Advanced Hydraulic Fracturing Project

Project Number 11122-20 (RPSEA)

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Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 16-18, 2016

Presentation Outline

- Benefit to Program
- Goals and Objectives
  - Specific Tasks
- Field Test #1
- Field Test #2
- Field Test #3
- Production Results
- HFTS
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Benefit to the Program

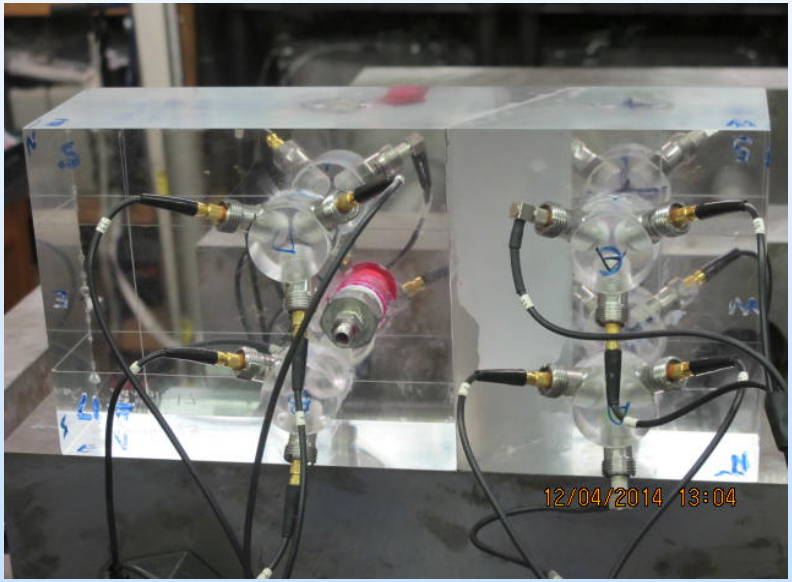
- The research project is focused on developing advanced methods and techniques for design and **execution of environmentally safe and economically efficient hydraulic fracturing operations**.
- More specifically, a novel fracture treatment design utilizing variable rate fracturing (VRF) was implemented in multiple producing wells in the Marcellus shale. The new fracturing technique has shown to increase production from a unit reservoir volume, leading to increased energy recovery per unit volume of water used used, thereby improving the economics of production from shales and other unconventional resources.

Project Overview: Goals and Objectives

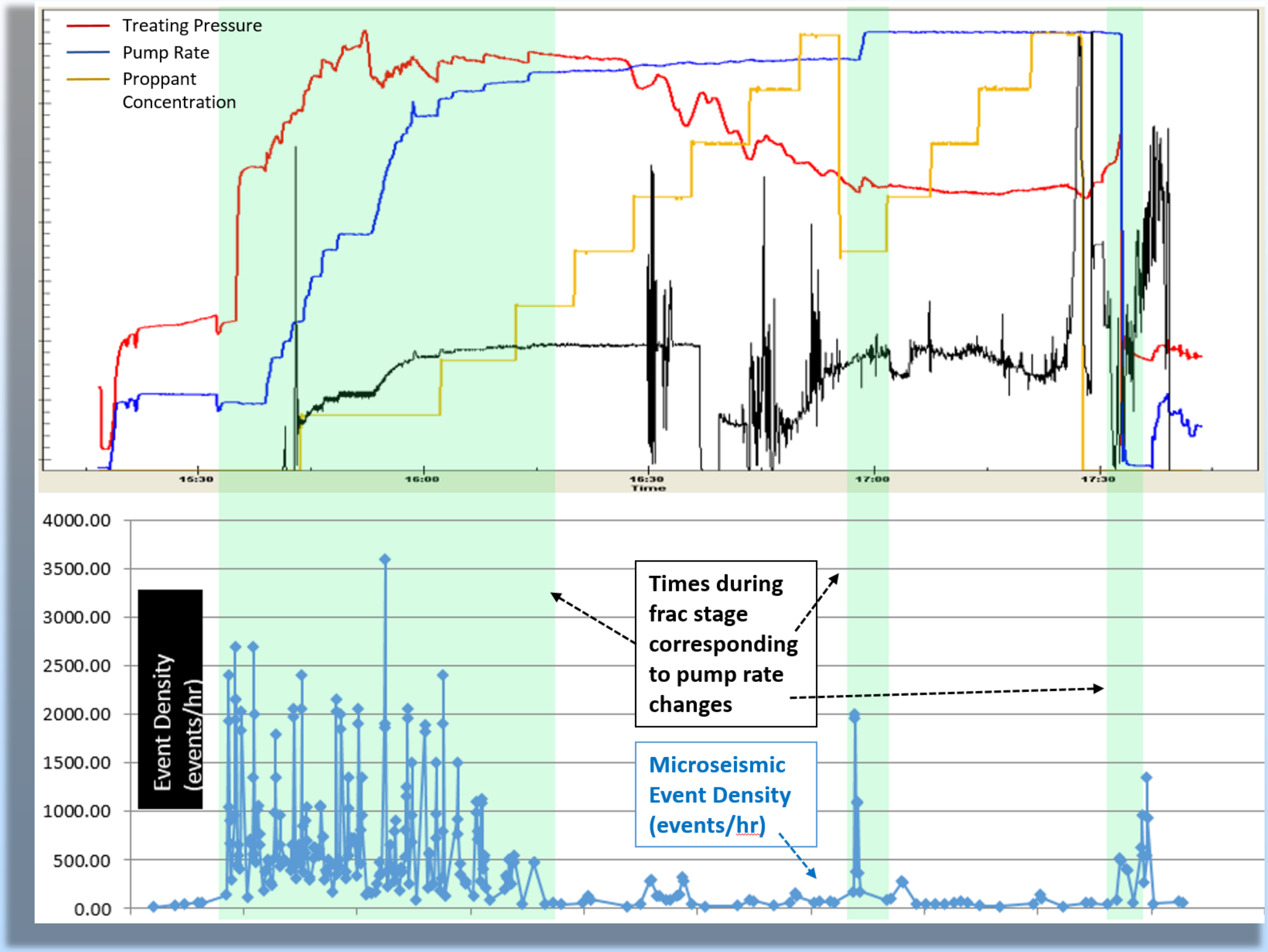
- The goal of this research project is to minimize the amount of water and additives used for fracture stimulation of a unit reservoir volume thereby alleviating the concerns relative to excessive use of fresh water, large volume of flow-back water, water disposal injections, and heavy truck traffic. The resulting optimization shall also reduce cost translating to sustainable production from gas shales.
  - The primary objective of this research project is to develop advanced methods and techniques for design and execution of environmentally safe and economically efficient hydraulic fracturing. Increased production utilizing same or decreased volume of fracturing fluid will meet the success criteria.

Specific Tasks

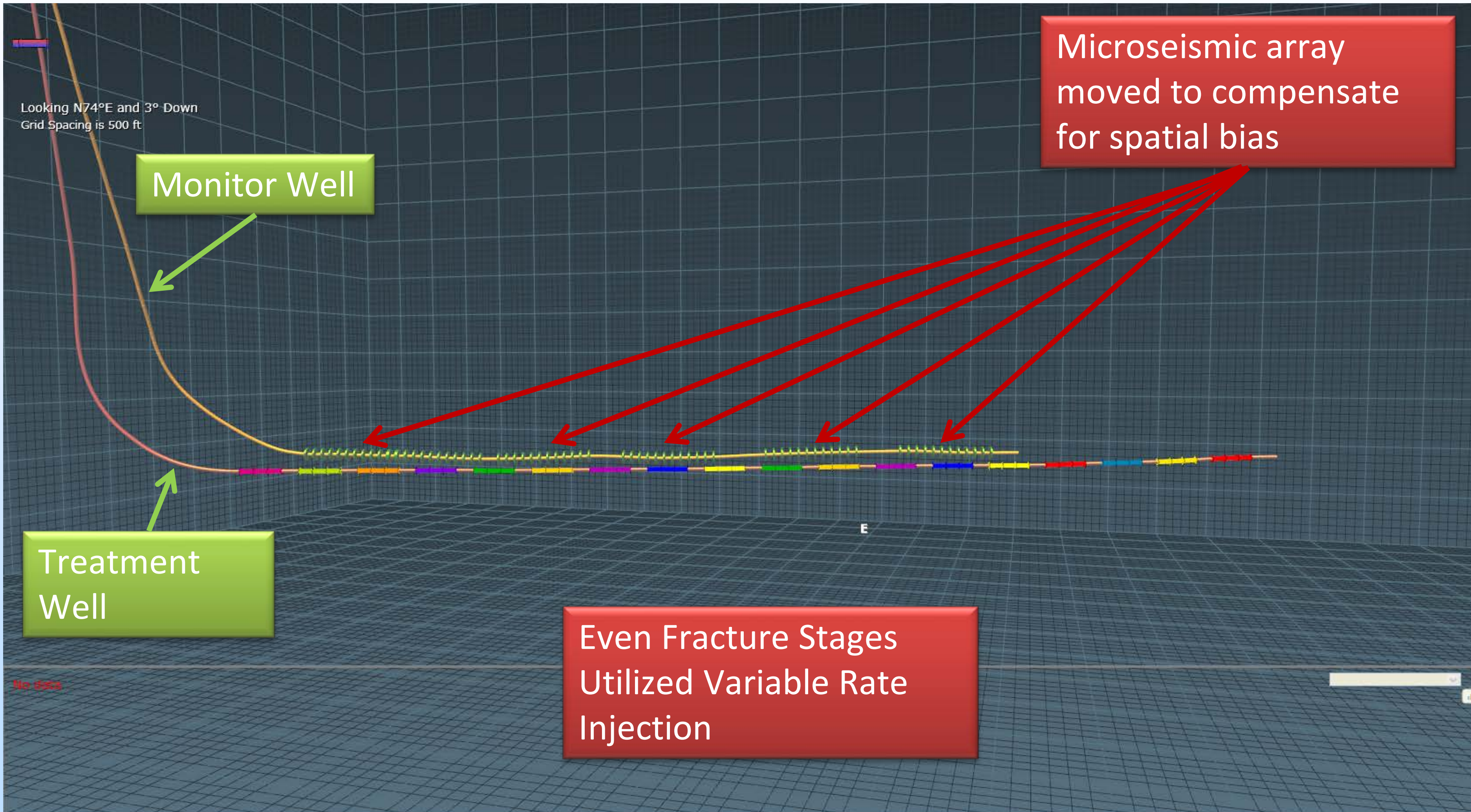
- Investigate significance and applications of variable rate fracturing
- Develop advanced microseismic data analysis techniques
- Perform laboratory experiments investigating tensile and shear mode microseismic signals
- Develop a user-friendly production analysis tool specific for shales
- Develop a project plan and scope of work for a Hydraulic Fracturing Test Site (HFTS)



Variable Rate Fracturing Background

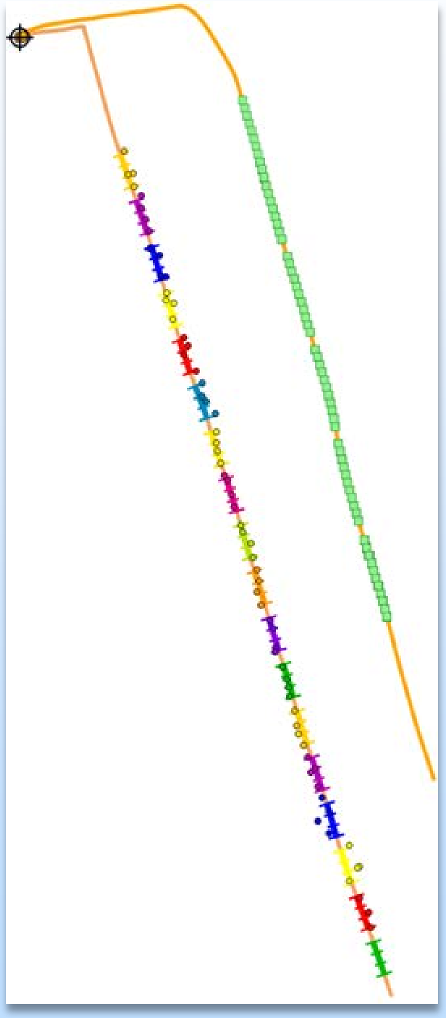


Field Test #1, Susquehanna Co.



Field Test #1

- Wells: Susquehanna Co, PA
  - 2 adjacent horizontal Marcellus wells
  - OH logs in horizontal, including image log
  - Designed and implemented a ramped pump schedule
  - Monitored with microseismic
  - Ran production logs

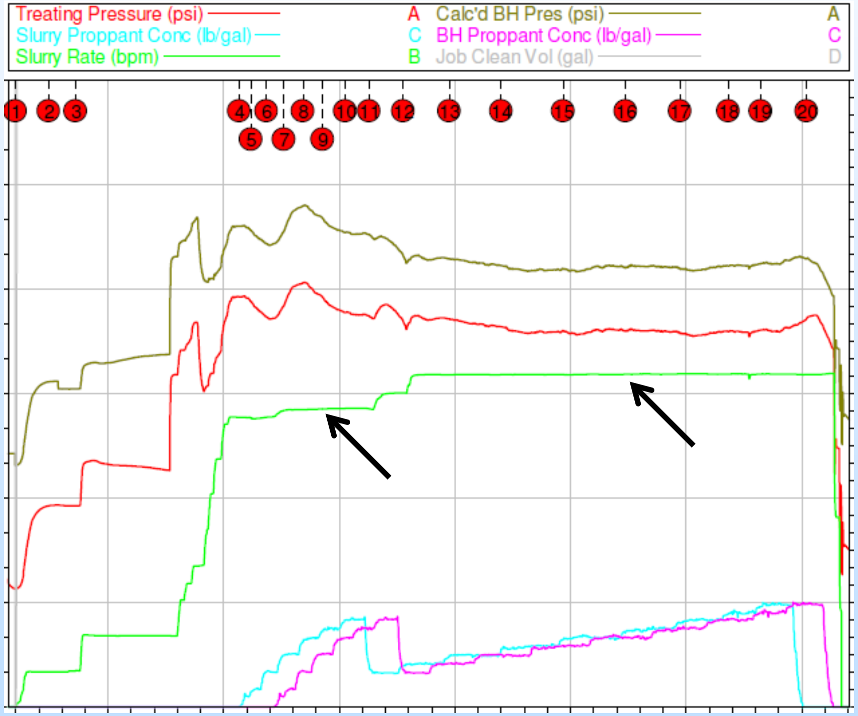


Cautious Approach

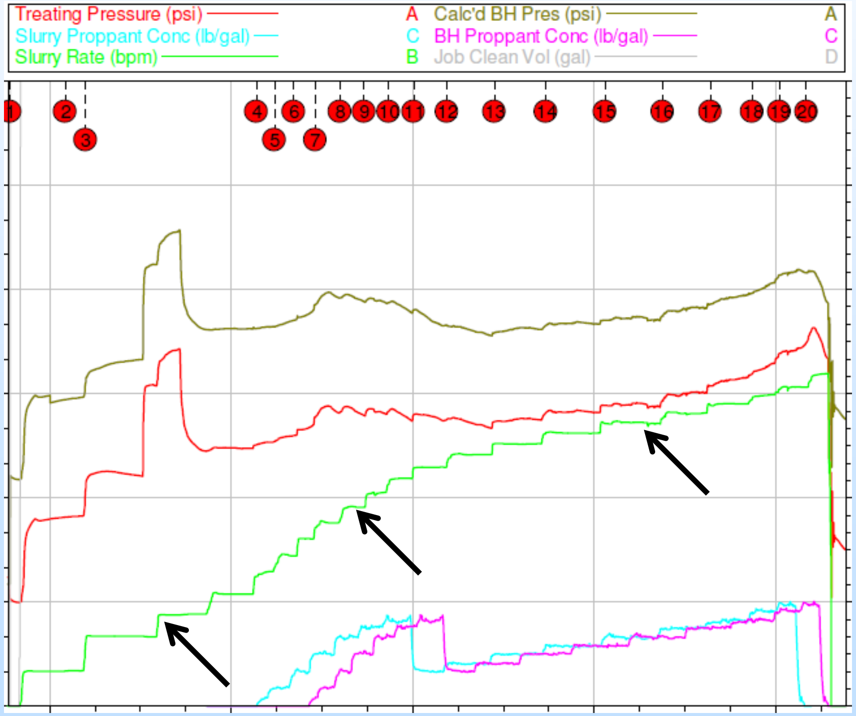
- Concerned with proppant transport at low pump rates
- Did not want to diverge too much from proven frac design as this was a producing well
- Concerns with deterioration of completion hardware if pump changes too aggressive

Field Test #1

Fixed Pump Rate



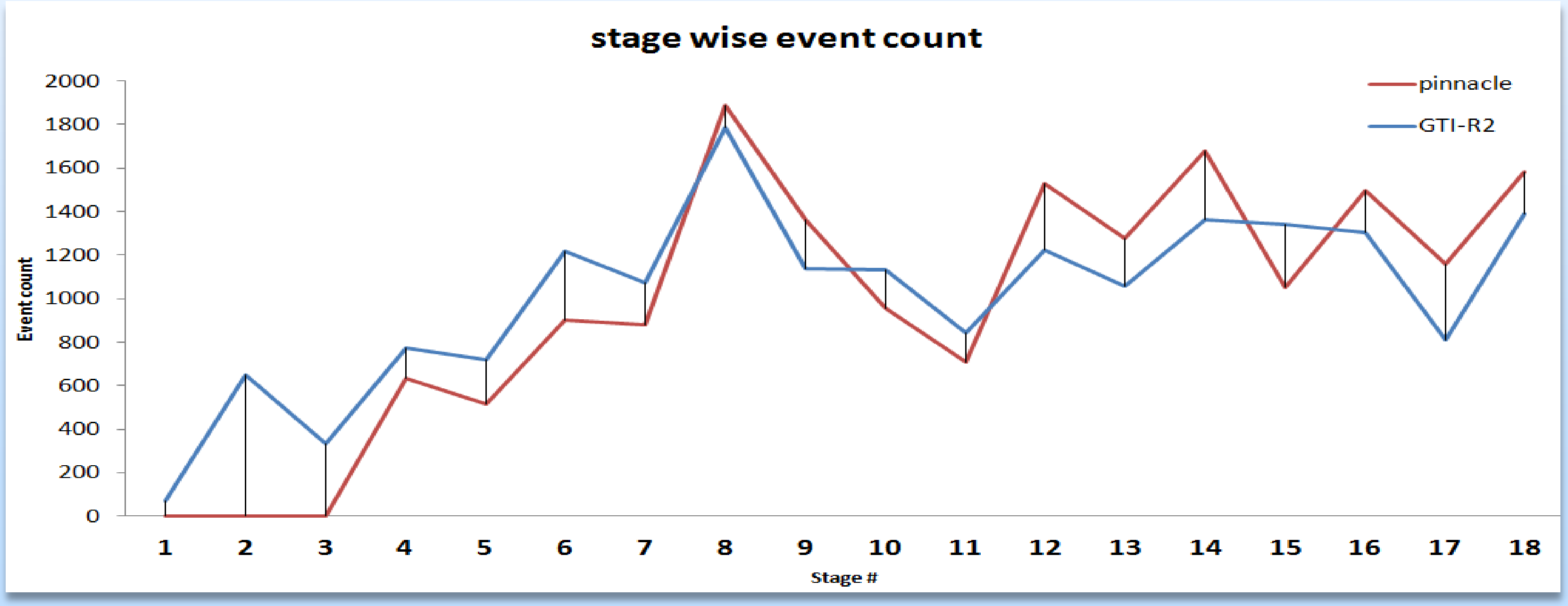
Variable Pump Rate



18 Fracture stages pumped – 9 stages variable rate, 9 stages constant rate alternating from toe to heel of horizontal well

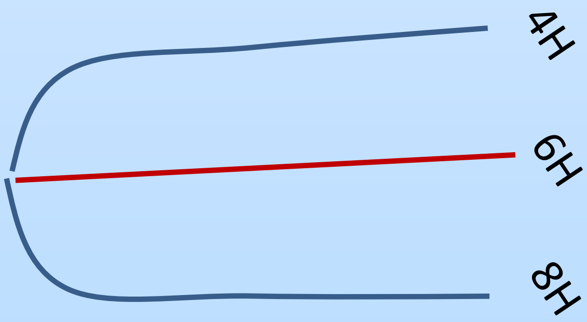
Field Test #1

- Proppant & water volume same for all stages, initial & final rate same for all stages
- No significant difference in production contribution between stages
  - Determined that rate changes were not aggressive enough
- However, variable rate stages (even) consistently showed more microseismicity than constant rate fracture stages, as notes by the number of events recorded, possibly due to longer pump time
  - No proppant transport issues or operational concerns → More aggressive field trials



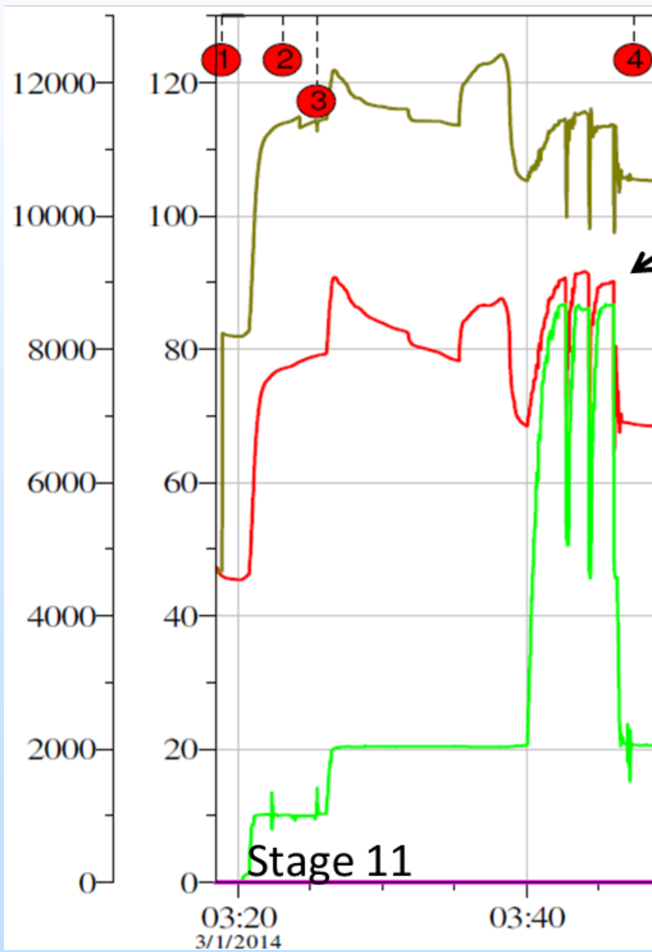
Field Test #2, Westmoreland Co.

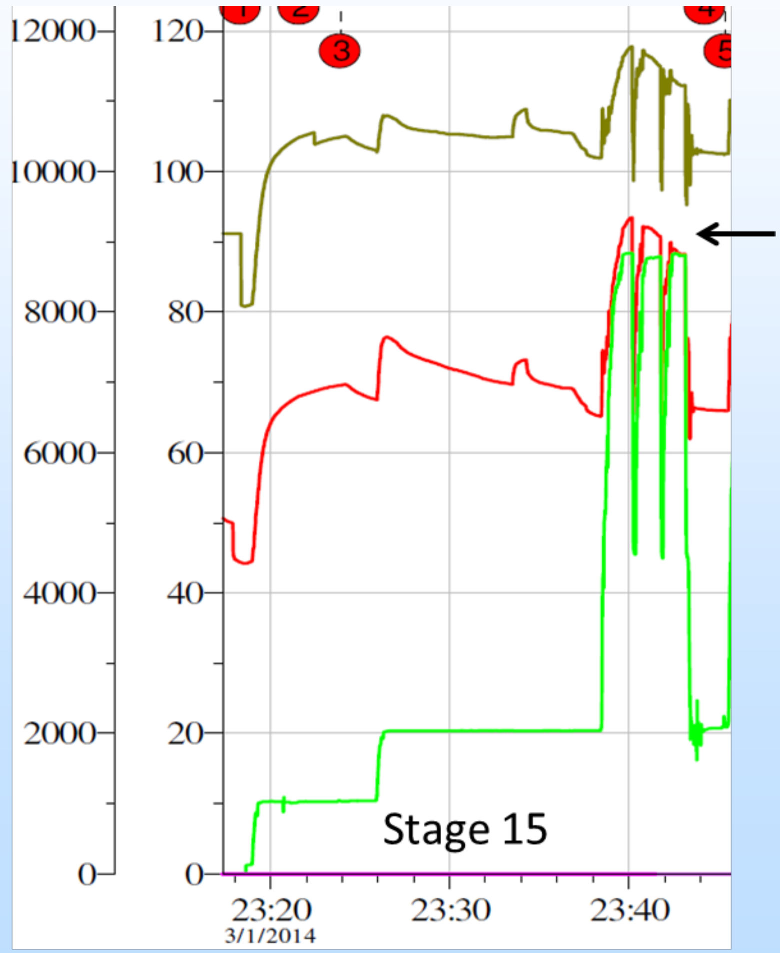
- Performed more aggressive rate variations
  - Up to 45 bpm fluctuations (90 to 45, back to 90)
  - Executed rapid rate changes in every other stage
- Review of post frac data indicated
  - Evidence of decreased treating pressure after rate variations
  - Significant differences in water hammer response
- Ran production log



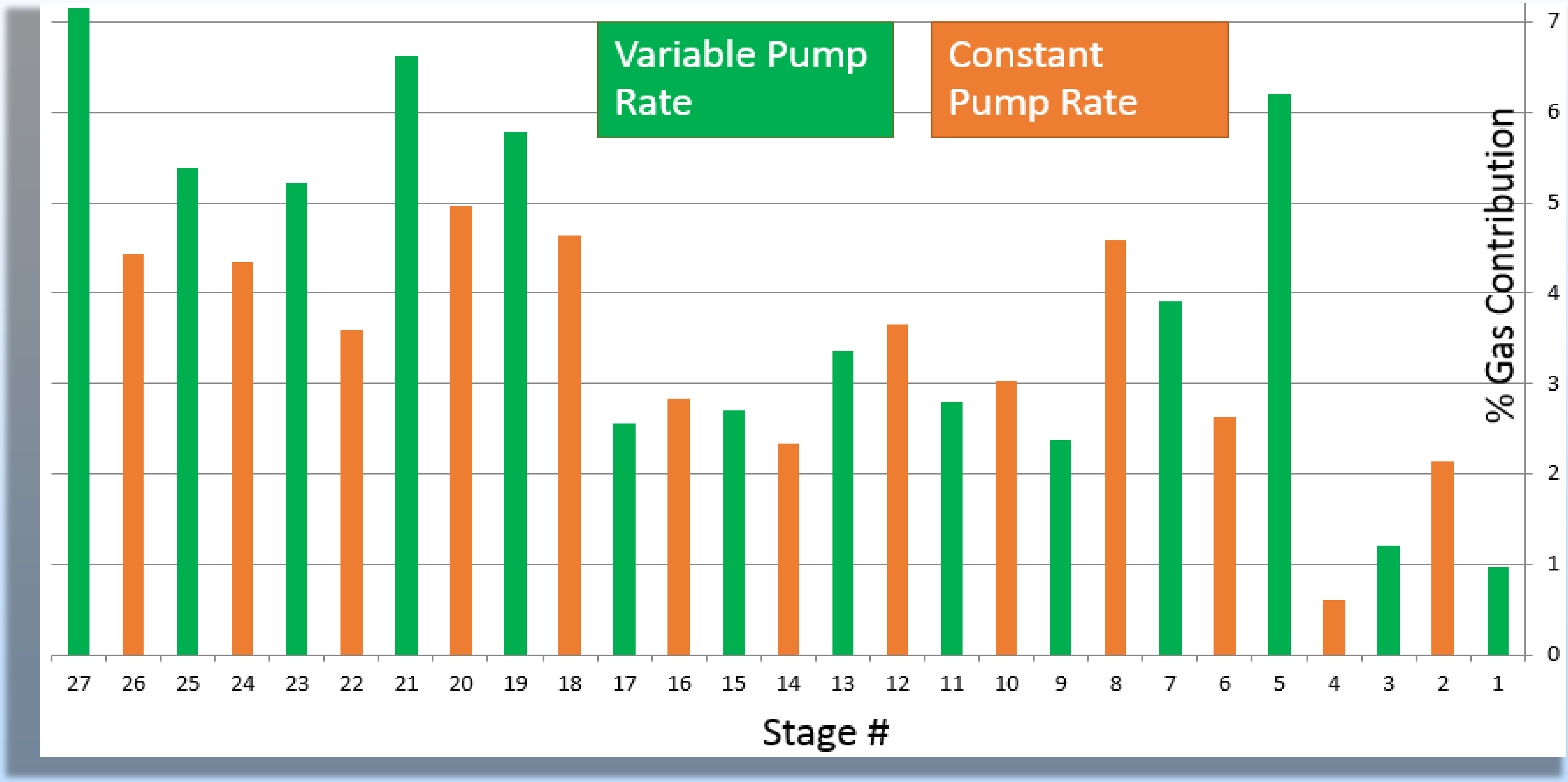
Field Test #2, Learning Curve

Field Test #2, Pressure Response





Field Test #2, Production Results

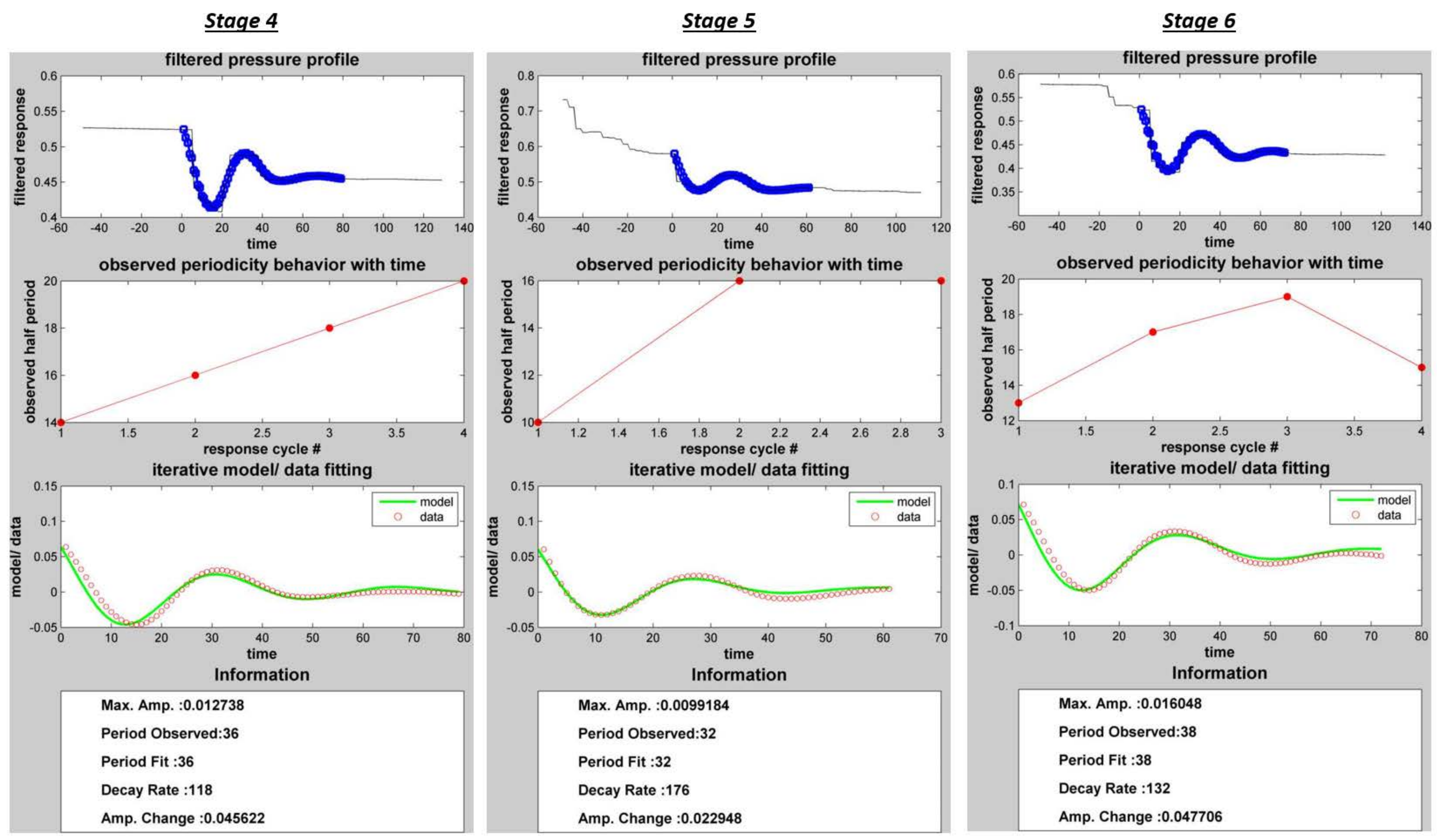


Field Test #2, Production Results

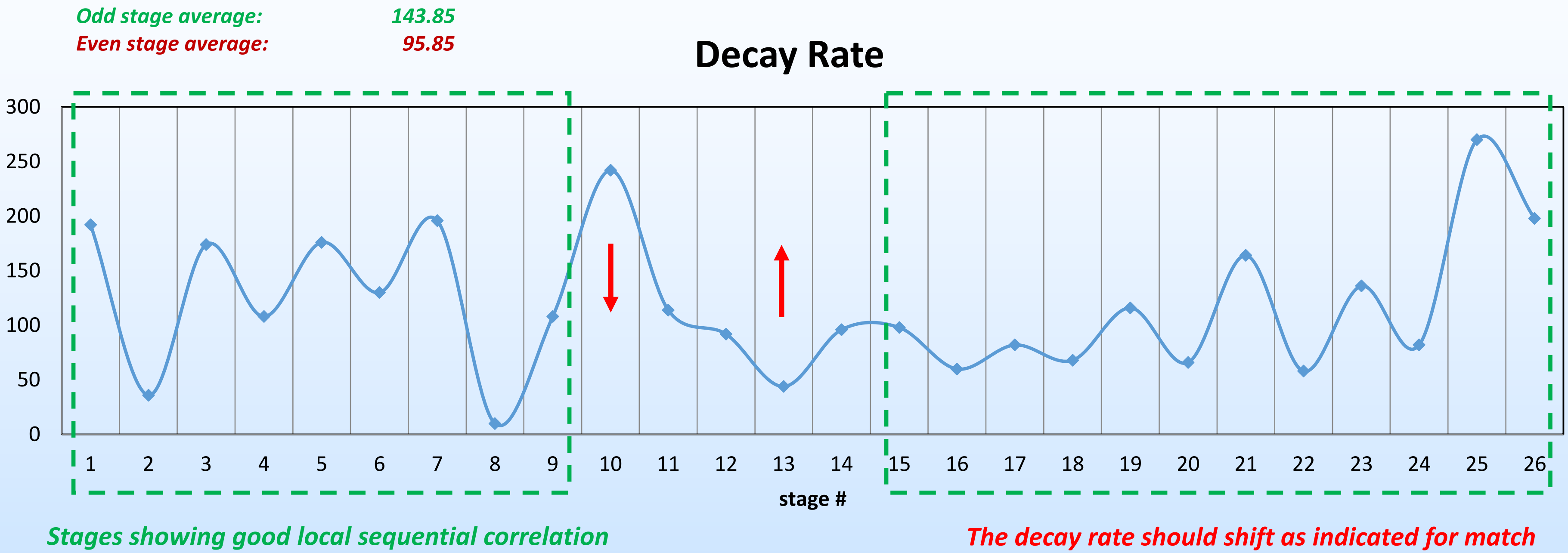
- Average Gas Production Per Stage – Odd Stages 4.02% of total gas
- Average Gas Production Per Stage – Even Stages 3.37% of total gas
- 19% Increase in production
- **38% Possible Increase in Production if entire well was fracced this way**

- 27 Stages total
  - Large data sample
  - Adjacent stages tested, removes reservoir variability issues
  - 13 Stages pumped with no intended rate variations (Even Stages)
  - 14 Stages pumped with intended rate variations (Odd Stages)
- Results could have been better. Poor rate changes in first 2 odd stages due to operations

Water Hammer Analysis

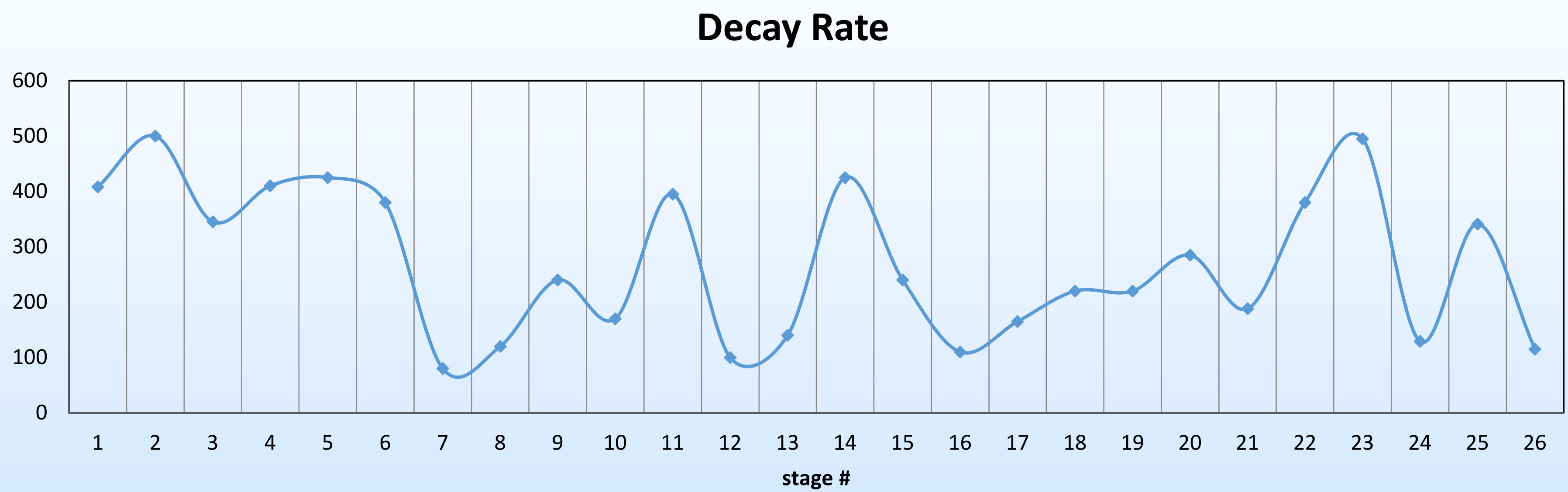


6H Water Hammer Analysis



The decay rate is obtained by best fit of response data in selected window with sinusoidal response model (& exponential decay). Note that there is very strong sequential correlation for the first 9 and the last 12 stages. However, from Goodness of fit plot (which makes use of both the misfit as well as the window size used in fit), we can clearly see that stages 10, 11, 12 & 13 show very low measures indicating bad model fits due to data quality issues (small window size).

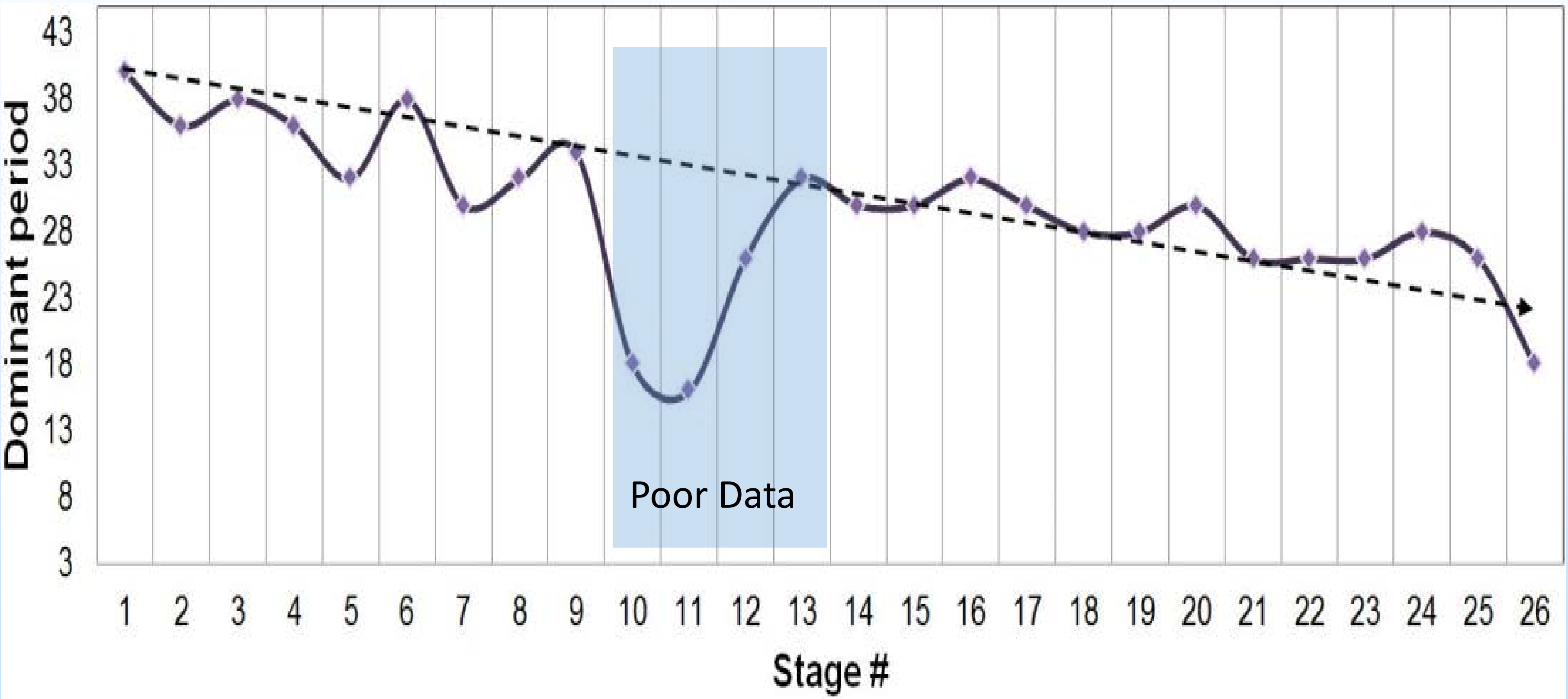
8H Water Hammer Analysis



Based on decay ratio behavior, we observe no identifiable sequential correlation as that observed for well 1-6H. Whether this is an artifact of overall data quality (1 sec. interval data in place of 0.333 sec. for 1-6H) cannot be verified.

We also observe the percentage differential b/w the odd and even stages in this case is much lower (8.2%) compared to well 1-6H (33.4%).

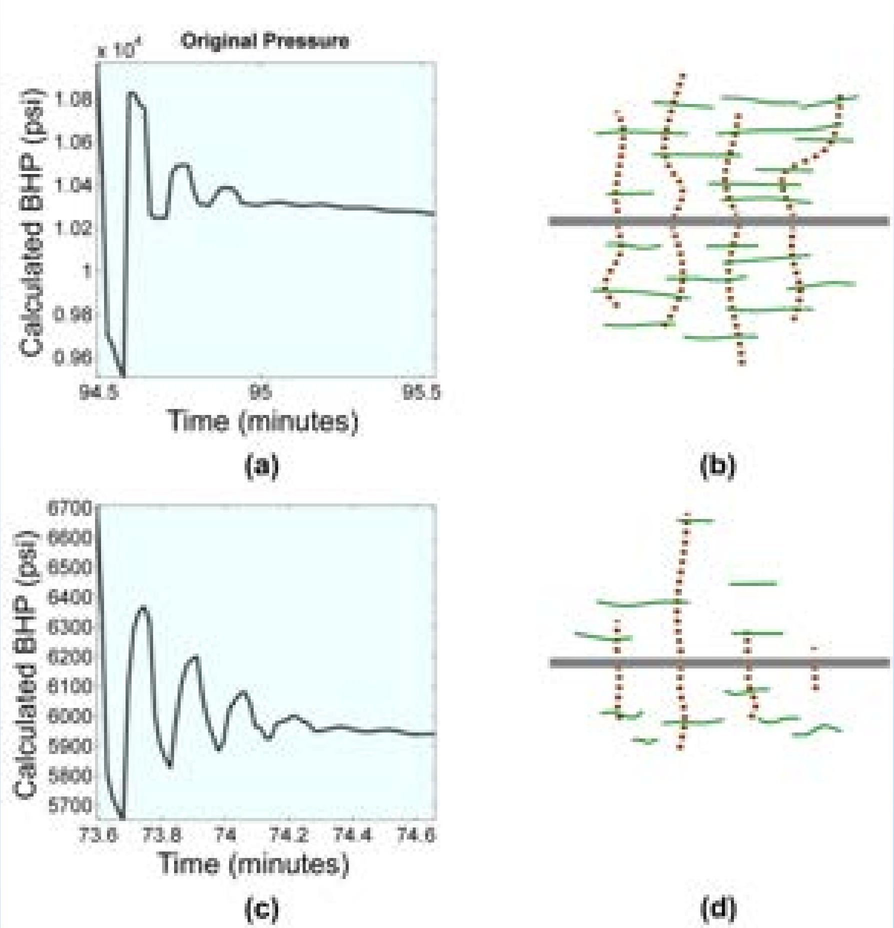
Water Hammer Sinusoid Period



Decreasing period due to shorter wellbore length

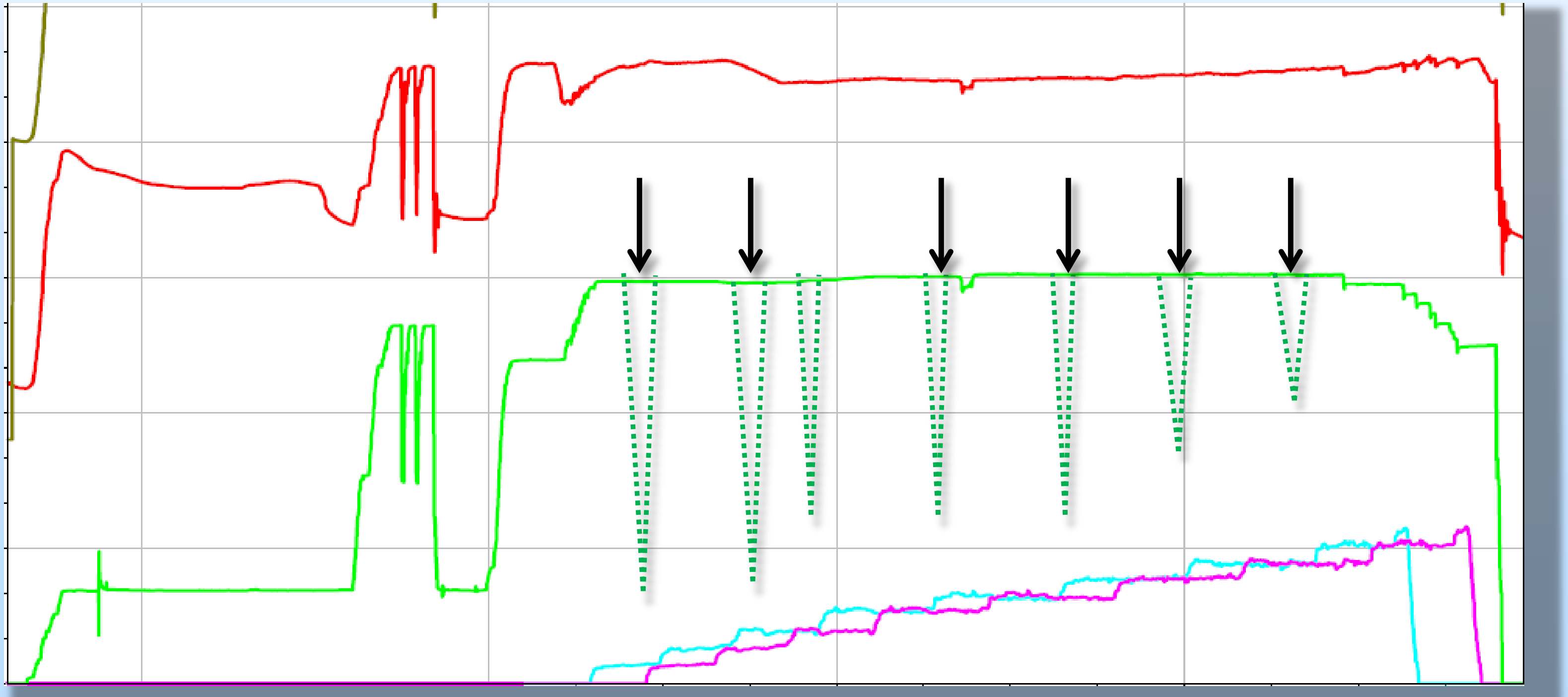
Conclusions from Water Hammer Analysis

- 6H shows distinctive water hammer pressure decay behavior which seems to be higher for odd stages (where variable rate fracturing was implemented).
- No such response is seen in the 8H where conventional fracturing was used in all frac stages
- Faster pressure decay would indicate better communication with reservoir (more fractures) that leads to more damping, as opposed to pressure pulse bouncing back from frac plug and not decaying much
- Another indication that more perforations were opened and more fractures were created.

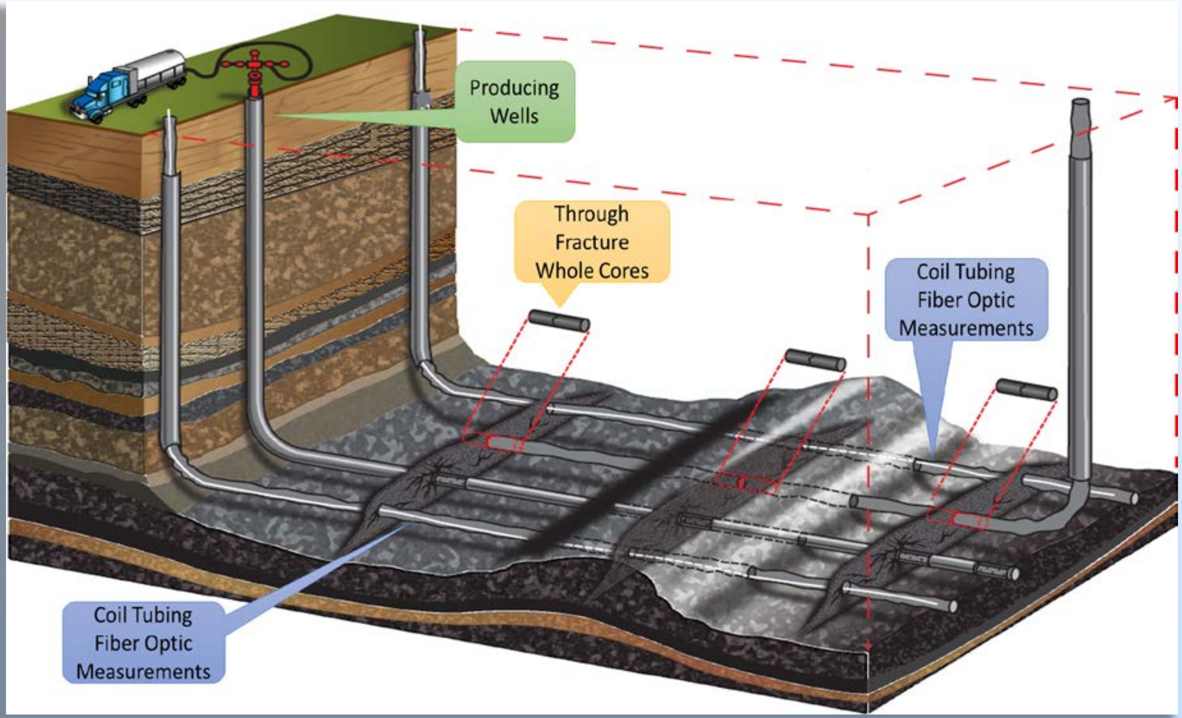


Field Test #3, Permian Basin TX

- Pad scale experiment to prove up variable rate
  Compare production in adjacent wells
- Fine tune rate changes: duration, magnitude, and frequency



Multi Basin Test Site - HFTS



- GTI held 3 Industry Workshops
- Houston, Pittsburgh and WebEx
- Over 60 companies attended
- Data and research gaps captured, tabulated, and prioritized
- Drafted a test plan
- Completed strategy report

Accomplishments to Date & Summary

- Successfully implemented Variable Rate Fracturing which has the potential to significantly increase production, with no additional cost, thus increasing energy output per unit of energy input and unit volume of water used
- Completed lab experiments which recorded microseismic signals during fracture creation, while capturing high speed and high resolution images of fracture propagation under bi-axial stress
- Developed novel microseismic processing techniques for analyzing high noise data (low SNR); self focusing adaptive beamformer, and semblance weighted emission mapping
- Developed a production analysis tool for gas shales based on bi-modal production decline
- Completed a strategy report for developing a multi basin test site (HFTS)
- Completed draft final report, wrapping up project

Synergy Opportunities

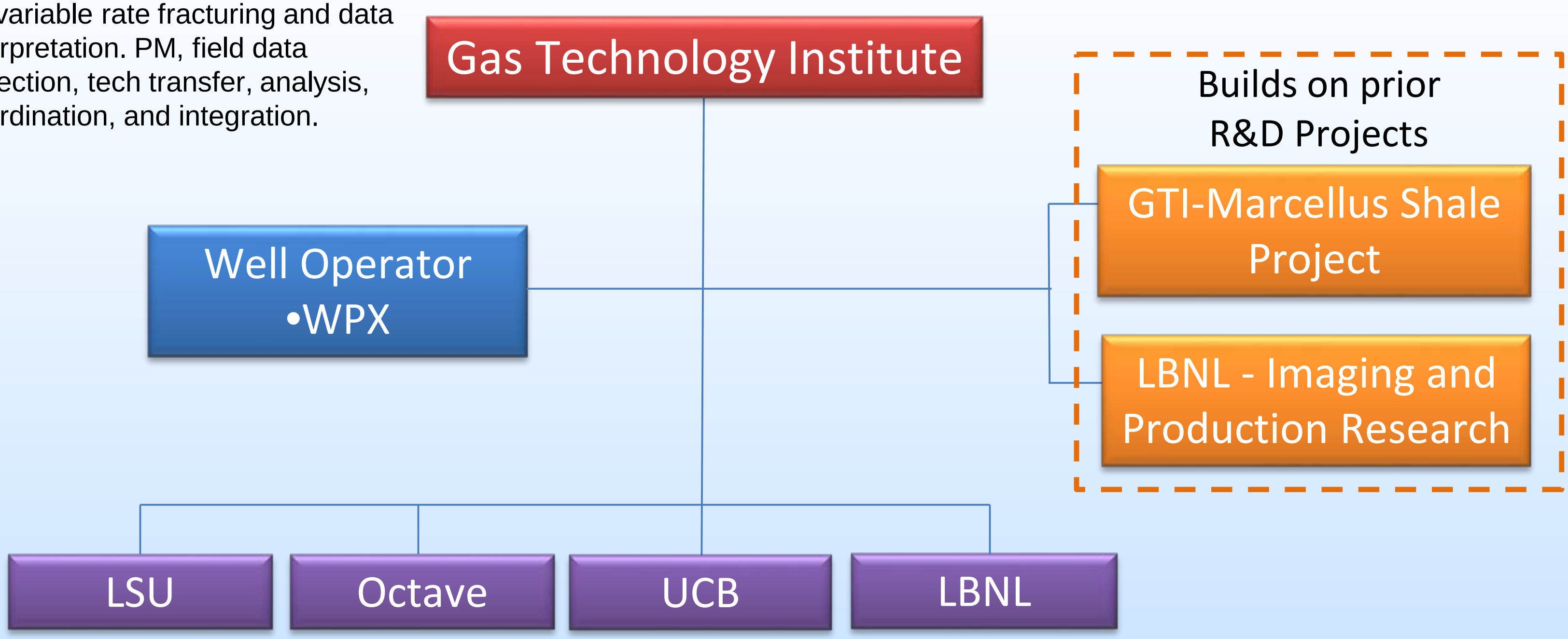
- Combine field based results with numerical simulations and lab testing, i.e. LBNL, UT work
- Utilize new fracture diagnostic techniques to assess fracture complexity resulting from VRF

Appendix

- These slides will not be discussed during the presentation, but are mandatory

Organization Chart

Improved fracture design methods for variable rate fracturing and data interpretation. PM, field data collection, tech transfer, analysis, coordination, and integration.



LSU: Improved data acquisition techniques including sensor frequency response to capture opening and shear mode fractures

Octave: Novel signal processing techniques utilizing adaptive beam forming to reduce microseismic location error and increased signal-to-noise ratio

UCB: Differentiate opening mode and shear mode microseismic signals as means for distinguishing connected and conductive fractures from far-field shear slippage.

LBNL: Bimodal decline analysis leading to accurate production forecasting with a short data sample, thus opening the opportunity for drilling and completion optimization before an entire field is completed.

Gantt Chart

Tasks		Year 1, 2013				Year 2, 2014				Year 3, 2015				Year 4, 2016		
Task #	Description	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**
1	Project Management Plan	R														
2	Technology Assessment	R														
3.1	Technology Transfer Plan		R													
3.2	RPSEA Technology Transfer (Unfunded)															
4.1	Field Data Acquisition		D1				D2						D3			
4.2	Microseismic Signal Analysis				AR				AR				AR			FR
4.3	Laboratory Experiments				AR				AR			FR				
4.4	Advanced Data Processing				AR				AR			FR				
5.1	Reservoir Engineering											FR				
5.2	Benefit Analysis											FR				
6	Multi-basin Test Sites				G		FR									
7	Integration, Analysis, Coordination								W1				W2			FR
8	Technology Transfer							P		P			P		P	

Events	**Description**
AR	Annual Report
D1,D2,D3	Field Data Acquisitions
R, FR	Report & Final Reports
G	Go/No-Go Milestone
P	Papers/Presentations
W1 & W2	Workshops

Project Deliverables

1 Environmentally safe and economically optimal fracturing guideline
2 Methods and techniques for high resolution microseismic data analysis
3 Design diagram for next generation microseismic data acquisition
4 Interactive tool for shale-specific decline curve analysis
5 Research quality data set

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