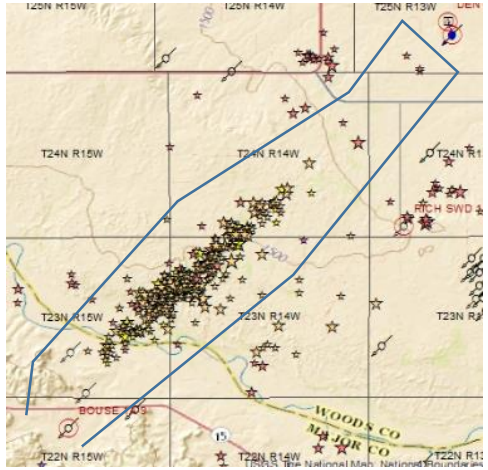
Fairview Area Seismicity Analysis aka a Busy Neighborhood

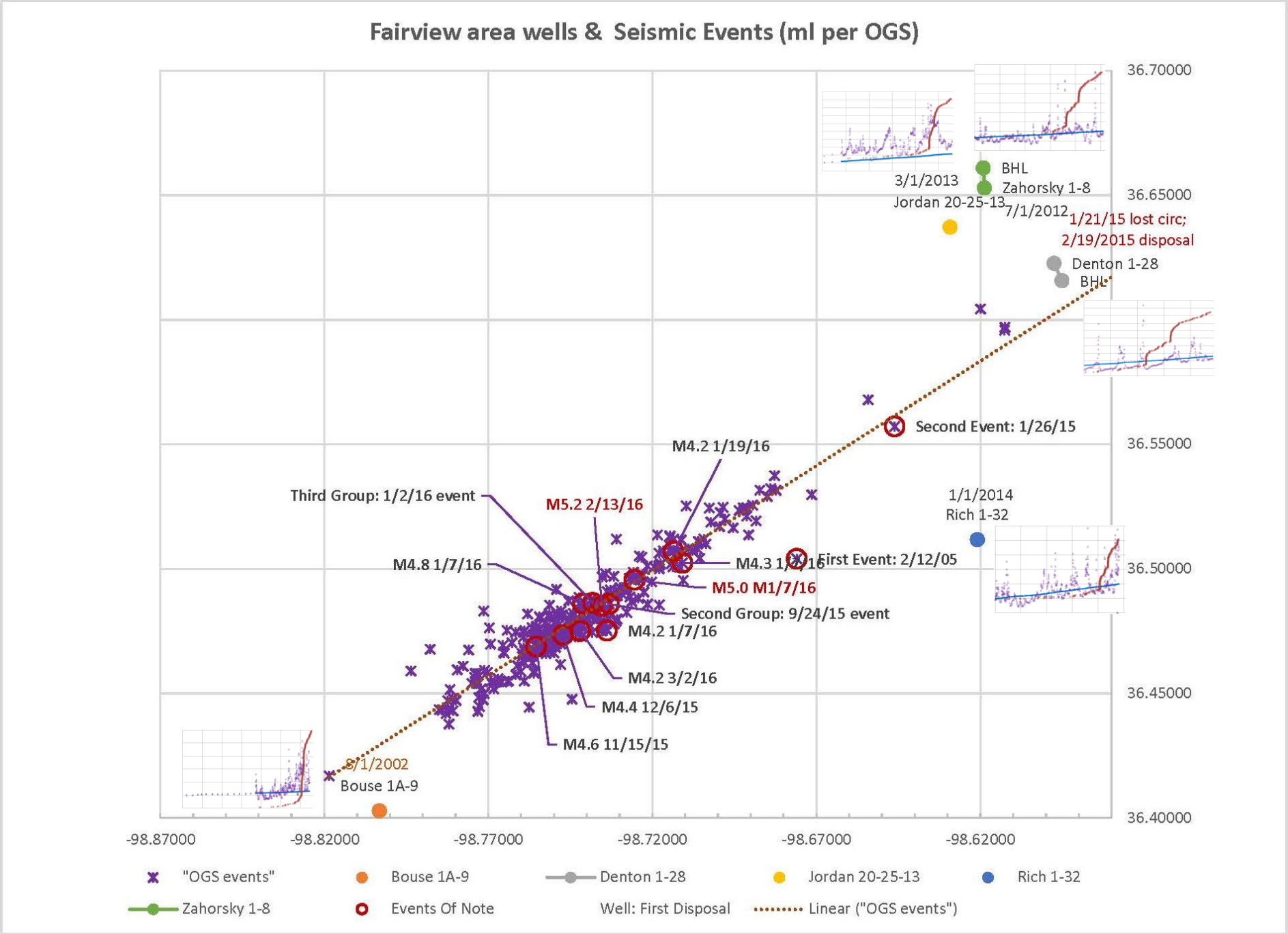
Using Petroleum Engineering Techniques



This analysis would not be possible without OCC having collected the daily data from virtually the beginning of 2015.

Support for the conclusion <u>that 'the cumulative effect of all the wells shown have contributed to the seismicity'</u> will be shown by:

1) Operational plots
   Changes over time
2) Pressure gradient plots
   Potential fractures
3) Hall (Tandem) plots
   Ease/difficulty of flow

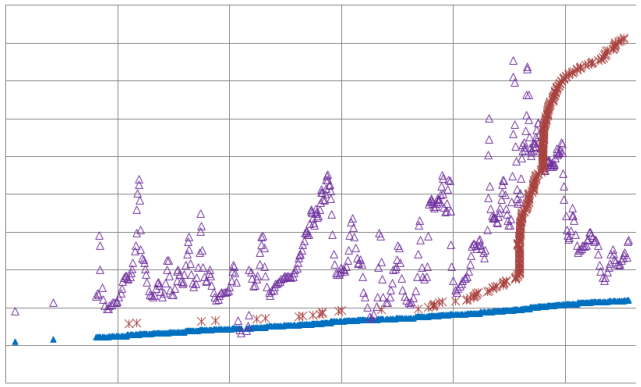


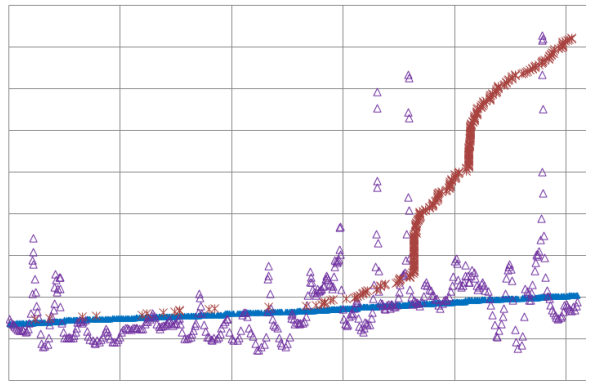
Hall (Tandem) plot characteristics:

The saw tooth appearance of the Hall plots indicates periods of repeated pressure build-up followed by enhanced injectivity. In this type of environment (fractured Arbuckle) a likely interpretation is disposal volumes moving along natural or hydraulic fractures. On reaching the end, pressure builds up sufficient to extend the fracture or connect to a new pathway. Eventually bringing the pressure front into contact with the overstressed portion of the active fault.

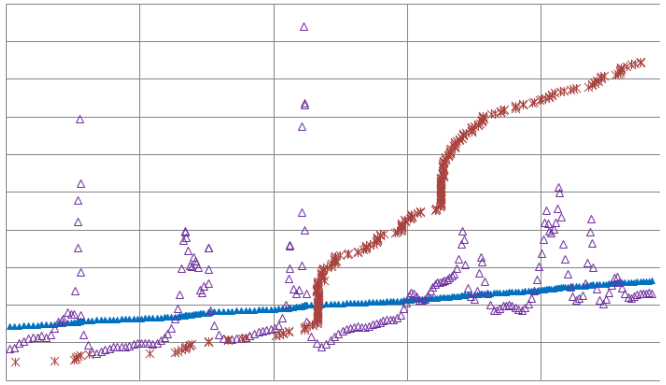
The fact that all of the wells have the same character in relations to the (single) suite of earthquakes, suggests that the wells are in communication with the same fault system.

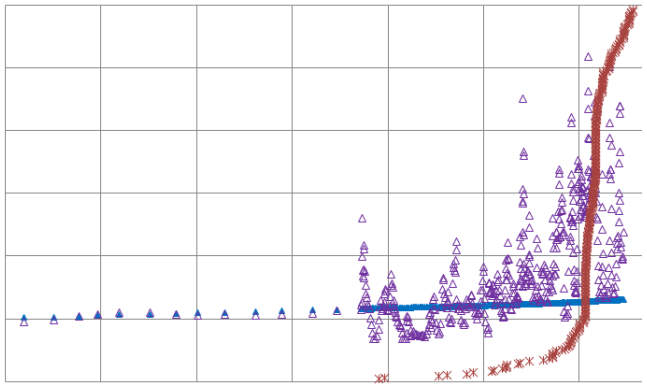
The effect may have been triggered by one injector, but the ultimate effect is a cumulative impact of a group of injectors in a common reservoir system.

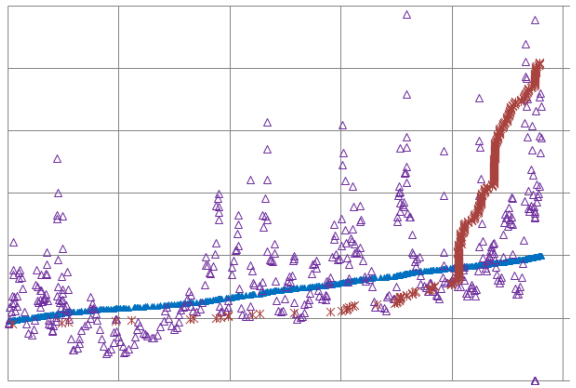




LEGEND
Blue line = Hall integral
Purple symbols = derivative
Red = cumulative EQ events

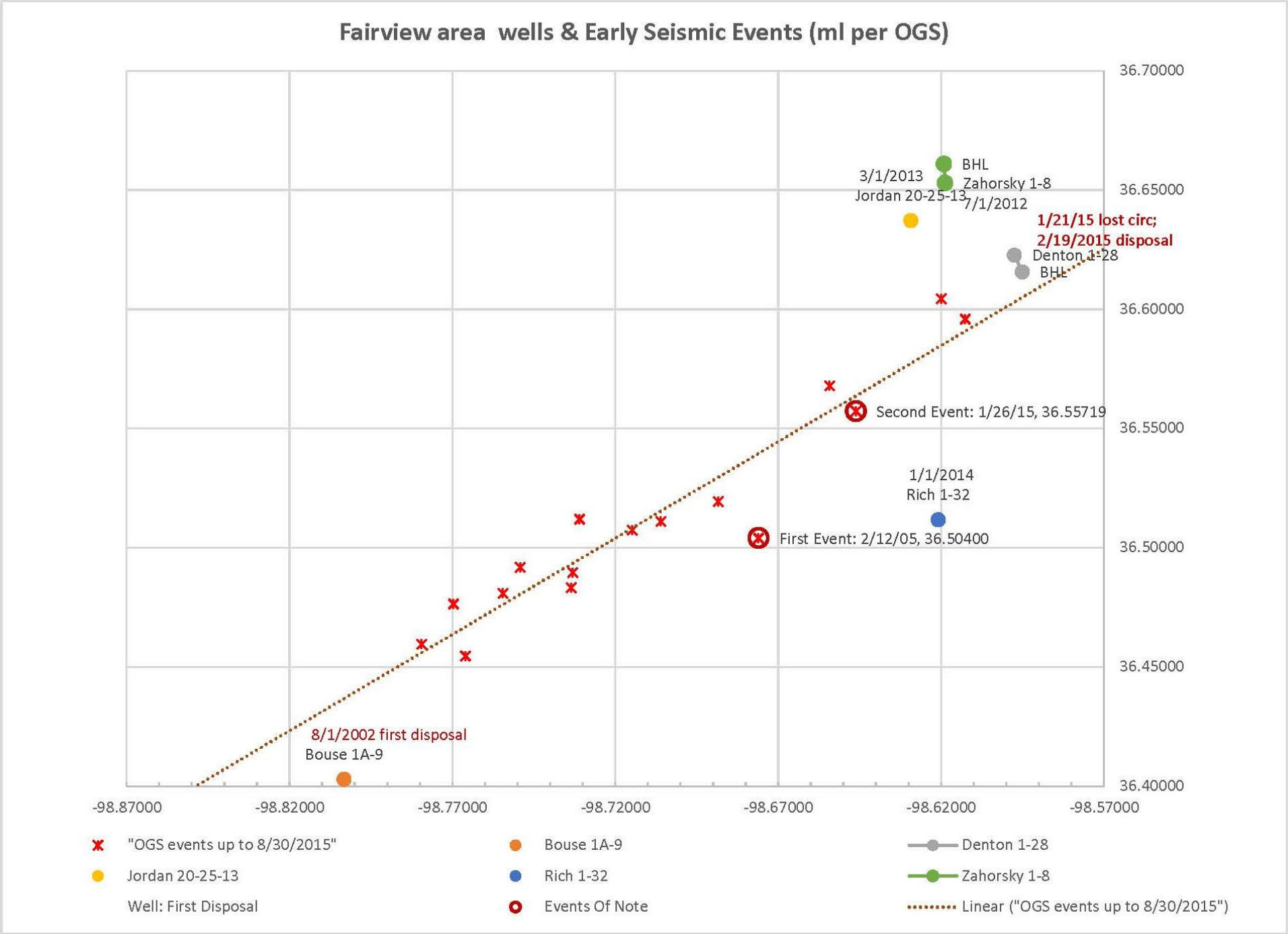






Location of area Arbuckle disposal wells and seismicity selected through GIS via polygon.

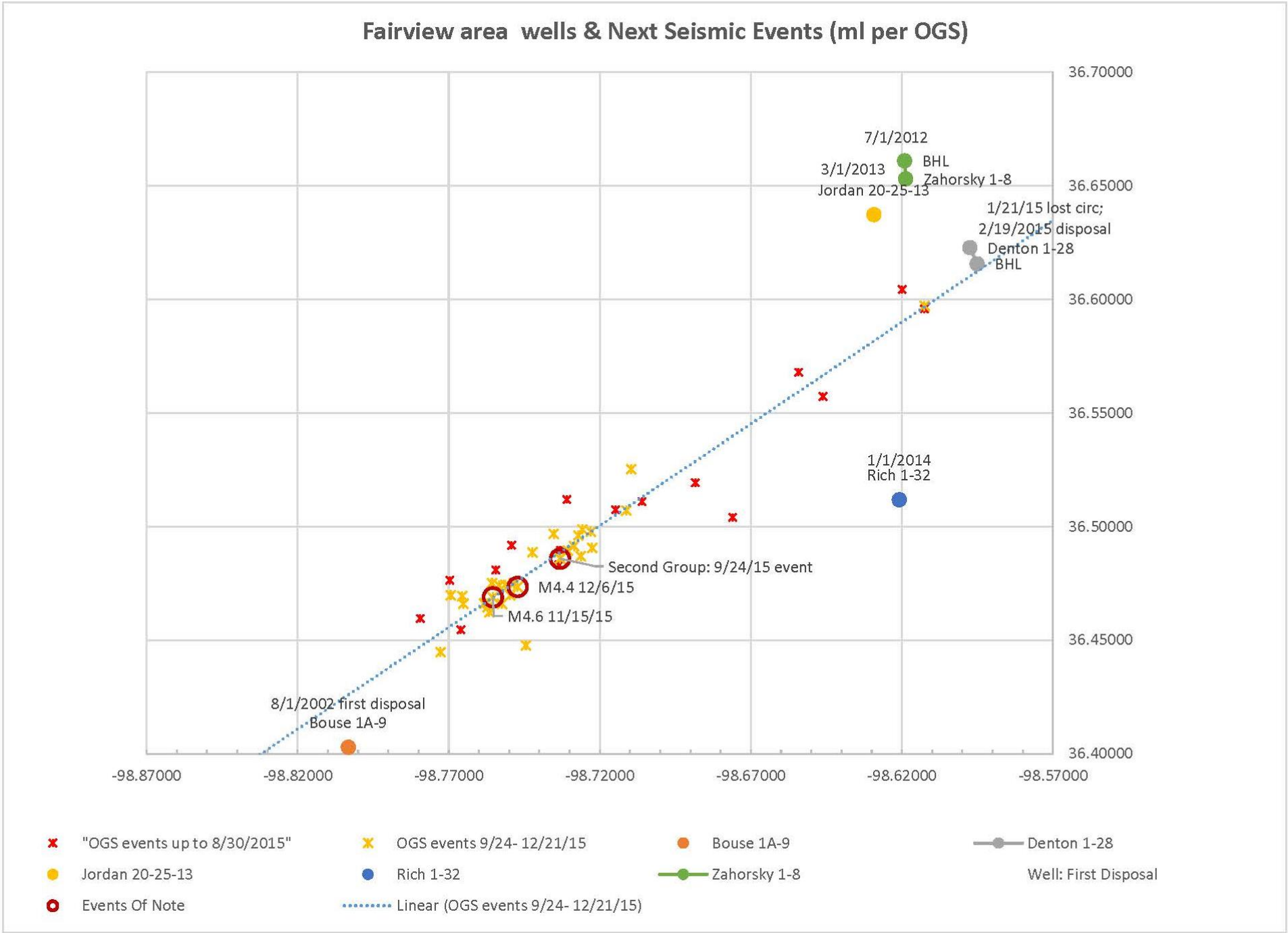
Seismic events, ‘x’, are color coded for time periods.
EARLIEST
2/12/2005 then
1/25/15-8/30/15



Location of area Arbuckle disposal wells and seismicity selected through GIS via polygon.

Seismic events, ‘x’, are color coded for time periods.
Red earliest (2/12/2005 then 1/25/15-8/30/15),

orange next 9/24/15-12/21/15,

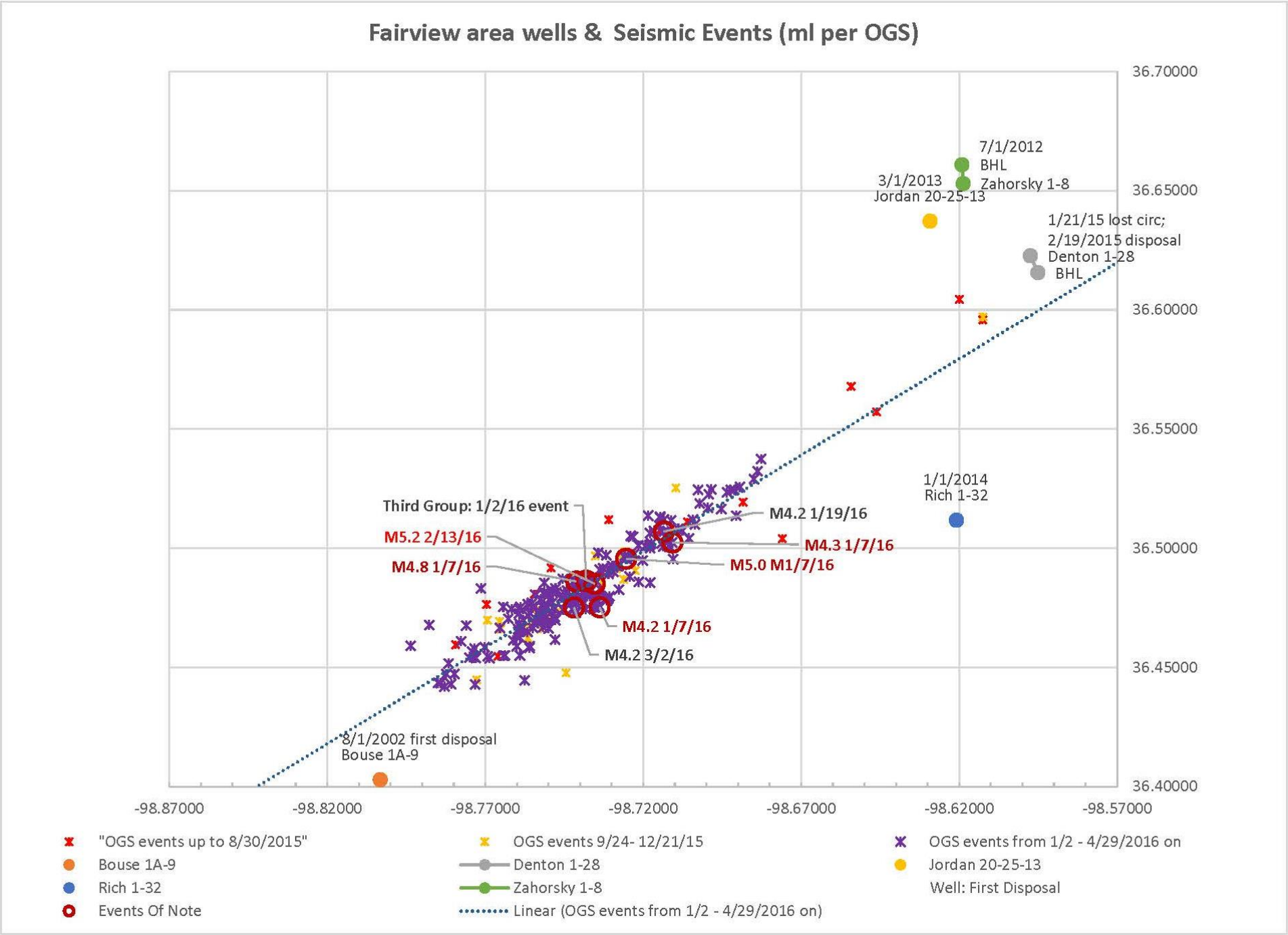


Location of area Arbuckle disposal wells and seismicity selected through GIS via polygon.

Seismic events, ‘x’, are color coded for time periods.
Red earliest (2/12/2005 then 1/25/15-8/30/15),

orange next (9/24/15-12/21/15),

purple in 2016 (1/2/16-4/29/16).



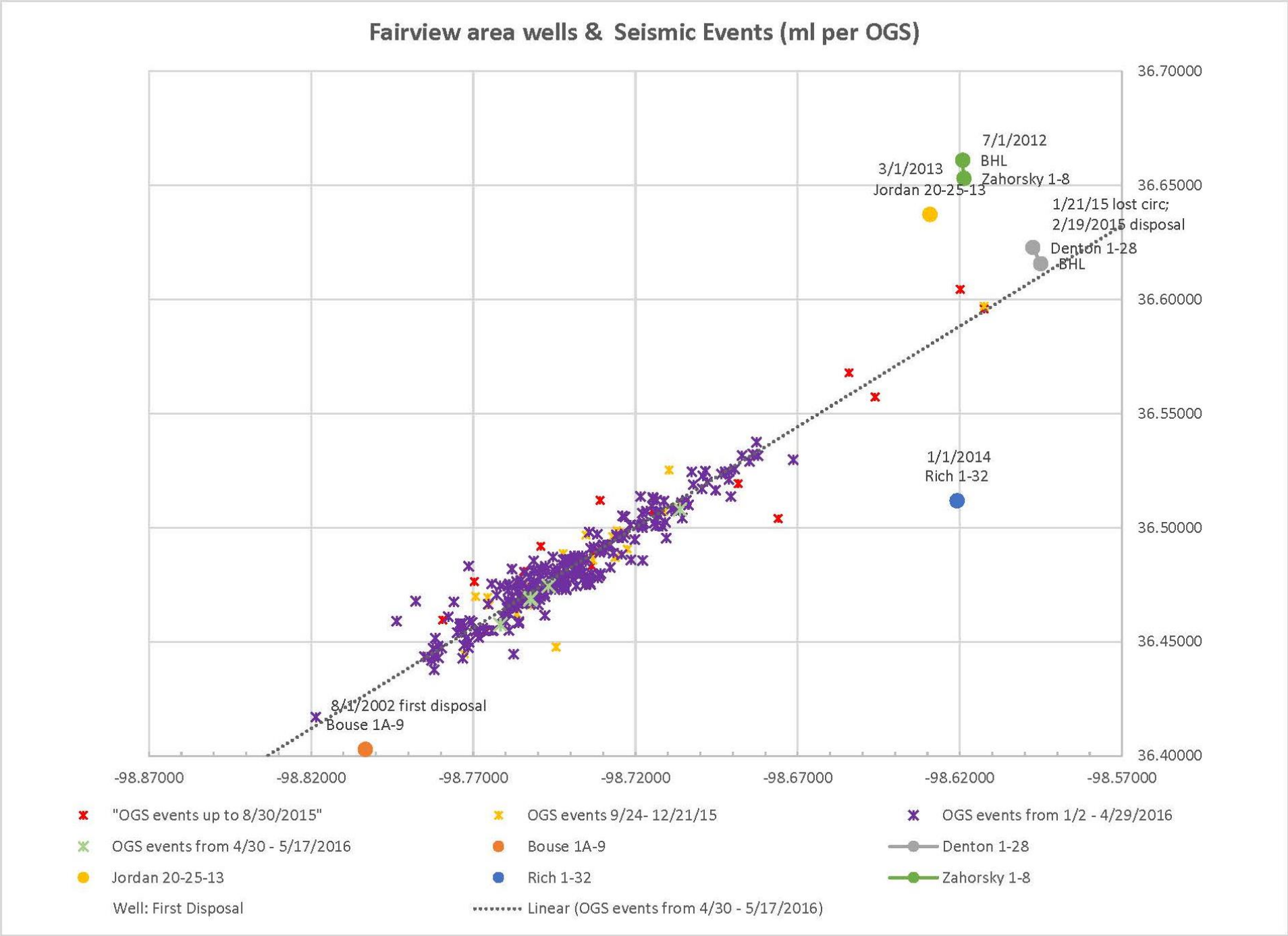
Location of area Arbuckle disposal wells and seismicity selected through GIS via polygon.

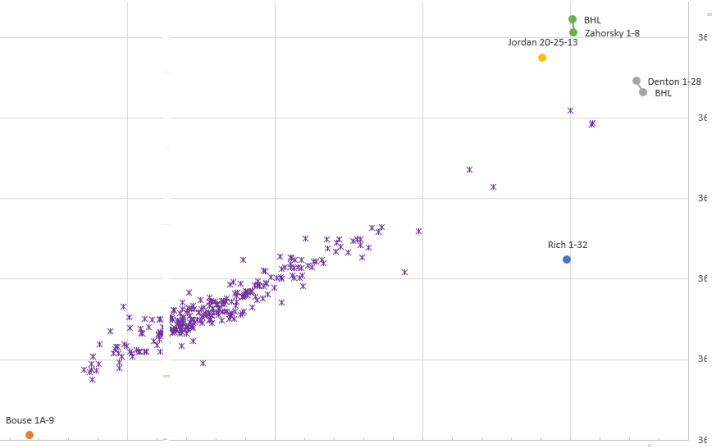
Seismic events, ‘x’, are color coded for time periods.
Red earliest (2/12/2005 then 1/25/15-8/30/15),

orange next (9/24/15-12/21/15),

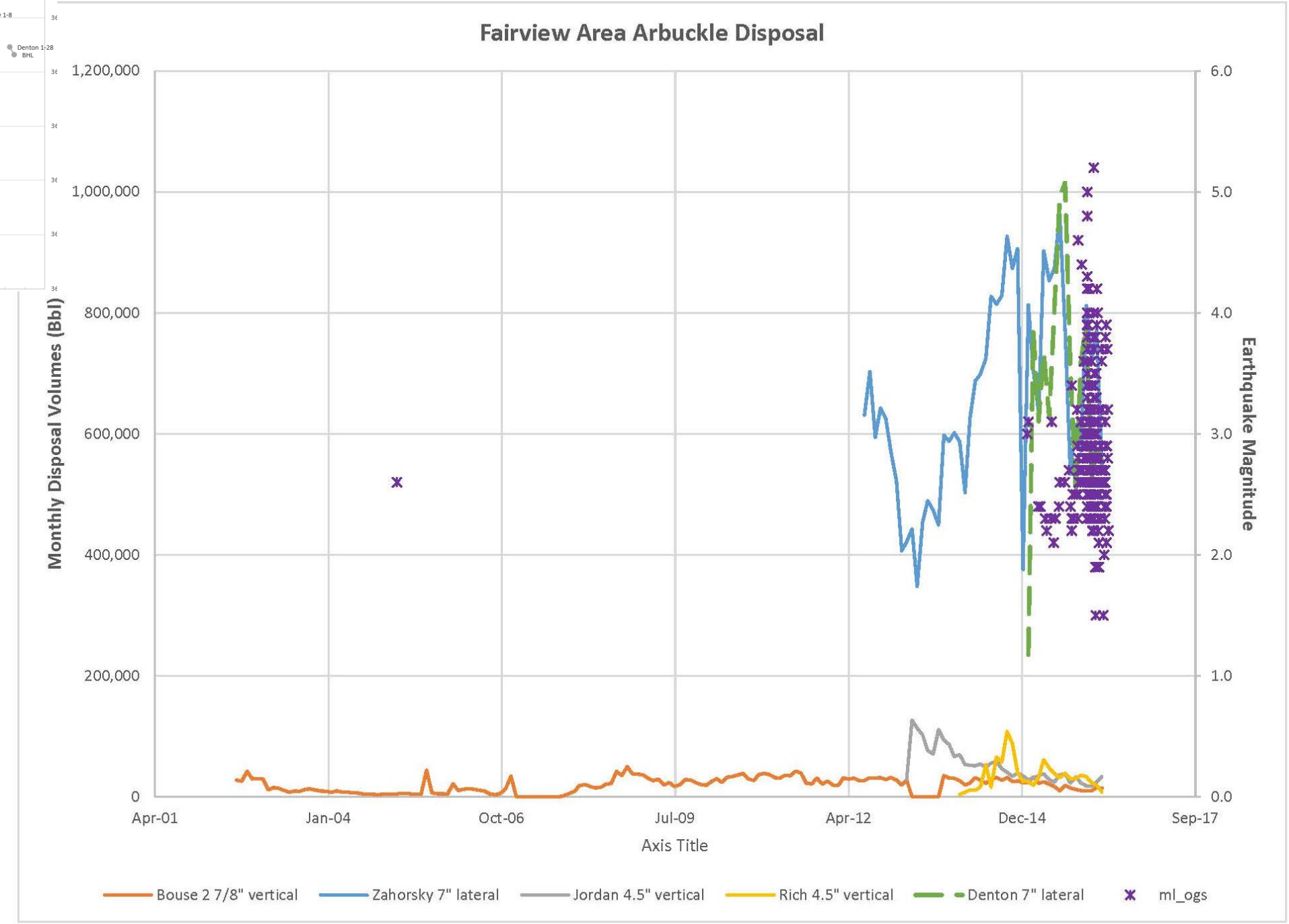
purple in 2016 REVISED (1/2/16-4/29/16)

Green (5/1-5/09/2016) search through 5/17 AM



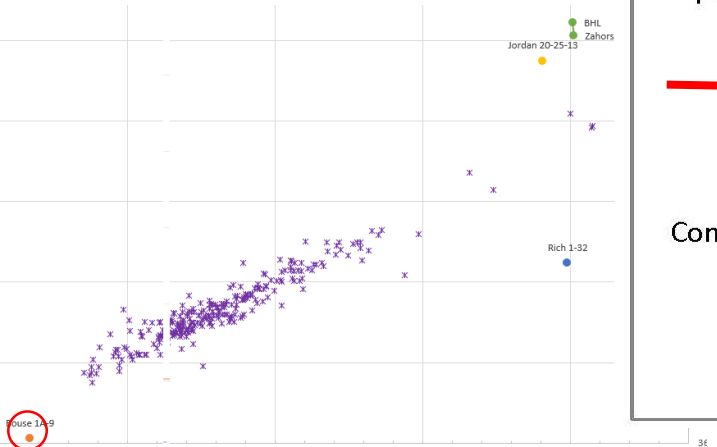


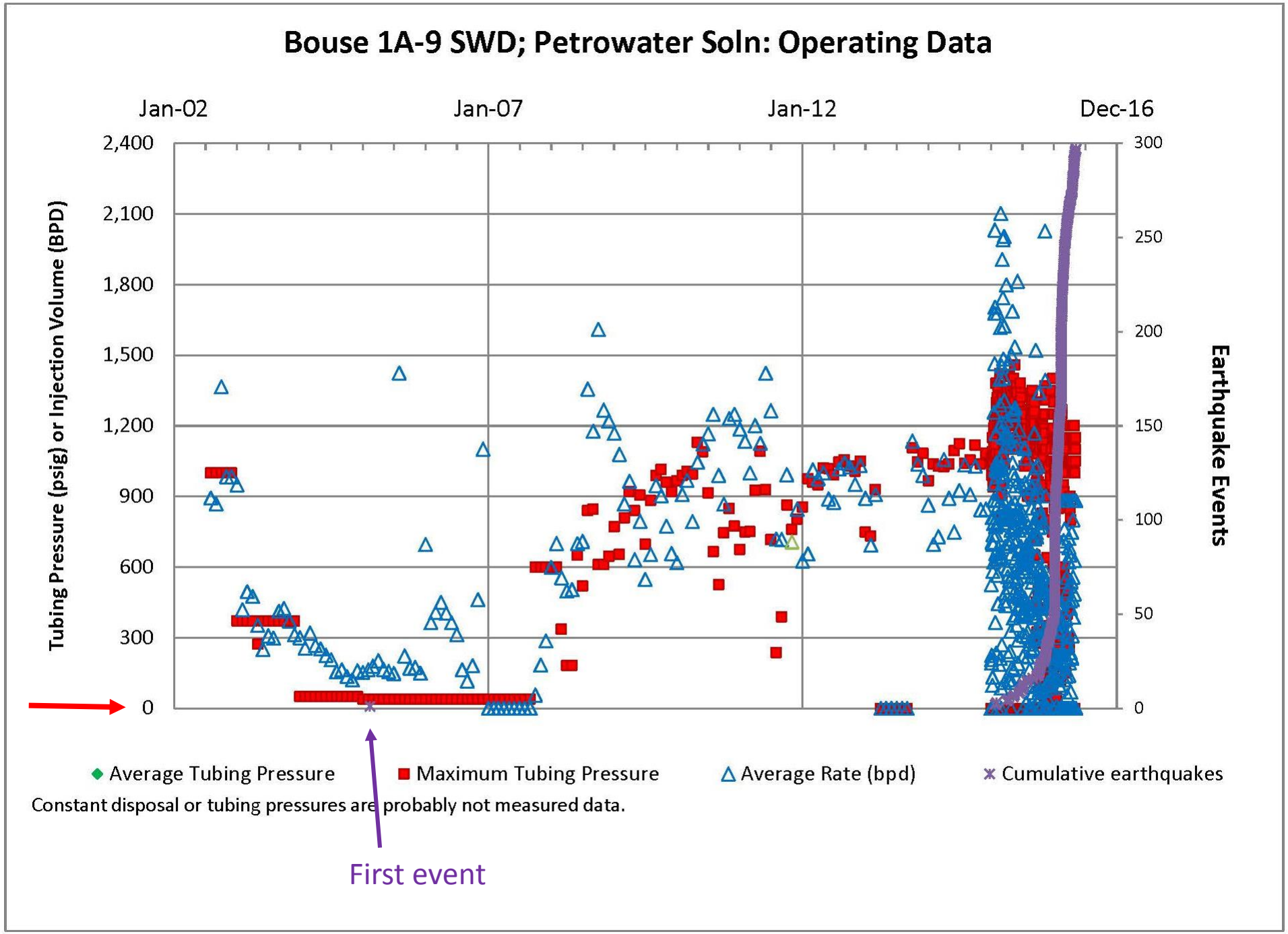
When analyzing seismicity versus well operations, a complete a sequence of seismicity is needed. i.e. do not remove the lower magnitude events from the analysis, when the goal is managing the situation.



Arbuckle: 9430-9728’
Permitted: 7500 BPD
1500 PSI
Packer: initial 9410’
1/1/08: 9360’
2 7/8” tbg
ASSUMED BHP:
3500 psi
9410’
Vertical well

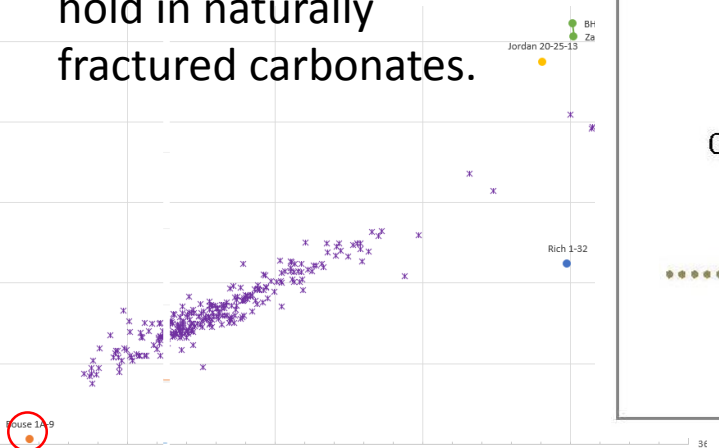
Initial pressures estimated; note: significant changes over reporting period

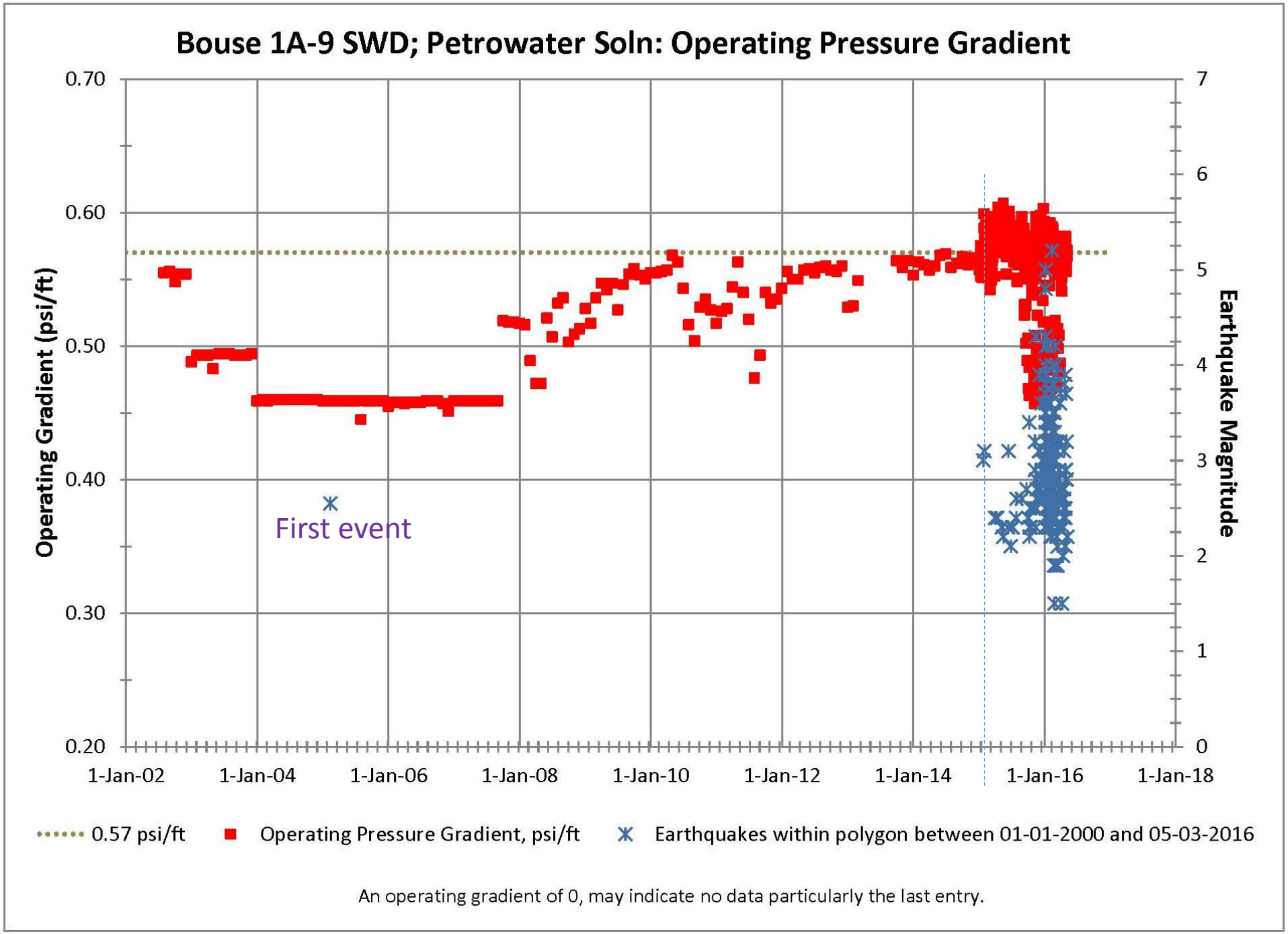




Arbuckle: 9430-9728’
Permitted: 7500 BPD
1500 PSI
Packer: initial 9410’
1/1/08: 9360’
2 7/8” tbg
ASSUMED BHP:
3500 psi
9410’
Vertical well

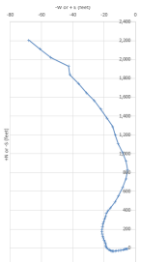
Deep (>2000’ depth) fractures are expected to have vertical height. Normal assumption 0.65-0.7 psi/ft may not hold in naturally fractured carbonates.

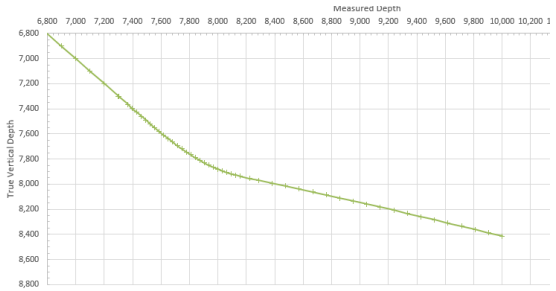


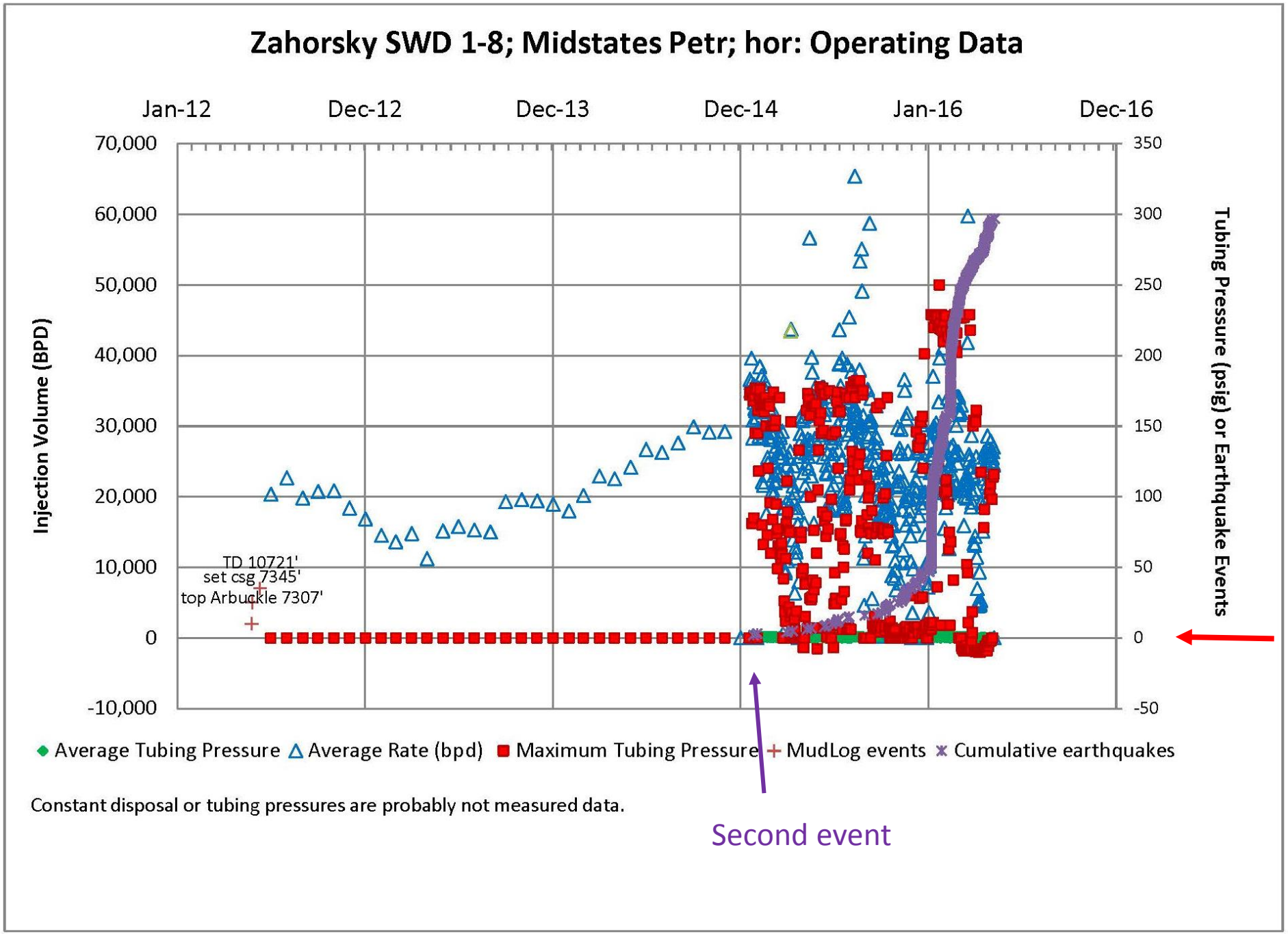


Arbuckle: 7324-9617’
TVD
Permitted: 70,000 BPD
1500 PSI
Packer: 7324’
7” tbg
ASSUMED BHP:
3000 psi
7324’
Highly dev. lateral well

Note: real pressures bounce 250 psi above vacuum!



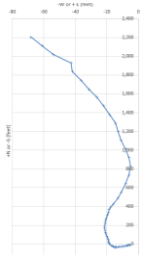


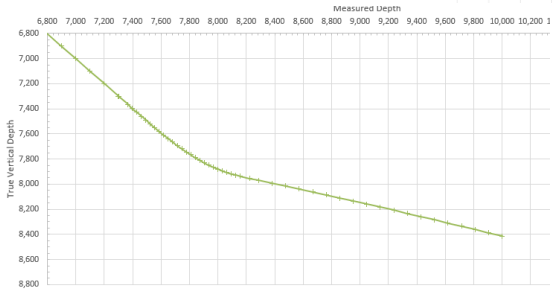


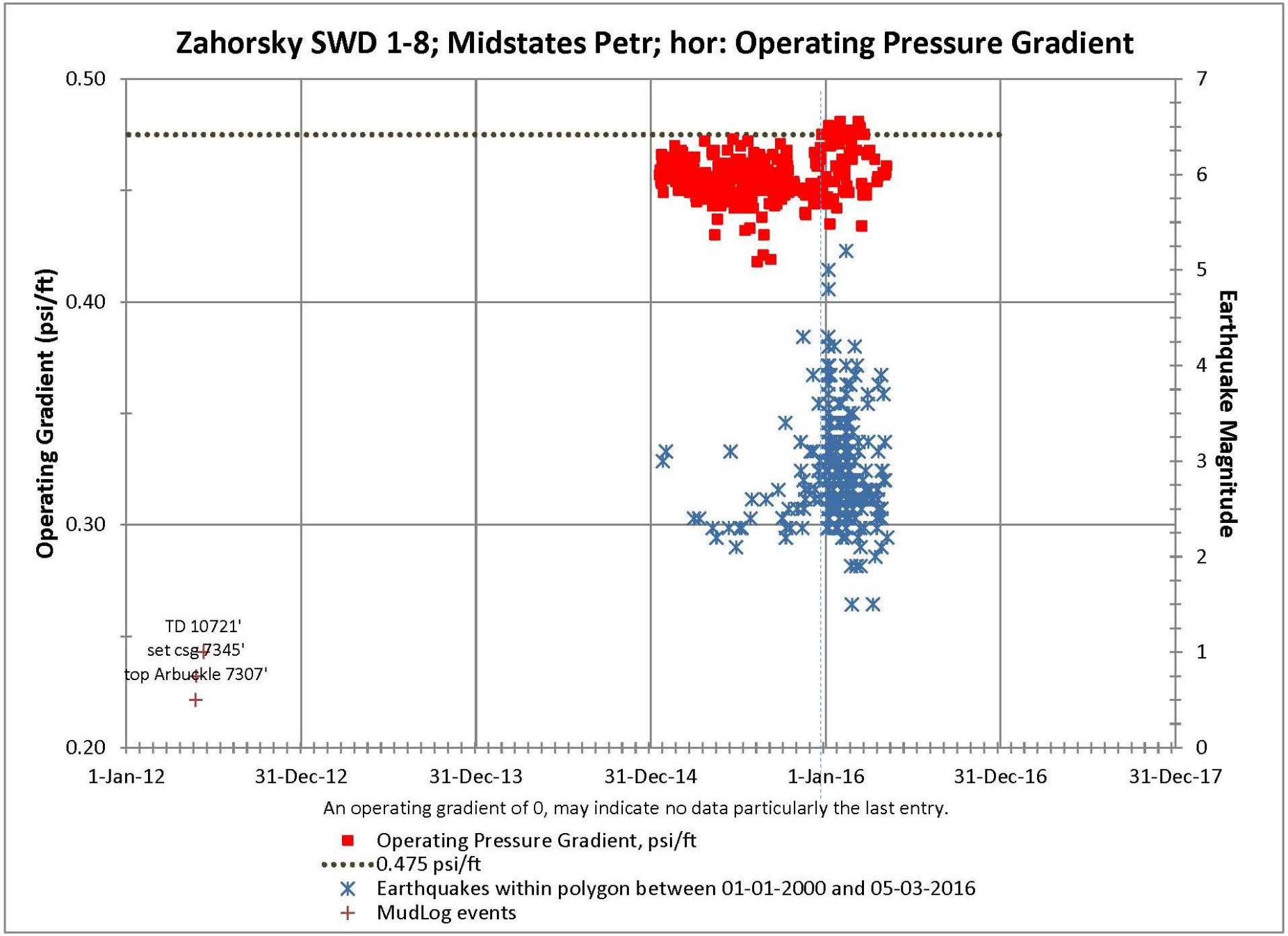
Arbuckle: 7324-9617’
TVD
Permitted: 70,000 BPD
1500 PSI
Packer: 7324’ 7” tbg
ASSUMED BHP:
3000 psi 7324’
Highly dev. lateral well

NOTE: Missing early January 2015 data; no pressures before 1/19/15. Bounces from vacuum to 250 psig. No gradient @ 0 psi tbg.

Eval ~ HF for frac Pr.

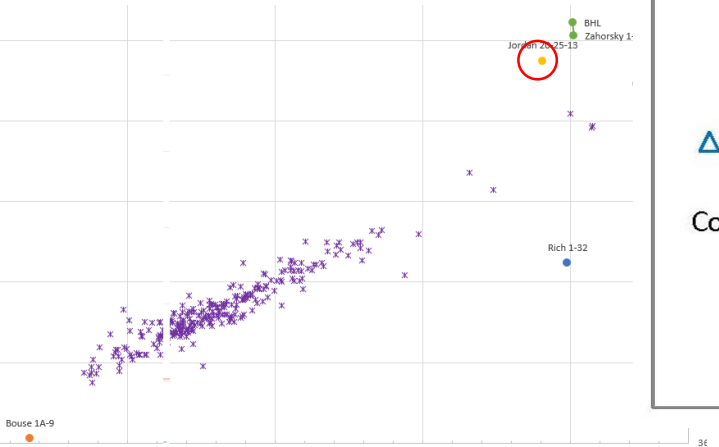


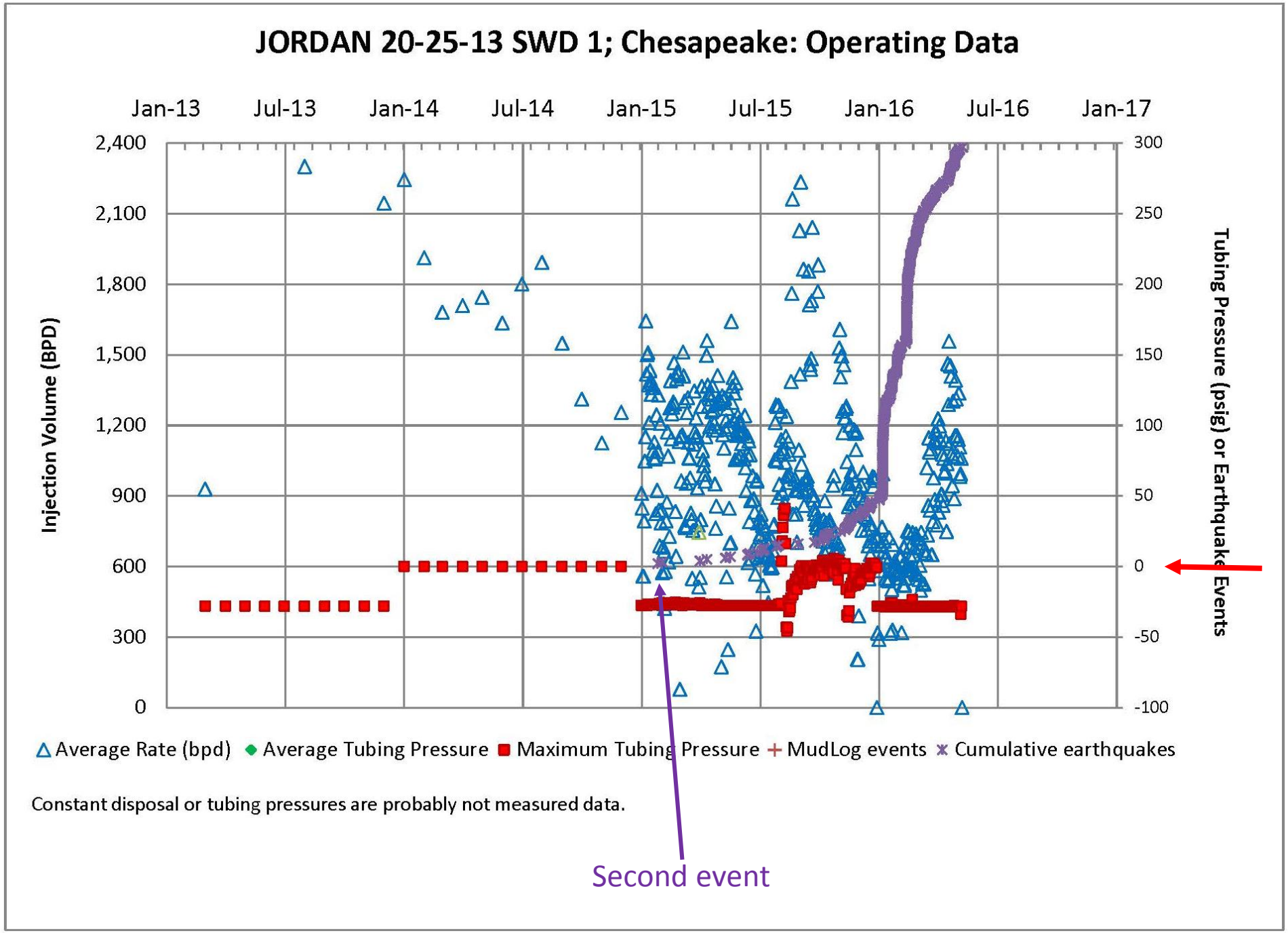




Arbuckle: 7474-8508’
Permitted: 80,000 BPD
1500 PSI
Packer: 7475’
4 1/2” tbg
ASSUMED BHP:
3300 psi
7475’
Vertical well

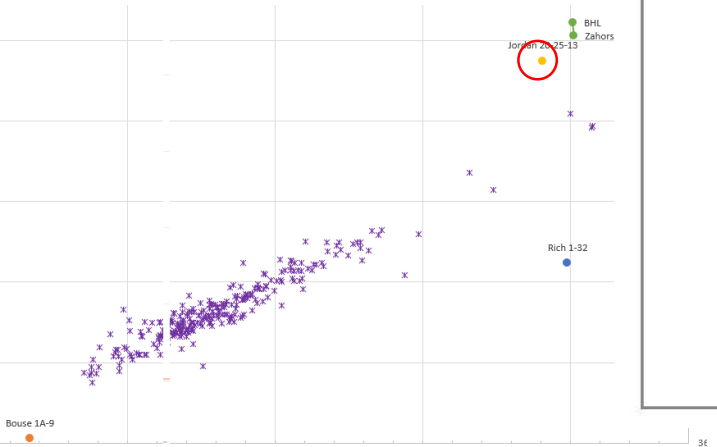
Note measured pressures on vacuum still indicate changes

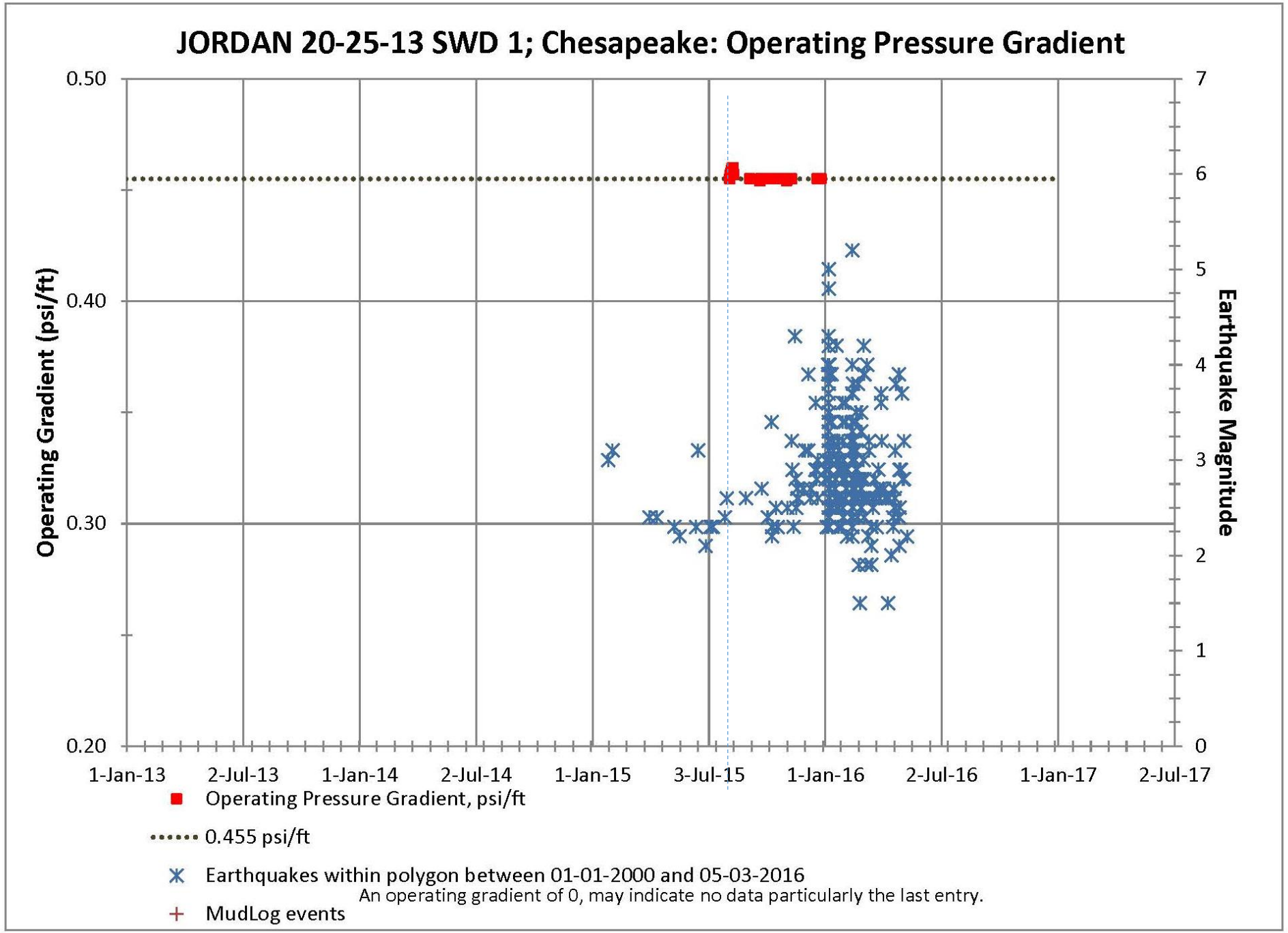




Arbuckle: 7474-8508’
Permitted: 80,000 BPD
1500 PSI
Packer: 7475’
4 1/2” tbg
ASSUMED BHP:
3300 psi
7475’
Vertical well

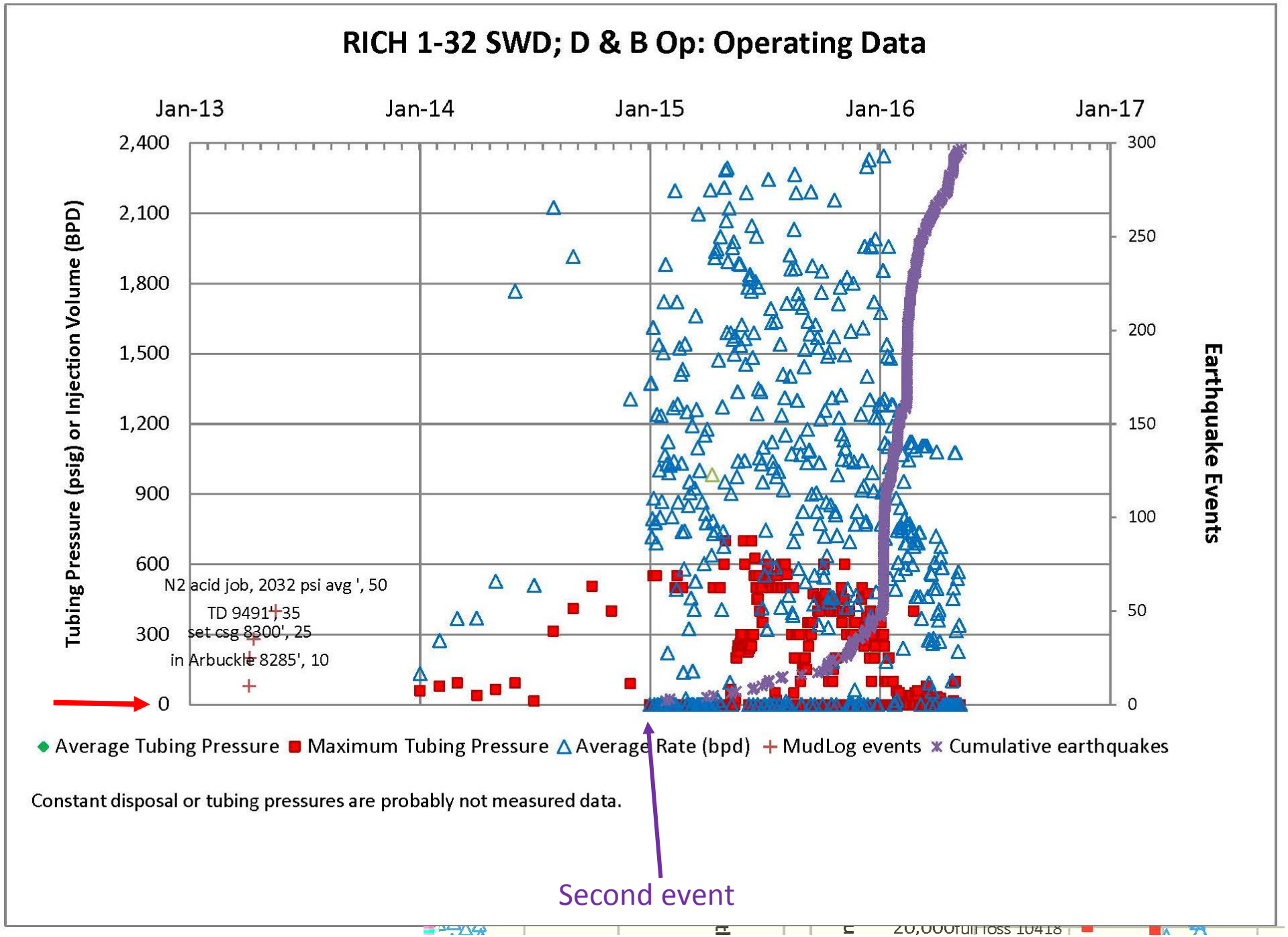
No gradient where on vacuum.

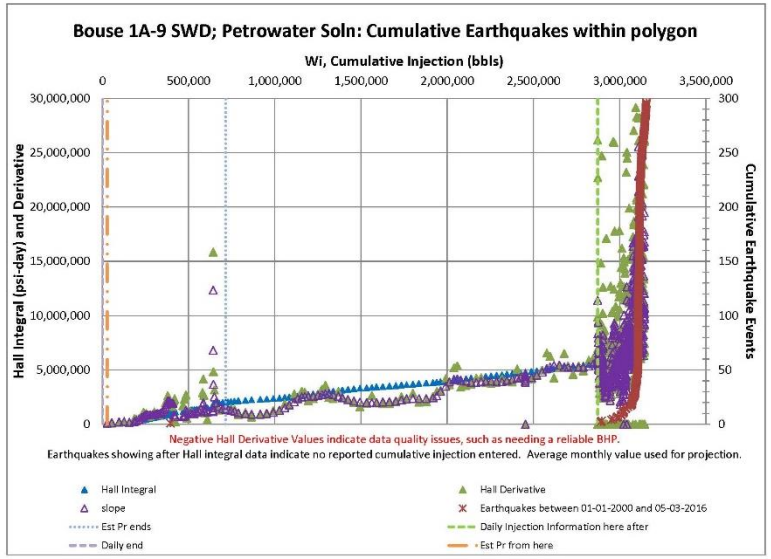


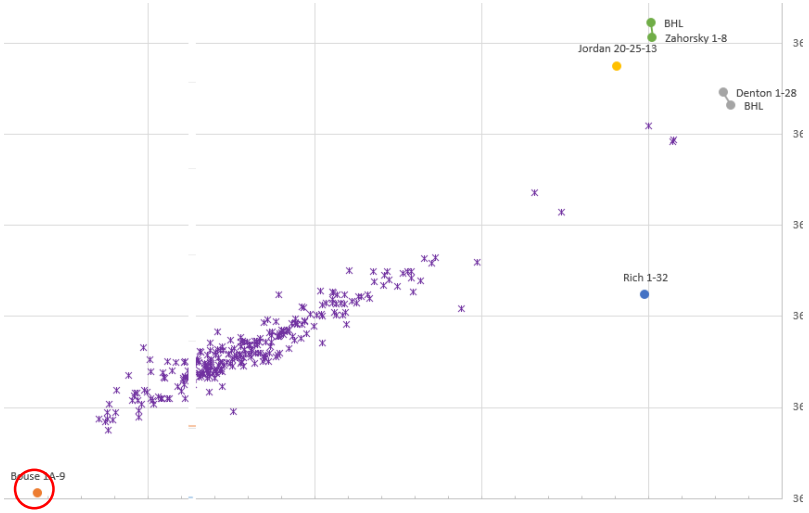


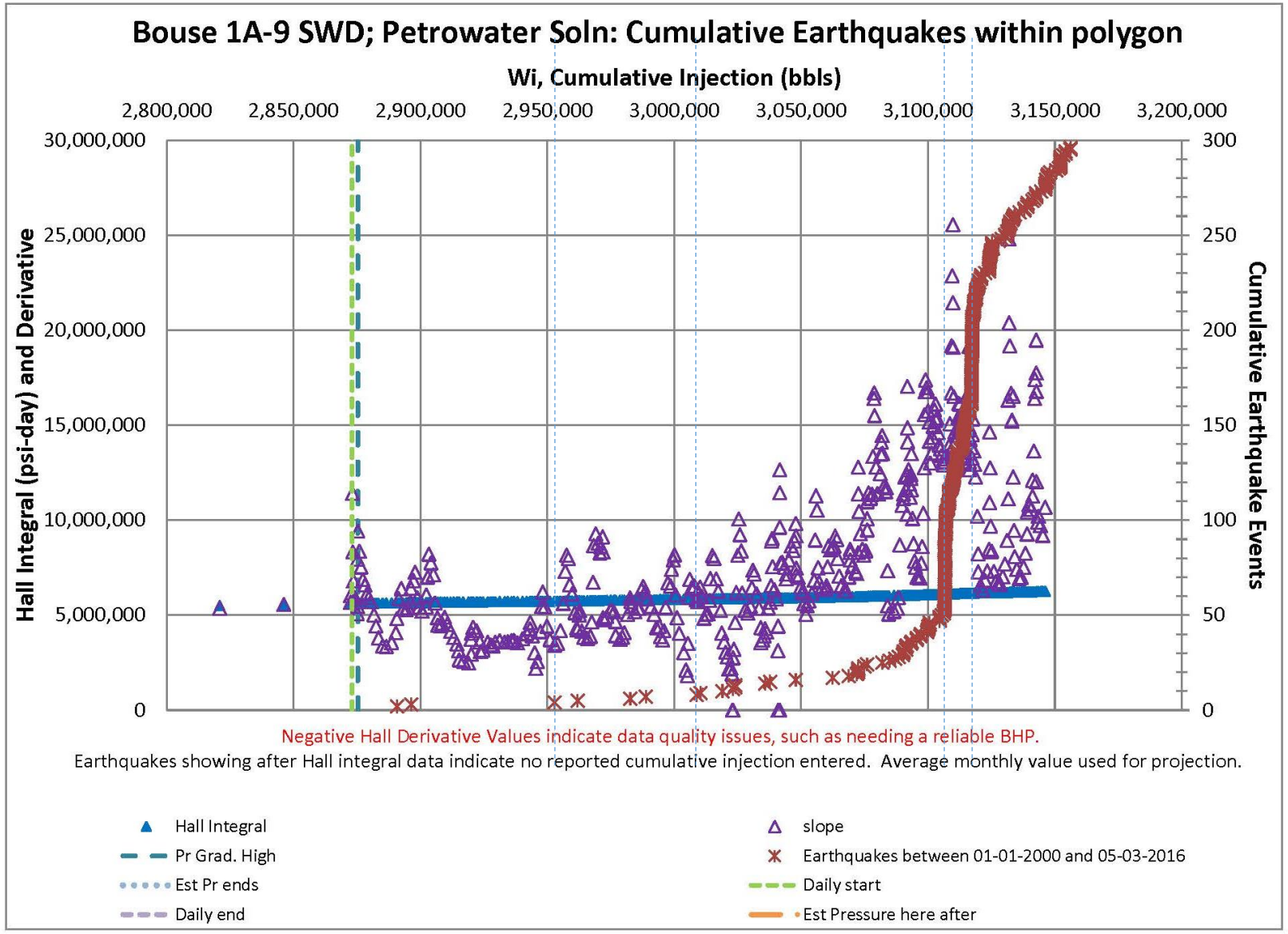
Arbuckle: 7500-9500’
csg: 8300’
Permitted: 35,000 BPD
2500 PSI
Packer: 8265’
4 1/2” tbg
ASSUMED BHP:
3100 psi
7455’
Vertical well

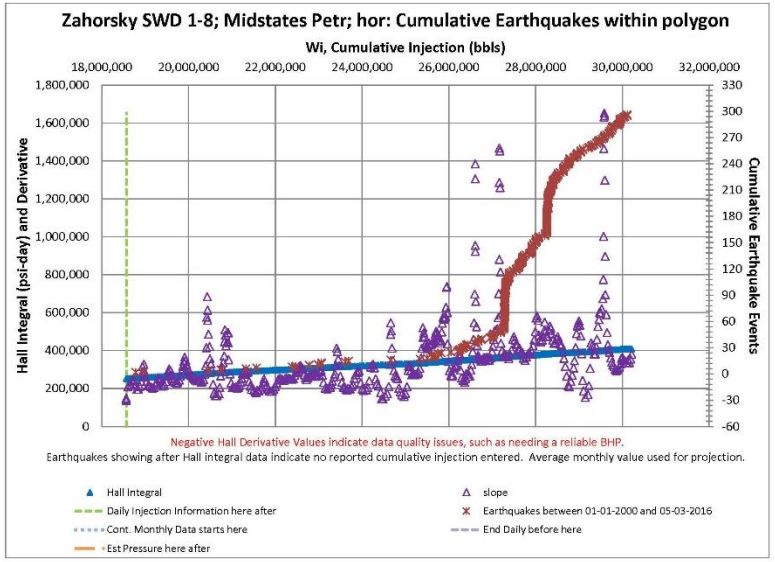
Note: well near vacuum, up to 700 psi tubing pressure. Also 2 weeks missing data (4/10-23/16).




Bouse 1A-9 SWD; Petrowater Soln: Cumulative Earthquakes within polygon
Wi, Cumulative Injection (bbls)
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
3,000,000
3,500,000
Hall Integral (psi-day) and Derivative
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
Cumulative Earthquake Events
300
250
200
150
100
50
0
Negative Hall Derivative Values indicate data quality issues, such as needing a reliable BHP.
Earthquakes showing after Hall integral data indicate no reported cumulative injection entered. Average monthly value used for projection.
Hall Integral
Hall Derivative
slope
Earthquakes between 01-01-2000 and 05-03-2016
Est Pr ends
Daily Injection Information here after
Daily end
Est Pr from here

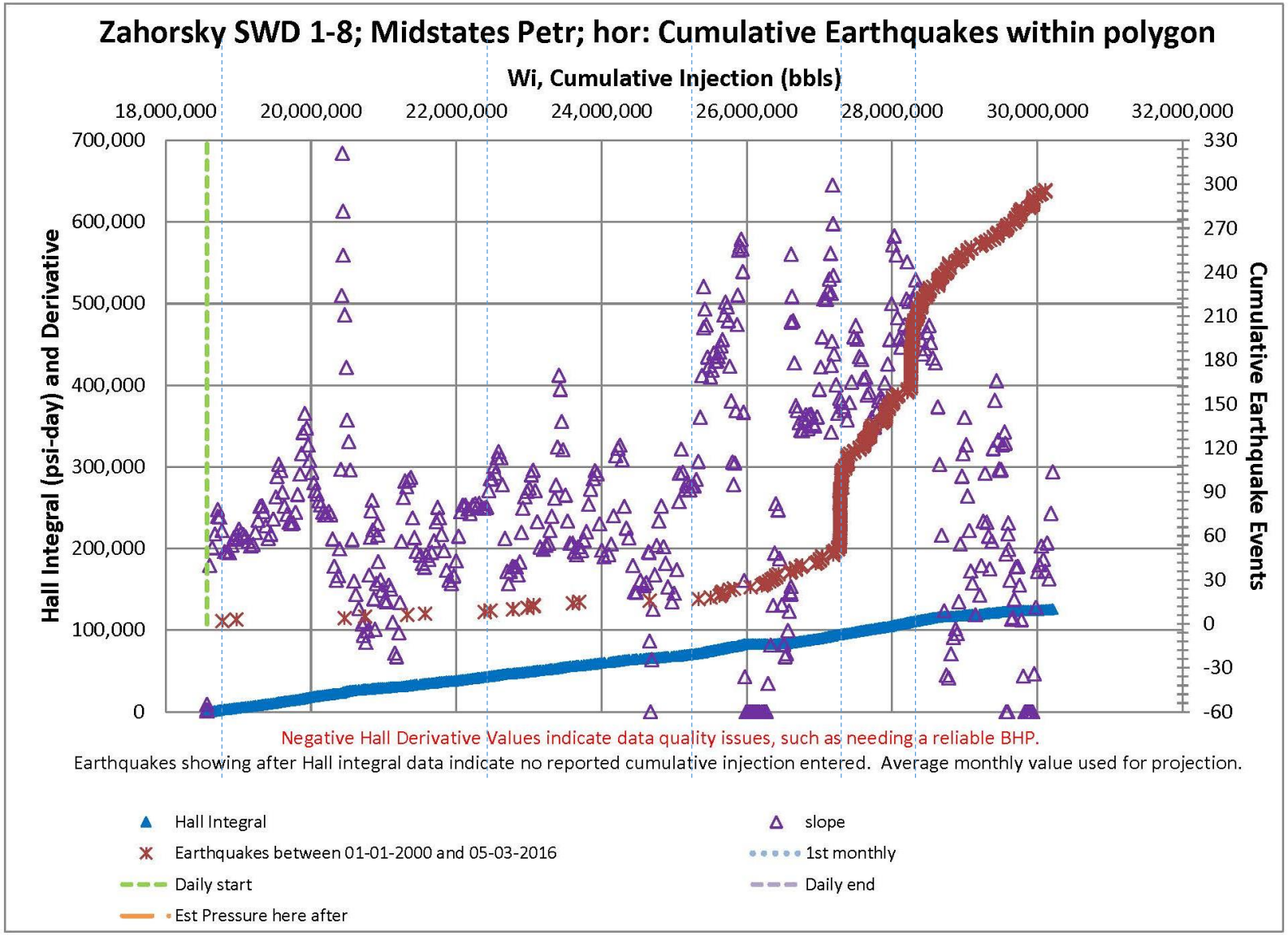

BHL
Zahorsky 1-8
Jordan 20-25-13
Denton 1-28
BHL
Rich 1-32
Bouse 1A-9

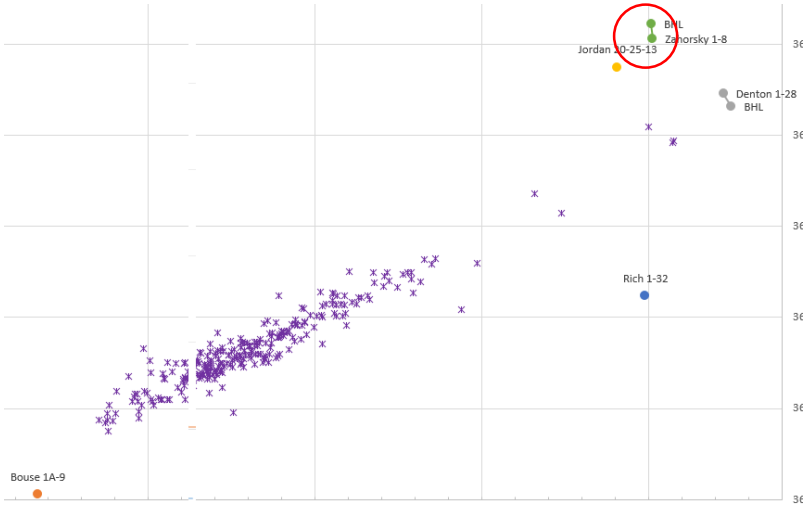

Bouse 1A-9 SWD; Petrowater Soln: Cumulative Earthquakes within polygon
Wi, Cumulative Injection (bbls)
2,800,000
2,850,000
2,900,000
2,950,000
3,000,000
3,050,000
3,100,000
3,150,000
3,200,000
Hall Integral (psi-day) and Derivative
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
Cumulative Earthquake Events
300
250
200
150
100
50
0
Negative Hall Derivative Values indicate data quality issues, such as needing a reliable BHP.
Earthquakes showing after Hall integral data indicate no reported cumulative injection entered. Average monthly value used for projection.
Hall Integral
slope
Pr Grad. High
Earthquakes between 01-01-2000 and 05-03-2016
Est Pr ends
Daily start
Daily end
Est Pressure here after

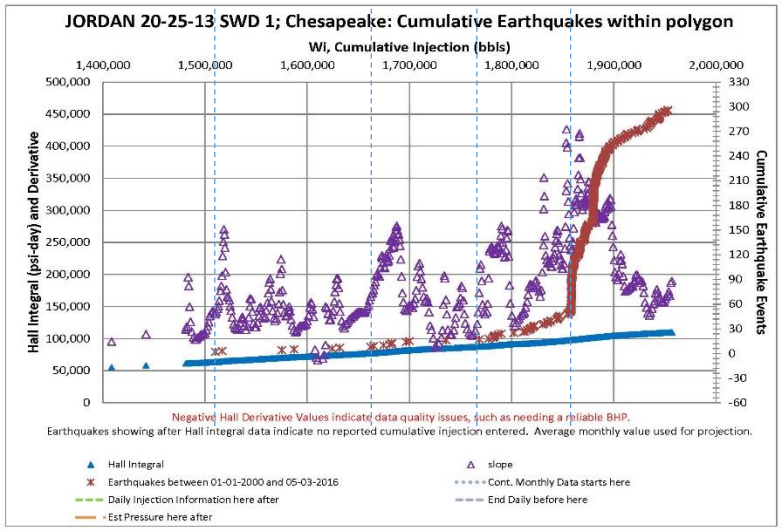


Hall analysis assuming brine filled wellbore

Hall analysis only calculated after first +pressure **same character**







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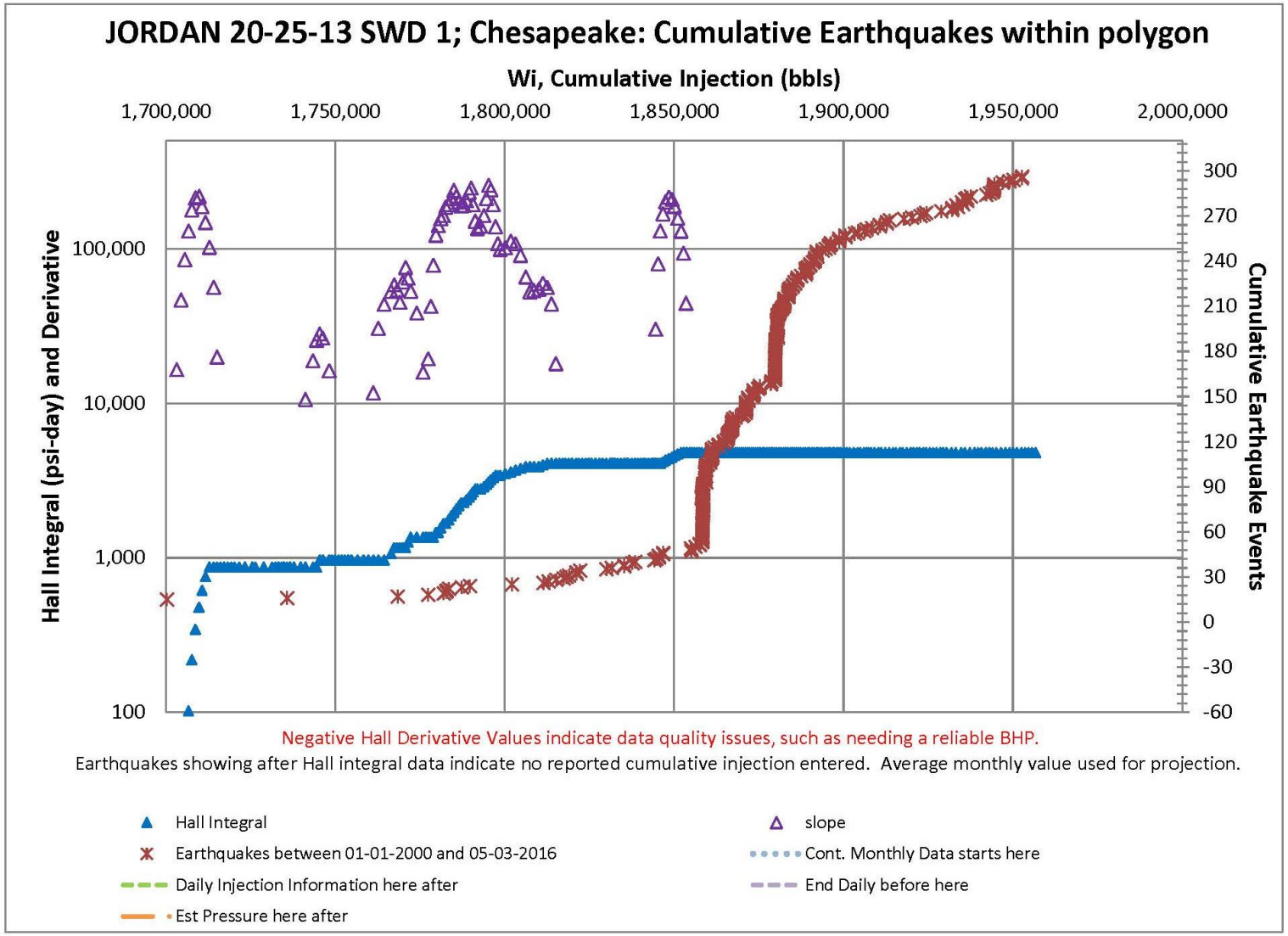
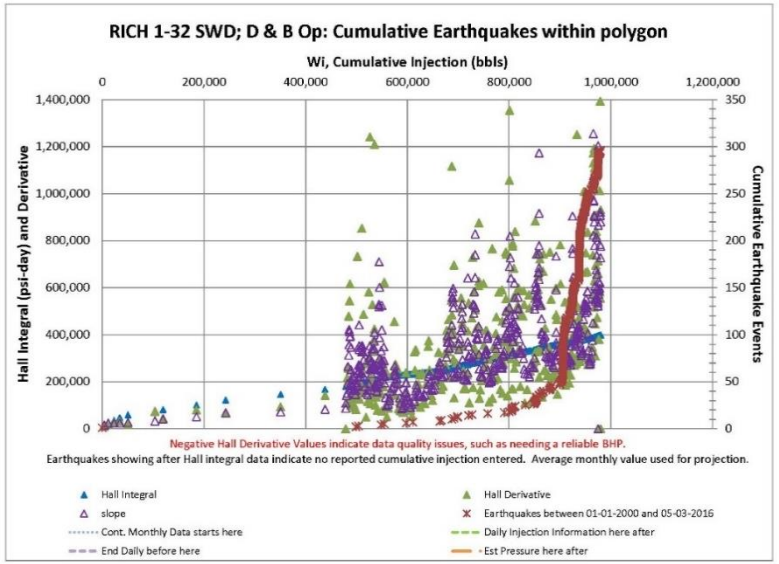
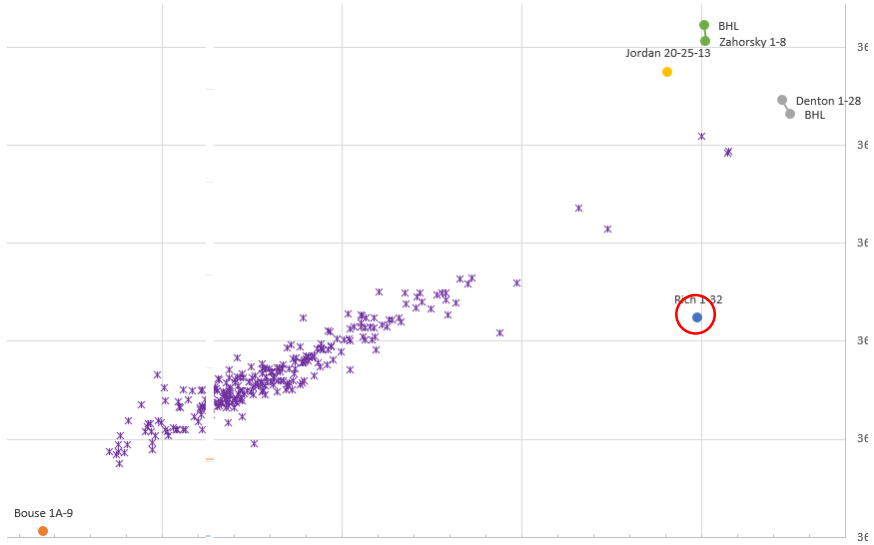
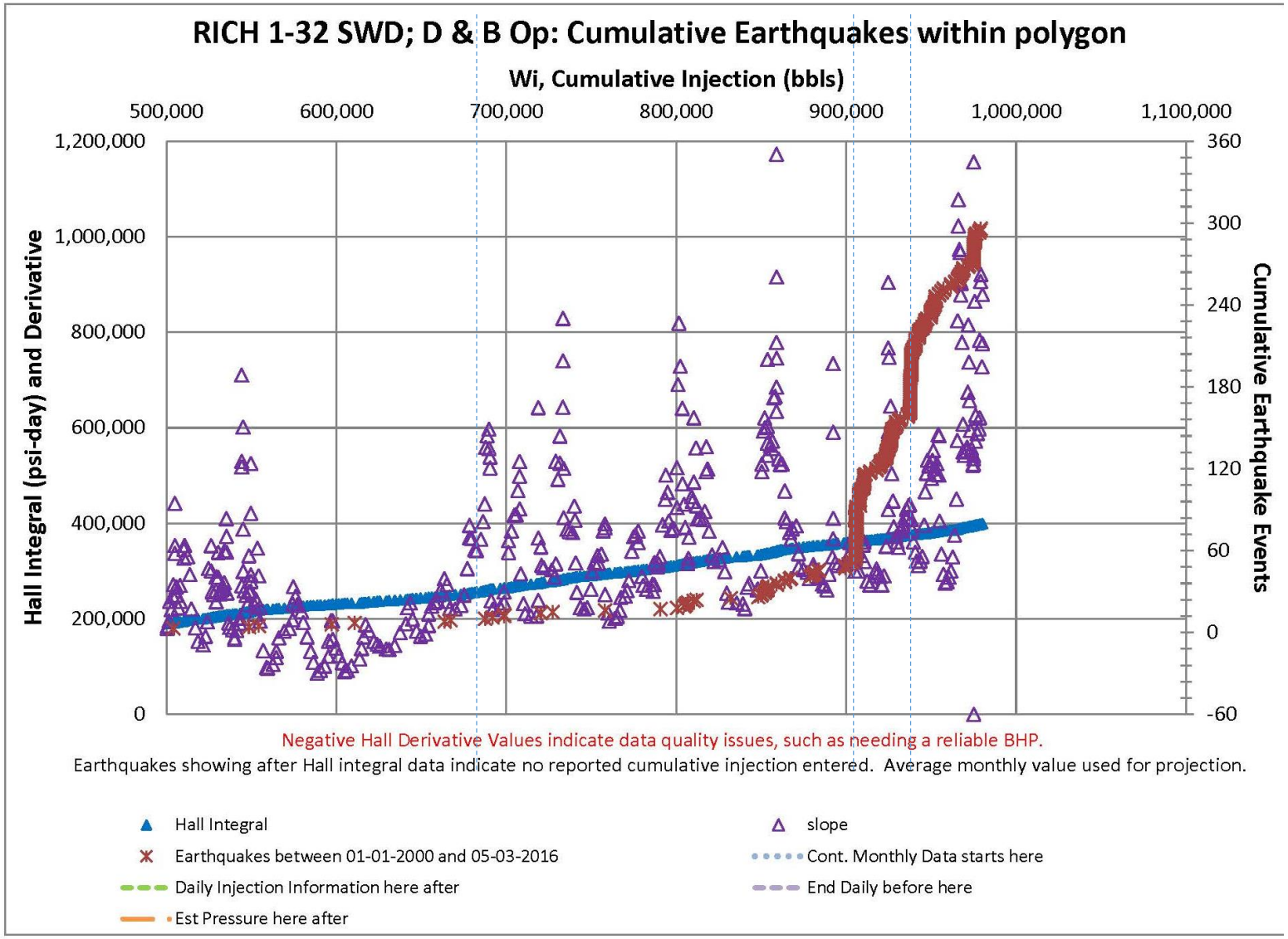
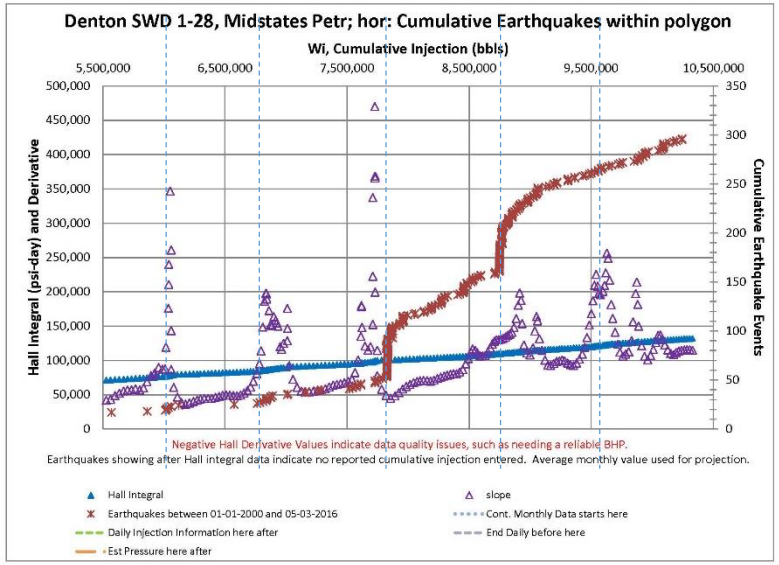
Hall analysis only calculated after first +pressure **same character**




RICH 1-32 SWD; D & B Op: Cumulative Earthquakes within polygon
Wi, Cumulative Injection (bbls)
Hall Integral (psi-day) and Derivative
Cumulative Earthquake Events
Negative Hall Derivative Values indicate data quality issues, such as needing a reliable BHP.
Earthquakes showing after Hall integral data indicate no reported cumulative injection entered. Average monthly value used for projection.
Hall Integral
Hall Derivative
slope
Earthquakes between 01-01-2000 and 05-03-2016
Cont. Monthly Data starts here
Daily Injection Information here after
End Daily before here
Est Pressure here after

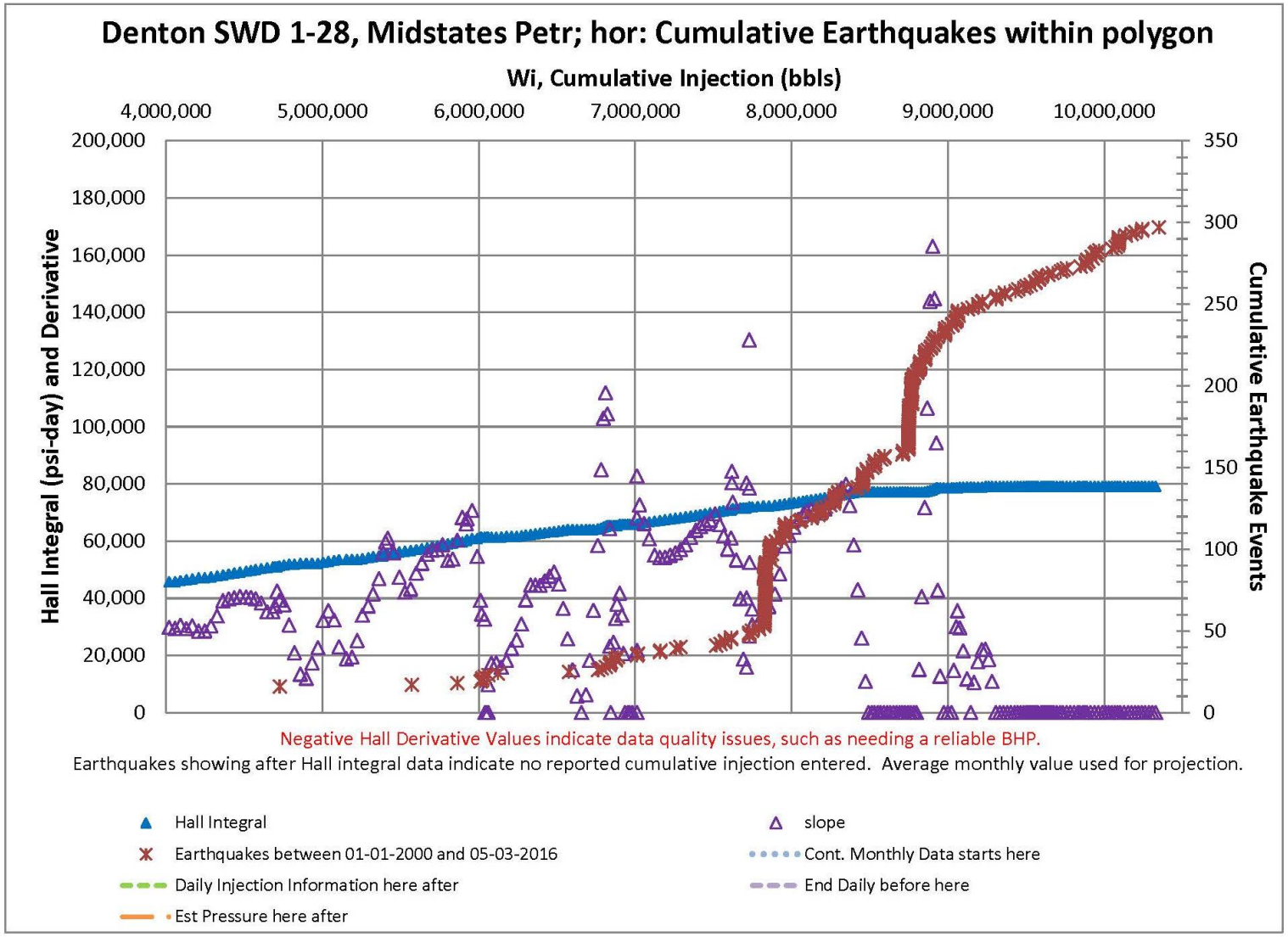

BHL
Zahorsky 1-8
Jordan 20-25-13
Denton 1-28
BHL
Rich 1-32
Bouse 1A-9

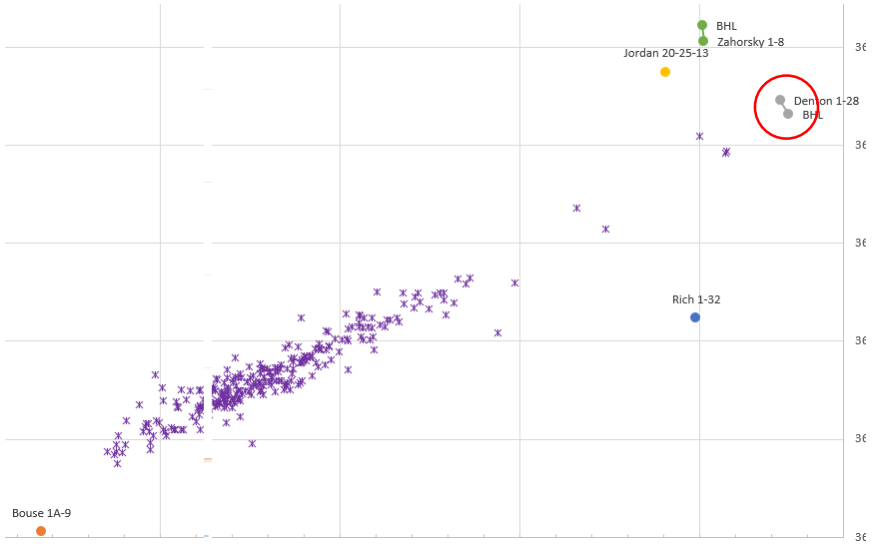

RICH 1-32 SWD; D & B Op: Cumulative Earthquakes within polygon
Wi, Cumulative Injection (bbls)
500,000
600,000
700,000
800,000
900,000
1,000,000
1,100,000
Hall Integral (psi-day) and Derivative
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Cumulative Earthquake Events
360
300
240
180
120
60
0
-60
Negative Hall Derivative Values indicate data quality issues, such as needing a reliable BHP.
Earthquakes showing after Hall integral data indicate no reported cumulative injection entered. Average monthly value used for projection.
Hall Integral
slope
Earthquakes between 01-01-2000 and 05-03-2016
Cont. Monthly Data starts here
Daily Injection Information here after
End Daily before here
Est Pressure here after



Hall analysis assuming brine filled wellbore

Hall analysis only calculated after first +pressure **same character**

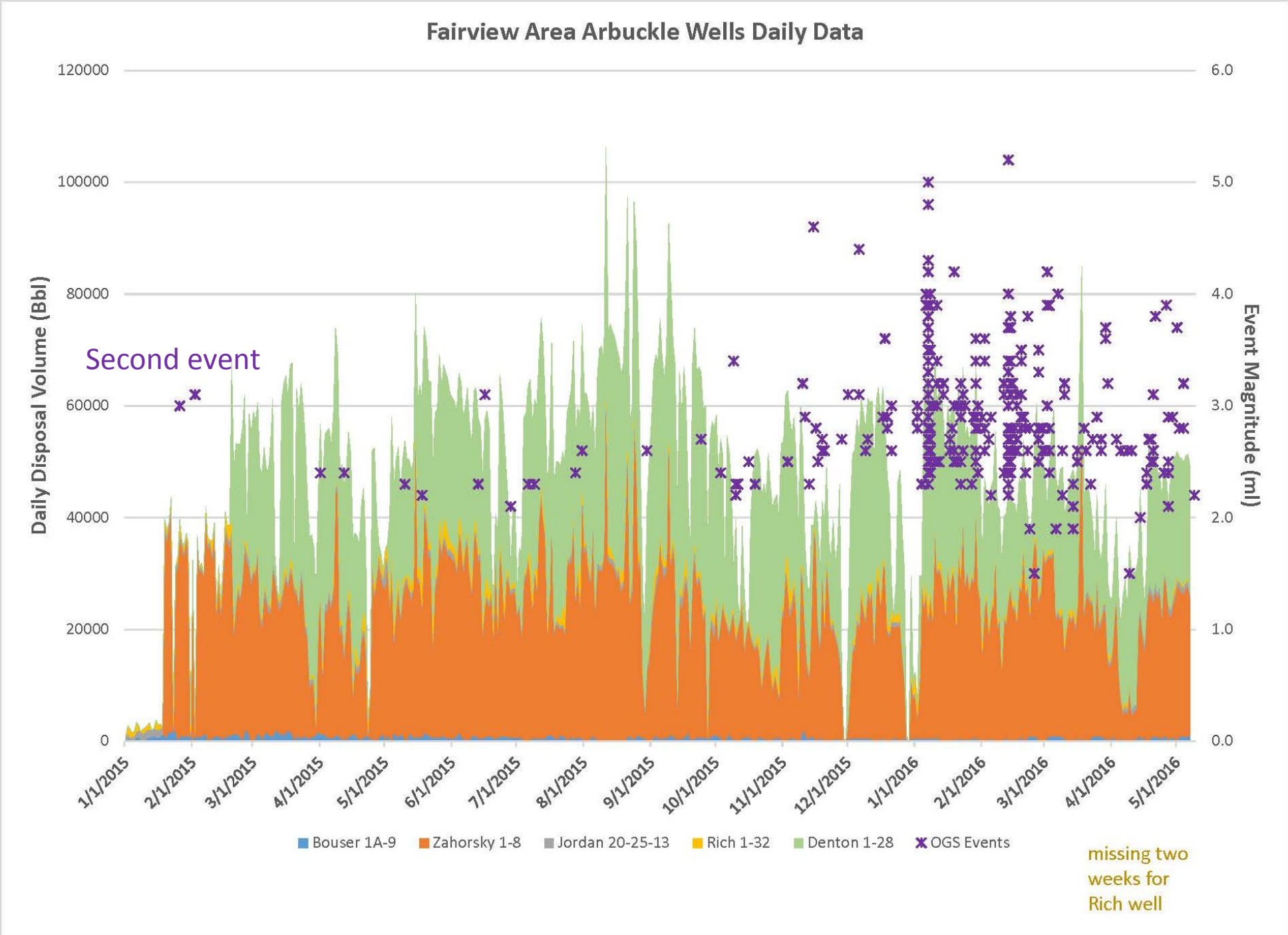




Each situation is unique. Sometimes the issue appears to be high rates, sometimes pressure. Is there a key fracture extension pressure?

Has the operator correctly reported…or will they change it on seeing the plots?

There appears to be a correspondence to all of the wells, though the timing of the last well drilled is suggestive…possibly too close to a fault or open fracture (repeated lost circulation).



AVAILABLE DATA:

- OCC is highly commended for instituting:
  - Daily reporting
  - Site visits to ensure reliability and proper gauge usage
- OGS is highly recommended for instituting:
  - Vast monitoring network
  - Fairly rapid analysis (and re-evaluation)

DATA STILL NEEDED:

- Reliable bottomhole pressures, even in wells on vacuum.
- Accurate tubing size and packer depth.

OTHER DATA IMPROVEMENTS

- Collecting both average and maximum tubing pressures along with hours (for daily) or days (for monthly) reporting

POSSIBLE MANAGEMENT OPTIONS (not to be confused with recommendations):

- Limit Arbuckle permit pressures to well below fracture extension pressure.
  - Based on review of data—it may vary by area.
- Limit tubing size of Arbuckle disposal wells.
- Limit use of laterals or multi-laterals for Arbuckle disposal wells.
- Limit or end future Arbuckle disposal.
- Train the operators to monitor the response of their wells, so they can cut back when the pressure starts rising.
- To combat data quality issues, do not accept questionable data