SPE-201376-MS

Pump-Down Diagnostics for Plug-and-Perf Treatments

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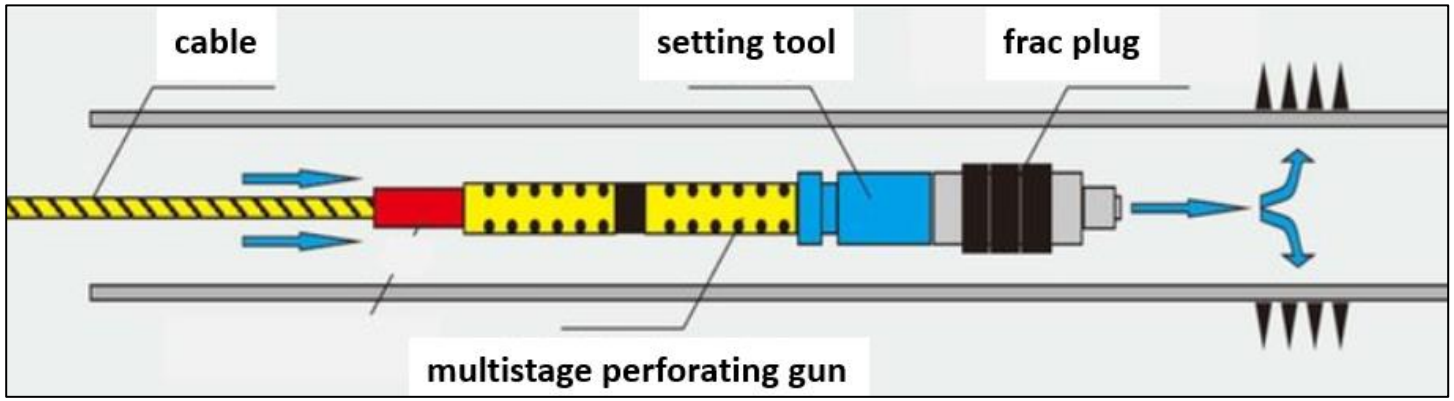
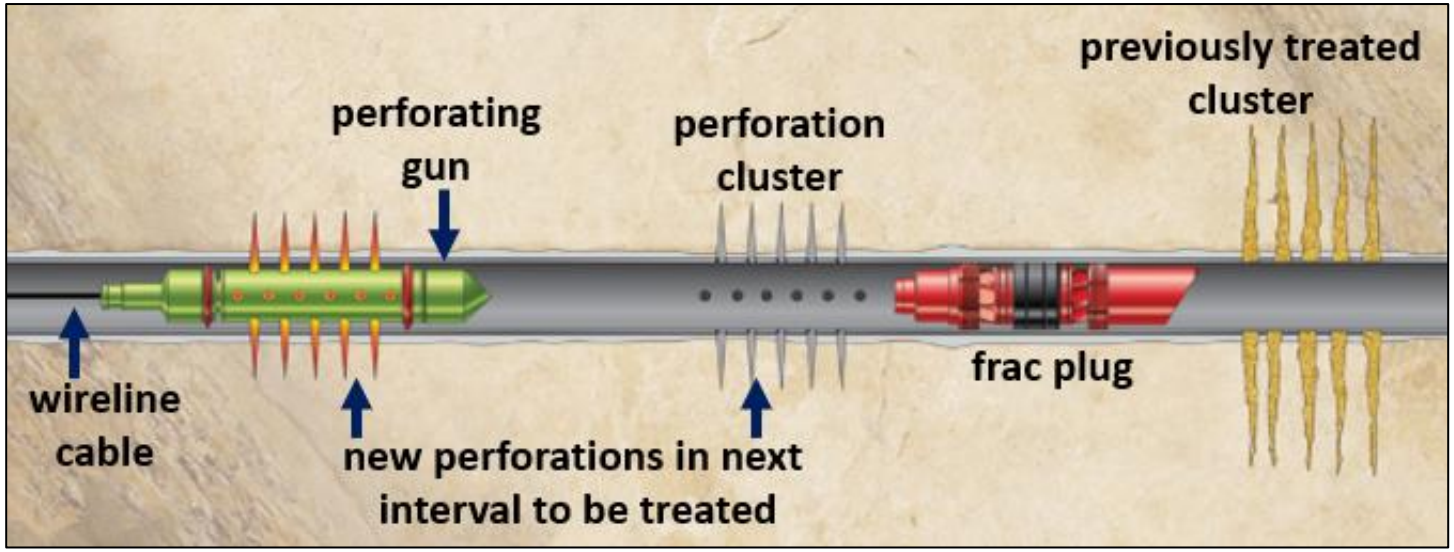
Agenda

- Describe pump-down and plug-and-perf methods
- Describe diagnostic testing and interpretation processes
- Review Poland and Eagle Ford case studies

Treating Multiple Intervals in a Horizontal Well



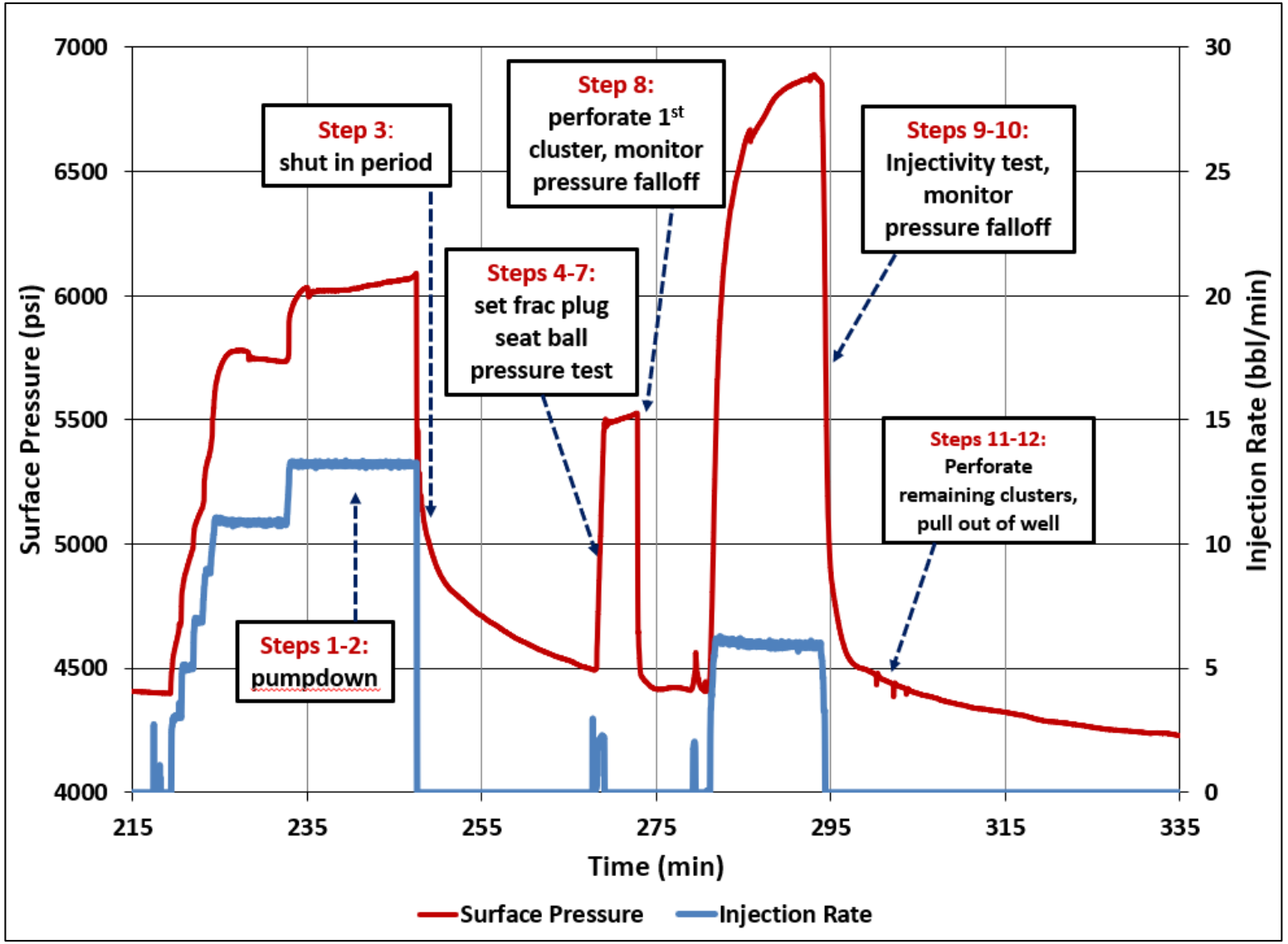
pump-down process

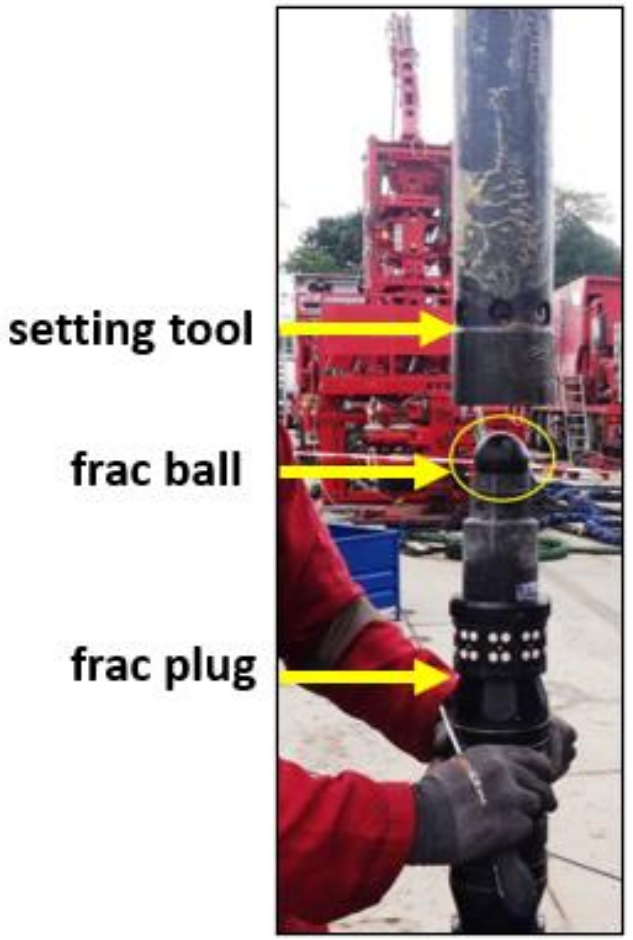


plug-and-perf

Once pumped to the desired location in the lateral and up-hole from pre-existing perforations, pumping is stopped, the frac plug is set, new perforation clusters are created, then the wireline with spent perforating guns and frac plug setting tool is retrieved.

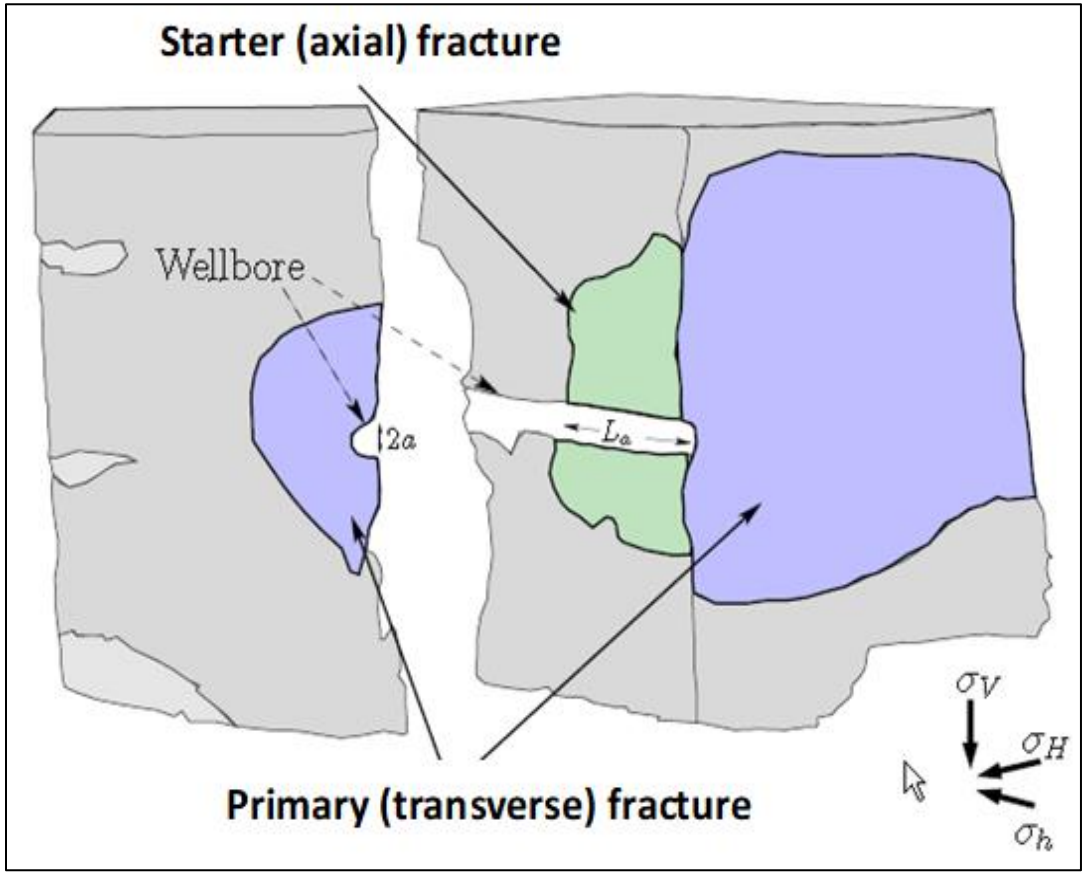
Pump-down Diagnostics Testing Process

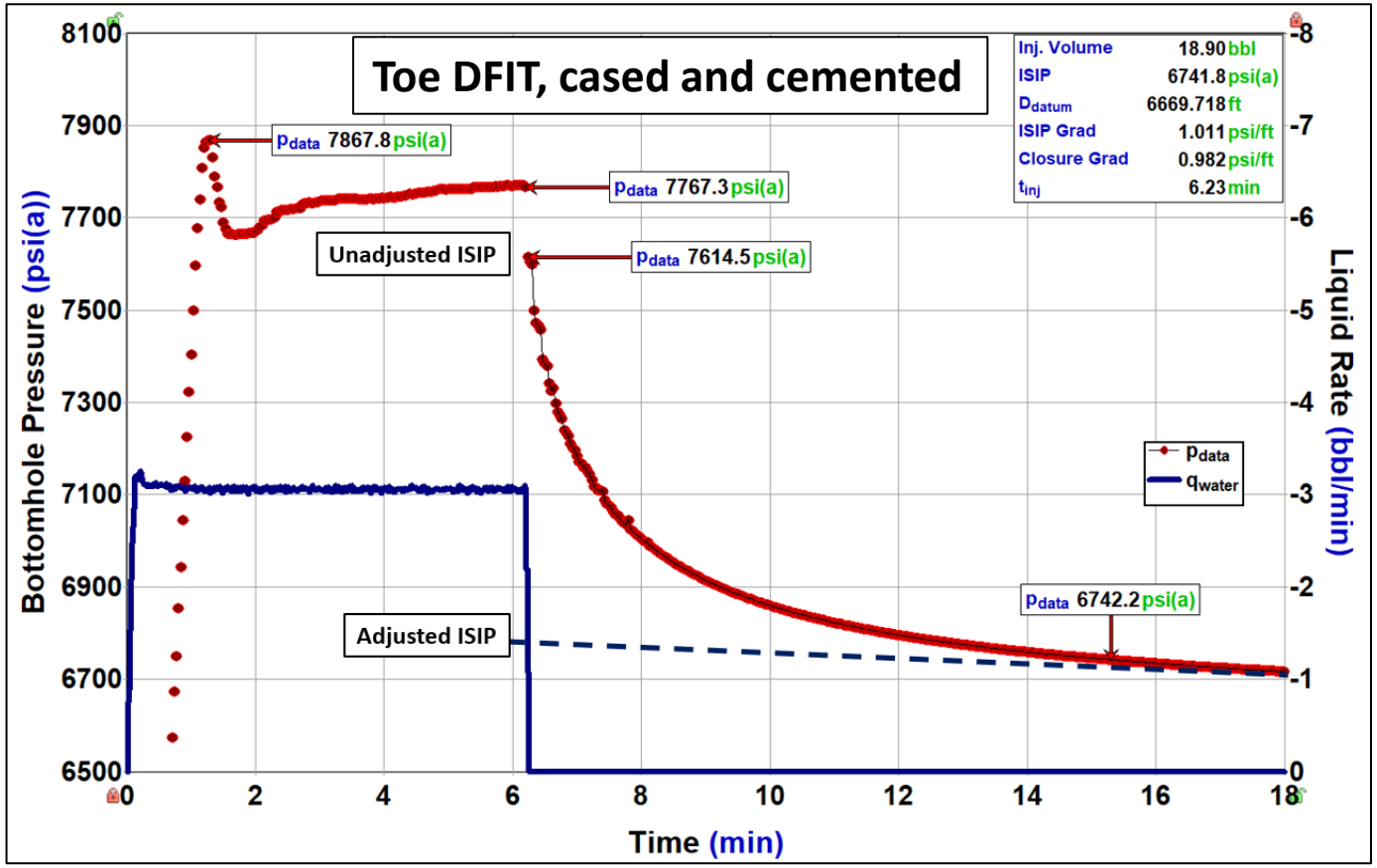




This process requires the frac ball to be run with the frac plug during pump-down operations. Pressure behavior following the pump-down, before and after perforating, and after an injection test are evaluated for characteristic responses.

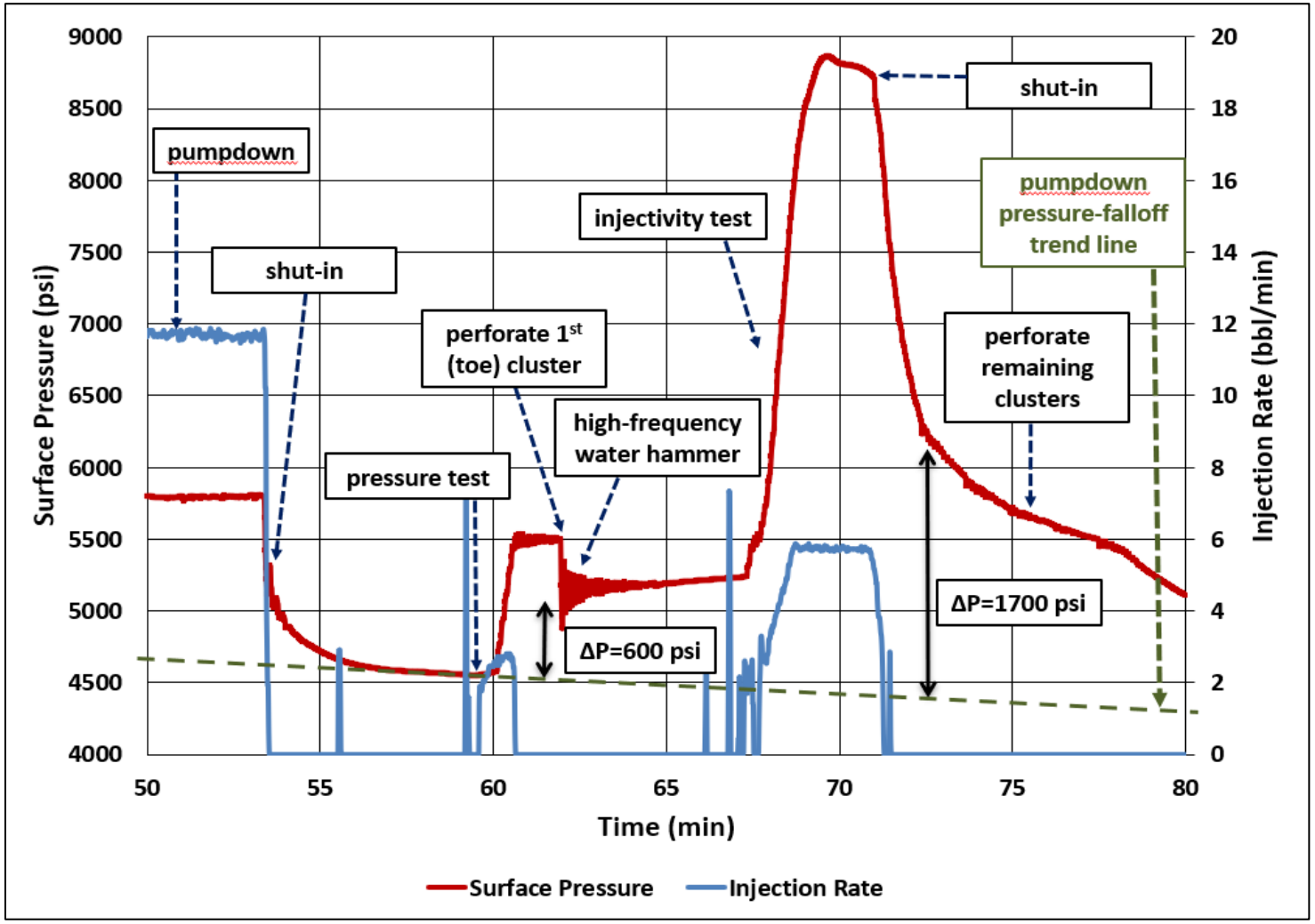
Axial Starter Fractures Promote Excessive Friction Pressure When Initiating Injection Into Previously Untreated Rock





Forcing fluid through the narrow axial fracture results in high friction and backpressure is slow to dissipate. This is exemplified by DFIT pressure behavior. Later, acid and proppant erode the cement-filled annular pathway, reducing or eliminating tortuosity.

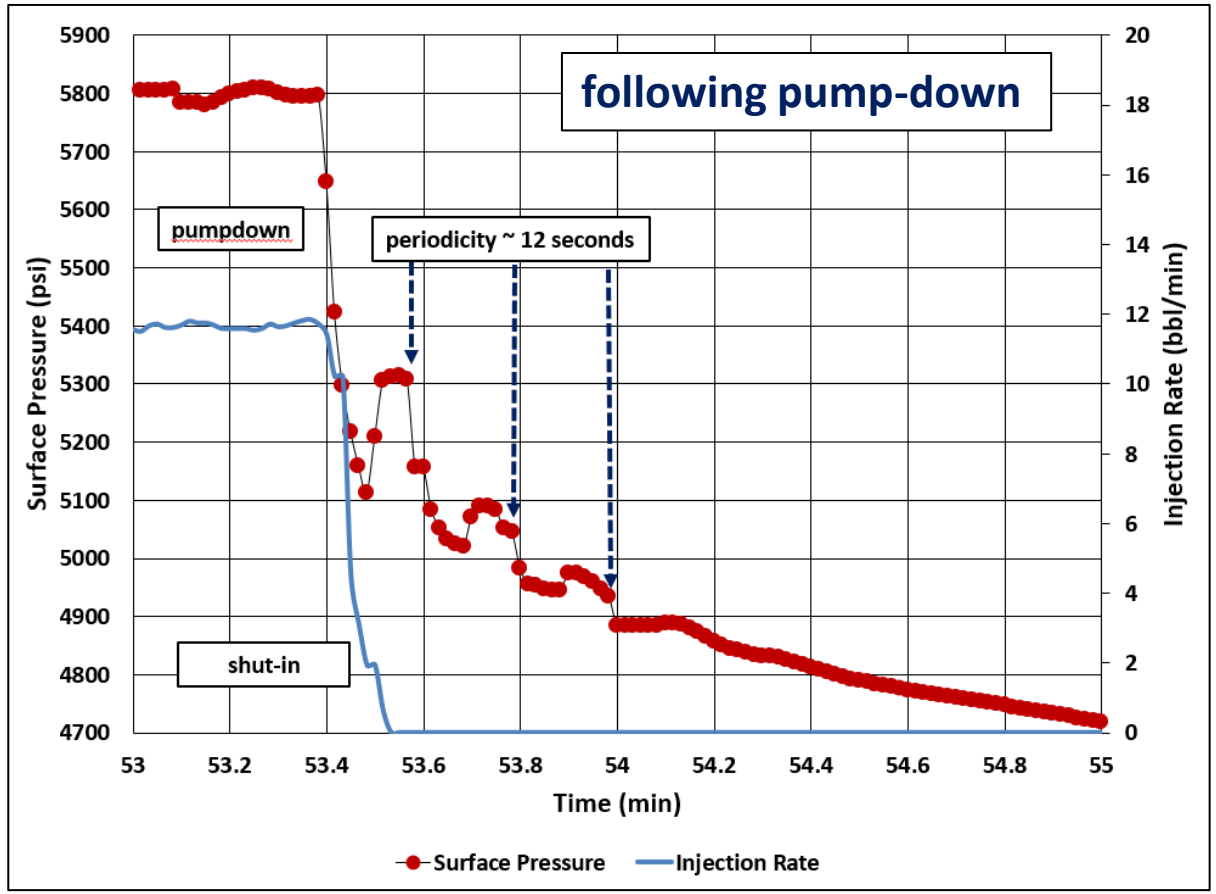
Example of Isolation from Previously-Treated Intervals

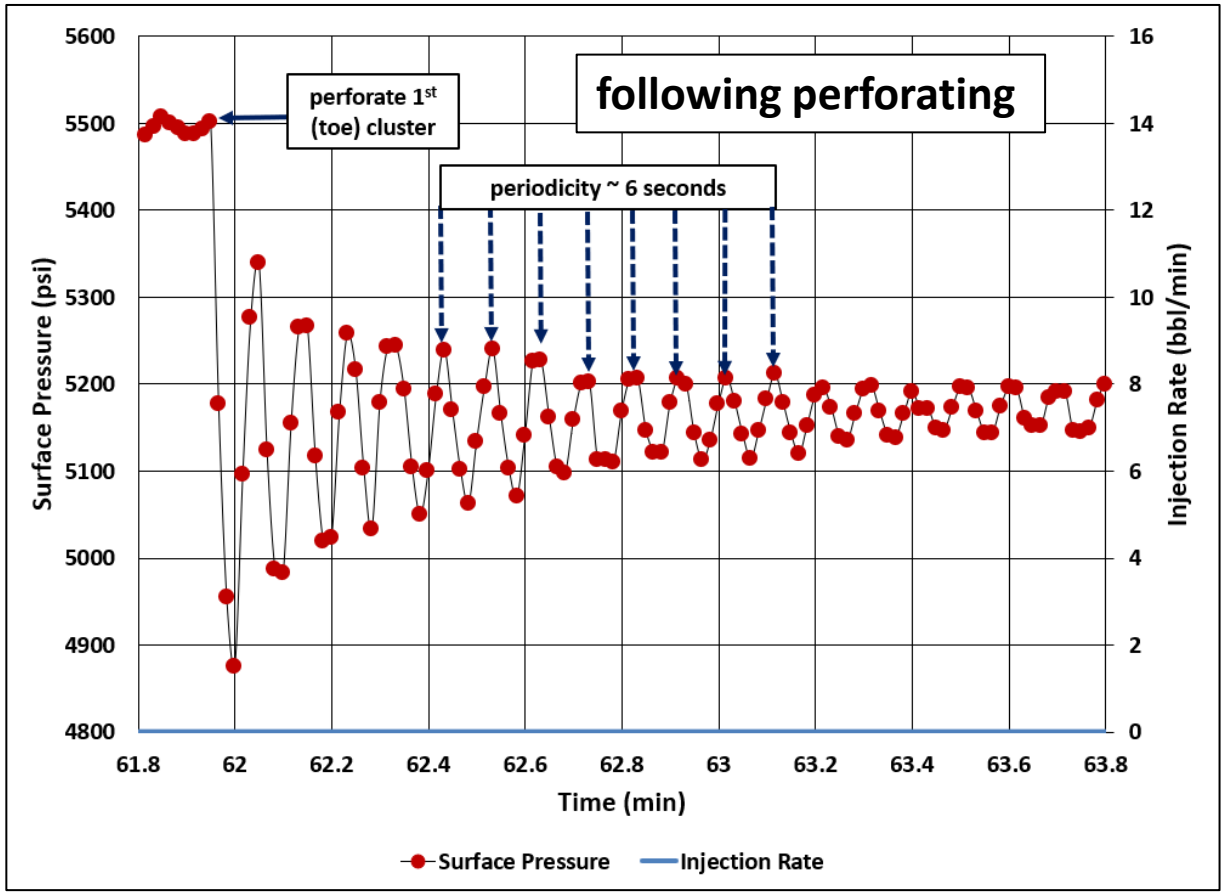


From Poland shale gas case study, 10 m cluster spacing

Pressure trends following perforating and the injection test were substantially above the pump-down pressure falloff trend.

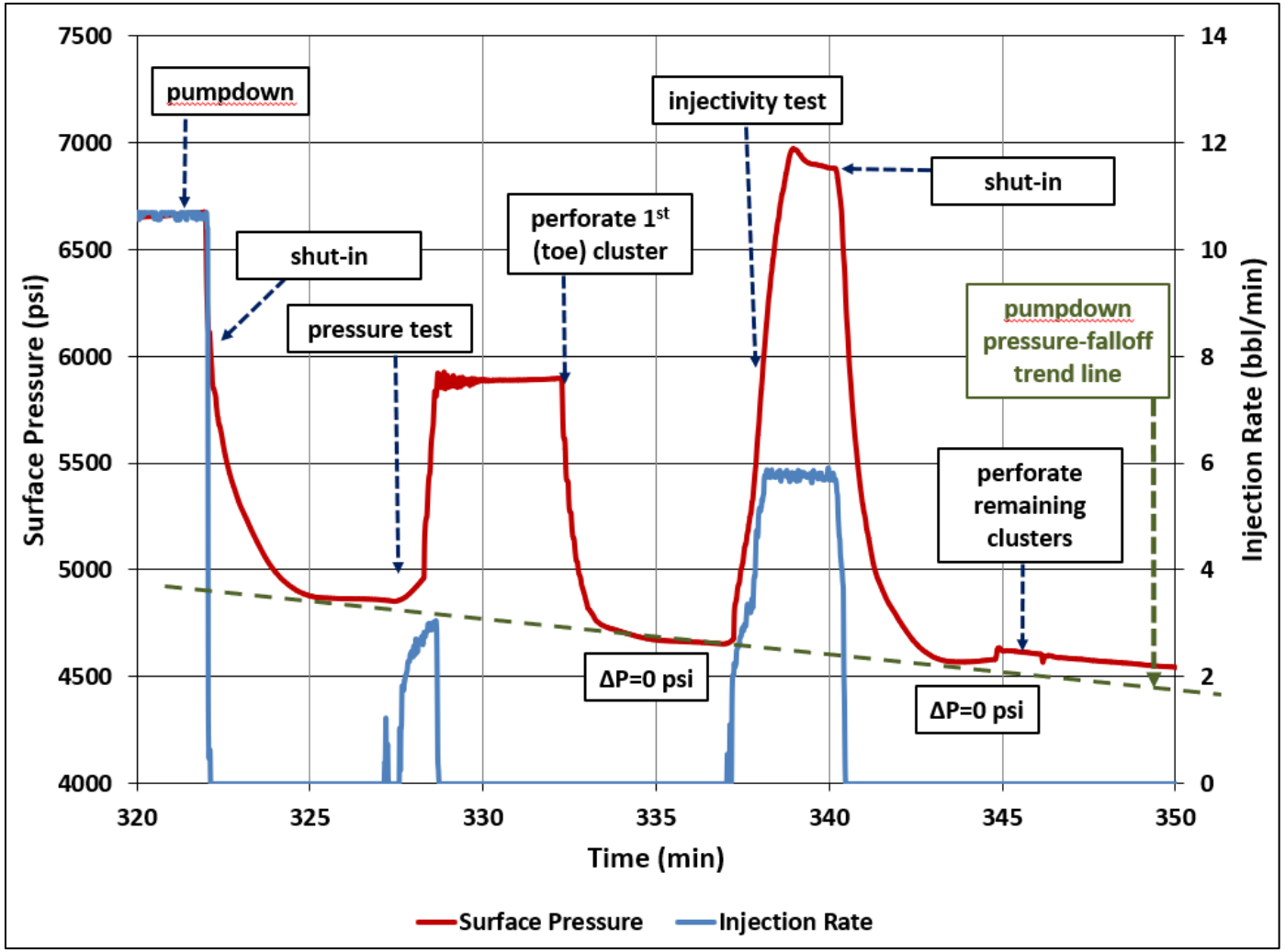
Water Hammer Signatures





Periodicity following pump-down and perforating events are indicative of large and nil fracture capacity, respectively.
Period time = travel path length (ft) ÷ speed of sound (ft/sec) x 4 (large fracture capacity) or 2 (nil fracture capacity).

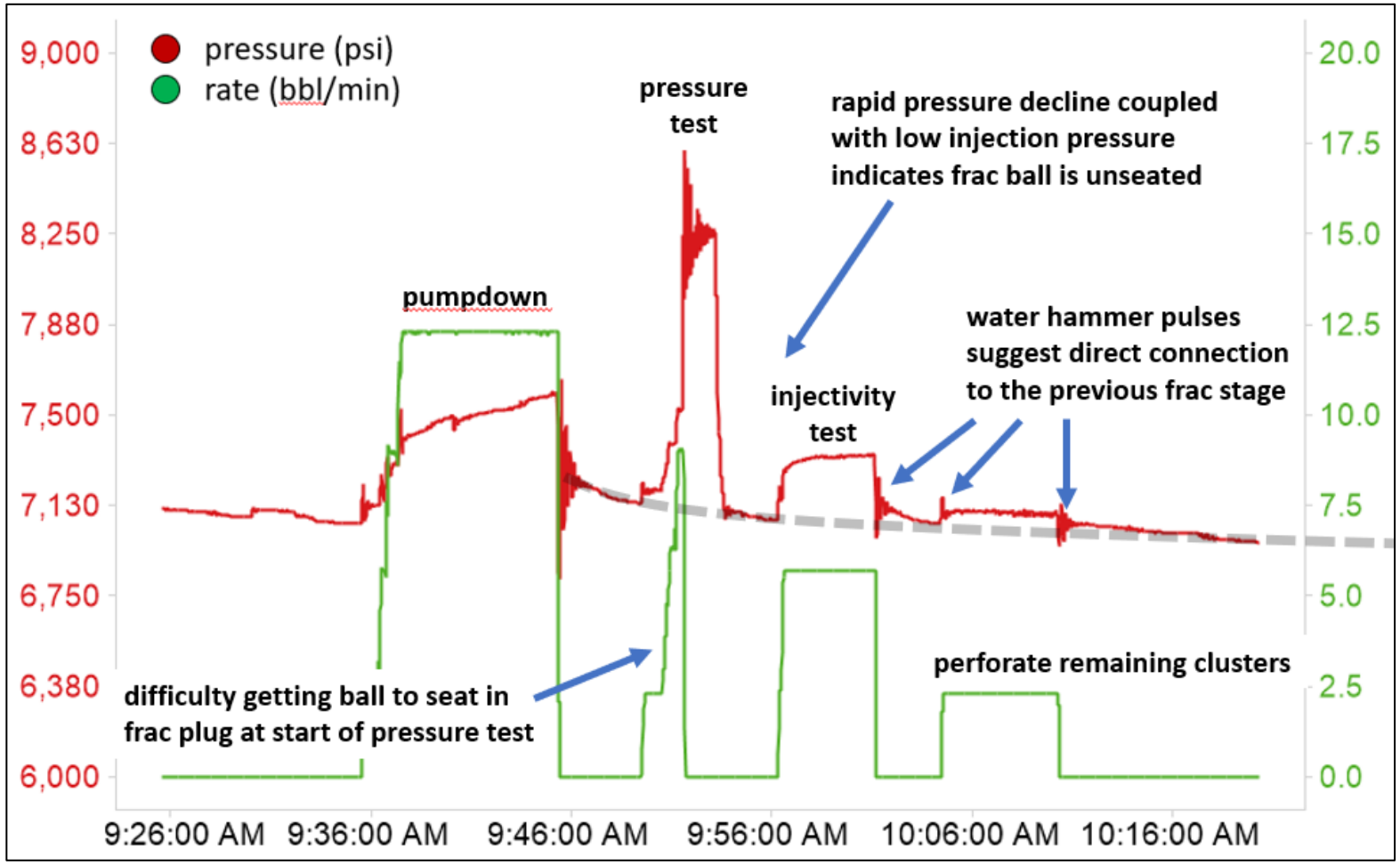
Example of Behind-Pipe Communication to Previously-Treated Intervals



From
Poland shale
gas case study,
10 m cluster spacing

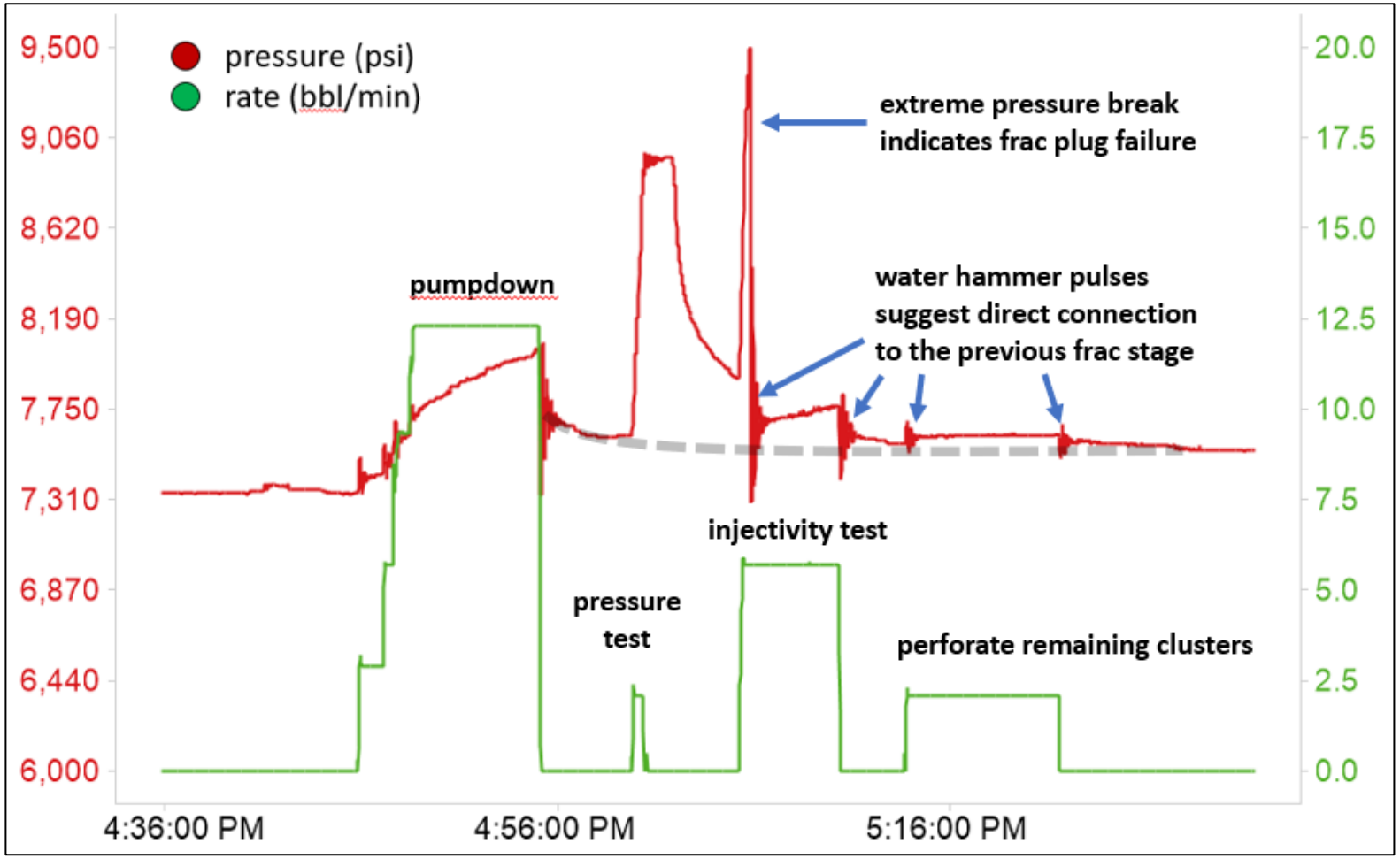
Pressure trends following perforating and the injection test rapidly declined to the pump-down pressure falloff trend.

Isolation Problems within the Wellbore: Frac Ball Unseated



During the injection test, the total system friction pressure was less than the expected friction for pumping all fluid through the single perforation cluster. Example is from the Eagle Ford case study.

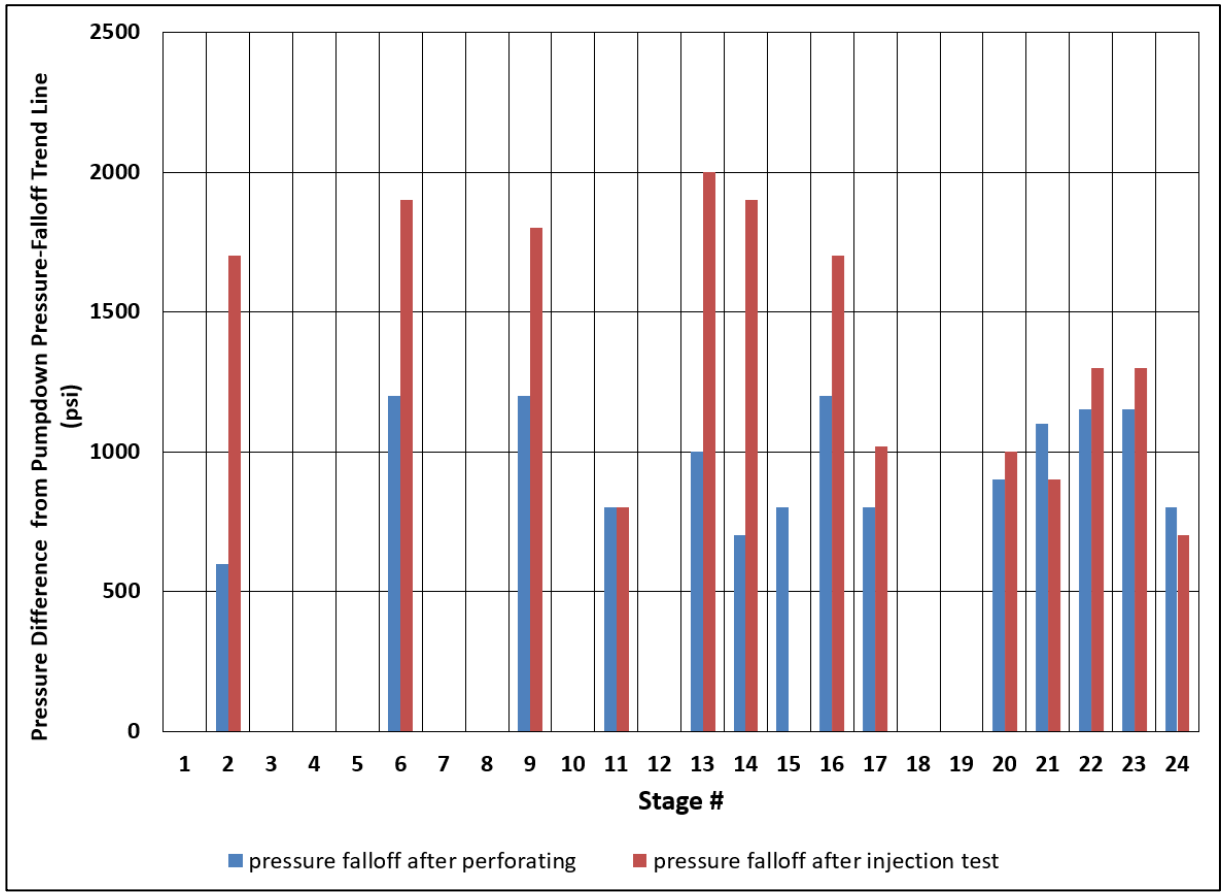
Isolation Problems within the Wellbore: Frac Plug Failure

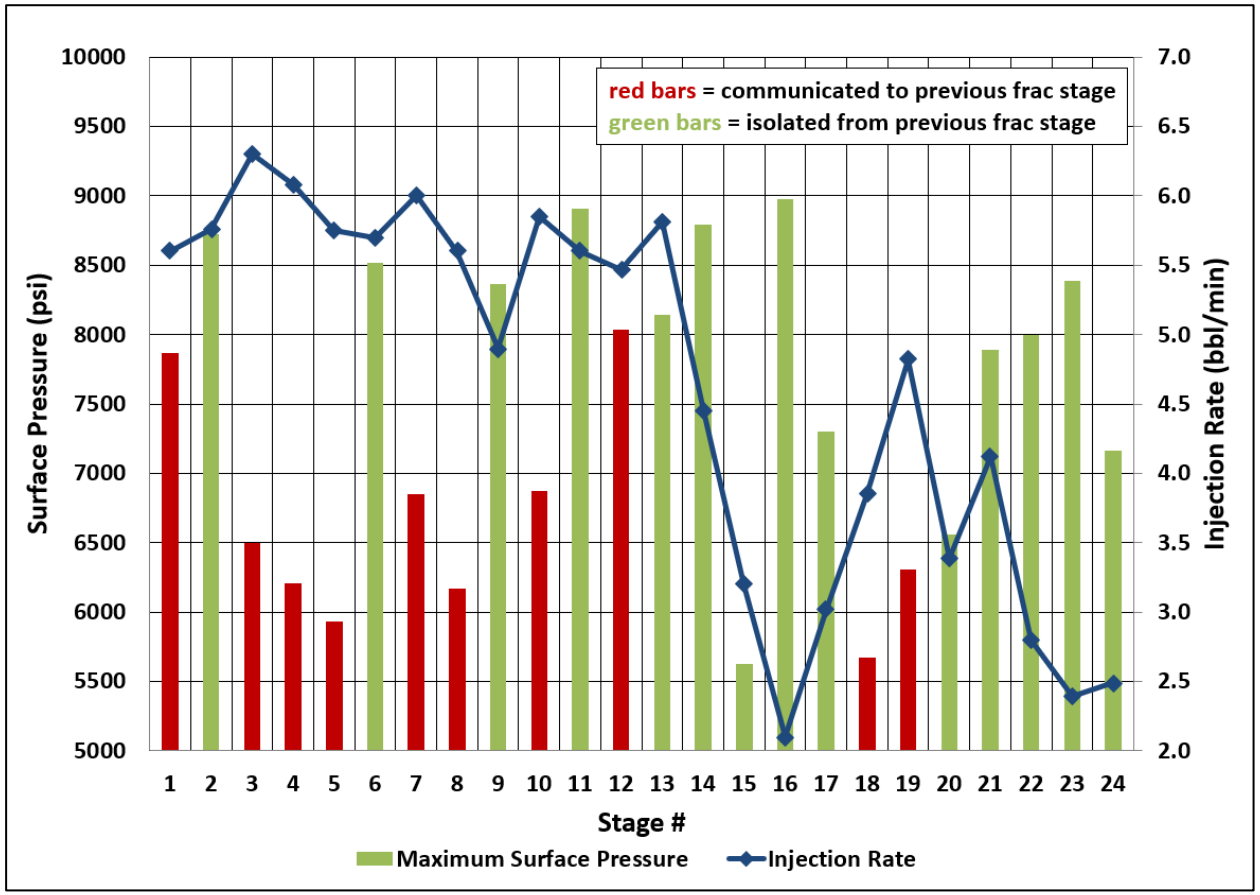


From Eagle Ford case study

Pressure falloff trend following perforating indicated behind-pipe containment. The total system friction pressure was less than the expected friction for pumping all fluid through the single perforation cluster or central opening in frac plug.

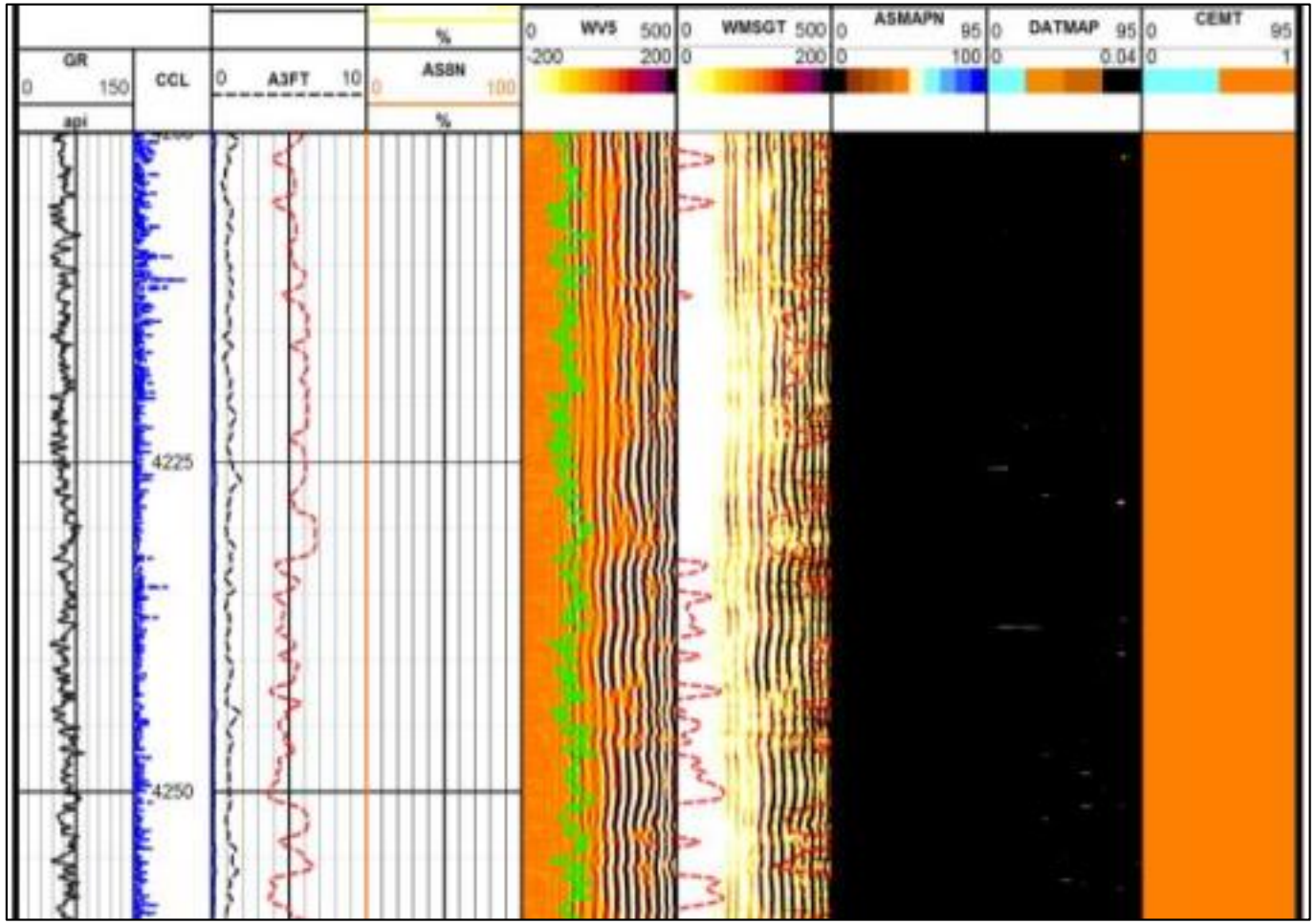
Poland Shale Gas Case Study





Failure to launch the top cementing plug resulted in severe channeling of displacement fluid into the cement slurry within the lateral, affecting the quality of the set cement sheath behind pipe. Cluster spacing was 10 meters.

Poland Shale Gas Case Study: Cement Evaluation Log

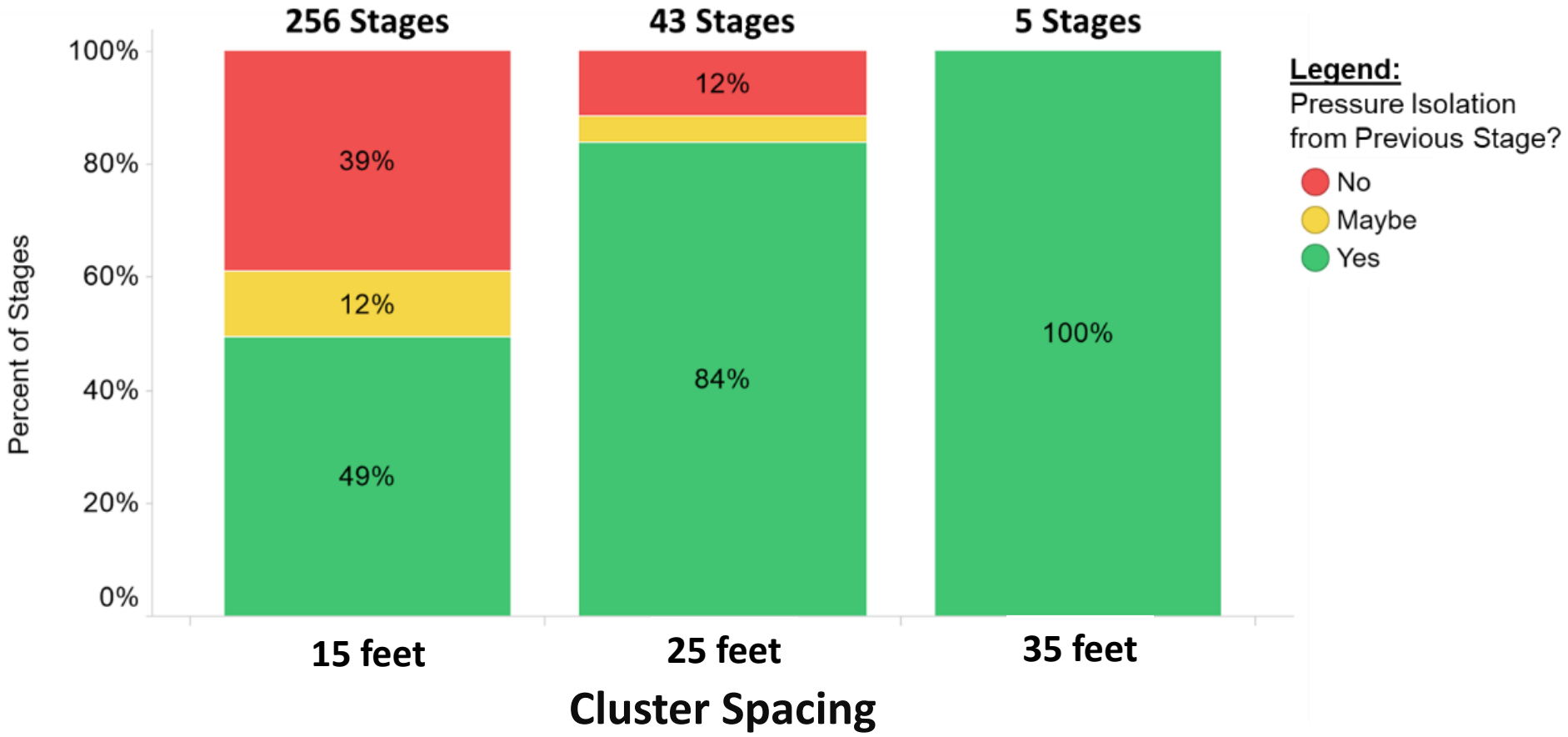


Poor-quality cement sheath in the heel-ward half of the lateral was not identified by the radial cement bond tool.

Eagle Ford Case Study

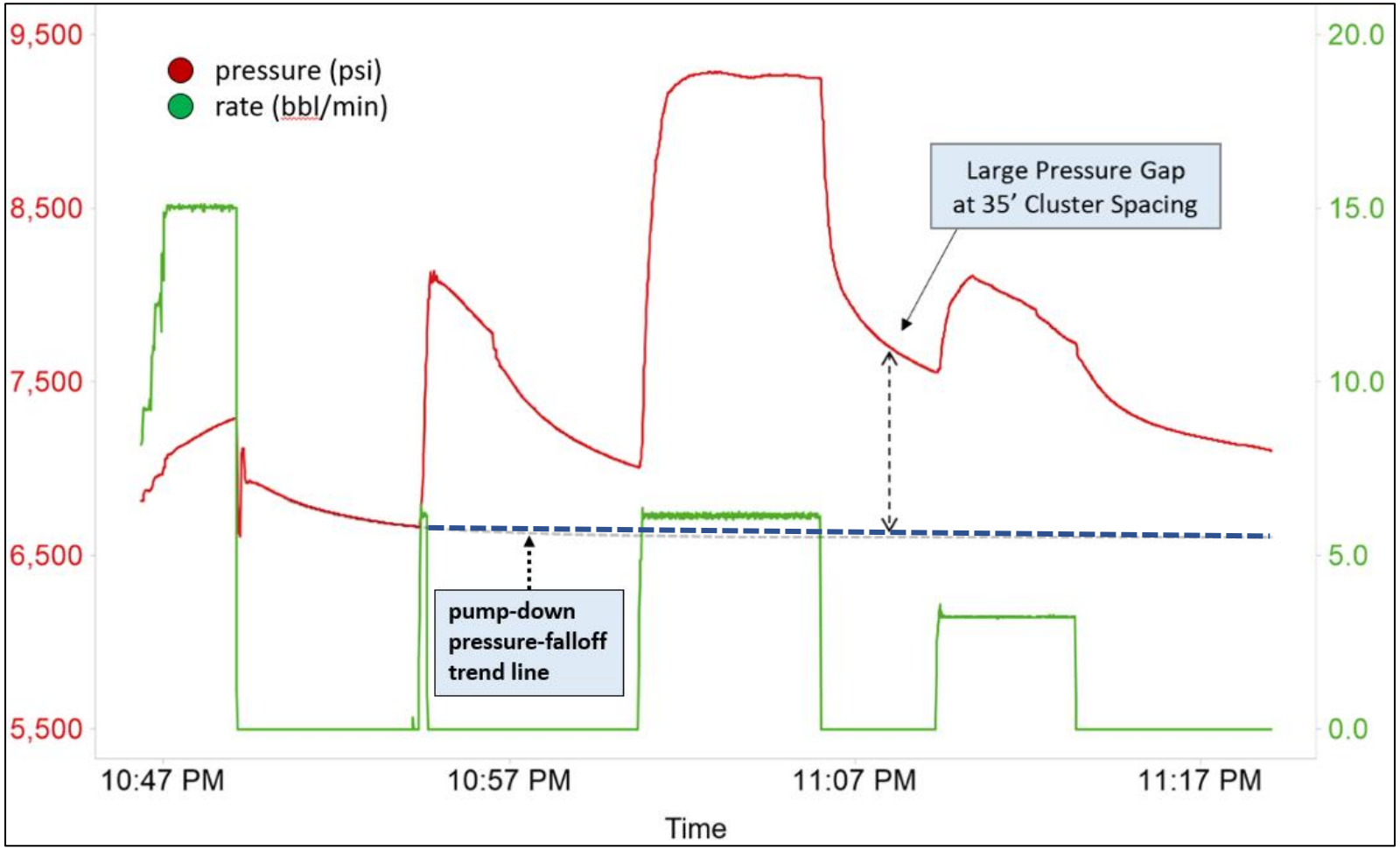
This project consisted of 304 frac stages in 27 wells for the purpose of determining pressure isolation from previous frac stages and by inference the quality of the cement sheath behind pipe.

Impact of Cluster Spacing
Eagle Ford Case Study



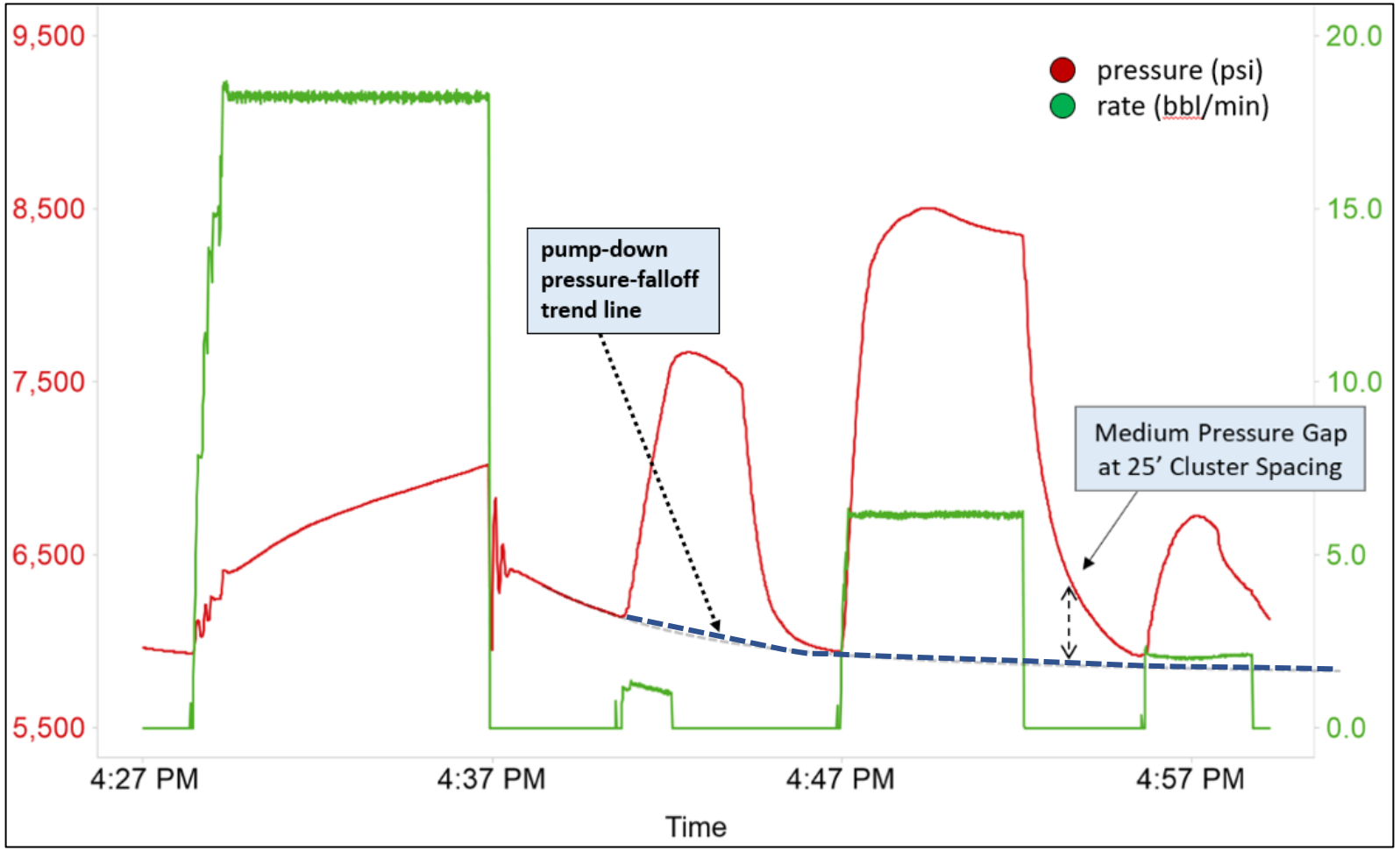
Incidences of communication decreased with increased distance between clusters.

Confined Case, Cluster Spacing = 35 feet
Eagle Ford Case Study



Relatively large differential between post-perforating and injection test pressure falloffs and pump-down pressure falloff. This indicates strong isolation from previously treated intervals.

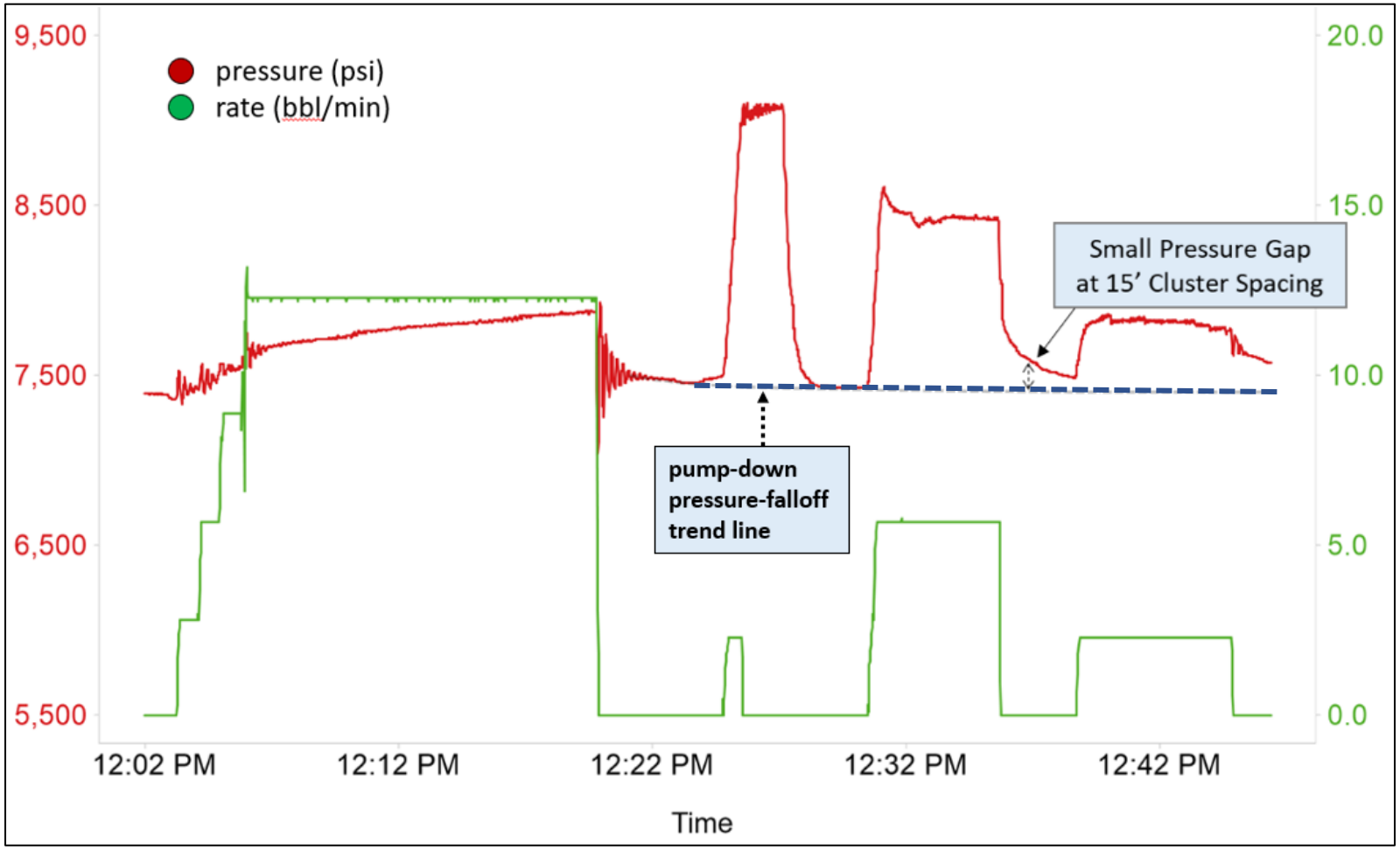
Confined Case, Cluster Spacing = 25 feet
Eagle Ford Case Study



Diminishing differential between post-perforating and injection test pressure falloffs and pump-down pressure falloff. This indicates some behind-pipe communication with previously treated intervals but still some restriction due to cement sheath.

Confined Case, Cluster Spacing = 15 feet

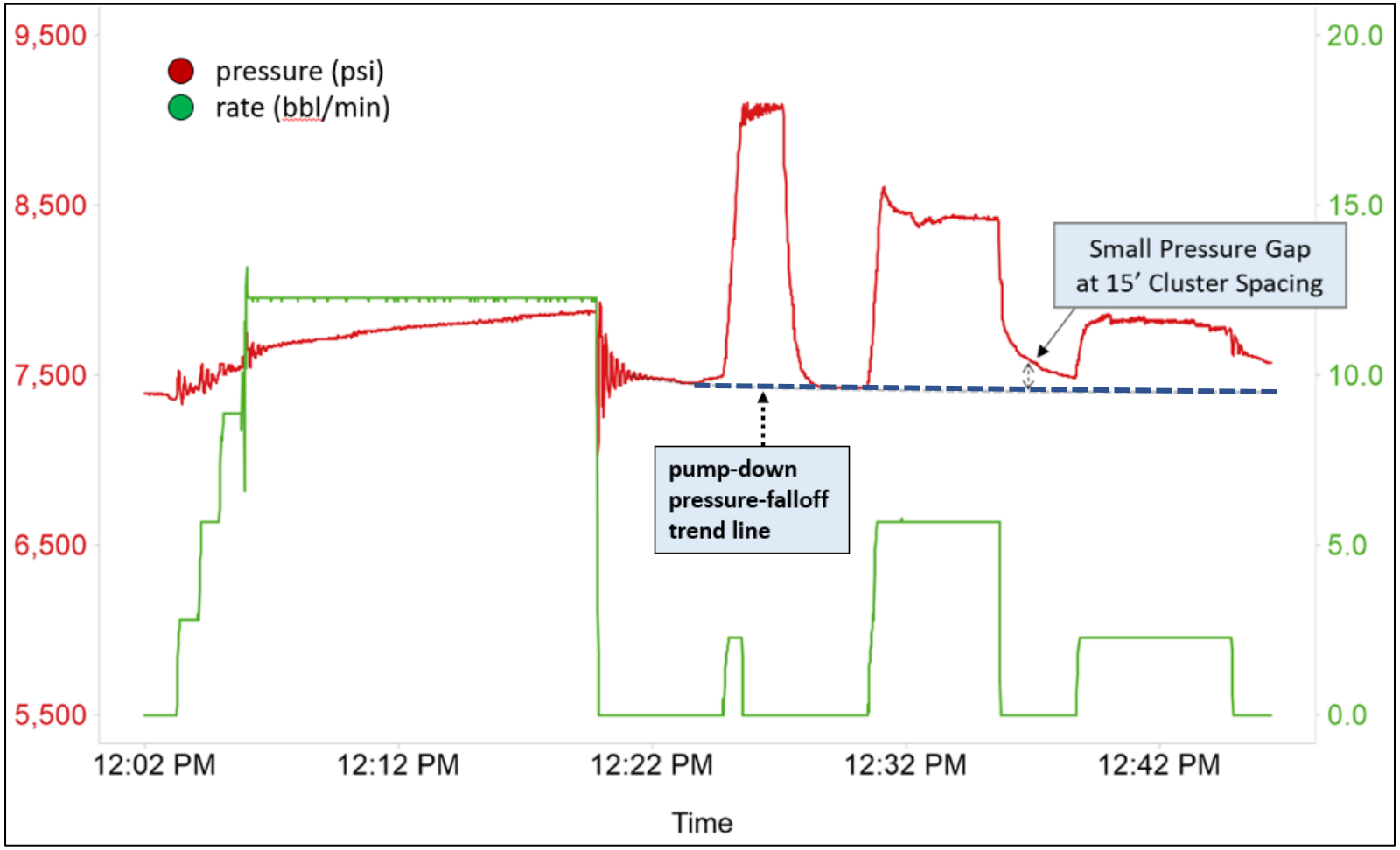
Eagle Ford Case Study



Minimal differential between post-perforating and injection test pressure falloffs and pump-down pressure falloff. This indicates stronger communication with previously treated intervals but still some restriction due to cement sheath.

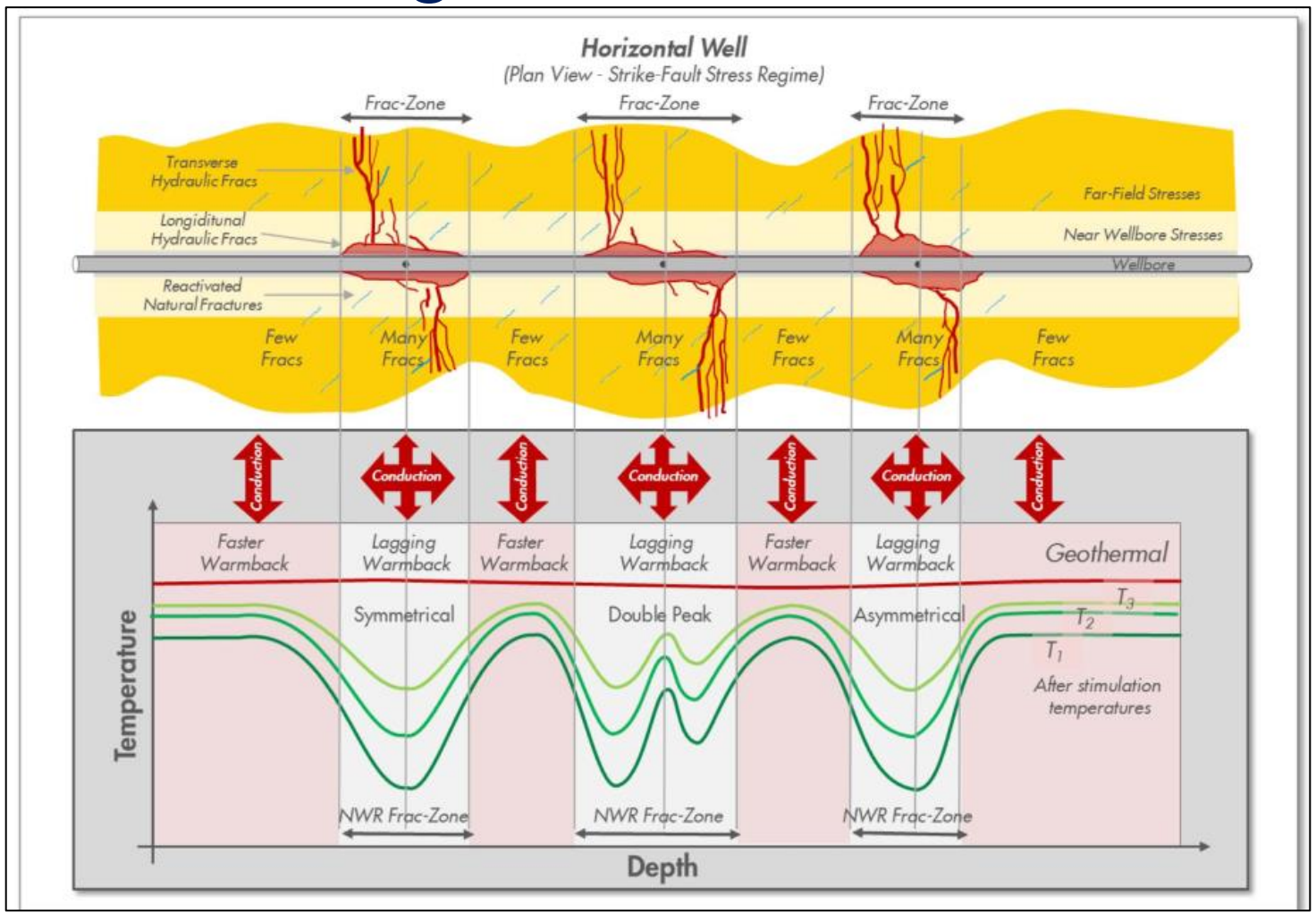
Confined Case, Cluster Spacing = 15 feet

Eagle Ford Case Study



Minimal differential between post-perforating and injection test pressure falloffs and pump-down pressure falloff. This indicates stronger communication with previously treated intervals but still some restriction due to cement sheath.

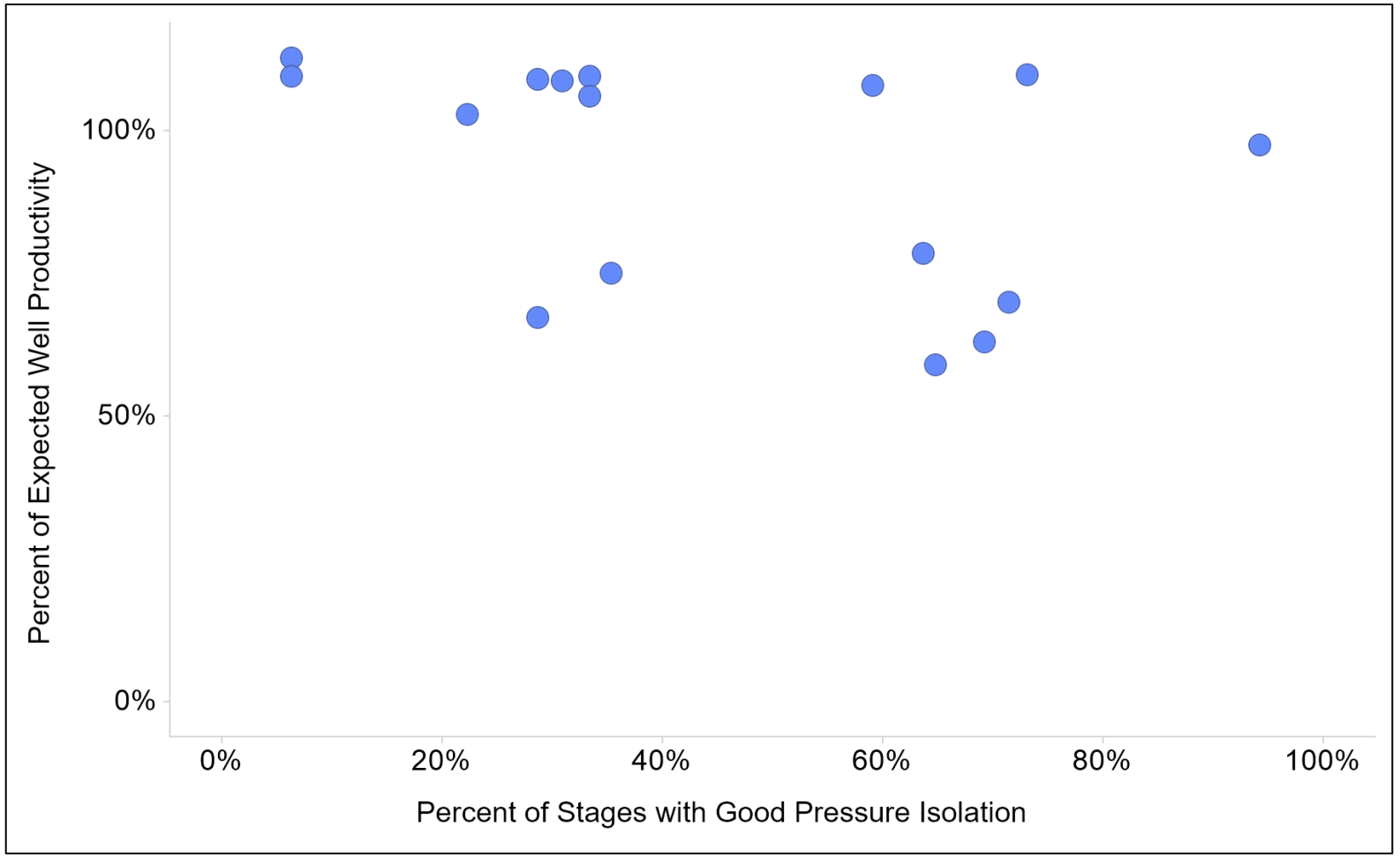
Breadth of Hydraulic Fracturing from a Single Initiation Point



Based on DTS interpretation (Ugueto et al., SPE-194371). Inferred longitudinal component is up to 26 feet, i.e., 13 ft in each direction from mid-point. At a critical cluster spacing, some degree of interstage communication may be inevitable.

Productivity for Wells with 15 ft Cluster Spacing

Eagle Ford Case Study



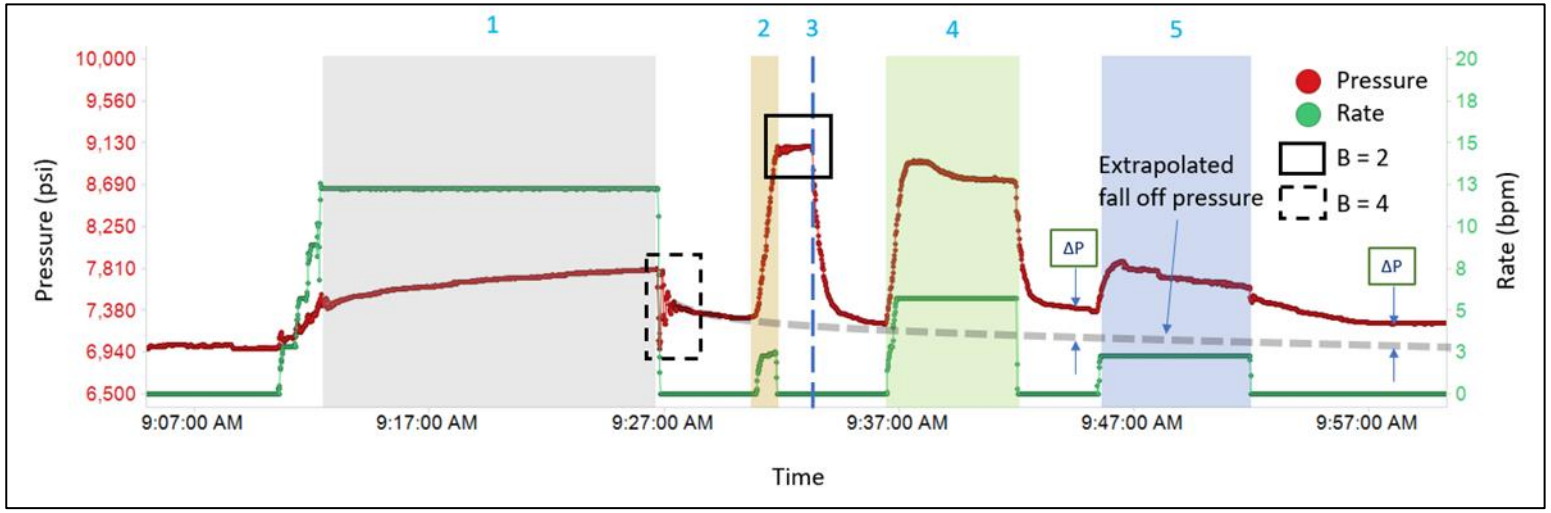
Short-term production results do not always capture the negative effects of irregular fracture coverage, especially when observations are limited to a small set of wells. But there is cause for concern of treatment overlap at 15 ft cluster spacing.

Summary

- Pump-down diagnostics provide a means of determining if communication is occurring between a just-perforated fracturing stage and previously treated intervals, which can serve as a key performance indicator for treatment control and cement sheath integrity.
- The pump-down diagnostic process is time efficient, typically requiring about 15 minutes per fracturing stage.
- The water hammer events observed during pump-down diagnostics testing offer additional clues to the nature of inter-stage communication.
- For closely spaced perforation clusters and frac stages, isolation may be significantly affected by the breadth of the longitudinal starter fracture and associated transverse fractures that are associated with each cluster.

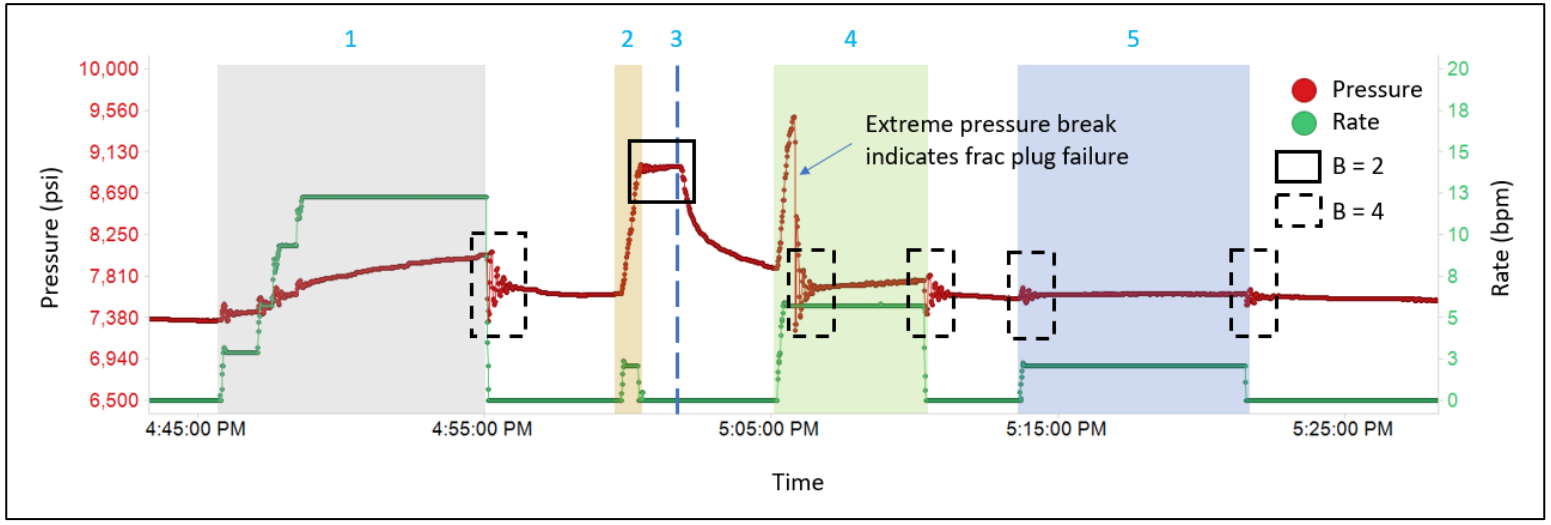
Incorporating Water Hammer Data into the Analysis Process

Case 1: Stage Isolation



1. Pump down frac plug and guns.
2. Pressure test frac plug.
3. Perforate 1st cluster.
4. Conduct Injectivity test.
5. Perforate remaining clusters.

Case 2: Loss of Stage Isolation



B = 2: indicates isolation from the prior stage

B = 4: indicates connection to a large fracture capacity