Webinars

Induced Seismicity and Recent Advances in Hydraulic Fracturing Diagnostics

Dr. Mike Brudzinski and Mary Van Domelen

April 18, 2022

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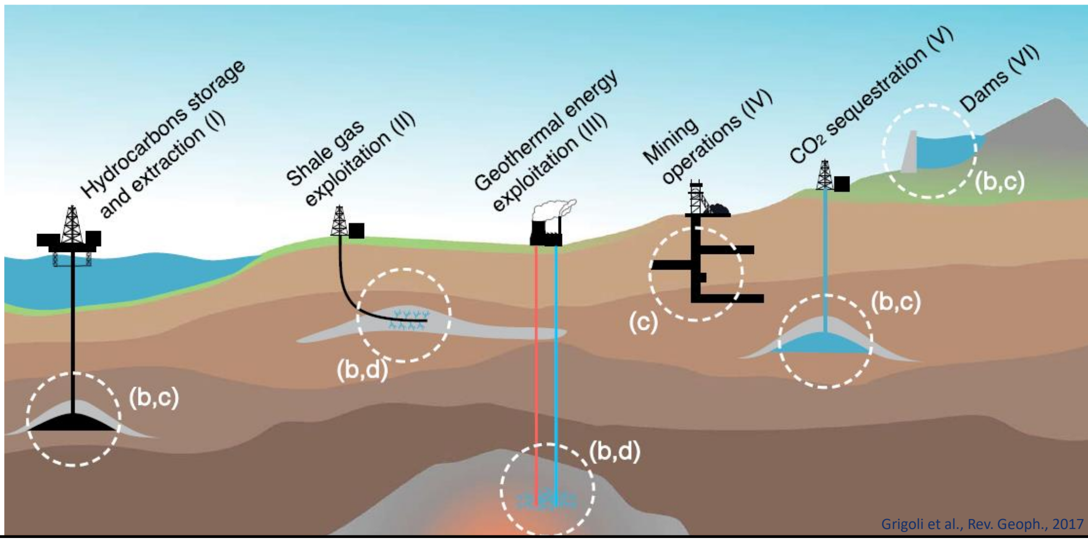
Industrial Activities that Induce Seismicity



Grigoli et al., Rev. Geoph., 2017

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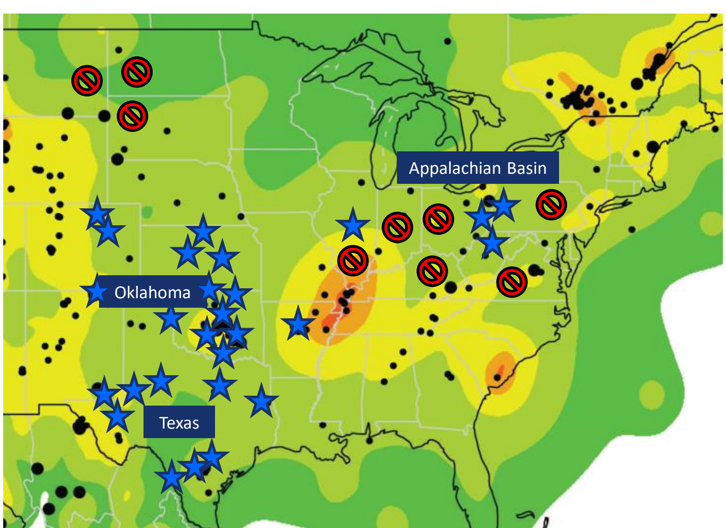
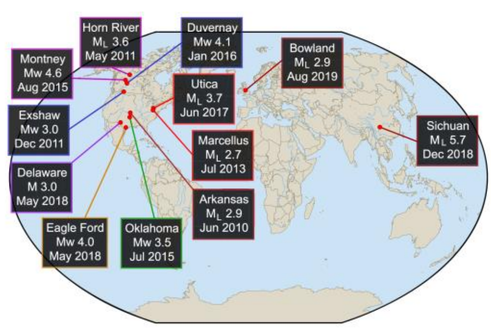
Many Injection Induced Seismicity Cases to Learn From





Ellsworth, Science, 2013; Schultz et al., Rev. Geoph., 2020; Brudzinski & Kozlowska, Acta Geop., 2019

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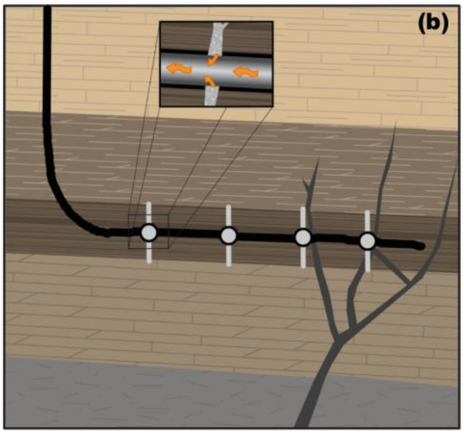
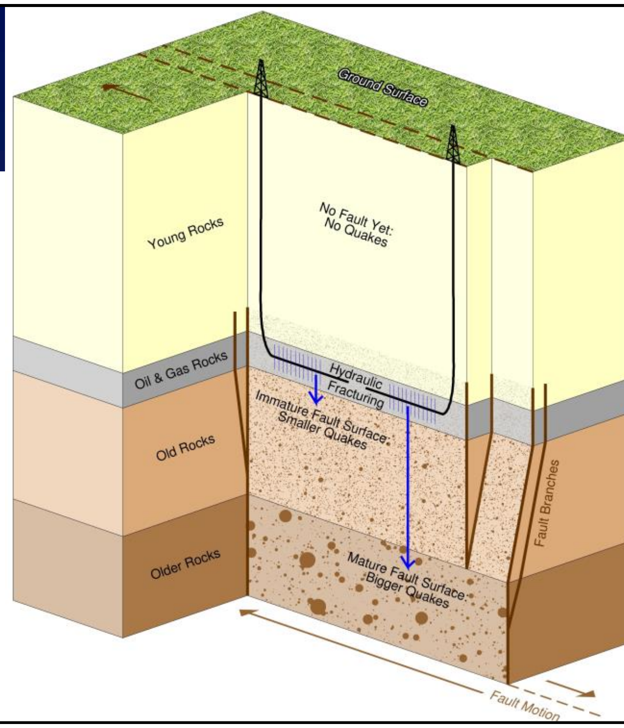
Hydraulic Fracturing Induced Seismicity





Schultz et al., Rev. Geoph., 2020; Kozlowska et al., PNAS, 2018

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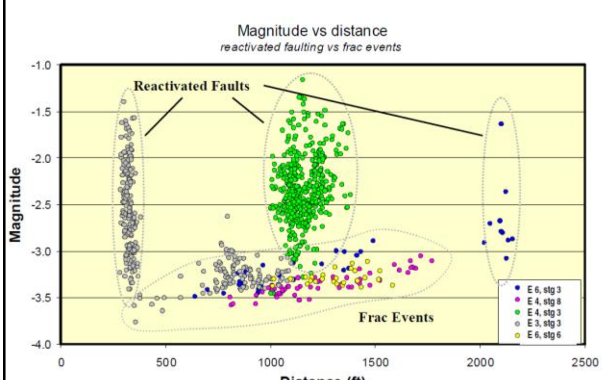
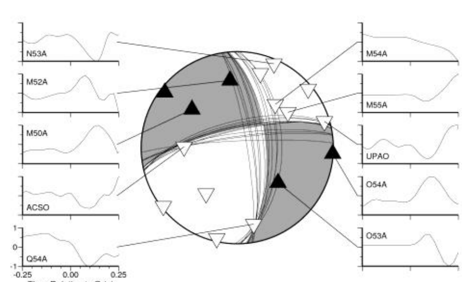
HF Induced Seismicity Occurs on Preexisting Faults

- In-formation shale fracturing typically M ~ -3
  - M > -2 indicates reactivation of out-of-zone pre-existing fault



- Focal mechanisms indicate reactivation of optimally oriented pre-existing faults



Wolhart et al., 2006; Kozlowska et al., PNAS, 2018

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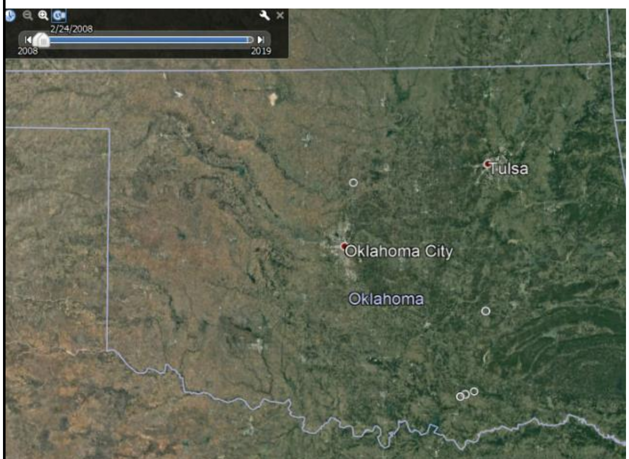
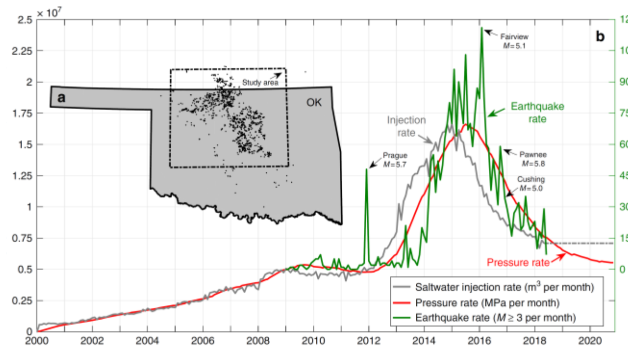
Salt Water Disposal Induced Seismicity in Oklahoma



- Seismicity rate matches fluid pressure rate modeled from injection



Dempsey & Riffault, WRR, 2019; Langenbruch et al., Nat.Com., 2018; Skoumal et al., J.Seis., 2020

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Salt Water Disposal Induced Seismicity in West Texas

- Deeper, western seismicity associated with deeper injection
- Shallower, southern seismicity associated with shallow injection
- Some cases of HF seismicity too

Skoumal et al., JGR, 2020; Tung et al., GRL, 2021; Zhai et al., PNAS, 2021

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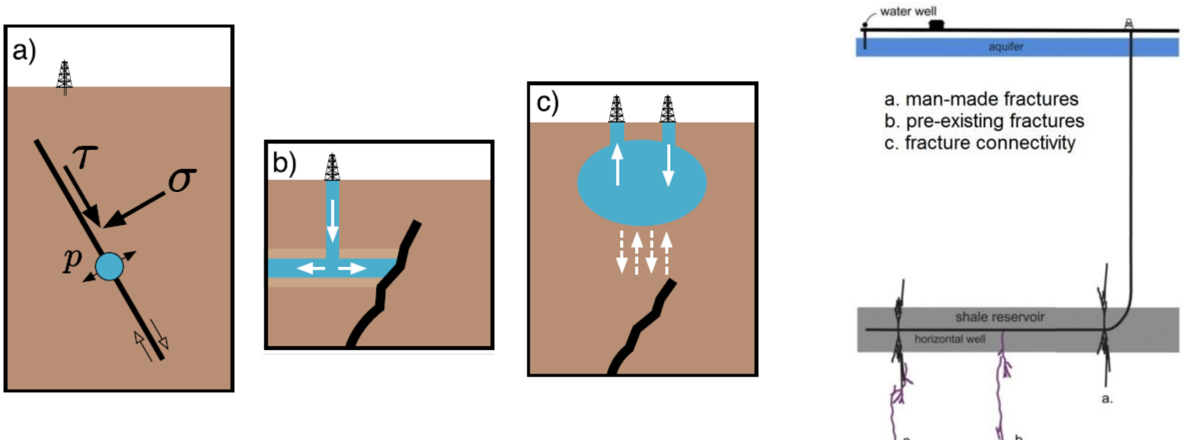
Physical Mechanism of Injection Induced Seismicity

- Increased pore fluid pressure reduces effective normal stress



Davies et al., MPG, 2013; Grigoli et al., Rev. Geoph., 2017

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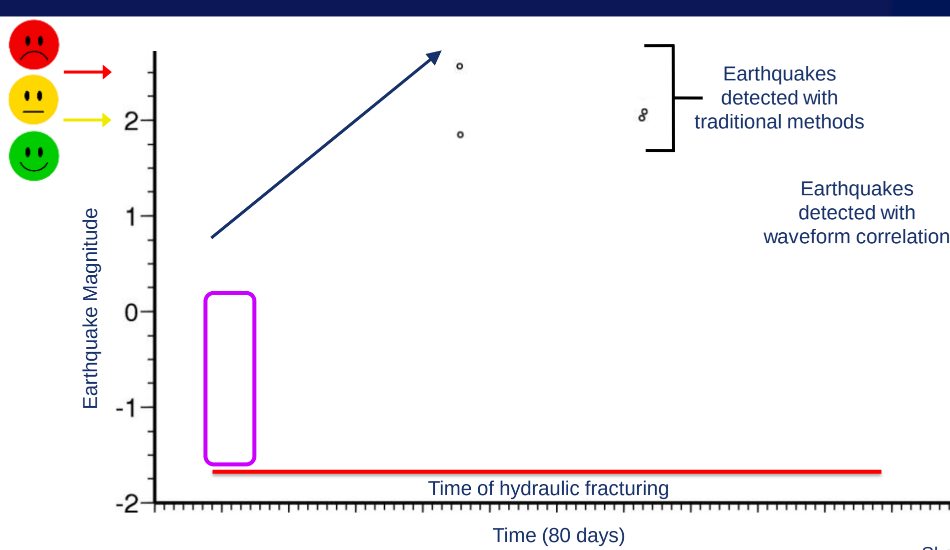
Typical Magnitude Patterns and Importance of Enhanced Detection



Skoumal et al., JGR, 2016

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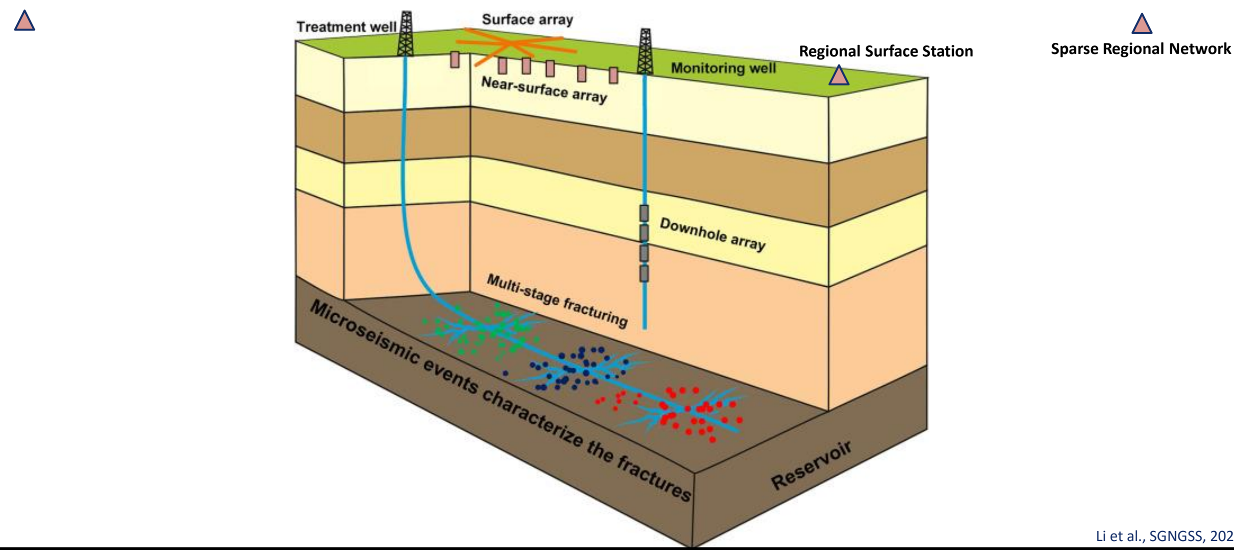
Commercial Microseismicity Monitoring



Li et al., SGNGSS, 2021

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Impacts of Larger Magnitude Cases

- Largest SWD Induced Earthquake: M 5.8 Pawnee, OK
  - Severe shaking, damage, limited injuries
- Largest HF Induced Earthquake: M 5.7 Sichuan, China
  - 100s of injuries, some deaths

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Example HF Induced Seismicity Regulations

OHIO

- ML ≥ 1.5 → Direct communication starts between operator & ODNR
- ML = 2.0-2.4 → Work with operator to propose or modify operation
- ML ≥ 2.5 → Temporary halt completions on lateral
- ML = 3.0+ → Completion on pad suspended until a plan is submitted by operator is approved

OKLAHOMA

- February 2018: OCC applied regulations to the SCOOP/STACK play
- Operator requirements if an earthquake of a given size within 5 km of a HF well:
- M ≥ 2.0 → Implement a seismicity response plan
- M ≥ 3.0 → Pause operations
- M ≥ 3.5 → Suspend (perhaps permanently shut down) operations

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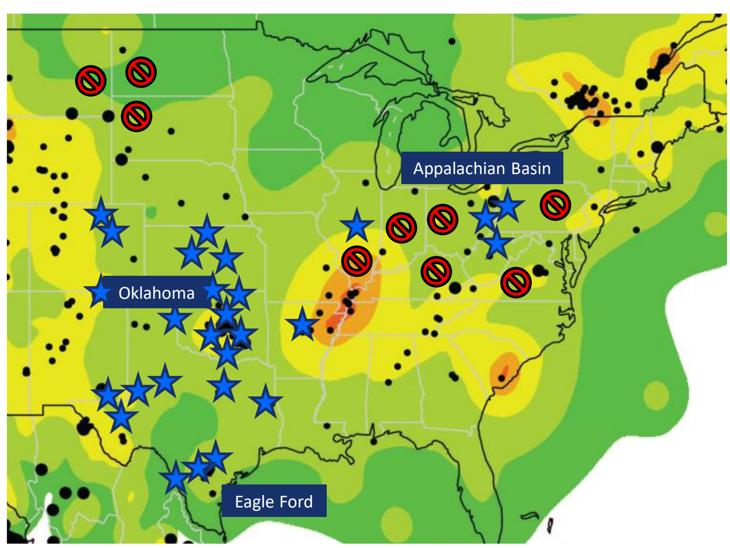
Factors Influencing When Induced Seismicity Occurs

- Proximity to optimally oriented, critically stressed faults
- Influence of well depth
- Volume of fluid injected per area per time



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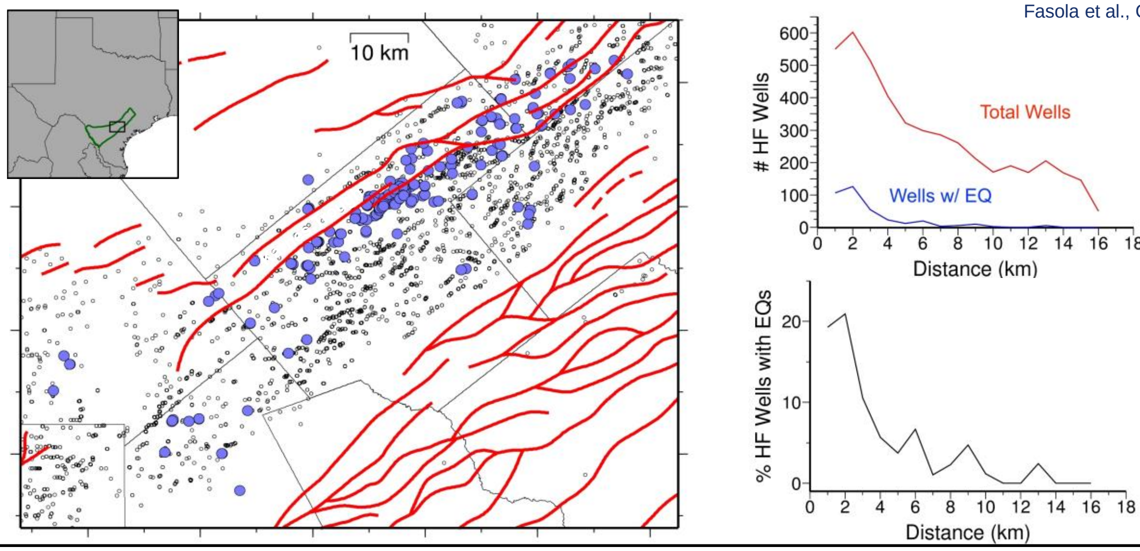
Seismicity More Likely Near Optimally Oriented Faults

Fasola et al., GRL, 2019



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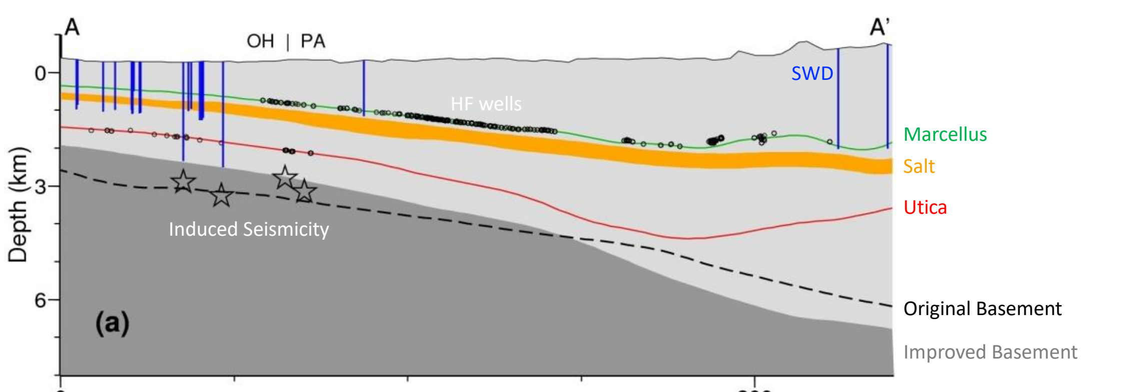
Distance to Basement as Proxy for Fault Proximity

- Improved basement map in Appalachian Basin indicates proximity of basement to Utica and deeper WD wells was a key factor



Skoumal et al., Geosphere, 2018

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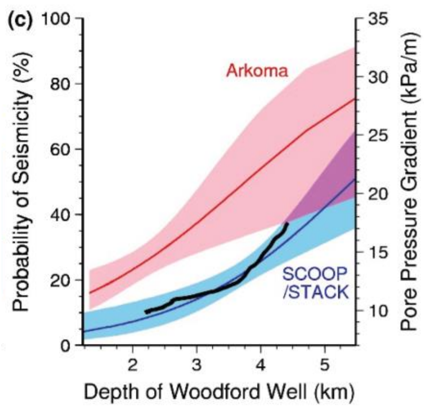
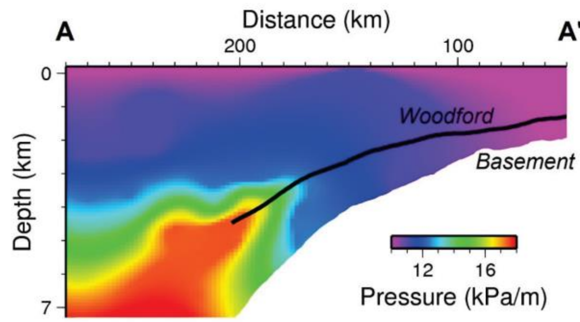
Well Depth (Not Proximity to Basement) Correlated Best in Oklahoma HF Cases

- Increased probability of seismicity with well/formation depth is consistent with observed increase in pore pressure gradient





Ries et al., BSSA, 2020; Lee and Deming, 2002

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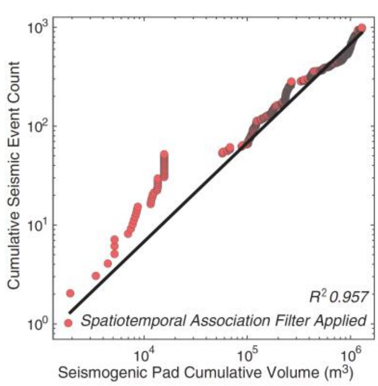
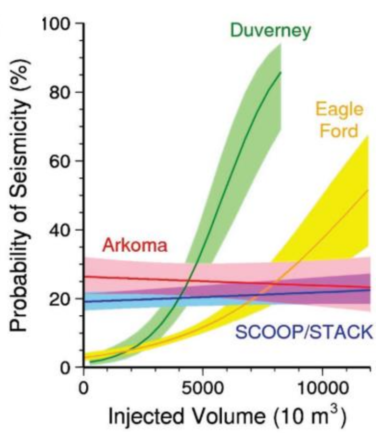
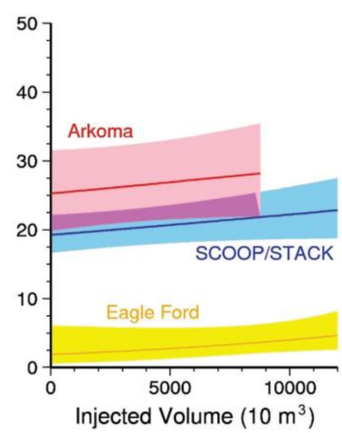
Influence of Injected Volume on Seismicity







Schultz et al., Science, 2018; Fasola et al., GRL, 2019; Ries et al., BSSA, 2020

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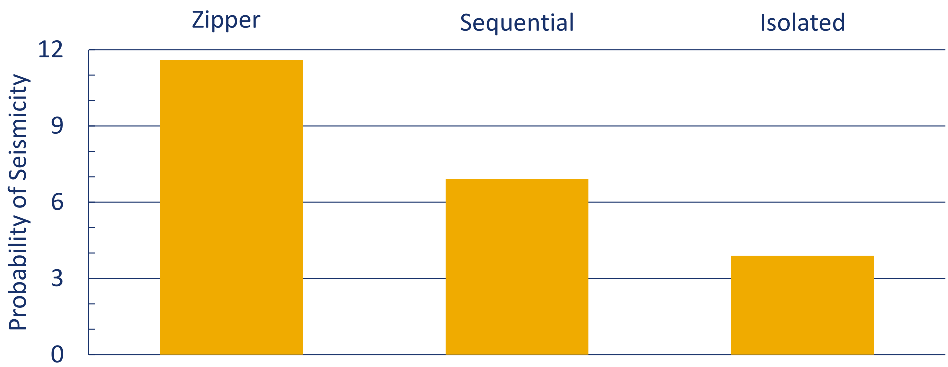
Influence of HF Stimulation Strategy (Eagle Ford)



- Zipper/Simultaneous is **3.2x** more likely to produce seismicity than Isolated ($p = 0.0002$)
- Zipper/Simultaneous is **1.8x** more likely to produce seismicity than Sequential ($p = 0.005$)

Fasola et al., GRL, 2019

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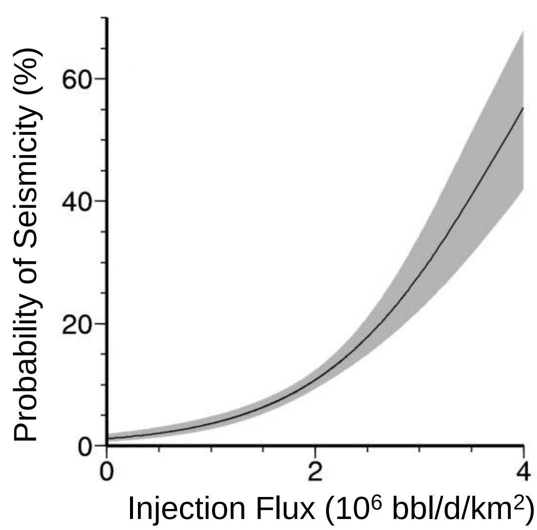
Injection Flux is Better than Injected Volume

- Calculated Injection Flux for Eagle Ford HF wells
- Volume per day per area
- Strongest trend for increased probability of seismicity we found



Fasola et al., GRL, 2019

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Advances in Hydraulic Fracturing Diagnostics

Mary Van Domelen
Senior Completions Advisor
Well Data Labs

4-18-2022

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What I have learned from Dr. Brudzinski

Avoid the 4 Ts to minimize the risk of induced seismicity

TOO much fluid

Injected **TOO** quickly

With **TOO** much pressure

TOO close to a fault

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Part 2: Advances in Hydraulic Fracturing

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Sealed wellbore pressure monitoring (SWPM)

- A breakthrough technology - SWPM
- Case study 1: Improved fluid design with high viscosity friction reducers (HVFR)
- Case study 2: Using SWPM for fault detection

Reducing costs by reducing completion times

- Zipper fracs vs. simul-fracs – monitoring simultaneous operations

Avoid the 4 Ts to minimize the risk of induced seismicity
TOO much fluid
Injected TOO quickly
With TOO much pressure
TOO close to a fault

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Sealed Wellbore Pressure Monitoring (SWPM)

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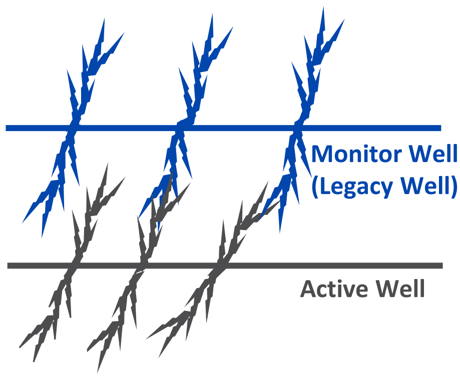
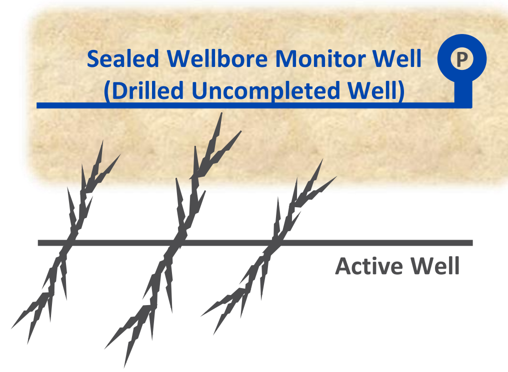
Fracture driven interactions (FDIs) vs. Sealed Wellbore Pressure Monitoring (SWPM)

Active fractures intersect one or more existing fractures, causing fluid migration from the new fractures into the existing fracture network (△P = 10's to 1000's of psi)

Active fractures propagate through unstimulated reservoir rock until the dominant fracture intersects the sealed wellbore (△P = 1's to 10's of psi)



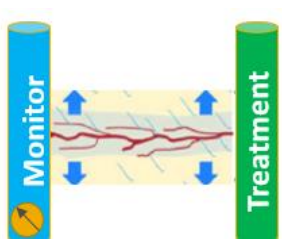


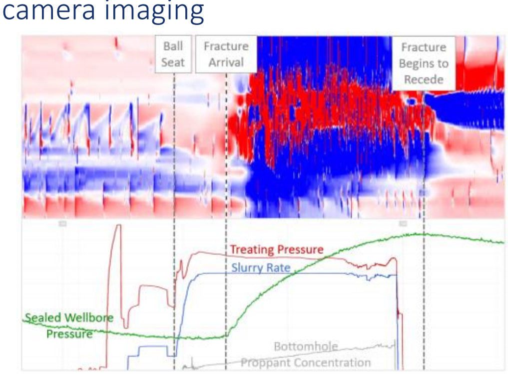
Note: fracture connections that occur during fracturing operations may not be permanent

Sealed Wellbore Pressure Monitoring (SWPM)

SWPM is a diagnostic method that utilizes one or more wells as a closed system to monitor fracture intersections from an offset well being hydraulically stimulated

Workflow has been validated with multiple data sets of cross-well strain, microseismic, optical fiber, production logs and downhole camera imaging





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SWPM | Adoption in the market

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SWPM has seen rapid growth and success since commercialization

70+ projects delivered or in-progress

~15,000 stages analyzed as of April 2022

>250 treatment wells analyzed

22 unique operators

16 major basins in North and South America, 3 countries

14 SPE papers and trade journal articles since introduction to industry in 2020

Hart Energy 2021 Meritorious Award for Engineering Innovation

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Primary parameter measured is the Volume to First Response (VFR)

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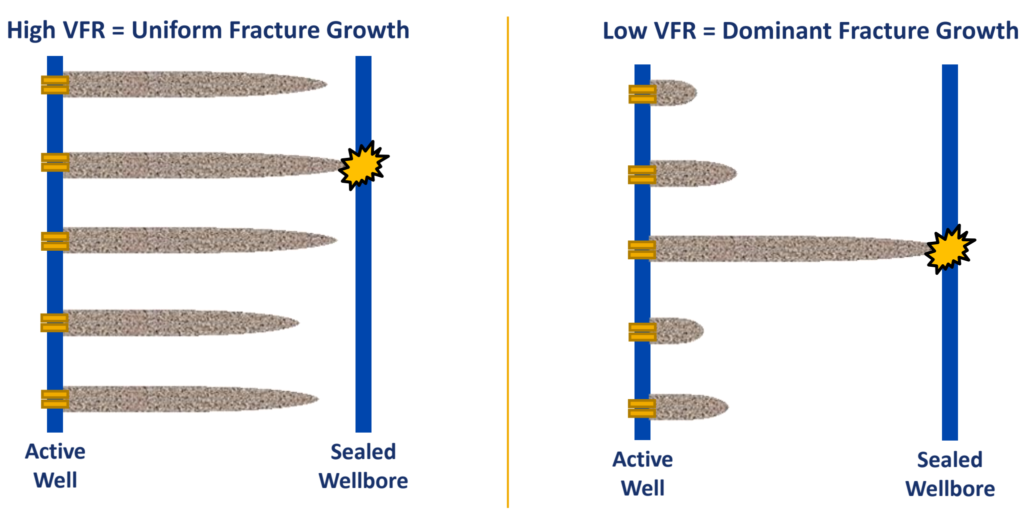

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Case study 1: SW vs. HVFR

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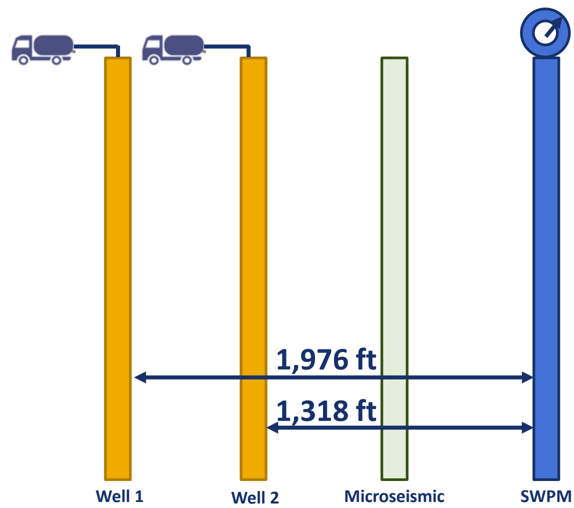
Project goals

- Compare relative efficiencies of slick water (SW) and high viscosity friction reducer (HVFR) frac designs
- Same perforation design, target injection rates and wellhead pressure limitations for all stages



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High Viscosity Friction Reducers (HVFRs)

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Technical advantages

- More efficient proppant transport
- Better fluid efficiency
- Cleaner, less damage to proppant pack
- Lower friction pressures
- Less blending equipment on location
- Less fluid required per pound of proppant placed

Environmental advantages

- Reduced truck traffic
- Dry version eliminates the need to transport solvent
- Reduced emissions
- Less flow back fluid to dispose
- Ability to recycle produced water

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High Viscosity Friction Reducers (HVFRs)

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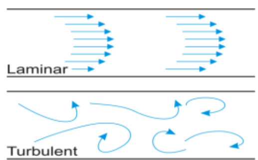
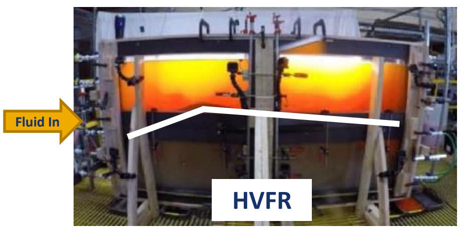
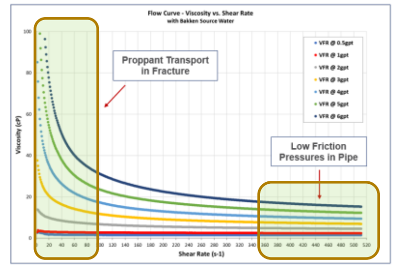
Friction reducers (both SW and HVFR) are polymers that decrease pumping pressures by reducing pipe friction due to turbulence

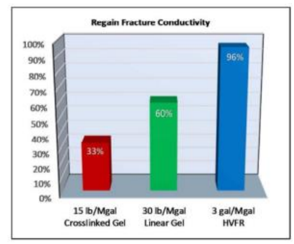


HVFRs are viscoelastic fluids which have high viscosity during proppant transport in the fractures but low viscosity while pumping down the tubing



Images compliments of PropTester Proppant Testing Consortium





Reference: SPE 189893 Figure 3

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Case study 1: observations

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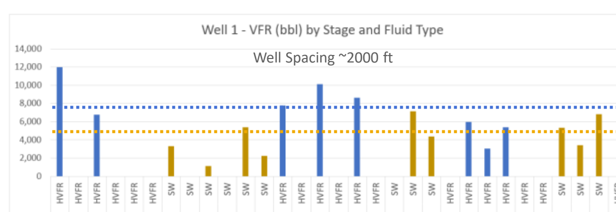
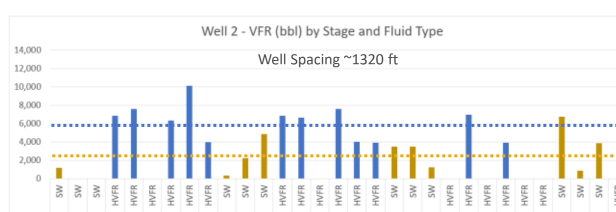
Observations:

- 62 stages were monitored, of which 24 utilized SW and 38 utilized HVFR
- A total of 39 responses were observed, with decreasing response count as well spacing increased
- The HVFR stages were more efficient, placing 58 lbs/bbl; compared to the SW stages placing only 36 lbs/bbl
  (47% reduction in fluid requirement)





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Case study 1: conclusions

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Microseismic and SWPM data demonstrated that the HVFR fluid resulted in higher cluster efficiencies and created a more complex fracture network

HVFR fluid design was more efficient than the slick water design based upon the **reduction in fluid volume** required per pound of proppant placed and **lower horsepower requirements**

A measurable production uplift was observed based on completion design changes suggested by SWPM

Learnings from on this project will lead to **significant cost savings** on future pads

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Case study 2: using SWPM to identify faults

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SWPM Applications

- Qualitative cluster efficiency/fluid distribution
- Fracture count in the far-field
- Fracture height and fracture half-length
- Depletion identification and mitigation
- Fracture model calibration
- Impact of faults or structure on fracture propagation

Early responses ⇨ small VFRs ⇨ high fracture growth rates

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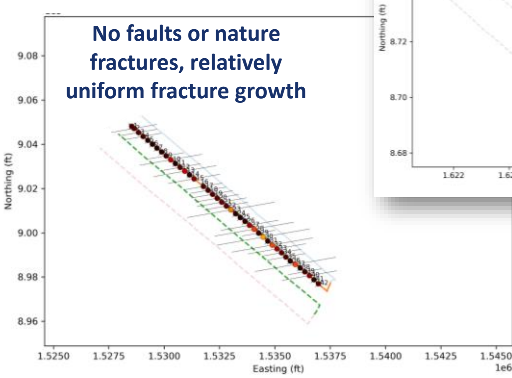
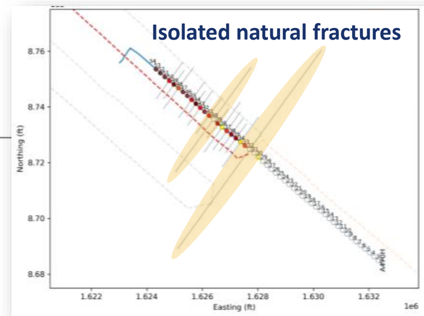
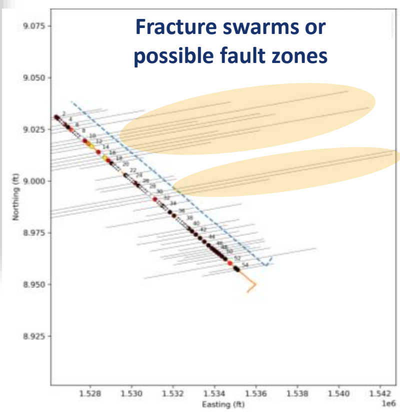
Fracture half-lengths estimated from VFRs







Lighter bubbles superimposed at stage level indicate small VFRs (early responses)
Small VFR = Long Fracture

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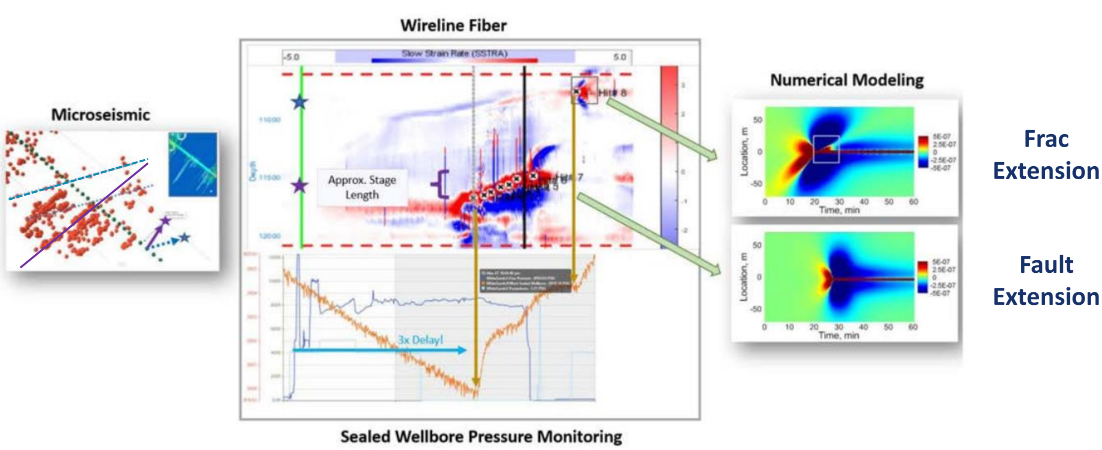
Published application (SPE 209140)



"These analyses are used to help interpret and predict field diagnostics as well as understand activation thresholds and the influence of these features on productivity."

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Reducing Costs by Reducing Completion Times

An evaluation using a Cloud Based Analytical Platform (CBAP)

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Increasing operational efficiency

- Single well completions: frac ⇨ wireline ⇨ frac ⇨ wireline .....

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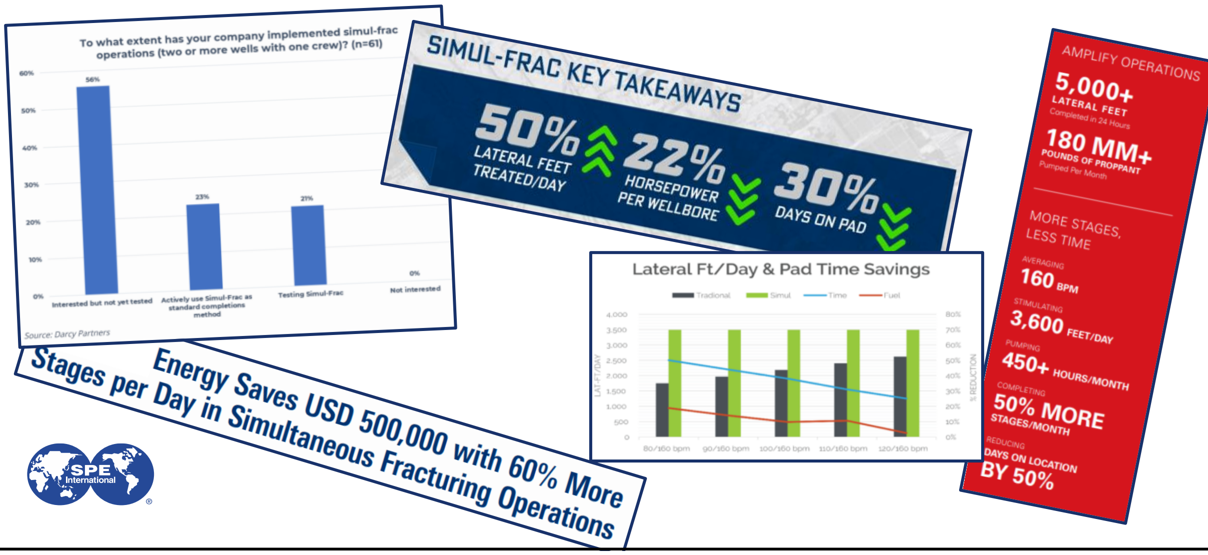
Simul-frac: the advertising hype



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Simul-frac vs. zipper frac completions

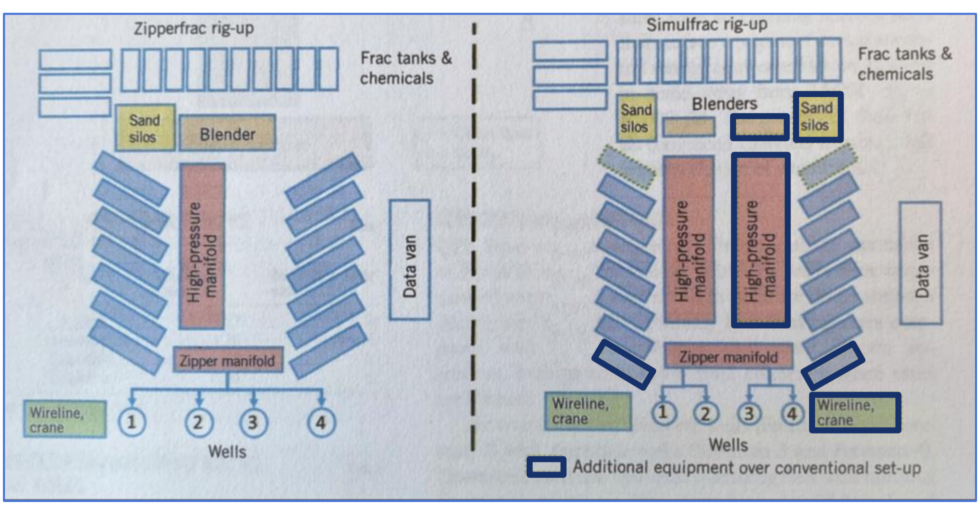

Image reference: Oil and Gas Journal | January 3, 2022 | Figure 1, page 36

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Case study: zipper vs simul-frac

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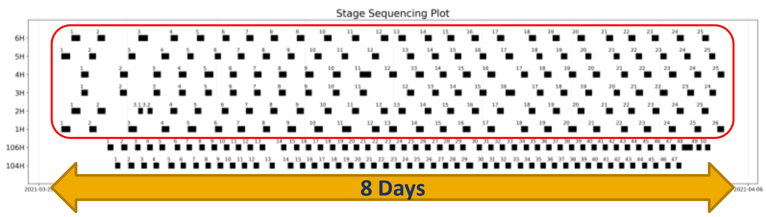

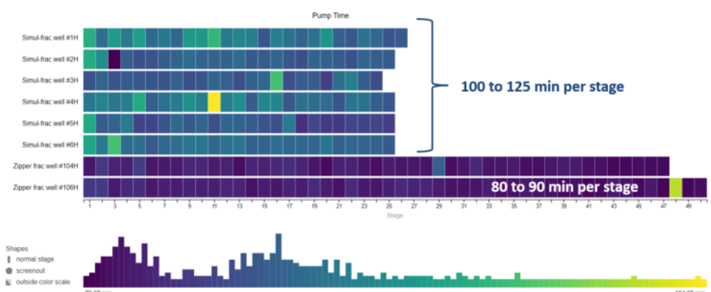

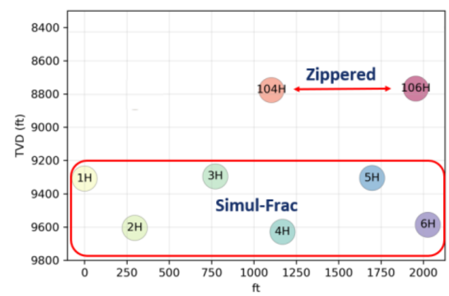

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Is the advertising hype true?

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6 well simul-frac

AVG STAGES/DAY	AVG PUMP TIME/DAY	AVG PROPPANT/DAY	AVG CLEAN VOLUME/DAY
18.88 stages	36:22 hh:mm	6,256,624 lbs	174,951 bbl
Completed Stages: 151	Avg Pump Time/Stage: 01:55	Total Proppant: 50,052,993	Total Clean Volume: 1,399,609
		Avg Proppant/Stage: 333,687	Avg Clean Volume/Stage: 9,331
+56%	2x	+28%	+84%

2 well zipper frac

AVG STAGES/DAY	AVG PUMP TIME/DAY	AVG PROPPANT/DAY	AVG CLEAN VOLUME/DAY
12.13 stages	17:47 hh:mm	4,856,138 lbs	94,771 bbl
Completed Stages: 97	Avg Pump Time/Stage: 01:28	Total Proppant: 38,849,103	Total Clean Volume: 758,164
	Avg Interstage Time: 00:13	Avg Proppant/Stage: 400,506	Avg Clean Volume/Stage: 7,816

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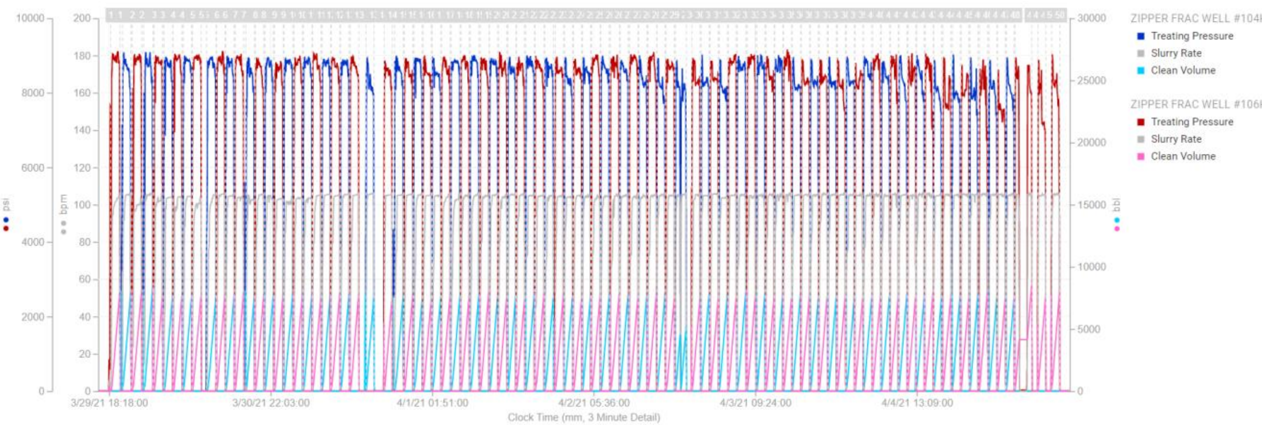
2-well zipper frac operations

8 pumping days | 97 stages



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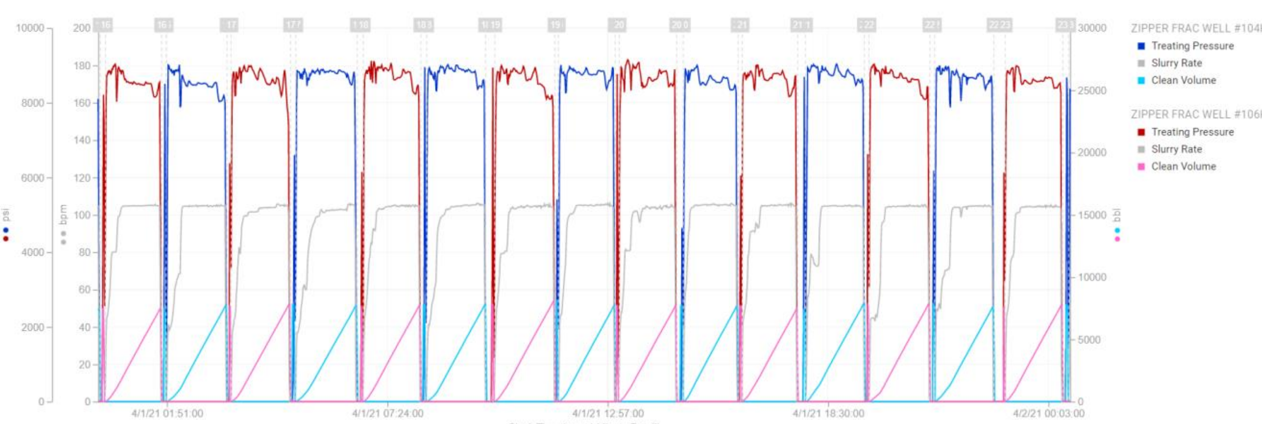
2-well zipper frac operations

24 hours | 15 stages



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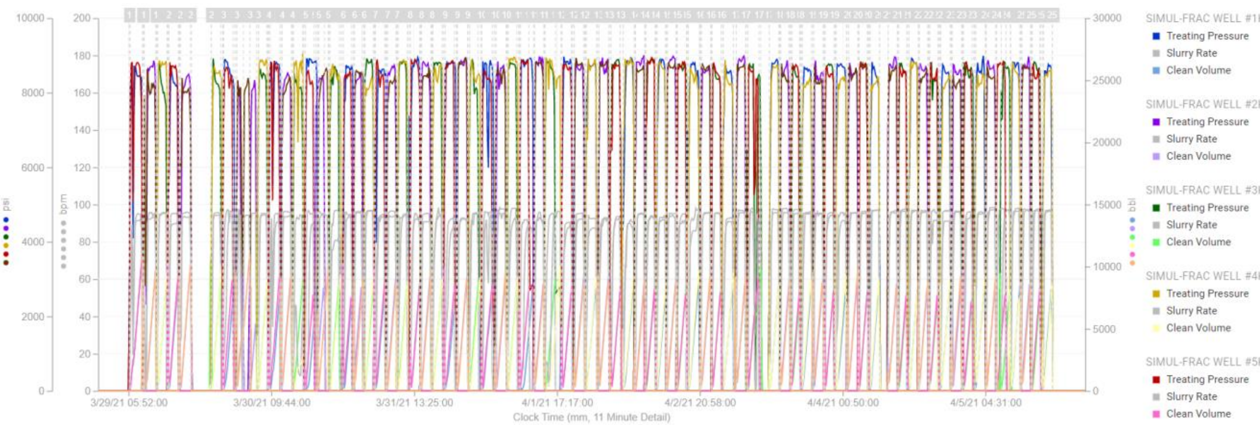
6-well simul-frac operations

8 pumping days | 150 stages



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6-well simul-frac operations

24 hours | 18 stages

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Instantaneous shut-in pressures (psi)

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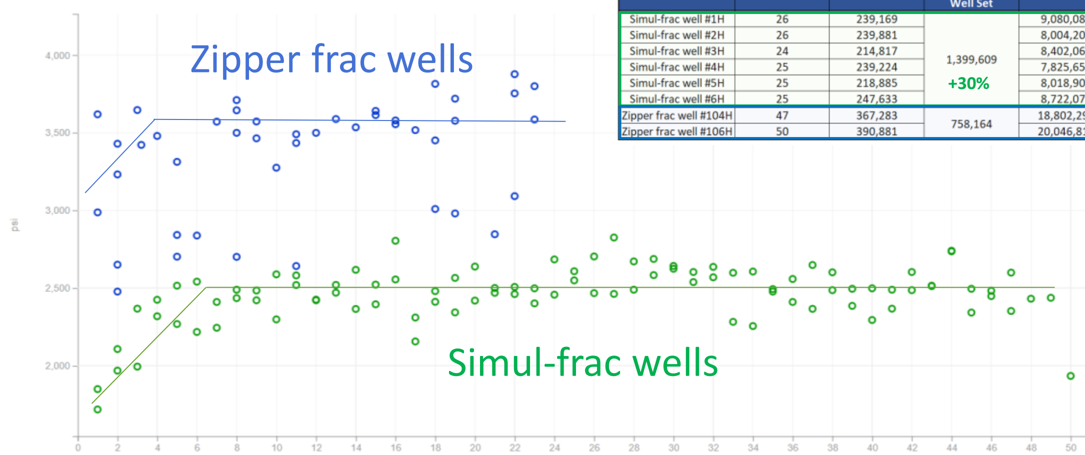

Well Name	Stage Count	CLEAN VOL (bbl)	Total Slurry Volume (bbl) for Well Set	TOTAL PROP (lbs)	Total Proppant (lbs) for Well Set
Simul-frac well #1H	26	239,169	1,399,609 +30%	9,080,080	50,052,996 +90%
Simul-frac well #2H	26	239,881		8,004,209	
Simul-frac well #3H	24	214,817		8,402,066	
Simul-frac well #4H	25	239,224		7,825,658	
Simul-frac well #5H	25	218,885		8,018,905	
Simul-frac well #6H	25	247,633		8,722,078	
Zipper frac well #104H	47	367,283	758,164	18,802,291	38,849,104
Zipper frac well #106H	50	390,881		20,046,814	

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Performance metrices

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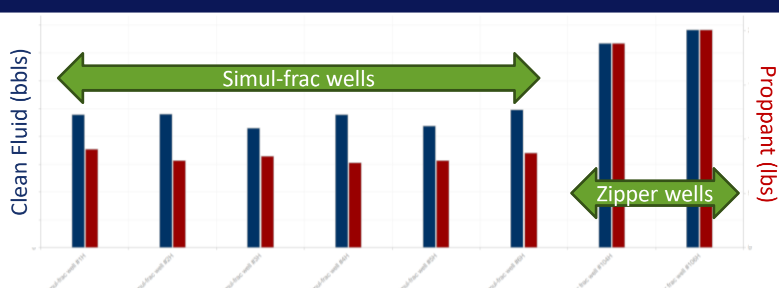
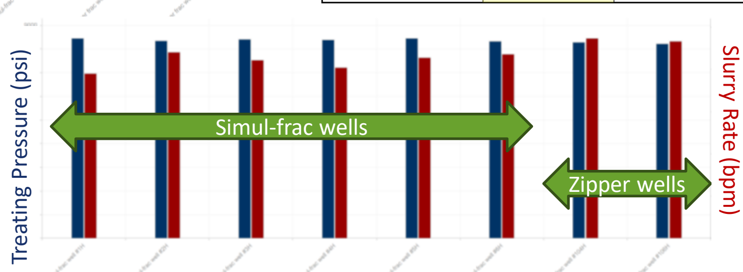


Well Name	hhp-hr "cost" per Pound of Proppant Placed	hhp-hr "cost" per Barrel of Fluid Pumped
Simul-frac well #1H	0.09	3.59
Simul-frac well #2H	0.11	3.58
Simul-frac well #3H	0.09	3.60
Simul-frac well #4H	0.11	3.56
Simul-frac well #5H	0.10	3.64
Simul-frac well #6H	0.10	3.54
Zipper frac well #104H	0.07	3.80
Zipper frac well #106H	0.08	3.87

Well Name	Average Fluid Injection Rate (BPD)
Simul-frac well #1H	230,705
Simul-frac well #2H	
Simul-frac well #3H	
Simul-frac well #4H	
Simul-frac well #5H	
Simul-frac well #6H	
Zipper frac well #104H	127,780
Zipper frac well #106H	

Based on pumping time only



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Thank You

Discussion, questions, comments

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