# Integrated Analysis of Borehole Microseismic, Completion and Production Data to Characterize Reservoir Depletion and Determine Infill Well Spacing in Tight Sands*

**Yashwanth Chitrala[1], Hemali Patel[1], Samuel Scheibal[1], and Jonathan Williams[1]**

Search and Discovery Article #42125 (2017)**
Posted August 14, 2017

*Adapted from oral presentation given at 2017 AAPG Annual Convention & Exhibition, Houston, Texas, April 2-5, 2017


[1]BP America, Houston, Texas (yashwanth.chitrala@BP.com)

## Abstract

BP America performed a borehole microseismic monitoring of a ten-stage cased hole hydraulic fracturing operation in the Cleveland Formation, Anadarko Basin. The Upper Pennsylvanian Cleveland sands have been extensively drilled and exploited with vertical wells over the past several decades. Though these sands are of low porosity (3-15 p.u) and permeability (4-400uD), hydraulic fracturing provided a renewed interest in this formation. Over the years, depletion not only changes the reservoir fluid state but also would affect the horizontal stress magnitudes. To understand the effect of nearby vertical well depletion and changed stress regime on hydraulic fractures, we designed a microseismic monitoring experiment on an infill horizontal well. Majority of the ~3700 ft lateral was drilled and stayed in a clean rock (< 70 GAPI), with minimal variation in rock quality among the various stages. Two offset producers, one on each side of a well bore, were shut in and turned into monitoring wells (~60 geophones), along with downhole pressure gauges capped by a bridge plug. A hybrid system of slickwater and crosslink gels was pumped at ~80 bpm along with a biodegradable diverter agent to enhance fracture propagation. From the microseismic event distribution, maximum horizontal stress direction was observed to be SSE-NNW which is in agreement with previous breakout and borehole image log studies in this area. Experimental results showed that the depletion had a profound effect on hydraulic fracturing fluid distribution and fracture half-lengths. In four stages where the fracture plane was in line with the offset well depletion, a lower number of events was recorded compared to the stages at virgin reservoir pressure. Also, a fracture reorientation was observed in three stages where the fracture was preferentially drawn to the low-pressure area. Chemical fluid tracer data and treatment plots supported the observations made from the microseismic events. This experiment provided a unique opportunity to observe and delineate depletion from existing producers, thereby providing us with guidelines for future infill drilling.

US Lower 48 onshore

# Integrated Analysis of Borehole Microseismic, Completion and Pressure Data to Characterize Reservoir Depletion and Determine Infill Well Spacing in Tight Sands

**Yashwanth Chitrala, Hemali Patel, Samuel Scheibal, Jonathan Williams**
**MidCon BU, BP America, Houston, TX, United States.**

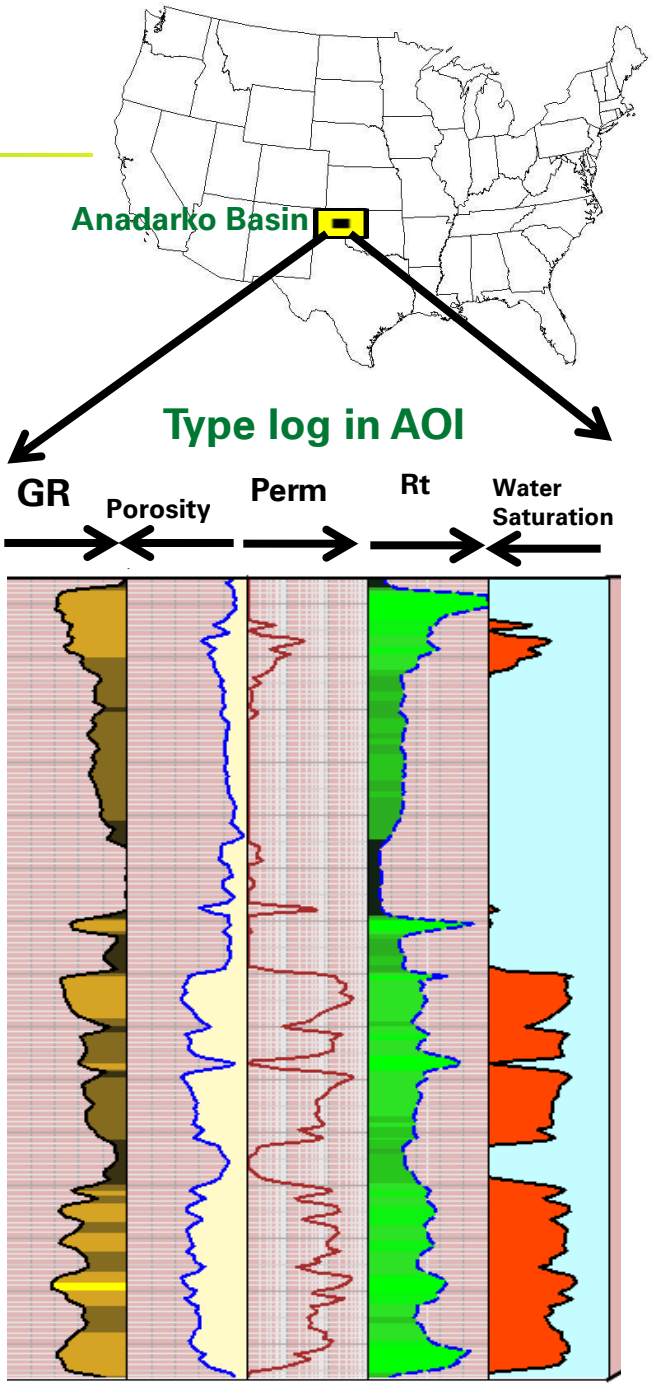
# Outline

US Lower 48 onshore

- Objective
  - *Changing degrees of Cleveland development (vertical and horizontal ) over the decades*
  - *Unpredictable fluid properties (GOR) in adjacent sections resulting from pressure change*
- Microseismic Monitoring set up
  - *Downhole monitoring from two vertical offsets*
- Microseismic Interpretation
  - *Integration of MS events with pressure data to understand depletion effects*
- Failure Envelope- Mohr Coulomb
  - *Failure mechanisms and effect of depletion explained*
- Summary

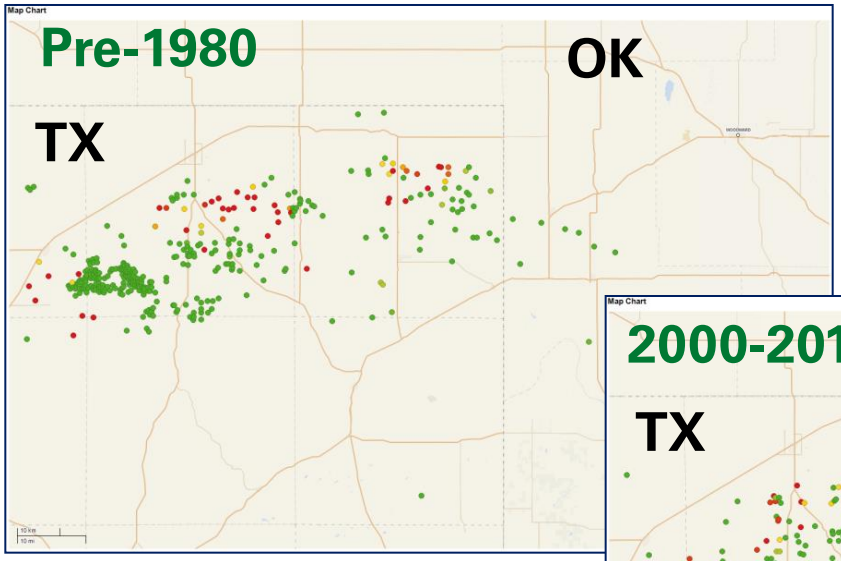
# Cleveland Rock Properties

- Geological Age: Middle Pennsylvanian
- Depositional systems:
  - Incised valley fill systems
  - Tidally reworked fluvial deltaic
- Well sorted fine grain tight sands
- Low Net to Gross
- Porosity: ~12 p.u
- Permeability: ~400 uD
- Water Saturation: ~35%

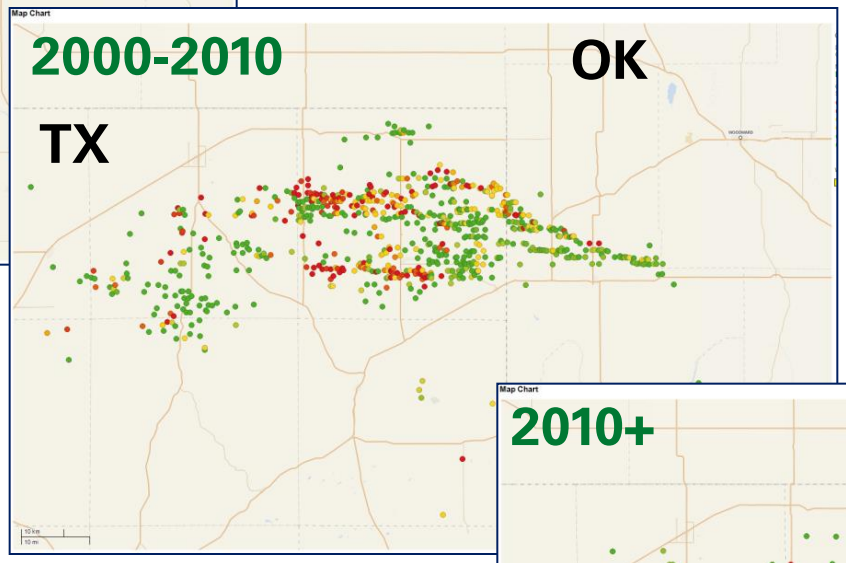


# Cleveland Play Overview
## Oily, Gassy & Oily Again

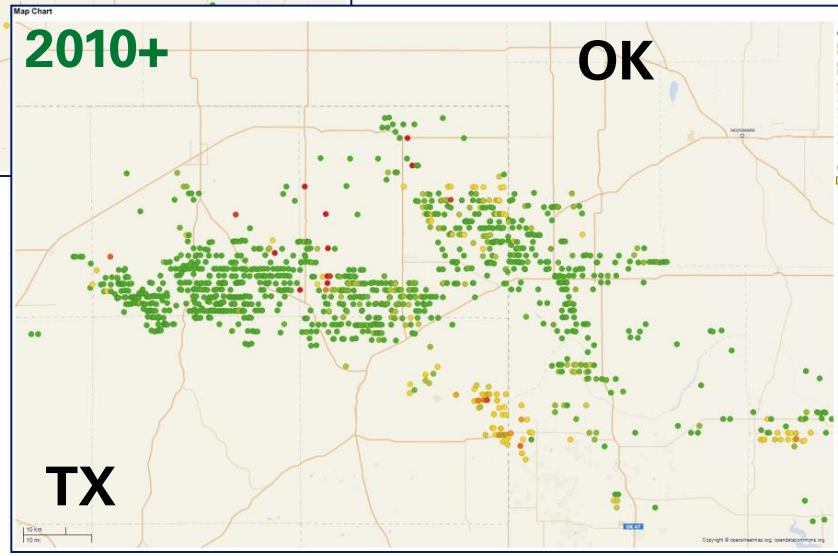

US Lower 48 onshore




**Pre-1980 (Oily)**
Vertical Wells
Oil Gravity: <50 API




**2000-2010 (Gassy)**
Vertical & Horizontal Wells
Oil Gravity: 40-60 API

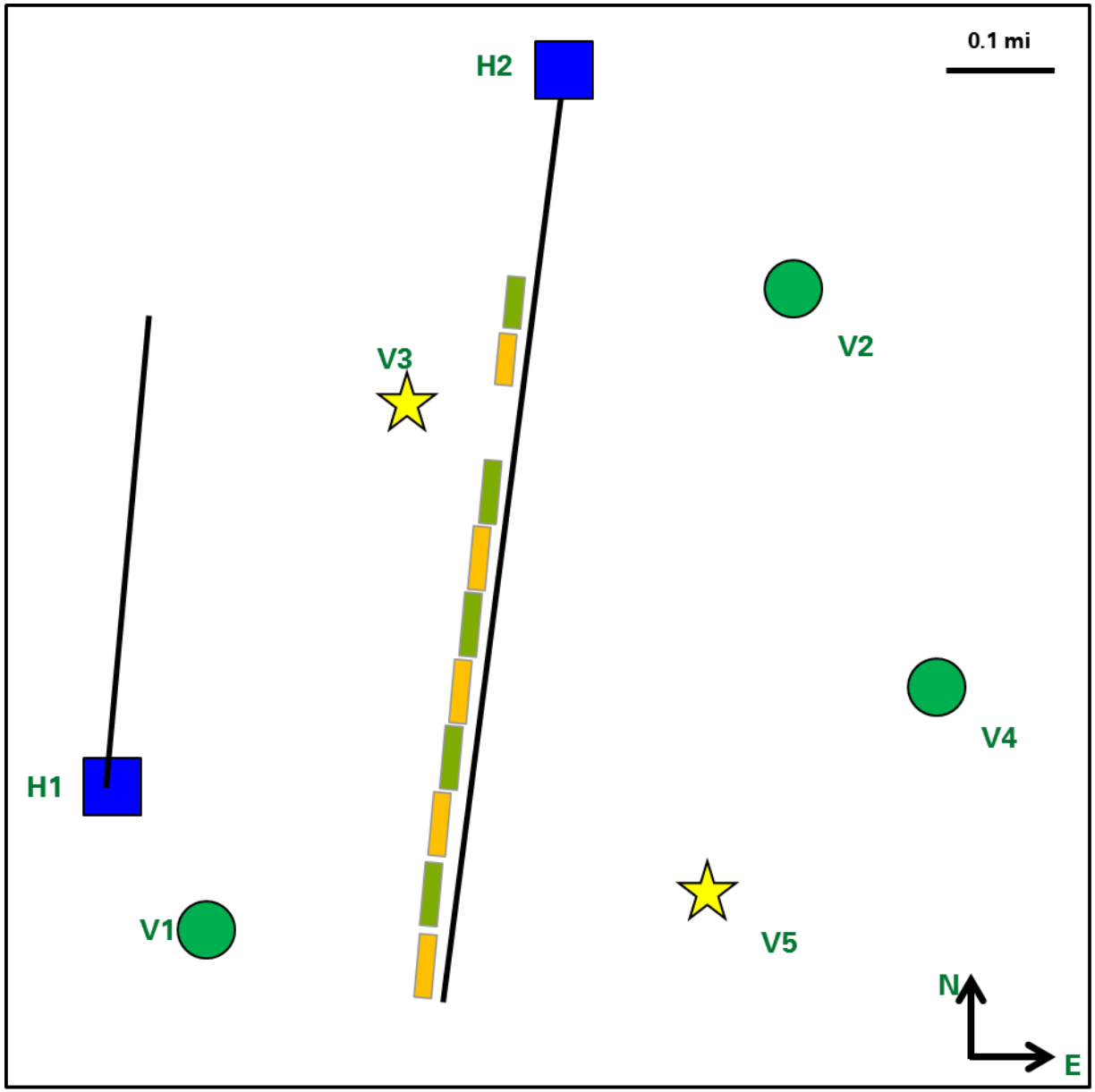



Color by
IP Oil Gravity API
- 70.00
- 60.00
- 55.00
- 50.00
- 45.00
- 40.00

**2010+ (Oil)**
Horizontal Wells
Play expanding
Oil Gravity <50API

# Microseismic Monitoring setup

US Lower 48 onshore




Active producers
(V1-V5, 1980-present)

Monitoring Wells
(V3, V5,60 geophones,
50’ intervals, Pressure guage)

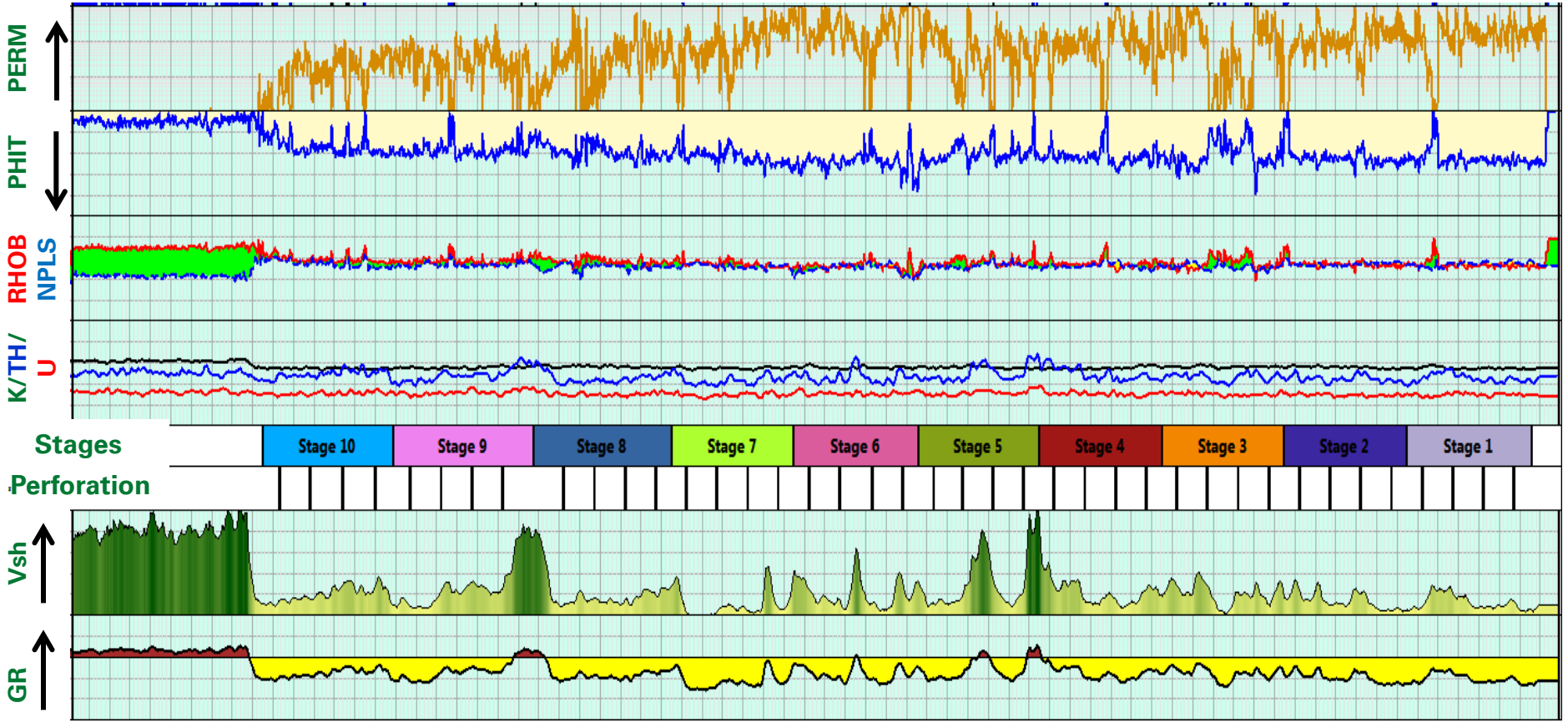
Even Stages

Odd Stages

Horizontal wells
(H1 active producer,
**H2 treatment well**)

# H2 Horizontal ThruBit log interpretation

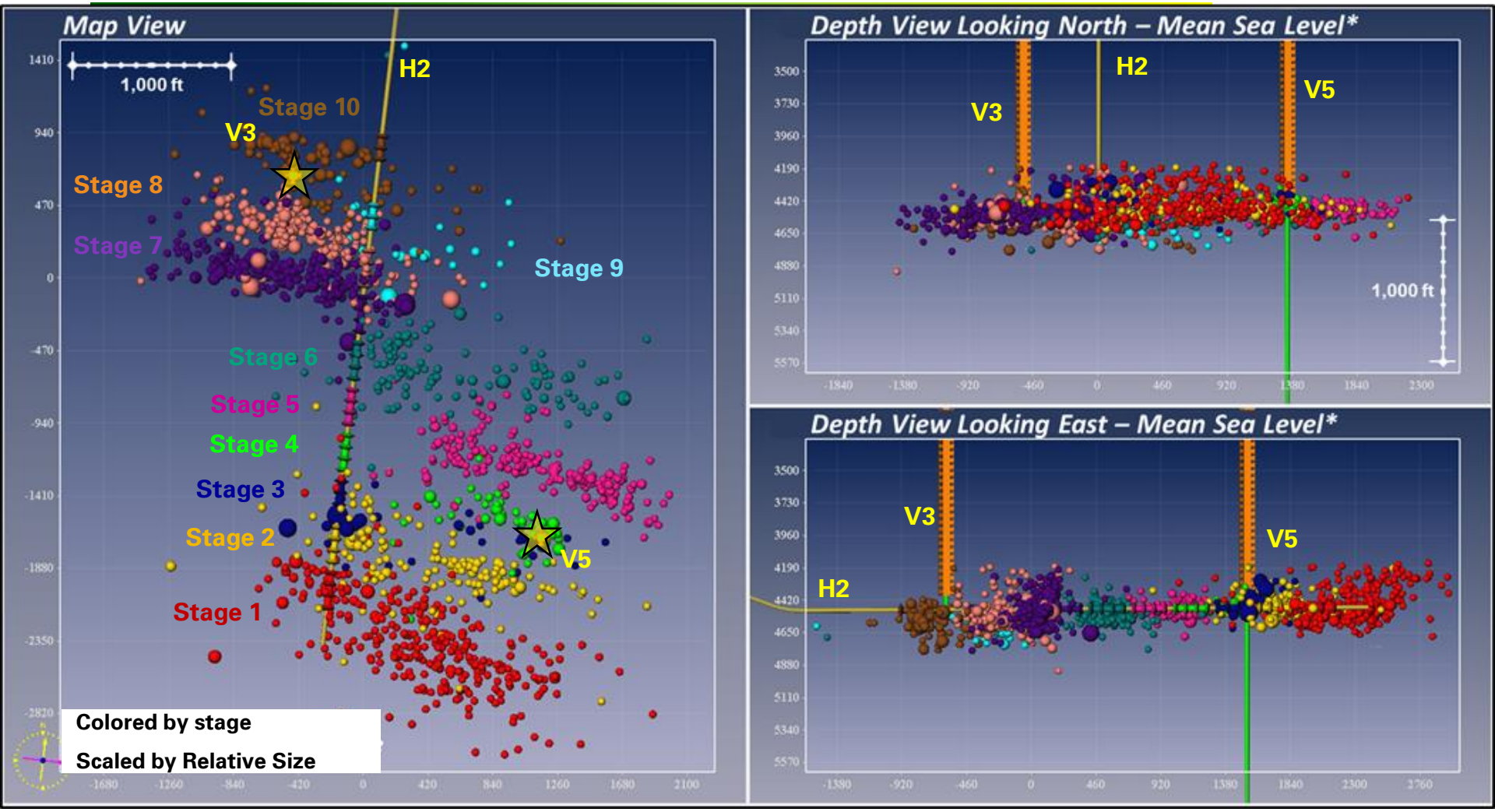
US Lower 48 onshore




- Majority of the lateral drilled in good rock quality
  - Similar reservoir properties in all stages
- High shale volume intervals are skipped intentionally
- Cased hole completion with geometric cluster spacing

# Microseismic (MS) Event Distribution


US Lower 48 onshore

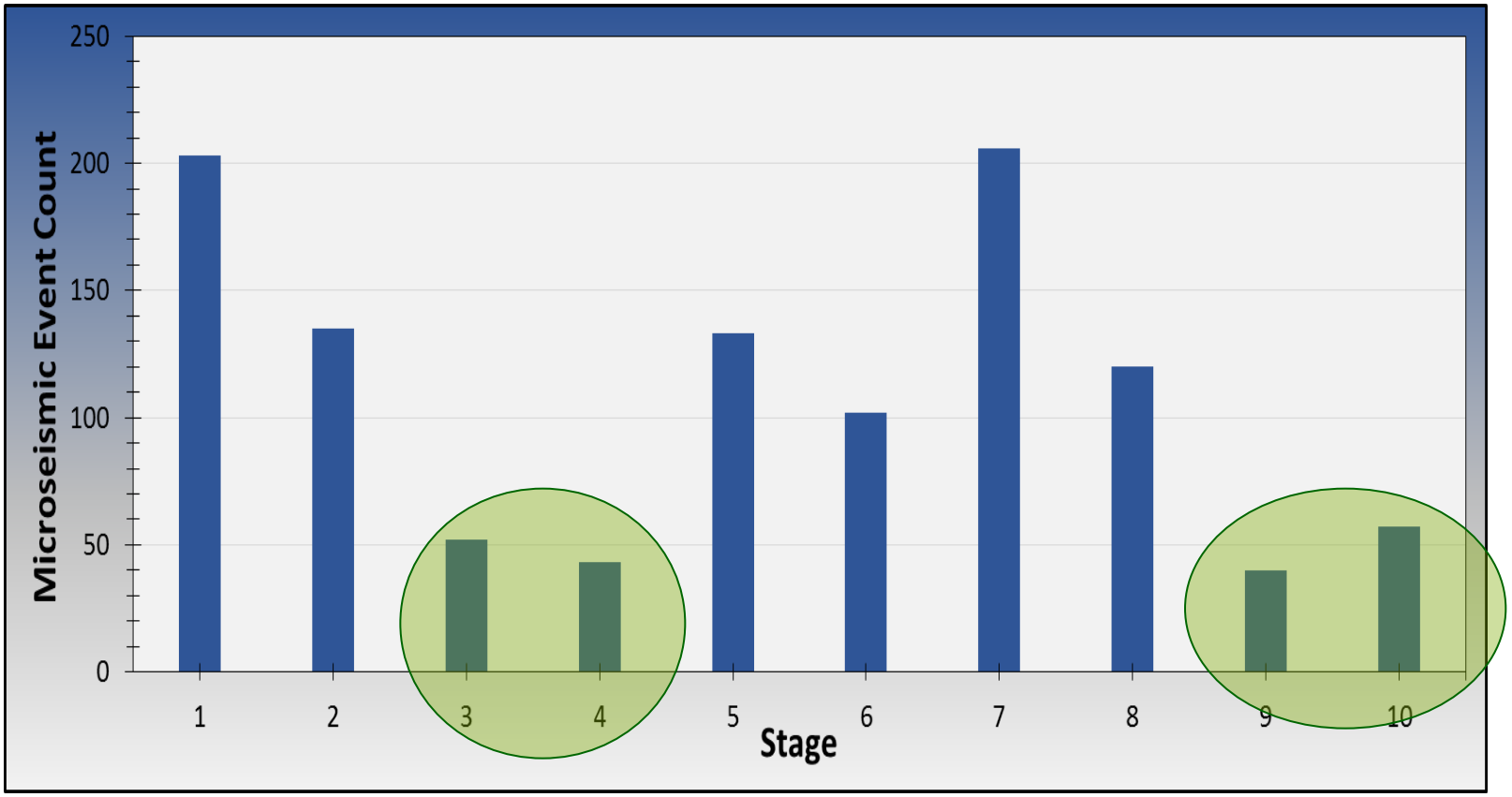



- MS events in the direction of maximum horizontal stress (ESE-WNW)
- Majority of the events confined within the target interval
- Symmetric bi-wing fracture propagation not observed

**V3, V5:** Offset Cleveland vertical producers, turned into monitoring wells

# MS Event distribution

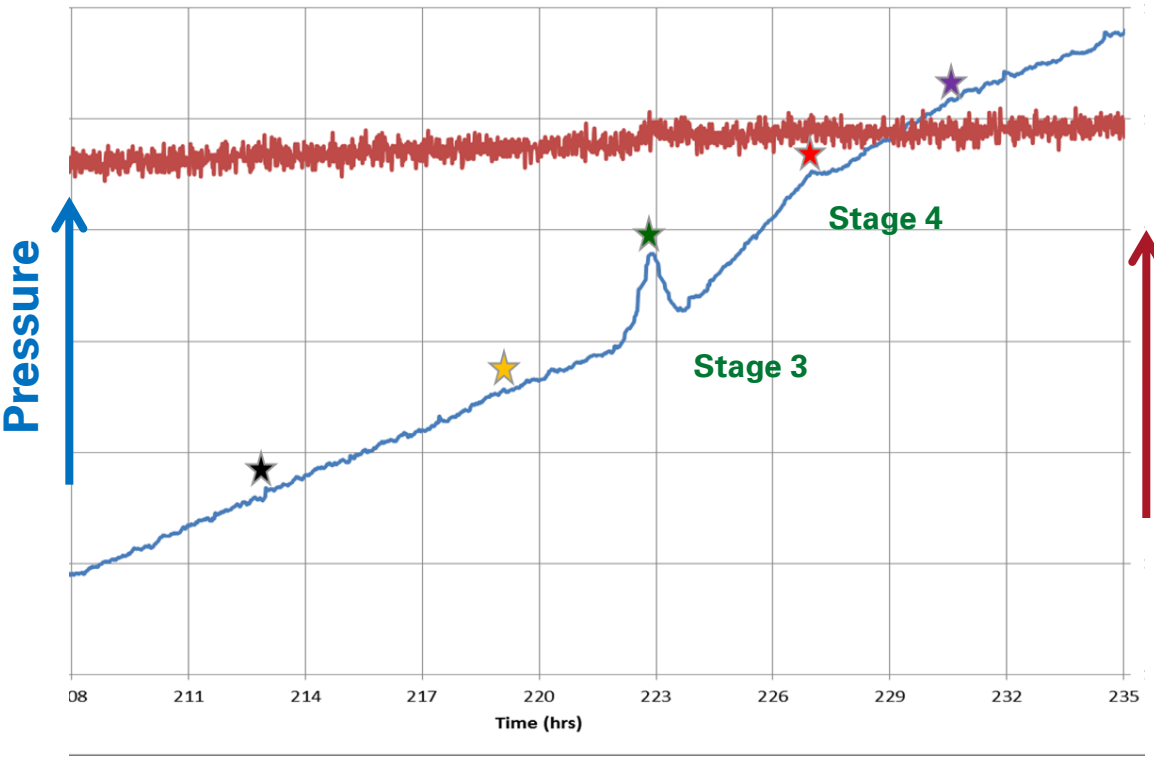

US Lower 48 onshore

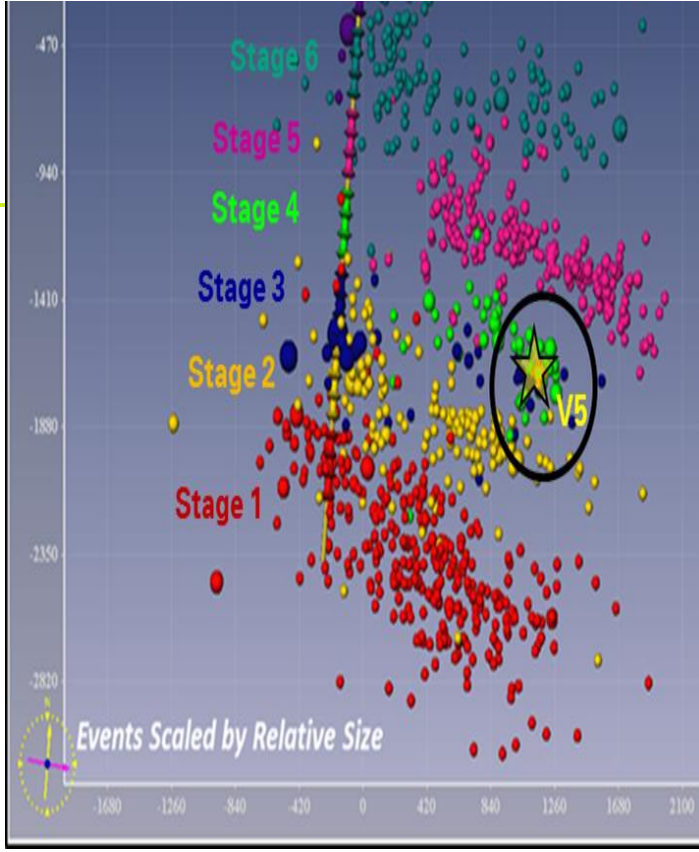


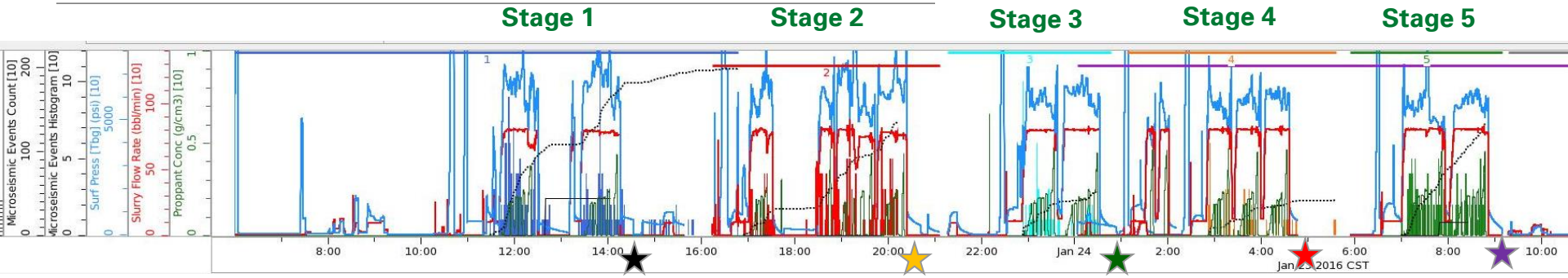

- Lower number of events recorded in Stages 3,4 and Stages 9,10
- Interaction of the induced fracture network with V3 (Stages 9, 10) and V5 (Stages 3, 4) drainage envelope

# Pressure response on V5

## Interference at the end of stage 3, 4



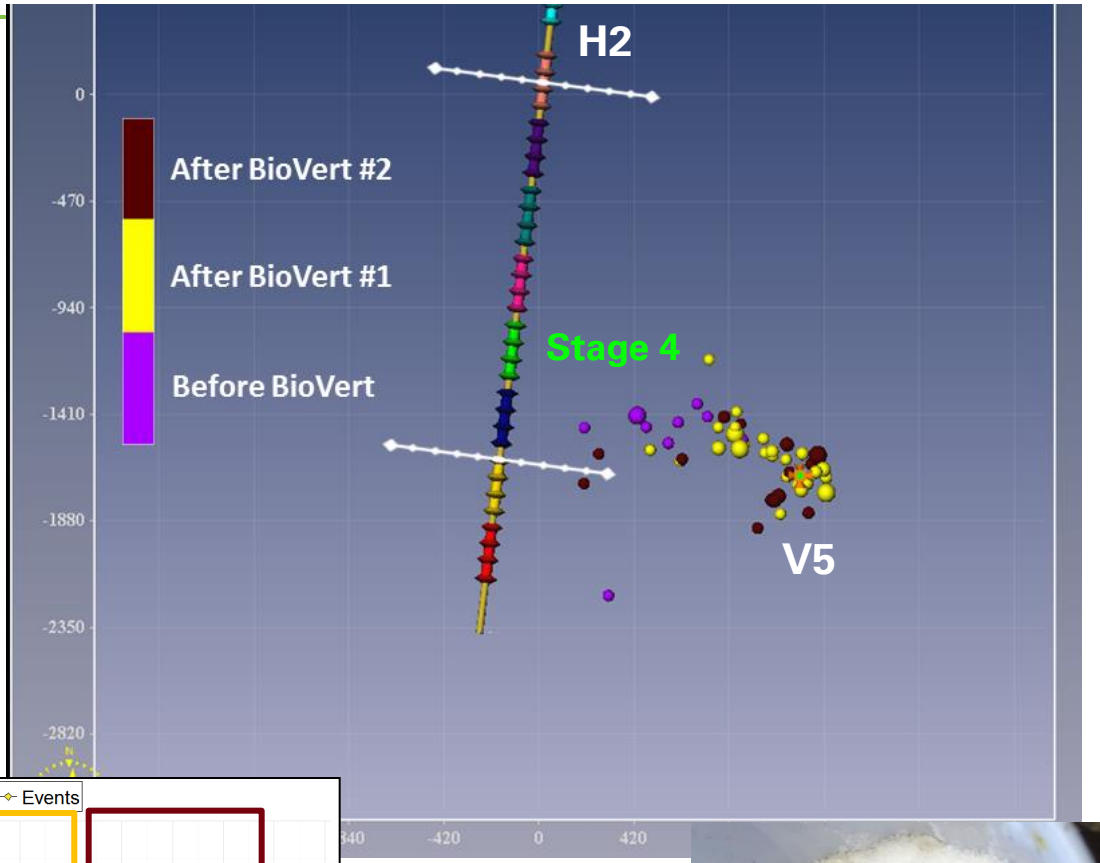

- Pressure buildup observed in V5 at the end of Stages 3 and 4
- No spikes observed in pressure treatment plots of Stages 3, 4 on H2 horizontal
- Fewer MS events observed overall in Stages 3,4

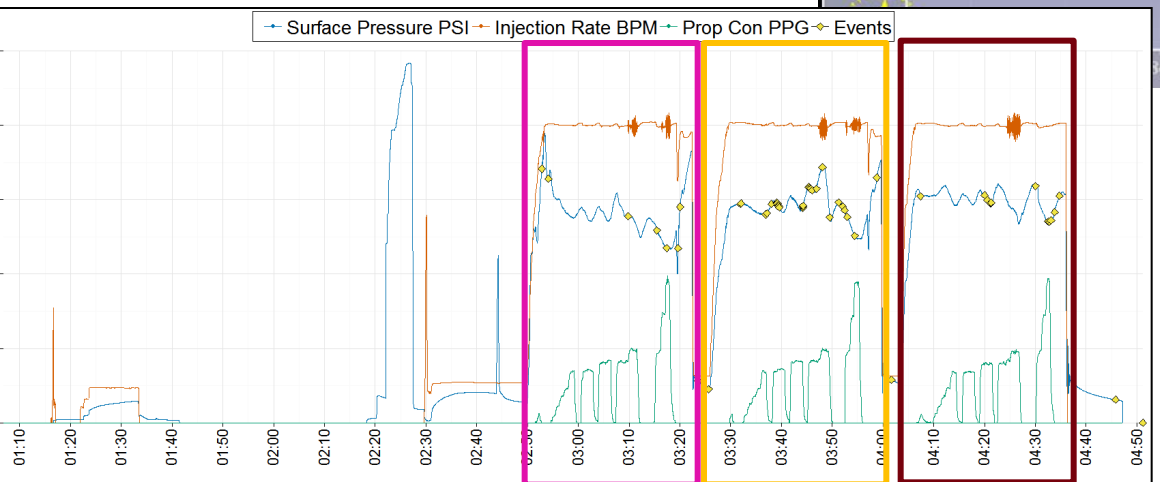
# Reservoir Depletion (Stage 4)

## MS observation of fracture propagation towards depletion

US Lower 48 onshore

- Stage 4 has less MS activity compared to other stages
- Spatial and temporal propagation of fracture front after each biovert pulse is observed
- Fracture propagation in the direction of Shmax but is influenced by V5 producer
- Majority of the events concentrated around the low pressure system at V5

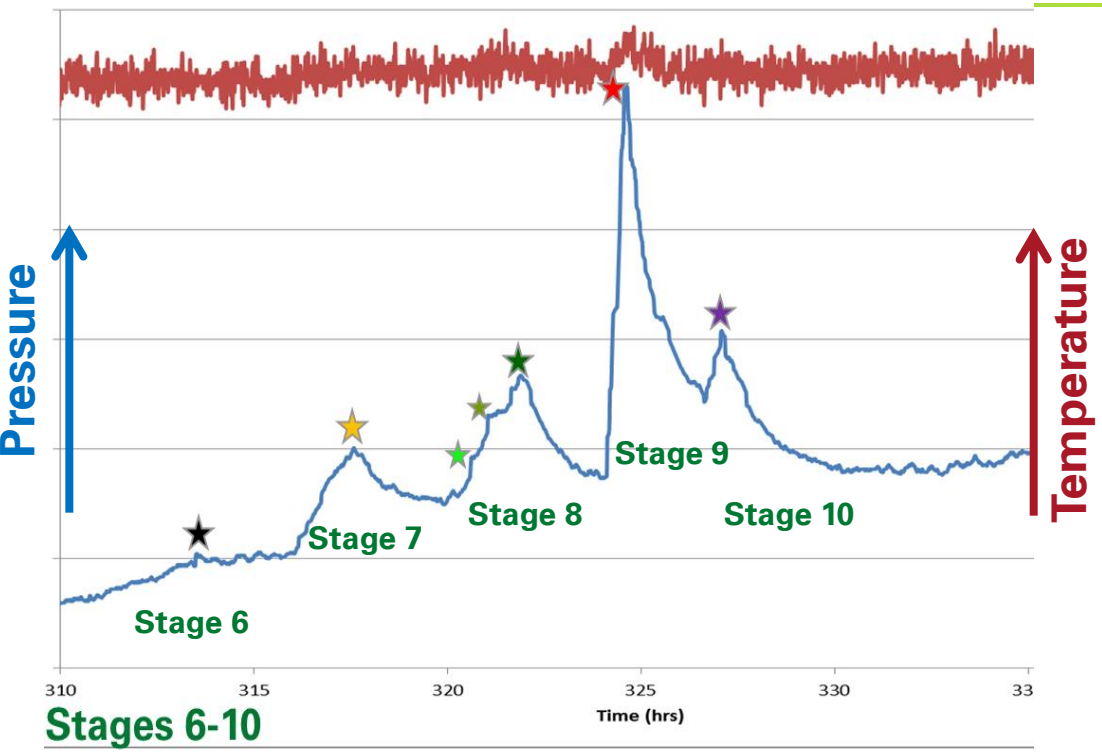


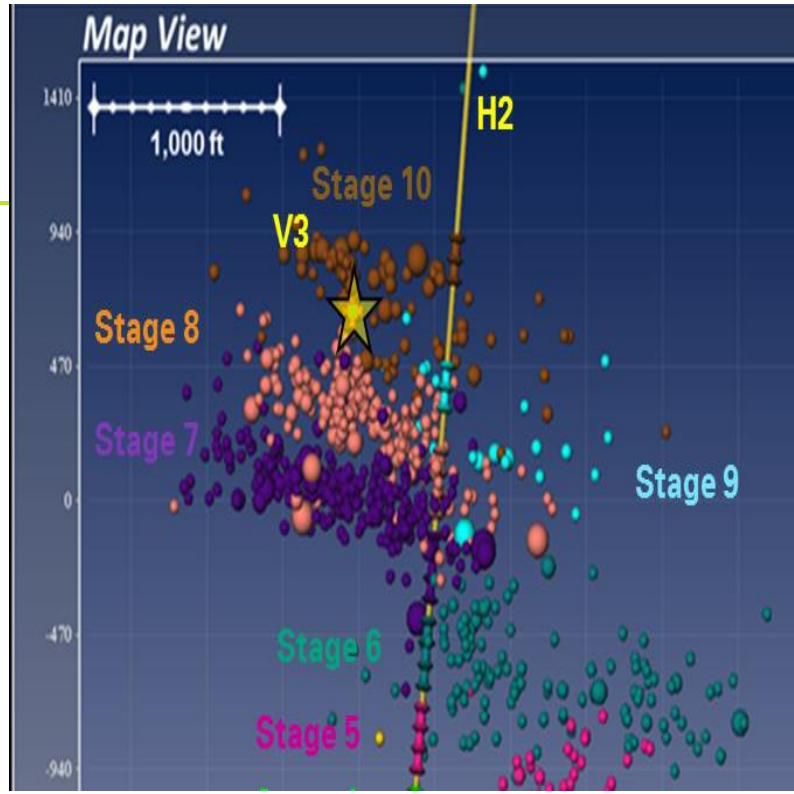



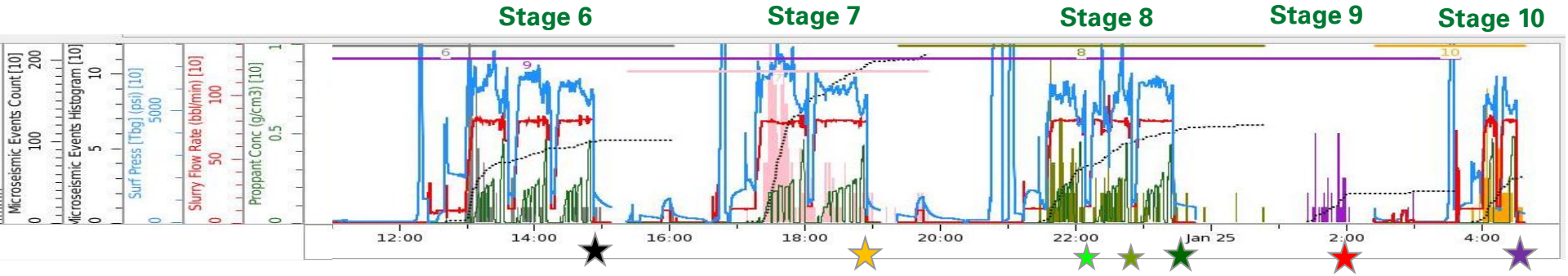

NWB Biovert

# Pressure response on V3

## Interference at the end of every stage 7-10



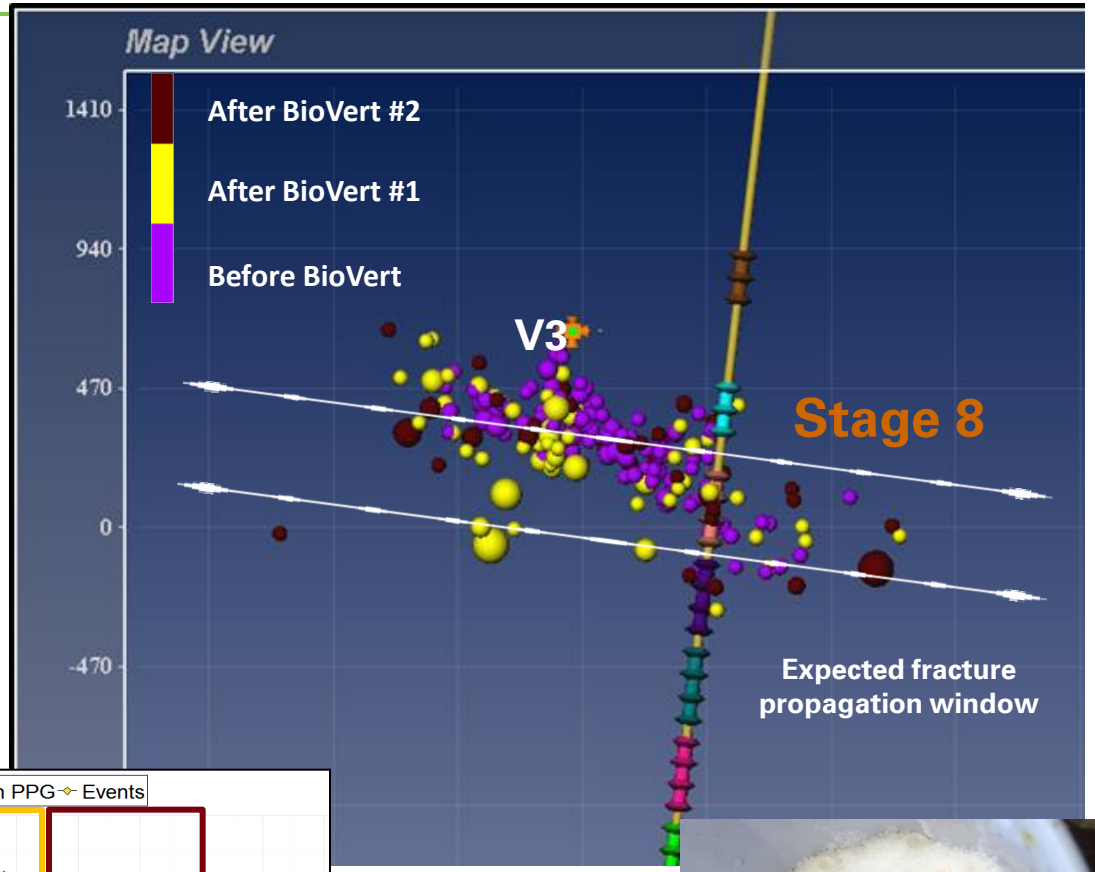

- Pressure buildup observed in V3 at the end of Stages 7-10
- No absurdities in pressure treatment plots of Stages 7-10
- Fewer MS events observed in Stages 9, 10

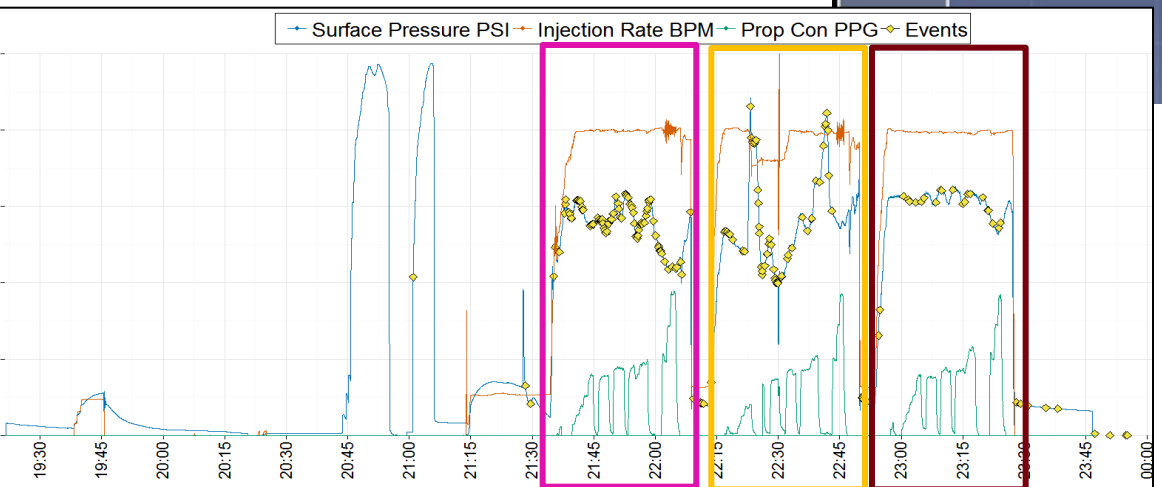
# Reservoir Depletion (Stage 8)

## MS observation of fracture propagation towards depletion

US Lower 48 onshore

- Asymmetric fracture propagation with a dominant west wing
- Fracture orientation influenced by the low pressure system around V3
- Second and third pump cycles result in a more planar fracture
- New rock is stimulated after every pulse of biovert
- Complex fracture network created around V3



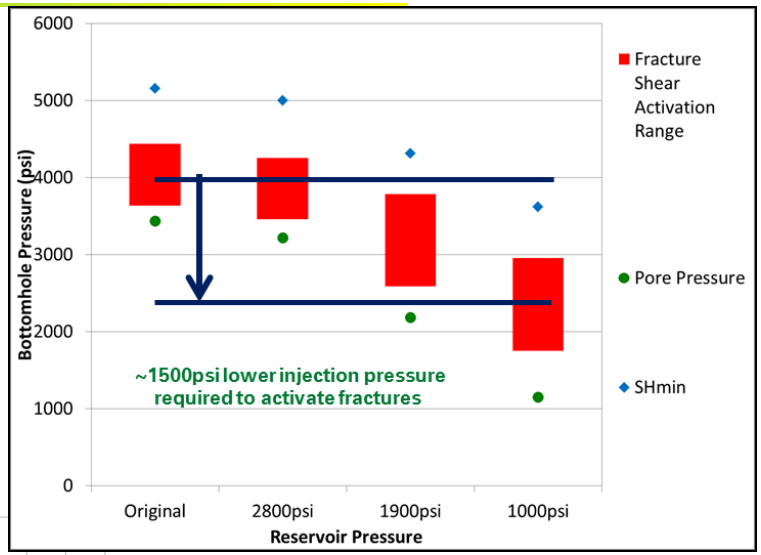



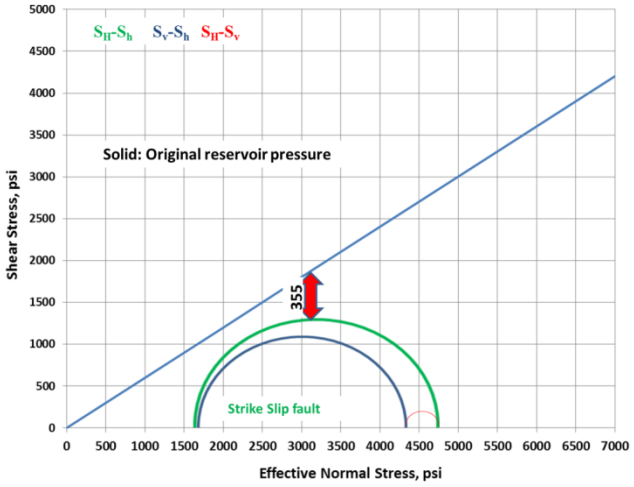

NWB Biovert

# Mohr Coulomb envelope to understand effects of reservoir depletion

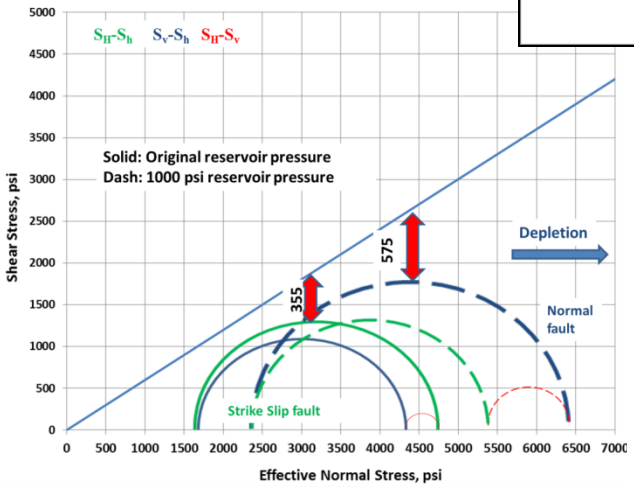
US Lower 48 onshore

- As reservoir pressure decreases, effective stress increases, BUT…
- At lower reservoir pressure, the pressure required to reactivate fractures in shear failure decreases.
- As frac progresses towards offset wells, frac fluid prefers to go near depleted producers.

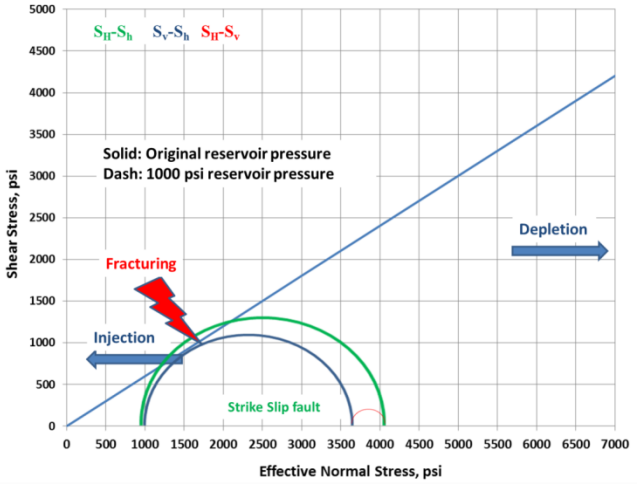



a) Initial reservoir condition. Cohesive forces is assumed to be negligible. Critical stress state need to be exceeded to create new fractures in the reservoir




b) Current day reservoir condition. Depletion has moved the failure envelope away from the critical stress line resulting in higher effective stresses in the horizontal direction.




c) Reservoir stress state post hydraulic fracturing. Smaller increase in effective stress can reactivate fractures in depleted zone. Different failure mechanisms observed in depleted stages compared to stages at virgin reservoir pressure

# Summary


US Lower 48 onshore

- Lower number of MS events observed in Stages 3,4,9,10
  - Symmetric bi-wing fracture not observed
  - Fracture orientation and propagation influenced by the low pressure system around offset producers
- Biovert is pumped for near wellbore diversion
  - Spatial and temporal propagation of fracture in new rock is observed after each pulse
  - Near and far wellbore complex fracture growth observed in few stages only (Stage 8)
- Pressure communication observed in offset monitoring wells (V3, V5) > 1500 ft away
  - Buildup rates depended on the proximity of the stage to offset producer
  - Varying pressure regime (depleted vs virgin pressure) along the well bore resulted in inconsistent and inefficient reservoir drainage causing the bubble point to break sooner than expected
  - Higher GOR observed in depleted sections compared to adjacent sections with minimal offset well production
- Mohr Coulomb envelope provides insights on failure mechanisms
  - In depleted zones, injection pressure to reactivate fractures is lower
  - Rapid pressure increase results in complex fracture regime