaggerated To Amplify Structure Details Along Well Trajectory

Wellbore Placement/Landing Point

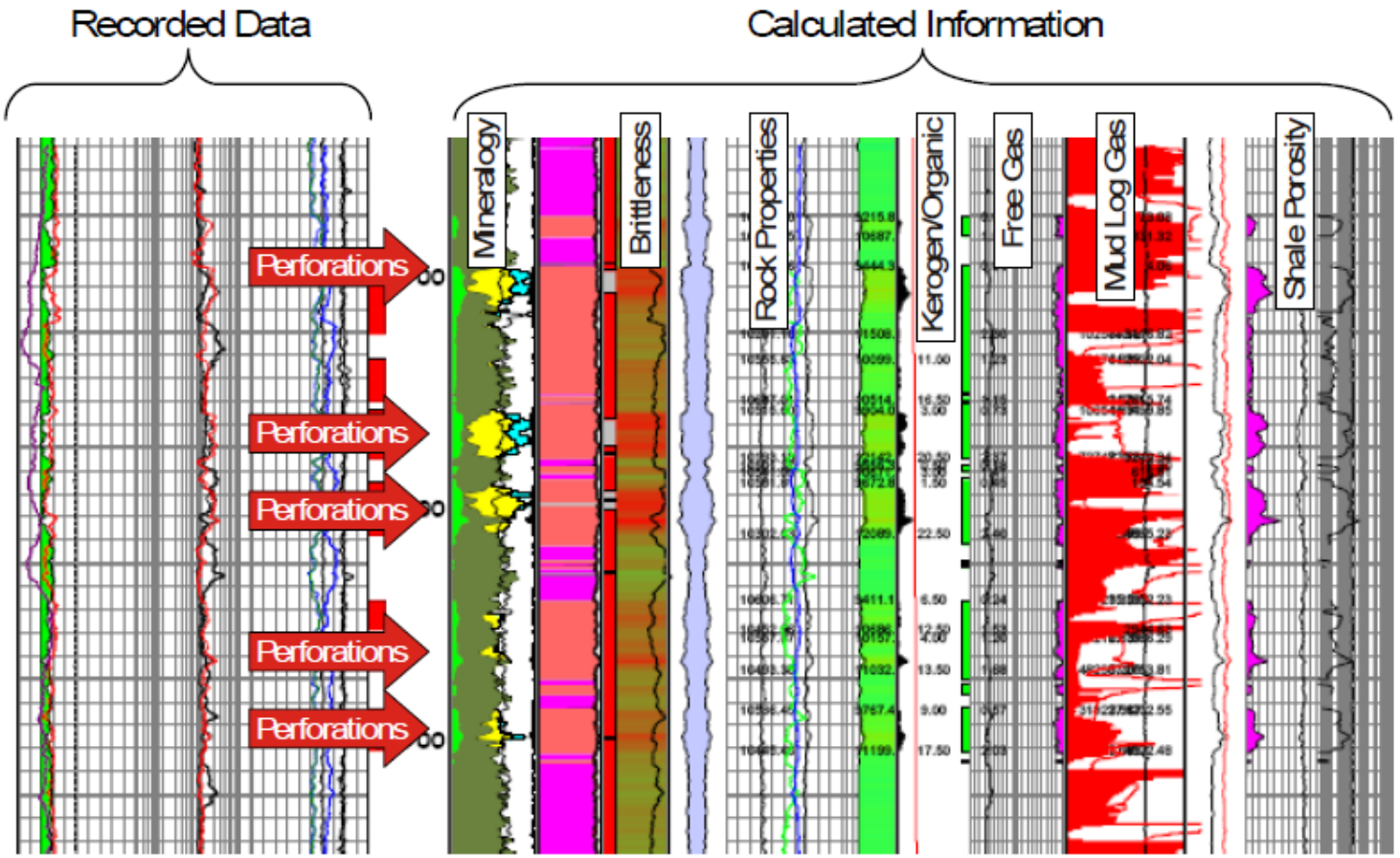




	Shallow Resistivity	Initiation Pressure
Stage 1	150 Ω-m	0.80 psi/ft
Stage 2	350 Ω-m	0.70 psi/ft
Stage 3	500 Ω-m	0.67 psi/ft
Stage 4	300 Ω-m	0.69 psi/ft

(SPE 110562)

Steps to determine the completion interval



A petrophysical-shale log model (SPE 123586)

Horizontal wellbore Lateral Length

- Lateral length is increasing over years
- Restrictions on lateral length

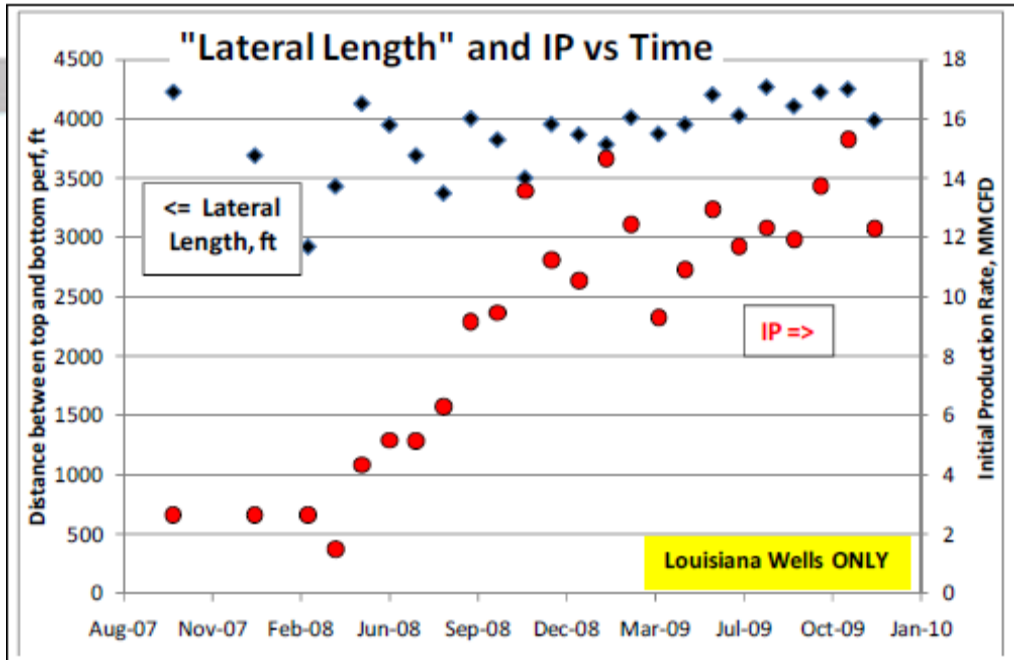
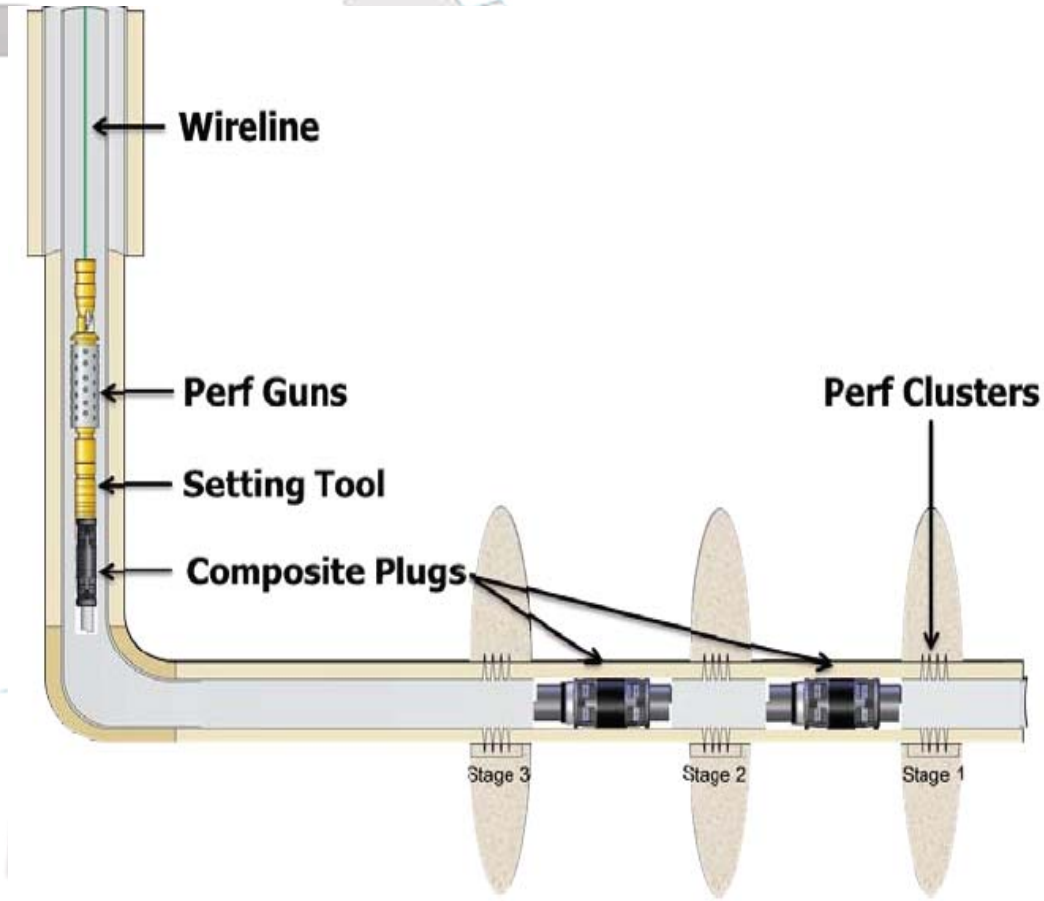


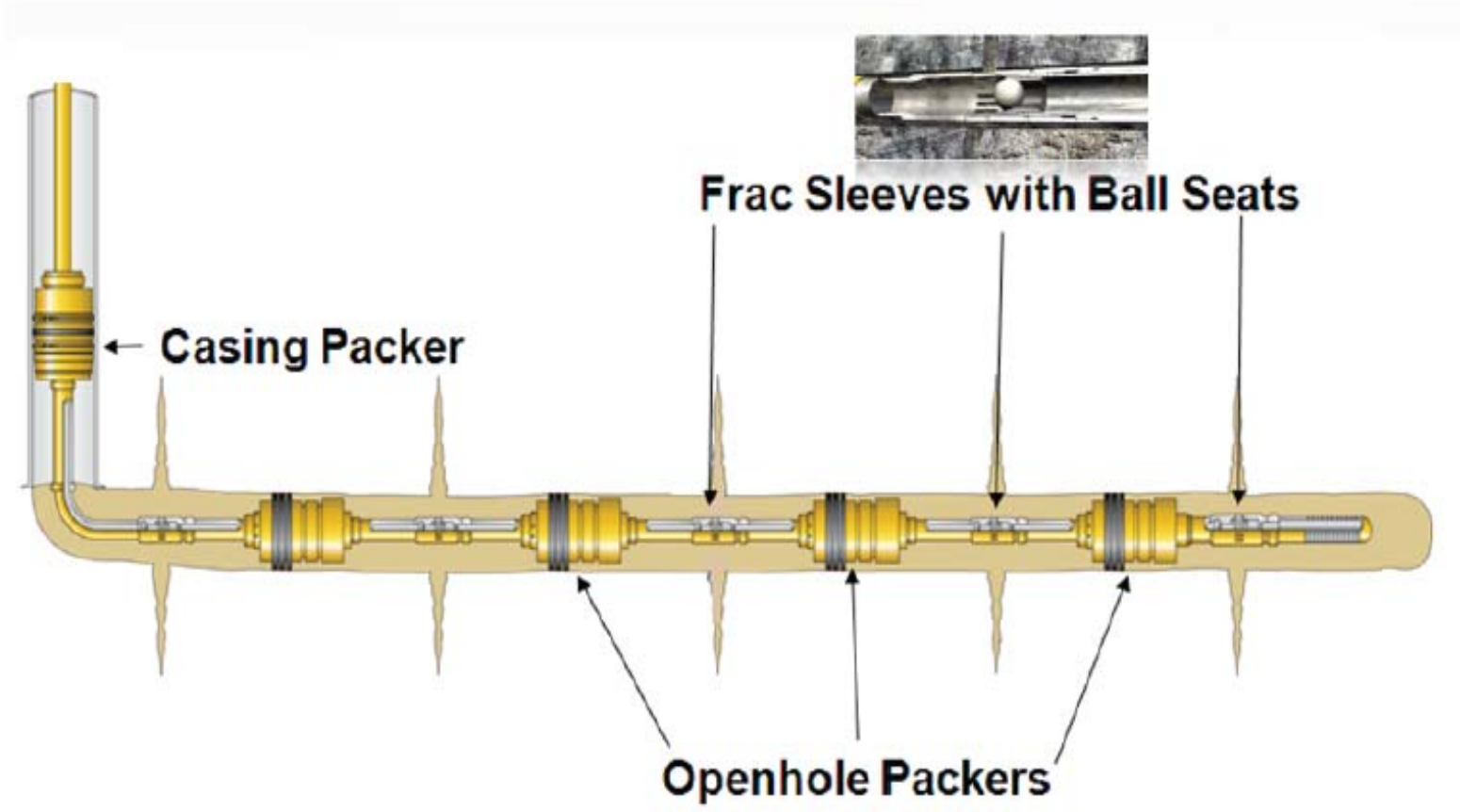
Figure 1 – Average horizontal lateral length in the Louisiana Haynesville Shale has shown a steady increase since development began in 2007, and a corresponding increase in average IP [Pope, 2010].

Completion Technique_ Casehole Plug & Perf Completion (SPE 162534)

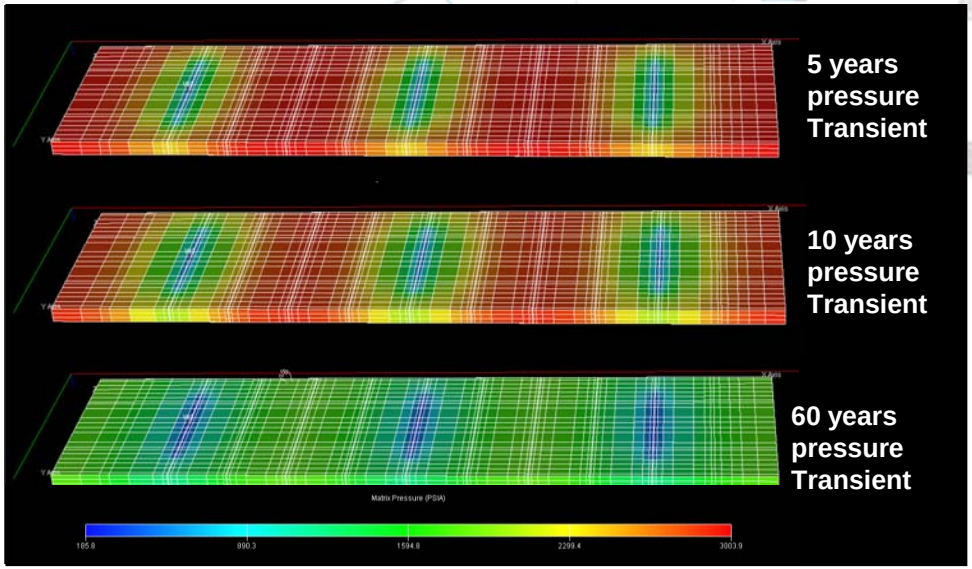
- First stage in a horizontal perforated on CT, or via burst-disk, all remaining stages run drillable plugs and perforate on wireline
- Run on coiled tubing or pump-down wireline
- Plug and gun(s) on wireline are pumped down in tandem, allowing plug to be set and guns to be shot on the same trip
- Plug (mechanical) isolation



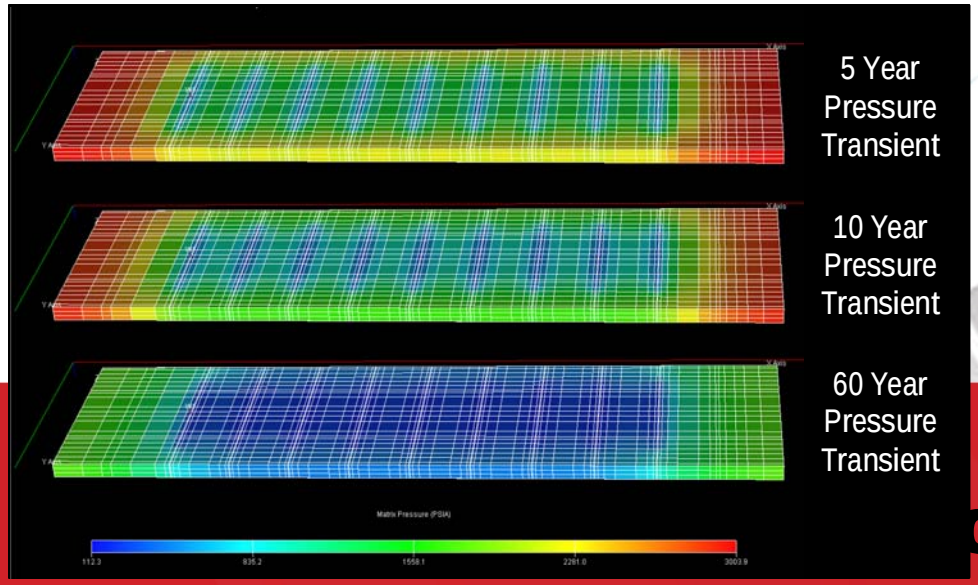
Completion Technique_ Openhole Ball-Activated Completion System (SPE 162534)



Hydraulically Fracturing Spacing and number of fracs



Reservoir pressure profile with hydraulic Fractures at 1,000 ft Spacing (400 nd)



Reservoir pressure profile with hydraulic Fractures at 250 ft Spacing (400 nd)

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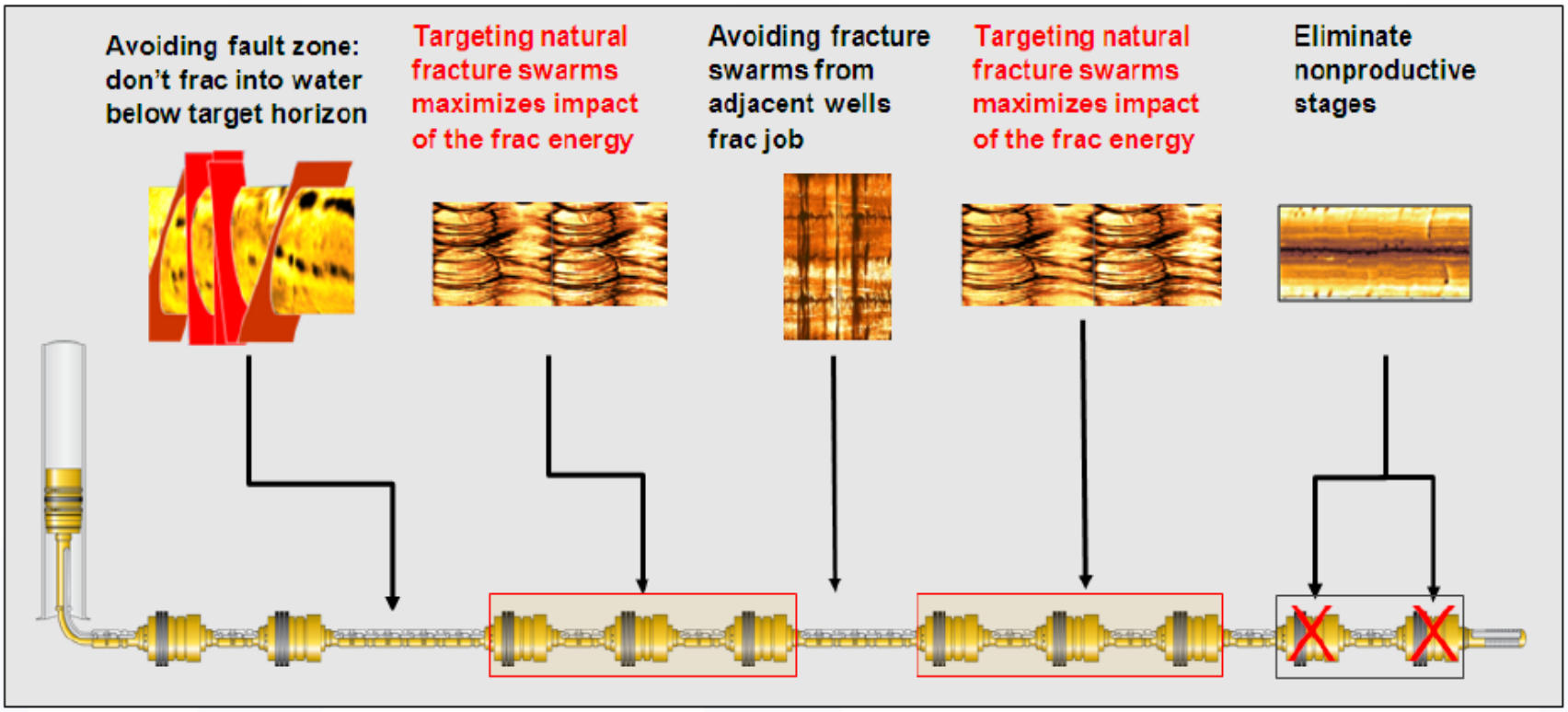
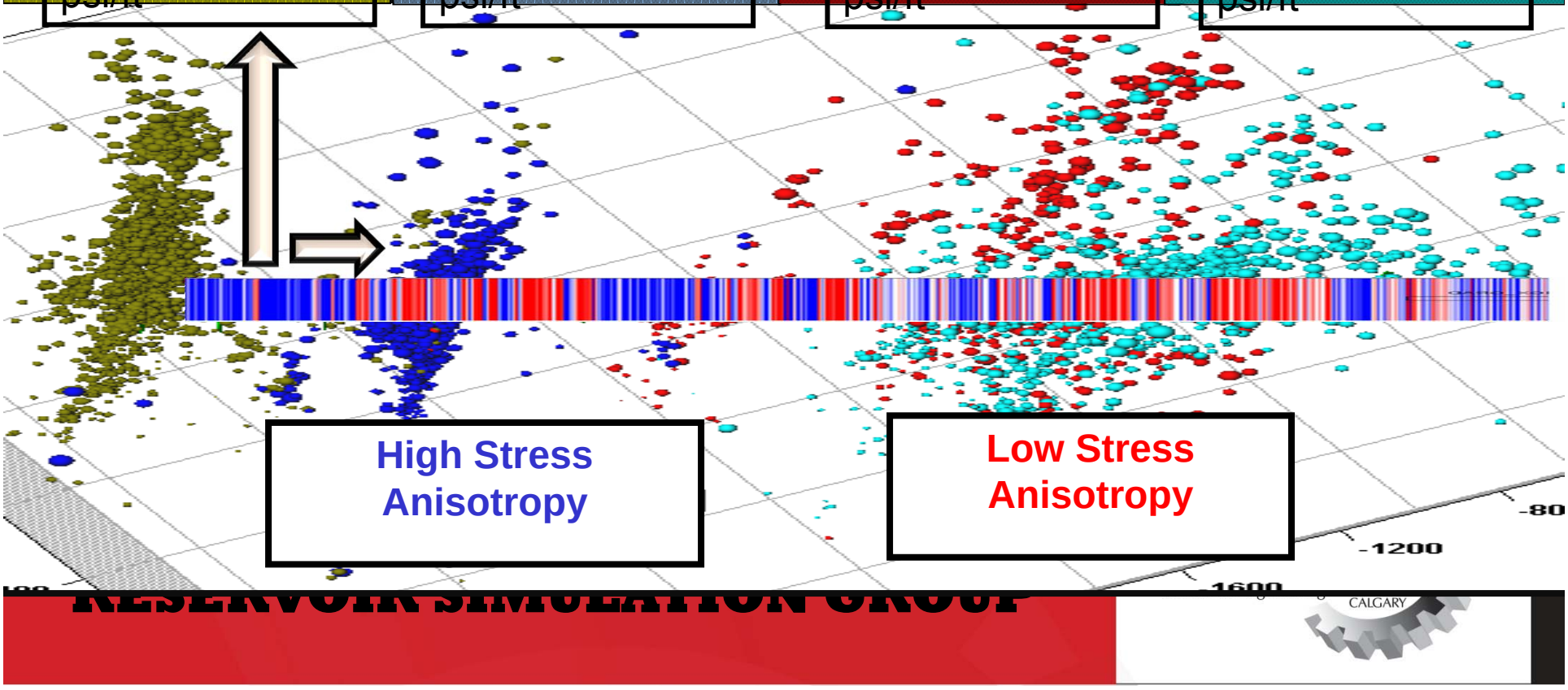
Spacing Design Example #1



LWD Resistivity Imaging Toll Provides Valuable information on frac stages placement (SPE 162534)

Spacing Design Example #2

Stage 1	Stage 2	Stage 3	Stage 4
σmax avg =0.77 psi/ft σmin ISIP = 0.70 psi/ft σM- σm = 0.07 psi/ft	σmax avg =0.74 psi/ft σmin ISIP = 0.64 psi/ft σM- σm = 0.1 psi/ft	σmax avg = 0.67 psi/ft σmin ISIP = 0.65 psi/ft σM- σm = 0.04 psi/ft	σmax avg = 0.65 psi/ft σmin ISIP = 0.62 psi/ft σM- σm =0.03 psi/ft



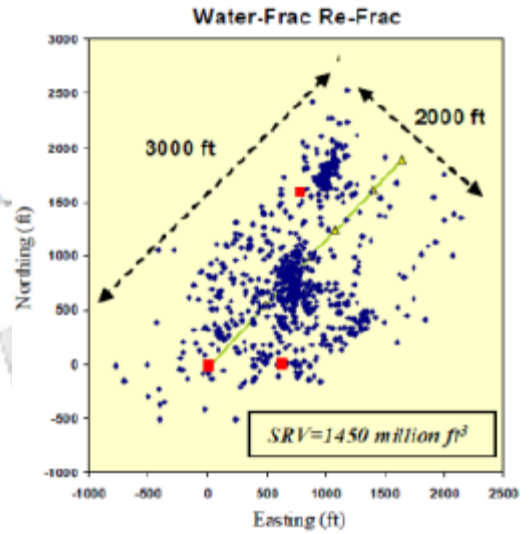
Hydraulic Fracturing Fluid Selection

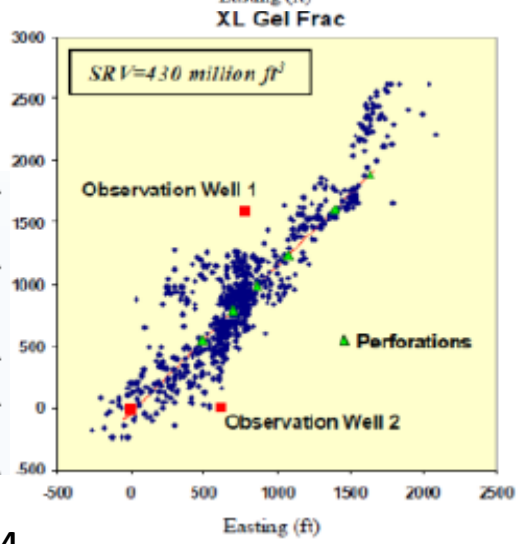
Slickwater

- More Surface Area/Unit Cost
- Wider Fracture "Fairways"
- Higher Stimulated Reservoir Volume

Hybrid Fracturing Fluid (Slick water + Gels)

- Fracture Initiation
- High conductivity fracture





FRAC FLUID TYPE	FORMATION	PUMP RATE	CONDUCTIVITY	PLAY APPLICATION
Slickwater / Linear Gel	Dry Gas or Low Liquid	High Rates 100+ Bpm	Infinite to Gas	Barnett, Marcellus, Fayetteville
Hybrid Frac	Gas Condensate	Low 60-80 Bpm	More Conductive Frac	Eagle Ford, Utica

Suggested Fracture Treatment types for Dry gas, Wet gas, SPE 162534

SPE 133456

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Other Fracturing Fluid Additives

Bactericides

- Untreated Water

Scale Inhibitors

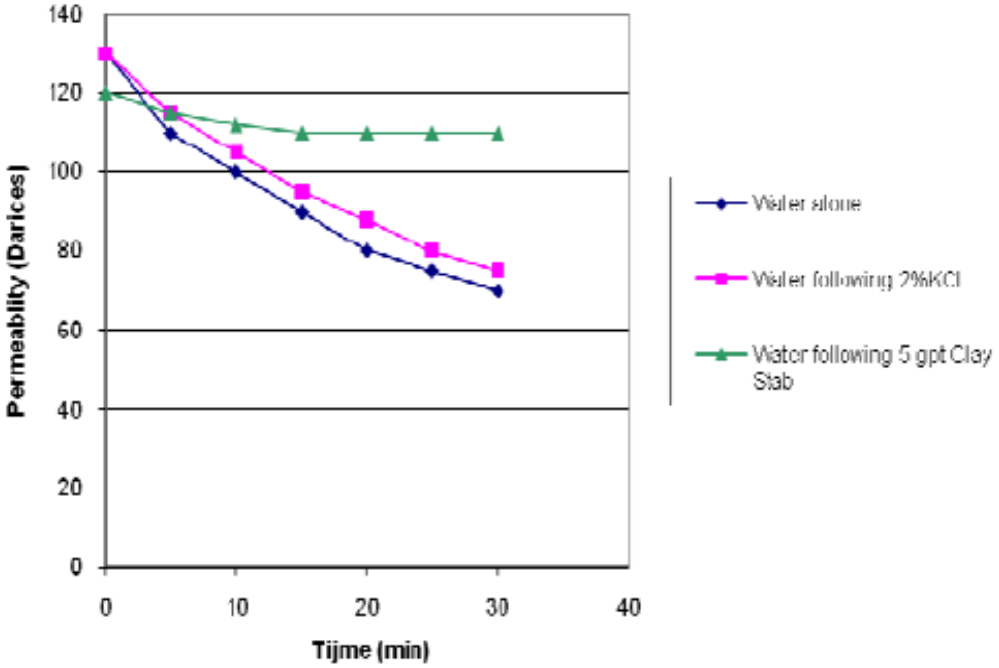
- Mixed/Reused Waters
- High TDS Waters

Clay stabilizer

- Clay migration
- Swelling Clays

Surfactants

- Lower surface tension
- Lower capillary pressure



Proppant pack permeability difference with and without clay control additives (SPE 119900)

Proppant Selection (size and type)

- 70/140 (100 mesh) sand has been found to be adequate in most of shale gas reservoirs
- Some of the lager sizes, 40/70, 30/50 and 20/40 have been used where conductivity is important
- Types of proppant selection must include economic analysis

SPE 151128

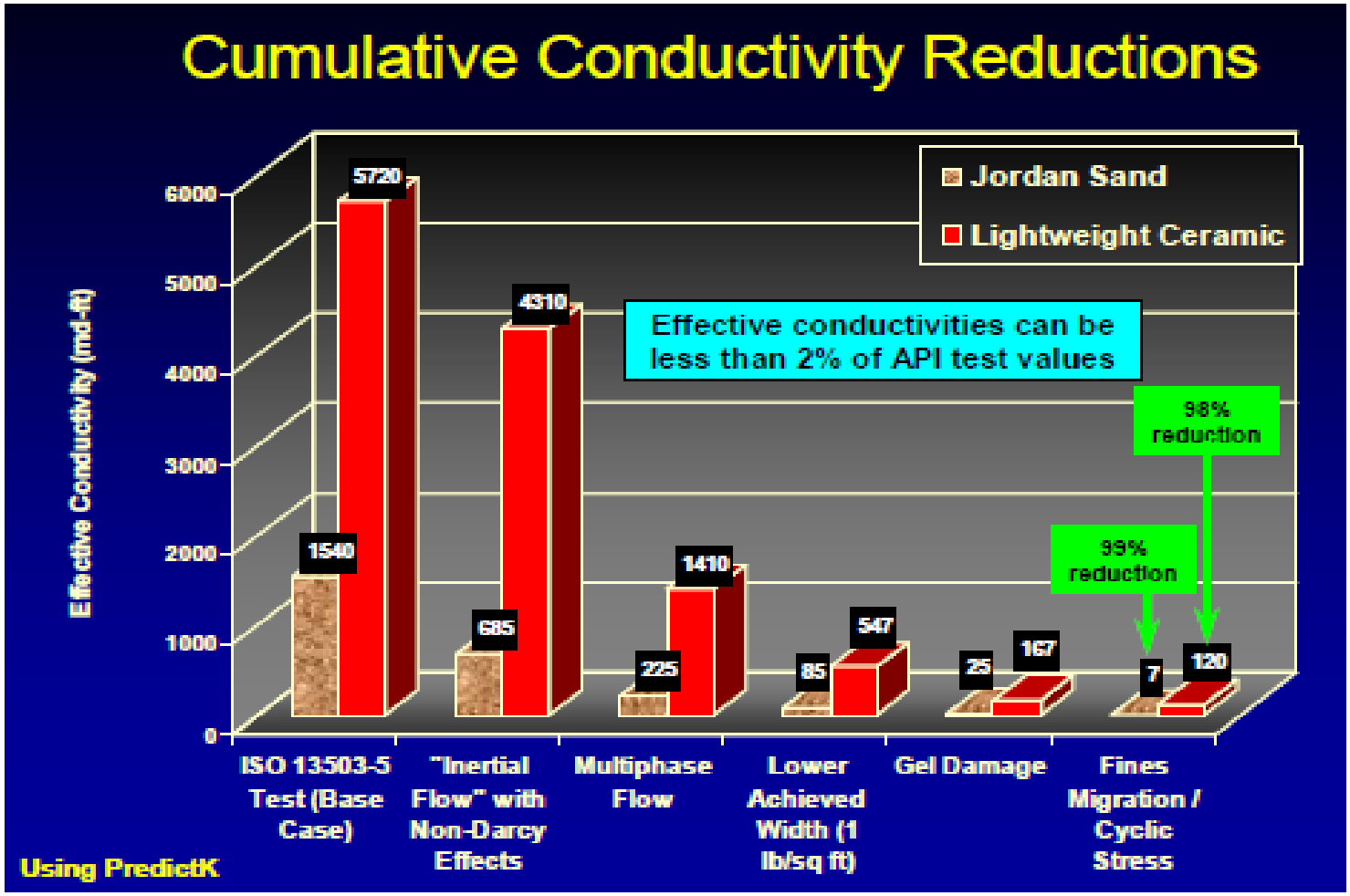


Figure 6 – The cumulative reduction in conductivity due to several damage mechanisms not accounted for in the standard ISO/API test [Palisch 2007].

Shale Gas Hydraulic Fracturing Pumping Schedule

Stage Name	Fluid	Pump Rate	Fluid Volume	Lbm/gal	Total Proppant	Percent of Job
Acid	7 1/2% FE acid	10	2,000	—	—	—
Pad	Slick water	20	10,000	—	—	—
Reactive fluid	Reactive fluid	20	10,000	—	—	—
Spacer	Slick water	30	4,000	—	—	—
0.5 lbm/gal, 100 mesh	Slick water	40	4,400	0.50	2,200	2.0
Spacer	Slick water	50	6,000	—	—	—
1.0 lbm/gal, 100 mesh	Slick water	60	8,800	1.00	8,800	8.0
Spacer	Slick water	60	6,000	—	—	—
0.5 lbm/gal, 40/70 Sand	Slick water	60	22,000	0.50	11,000	10.0
Spacer	Slick water	60	8,000	—	—	—
0.5 lbm/gal, 40/70 Sand	Slick water	60	22,000	0.50	11,000	10.0
Spacer	Slick water	60	10,000	—	—	—
0.75 lbm/gal, 40/70 Sand	Slick water	60	22,000	0.75	16,500	15.0
Spacer	Slick water	60	8,000	—	—	—
0.75 lbm/gal, 40/70 Sand	Slick water	60	22,000	0.75	16,500	15.0
Spacer	Slick water	60	8,000	—	—	—
1.0 lbm/gal, 40/70 Sand	Slick water	60	22,000	1.00	22,000	20.0
Spacer	Slick water	60	6,000	—	—	—
1.0 lbm/gal, 40/70 Sand	Slick water	60	22,000	1.00	22,000	20.0
Total			221,200		110,000	100.0

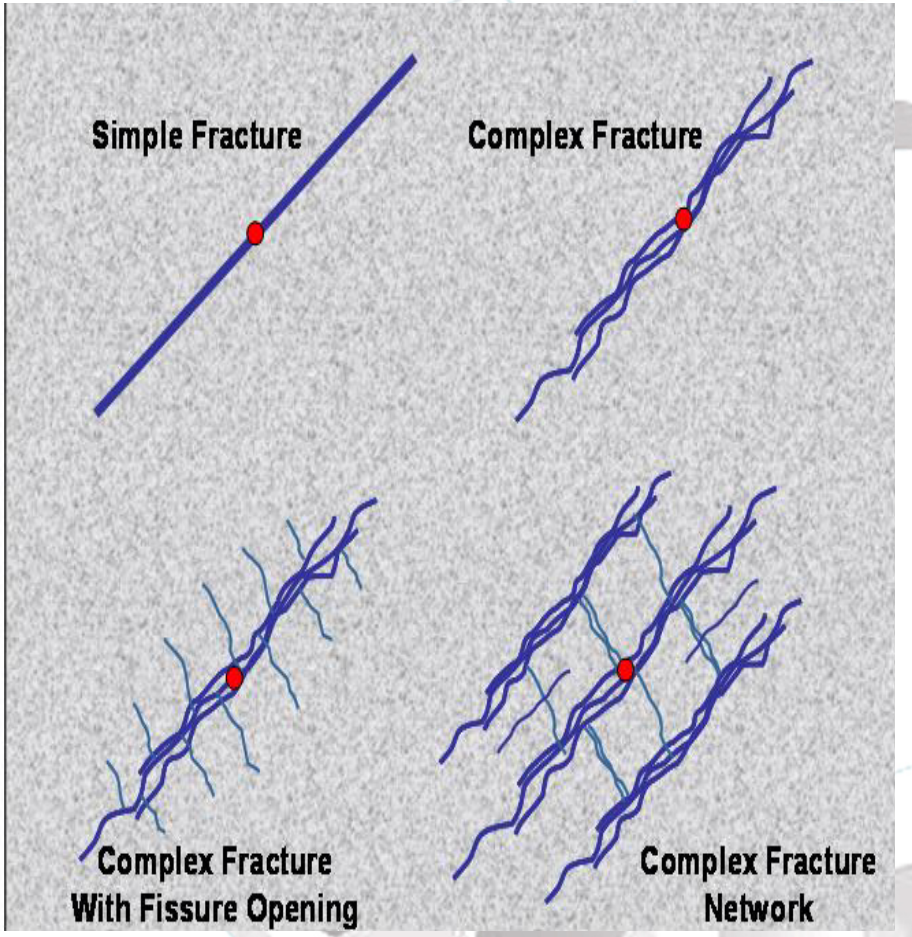
Example Slickwater Pumping Schedule (SPE 123586)

Typical Fracturing Treatments of Some of the Major Shale Plays

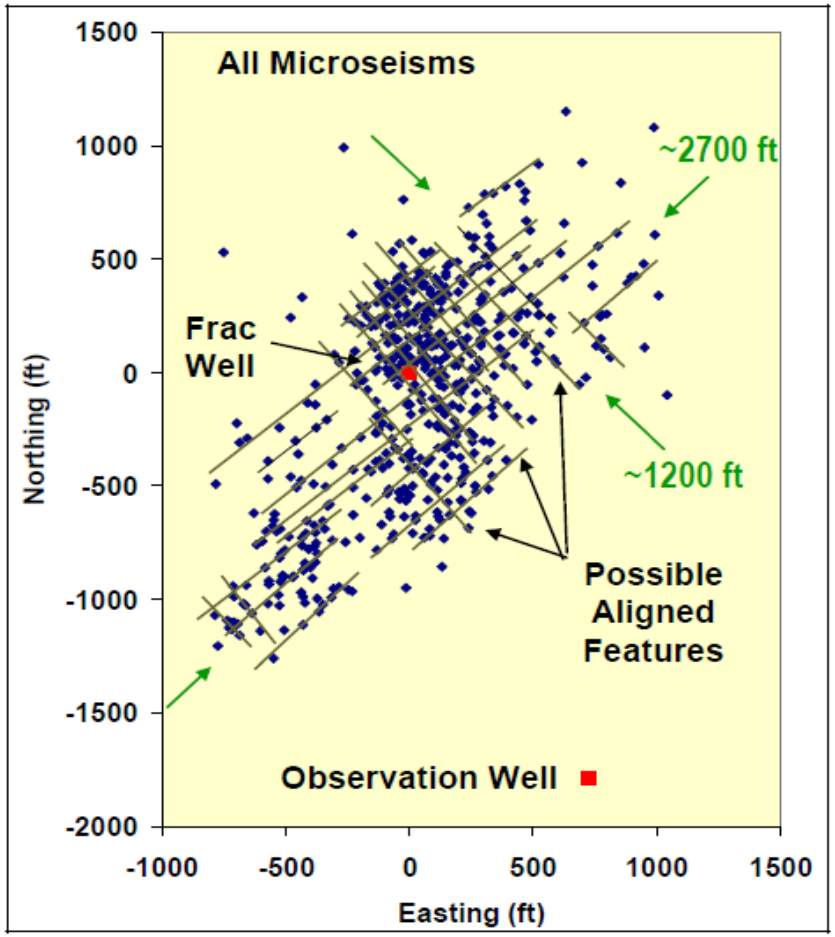
	Bakken	Barnett	Eagle Ford	Haynesville	Marcellus
Avg. MD, ft	17,535	10,873	14,643	16,566	10,722
Avg. TVD, ft	10,207	7,331	9,392	11,941	6,937
Horiz Perfed, ft	7,401	2,788	4,311	4,355	3,331
Avg. ft /stage	550	450	270	325	275
Avg. BHP, psi	5,310	4,213	7,550	10,870	7,650
Avg. rate BPM	24.8	73.3	81.6	71.2	83.5
Avg. No. Stages	13	6	16	13.3	12
Avg. No. Stages/day	3.4	1.9	2.6	1.9	1.5
Amt Prop / Stage, lbm	160,300	286,000	292,600	357,800	399,500
Amt Prop / Well, lbm	1,998,000	1,515,000	4,304,000	4,675,500	4,425,600

SPE 162534

Stimulated Reservoir Volume (SRV)

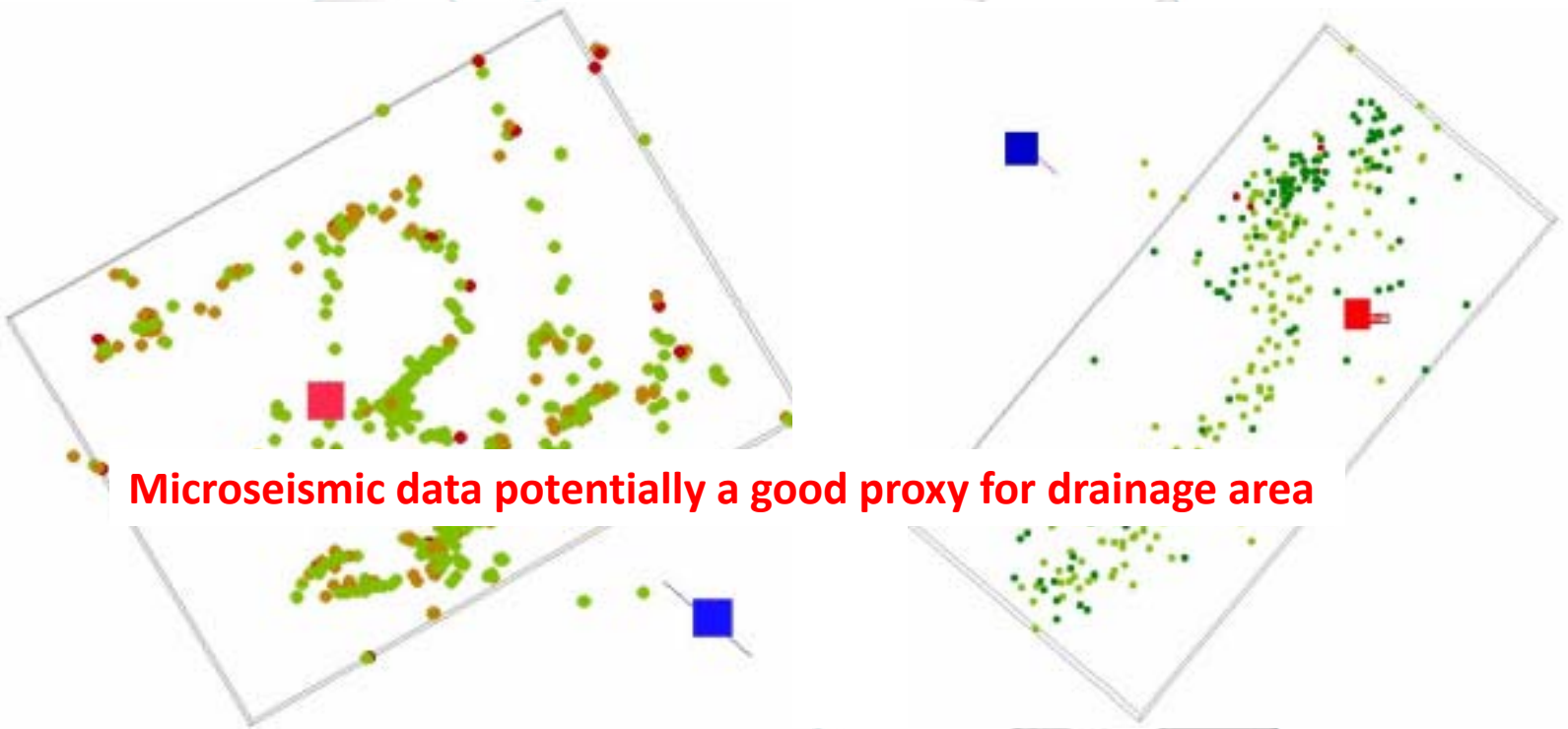


Types of Fracture growth (SPE 114173)



Microseimic shows complex fracture (SPE 114173)

Drainage Areas Defined by Fracturing

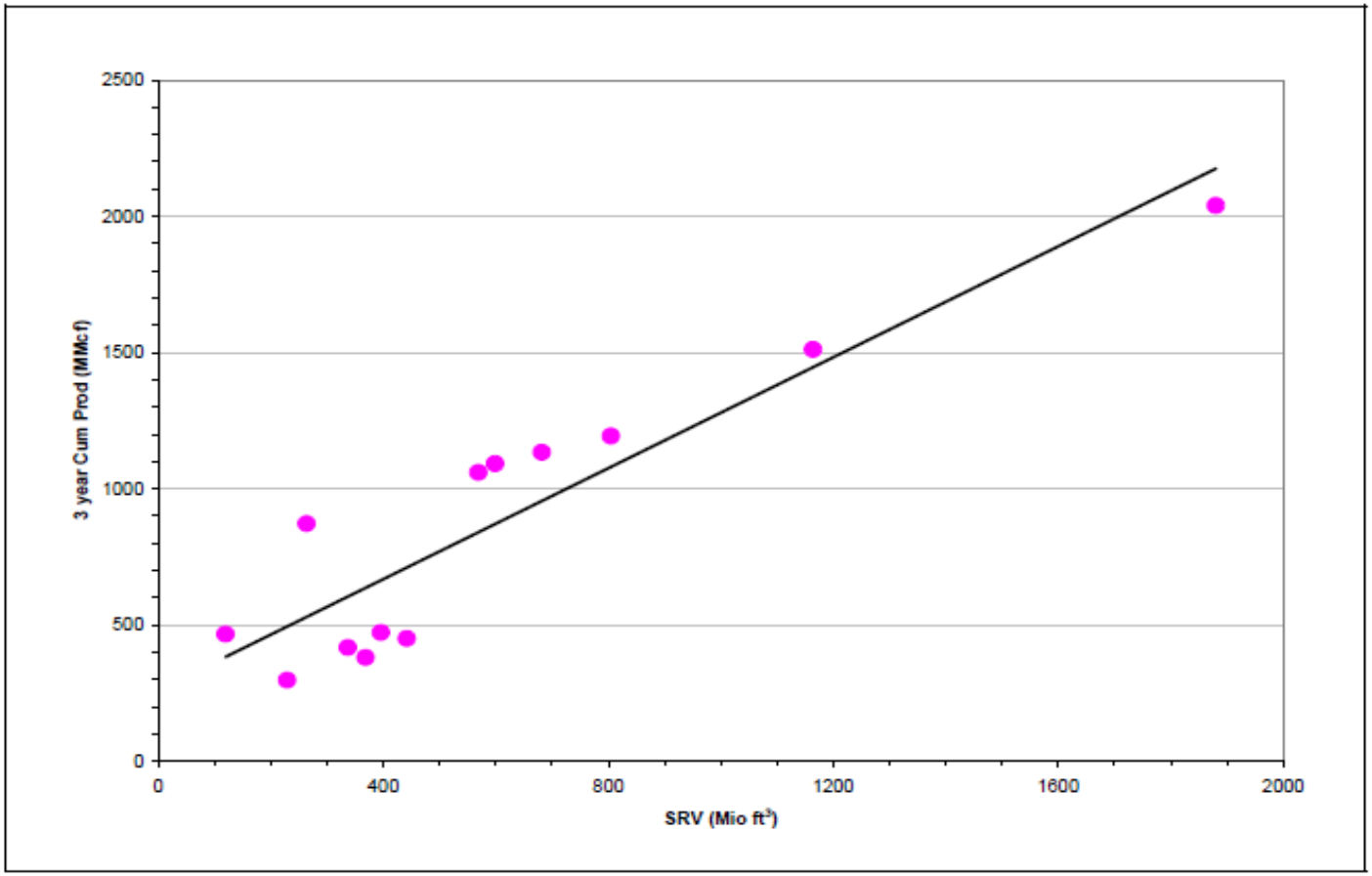


Microseismic data potentially a good proxy for drainage area

- Rock fabric type
- Low stress anisotropy
- Wide fracture fairway
- Complex fracturing

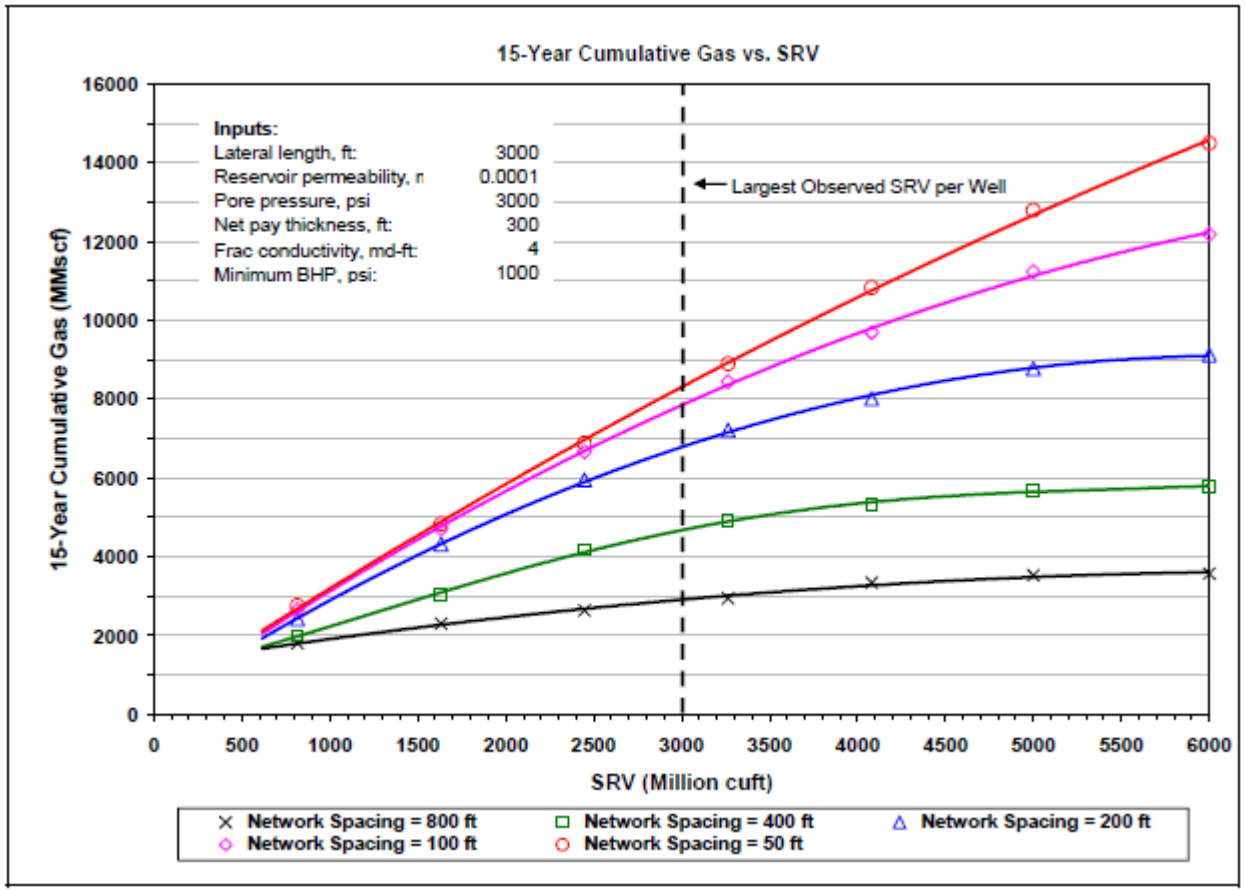
- Rock fabric type
- High stress anisotropy
- Narrow fracture fairway
- Planar fracturing

Stimulated Reservoir Volume vs. Well Performance Case Study #1



SRV trend versus 3-year cumulative horizontal well production for one Barnett shale county (SPE 119890)

Stimulated Reservoir Volume vs. Well Performance Simulation #1



Simulated SRV versus 15-year cumulative horizontal well production (SPE 119890)

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Evaluation Techniques

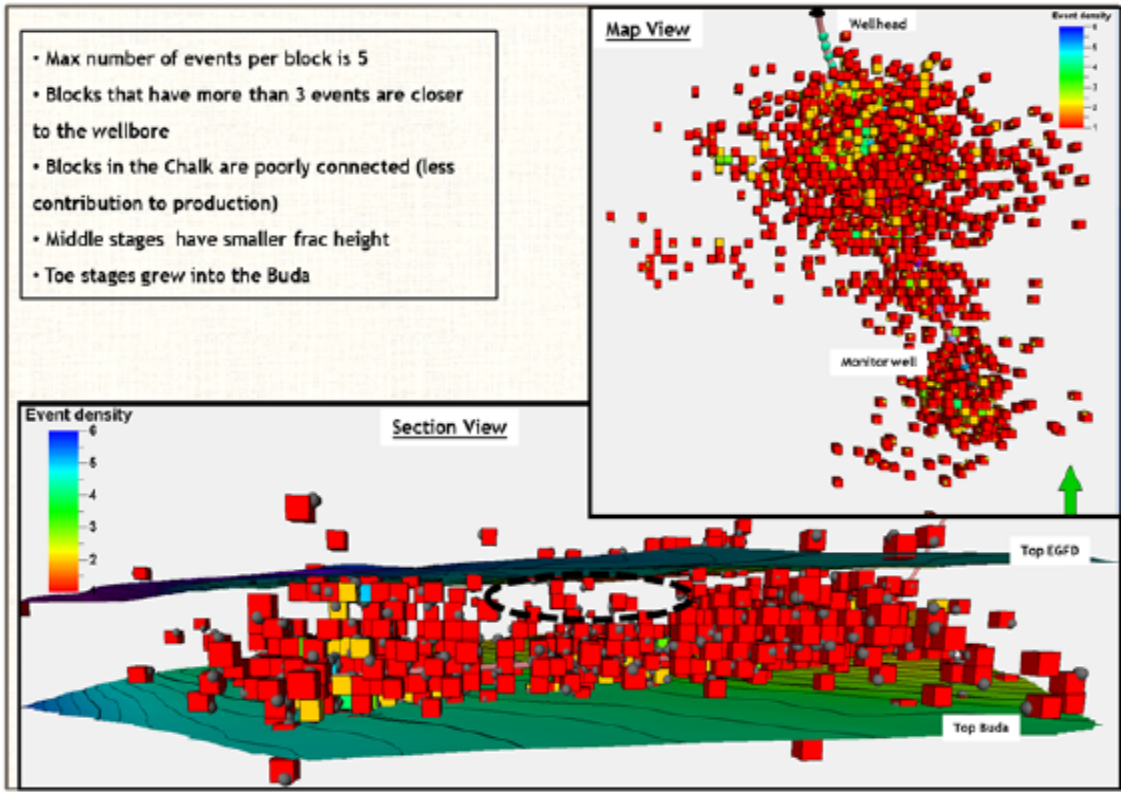
Microseismic – Extensive Horizontal Use

•Best Method for determining fracture geometry (SRV) in horizontal wells

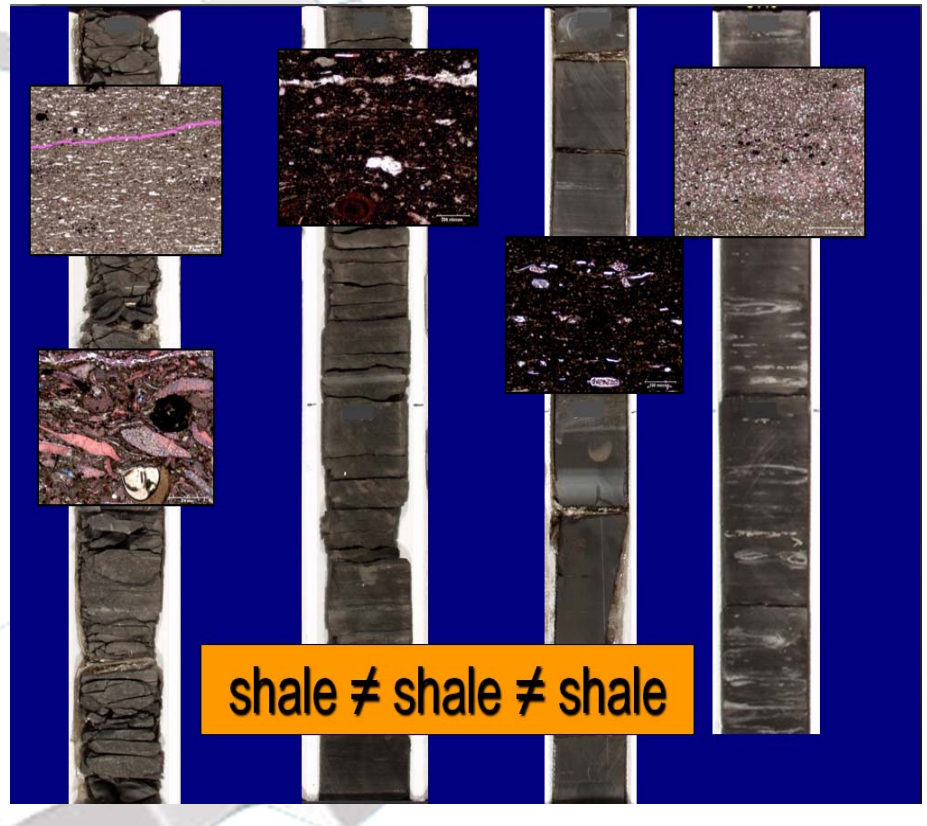
•Indicates where fluid went

•"Live" data to make changes to job (Diversion technique application)

•Multiple deployment variations



Geometry of the Hydraulic SRV (SPE 164546)

Comments

- No shales are alike.
- Optimize stimulation design must start from well planning
- Slickwater/Gel high rate fracturing job proved to be most effective in shale gas plays
- SRV, fracture network spacing and conductivity are identified key factors linked to well performance