Real-Time Borehole-Based Microseismic Monitoring of Hydraulic Fracturing Treatments in Adjacent Horizontal Wells in the Barnett Shale: Example of a Faulted Reservoir*

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Abstract

Large amount of gas are currently being produced from unconventional shale reservoirs. These plays are mainly technology- and economics-driven. These reservoirs must be effectively hydraulically fracture stimulated. Large-scale faulting and fracturing are critical factors controlling stress distribution hence hydraulically induced fracture system development. Almost all predictive models used to estimate recovery in stimulated wells are based on assumptions that lead to oversimplified fracture geometry. To avoid making assumptions and to better understand the created fracture geometry, borehole-based monitoring of the induced microseismicity may be used. We present the results of a multi-stage, multi-lateral microseismic monitoring campaign performed in the Barnett Shale formation in Denton County, Texas. The primary objectives of this project were to drill and to successfully complete Barnett shale wells in and around faults located on the prospect acreage using 3D surface seismic and microseismic monitoring of the hydraulic fracture process. Three horizontal wells were drilled 500 ft apart with the center well landed about 80 ft shallower than the outside laterals. All three laterals have been placed in the Lower Barnett Shale section. 3D surface seismic indicates that the surface locations are on top of a major fault complex with the lateral sections drilling away from the major fault system and through a smaller fault. We stimulated the wells using real-time microseismic monitoring in order to avoid the faulted zones and to modify as needed perforation scheme and stimulation schedule. All three Paddock wells have been successfully completed with initial production of over three MMCF gas per day each.

Initial production and early decline rates have proven that the completion process performed on these wells have been successful in avoiding the faulted areas. This ongoing project in the Fort Worth Basin highlights how integrating information gathered at different scale from different investigation method both in the geosciences and engineering domains is improving our understanding of the relation that exist between surface seismic, borehole measurements and the physical response of the reservoir formation when it is stimulated using hydraulically-induced fracturing. Evaluation of the production results appear to show that large-scale faulting features are not necessarily detrimental as long as treatment schedule and placement is properly controlled.

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AAPG Annual Convention, 11-14 April 2010

EAGLERIDGE ENERGY LLC

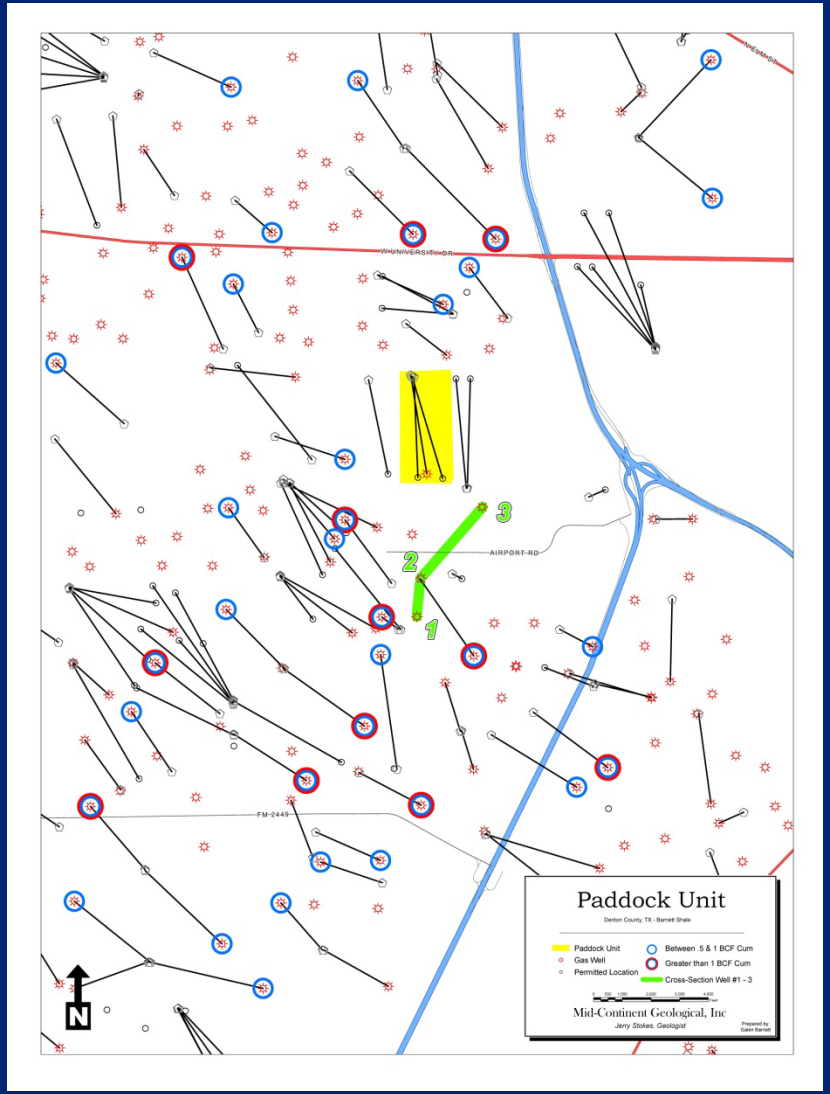
Schlumberger

Outline

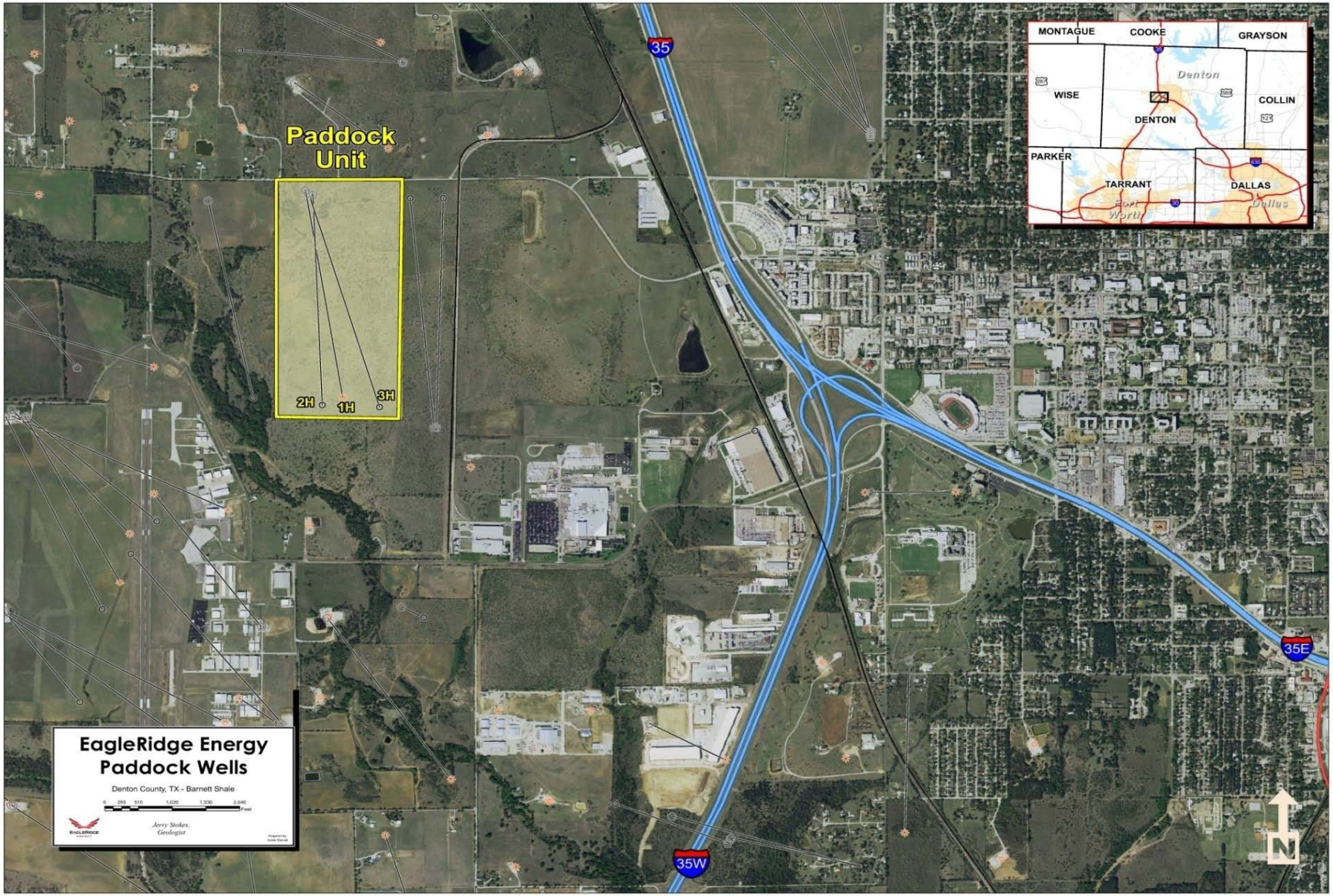
- Job Overview and Design Summary
- 3D Seismic
- Microseismic results
- Conclusions
- Questions and Discussion

Paddock area – Denton county, TX

- - Drill and Complete 3 horizontal wells in Denton City limits,
- - Commercially developing building area,
- - Vertical and Horizontal Barnett wells shown.



Aerial view


Paddock Unit
2H
1H
3H
35
35W
35E
N
MONTAGUE
COOKE
GRAYSON
WISE
DENTON
COLLIN
PARKER
TARRANT
DALLAS
Denton
Fort Worth
Dallas
EagleRidge Energy
Paddock Wells
Denton County, TX - Barnett Shale
Jerry Stokes, Geologist

Commercially developing area

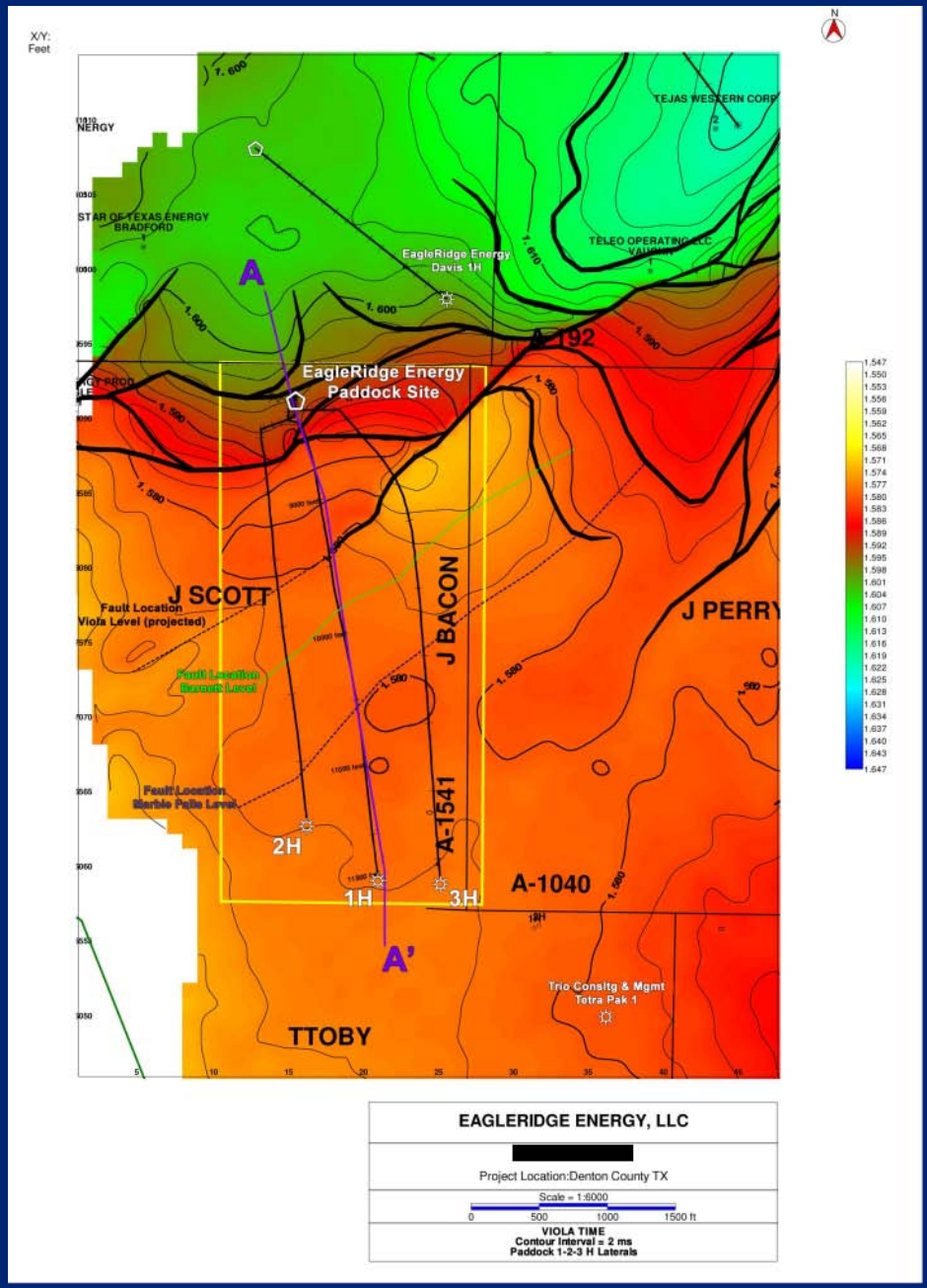
Viola time horizon

Seismic line

- Indicated with A-A’ labels

Faults

- Thick black lines indicate faults



Seismic line along Paddock 1H

Horizons

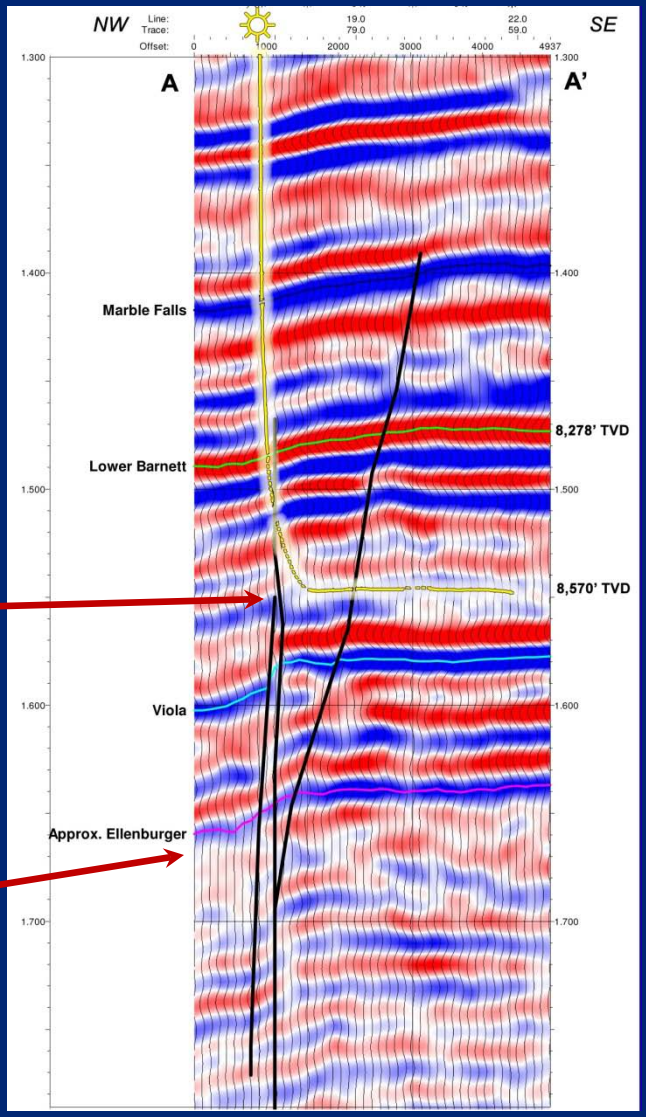
- Indicated with labels

Faults

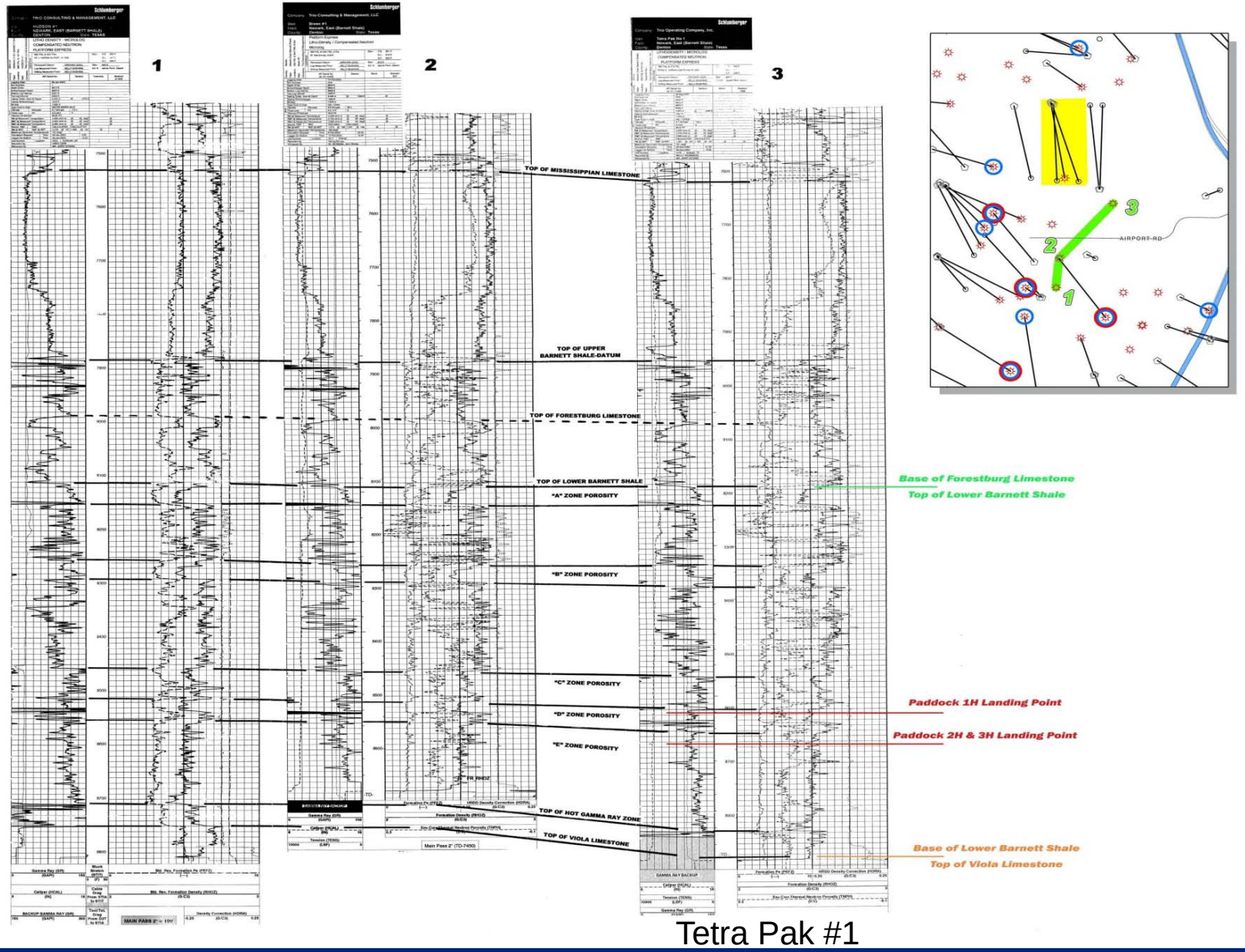
- Thick black lines indicate intersection of faults with seismic line

- Cross wells fairly close to heel
  - - Real-time microseismic monitoring used to avoid fracturing into fault.

- Faulted Ellenburger



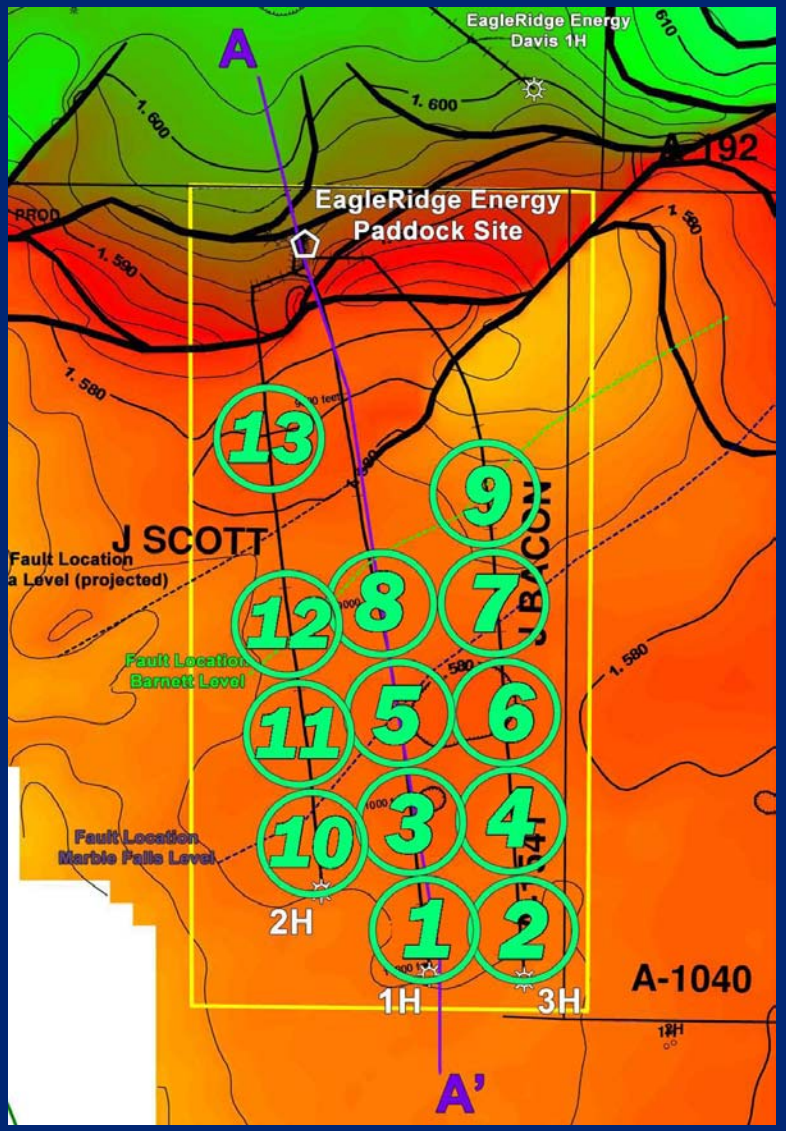
Log Overview



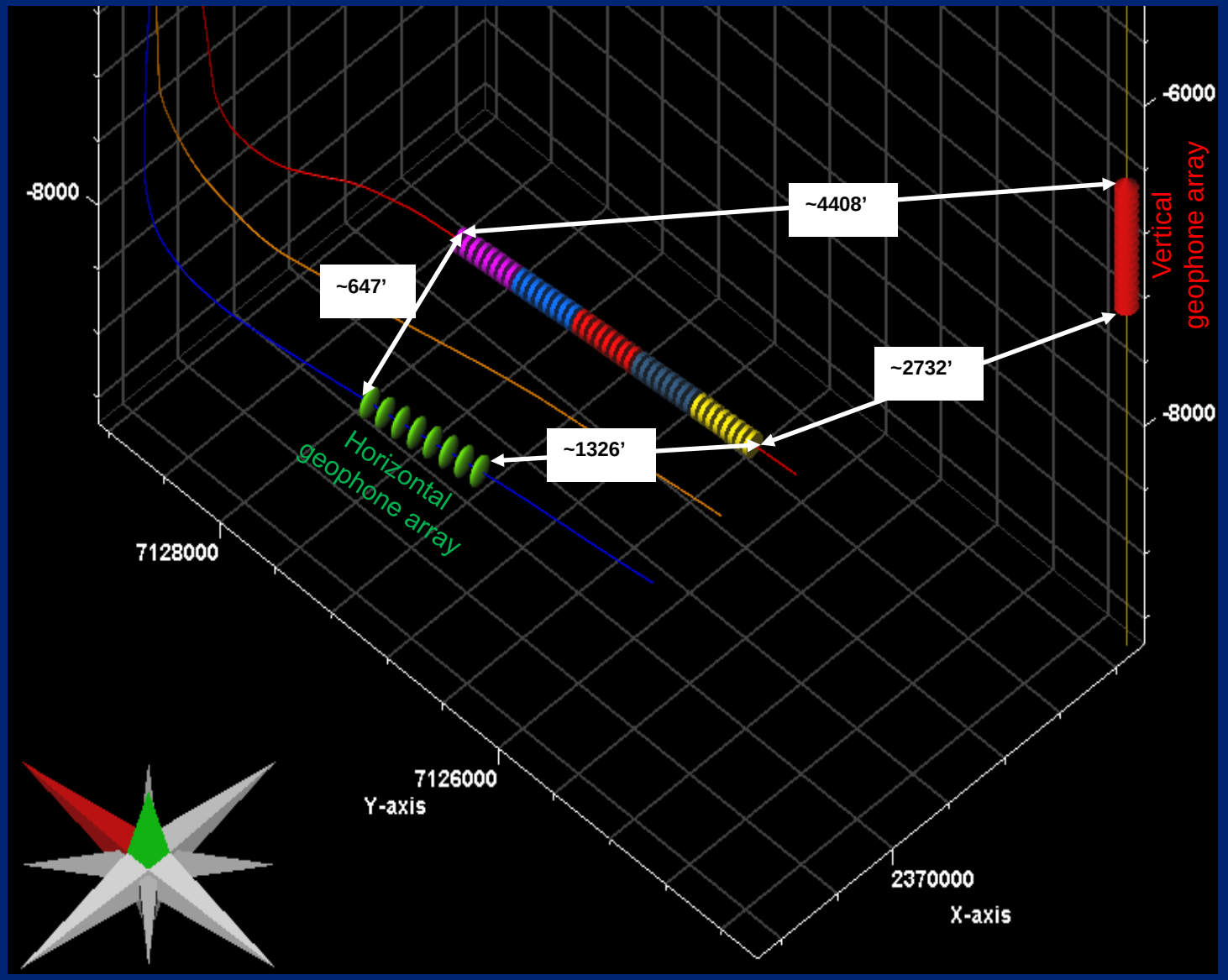
Tetra Pak #1

Treatment schedule overview

- - Zipper-style frac on Paddock 1H and 3H,
- - Zipper frac monitored from Paddock 2H (horizontal monitoring),
- - Paddock 2H frac monitored from 3H (vertical monitoring).

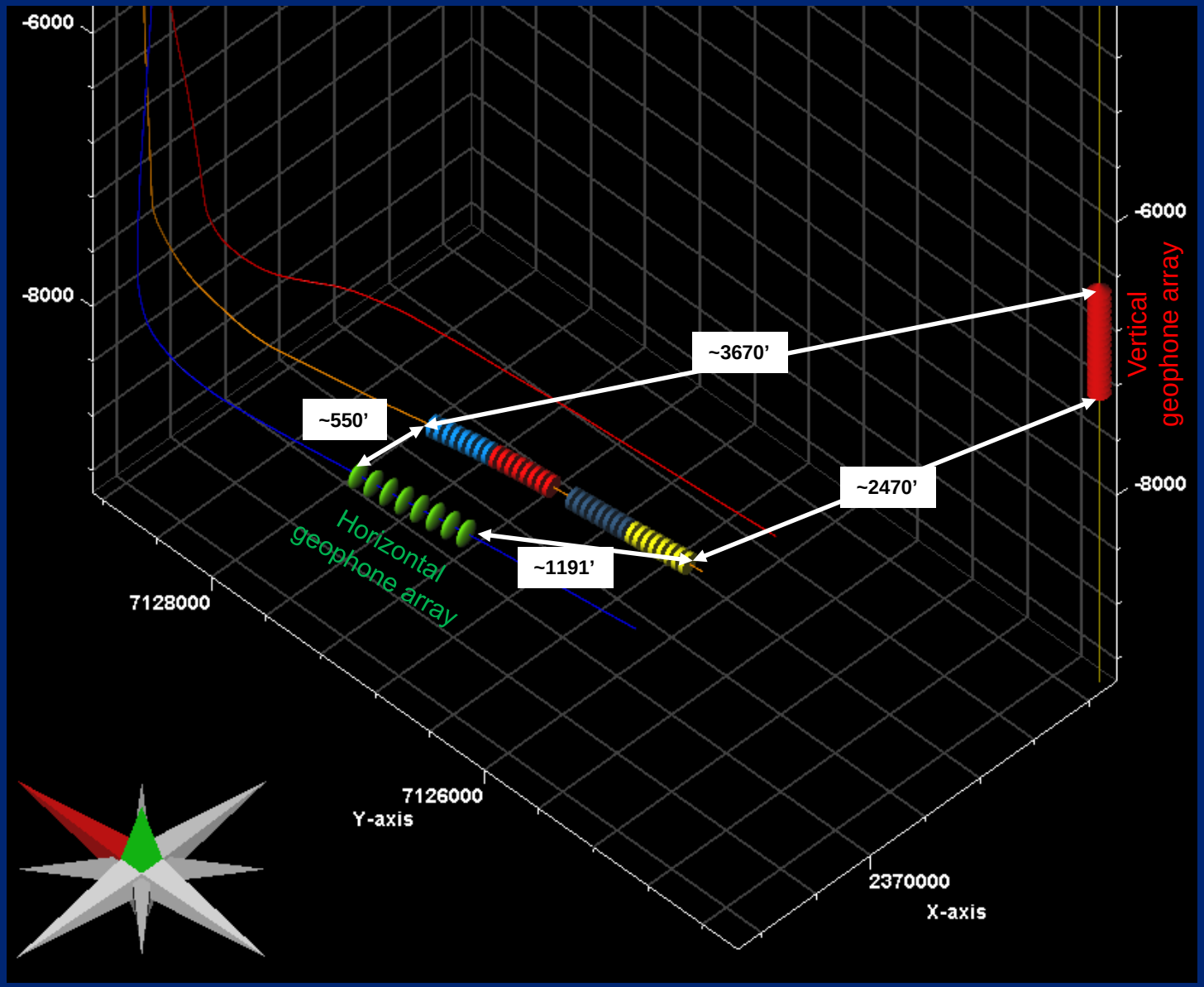


3H microseismic monitoring geometry



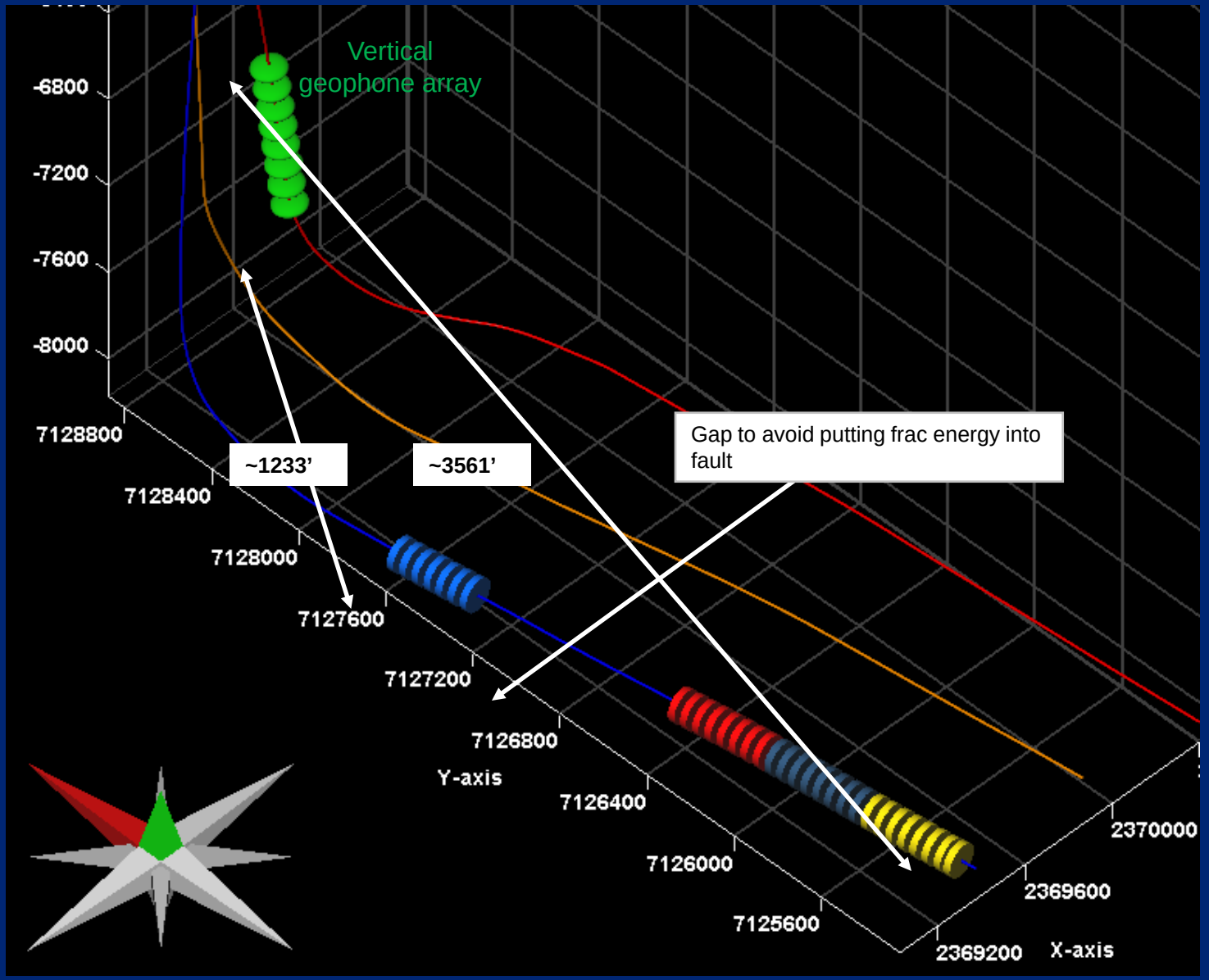
Paddock 1H
Paddock 2H
Paddock 3H
Tetra Pack 1

1H microseismic monitoring geometry



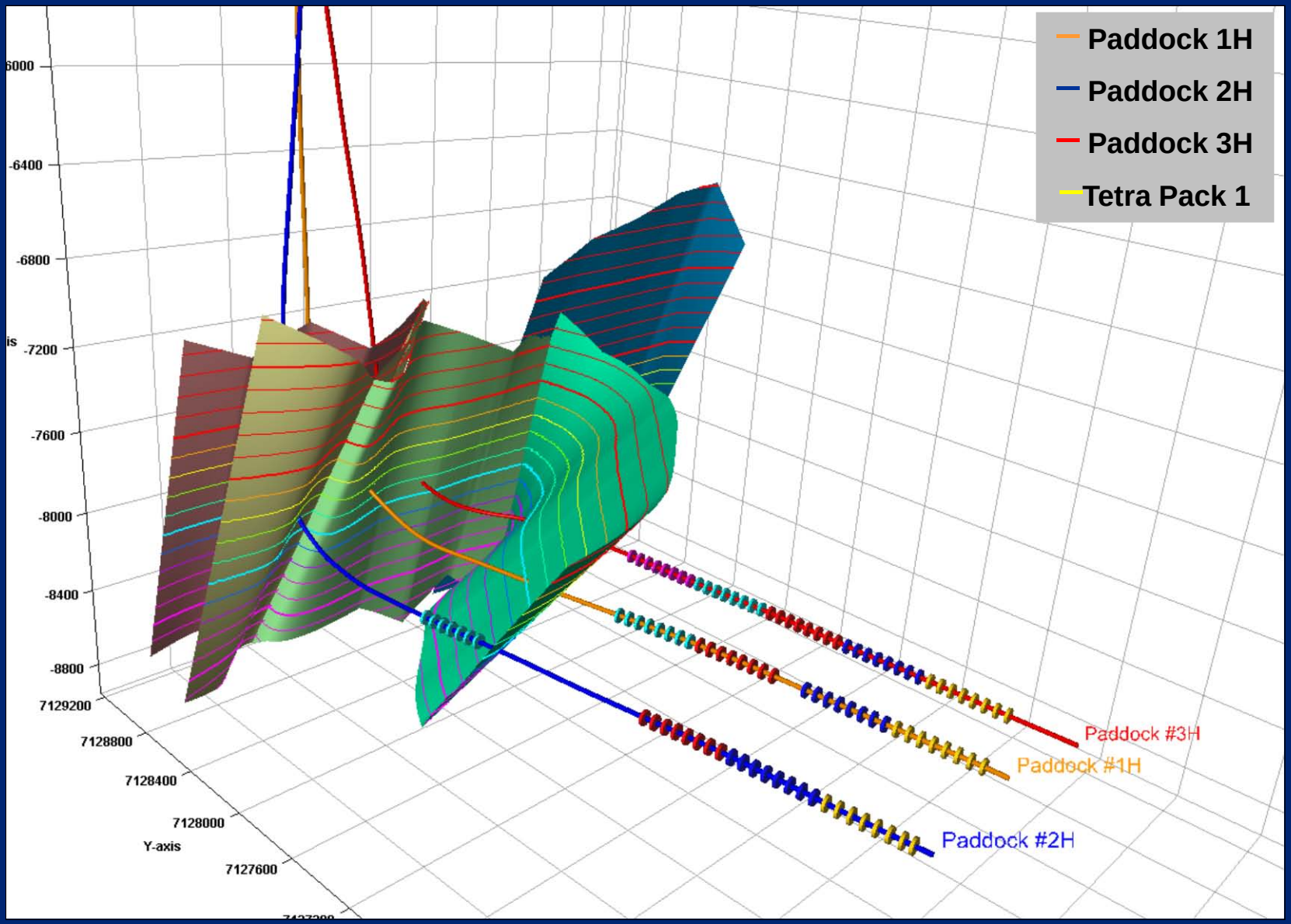
Paddock 1H
Paddock 2H
Paddock 3H
Tetra Pack 1

2H microseismic monitoring geometry



Paddock 1H
Paddock 2H
Paddock 3H
Tetra Pack 1

3D view of faults



Job design summary

Completion

- 5 ½”, 17# N-80 Cemented casing
- Perforate-and-Plug

Treatment Design

- 15,375 bbls
- 360,000 100 Mesh
- 170,000 40/70 Ottawa

Original design was for 15,375 BBLS 360k 100 MESH & 170k 40/70				
	Paddock 2H	Paddock 1H	Paddock 3H	
Stage 5			4/25 9:26am 9 9,563 190,800 130,500	Date/Time BBLS LBS 100 Mesh LBS 40/70
Stage 4	4/29 1:48pm 13 5,799 45,000 202,000	4/24 7:41pm 8 15,887 360,252 170,000	4/24 8:22am 7 16,700 361,200 171,000	Date/Time BBLS LBS 100 Mesh LBS 40/70
Stage 3	4/29 7:30am 12 14,100 280,000 174,000	4/23 7:50am 5 15,600 360,000 175,000	4/23 12:17pm 6 15,800 360,000 175,000	Date/Time BBLS LBS 100 Mesh LBS 40/70
Stage 2	4/28 1:09pm 11 15,504 360,000 145,900	4/22 11:40am 3 15,625 360,000 175,000	4/22 5:40pm 4 16,167 360,000 170,000	Date/Time BBLS LBS 100 Mesh LBS 40/70
Stage 1	4/28 7:33am 10 14,583 285,000 180,000	4/21 9:13am 1 12,413 317,000 68,000	4/22 6:40am 2 15,665 360,000 175,000	Date/Time BBLS LBS 100 Mesh LBS 40/70
TOTAL	**49,986** **970,000** **701,900**	**59,525** **1,397,252** **588,000**	**73,895** **1,632,000** **821,500**	**183,406** **3,999,252** **2,111,400**

Microseismic monitoring of a stage

Paddock 3H Stage 2

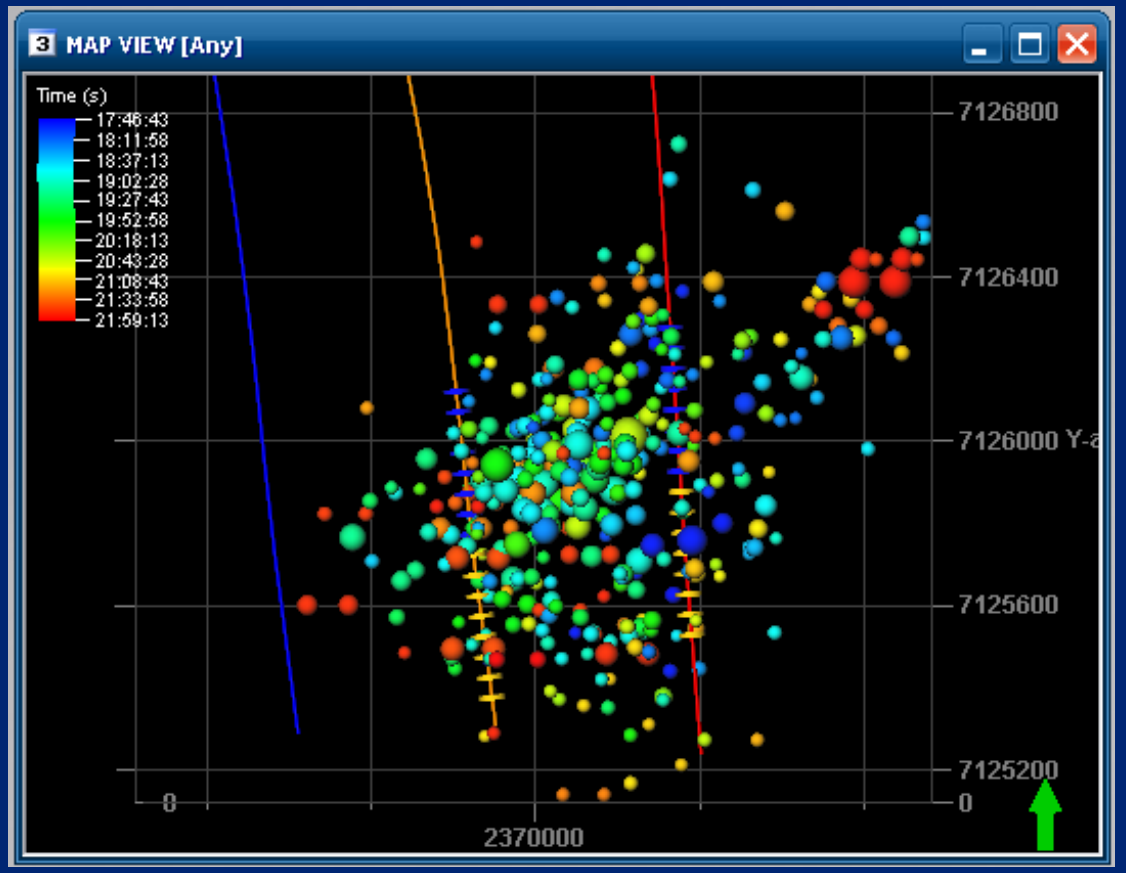
Items analyzed

-Microseismic event locations

- •Map view
- •Frac azimuth ~ N50°E
- •Perp to frac ~ N140°E

-Pumping data

-Event statistics



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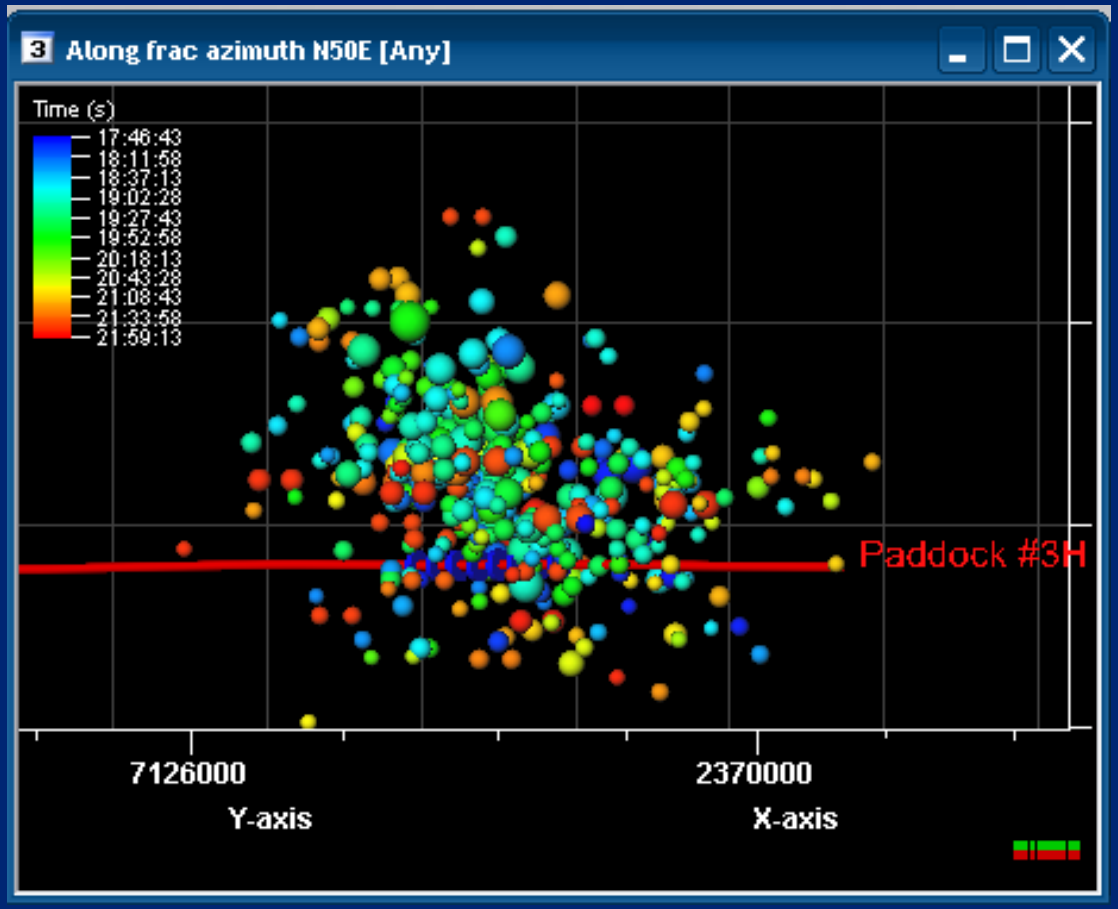

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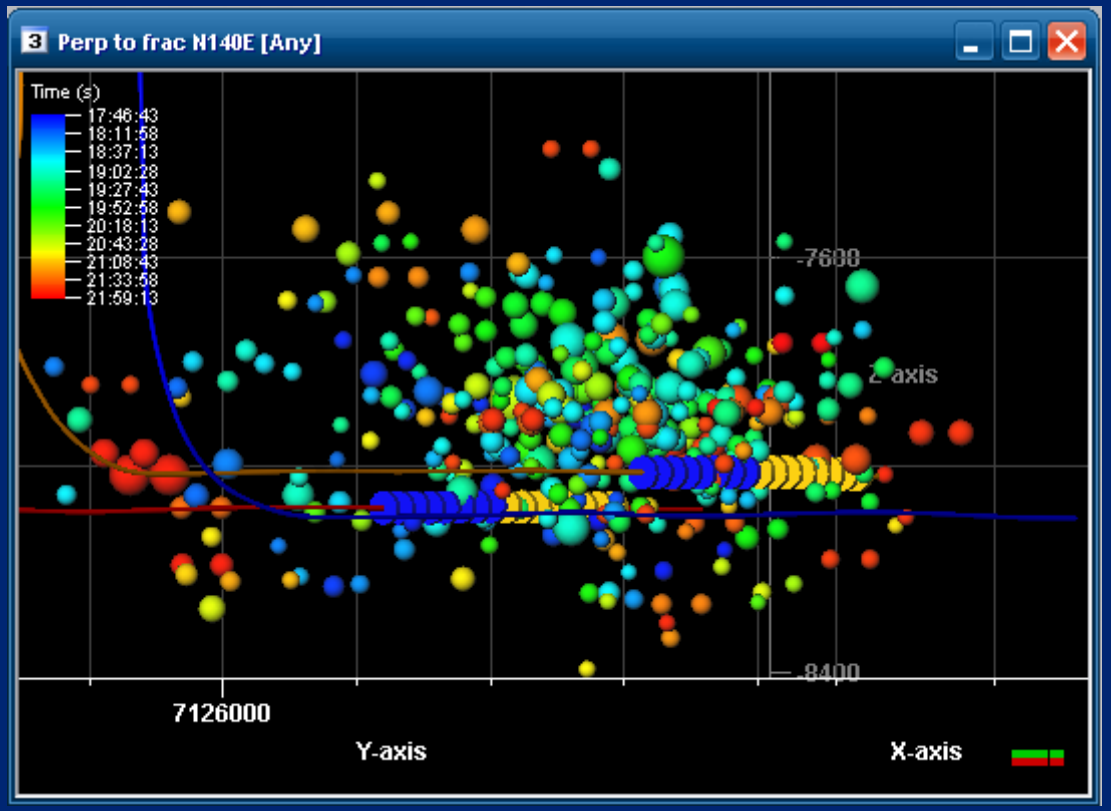

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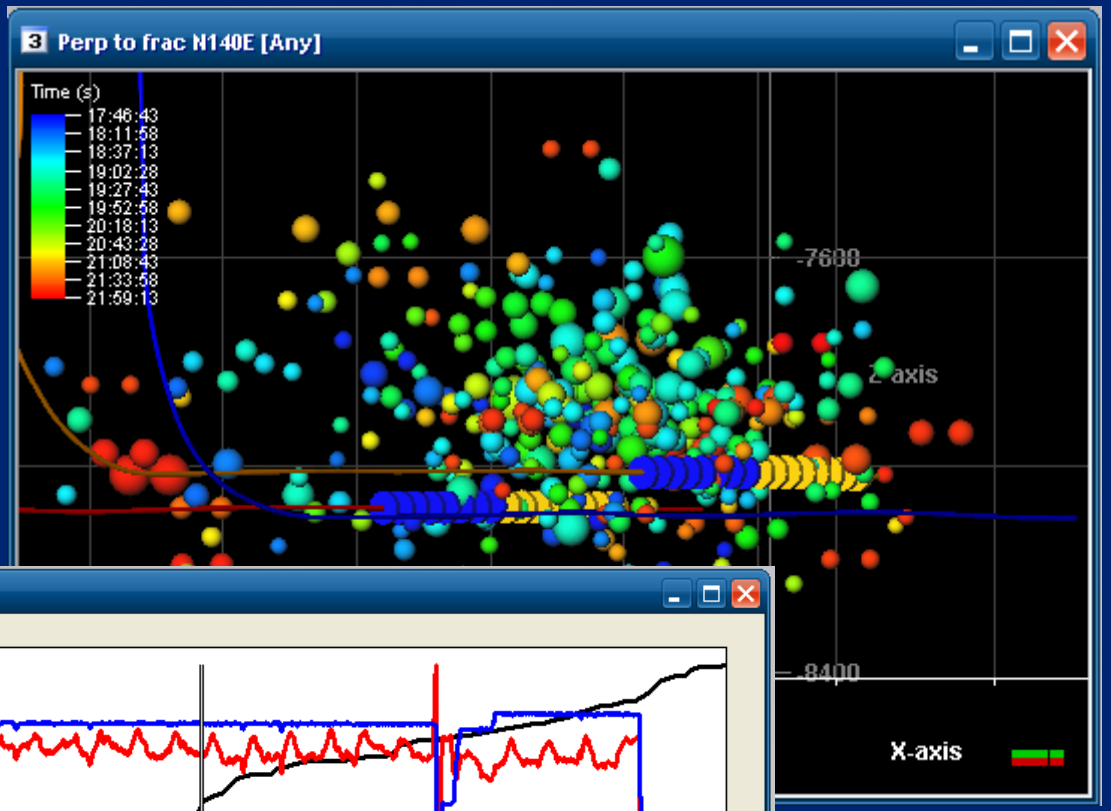
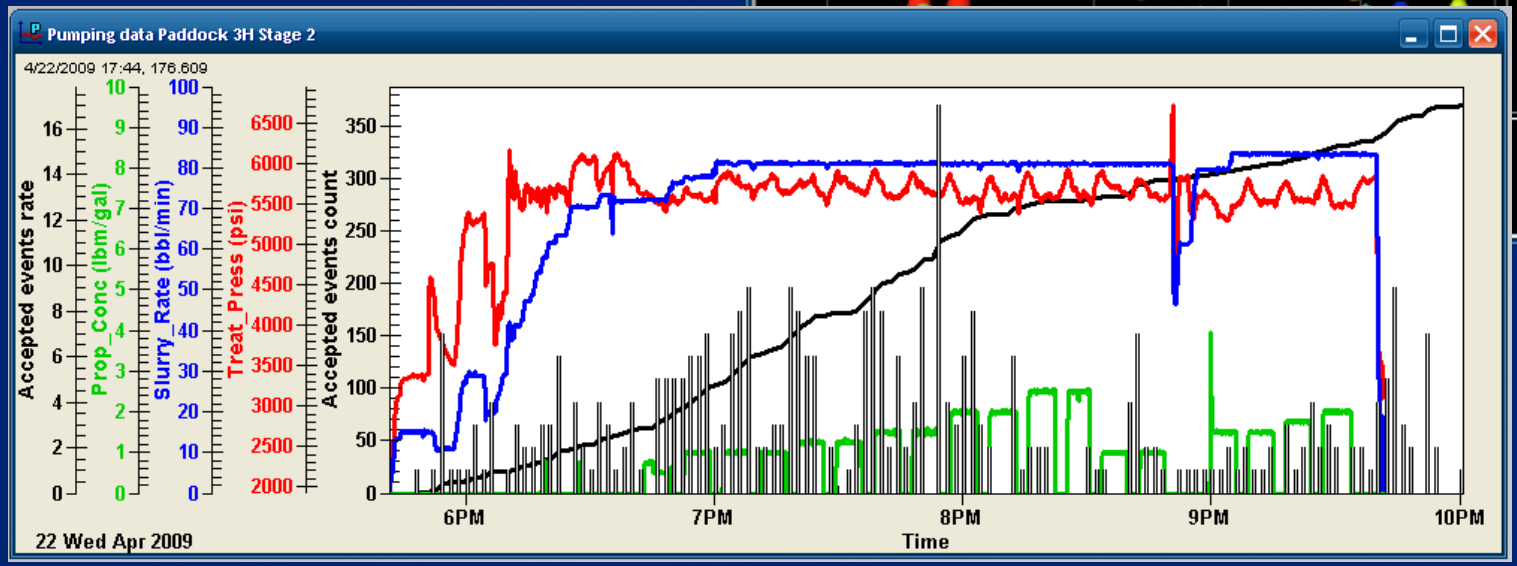


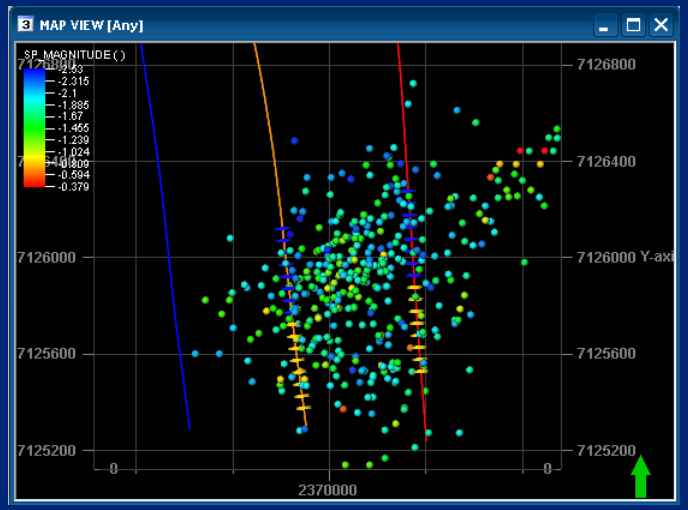


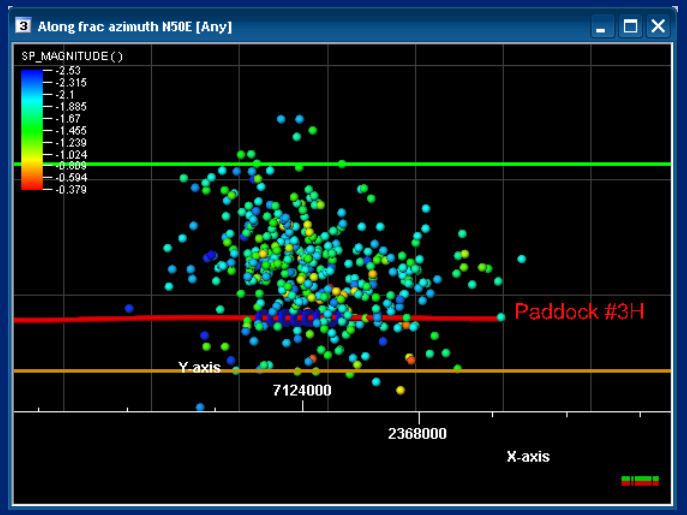
Paddock 1H
Paddock 2H
Paddock 3H

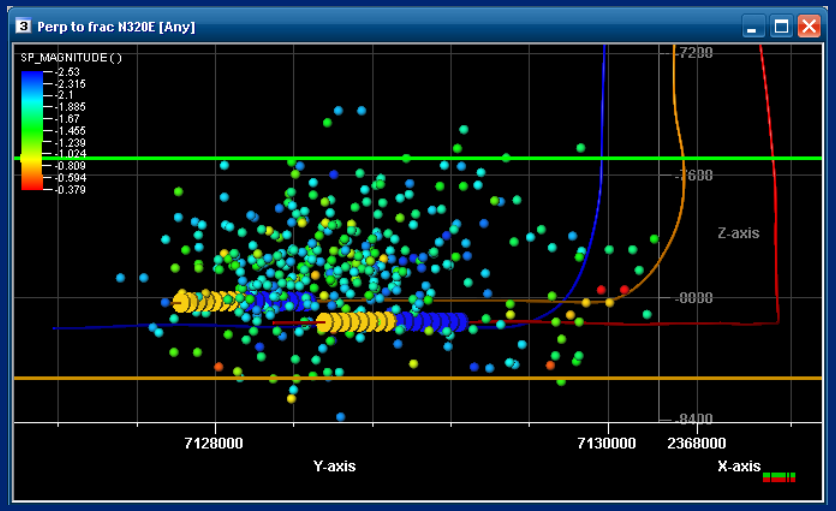
Paddock 3H Stage 2

Fracture Geometry

- Events colored by magnitude
  - Redder color means larger magnitude
  - Magnitudes from -2.5 to -0.75
- Zipper frac
  - Stress changes can affect future treatments
  - Stage 1 perfs are yellow disks
  - Stage 2 perfs are blue disks
  - So far have treated:
    - 1H stage 1
    - 3H stage 1
    - 1H stage 2





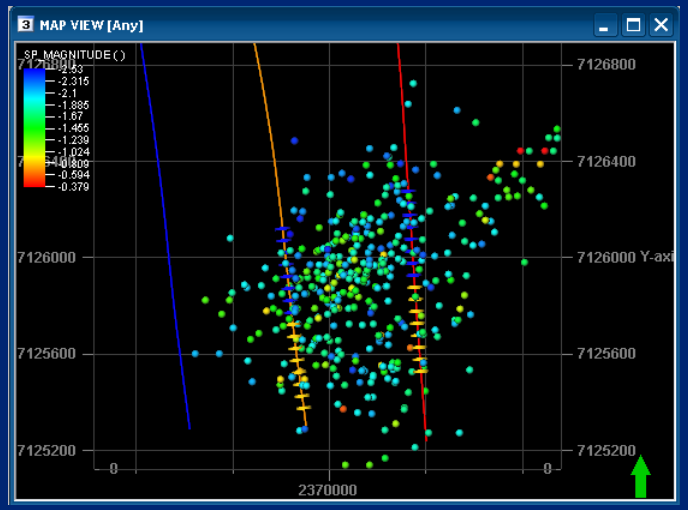


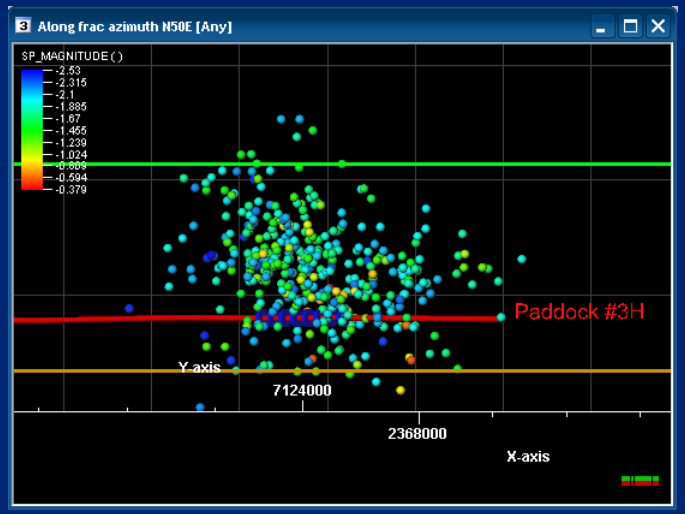
Paddock 1H
Paddock 2H
Paddock 3H

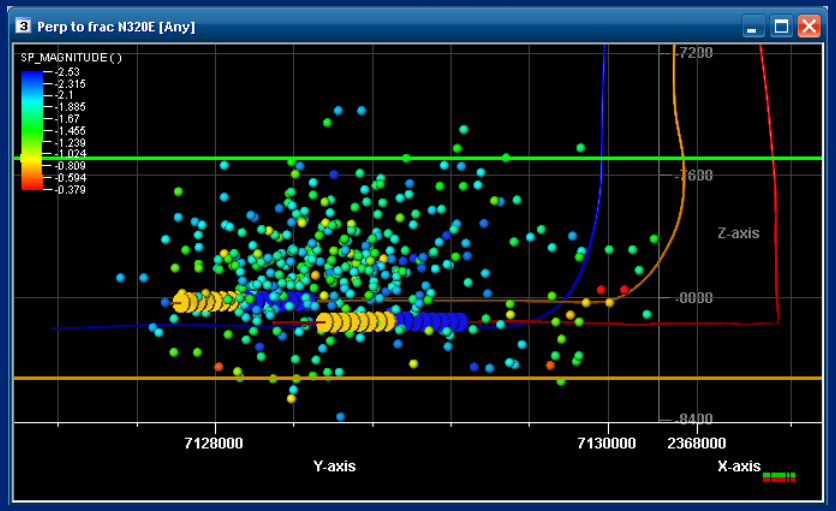
Paddock 3H Stage 2

Fracture Geometry

- Events colored by magnitude
- Zipper frac
- Events occur across lateral
- Growth mostly in Barnett Shale target
  - Clear in section views
  - Green line is Top Barnett
  - Orange line is Bottom Barnett
  - Fracture azimuth is ~N50°E







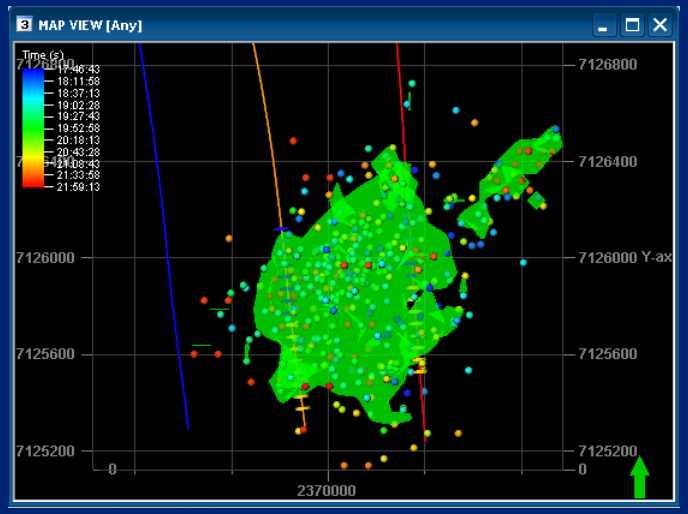
Paddock 1H
Paddock 2H
Paddock 3H

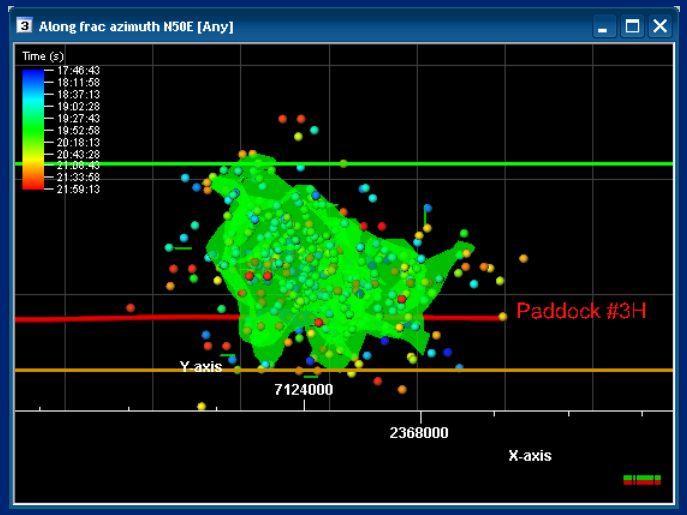
Paddock 3H Stage 2

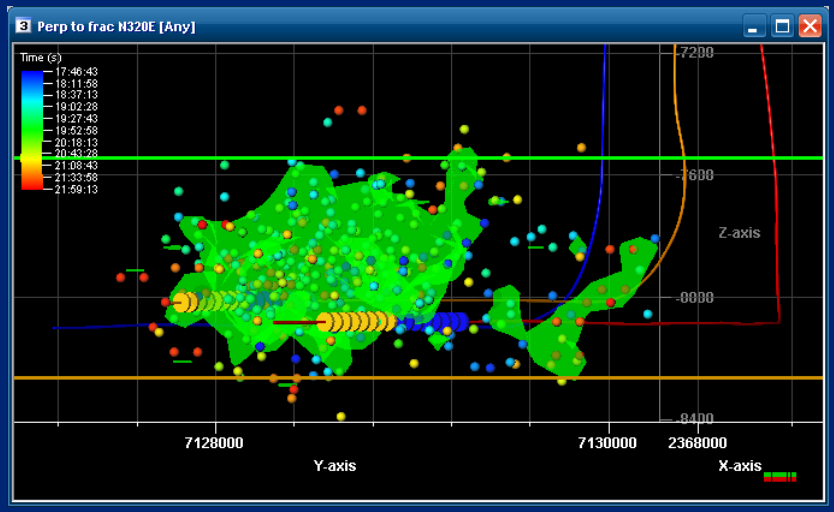
Estimated Stimulated Volume

- Events now colored by *time*
- Estimated Stimulated Volume (ESV)
  1. Build cells
  2. Count number of events in each cell
  3. Calculate volume enclosing cells whose population is high enough
  4. Envelope around these cells gives ESV
- Cumulative ESV for 3H Stage 2

  164.5 10^6 ft^3

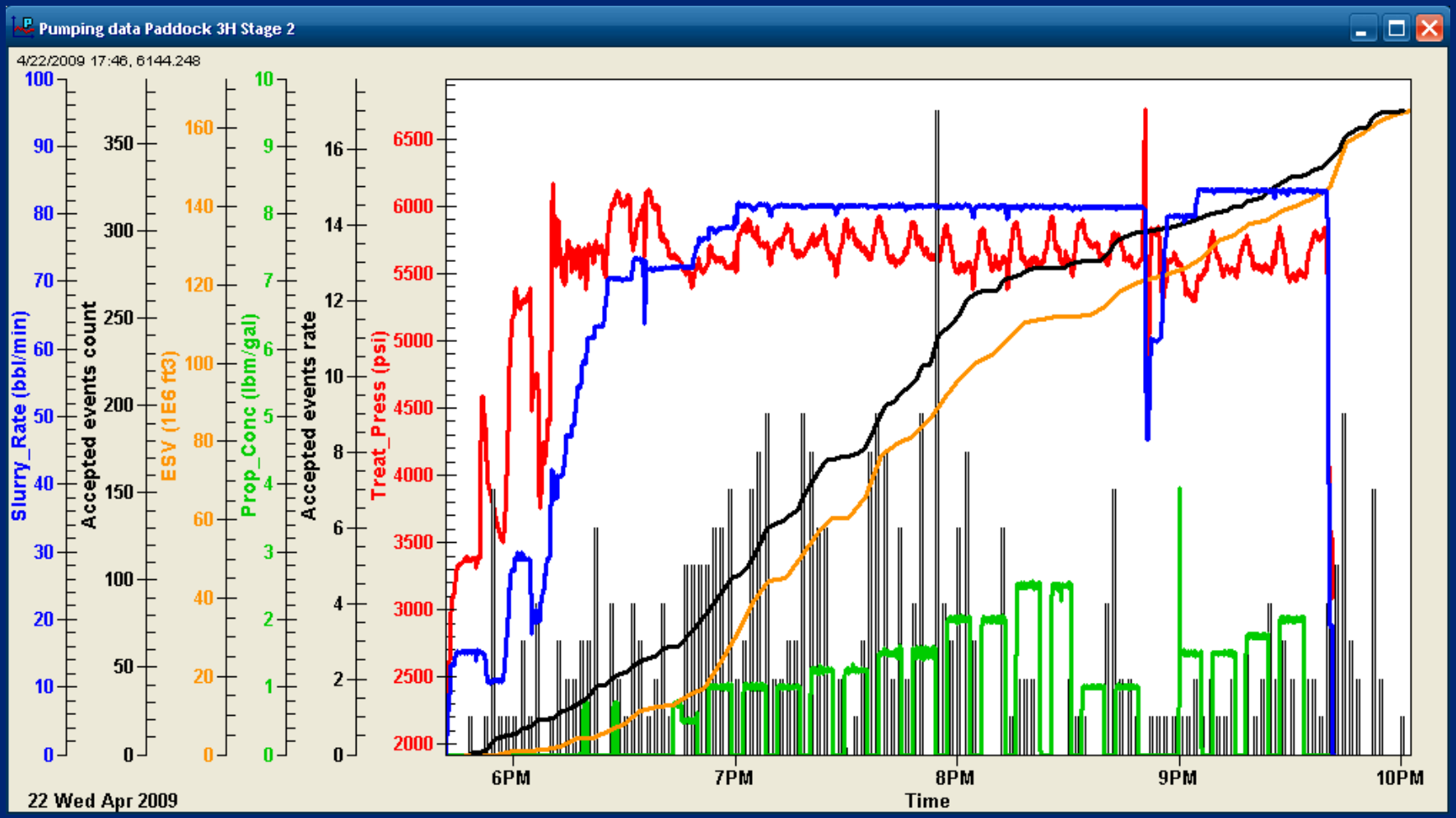






Paddock 3H Stage 2

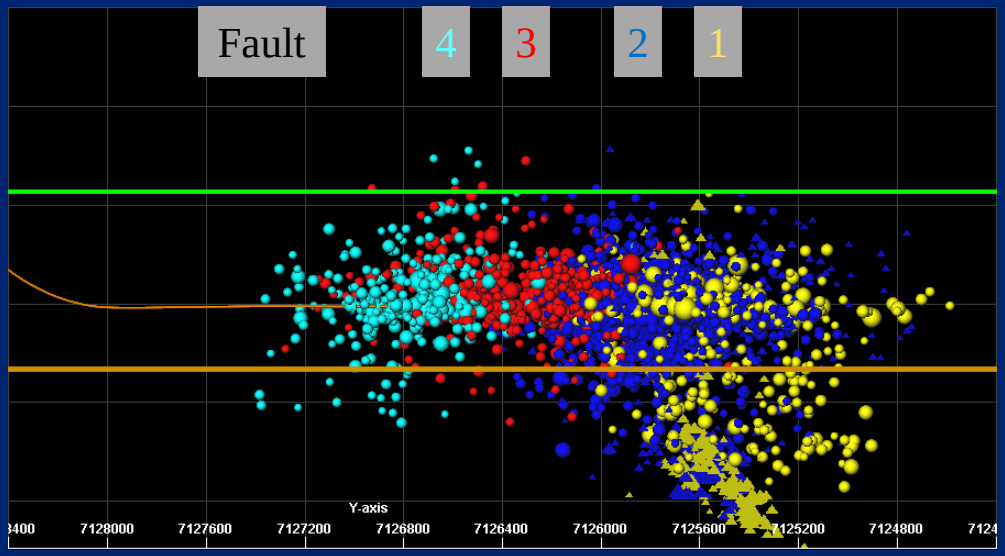
Pumping Data

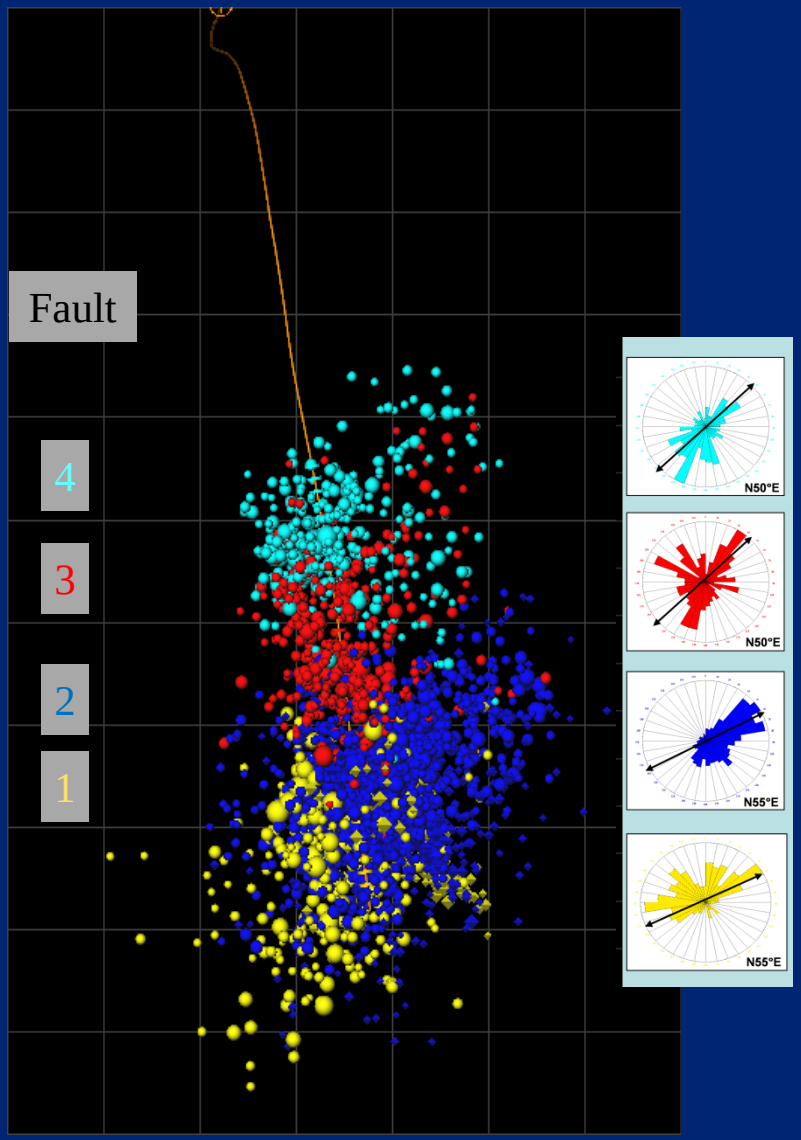


Paddock 1H – Microseismic results overview

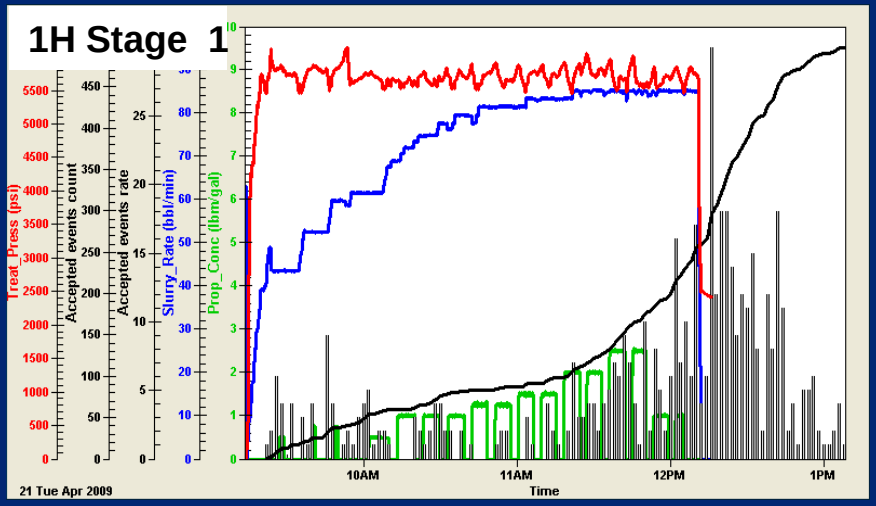
Fracture Geometry

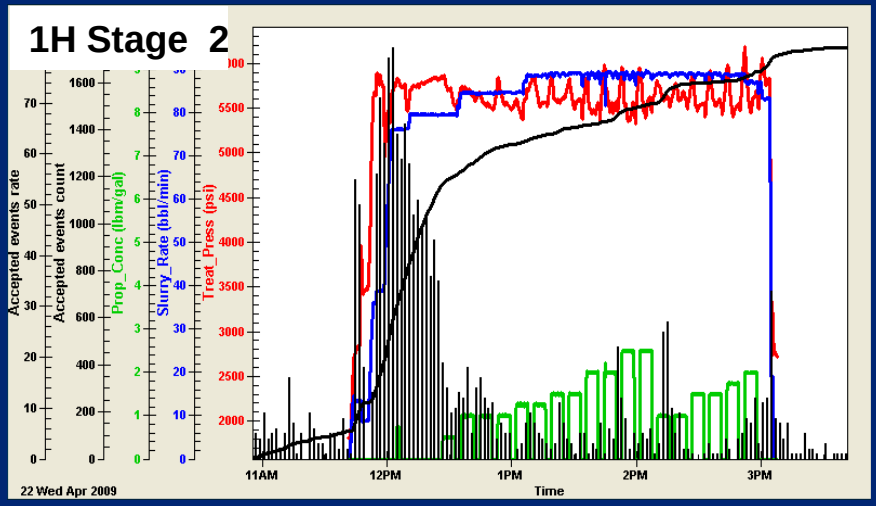
- Events occurred across lateral in all stages
- Significant growth down into Viola
  - Stages 1 and 2
- Acoustic overlap for some adjacent stages
  - Stages 1 and 2
  - Stages 3 and 4

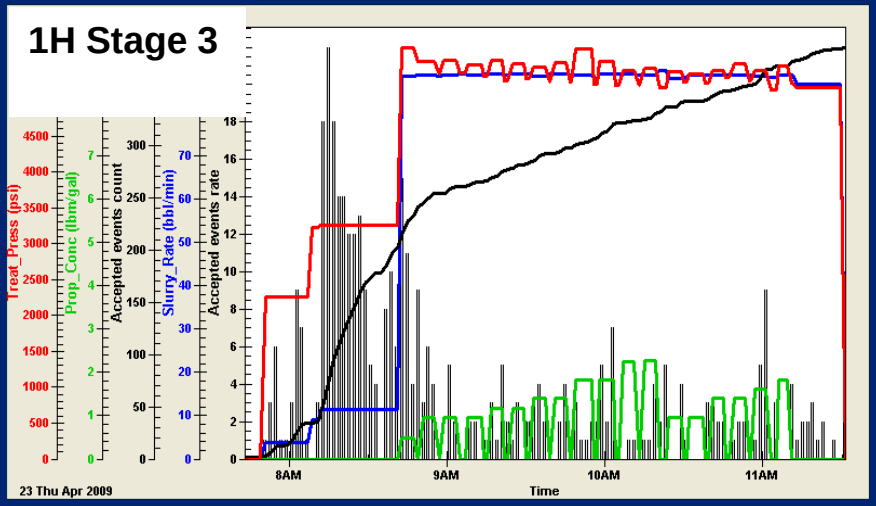


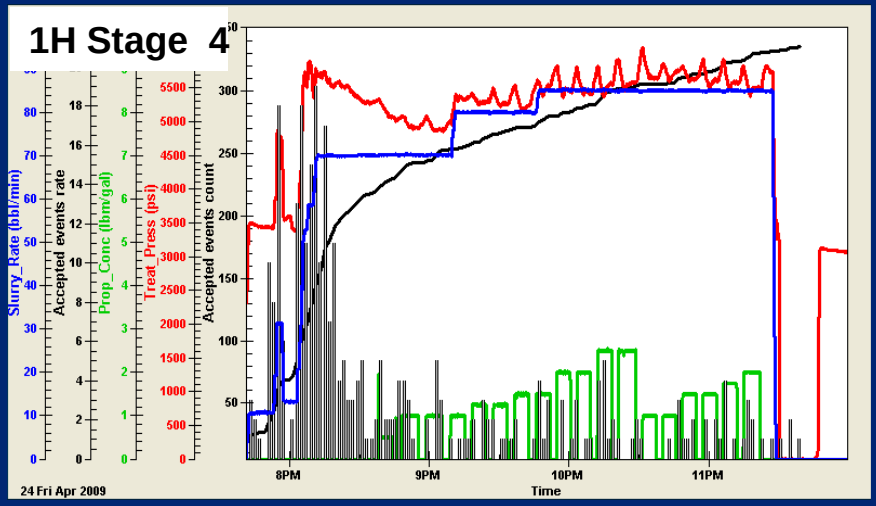


Paddock 1H – Microseismic event rates





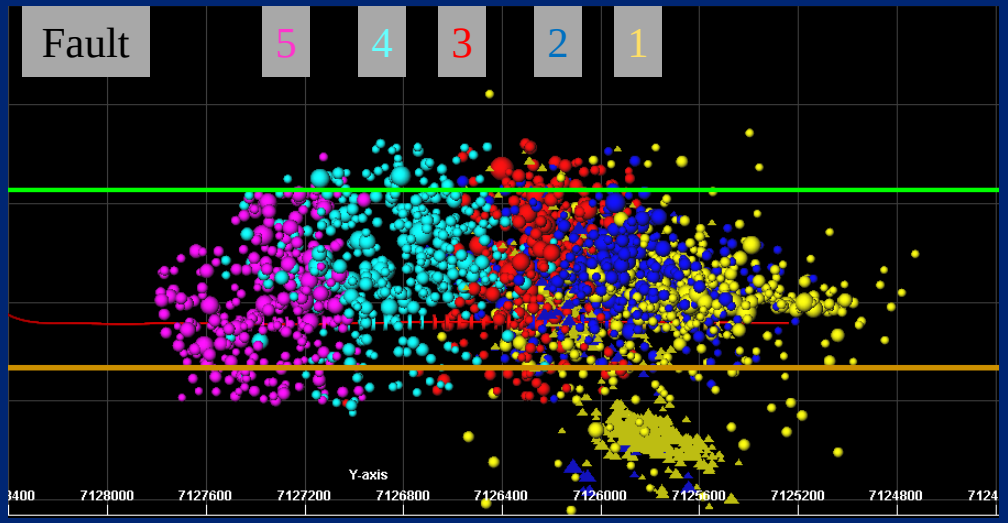


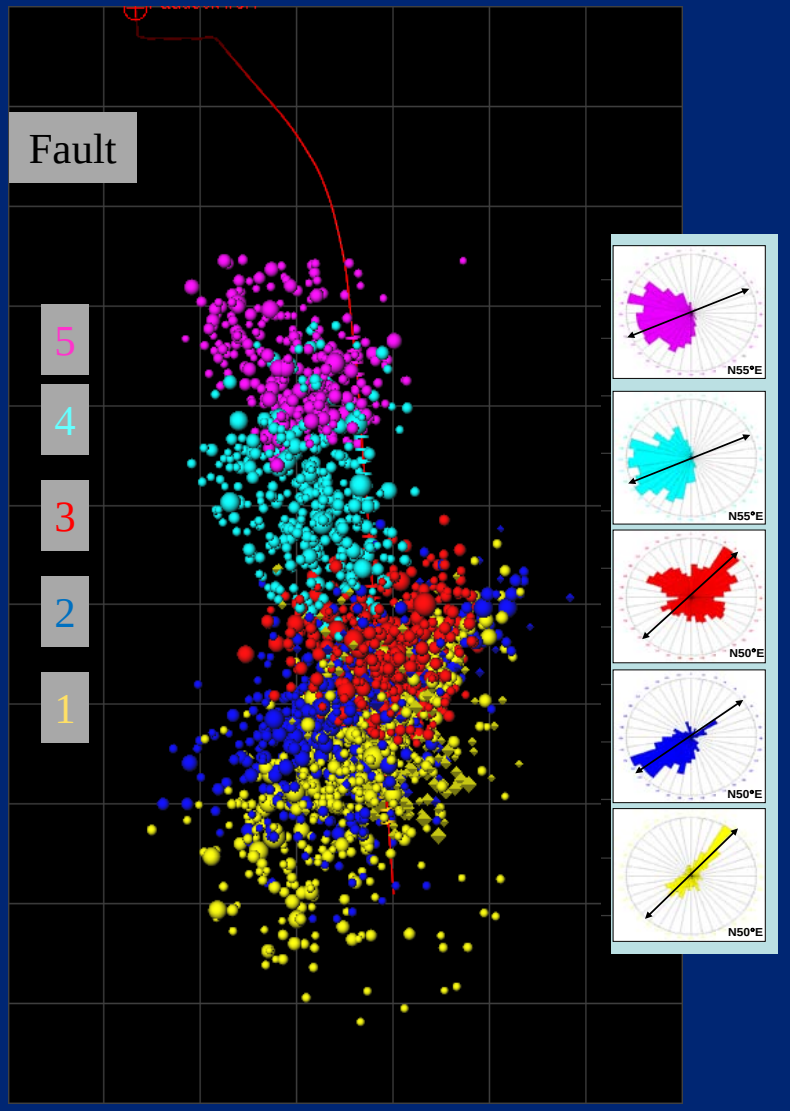


Paddock 3H – Microseismic results overview

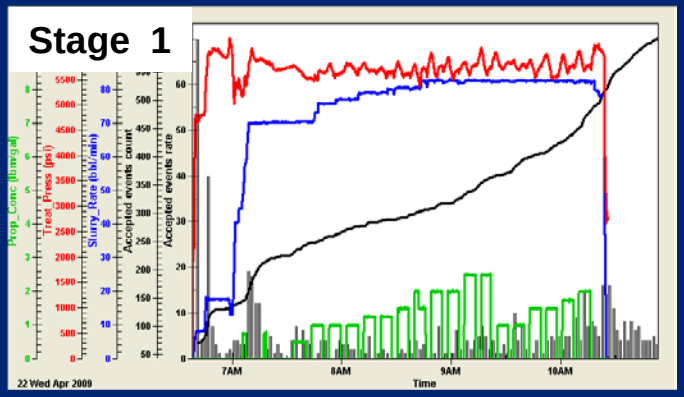
Fracture Geometry

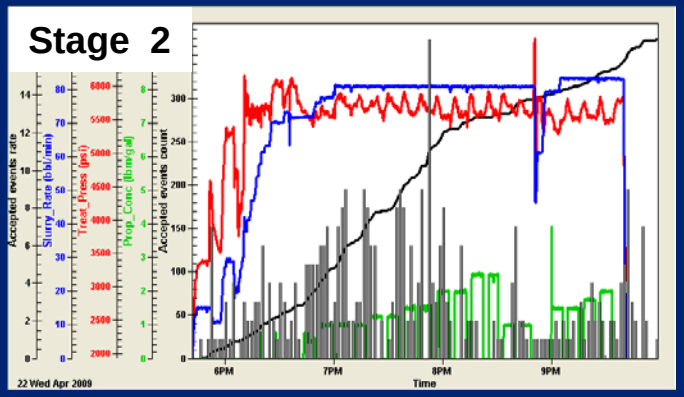
- Events occurred across lateral in stages 1-3
- Events occurred mostly westward in stages 4-5
- Significant growth down into Viola in stage 1
- Acoustic overlap for some adjacent stages
  - Stages 1 and 2
  - Stages 2 and 3
  - Stages 4 and 5

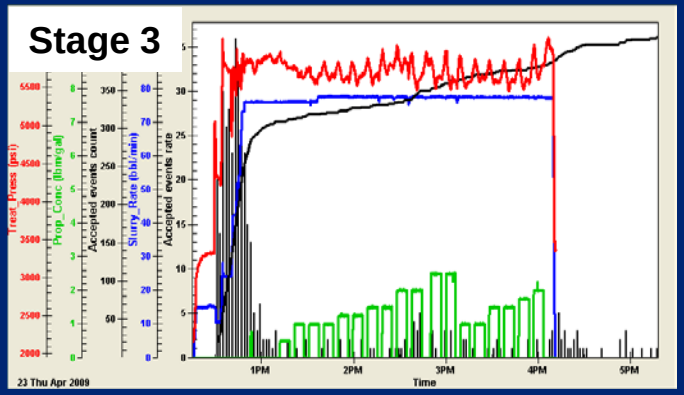


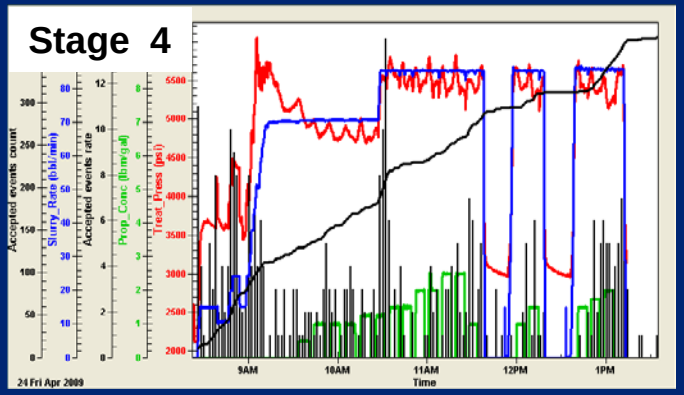


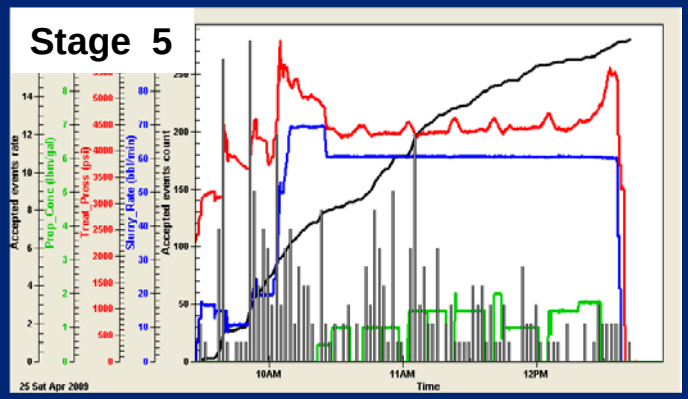
Paddock 3H – Microseismic event rates







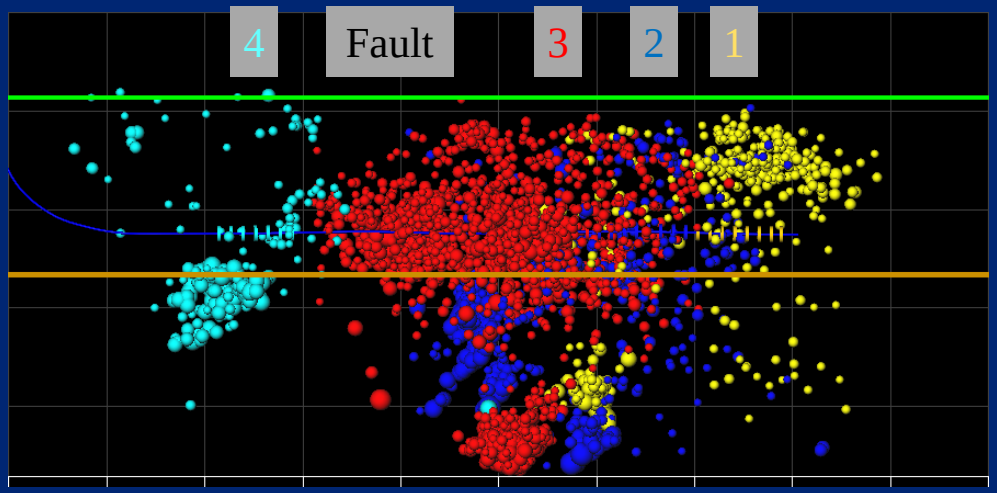


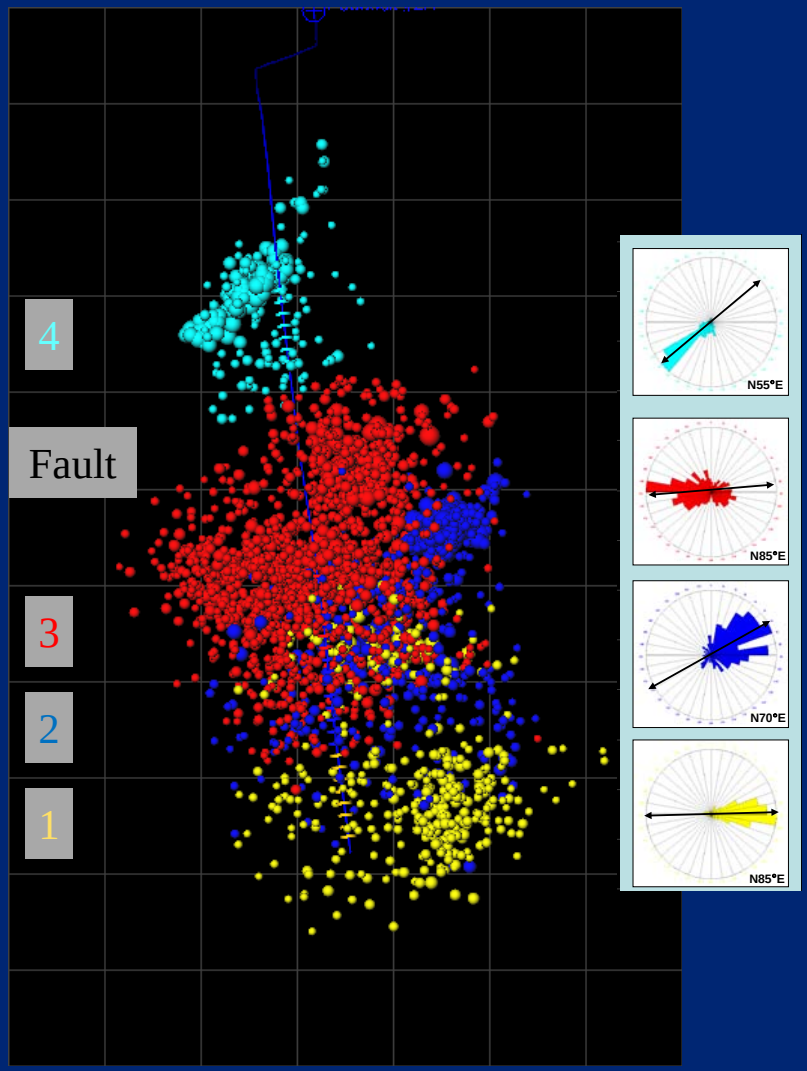


Paddock 2H – Microseismic results overview

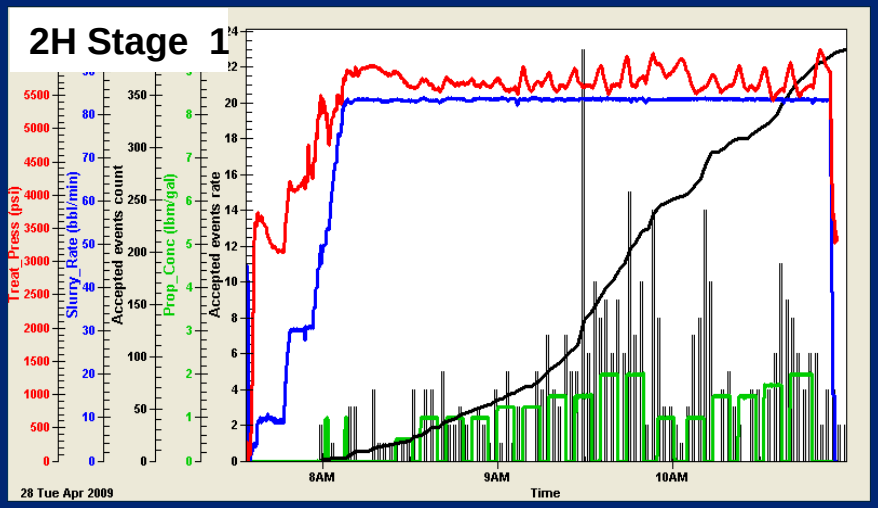
Fracture Geometry

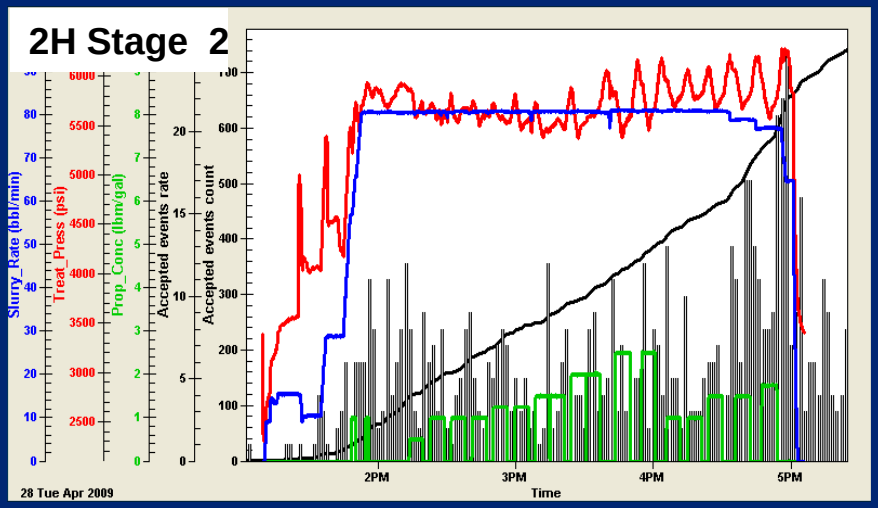
- Events occurred across lateral in stages 1-3
- Events occurred mostly westward in stage 4
- Significant growth down into Viola in stages 1-2
- Avoided ‘fracing’ into fault
  - Real-time microseismic monitoring
- Acoustic overlap for some adjacent stages
  - Stages 1, 2, and 3

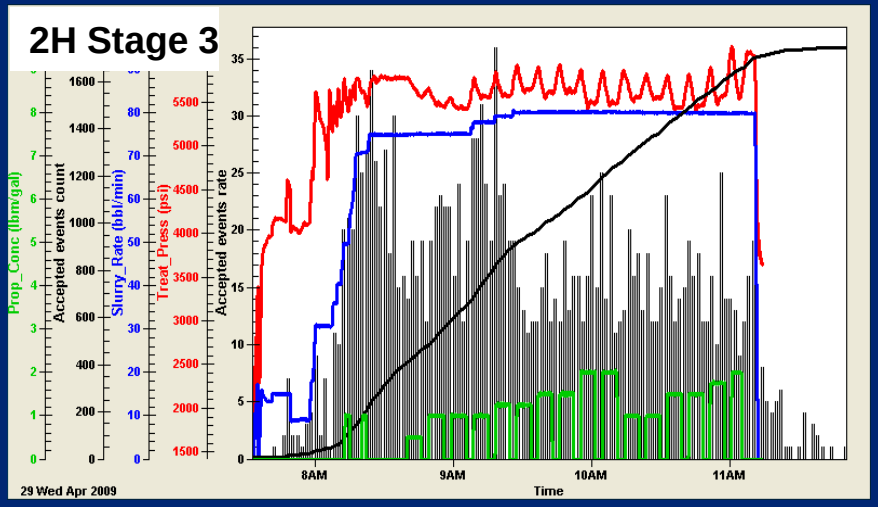


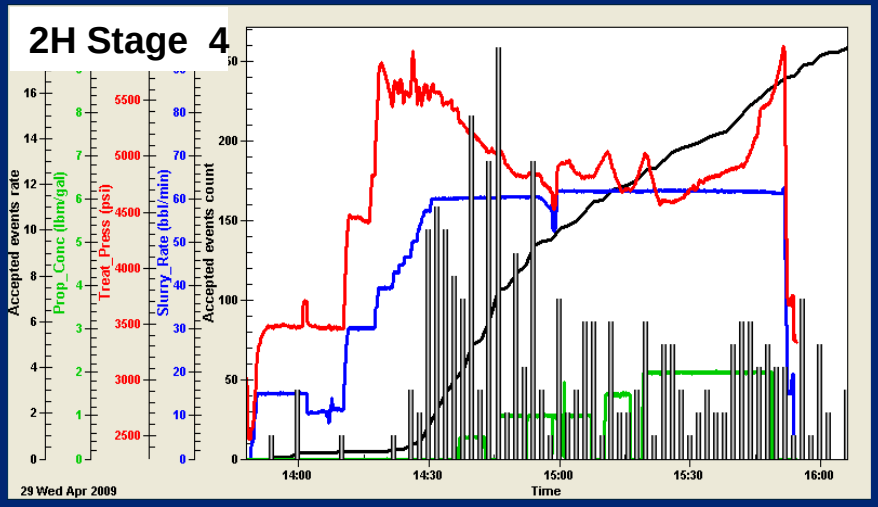


Paddock 2H – Microseismic event rates



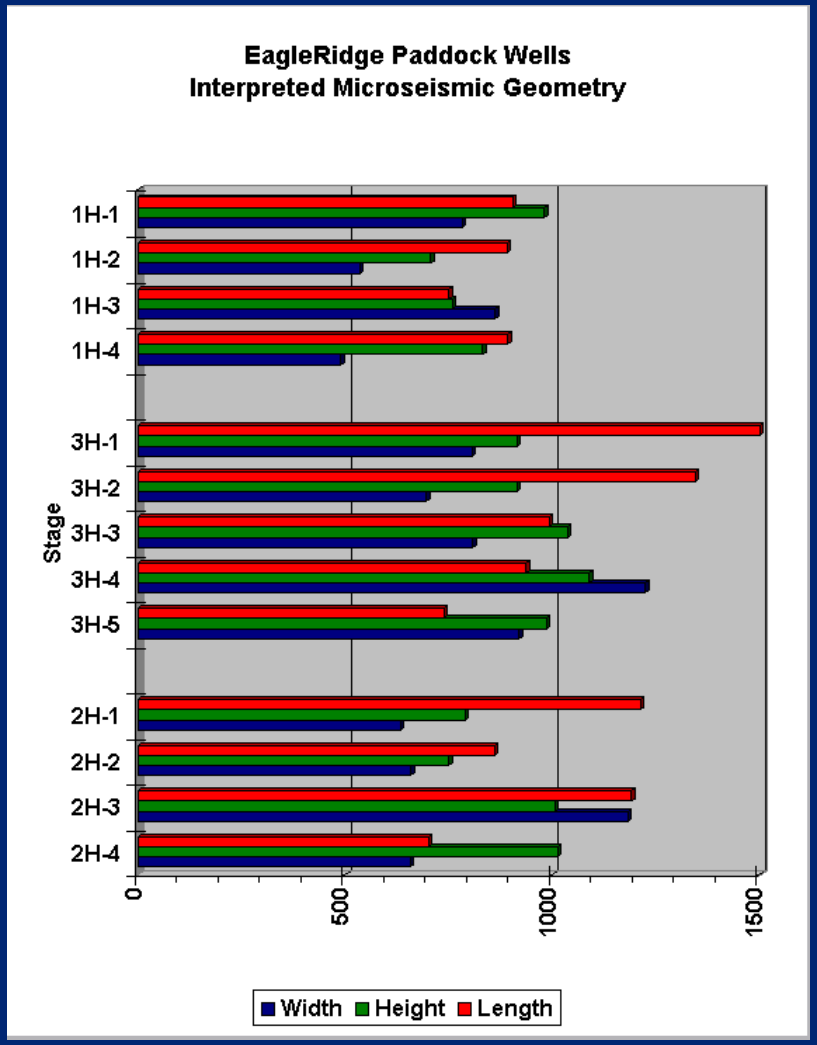


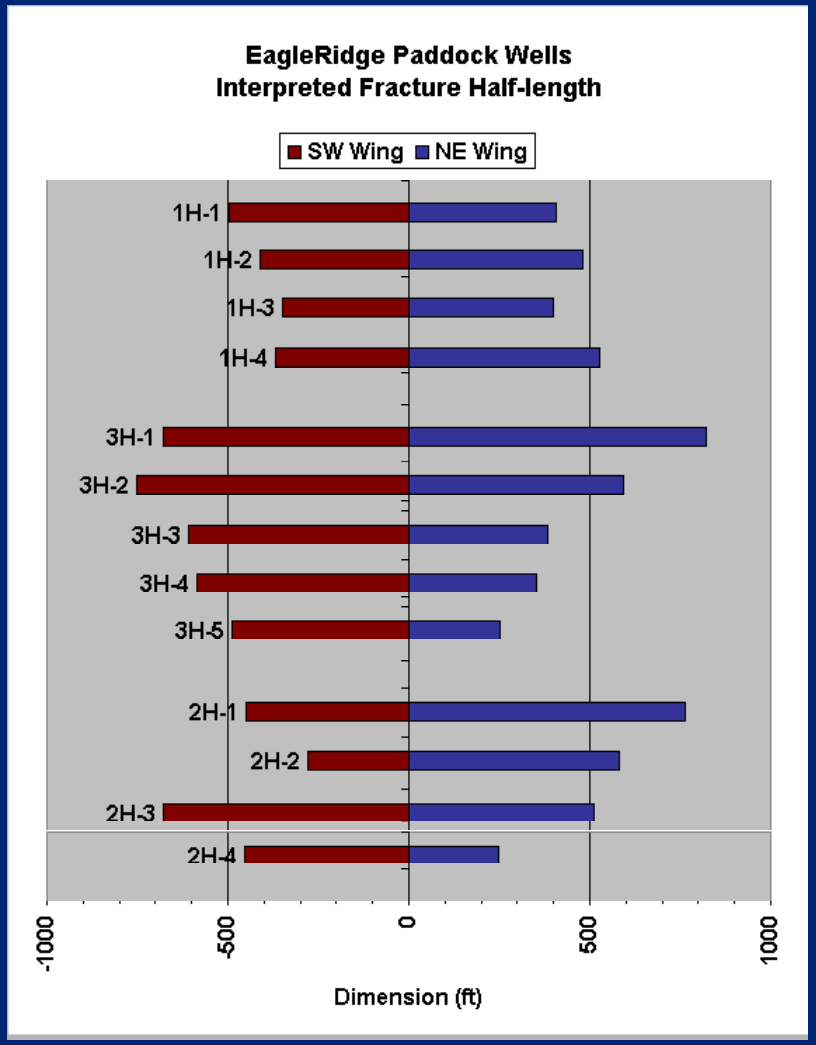




Paddock wells – Microseismic results overview

Fracture Geometry

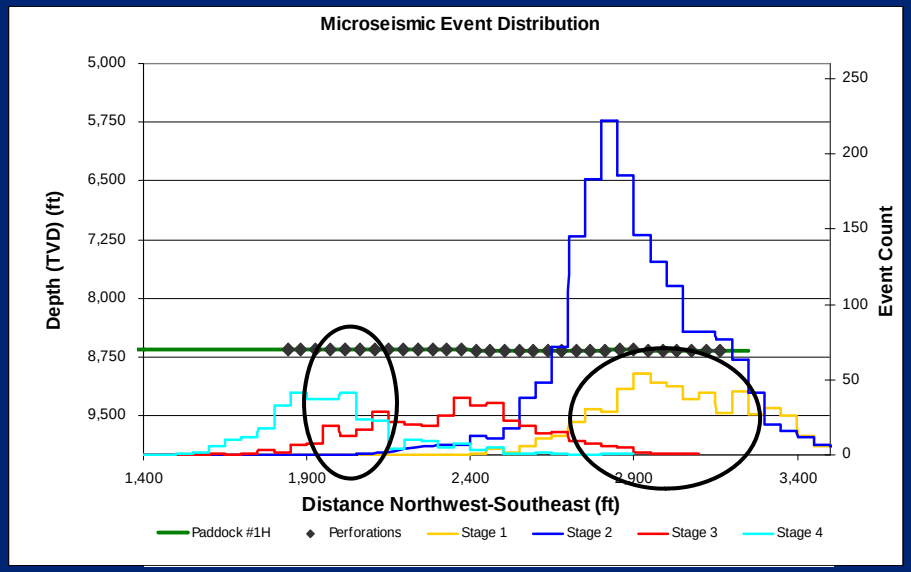


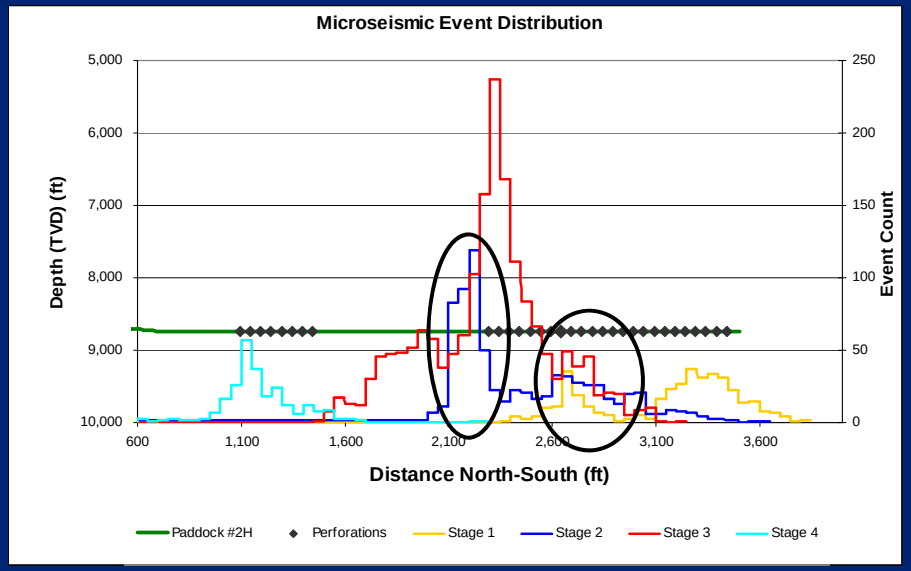


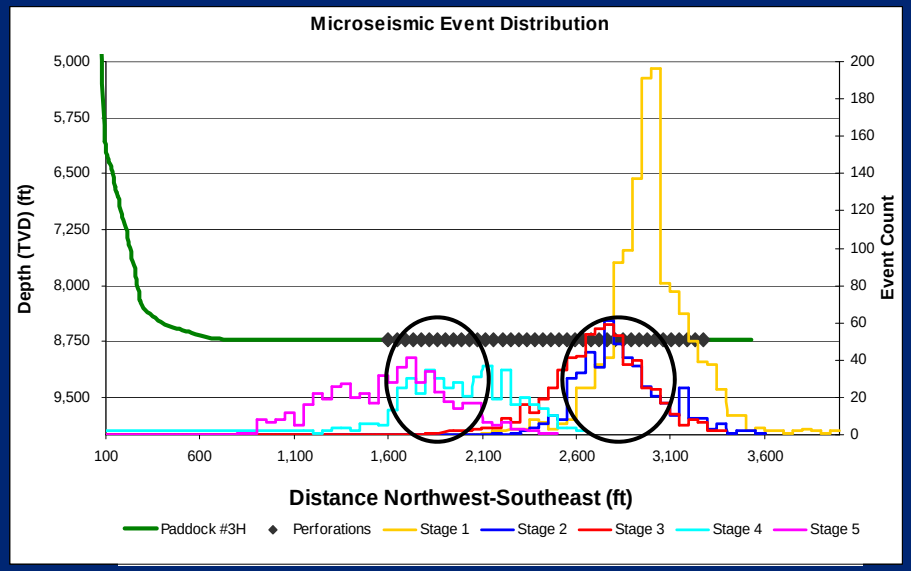
Paddock wells – Microseismic results overview

Acoustic Overlap

- Insufficient fracture isolation
  - *Later treatment stages reactivated networks from previous stages*

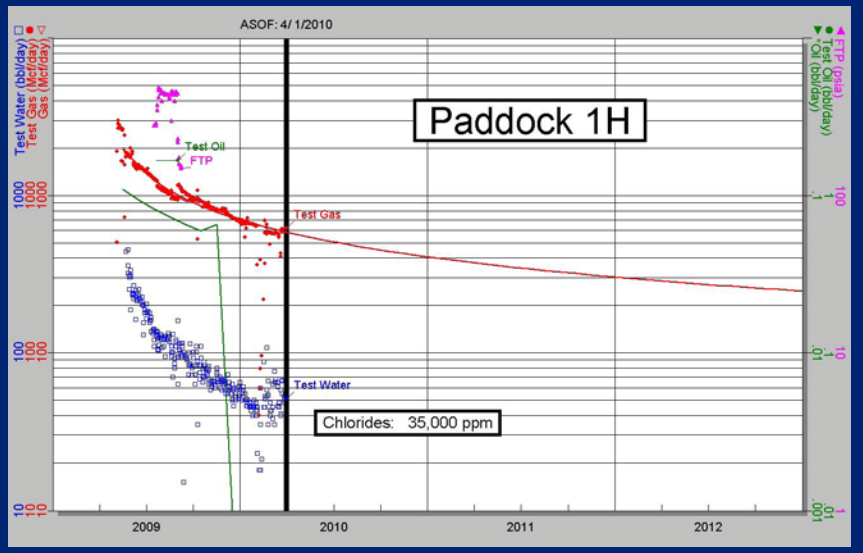


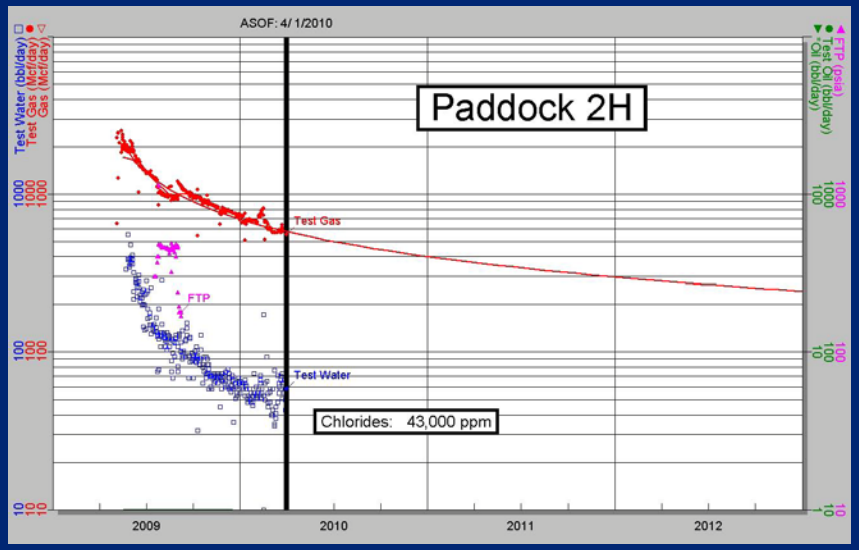


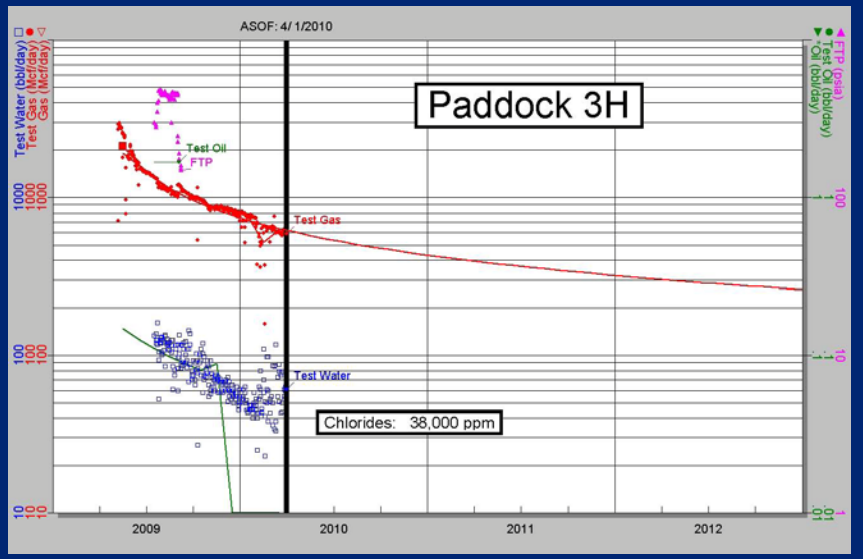


Decline curves

- - All three wells IP 2mm/d
- - Highest Chl 43,000 ppm
  (i.e., not Ellenburger water @120,000 ppm)
- - Est. EUR 2+ BCF/ well







Paddock Wells – Conclusions

- Microseismic activity observed across all intended stage intervals

- Fracture azimuths:
  - *1H and 3H were N50-55°E overall*
  - *2H was N55-85°E overall*

- Fracture growth patterns:
  - *Stages closer to fault tended to be more compact*
  - *Longer fracture wings in toeward stages than in heelward stages*

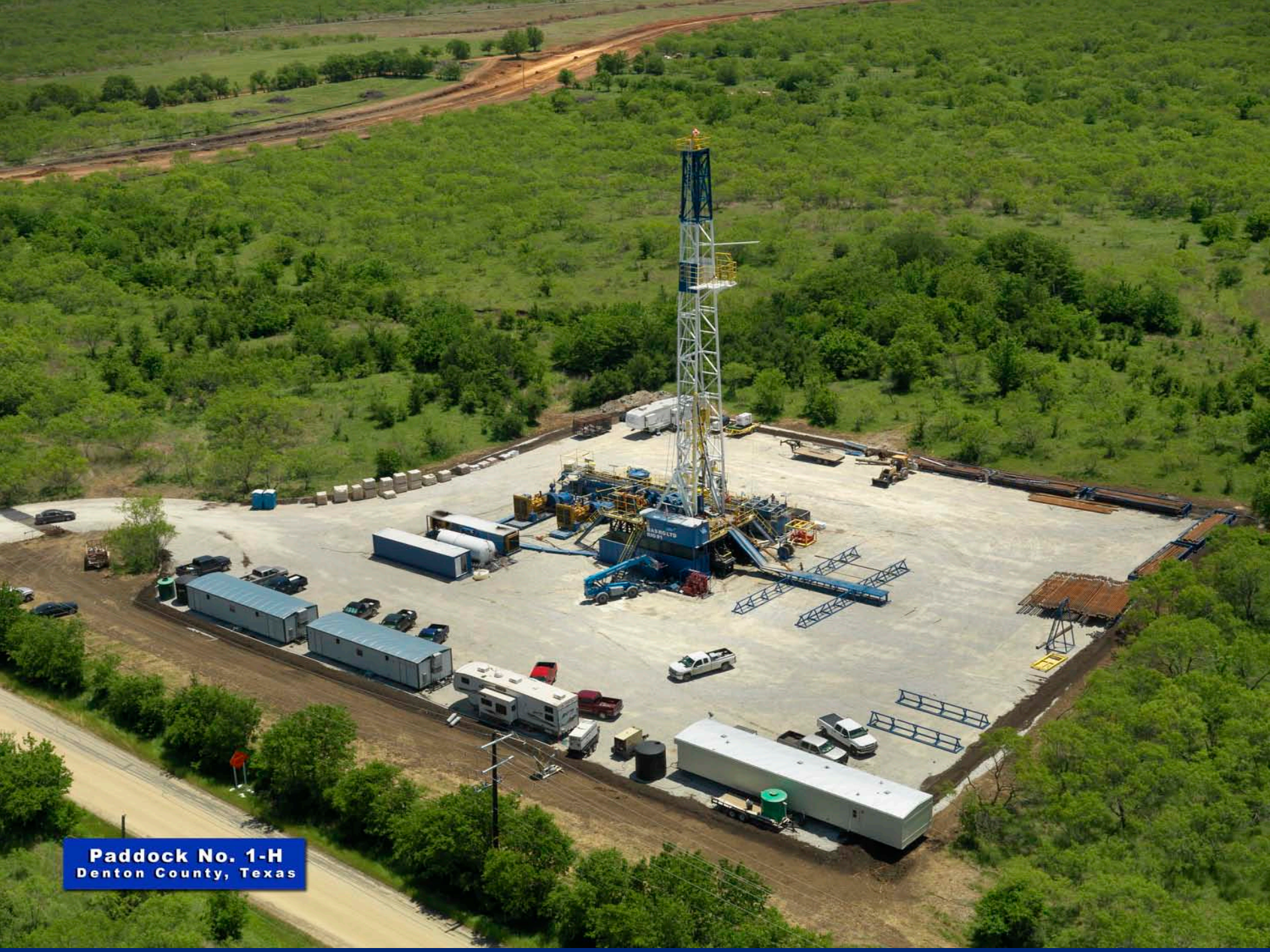
- Overlapping fracture networks:
  - *Acoustic overlap observed between successive stages indicates insufficient fracture isolation*

Paddock Wells – Conclusions

- Vertical growth out of lower Barnett observed
  - *1H: Stages 1 and 2*
  - *3H: Stage 1*
  - *2H: Stages 1, 2, and 3*

- Microseismic event rates tend to correlate with strong changes in treatment parameters (pressure, proppant concentration)

- Completion design
  - *Horizontal stress anisotropy can be used to improve placement of perforations*
  - *Perforation spacing should be increased to reduce overlap*


Paddock No. 1-H
Denton County, Texas