

Microseismic Processing HFTS2 Project Final Results

June 27th, 2019

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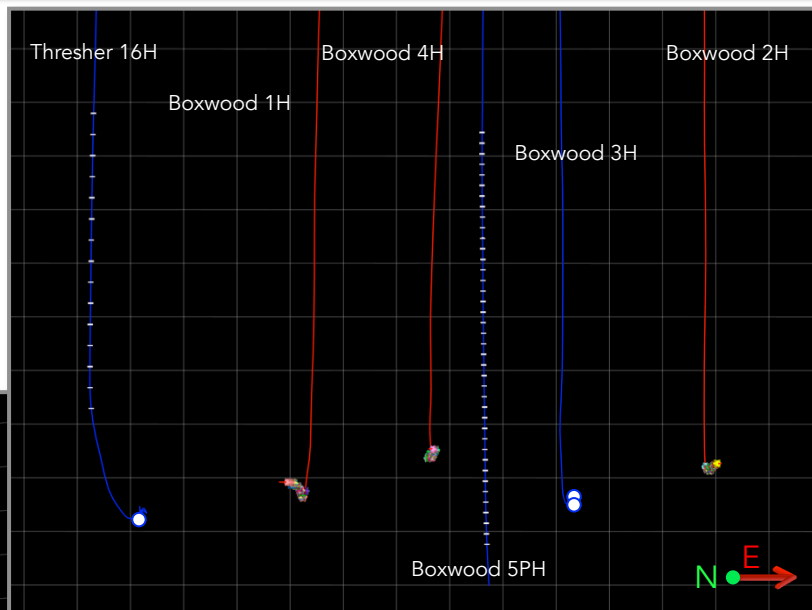
Location Map and Microseismic Job Info

Geometry Design:

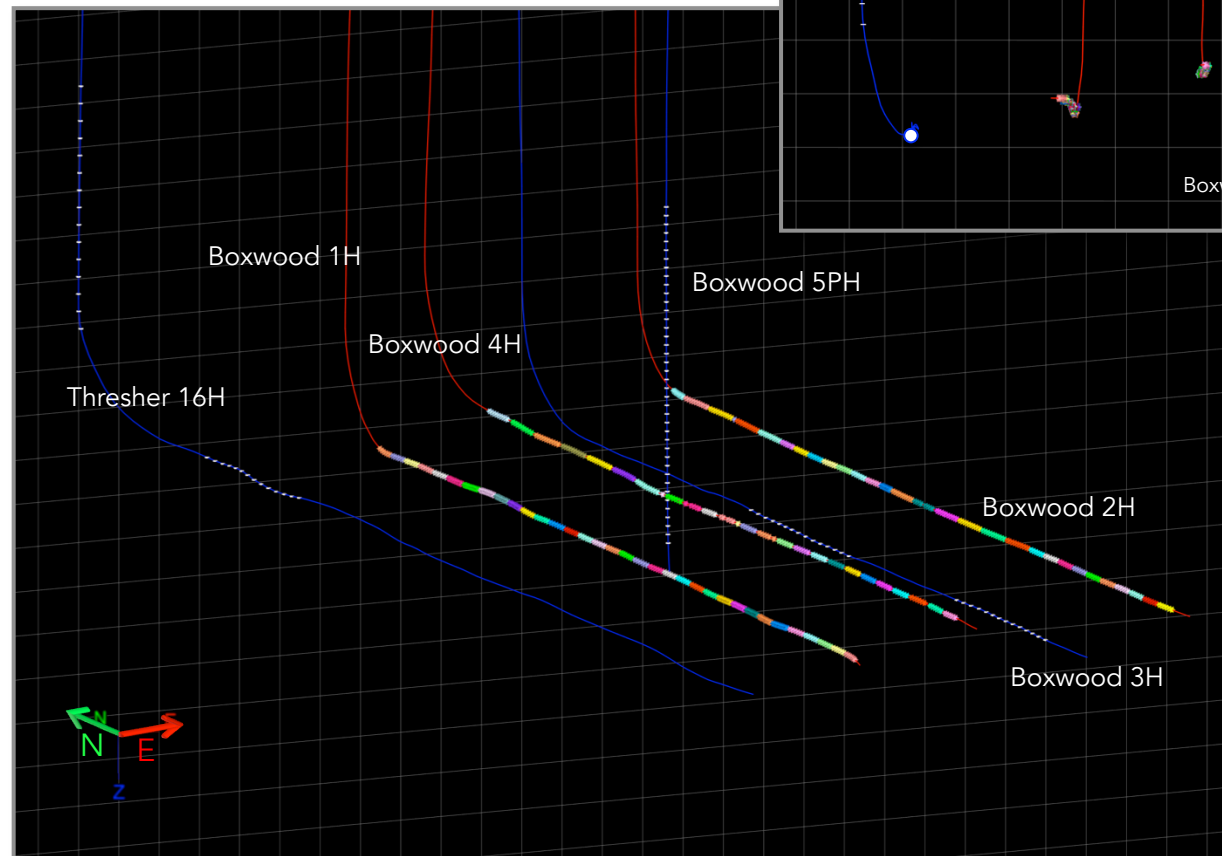
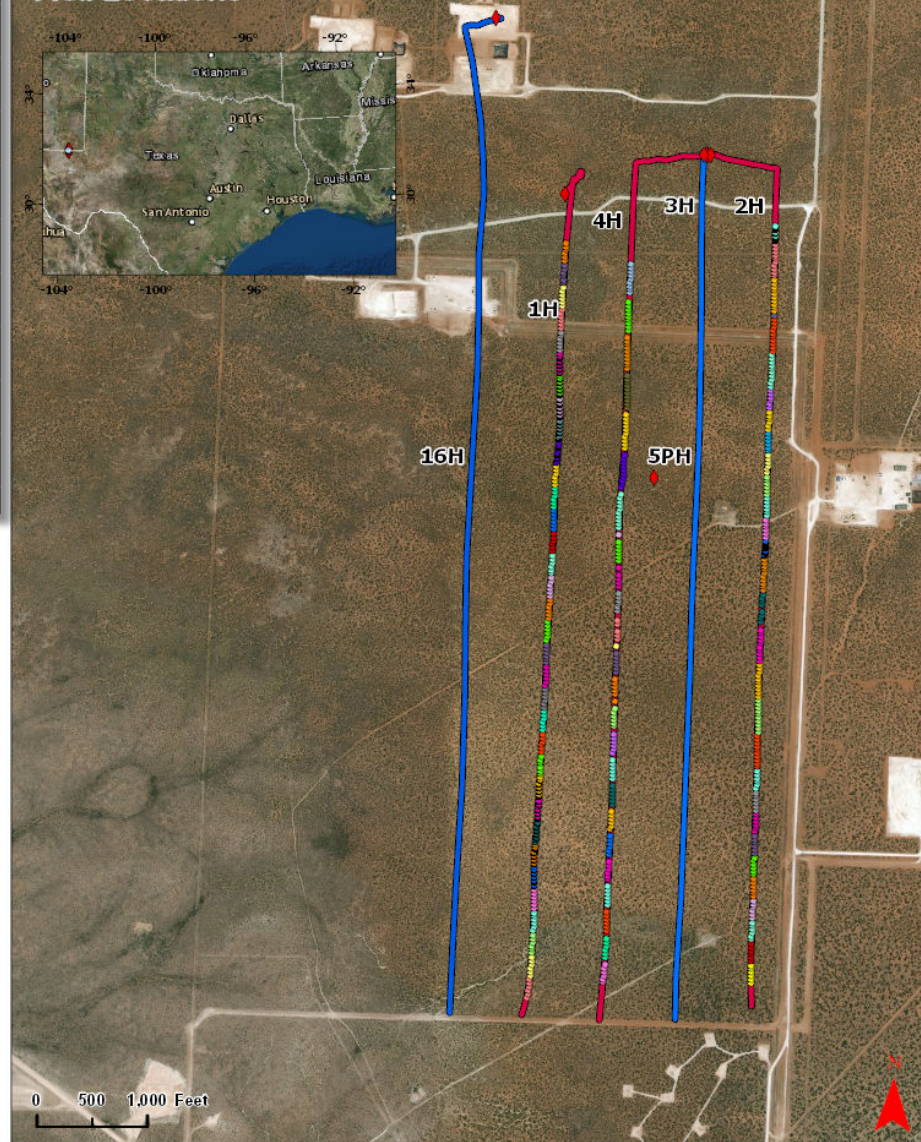
40 - Level Vertical-Array in Boxwood 55-1-12 Unit 5PH

14 - Level Horizontal-Array & 15 - Level Horizontal-Array in Boxwood 55-1-12 Unit 3H

14 - Level Horizontal-Array & 15 - Level Vertical-Array in Thresher 55-1-12 Unit A 16H



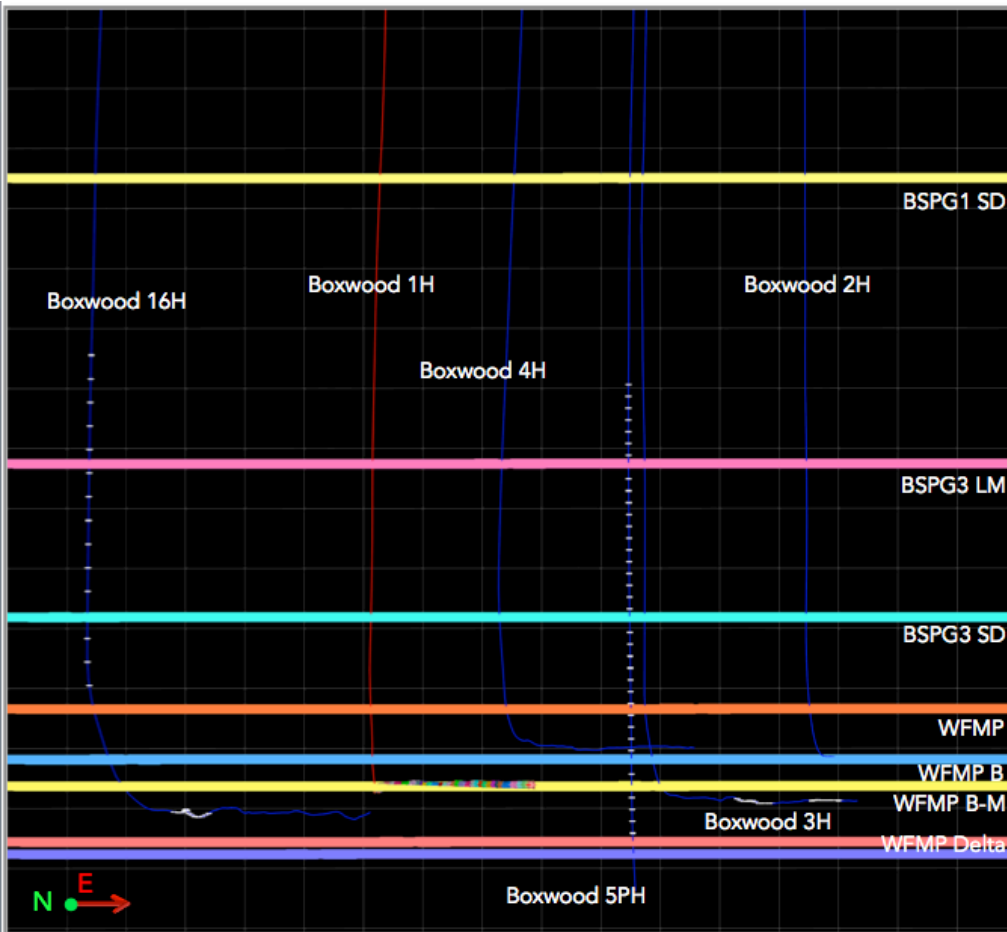
HFTS2 - Microseismic Fracturing Well Locations



HFTS2 Monitoring Timeline & Processing Info



AWARDED PROJECT NAME	START DATE	END DATE	DURATION	MARCH														APRIL																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
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March-19-2019
Borehole Started Monitoring Single Well Frac.
Boxwood 1H & March-28-2019
Ended Monitoring Single Well Frac. Boxwood 1H

April-12-2019
Borehole Started Monitoring Single Well Frac.
Boxwood 4H & April-20-2019
Ended Monitoring Single Well Frac. Boxwood 4H

March-30-2019
Borehole Started Monitoring Single Well Frac.
Boxwood 2H & April-09-2019
Ended Monitoring Single Well Frac. Boxwood 2H

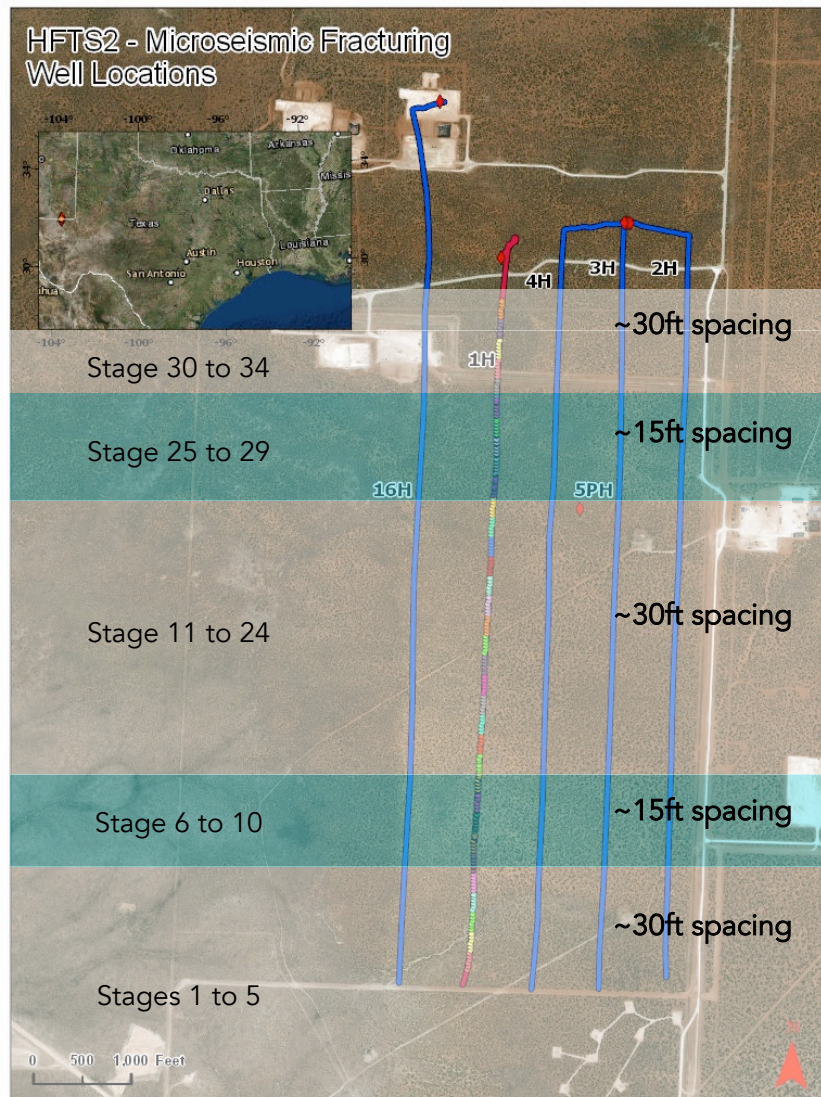
Borehole Seismic processed a total of 89 stages on HFTS2 Project

Geometry Design:

- 40 - Level Vertical-Array in Boxwood 55-1-12 Unit 5PH
- 14 - Level Horizontal-Array & 15 - Level Horizontal-Array in Boxwood 55-1-12 Unit 3H
- 14 - Level Horizontal-Array & 15 - Level Vertical-Array in Thresher 55-1-12 Unit A 16H

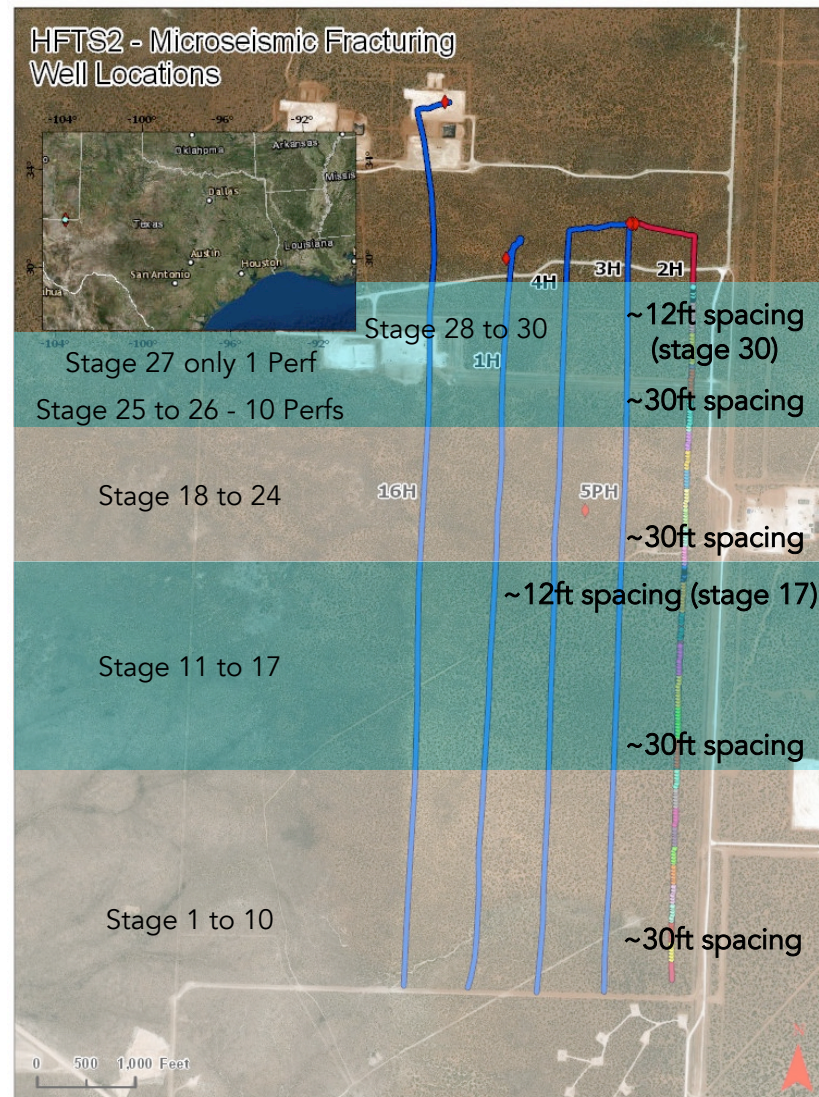
Location Map and Microseismic Job Info

Boxwood 1H



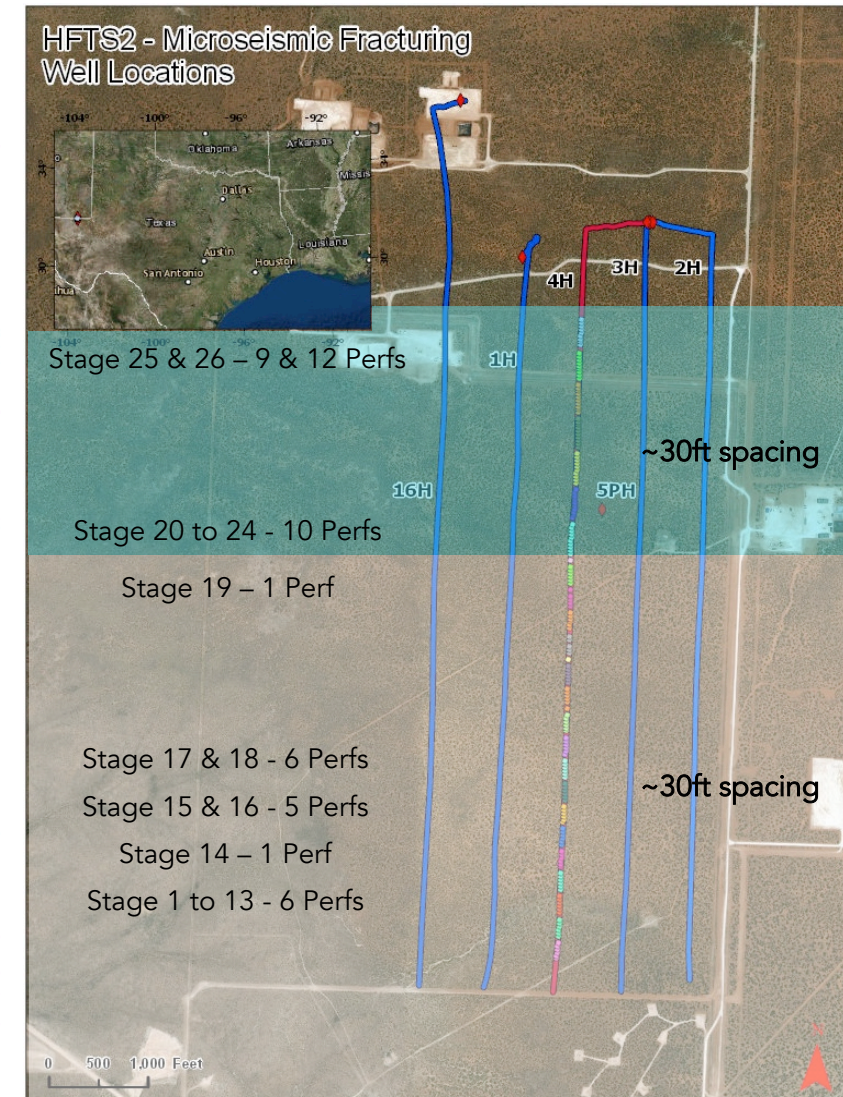
9, 10 & 12 Perforations shots

Boxwood 2H

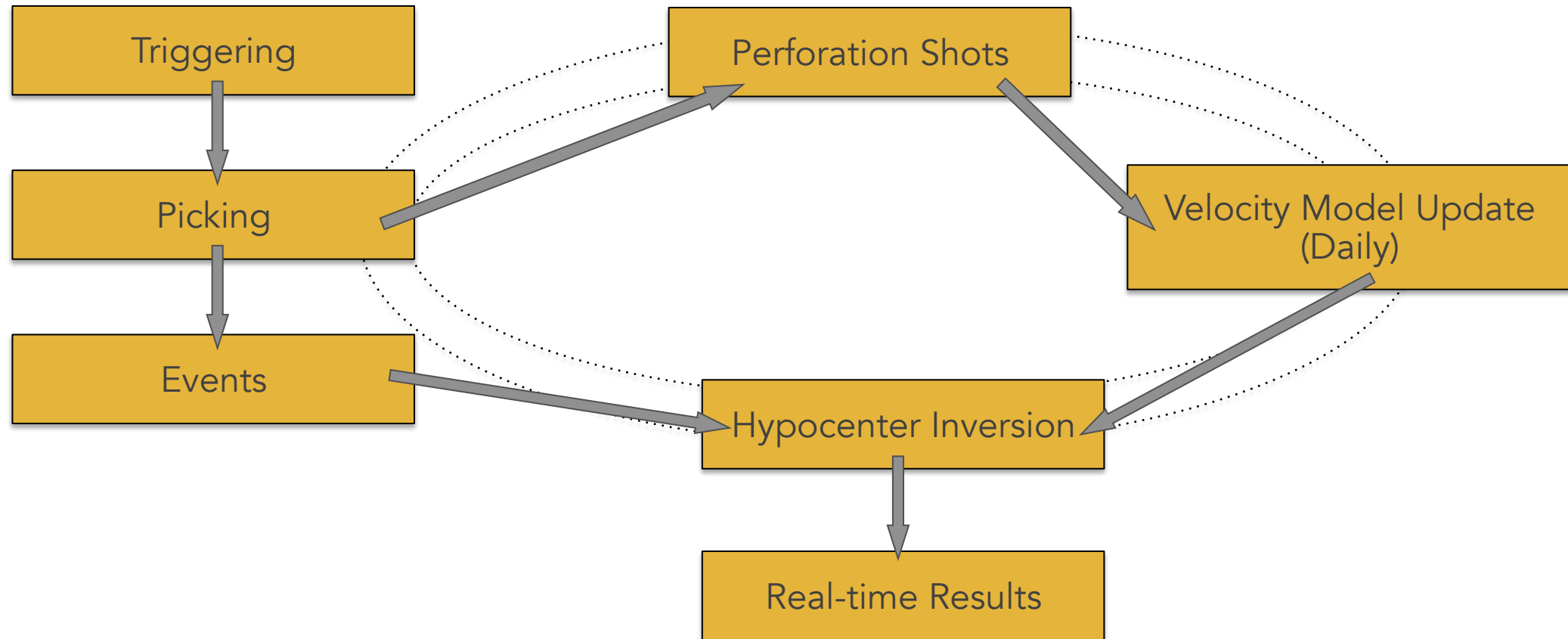


5 & 6 Perforations shots

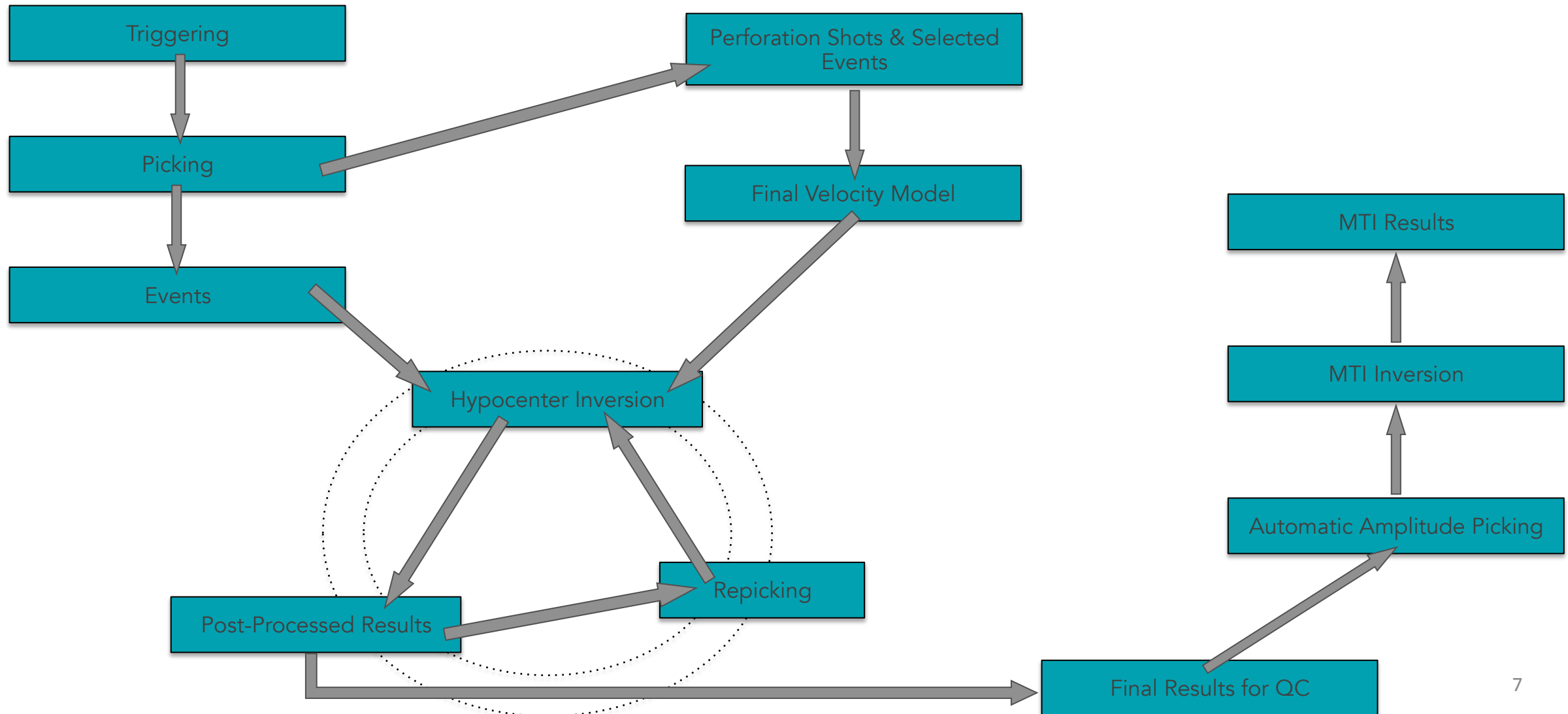
Boxwood 4H



Real-Time Processing



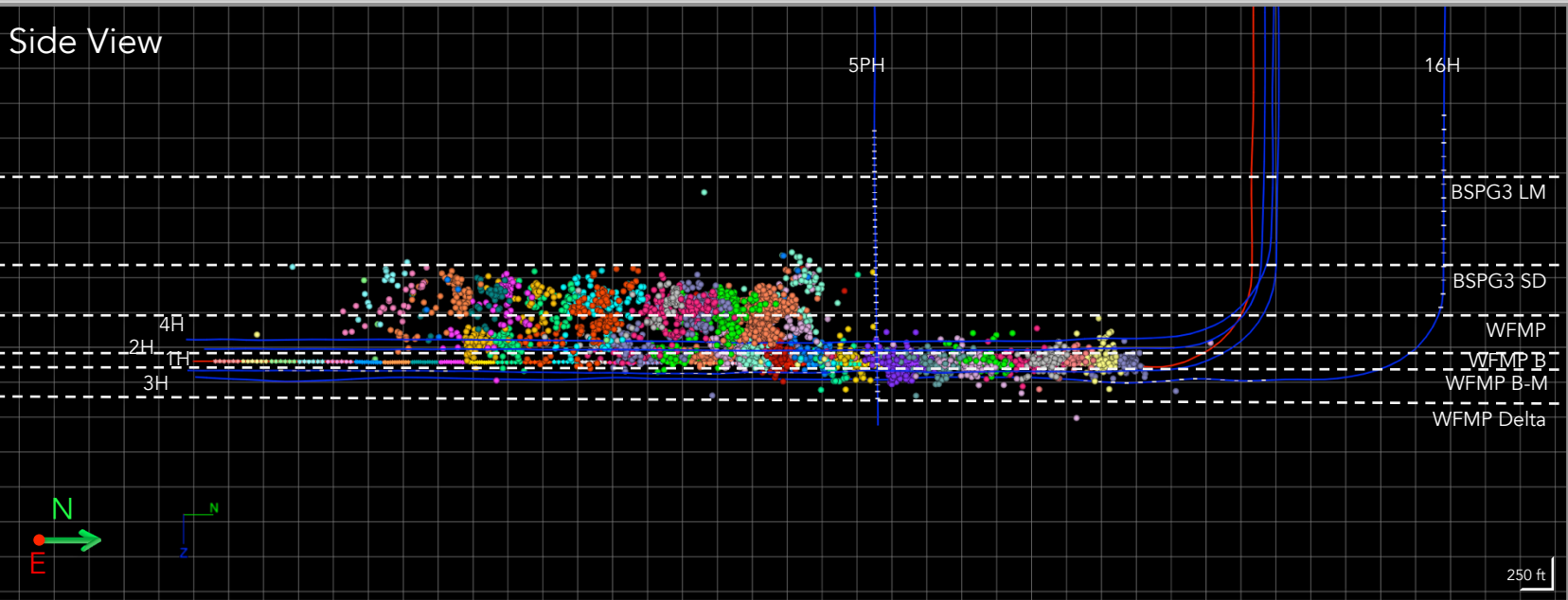
Post-Processing



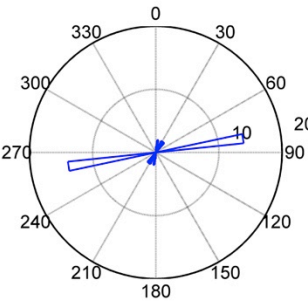
Event Location HFTS2 Project – Boxwood 1H – Colored by Stage

Post-Processing – Multi-well + 2.5ms Misfit cut-off

Side View

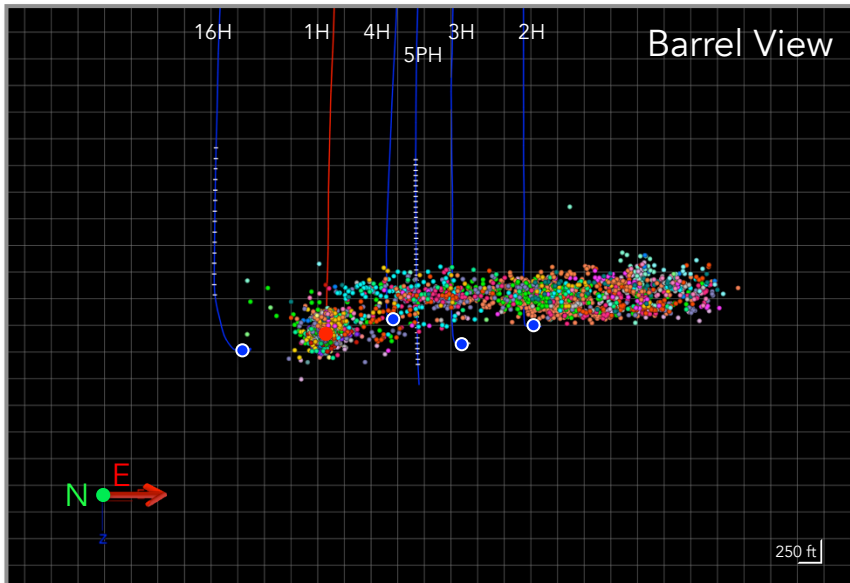


Rose Diagram: Cloud Azimuth
Boxwood 1H
Weighted Mean Value: 67.4289 (deg) of 24 Stages

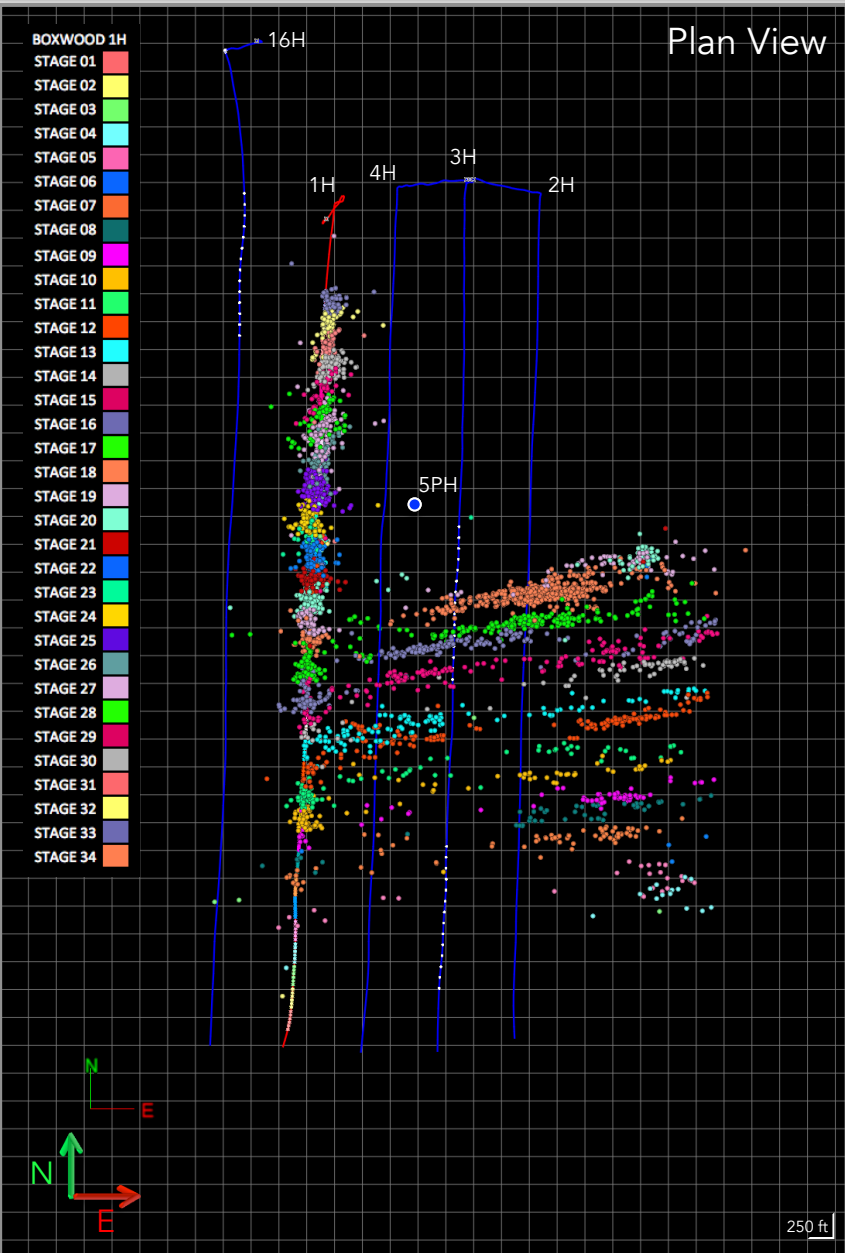


Total Events
3,326

Barrel View

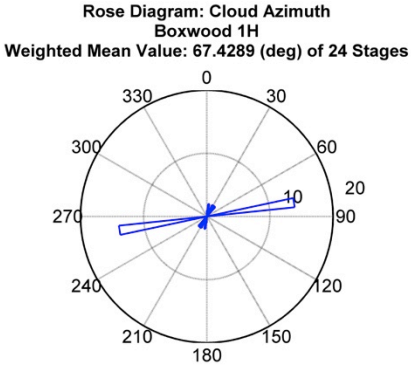
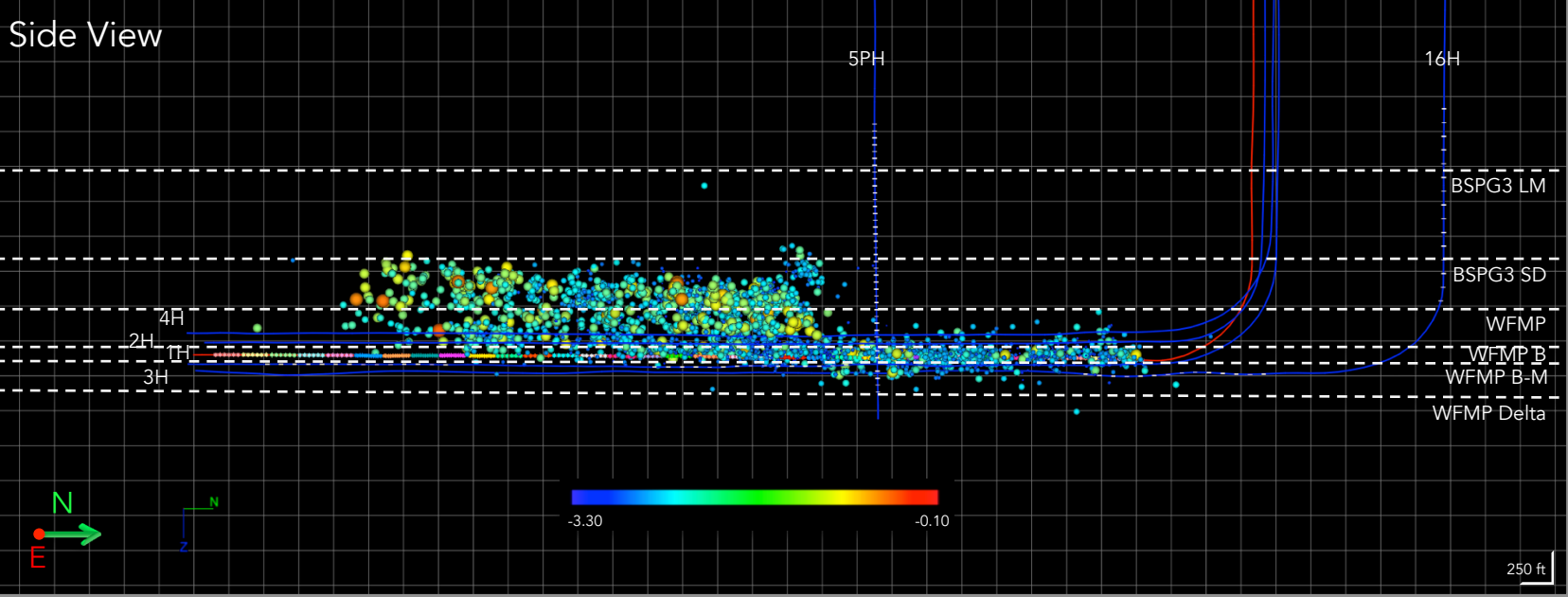


Plan View

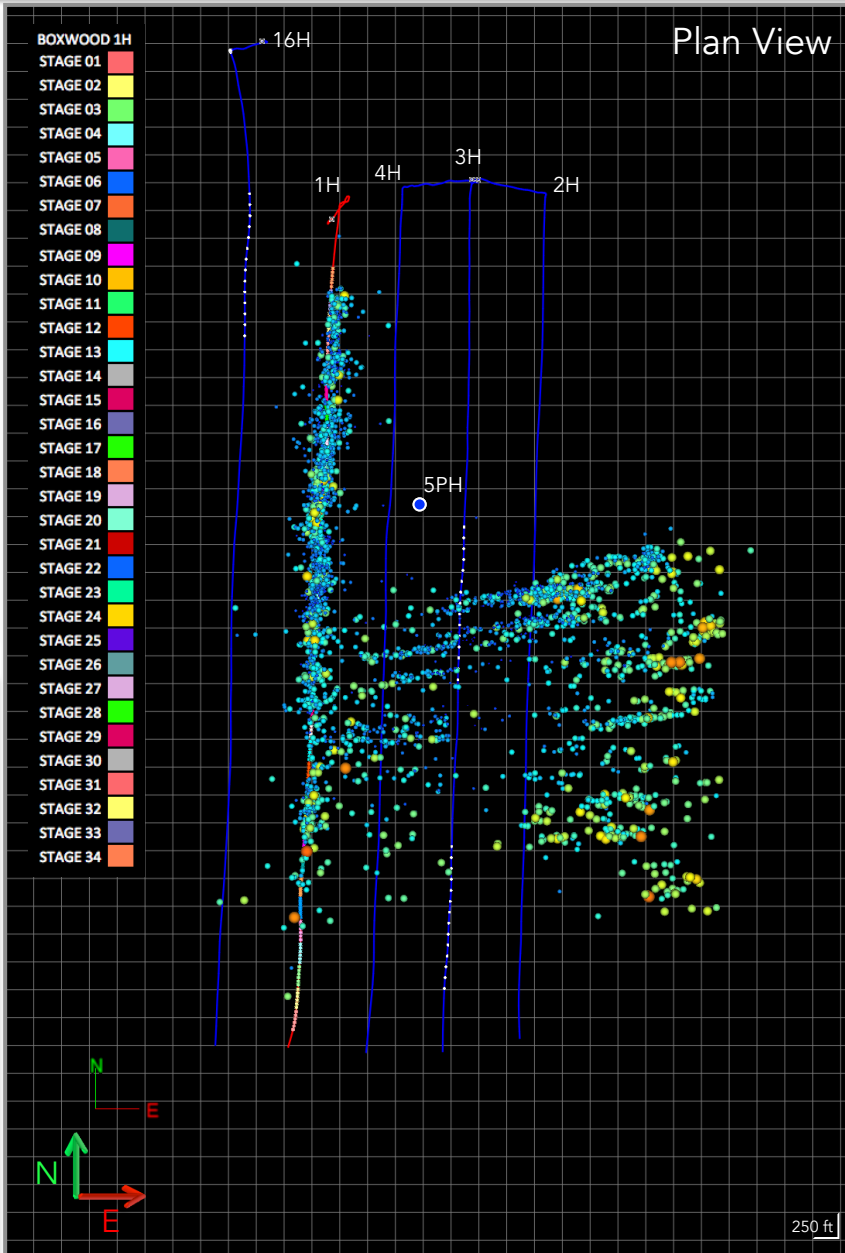
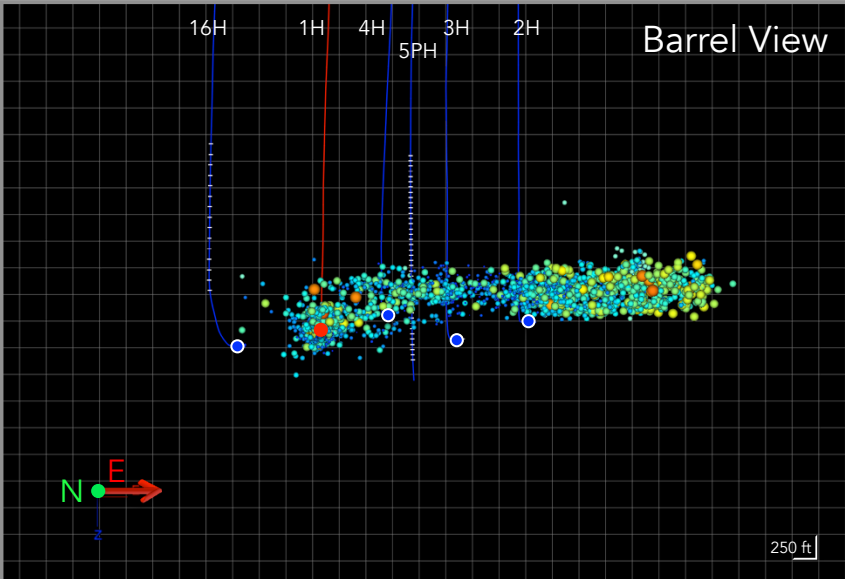


Event Location HFTS2 Project – Boxwood 1H – Colored and Sized by Magnitude

Post-Processing – Multi-well + 2.5ms Misfit cut-off



Total Events
3,326

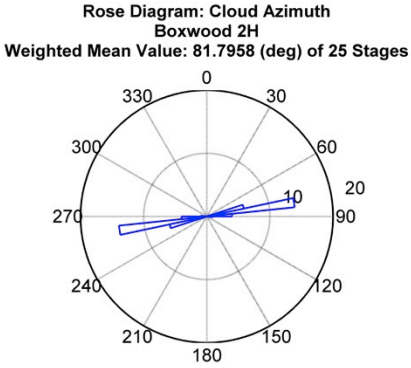
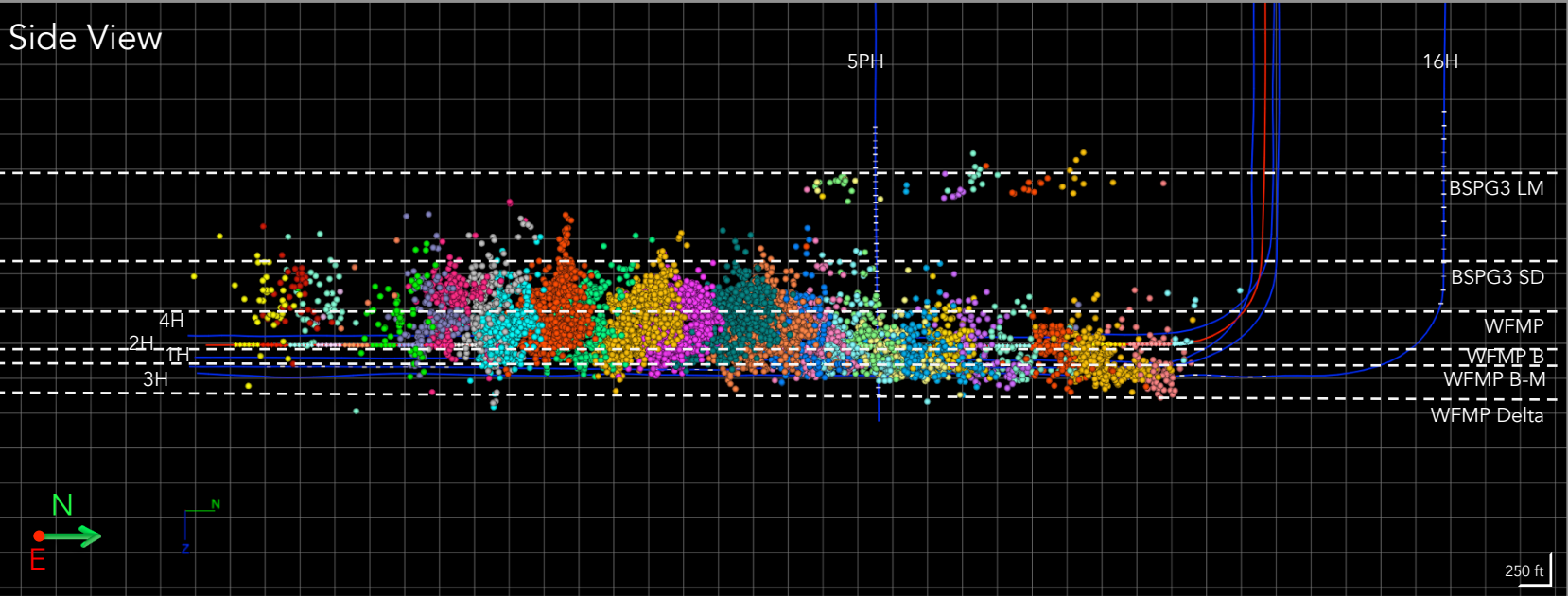


- BOXWOOD 1H
- STAGE 01
 - STAGE 02
 - STAGE 03
 - STAGE 04
 - STAGE 05
 - STAGE 06
 - STAGE 07
 - STAGE 08
 - STAGE 09
 - STAGE 10
 - STAGE 11
 - STAGE 12
 - STAGE 13
 - STAGE 14
 - STAGE 15
 - STAGE 16
 - STAGE 17
 - STAGE 18
 - STAGE 19
 - STAGE 20
 - STAGE 21
 - STAGE 22
 - STAGE 23
 - STAGE 24
 - STAGE 25
 - STAGE 26
 - STAGE 27
 - STAGE 28
 - STAGE 29
 - STAGE 30
 - STAGE 31
 - STAGE 32
 - STAGE 33
 - STAGE 34

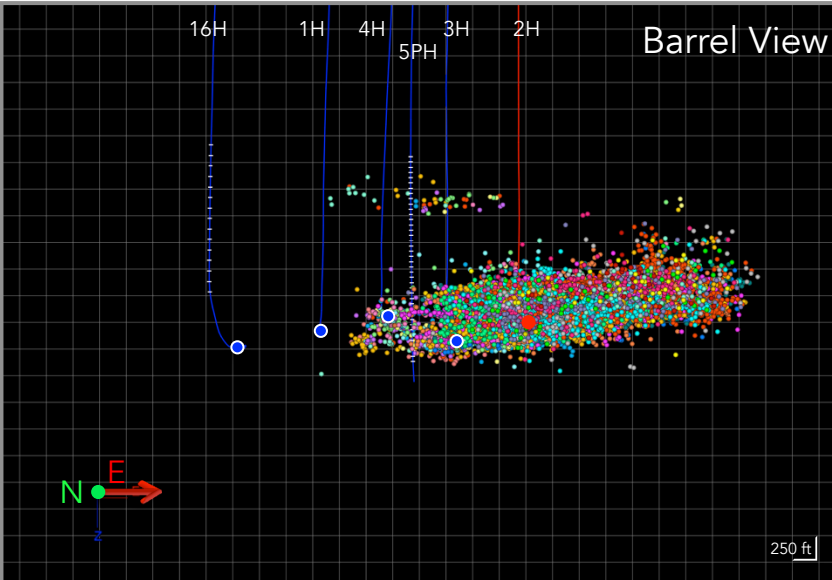
Event Location HFTS2 Project – Boxwood 2H – Colored by Stage

Post-Processing – Multi-well + 2.5ms Misfit cut-off

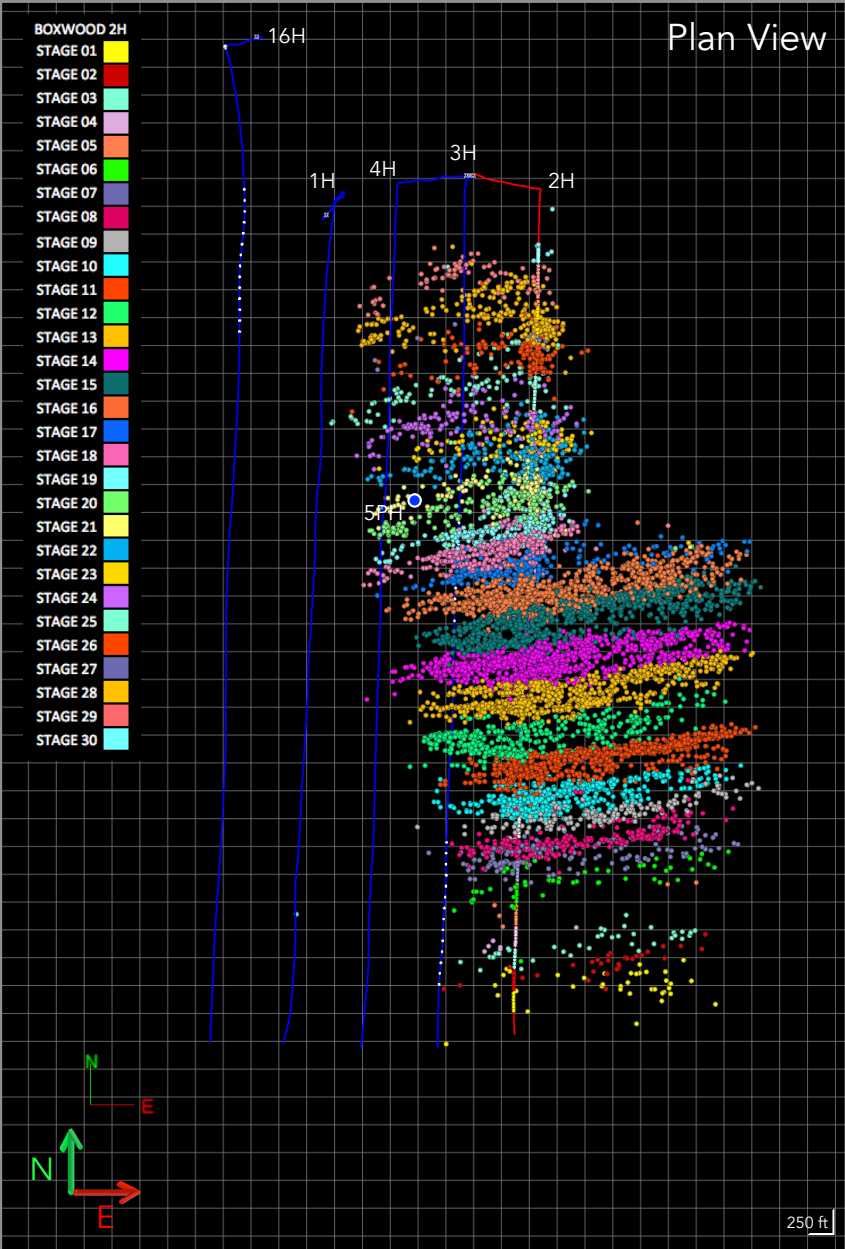
Side View



Total Events
8,700



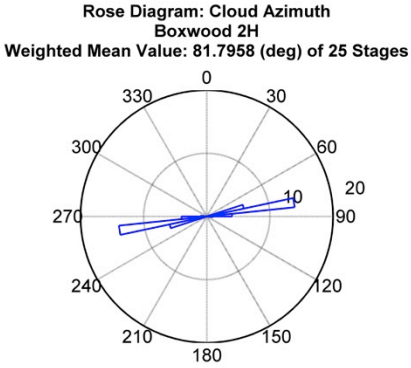
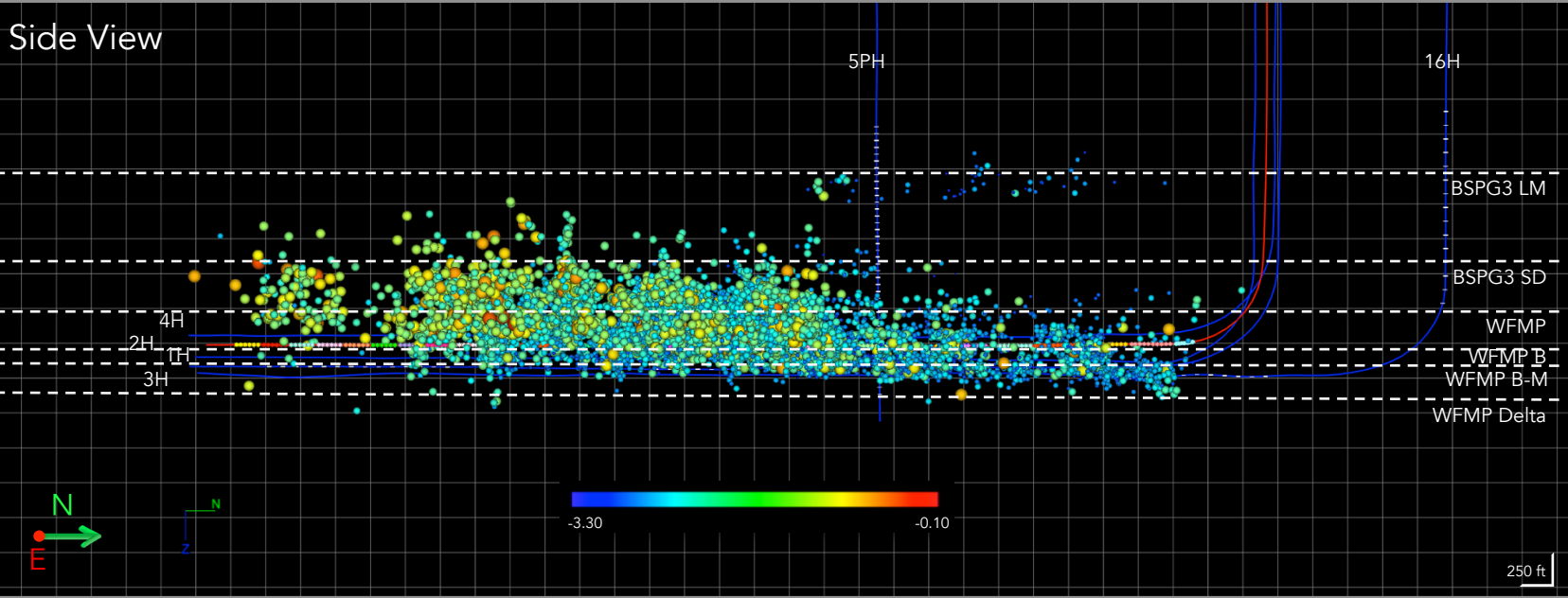
Plan View



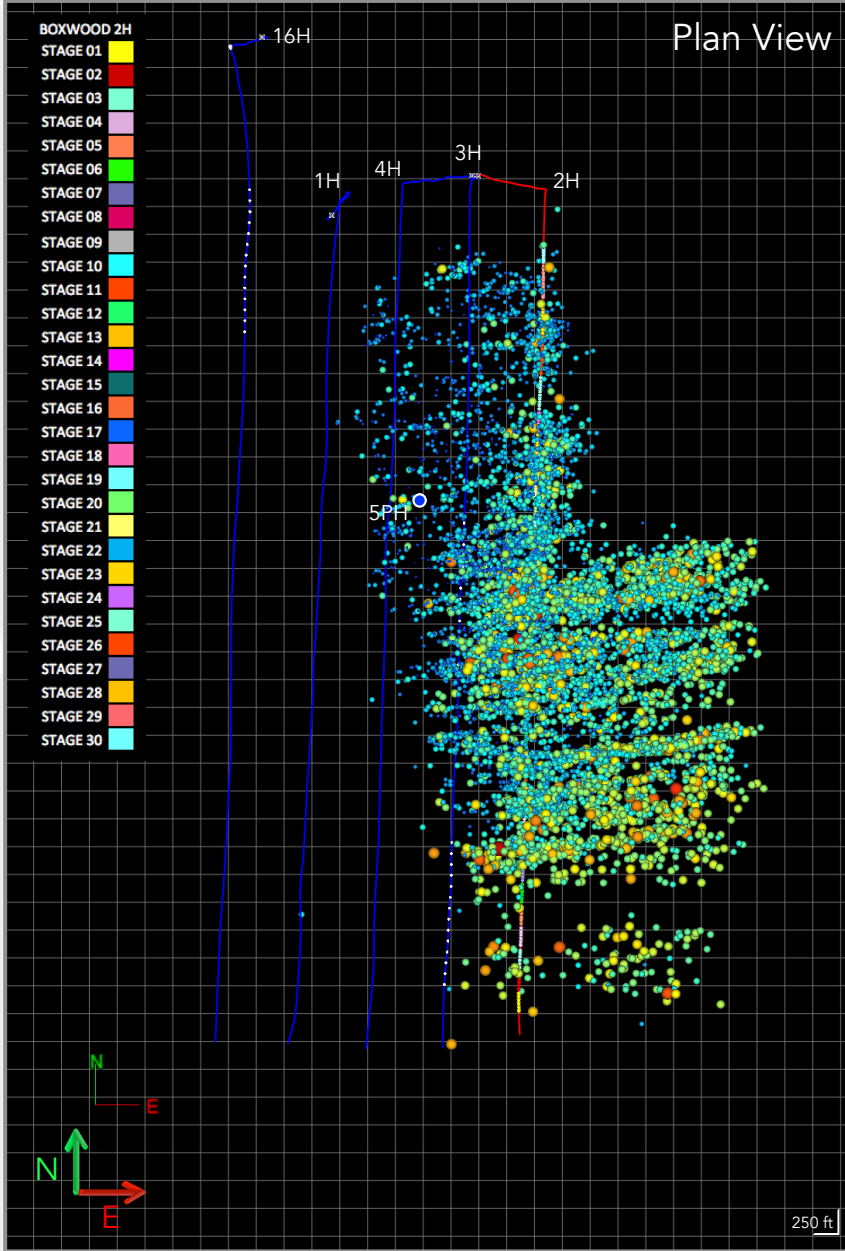
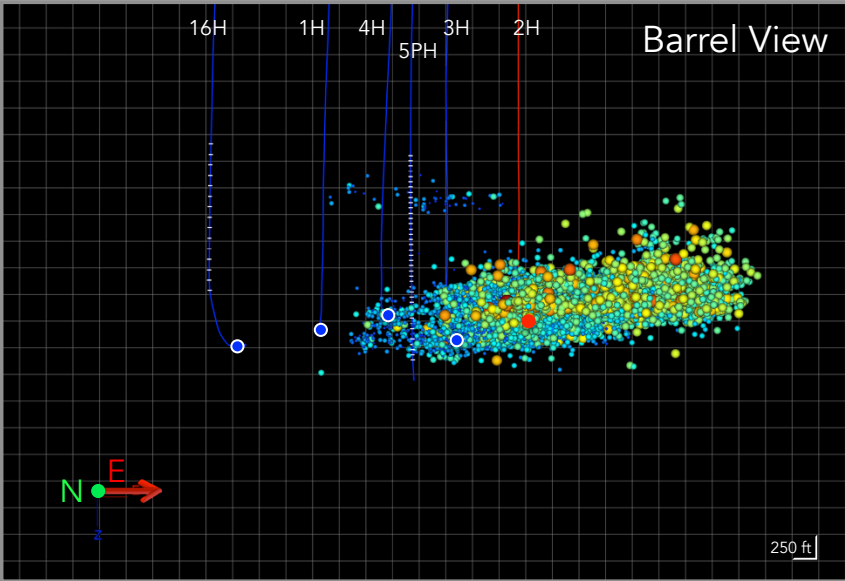
- BOXWOOD 2H
- STAGE 01
 - STAGE 02
 - STAGE 03
 - STAGE 04
 - STAGE 05
 - STAGE 06
 - STAGE 07
 - STAGE 08
 - STAGE 09
 - STAGE 10
 - STAGE 11
 - STAGE 12
 - STAGE 13
 - STAGE 14
 - STAGE 15
 - STAGE 16
 - STAGE 17
 - STAGE 18
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 - STAGE 22
 - STAGE 23
 - STAGE 24
 - STAGE 25
 - STAGE 26
 - STAGE 27
 - STAGE 28
 - STAGE 29
 - STAGE 30

Event Location HFTS2 Project – Boxwood 2H – Colored and Sized by Magnitude

Post-Processing – Multi-well + 2.5ms Misfit cut-off



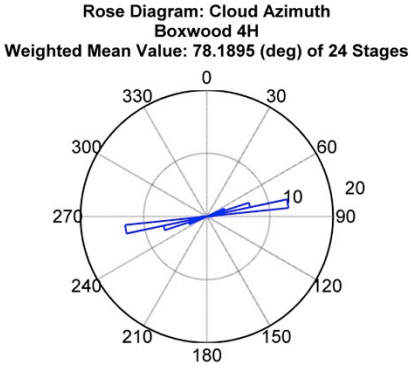
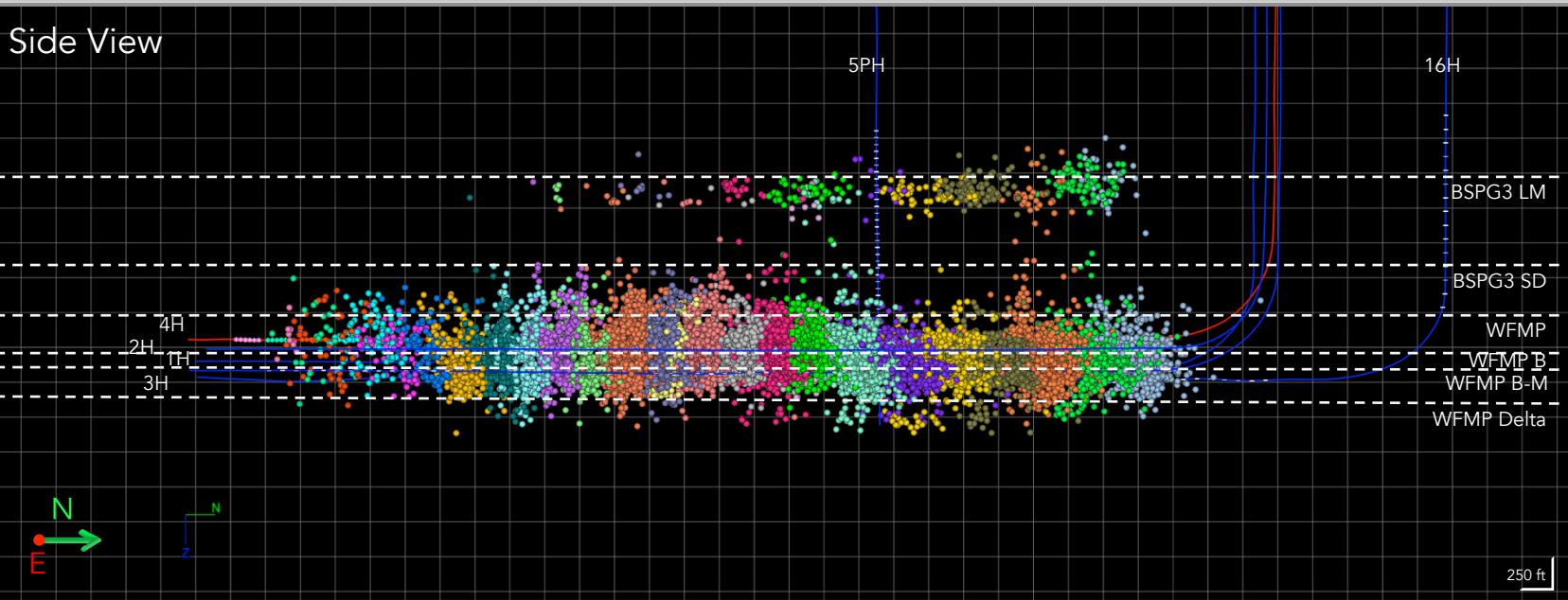
Total Events
8,700



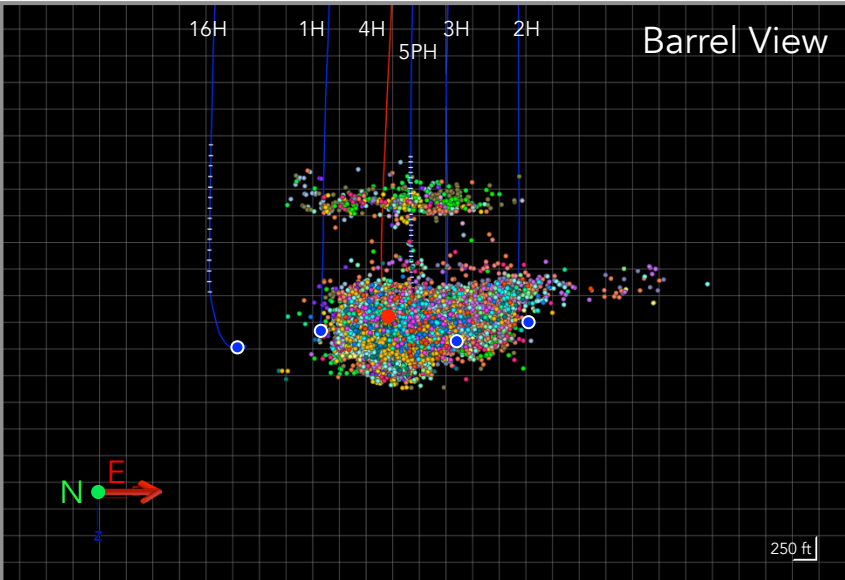
Event Location HFTS2 Project – Boxwood 4H – Colored by Stage

Post-Processing – Multi-well only + 2.5ms Misfit cut-off

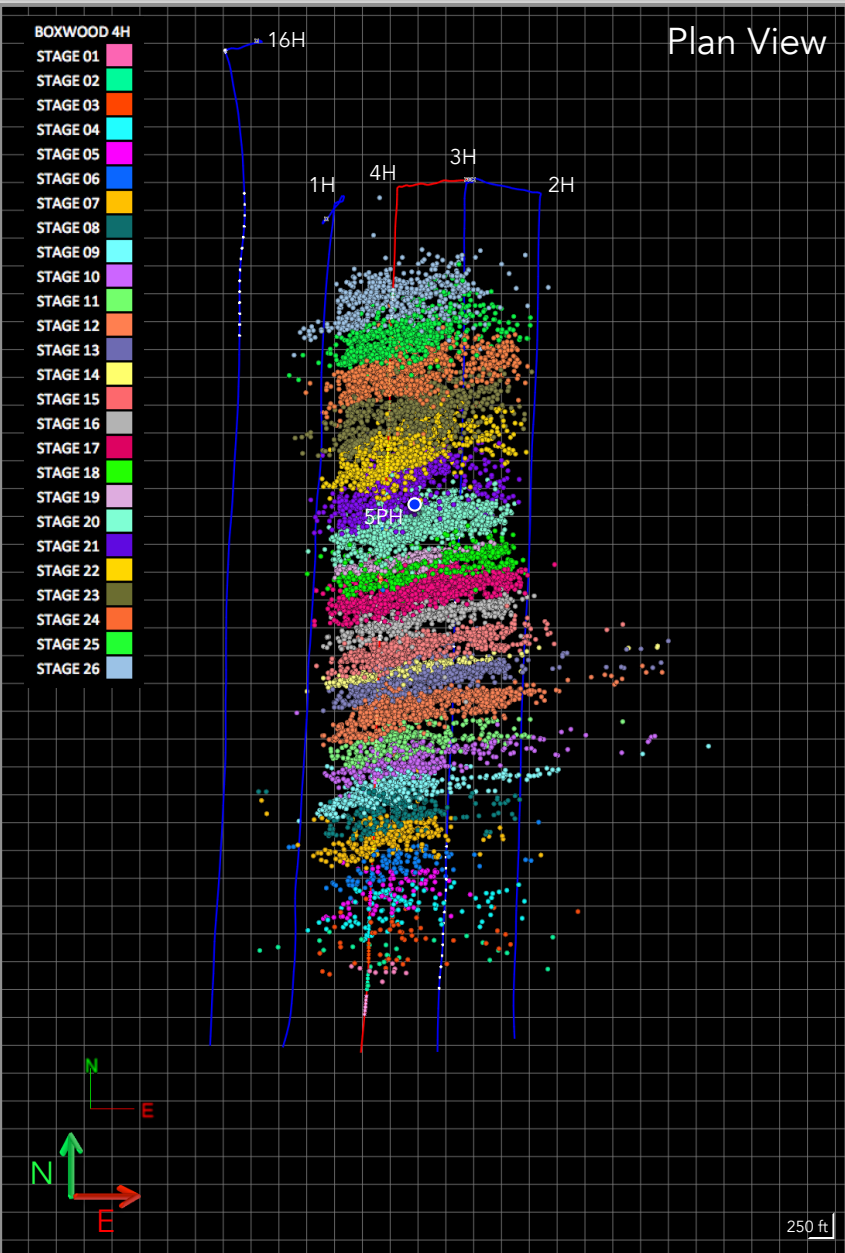
Side View



Total Events
15,226



Plan View

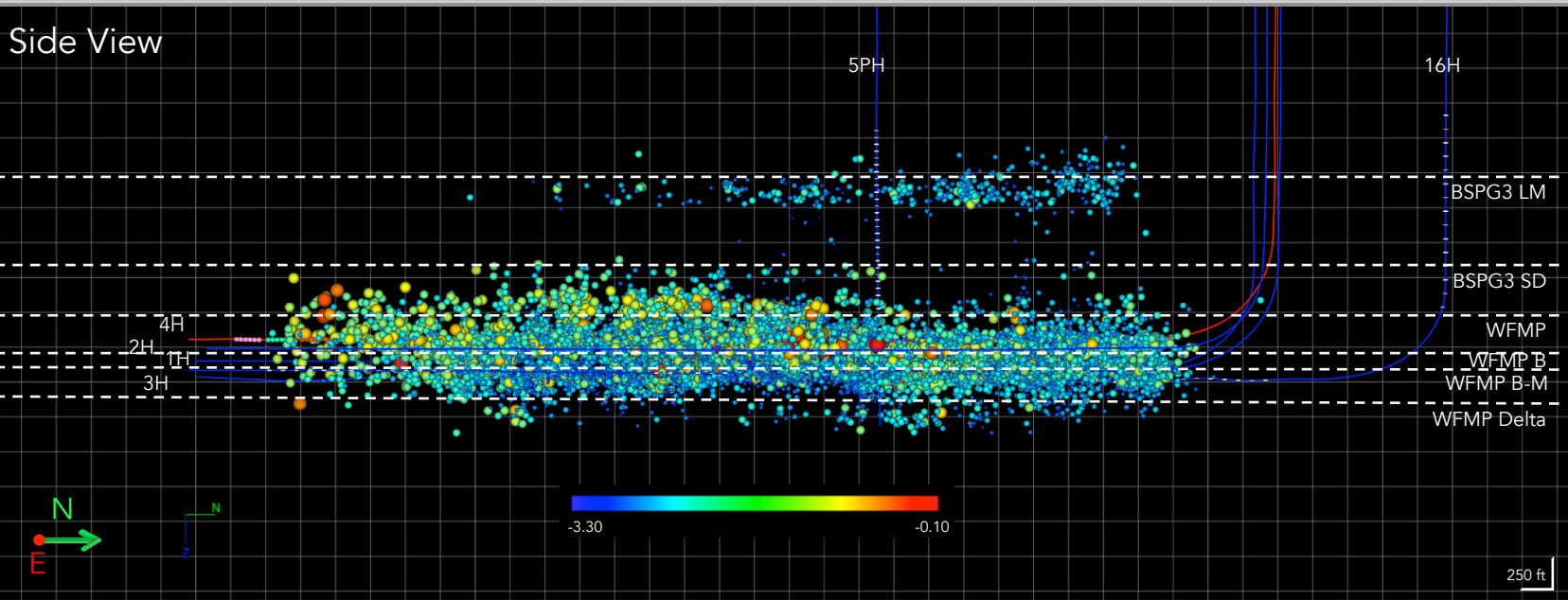


- BOXWOOD 4H
- STAGE 01
 - STAGE 02
 - STAGE 03
 - STAGE 04
 - STAGE 05
 - STAGE 06
 - STAGE 07
 - STAGE 08
 - STAGE 09
 - STAGE 10
 - STAGE 11
 - STAGE 12
 - STAGE 13
 - STAGE 14
 - STAGE 15
 - STAGE 16
 - STAGE 17
 - STAGE 18
 - STAGE 19
 - STAGE 20
 - STAGE 21
 - STAGE 22
 - STAGE 23
 - STAGE 24
 - STAGE 25
 - STAGE 26

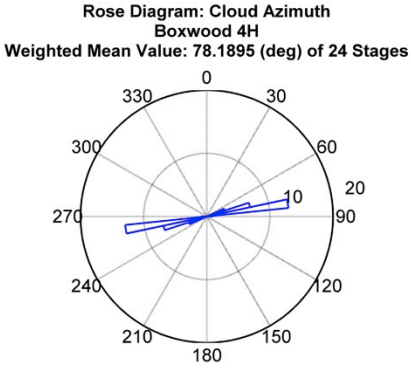
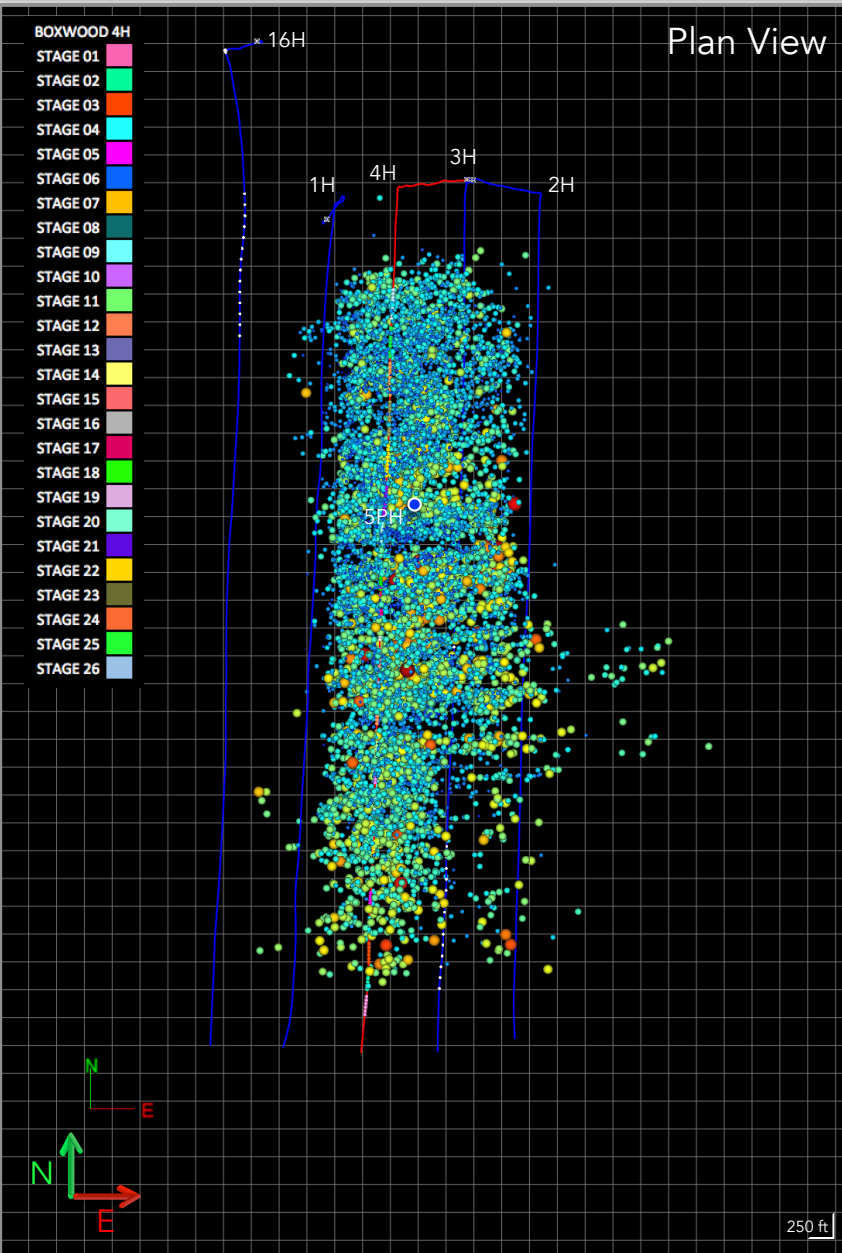
Event Location HFTS2 Project – Boxwood 4H – Colored by Stage

Post-Processing – Multi-well only + 2.5ms Misfit cut-off

Side View

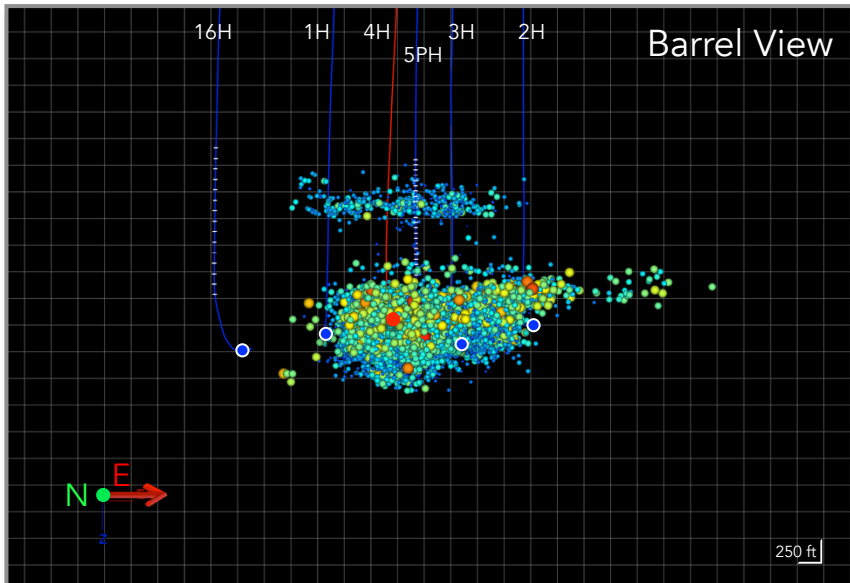


Plan View



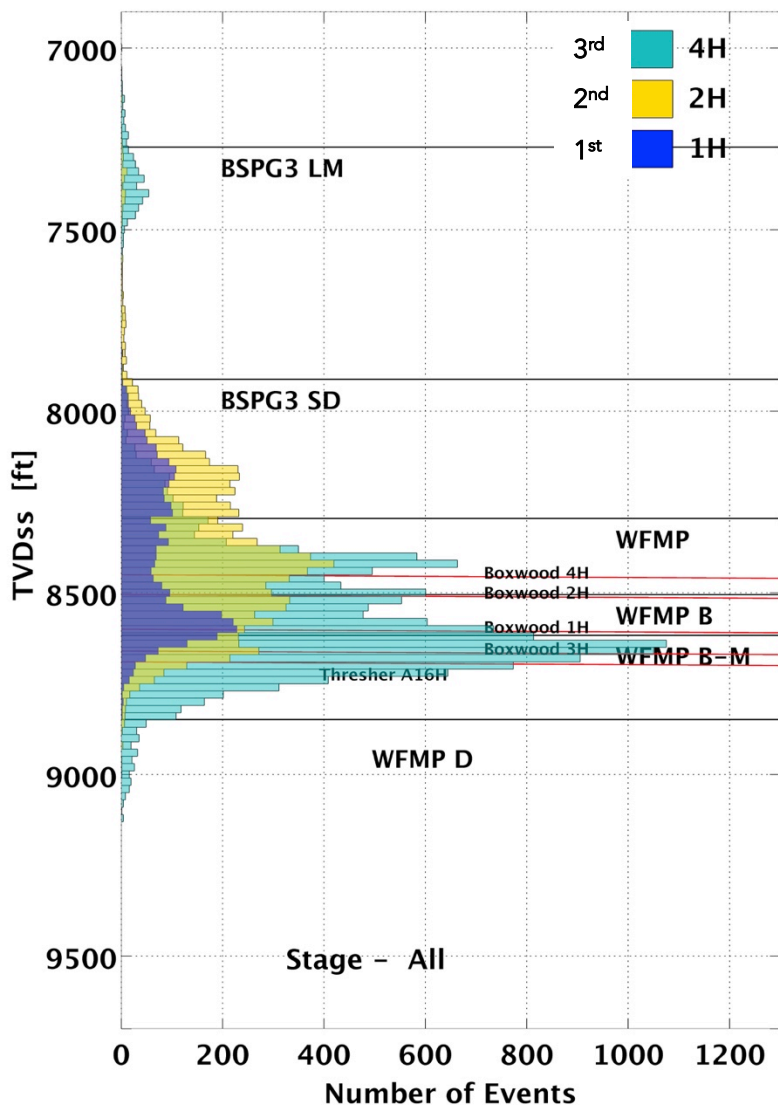
Total Events
15,226

Barrel View

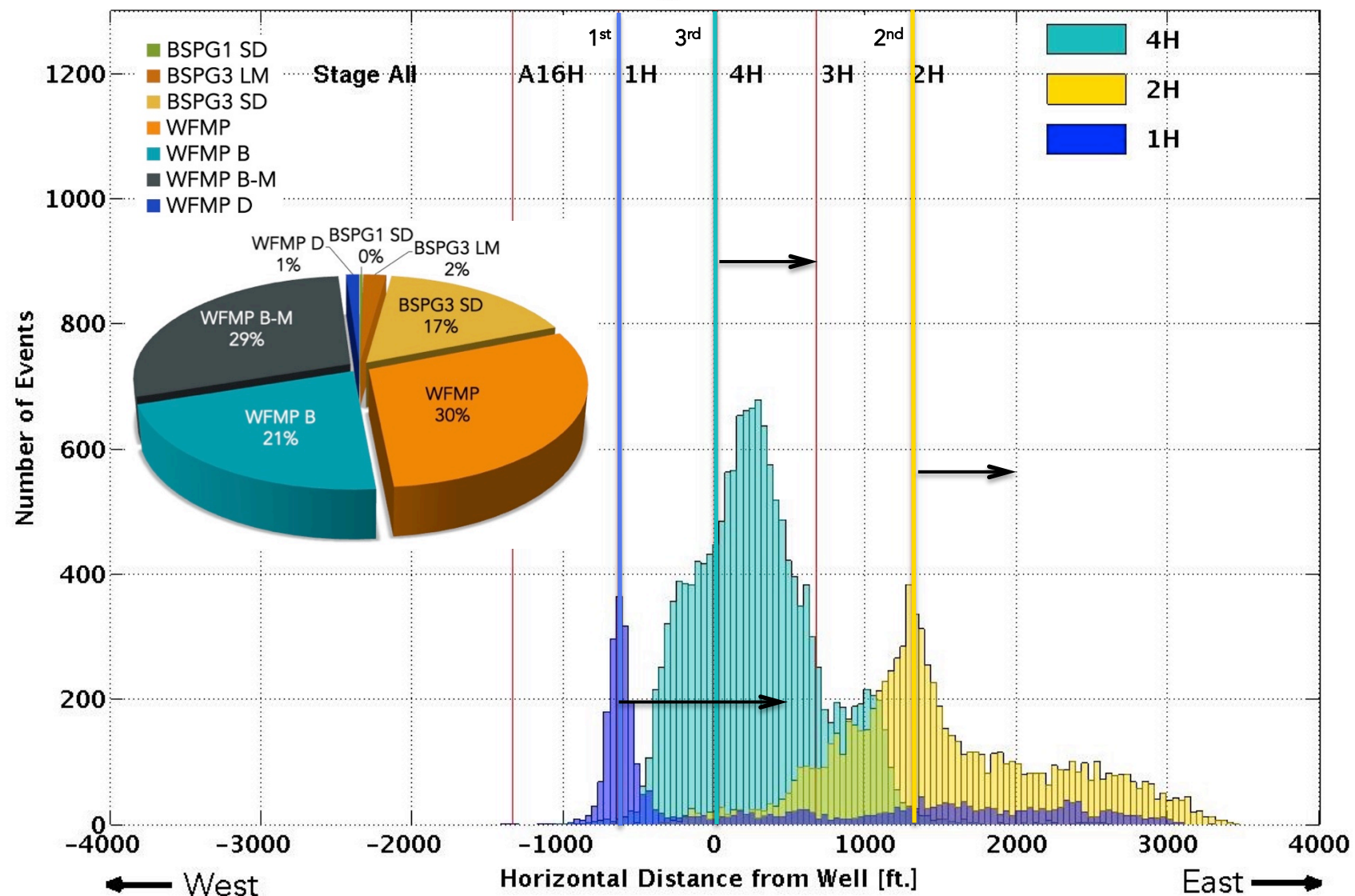


HFTS2 Project Results Overview

Anadarko - HFTS2 Well - All Wells

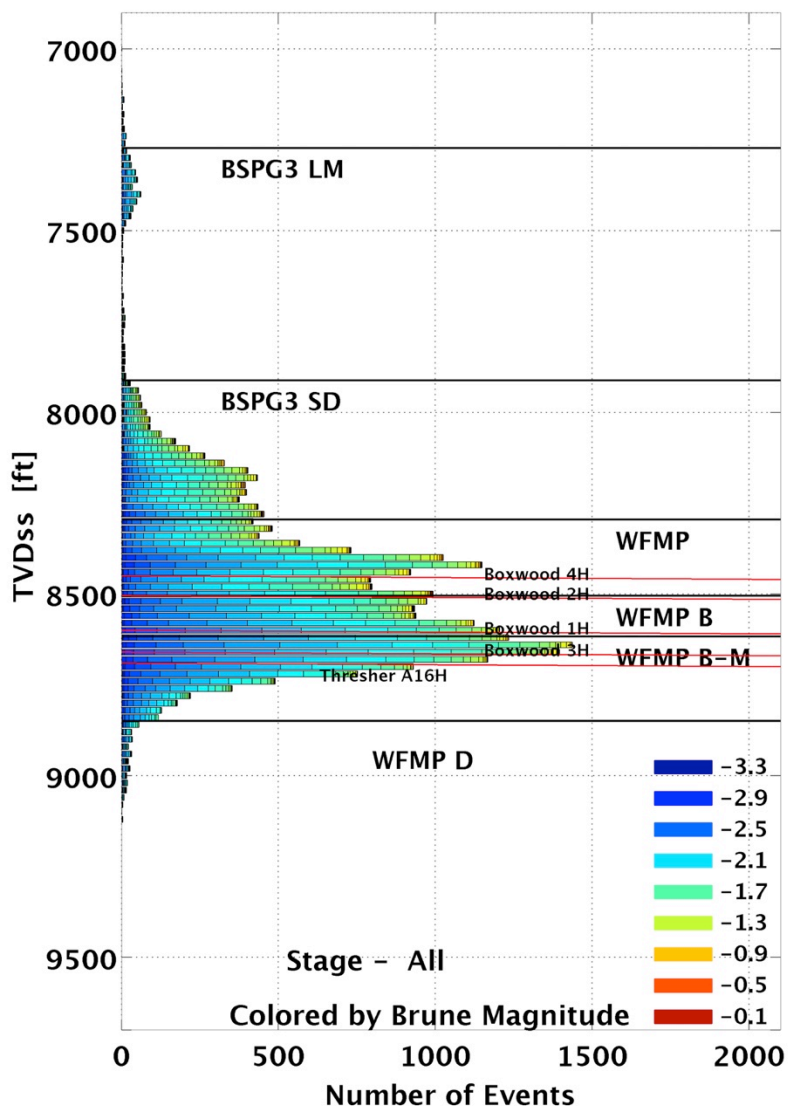


RT Histogram - All Wells

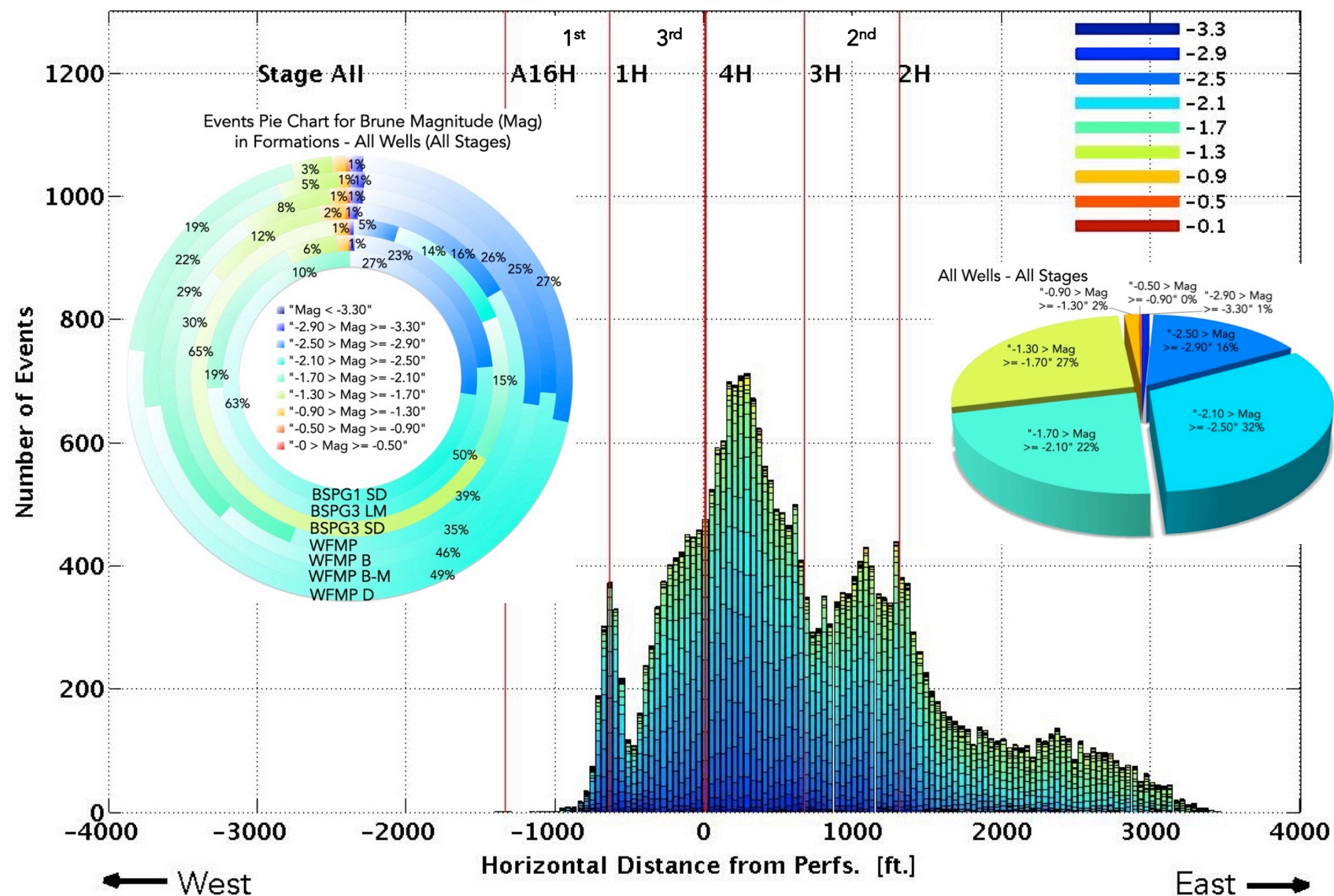


HFTS2 Project Results Overview

Anadarko - HFTS2 Well - All Wells



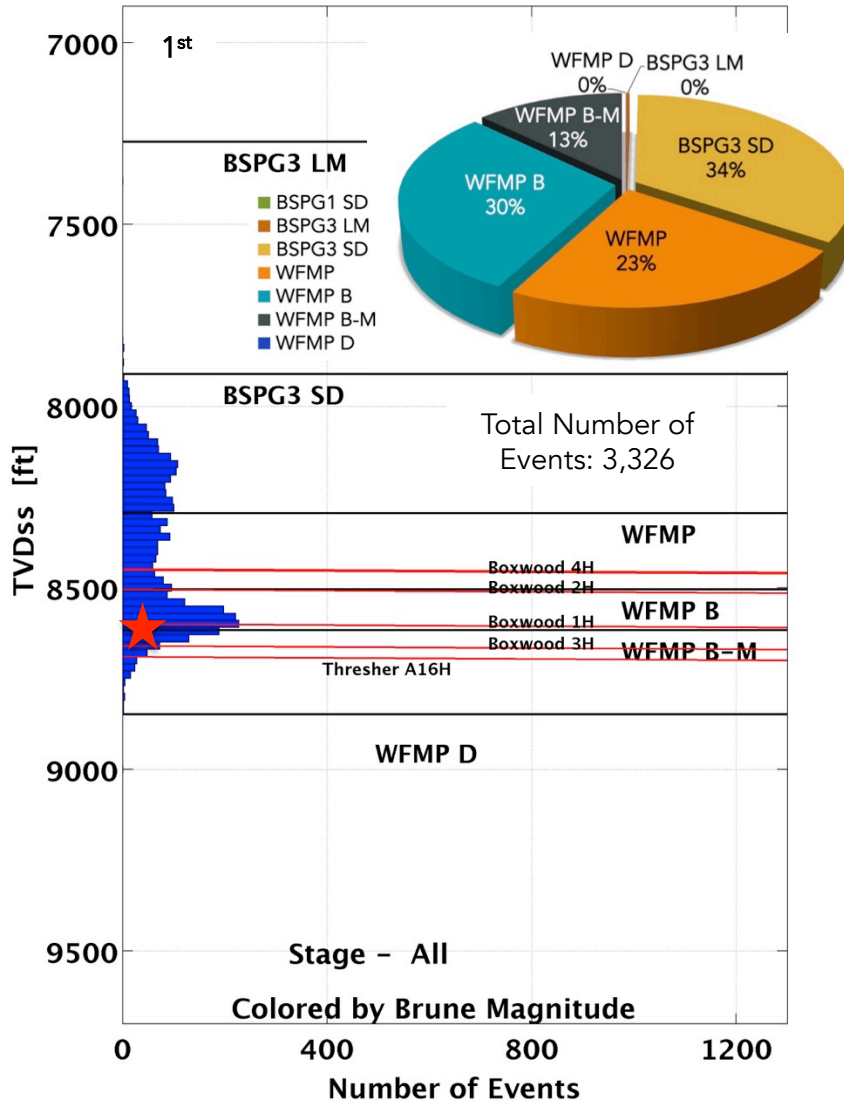
RT Histogram Colored by Magnitude - All Wells



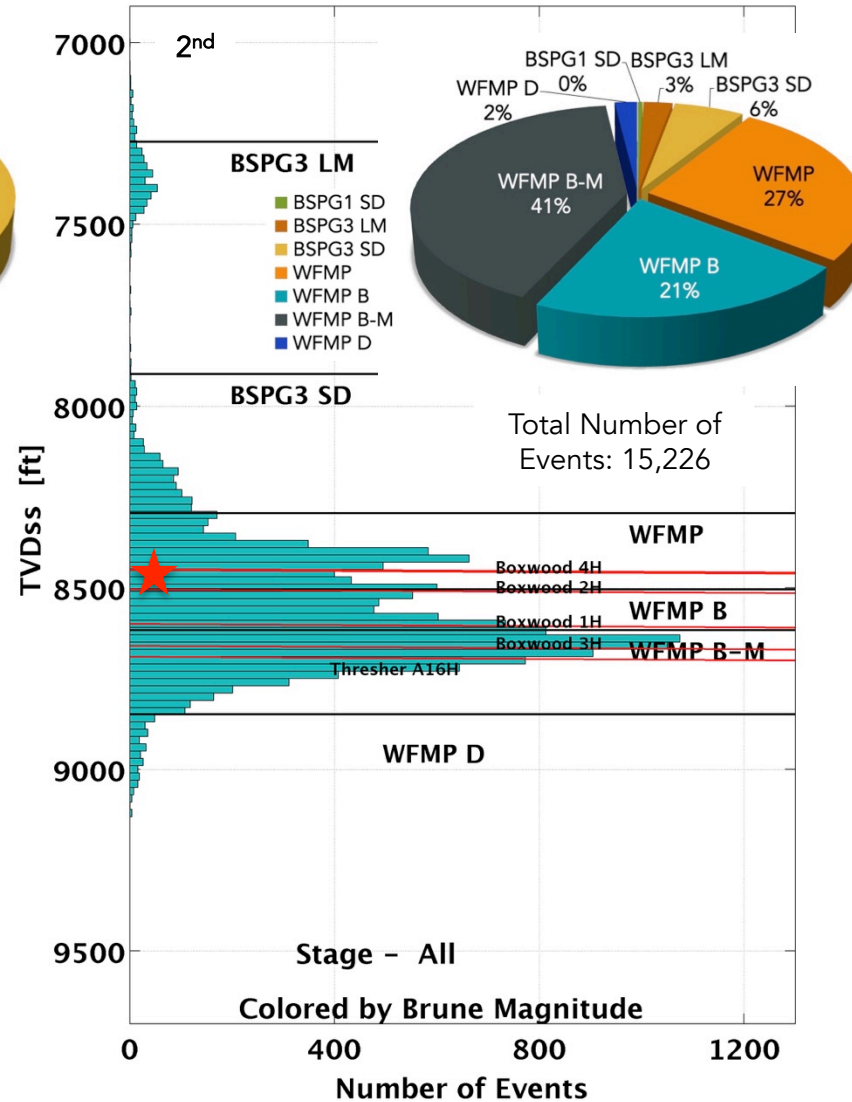
HFTS2 Events by Layer Analysis

Histograms and Pie-Charts

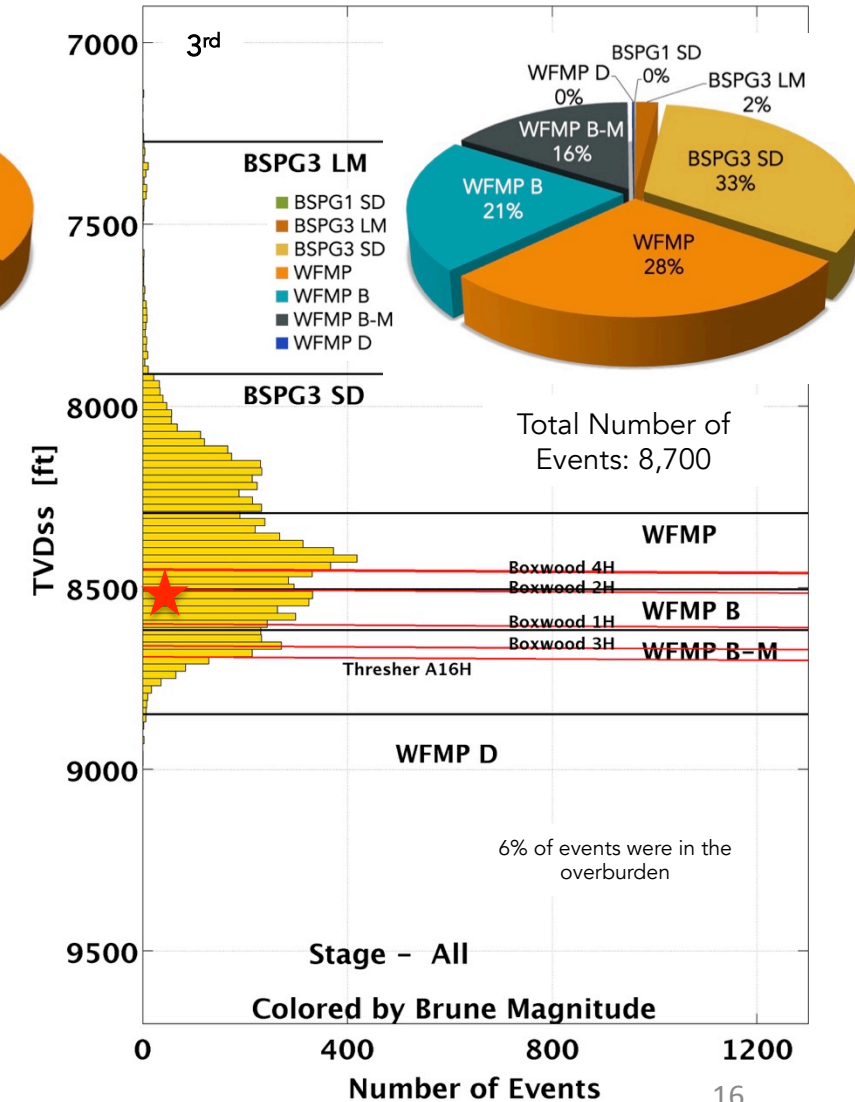
Anadarko – HFTS2 Well – Boxwood 1H



Anadarko – HFTS2 Well – Boxwood 4H

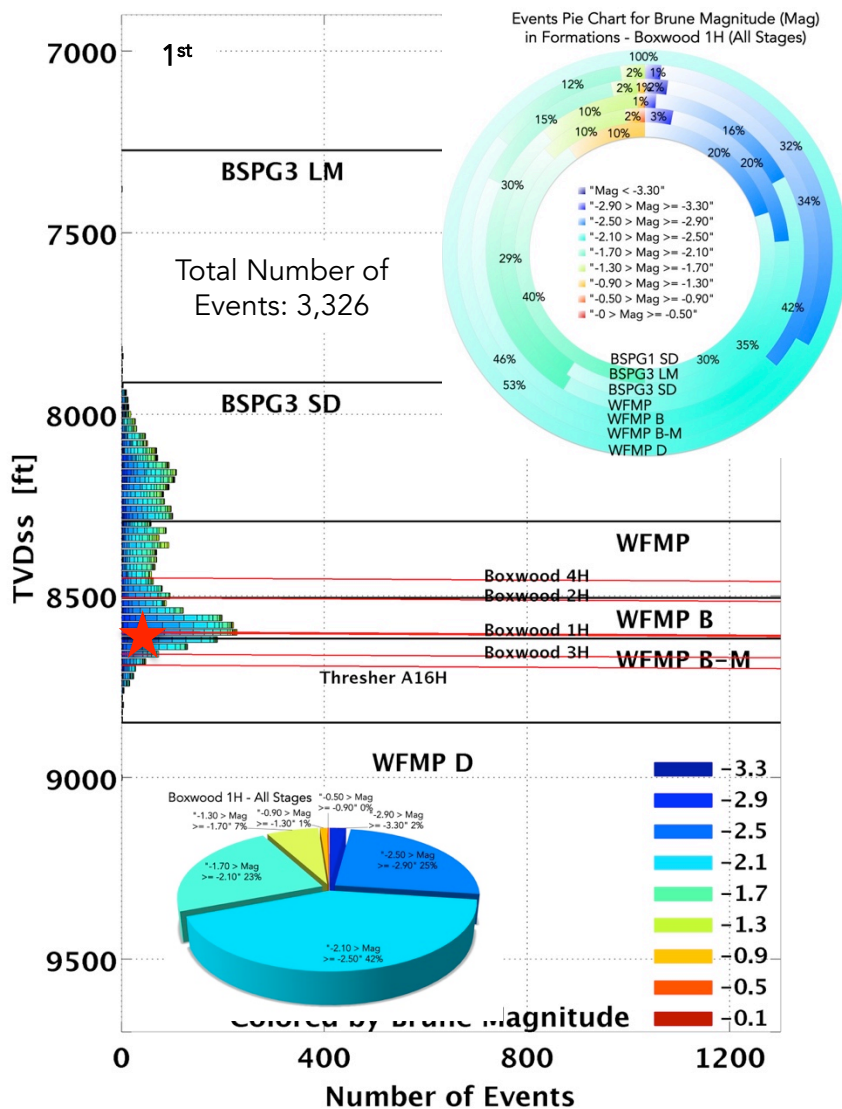


Anadarko – HFTS2 Well – Boxwood 2H

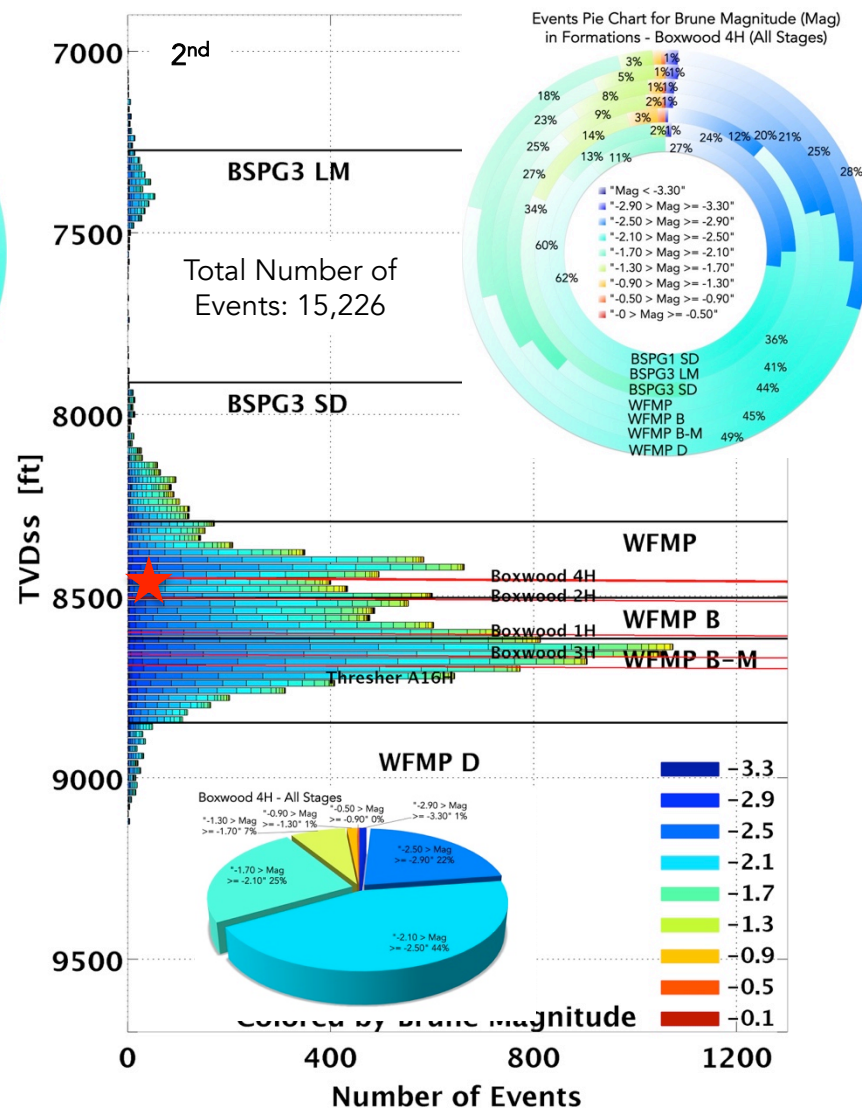


HFTS2 Events by Layer Analysis Magnitude Histograms and Pie-Charts

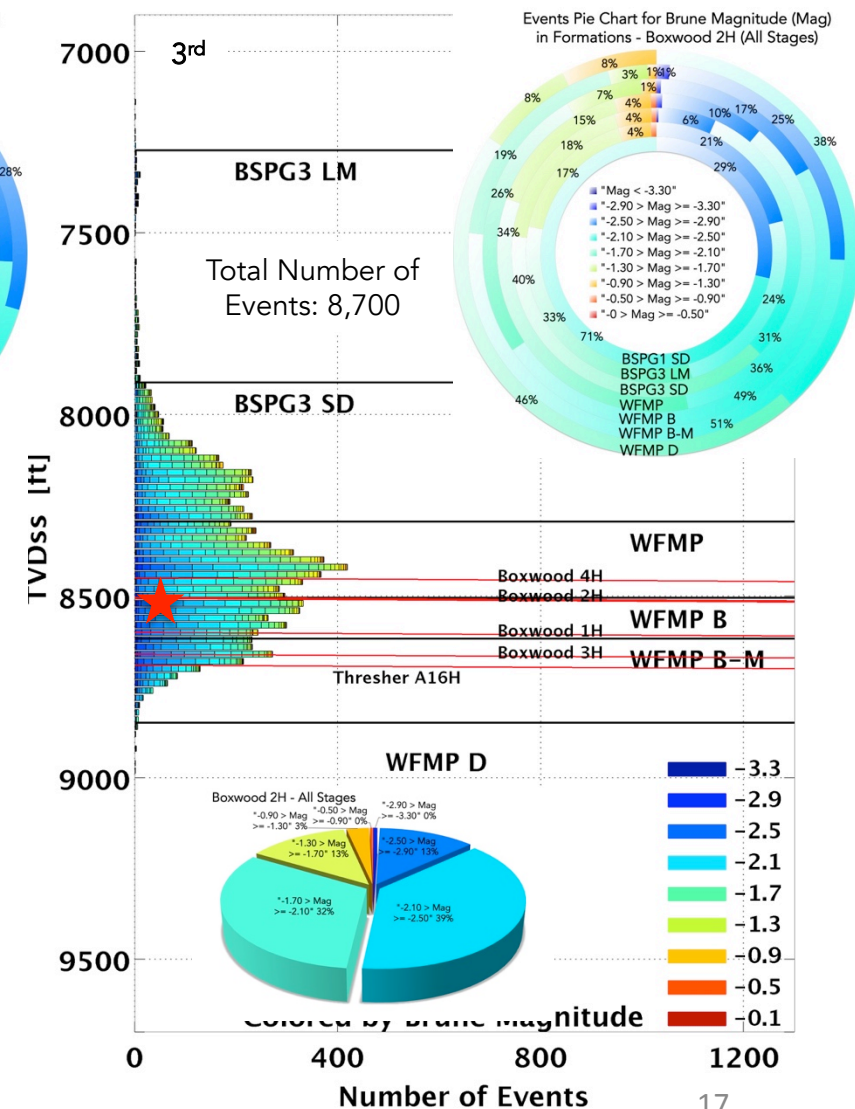
Anadarko - HFTS2 Well - Boxwood 1H



Anadarko - HFTS2 Well - Boxwood 4H

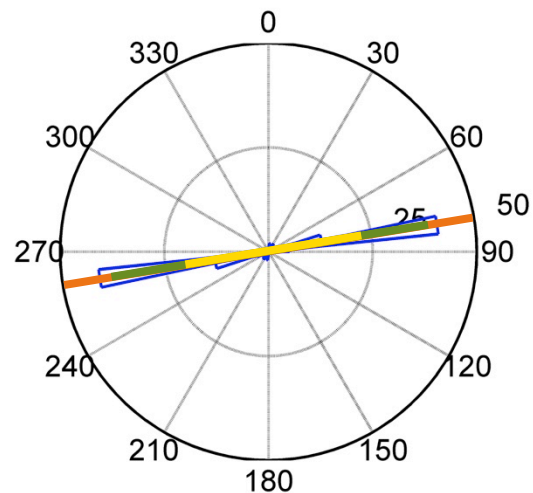


Anadarko - HFTS2 Well - Boxwood 2H

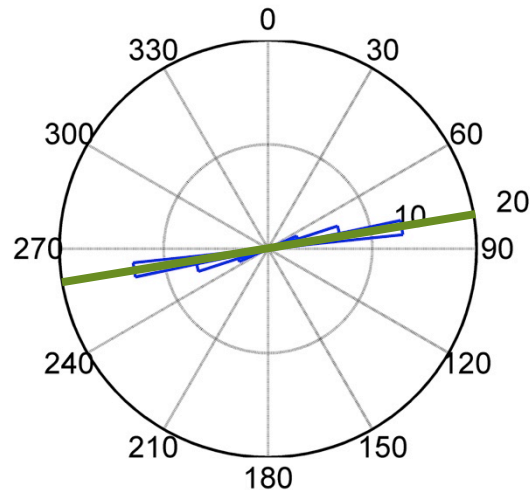


HFTS2 – Event Cloud Azimuth Rose Diagrams

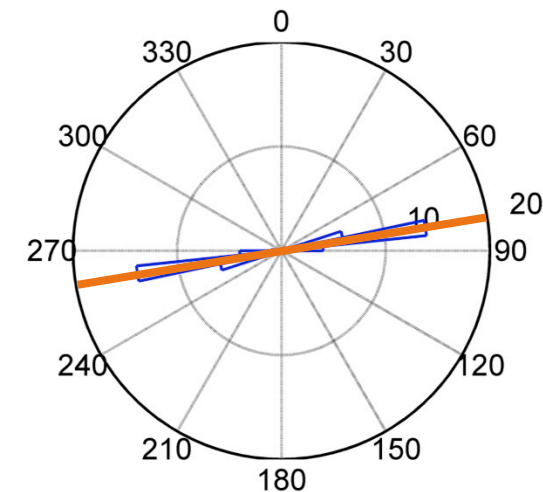
Rose Diagram: Cloud Azimuth
Boxwood 1H 2H 4H
Weighted Mean Value: 76.0469 (deg) of 73 Stages



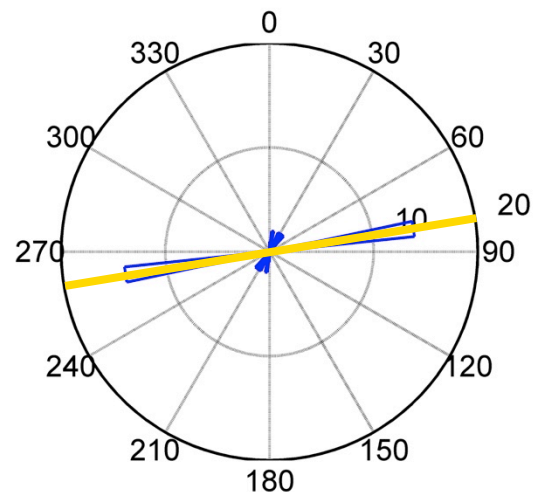
Rose Diagram: Cloud Azimuth
Boxwood 4H
Weighted Mean Value: 78.1895 (deg) of 24 Stages



Rose Diagram: Cloud Azimuth
Boxwood 2H
Weighted Mean Value: 81.7958 (deg) of 25 Stages

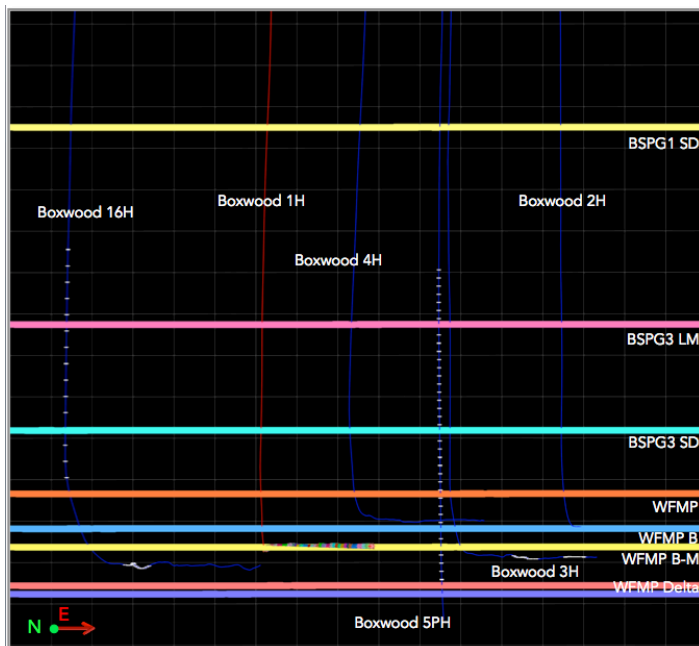


Rose Diagram: Cloud Azimuth
Boxwood 1H
Weighted Mean Value: 67.4289 (deg) of 24 Stages



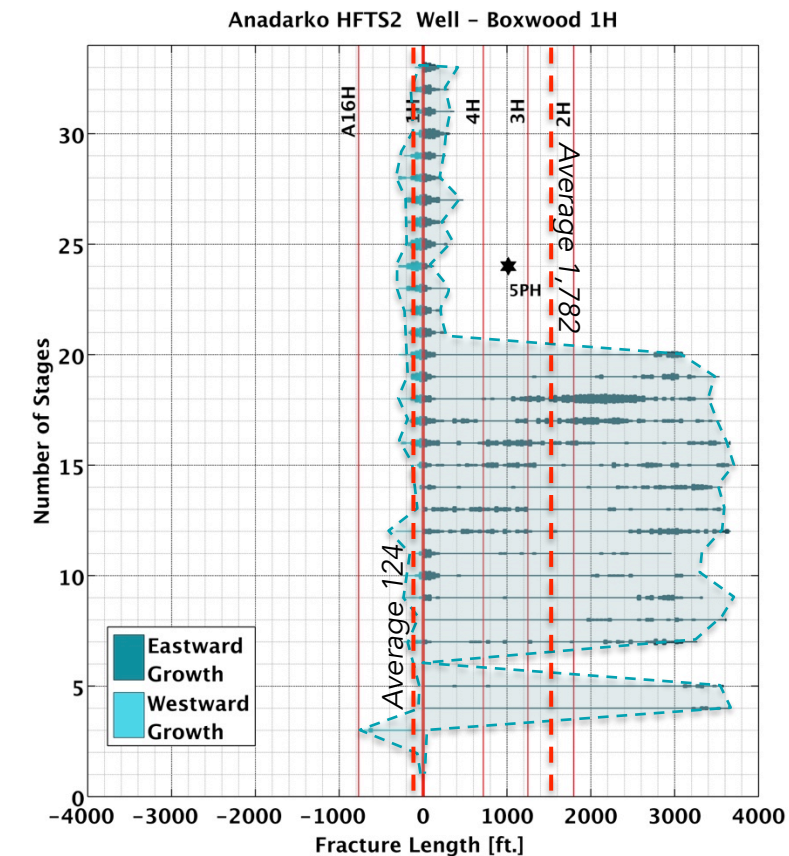
--- Approximate Direction
Perpendicular to the well

--- Approximate Direction of
the Well

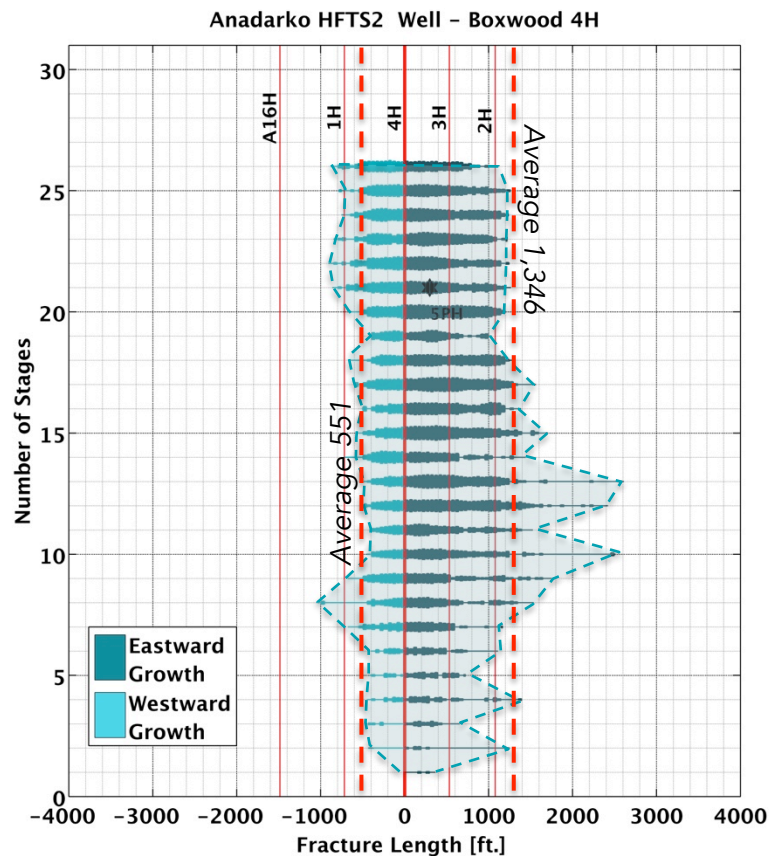


Fracture Statistics – Length

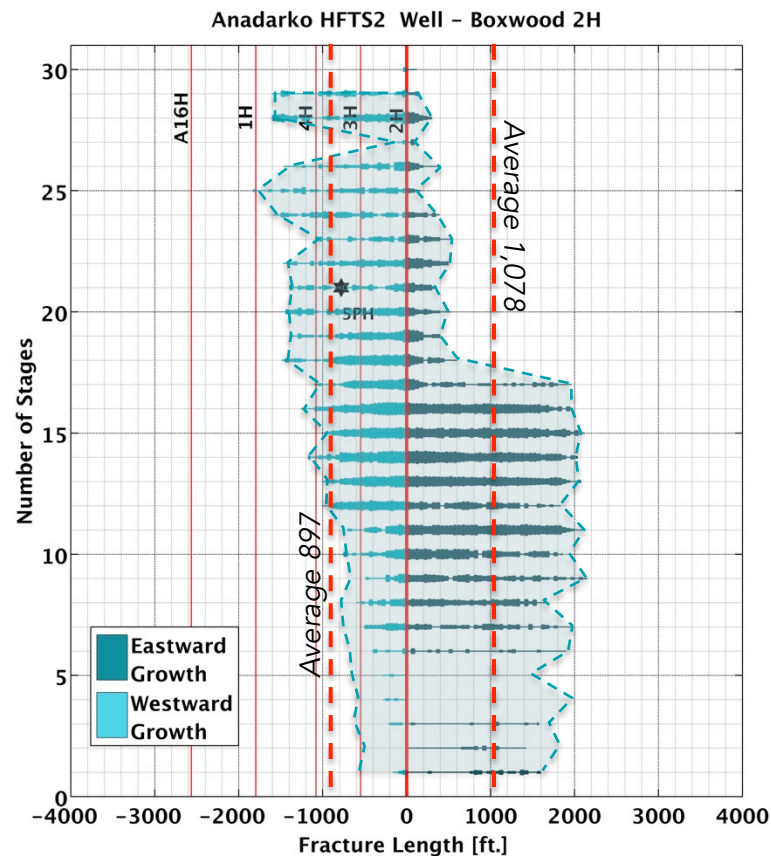
Post-Processing – Multi-well only + 2.5ms Misfit cut-off



Length Averages (ft)	
West	East
171	1,782



Length Averages (ft)	
West	East
551	1,346



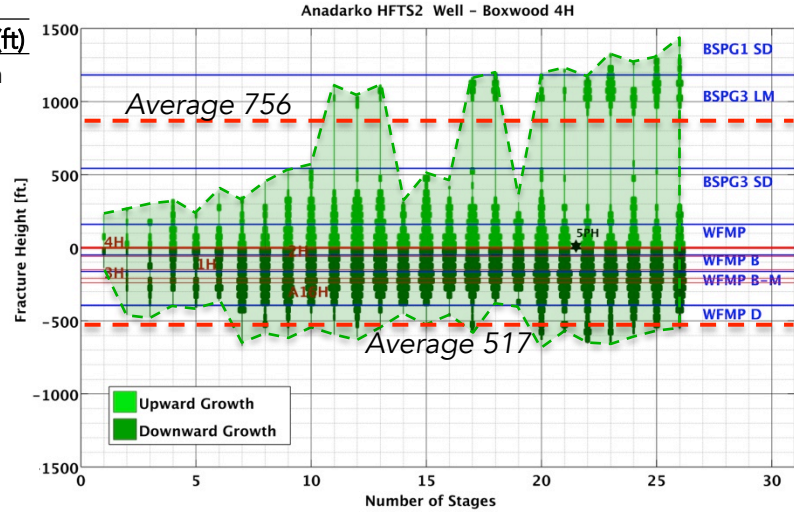
Length Averages (ft)	
West	East
897	1,078

Fracture Statistics – Height

Post-Processing – Multi-well only + 2.5ms Misfit cut-off

Height Averages (ft)

Up	Down
756	517

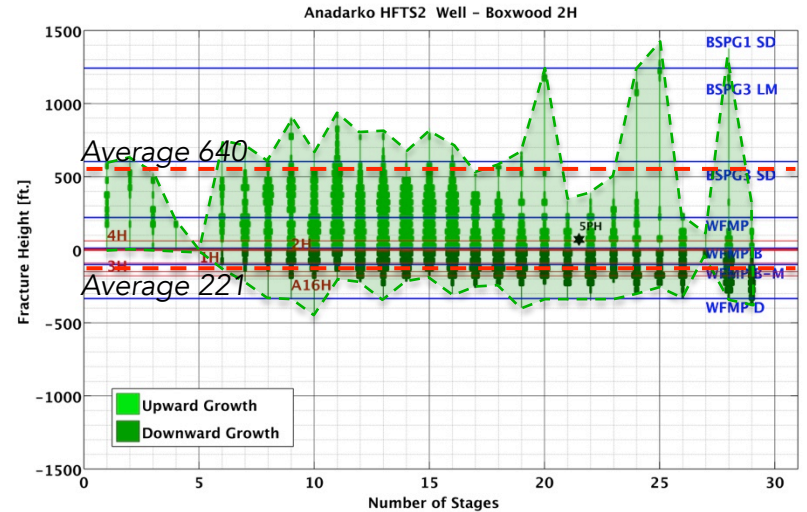
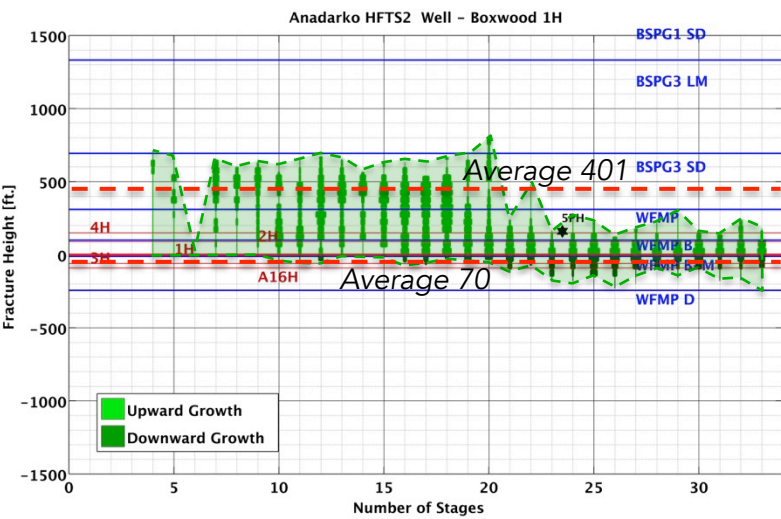


Height Averages (ft)

Up	Down
401	70

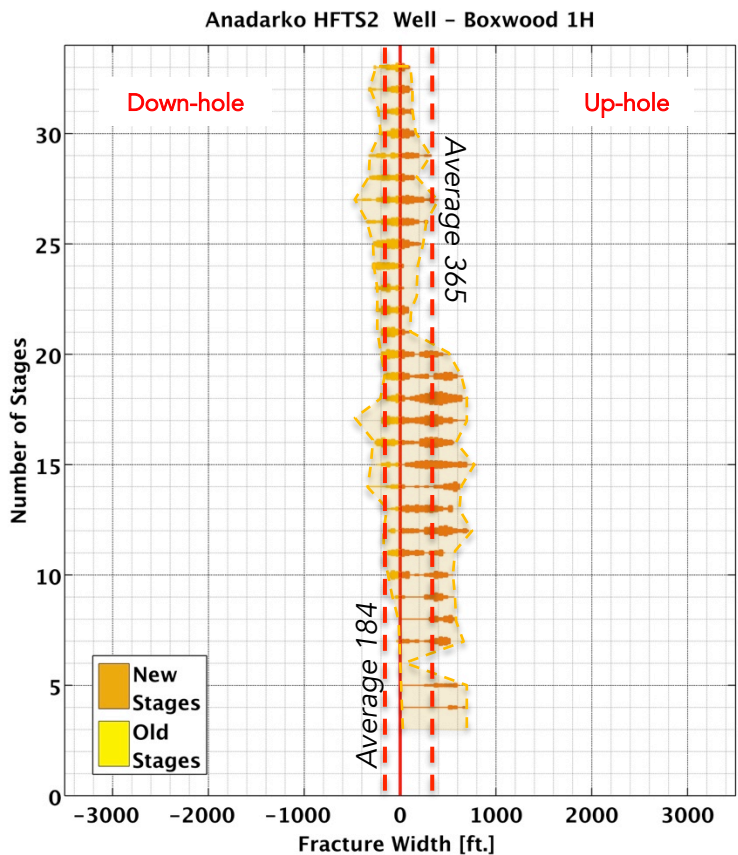
Height Averages (ft)

Up	Down
640	221

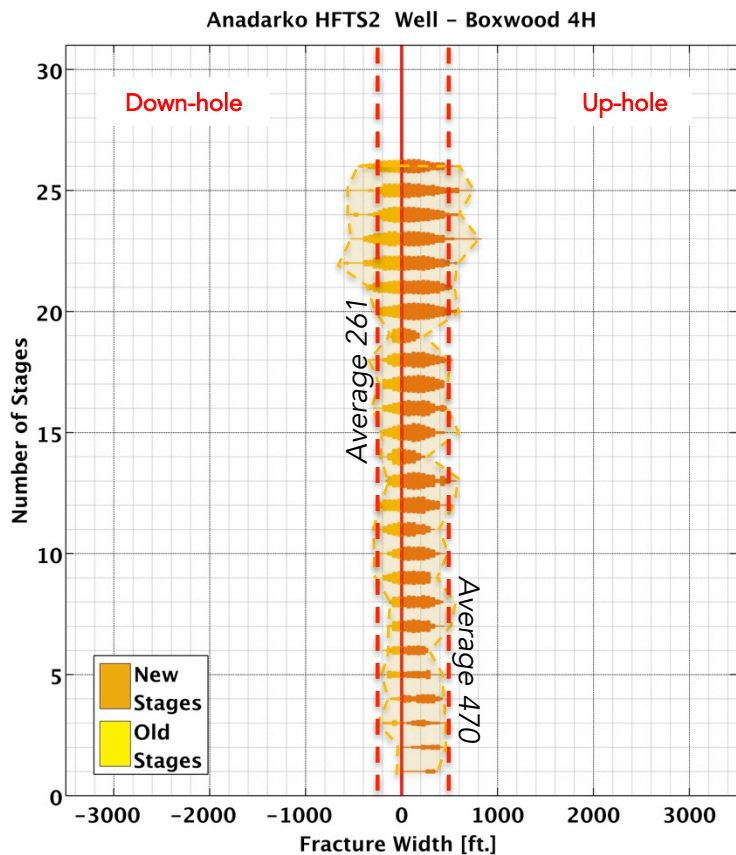


Fracture Statistics – Height

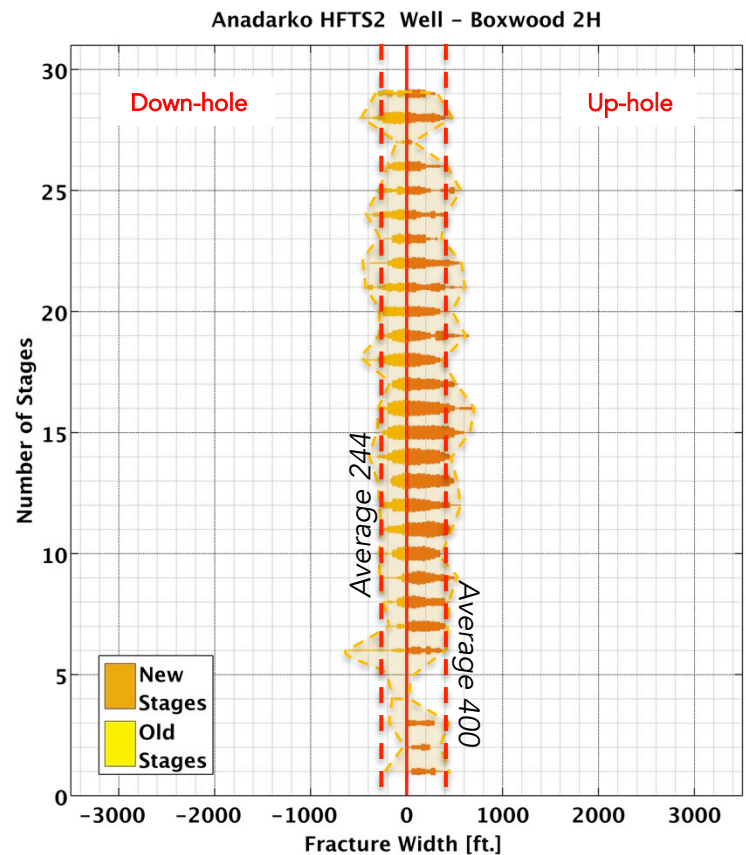
Post-Processing – Multi-well only + 2.5ms Misfit cut-off



Width Averages (ft)	
Old Stages	New Stages
184	365



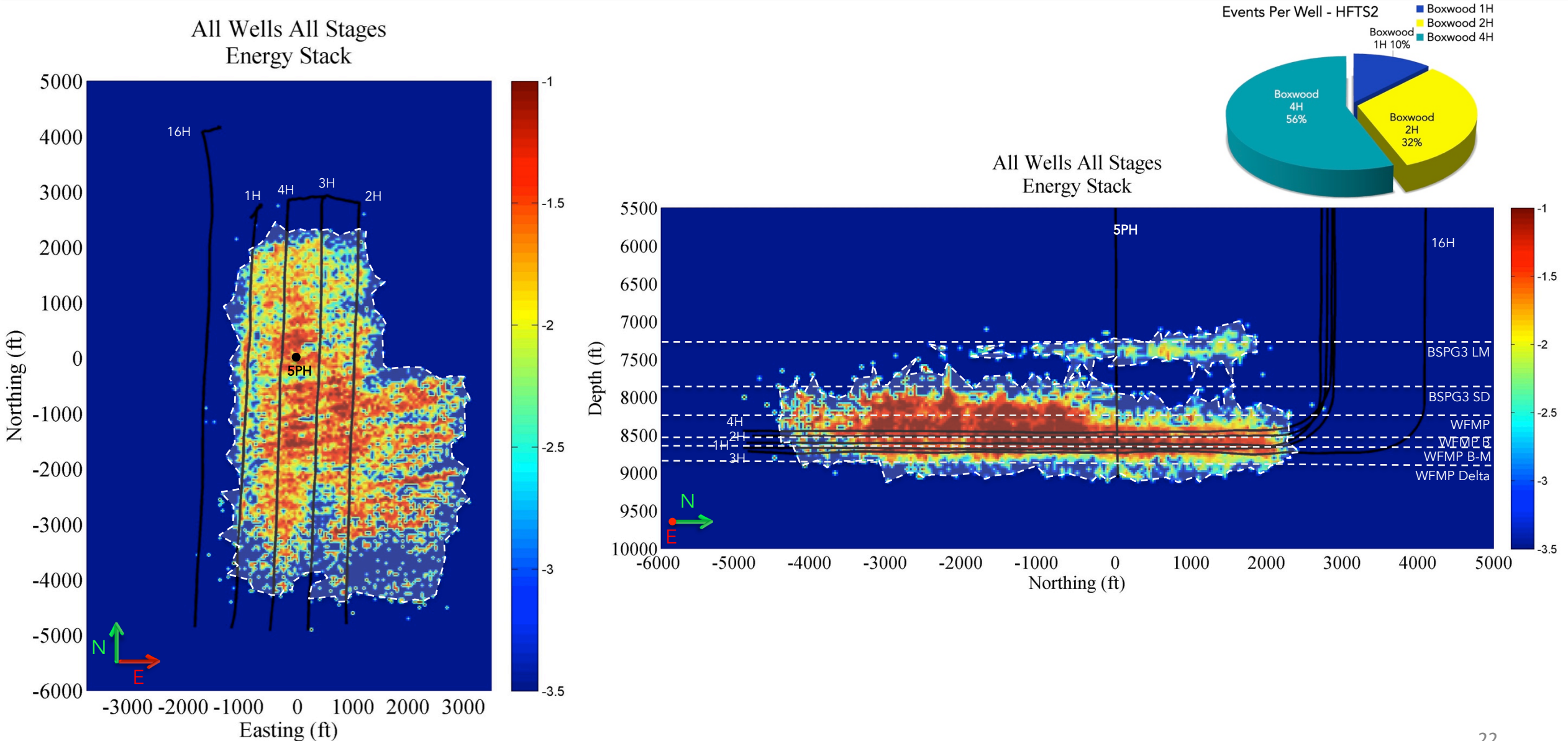
Width Averages (ft)	
Old Stages	New Stages
261	470



Width Averages (ft)	
Old Stages	New Stages
244	400

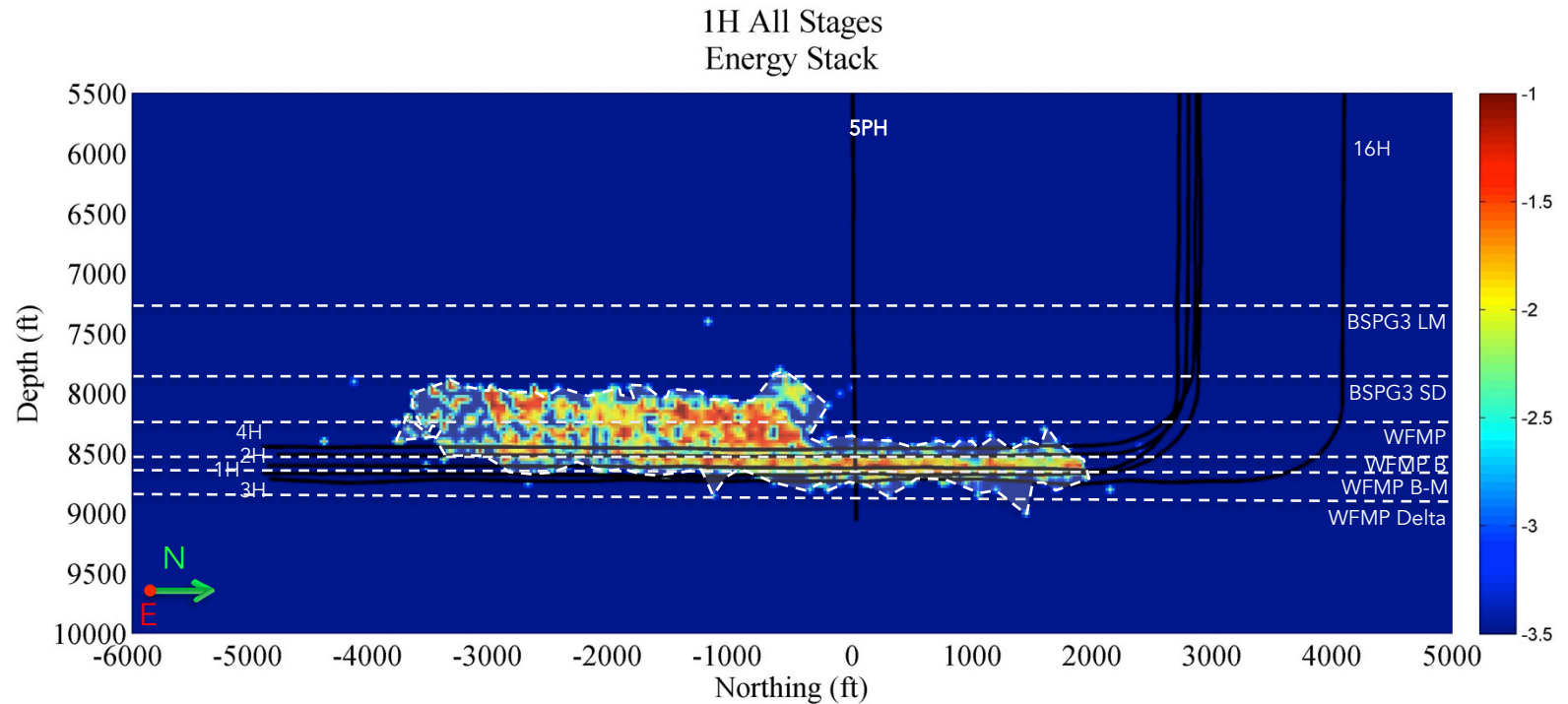
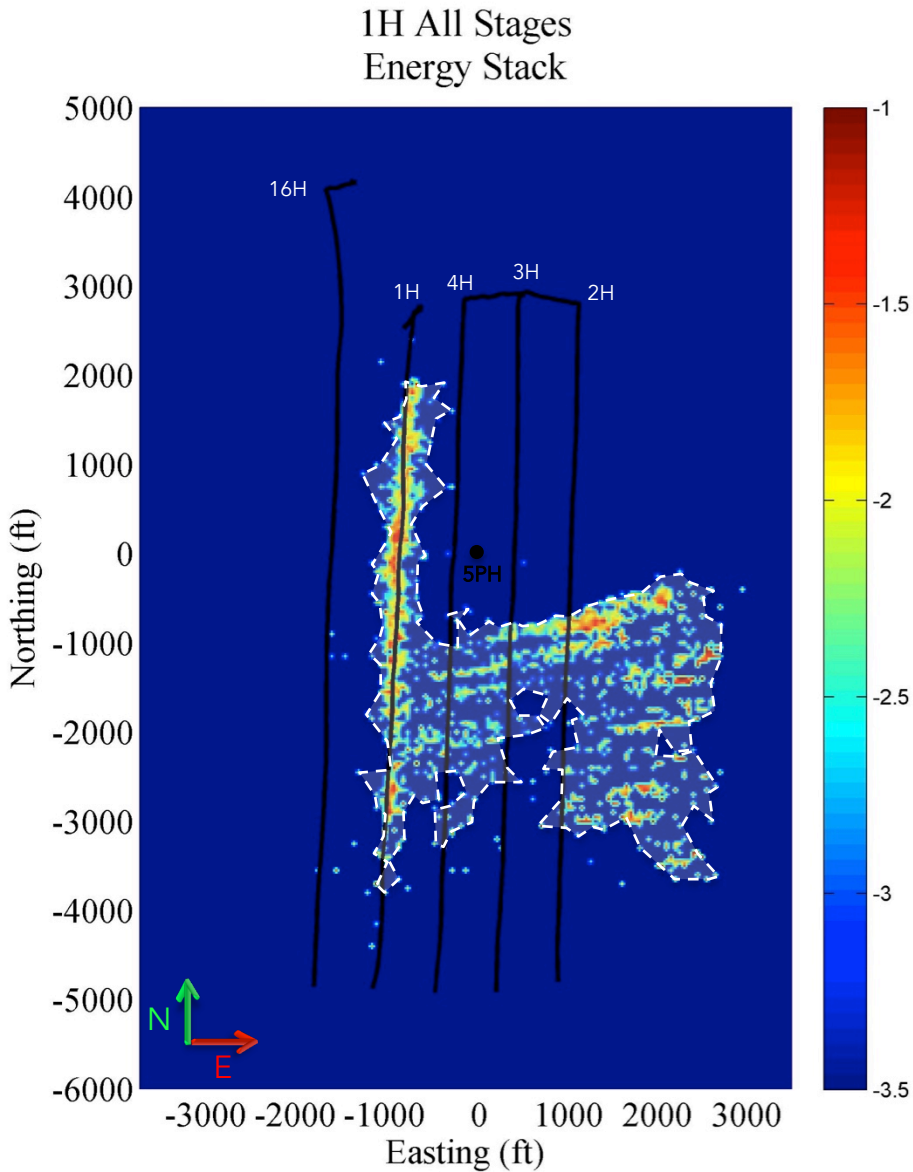
HFTS2 Energy Stack – All Wells

2.5ms Misfit cut-off + Multi-well only



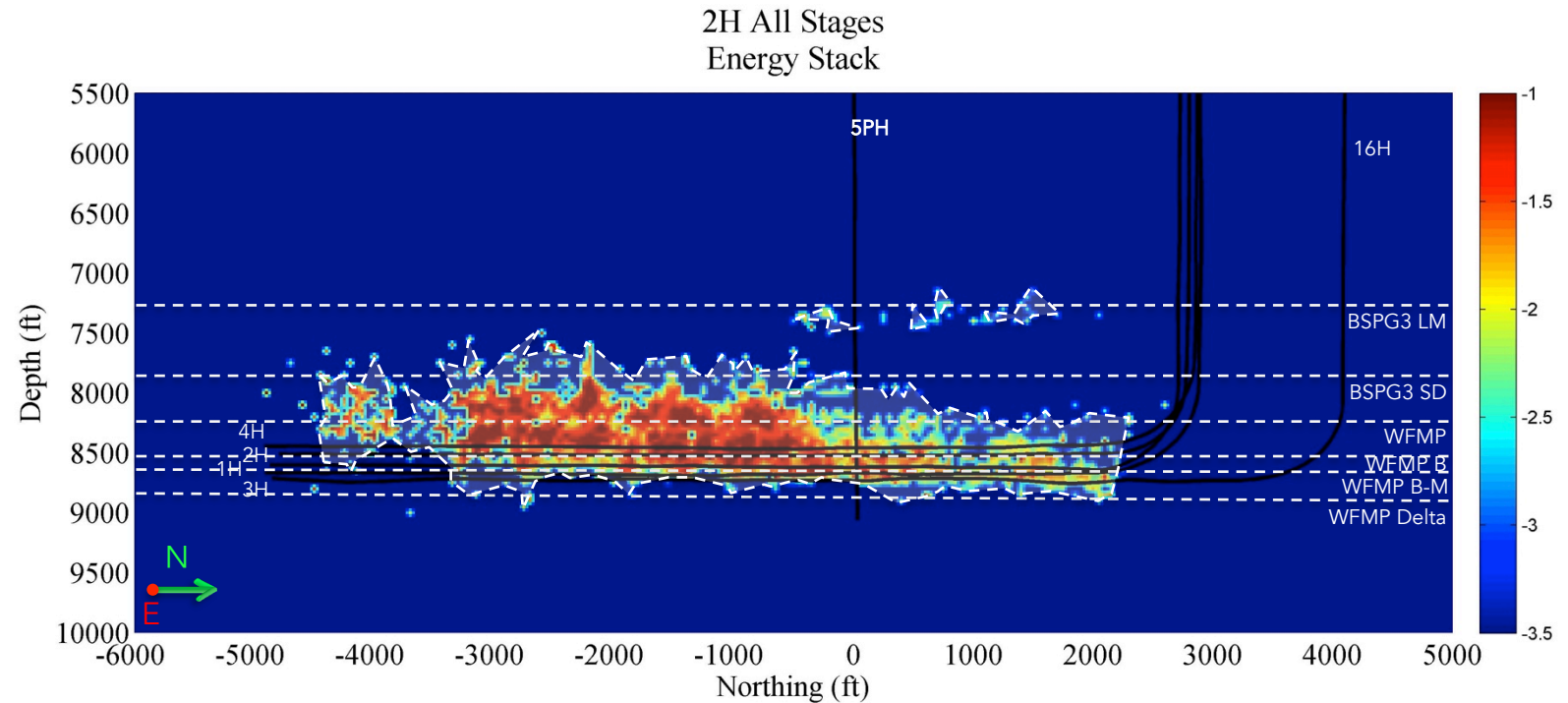
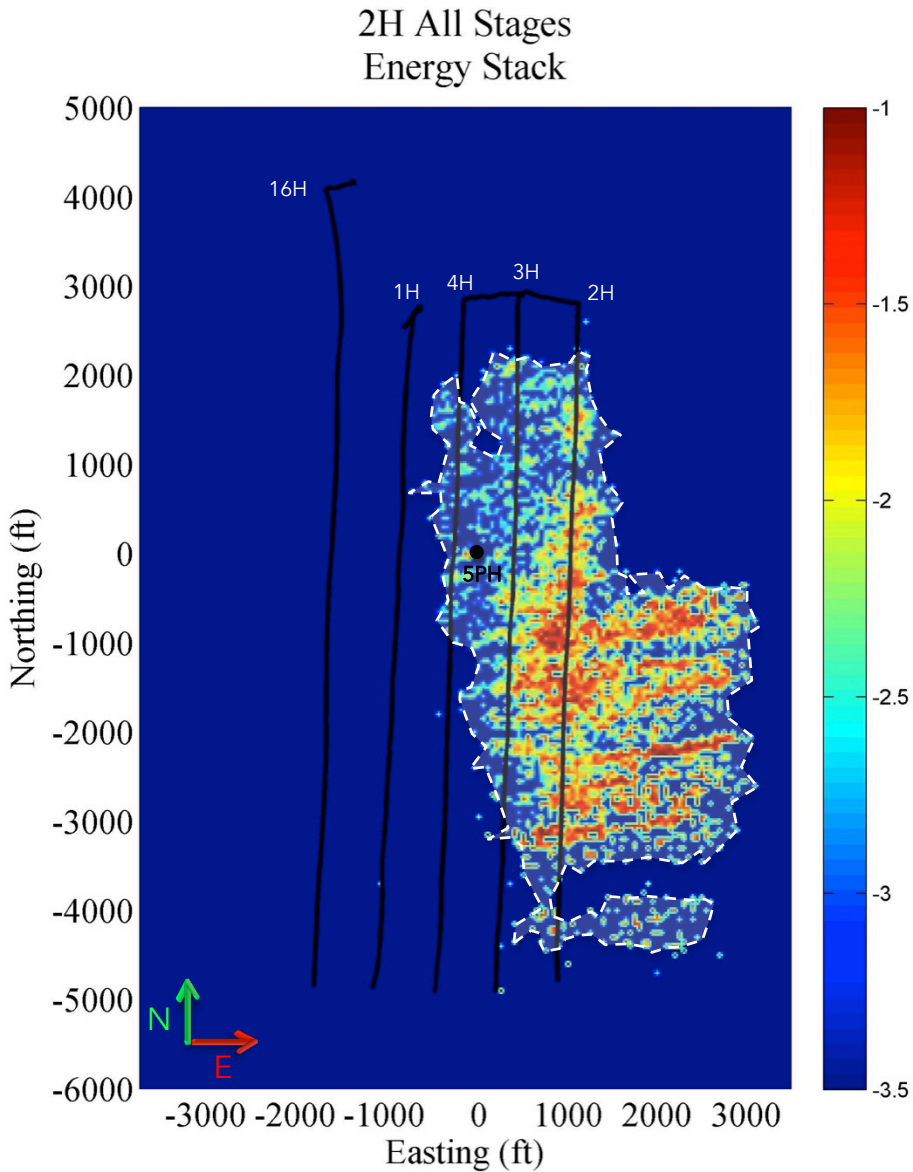
HFTS2 Energy Stack – Boxwood 1H

2.5ms Misfit cut-off + Multi-well only



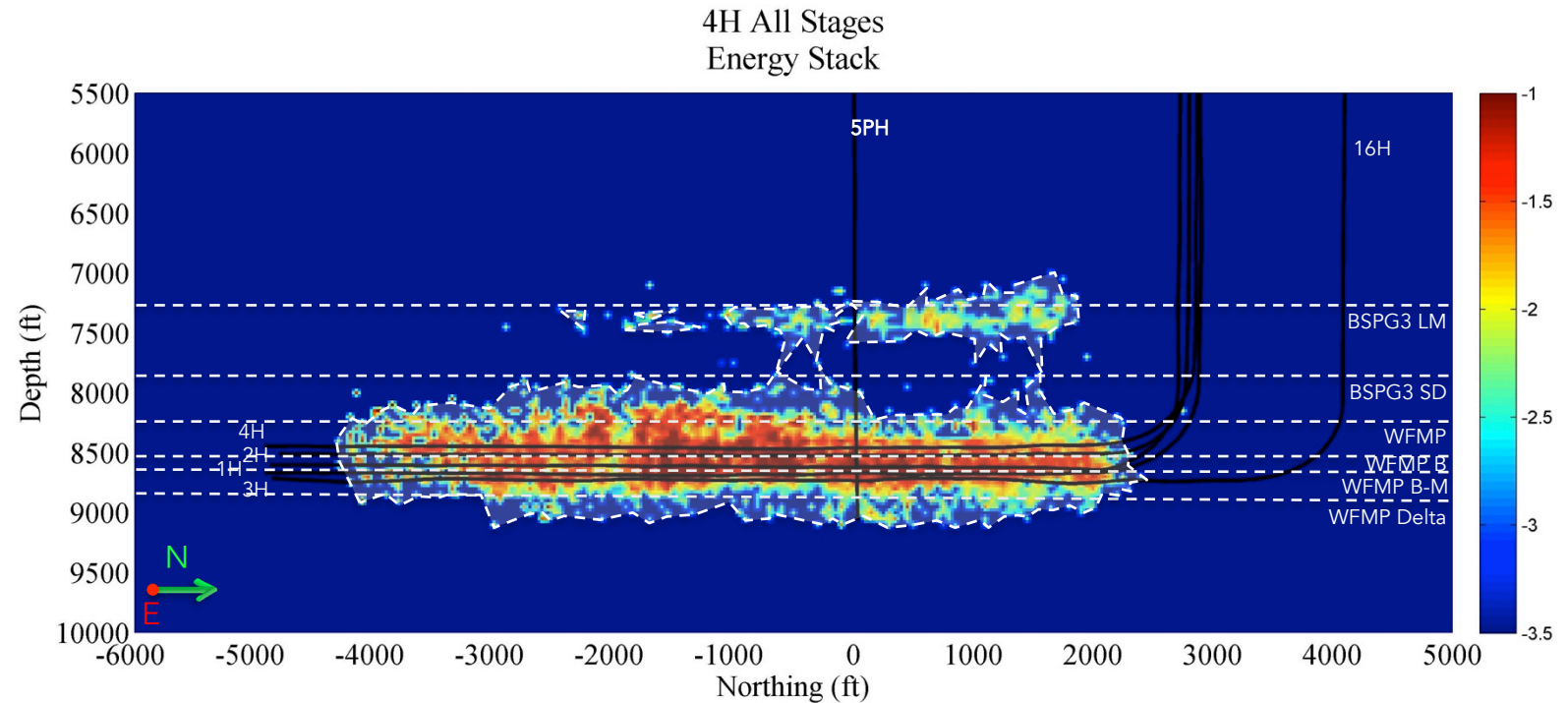
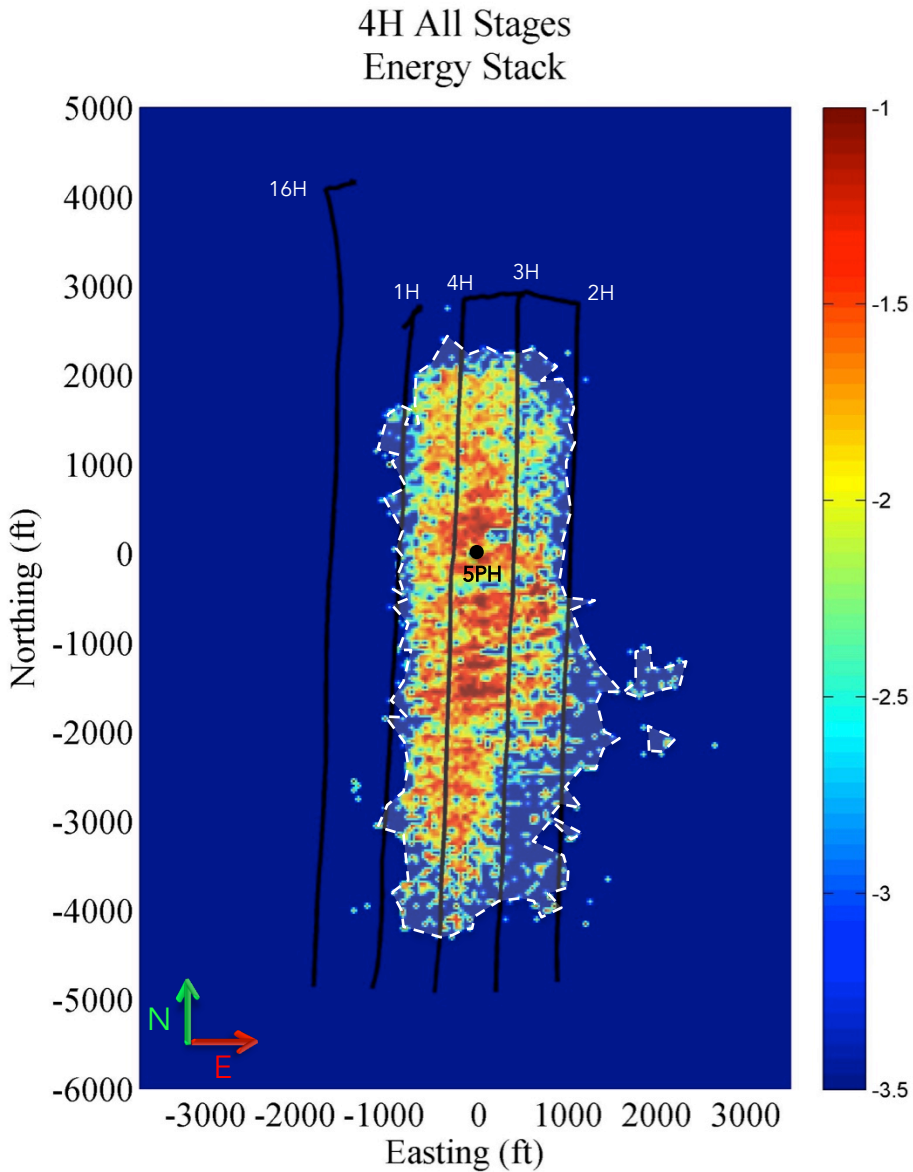
HFTS2 Energy Stack – Boxwood 2H

2.5ms Misfit cut-off + Multi-well only



HFTS2 Energy Stack – Boxwood 4H

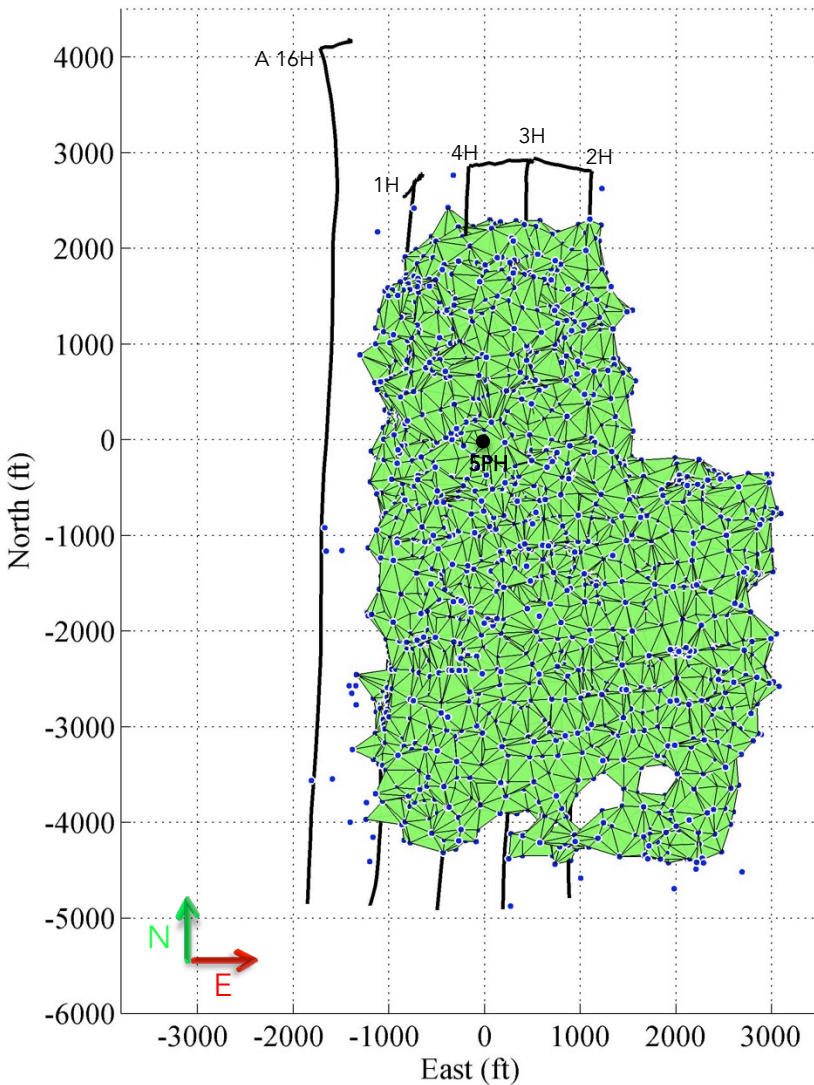
2.5ms Misfit cut-off + Multi-well only



Stimulated Reservoir Volume – All wells

2.5ms Misfit cut-off + Multi-well only

All Wells
- Enclosed volume

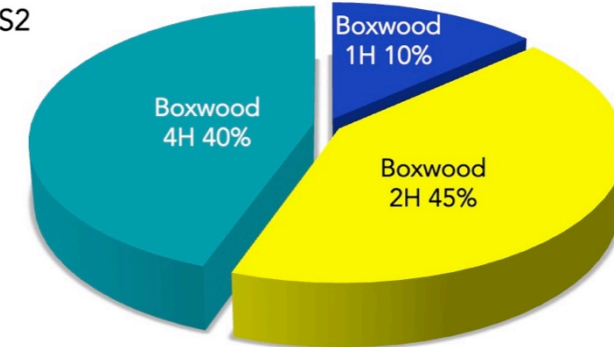


Total Stimulated Reservoir Volume Boxwood 1H
1,955,188,419.57 ft ³ 2.0 Billions ft ³
Total Stimulated Reservoir Volume Boxwood 2H
6,089,080,421.43 ft ³ 6.0 Billions ft ³
Total Stimulated Reservoir Volume Boxwood 4H
6,455,854,387.20 ft ³ 6.5 Billions ft ³

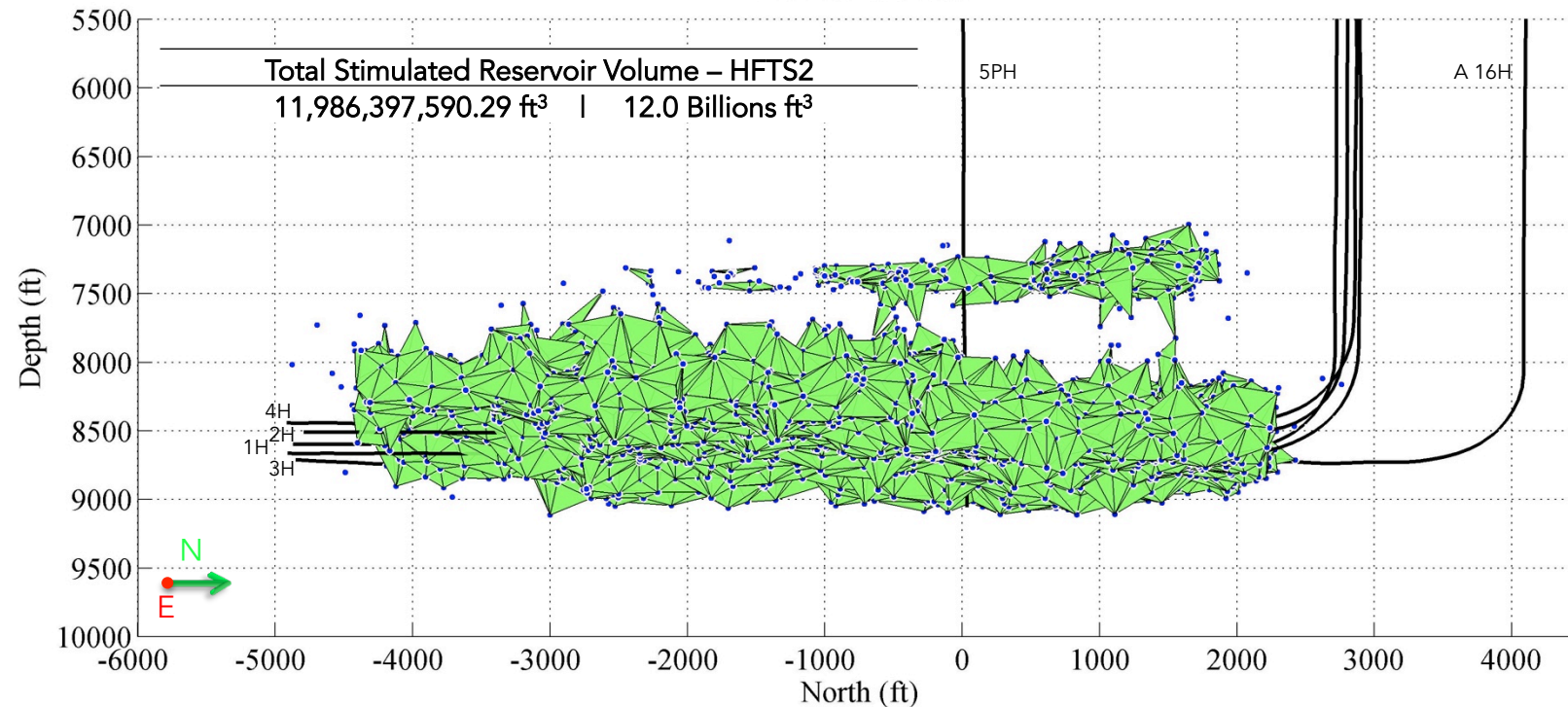
SRV Per Well - HFTS2

Increasing SRV
with order of
treatment

Boxwood 1H
Boxwood 2H
Boxwood 4H



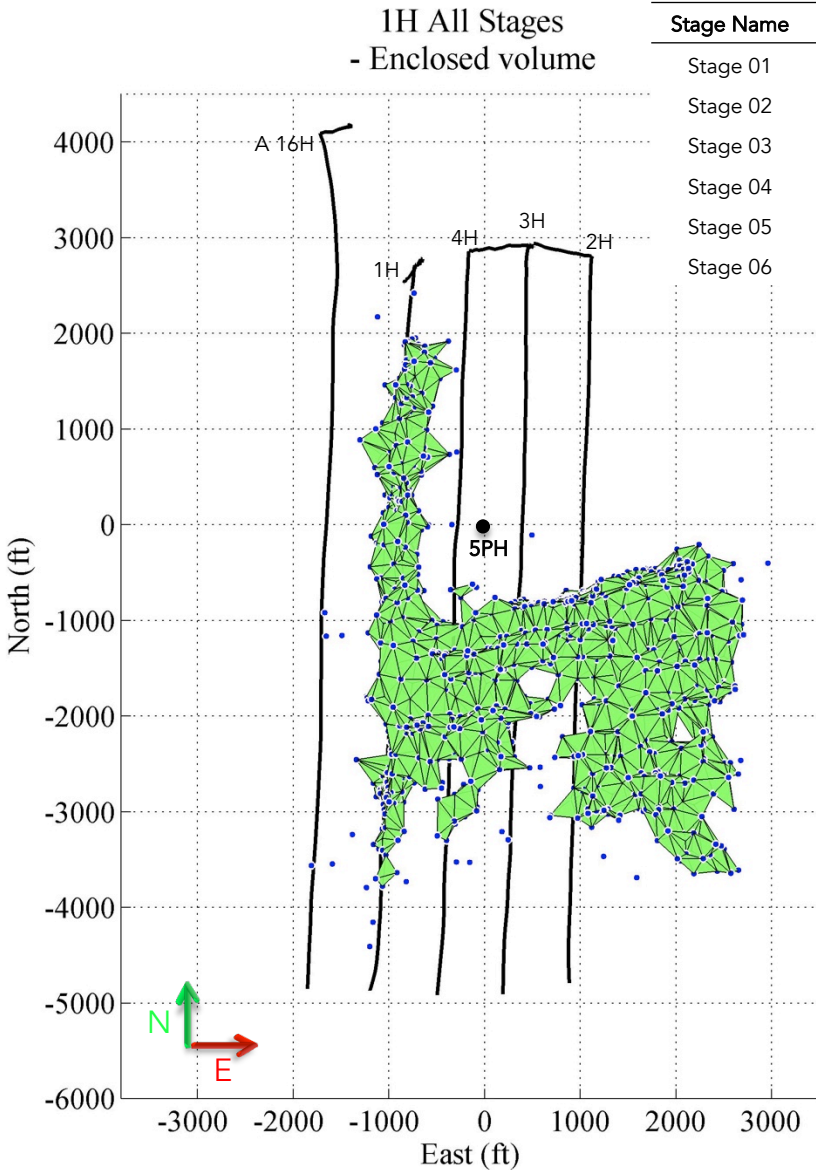
All Wells
- Enclosed volume



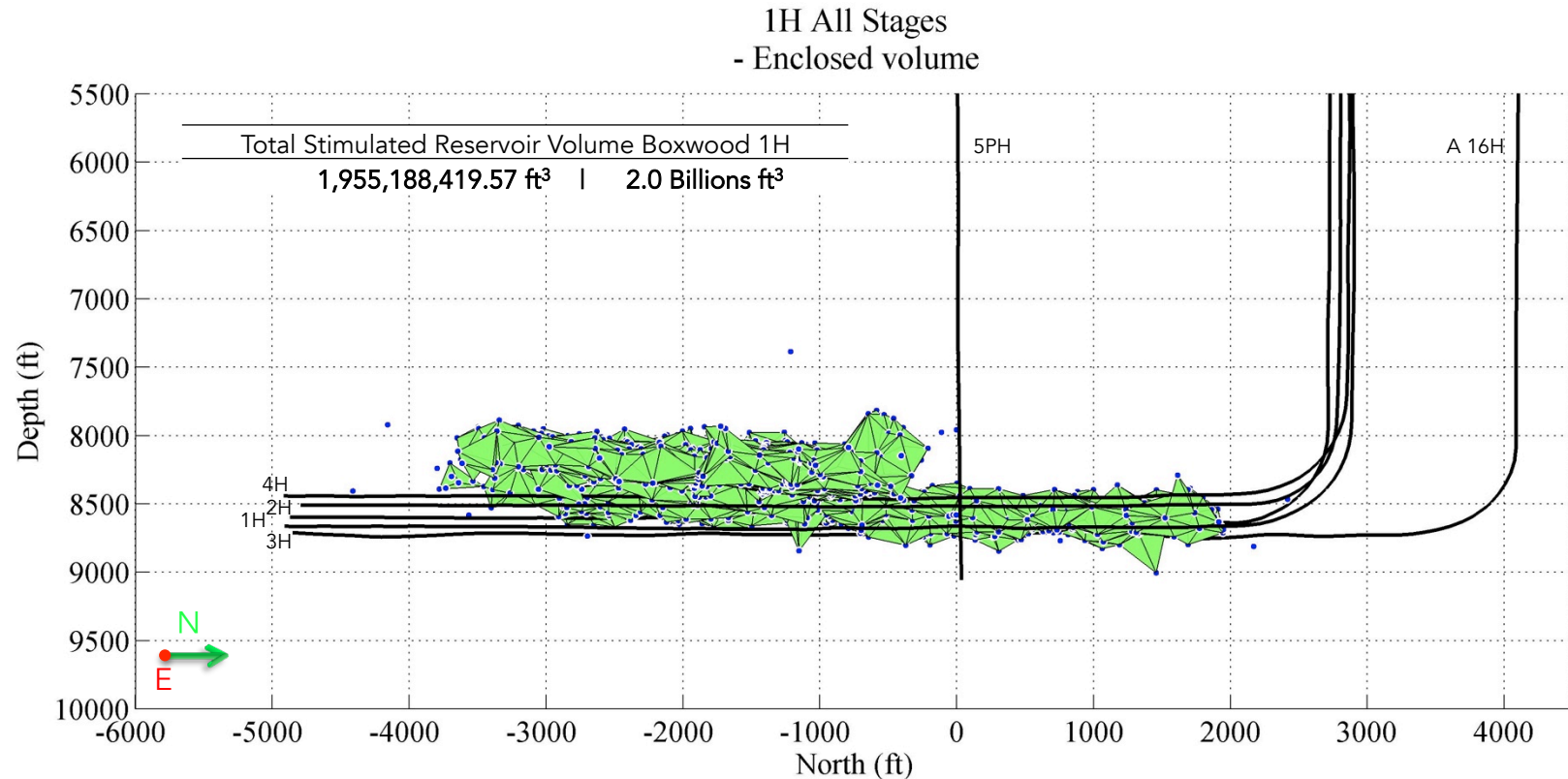
Total Stimulated Reservoir Volume – HFTS2
11,986,397,590.29 ft³ | 12.0 Billions ft³

Stimulated Reservoir Volume – Boxwood 1H

2.5ms Misfit cut-off + Multi-well only

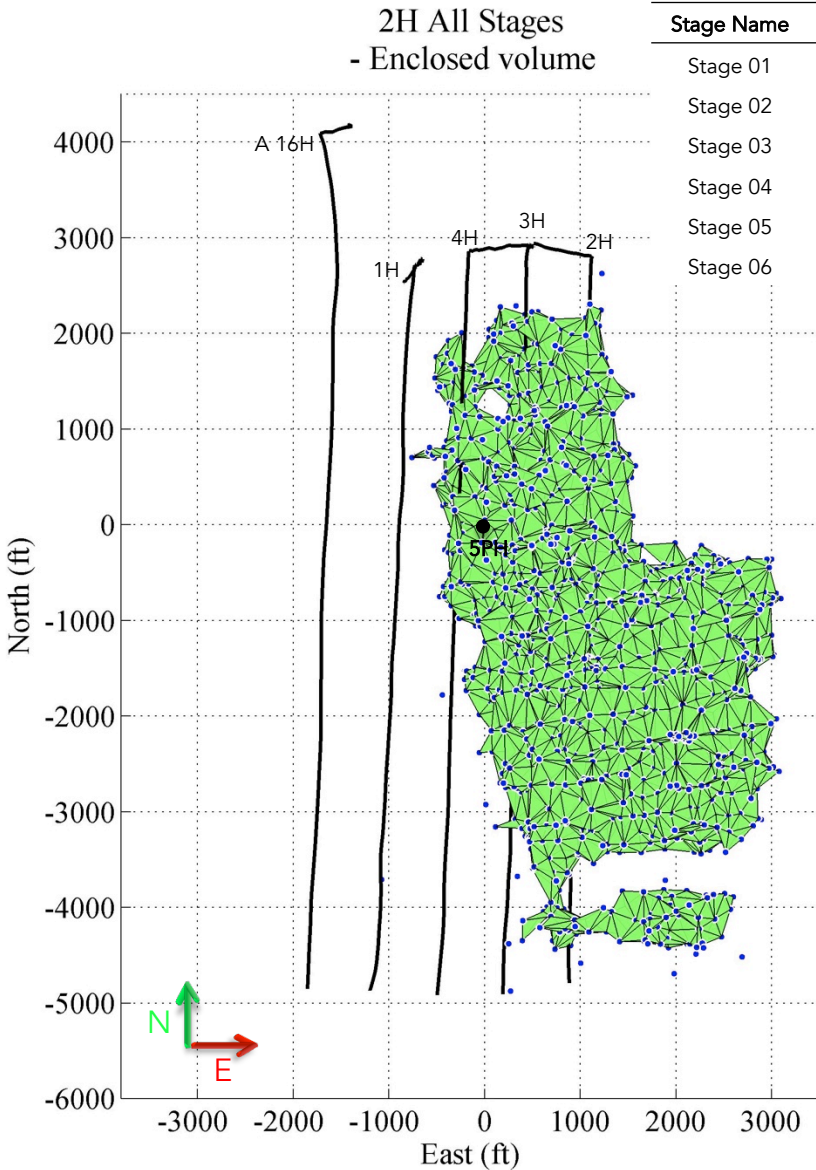


Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)
Stage 01	-	Stage 07	13,497,683.2	Stage 13	54,791,432.4	Stage 19	27,793,123.1	Stage 25	19,598,517.9	Stage 31	9,447,371.5
Stage 02	-	Stage 08	10,088,455.6	Stage 14	12,223,092.2	Stage 20	24,430,536.0	Stage 26	14,921,161.2	Stage 32	11,160,907.2
Stage 03	-	Stage 09	6,062,257.7	Stage 15	63,814,470.8	Stage 21	12,444,202.6	Stage 27	23,384,481.8	Stage 33	5,040,961.6
Stage 04	3,835,768.6	Stage 10	8,869,088.1	Stage 16	53,340,137.5	Stage 22	13,693,791.1	Stage 28	19,020,344.6		
Stage 05	5,620,890.0	Stage 11	12,612,908.9	Stage 17	64,223,848.4	Stage 23	7,814,213.1	Stage 29	12,637,345.6		
Stage 06	-	Stage 12	54,130,940.4	Stage 18	109,385,141.8	Stage 24	17,639,392.2	Stage 30	9,816,466.6		

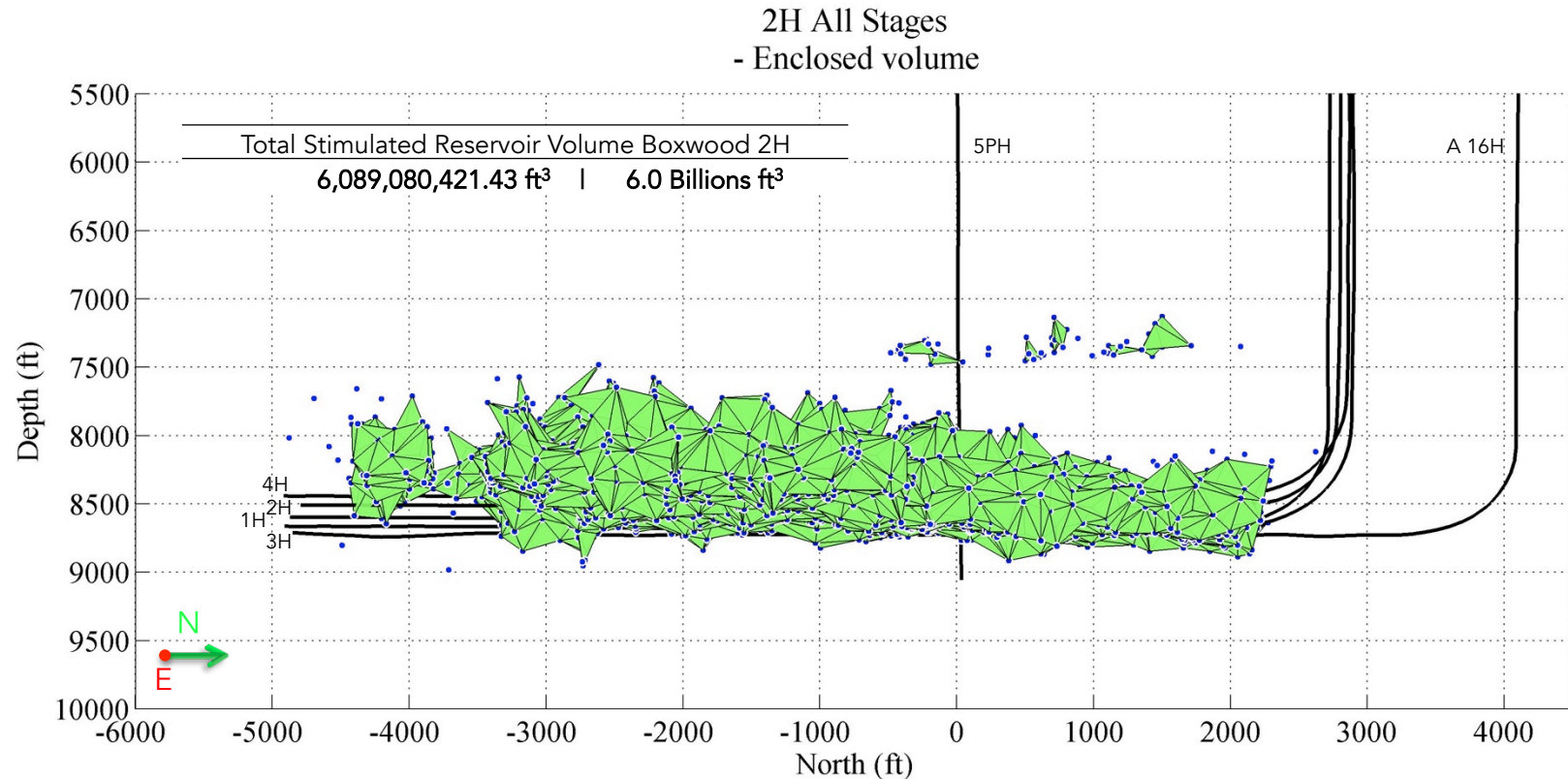


Stimulated Reservoir Volume – Boxwood 2H

2.5ms Misfit cut-off + Multi-well only

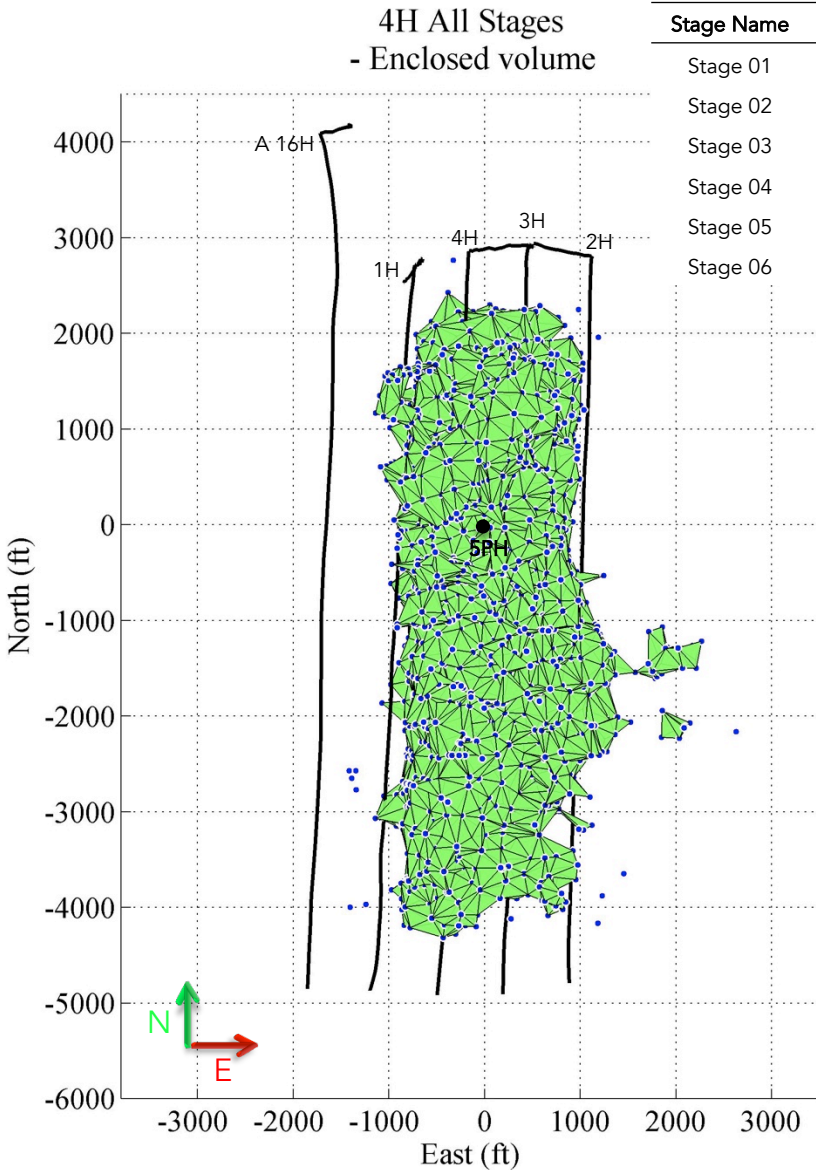


Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)
Stage 01	26,541,198.1	Stage 07	119,089,103.4	Stage 13	311,813,111.5	Stage 19	121,400,081.6	Stage 25	48,148,200.8	Stage 31	-
Stage 02	10,593,456.1	Stage 08	125,561,181.9	Stage 14	401,215,863.9	Stage 20	91,735,133.2	Stage 26	68,078,375.4	Stage 32	-
Stage 03	3,631,863.3	Stage 09	120,861,736.8	Stage 15	423,755,534.2	Stage 21	81,784,917.6	Stage 27	872,324.7	Stage 33	-
Stage 04	66,153.5	Stage 10	218,671,656.5	Stage 16	423,501,618.9	Stage 22	155,312,045.0	Stage 28	117,649,313.1		
Stage 05	0	Stage 11	287,850,074.8	Stage 17	149,549,384.3	Stage 23	59,247,550.6	Stage 29	54,044,221.7		
Stage 06	18,896,421.8	Stage 12	276,371,526.7	Stage 18	176,623,428.7	Stage 24	107,264,943.5	Stage 30	0		

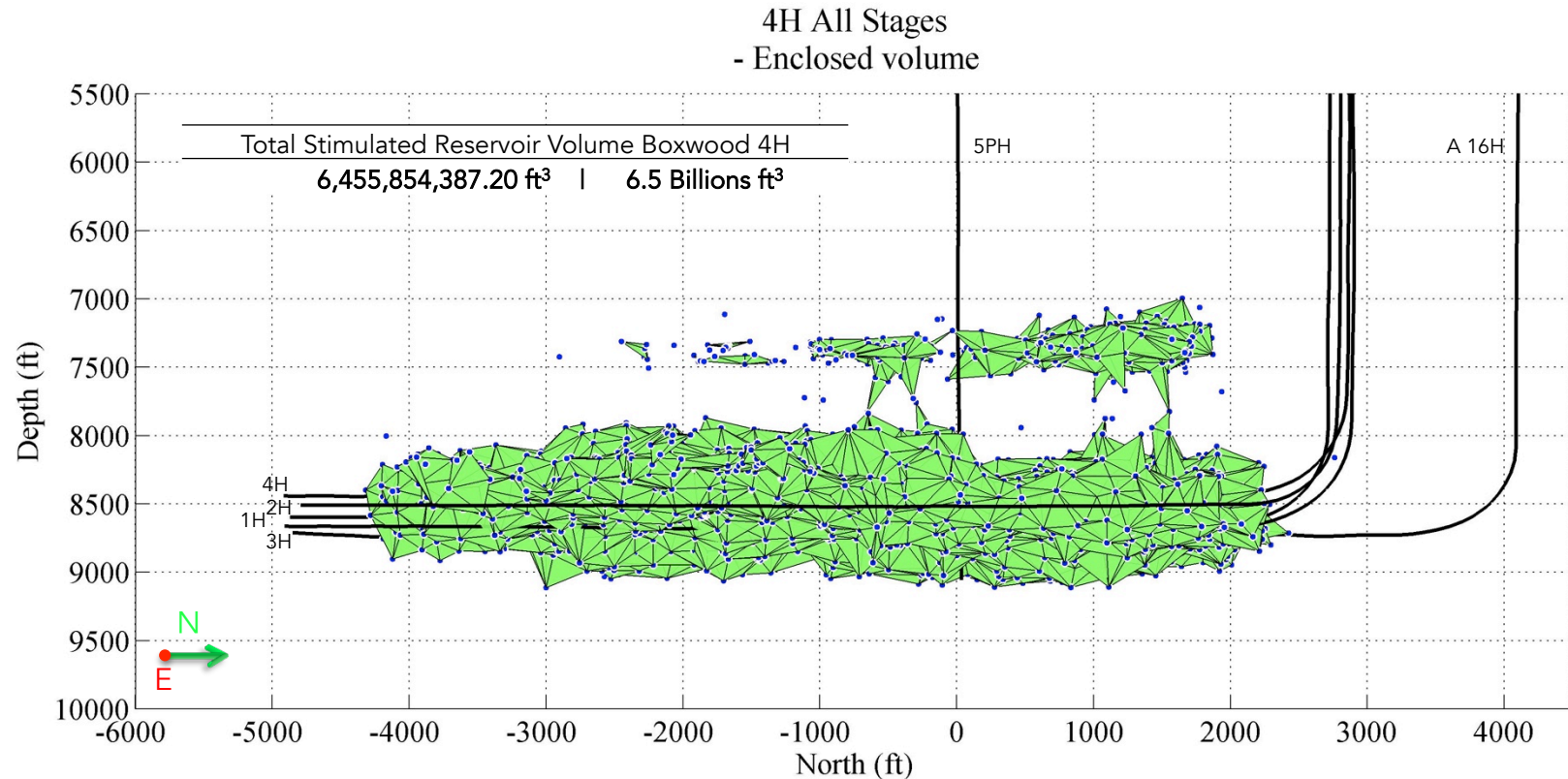


Stimulated Reservoir Volume – Boxwood 4H

2.5ms Misfit cut-off + Multi-well only

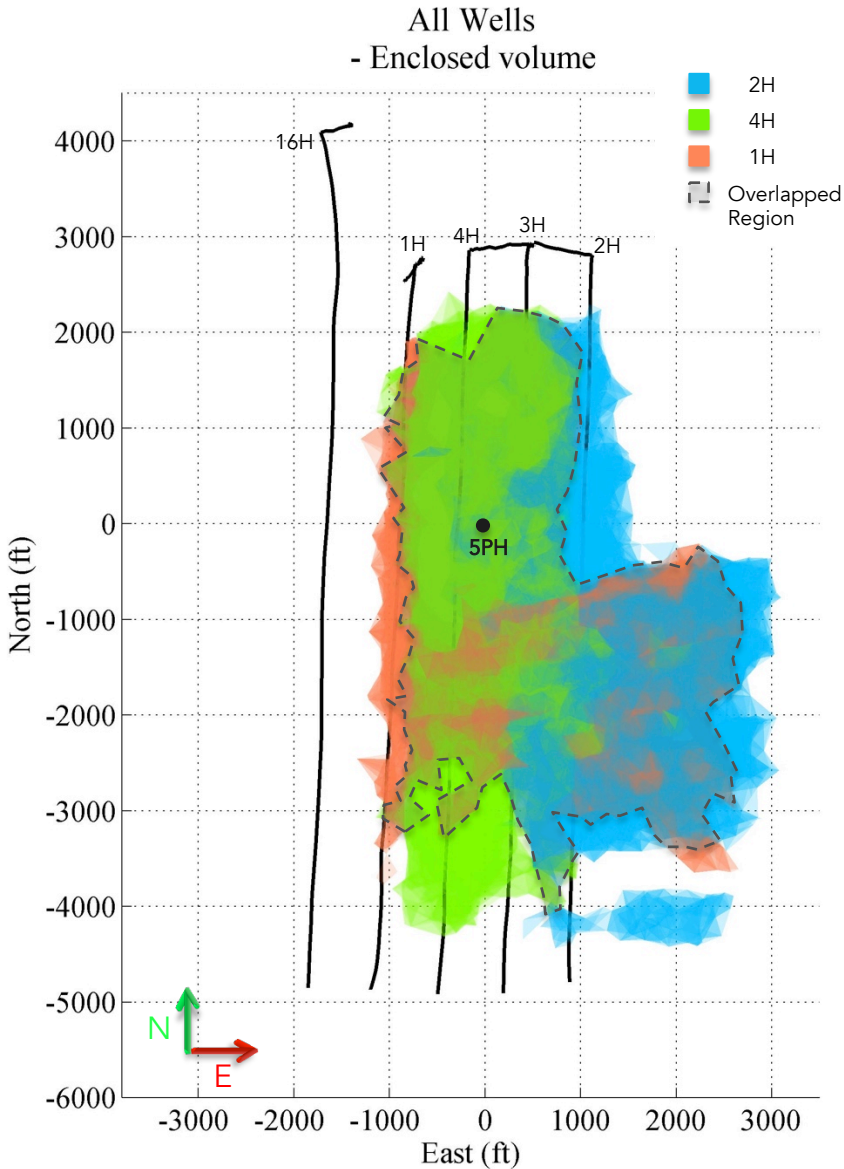


Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)	Stage Name	SRV (ft ³)
Stage 01	1,444,895.1	Stage 07	151,182,427.2	Stage 13	218,715,876.7	Stage 19	38,592,364.6	Stage 25	391,282,331.4	Stage 31	-
Stage 02	6,175,133.8	Stage 08	157,254,819.3	Stage 14	72,465,705.8	Stage 20	383,935,542.8	Stage 26	359,321,981.1	Stage 32	-
Stage 03	49,553,402.2	Stage 09	186,118,778.2	Stage 15	252,336,959.9	Stage 21	360,570,215.1	Stage 27	-	Stage 33	-
Stage 04	123,427,011.3	Stage 10	169,699,760.6	Stage 16	208,143,236.6	Stage 22	390,325,796.0	Stage 28	-		
Stage 05	71,212,975.0	Stage 11	168,465,089.5	Stage 17	308,310,405.6	Stage 23	417,861,799.9	Stage 29	-		
Stage 06	75,171,568.4	Stage 12	279,786,373.7	Stage 18	221,440,232.3	Stage 24	445,314,183.8	Stage 30	-		

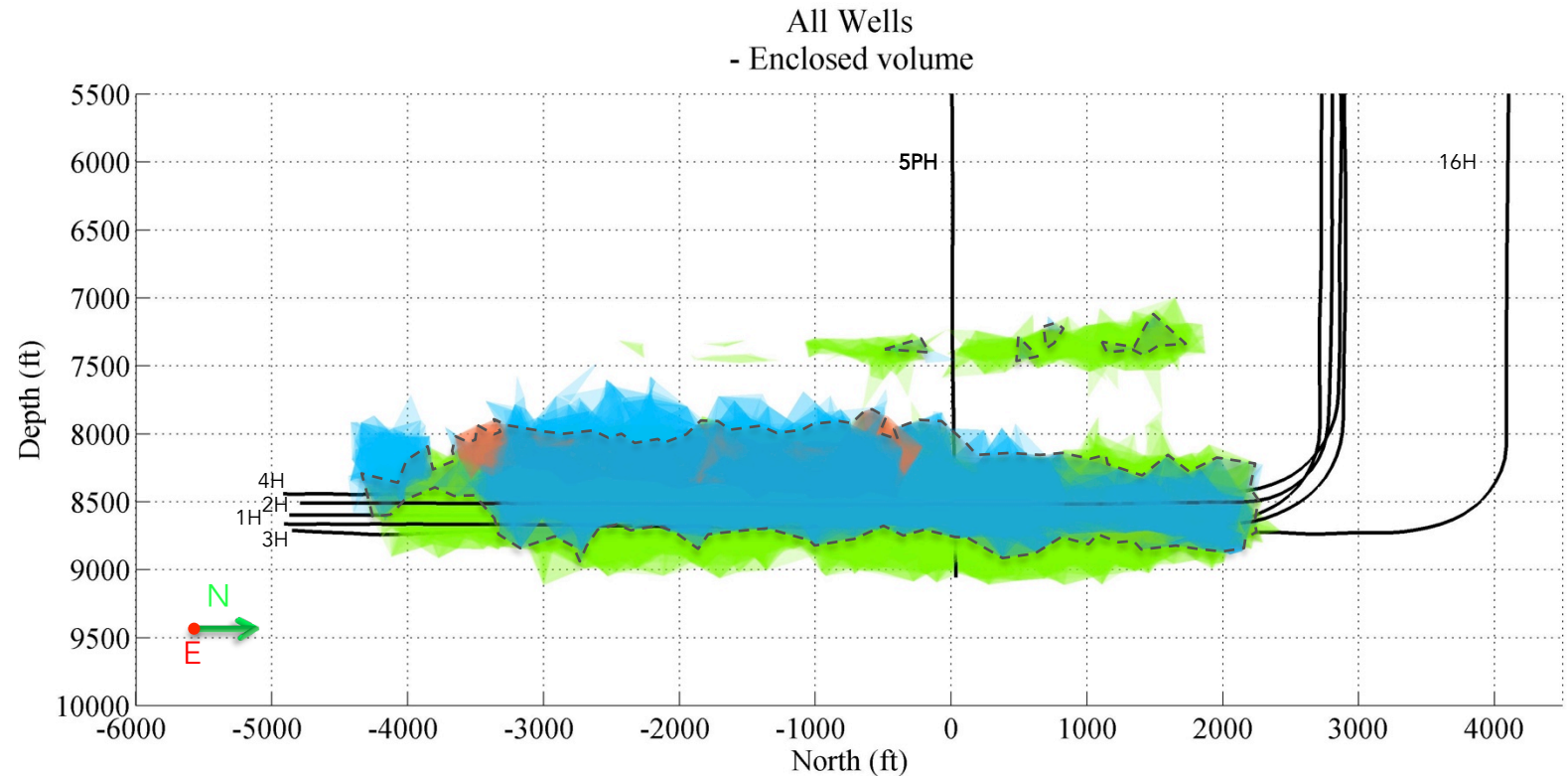


Stimulated Reservoir Volume – All wells

2.5ms Misfit cut-off + Multi-well only

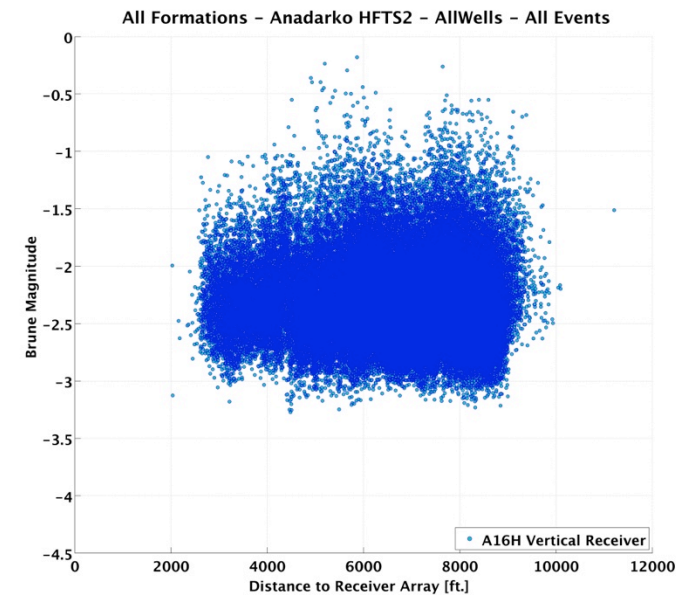
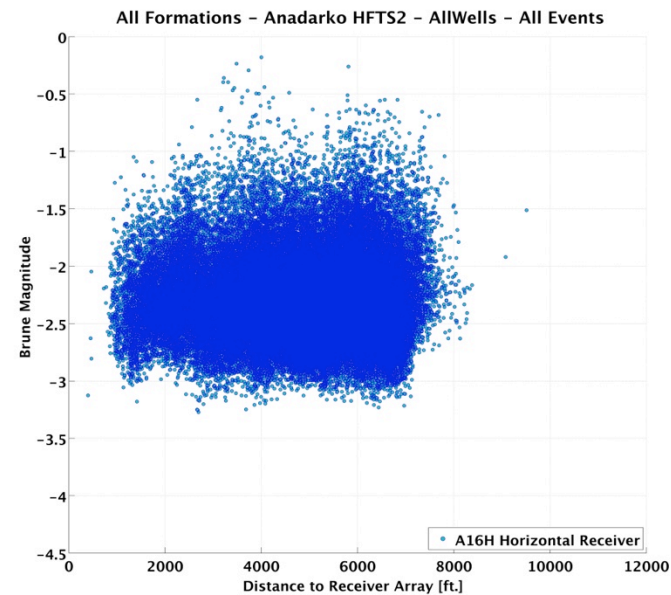
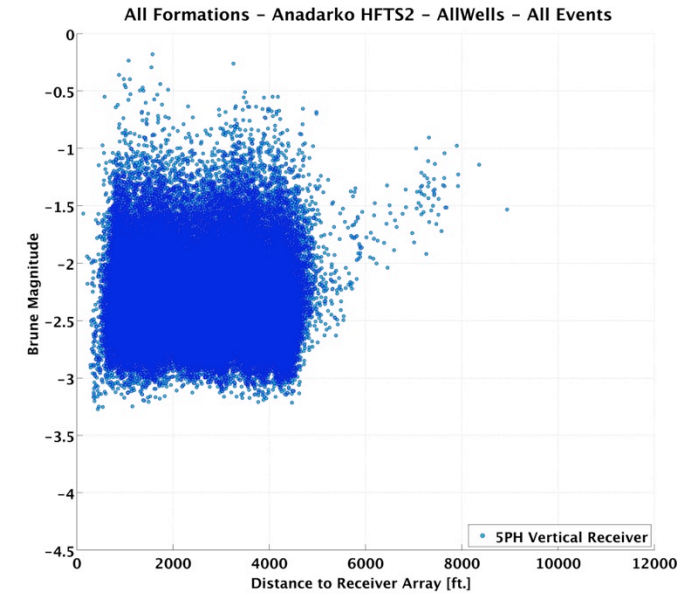
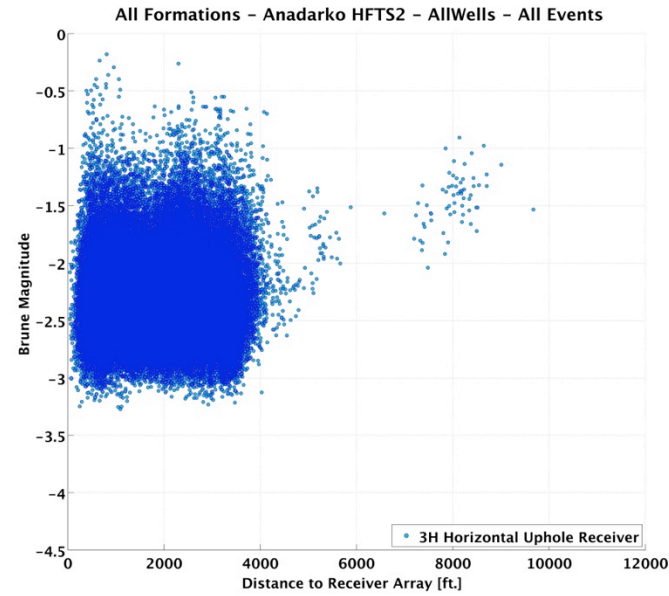
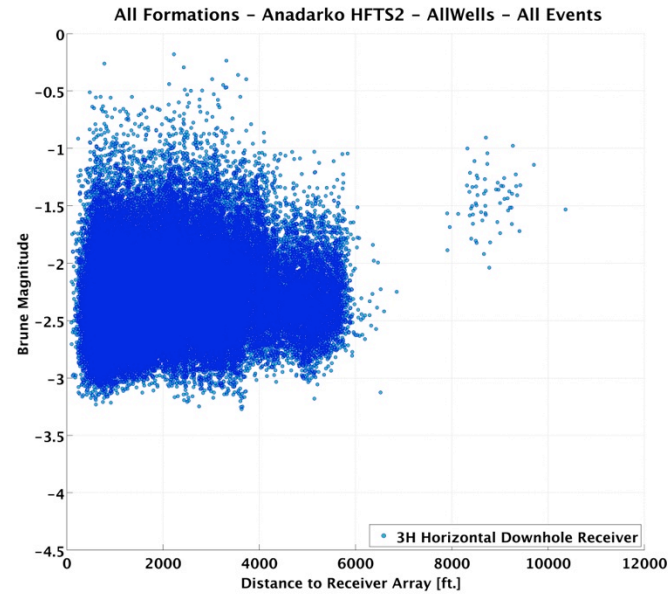


Approximately 17.34% of the Total Stimulated Reservoir Rock is overlapped by the wells in the entire Project. That represents approximately $\frac{1}{6}$ of the SRV is re-fracked by other wells.



Magnitude vs. Distance Plots

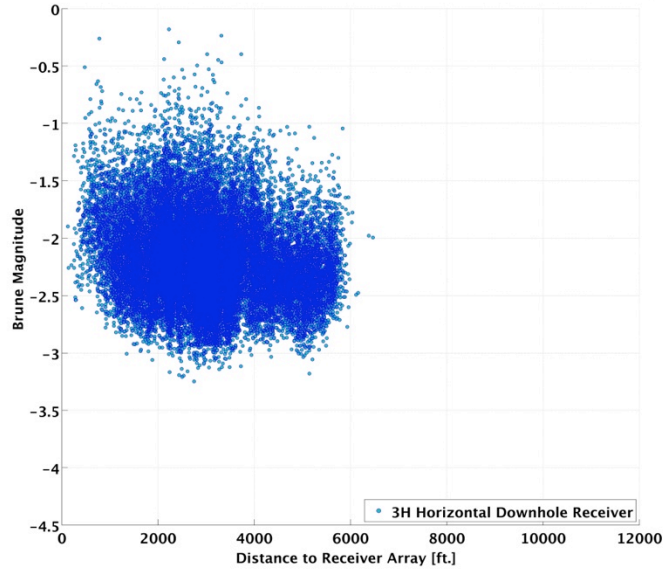
All events



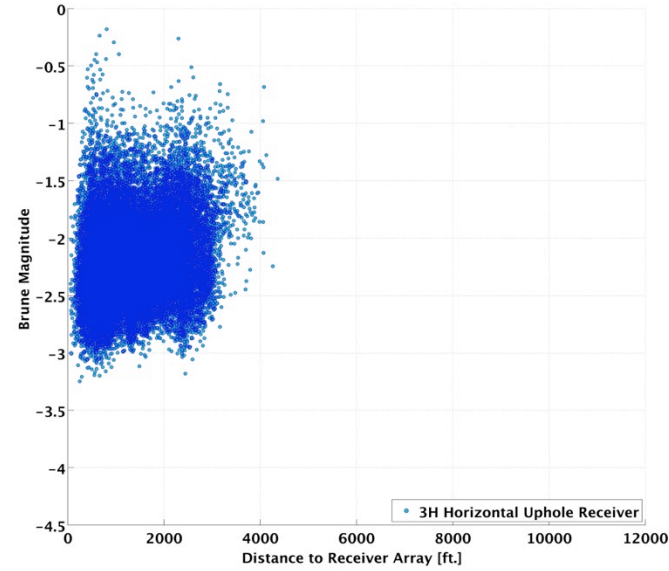
Magnitude vs. Distance Plots

2.5ms Misfit cut-off + Multi-well only

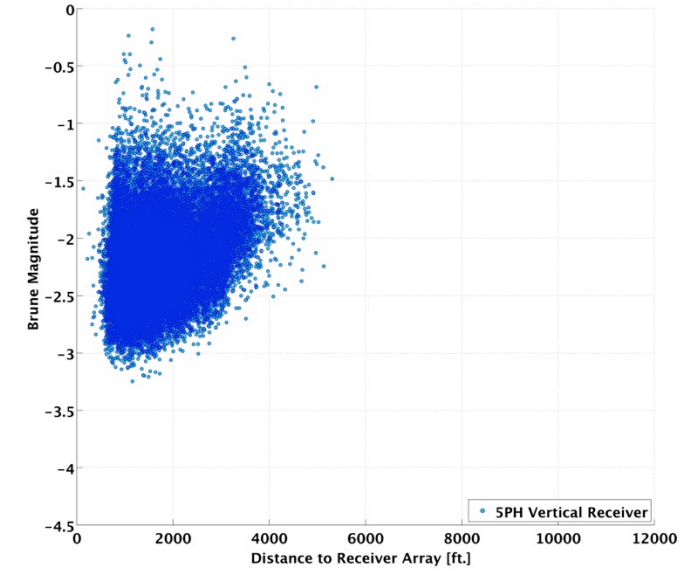
All Formations - Anadarko HFTS2 - AllWells - MultiWell Events Below 2.5ms



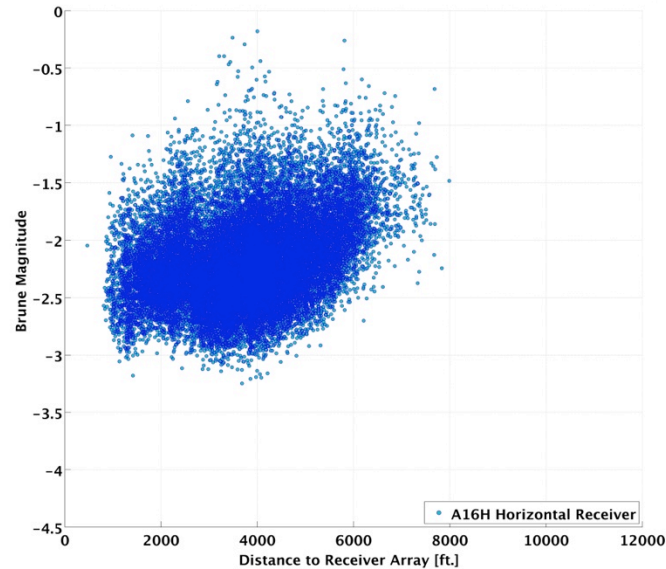
All Formations - Anadarko HFTS2 - AllWells - MultiWell Events Below 2.5ms



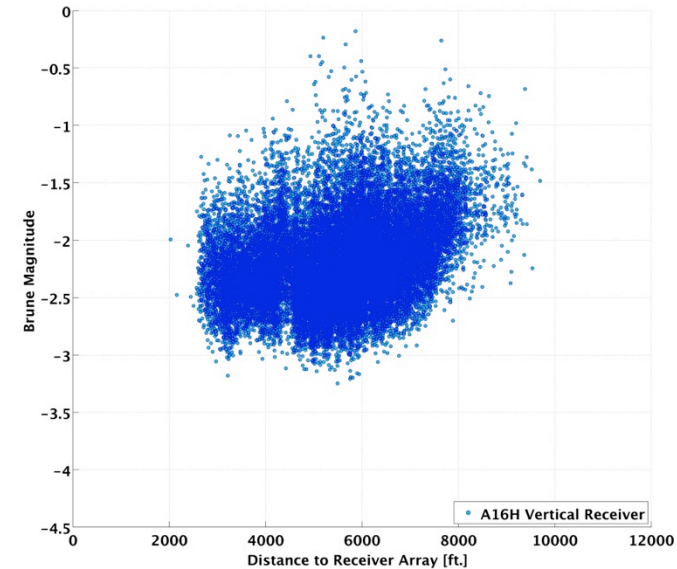
All Formations - Anadarko HFTS2 - AllWells - MultiWell Events Below 2.5ms



All Formations - Anadarko HFTS2 - AllWells - MultiWell Events Below 2.5ms



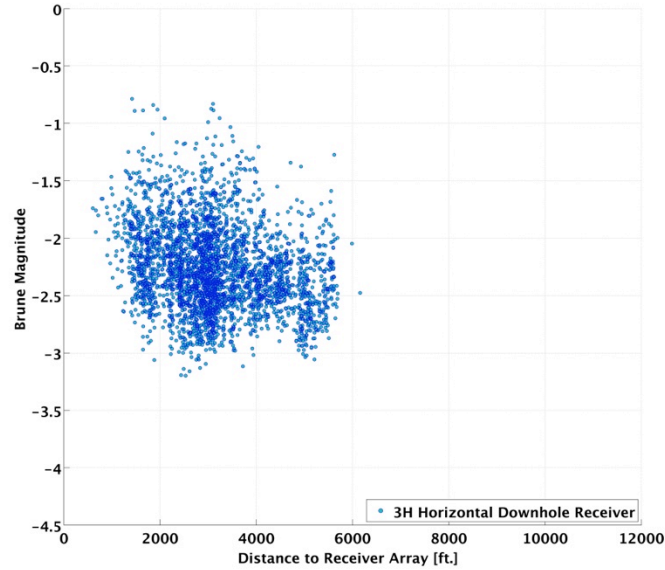
All Formations - Anadarko HFTS2 - AllWells - MultiWell Events Below 2.5ms



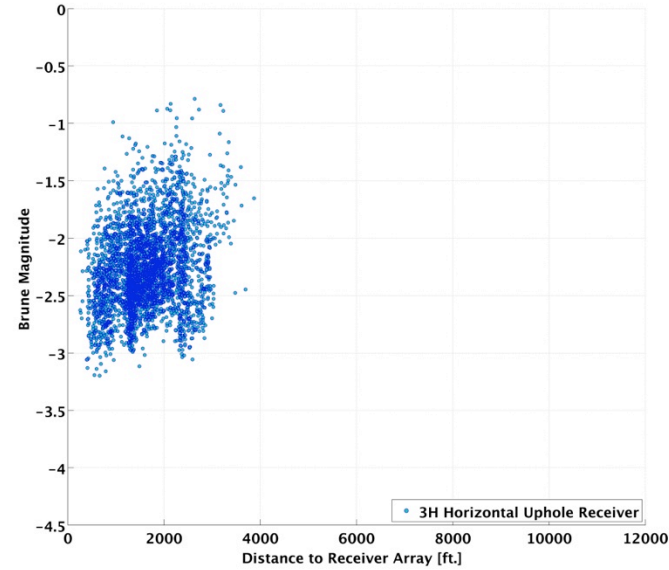
Magnitude vs. Distance Plots – Boxwood 1H

2.5ms Misfit cut-off + Multi-well only

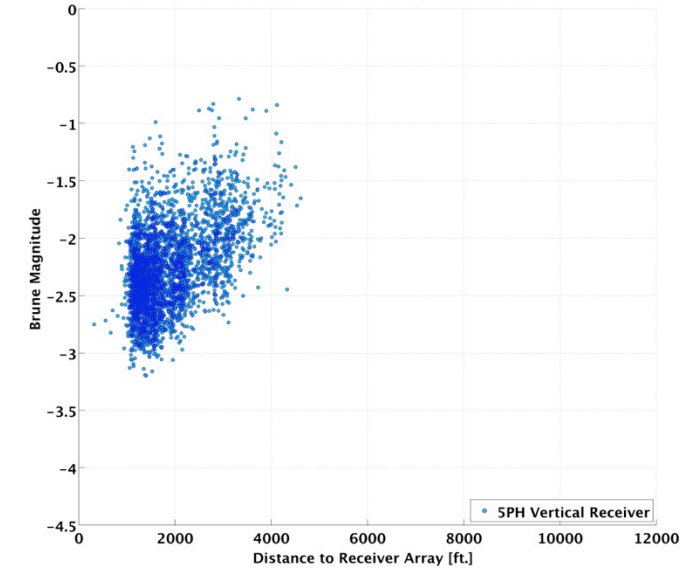
All Formations – Anadarko HFTS2 – Boxwood 1H – MultiWell Events Below 2.5ms



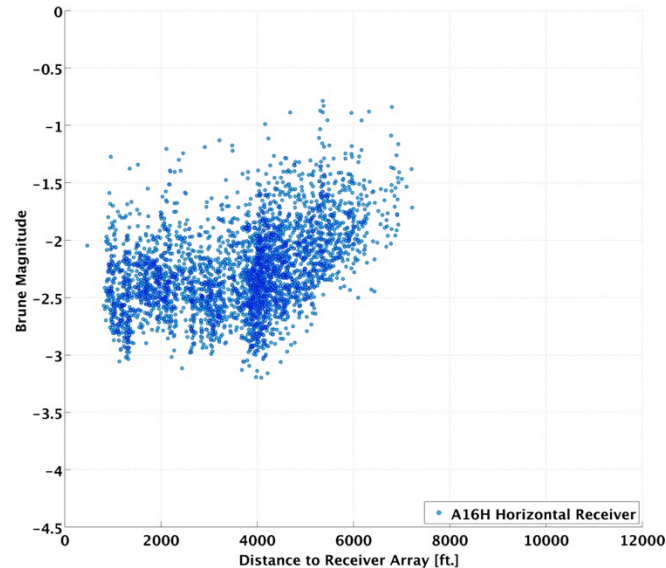
All Formations – Anadarko HFTS2 – Boxwood 1H – MultiWell Events Below 2.5ms



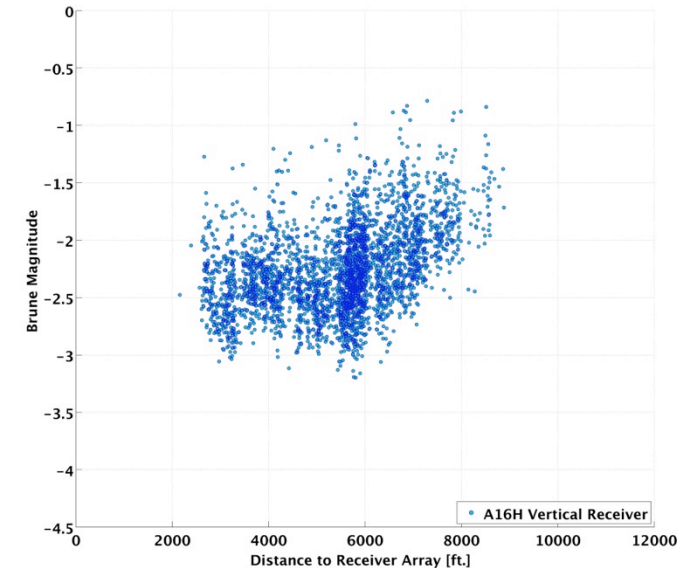
All Formations – Anadarko HFTS2 – Boxwood 1H – MultiWell Events Below 2.5ms



All Formations – Anadarko HFTS2 – Boxwood 1H – MultiWell Events Below 2.5ms



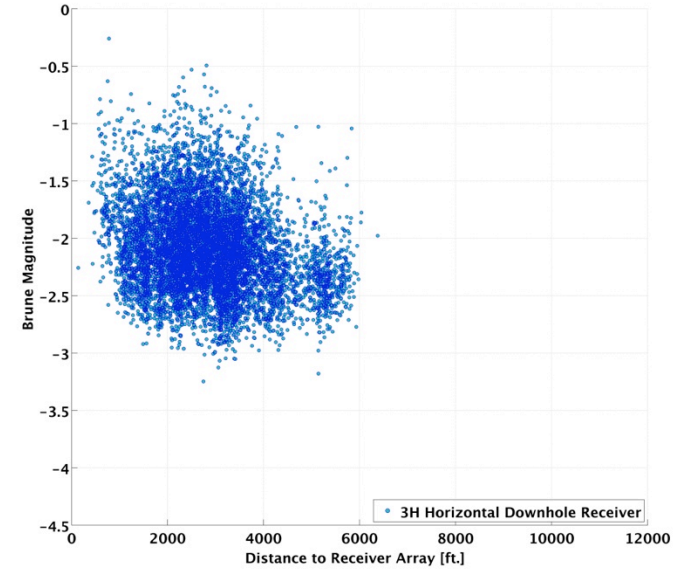
All Formations – Anadarko HFTS2 – Boxwood 1H – MultiWell Events Below 2.5ms



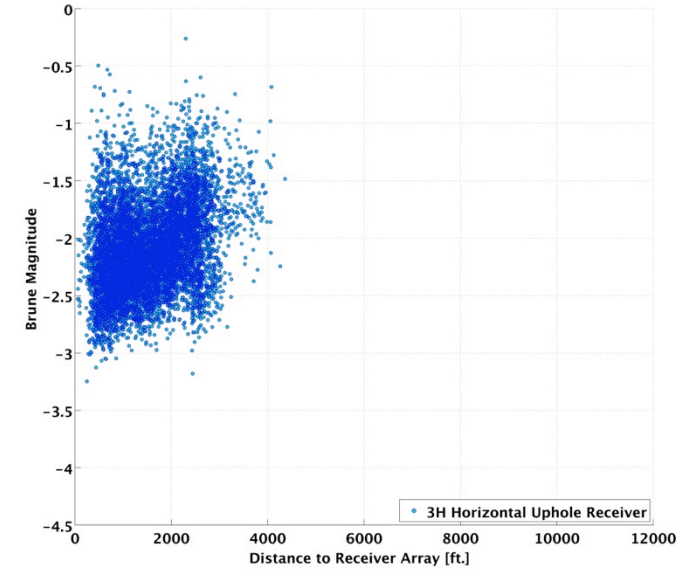
Magnitude vs. Distance Plots – Boxwood 2H

2.5ms Misfit cut-off + Multi-well only

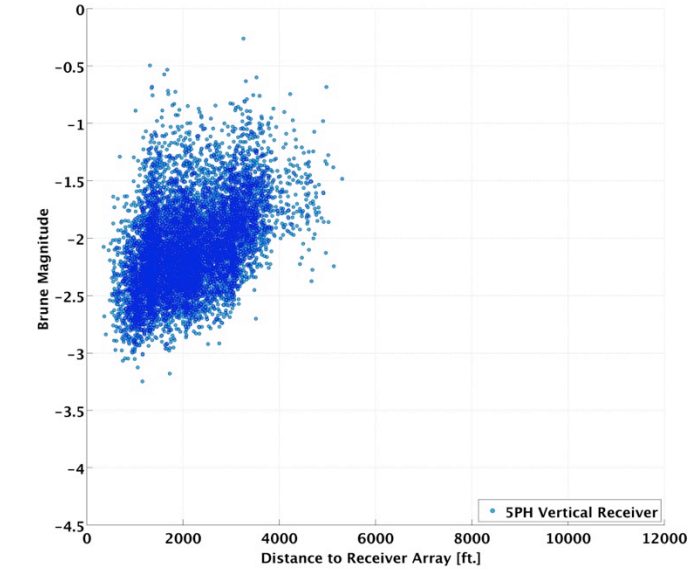
All Formations – Anadarko HFTS2 – Boxwood 2H – MultiWell Events Below 2.5ms



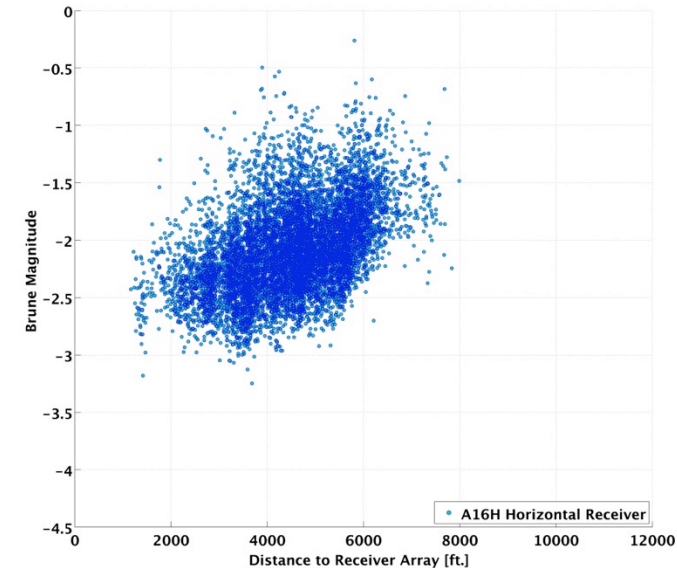
All Formations – Anadarko HFTS2 – Boxwood 2H – MultiWell Events Below 2.5ms



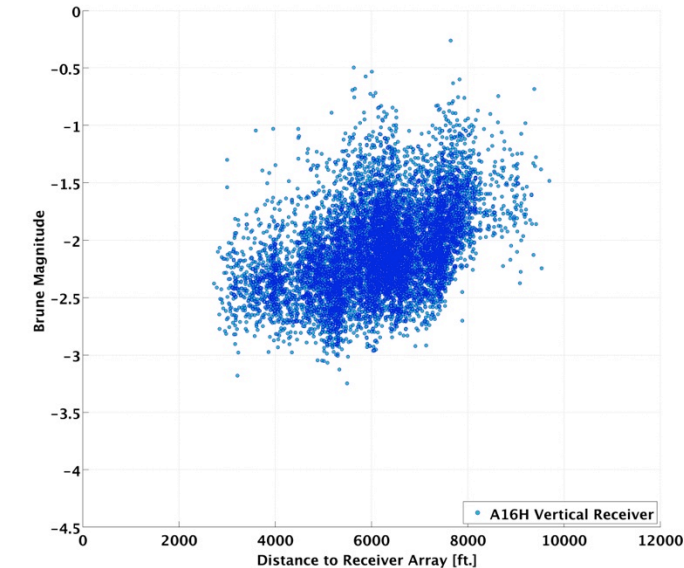
All Formations – Anadarko HFTS2 – Boxwood 2H – MultiWell Events Below 2.5ms



All Formations – Anadarko HFTS2 – Boxwood 2H – MultiWell Events Below 2.5ms



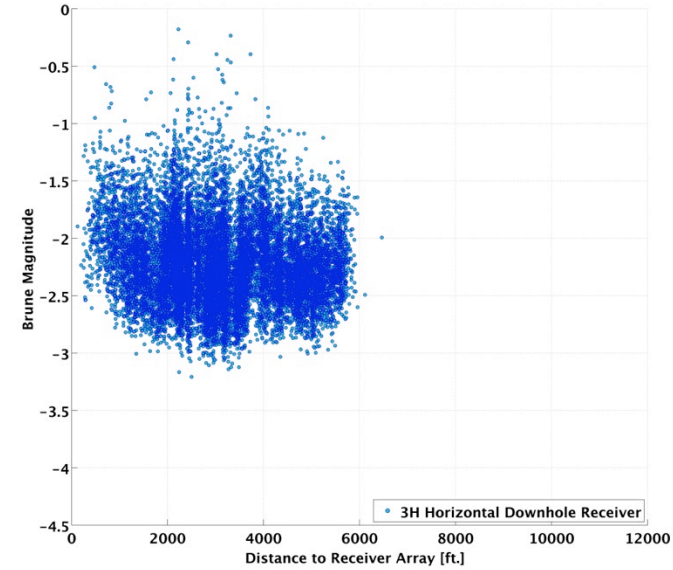
All Formations – Anadarko HFTS2 – Boxwood 2H – MultiWell Events Below 2.5ms



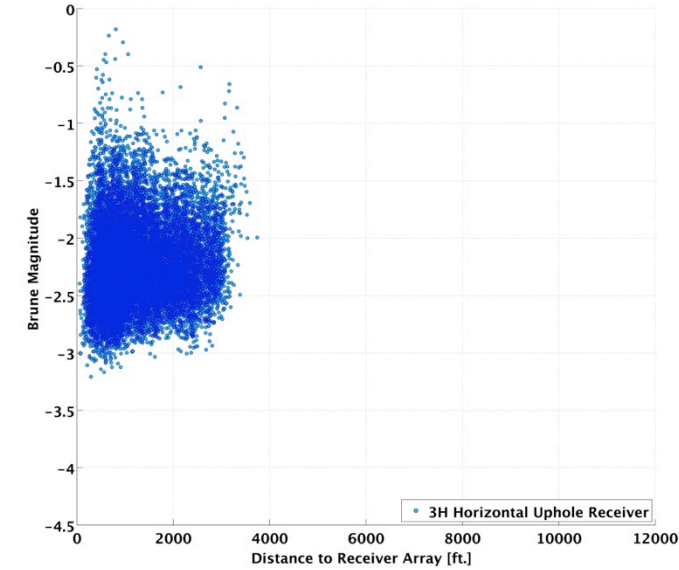
Magnitude vs. Distance Plots – Boxwood 4H

2.5ms Misfit cut-off + Multi-well only

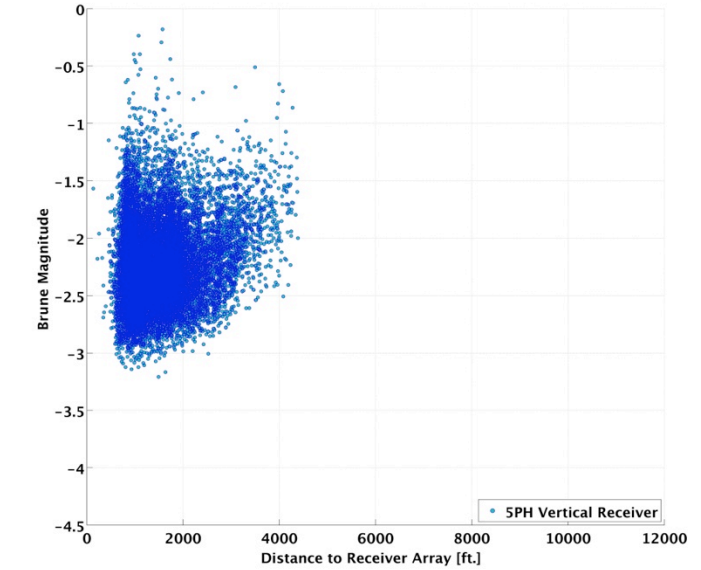
All Formations – Anadarko HFTS2 – Boxwood 4H – MultiWell Events Below 2.5ms



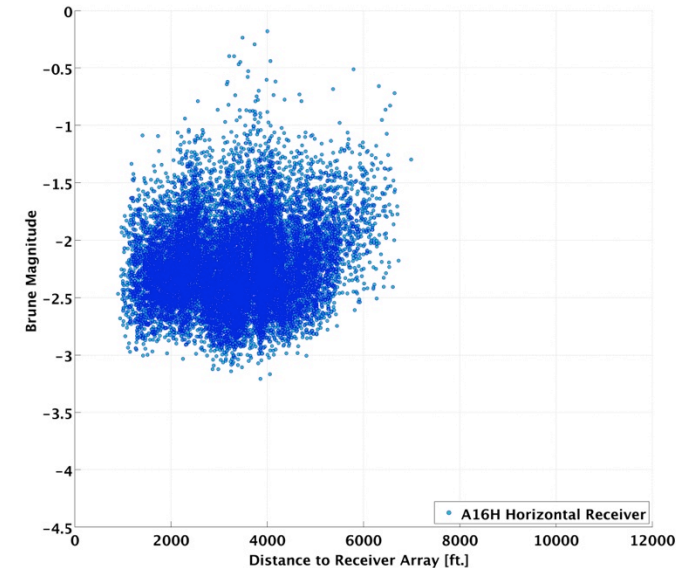
All Formations – Anadarko HFTS2 – Boxwood 4H – MultiWell Events Below 2.5ms



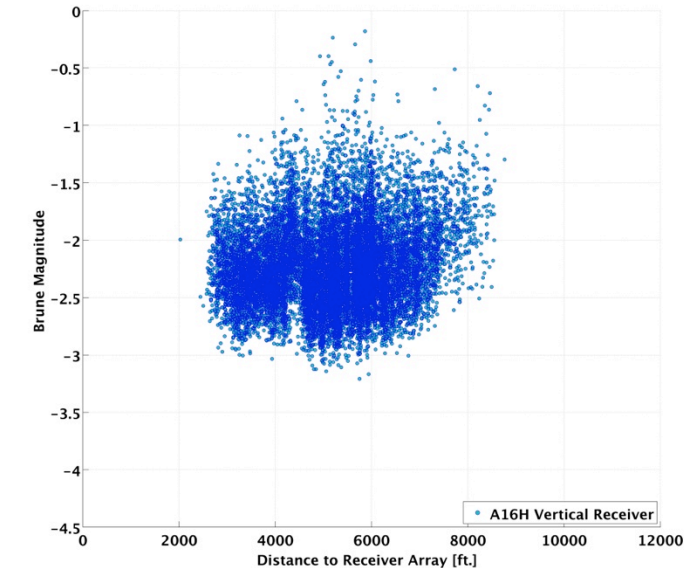
All Formations – Anadarko HFTS2 – Boxwood 4H – MultiWell Events Below 2.5ms



All Formations – Anadarko HFTS2 – Boxwood 4H – MultiWell Events Below 2.5ms

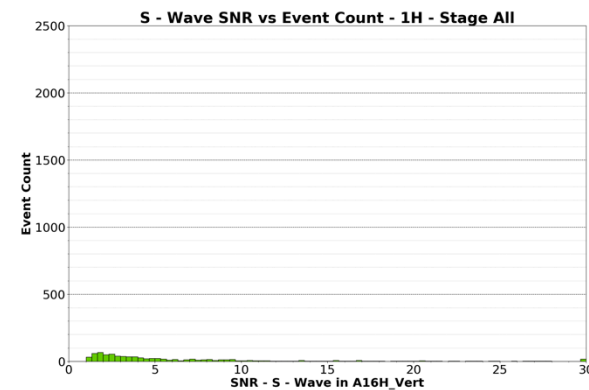
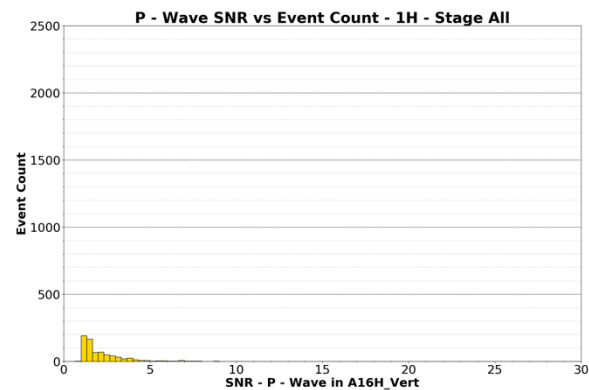
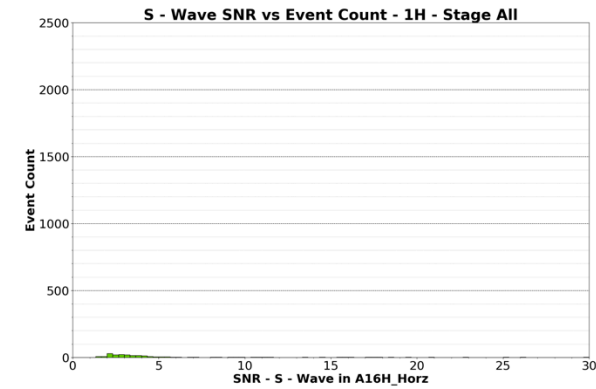
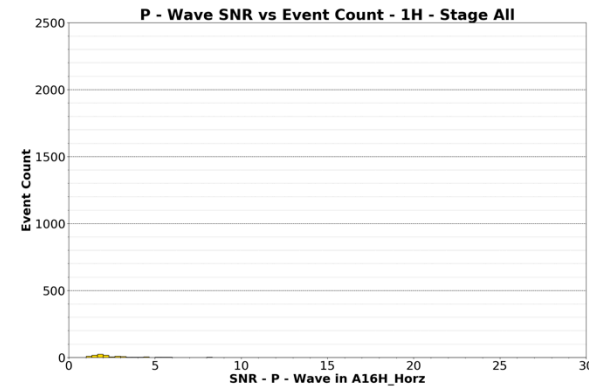
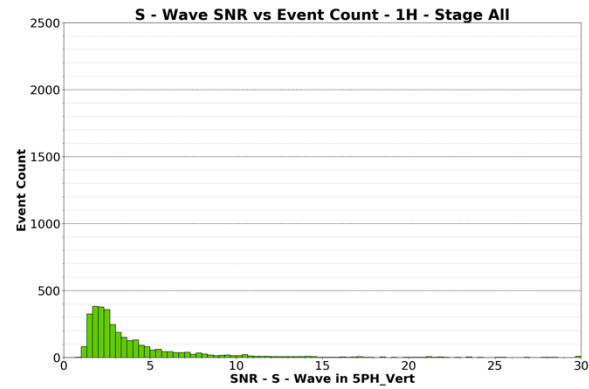
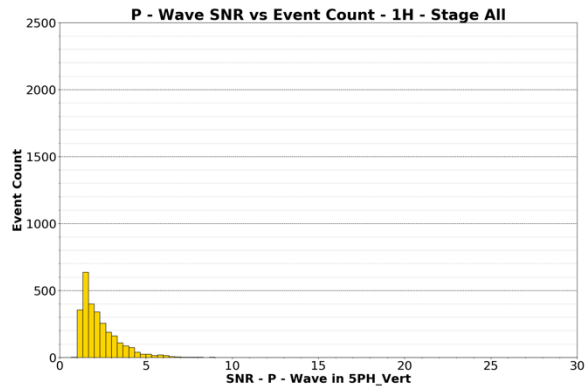
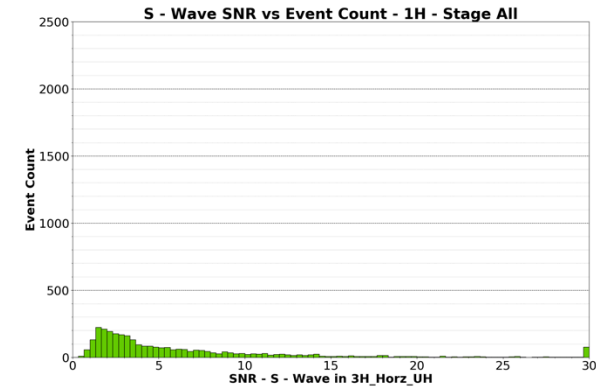
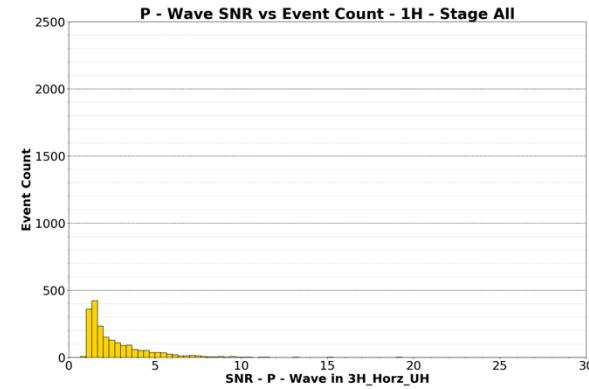
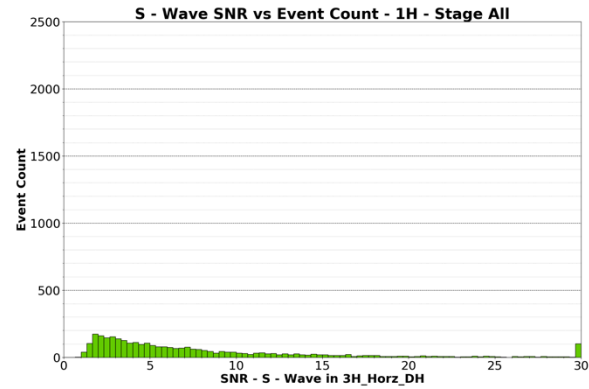
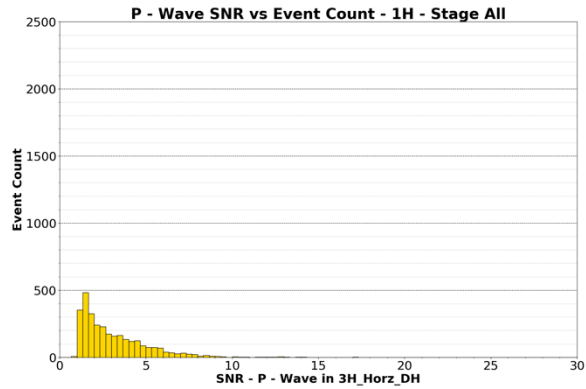


All Formations – Anadarko HFTS2 – Boxwood 4H – MultiWell Events Below 2.5ms



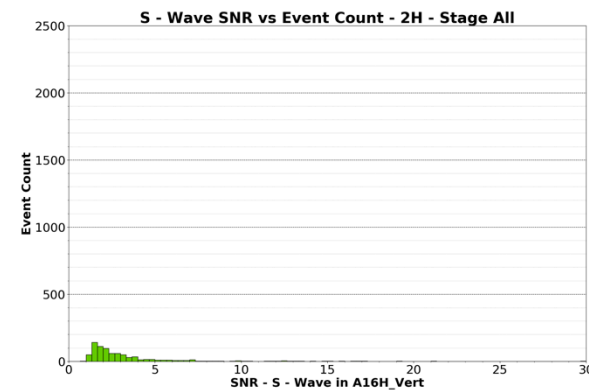
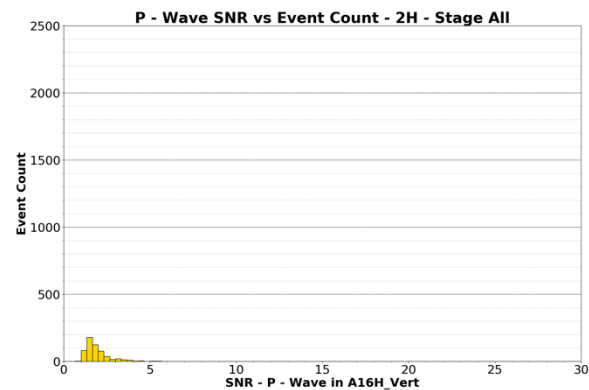
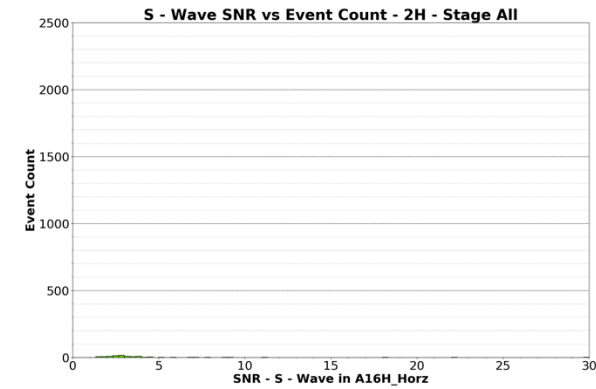
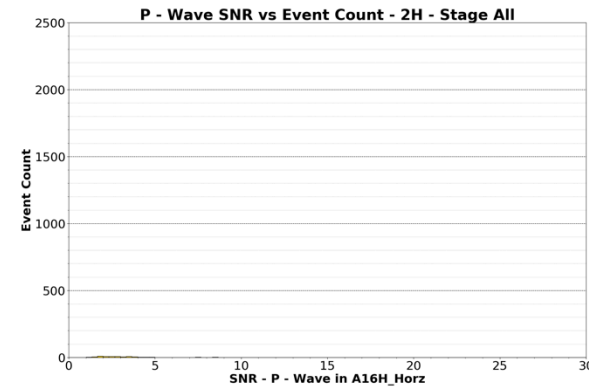
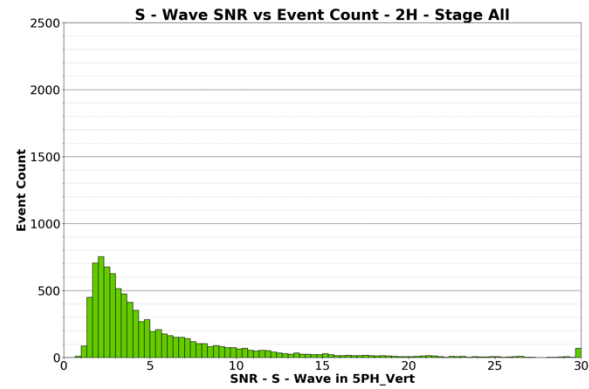
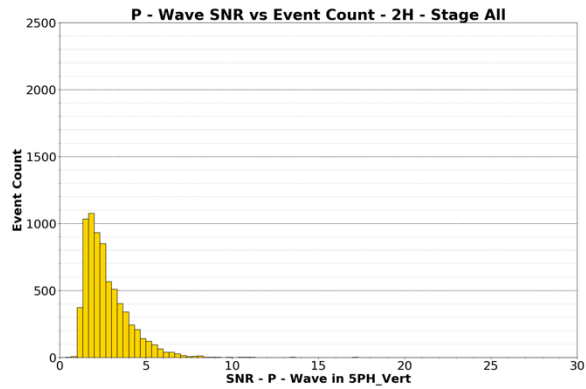
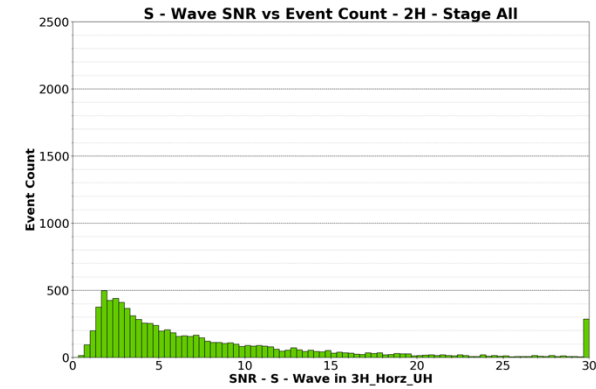
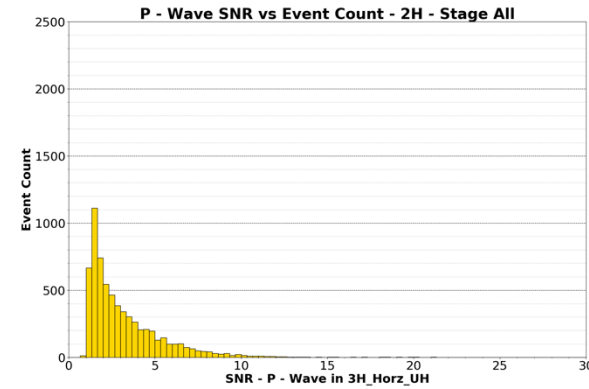
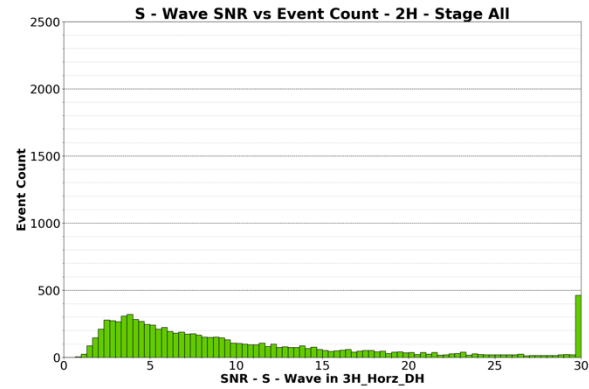
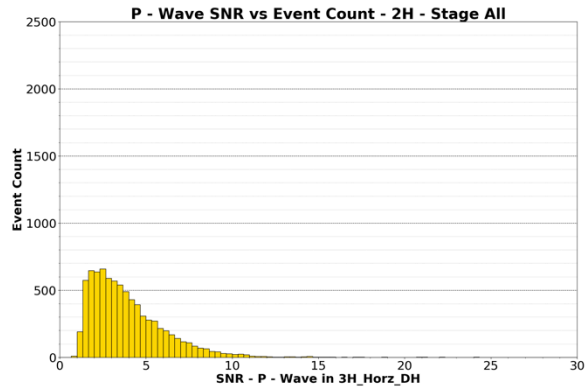
Signal-to-Noise Ratio – Boxwood 1H

2.5ms Misfit cut-off + Multi-well only



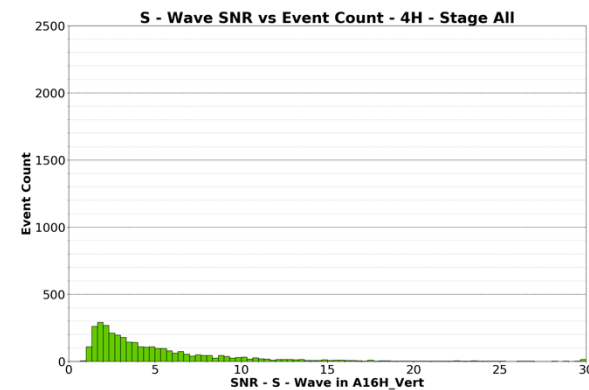
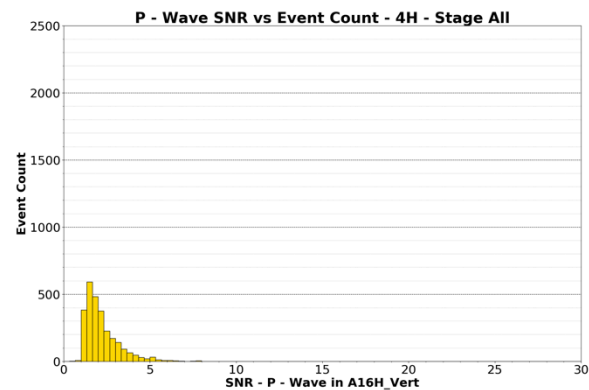
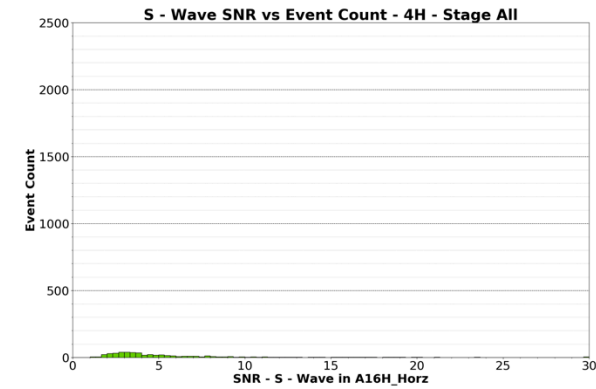
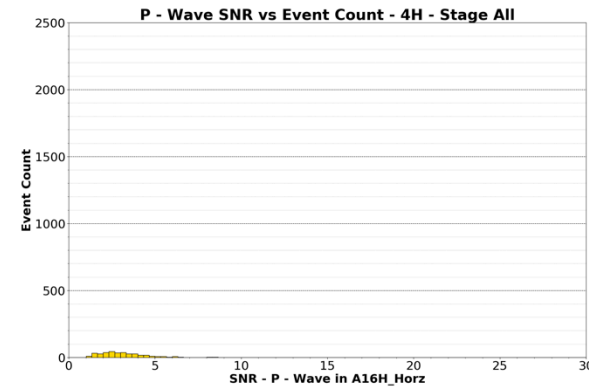
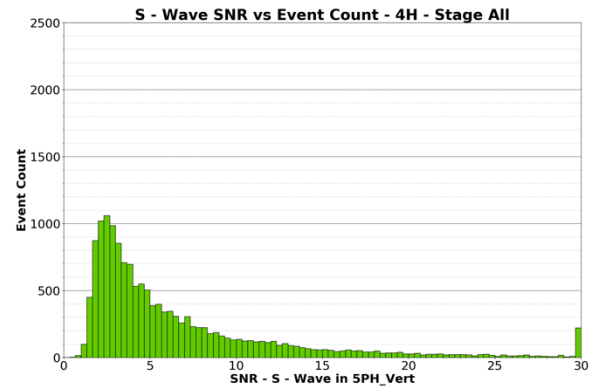
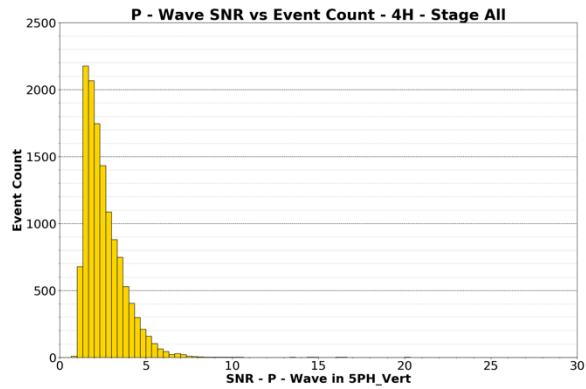
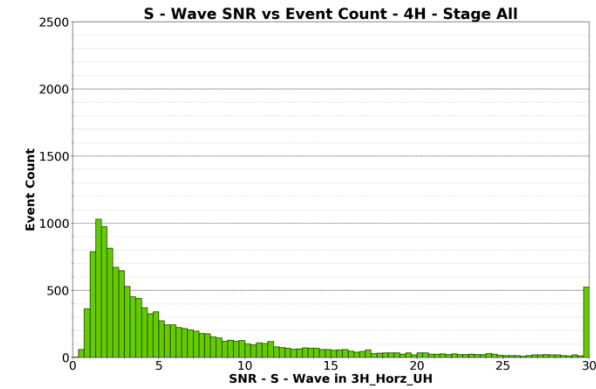
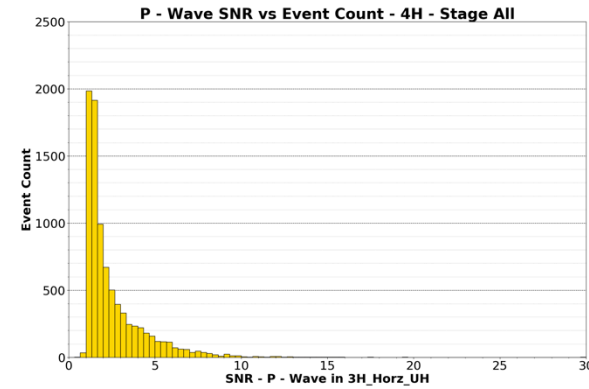
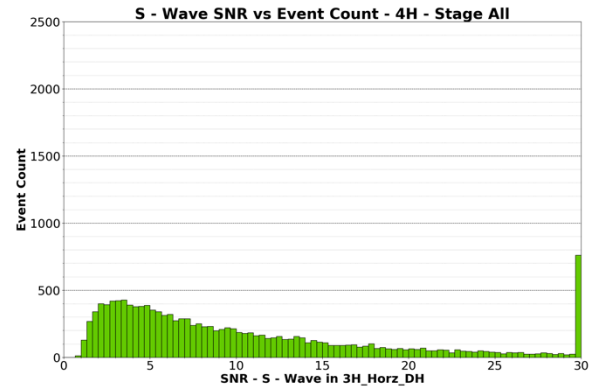
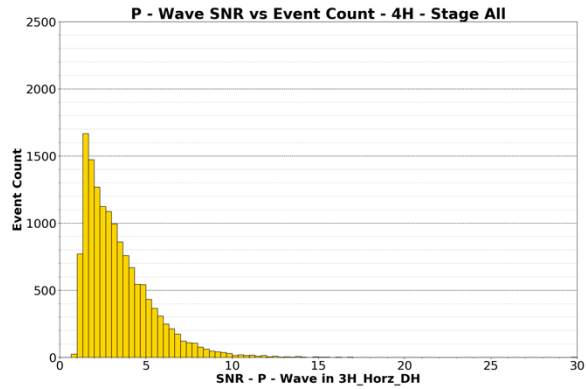
Signal-to-Noise Ratio – Boxwood 2H

2.5ms Misfit cut-off + Multi-well only



Signal-to-Noise Ratio – Boxwood 4H

2.5ms Misfit cut-off + Multi-well only

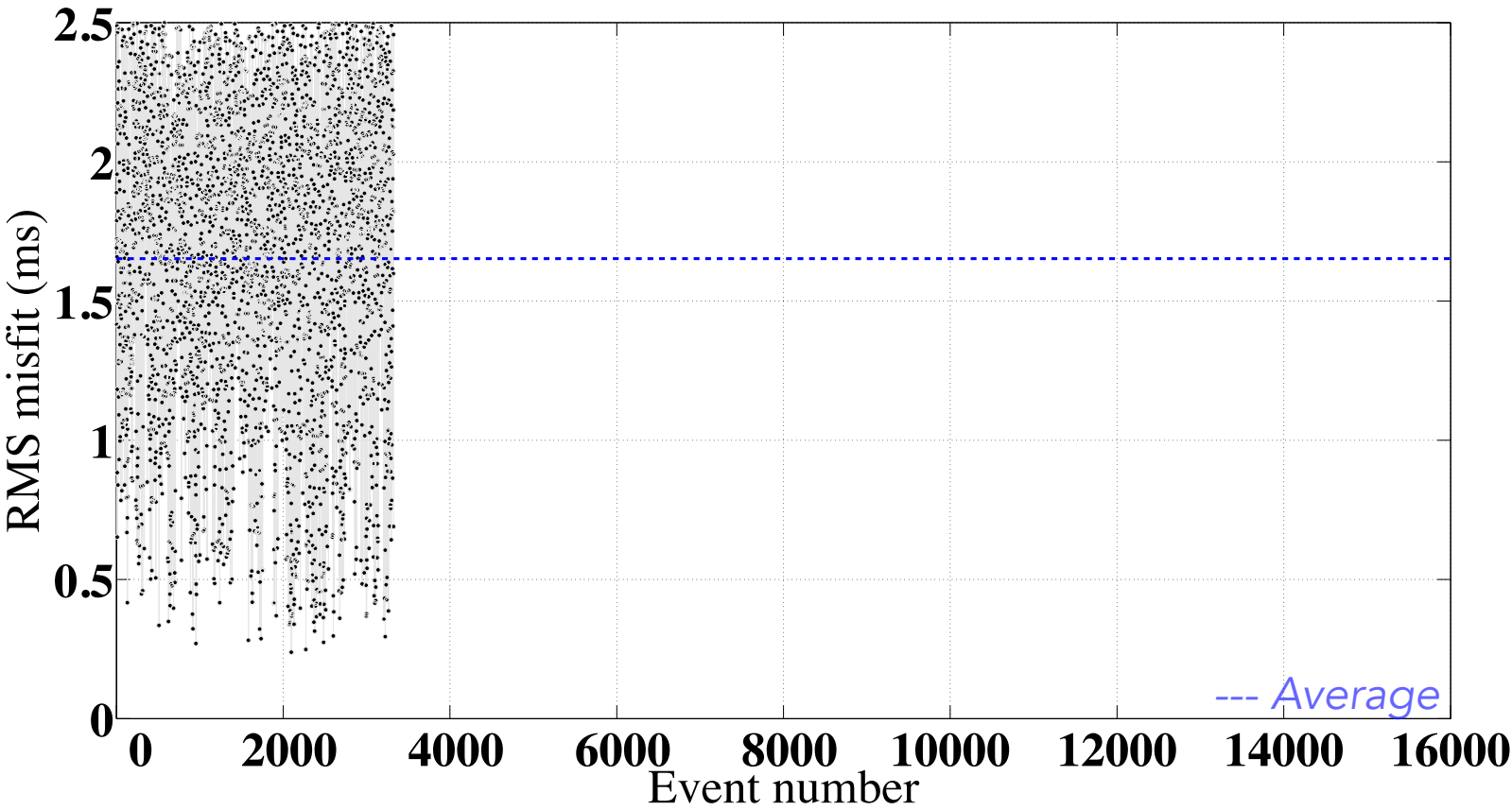




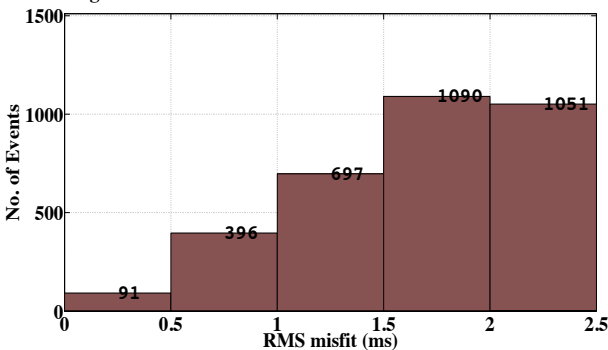
Statistics	
Total Located Events	3,736
Maximum Misfit	28.2105 ms
Minimum Misfit	0.23865 ms
Events with misfit below 2.5 ms	3,325
Mean misfit below 2.5 ms	1.6495 ms

The events misfit distribution over 10 ms behaves randomly. This may be due to inaccurate picking in conjunction with low SNR causing model time to be very off from picked times. While we believe events below 10 ms and greater than 2.5 ms can be improved through re-picking and refining velocity model, we do not believe the true outliers that are above 10 ms or that have extremely high misfit can be improved via such methods. For such reason, here we are presenting three histograms; events below 2.5 ms, below 10 ms, and for all events.

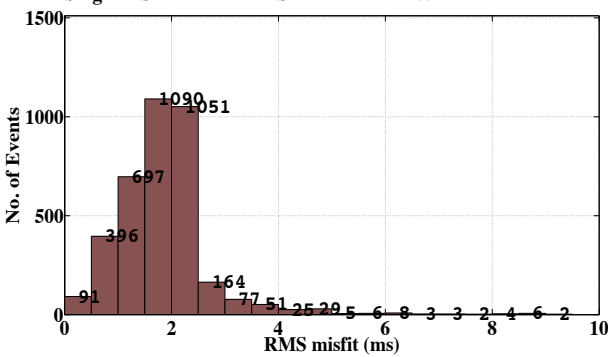
All Stages – Statistics of RMS Misfit – MultiWell Events



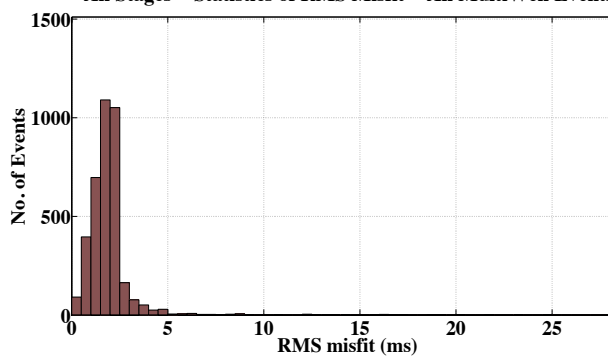
All Stages – Statistics of RMS Misfit – MultiWell Events below 2.5 ms.



All Stages – Statistics of RMS Misfit – MultiWell Events below 10 ms.



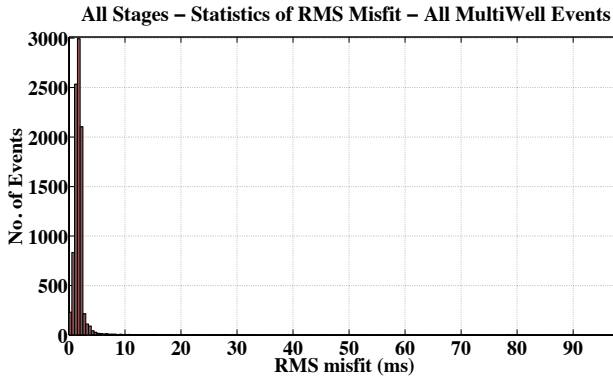
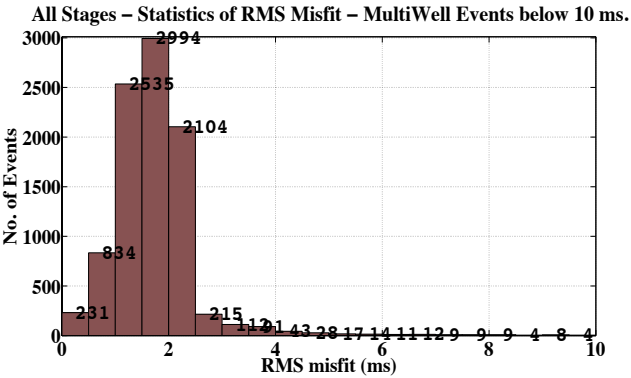
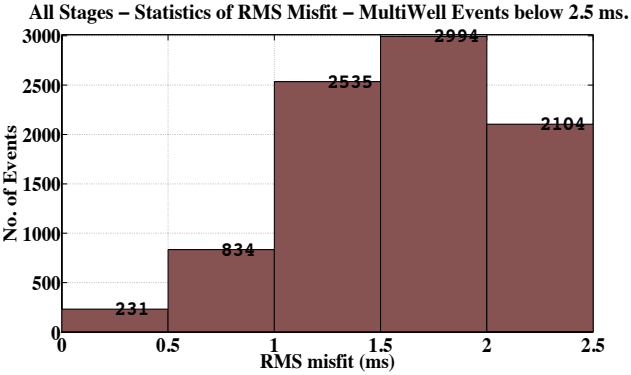
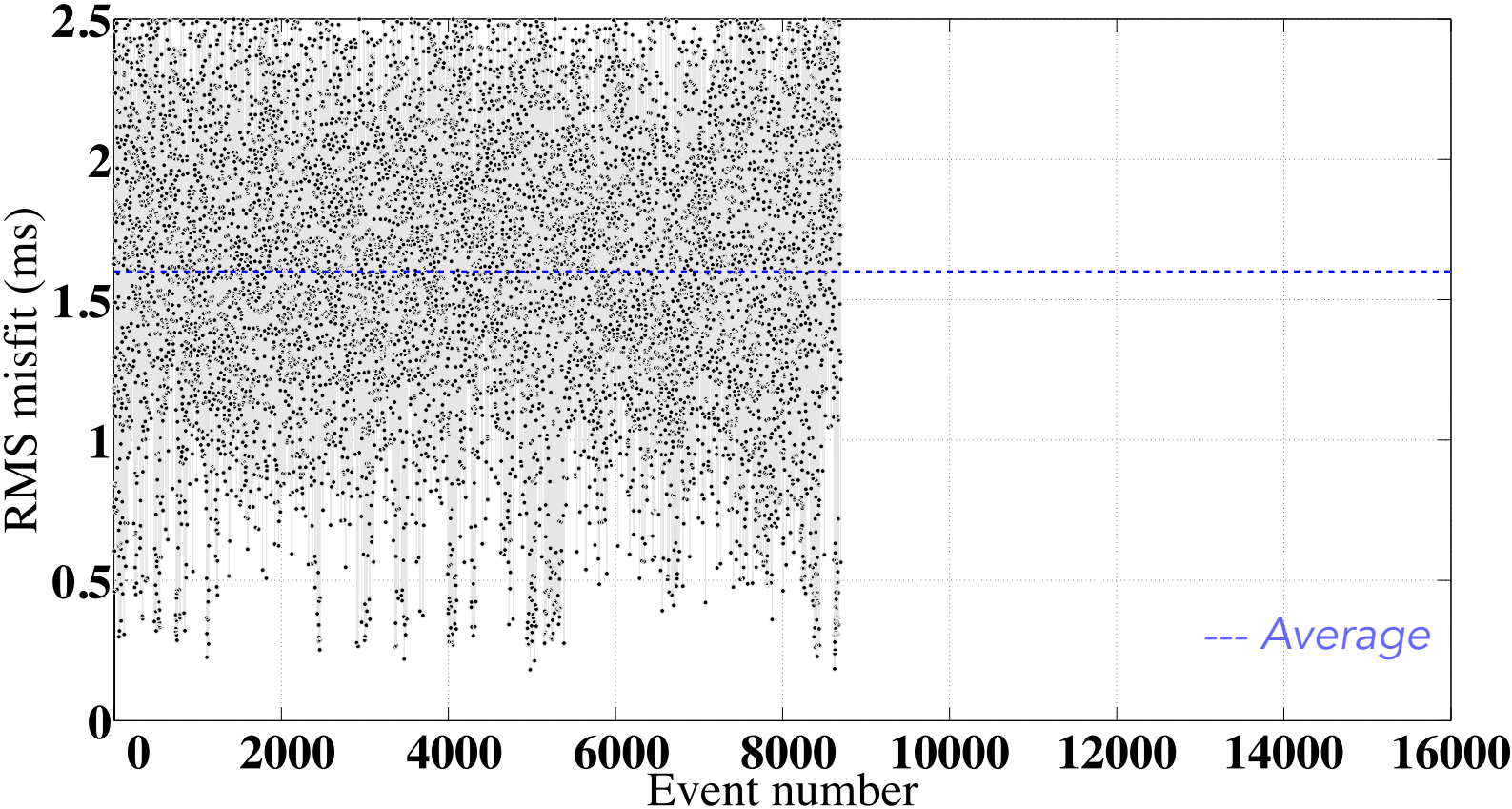
All Stages – Statistics of RMS Misfit – All MultiWell Events



Statistics	
Total Located Events	9,358
Maximum Misfit	97.8660 ms
Minimum Misfit	0.1817 ms
Events with misfit below 2.5 ms	8,698
Mean misfit below 2.5 ms	1.6001 ms

The events misfit distribution over 10 ms behaves randomly. This may be due to inaccurate picking in conjunction with low SNR causing model time to be very off from picked times. While we believe events below 10 ms and greater than 2.5 ms can be improved through re-picking and refining velocity model, we do not believe the true outliers that are above 10 ms or that have extremely high misfit can be improved via such methods. For such reason, here we are presenting three histograms; events below 2.5 ms, below 10 ms, and for all events.

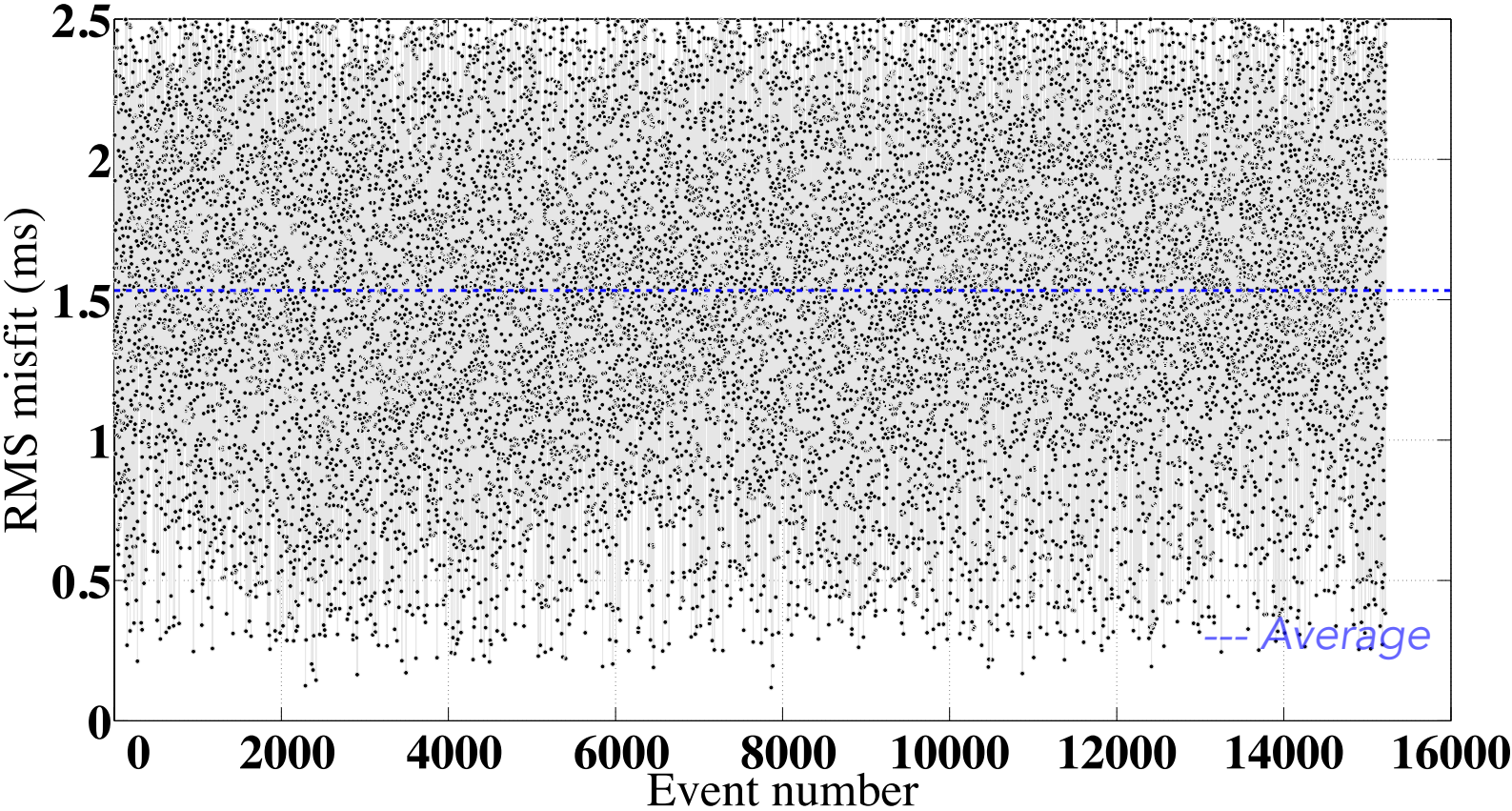
All Stages – Statistics of RMS Misfit – MultiWell Events



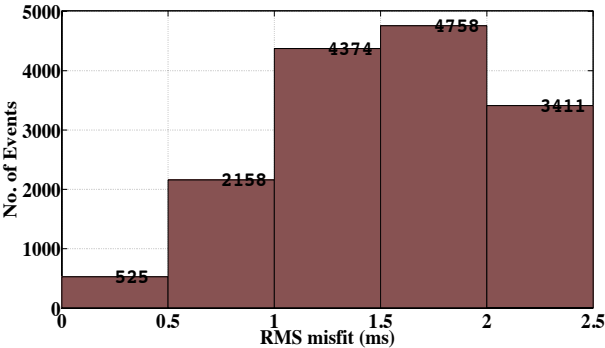
Statistics	
Total Located Events	17,075
Maximum Misfit	84.0231 ms
Minimum Misfit	0.1181 ms
Events with misfit below 2.5 ms	15,226
Mean misfit below 2.5 ms	1.5330 ms

The events misfit distribution over 10 ms behaves randomly. This may be due to inaccurate picking in conjunction with low SNR causing model time to be very off from picked times. While we believe events below 10 ms and greater than 2.5 ms can be improved through re-picking and refining velocity model, we do not believe the true outliers that are above 10 ms or that have extremely high misfit can be improved via such methods. For such reason, here we are presenting three histograms; events below 2.5 ms, below 10 ms, and for all events.

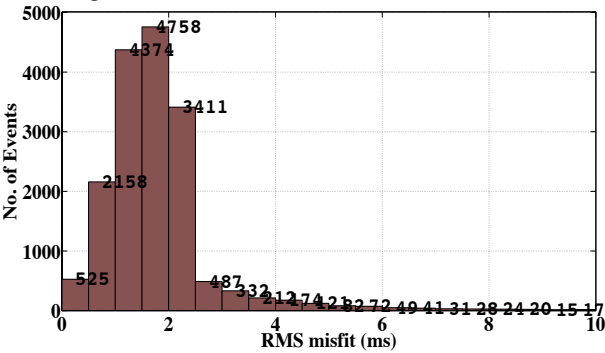
All Stages – Statistics of RMS Misfit – MultiWell Events



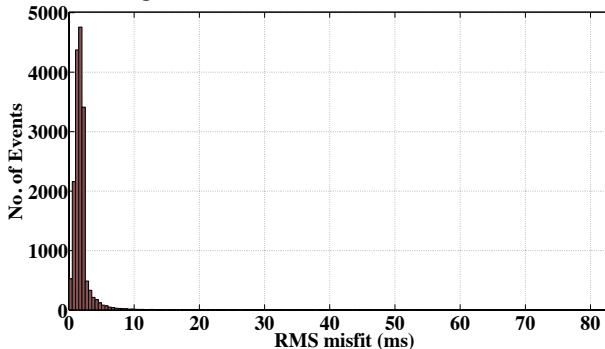
All Stages – Statistics of RMS Misfit – MultiWell Events below 2.5 ms.



All Stages – Statistics of RMS Misfit – MultiWell Events below 10 ms.



All Stages – Statistics of RMS Misfit – All MultiWell Events

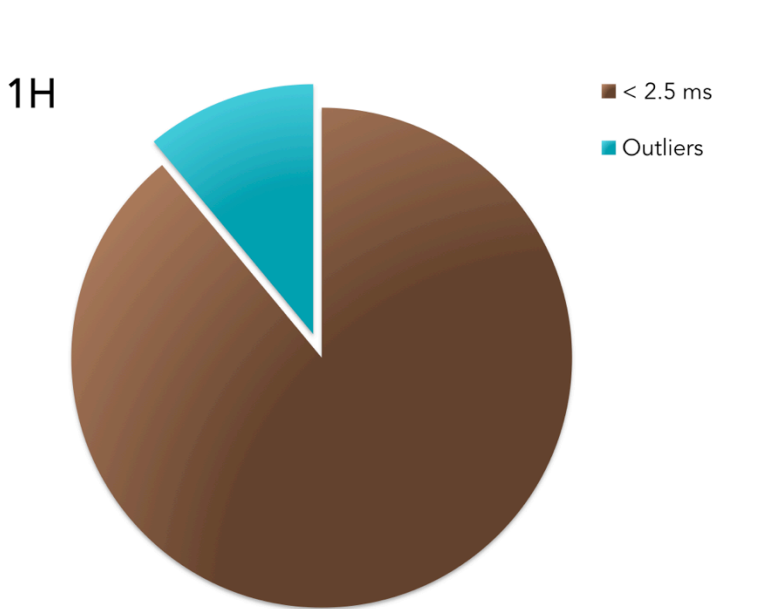
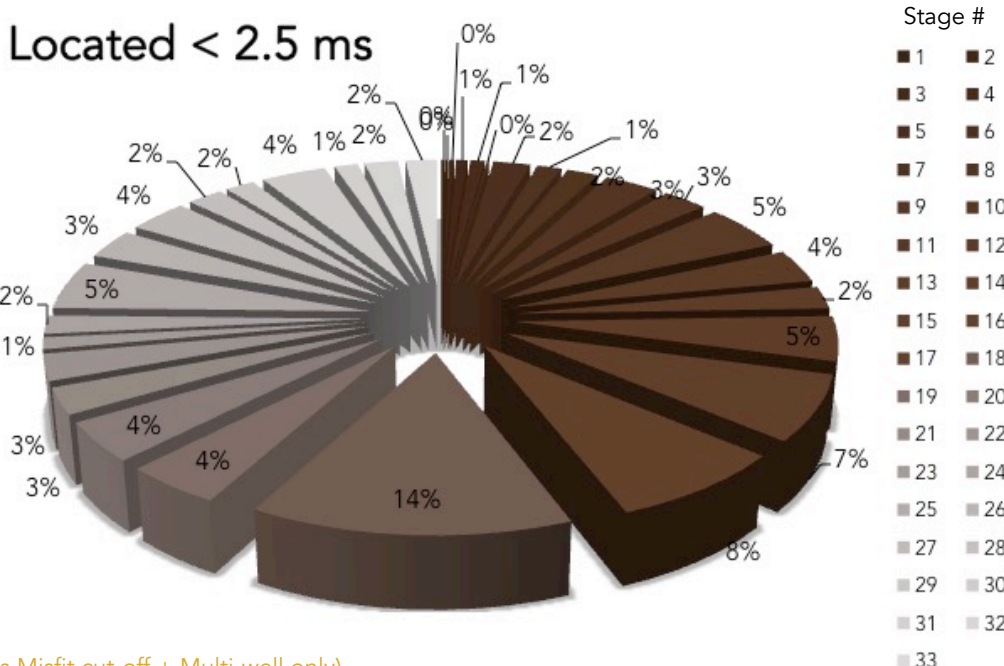
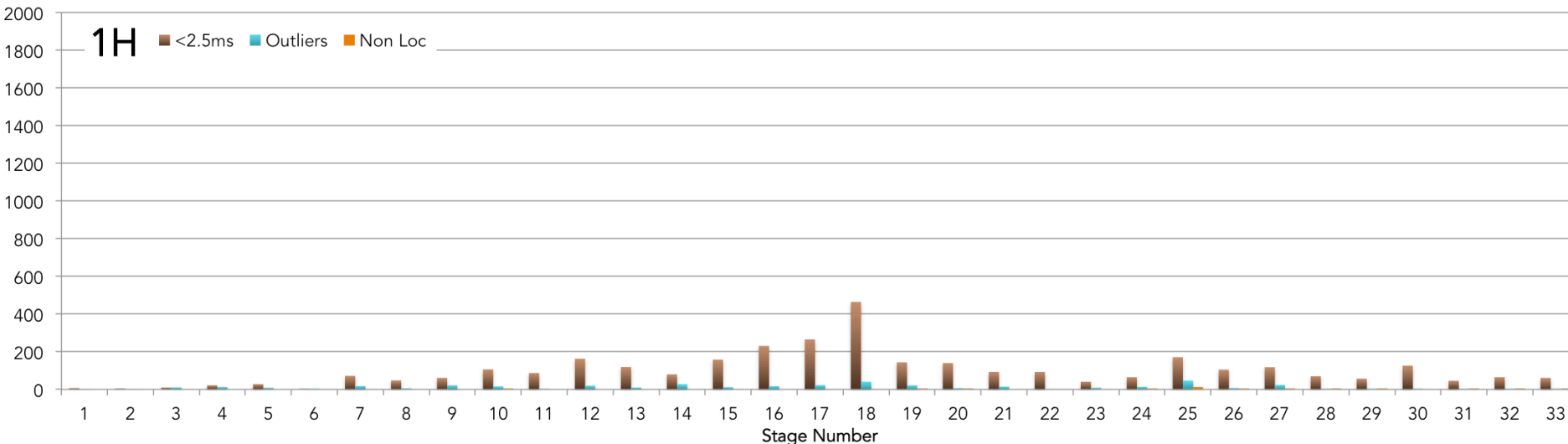


Boxwood 1H Outliers Review Statistics

2.5ms Misfit cut-off + Multi-well only

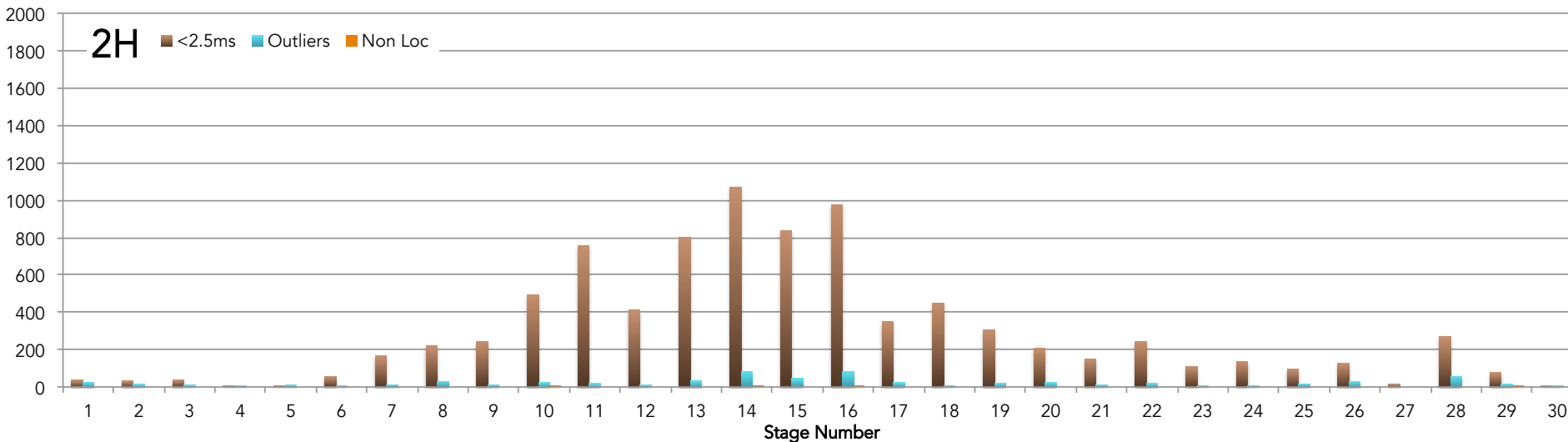


Boxwood 1H			
STAGE #	< 2.5 MS	OUTLIERS	NON-LOCATED
1	7	0	0
2	5	0	0
3	10	11	0
4	22	13	0
5	28	9	0
6	4	4	0
7	72	18	0
8	48	6	0
9	61	22	0
10	106	16	2
11	87	2	0
12	163	20	0
13	119	10	0
14	80	28	0
15	158	12	0
16	231	17	0
17	265	23	0
18	464	41	0
19	144	22	1
20	140	7	1
21	93	15	0
22	93	0	0
23	41	9	0
24	65	14	1
25	171	47	11
26	105	8	2
27	118	24	1
28	70	1	1
29	57	1	1
30	126	4	0
31	46	2	1
32	65	2	1
33	61	3	3
TOTAL	3,325	411	26

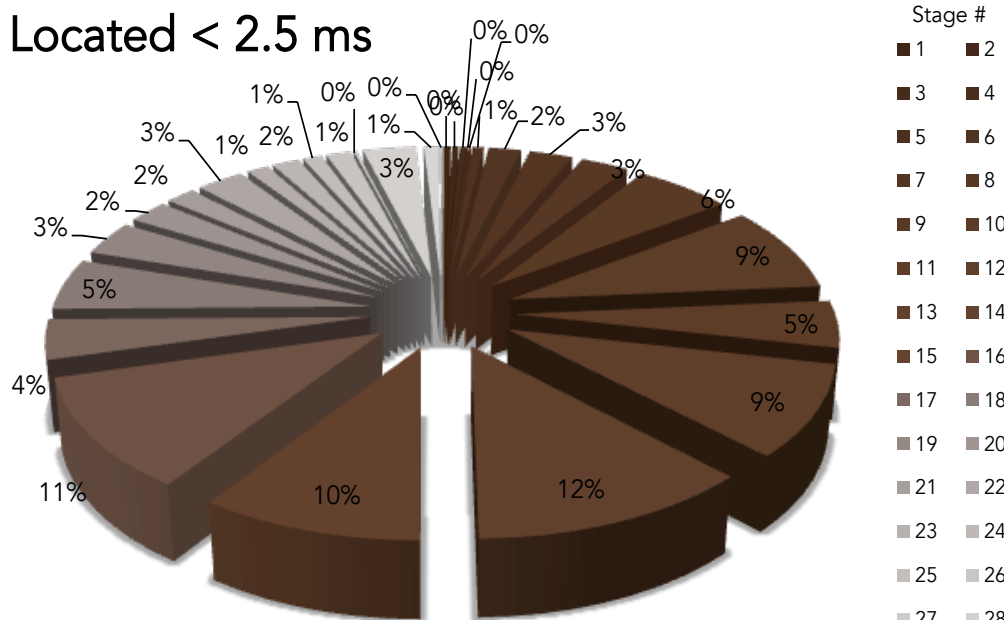


- TOTAL represent the total values for the 2H Treatment Well (2.5ms Misfit cut-off + Multi-well only).

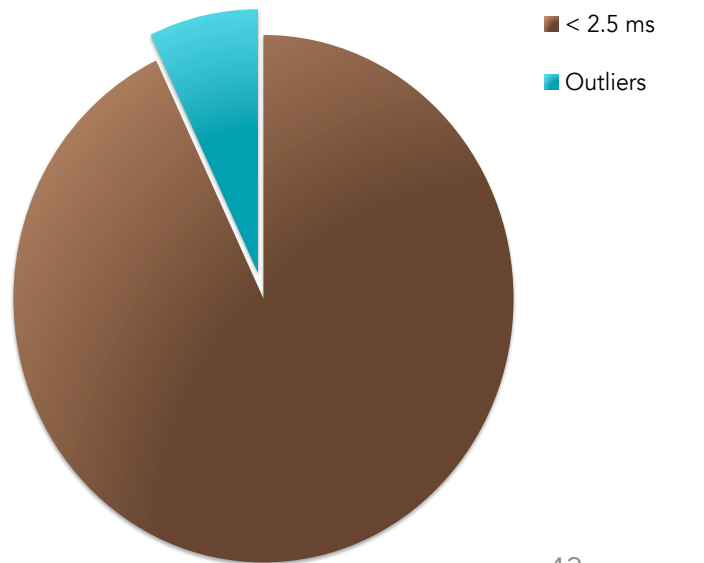
2H			
STAGE #	< 2.5 MS	OUTLIERS	NON-LOCATED
1	37	25	0
2	32	14	0
3	38	10	0
4	6	3	0
5	5	10	0
6	57	1	0
7	166	12	0
8	222	31	0
9	243	13	0
10	494	24	2
11	755	18	0
12	412	11	0
13	801	33	0
14	1071	82	2
15	837	45	0
16	978	83	1
17	349	25	0
18	451	8	0
19	304	20	0
20	206	25	0
21	151	12	0
22	243	20	0
23	111	4	0
24	137	5	0
25	96	17	0
26	127	29	0
27	15	0	0
28	270	58	0
29	77	15	1
30	7	8	0
31	-	-	-
32	-	-	-
33	-	-	-
TOTAL	8,698	661	6



Located < 2.5 ms



2H



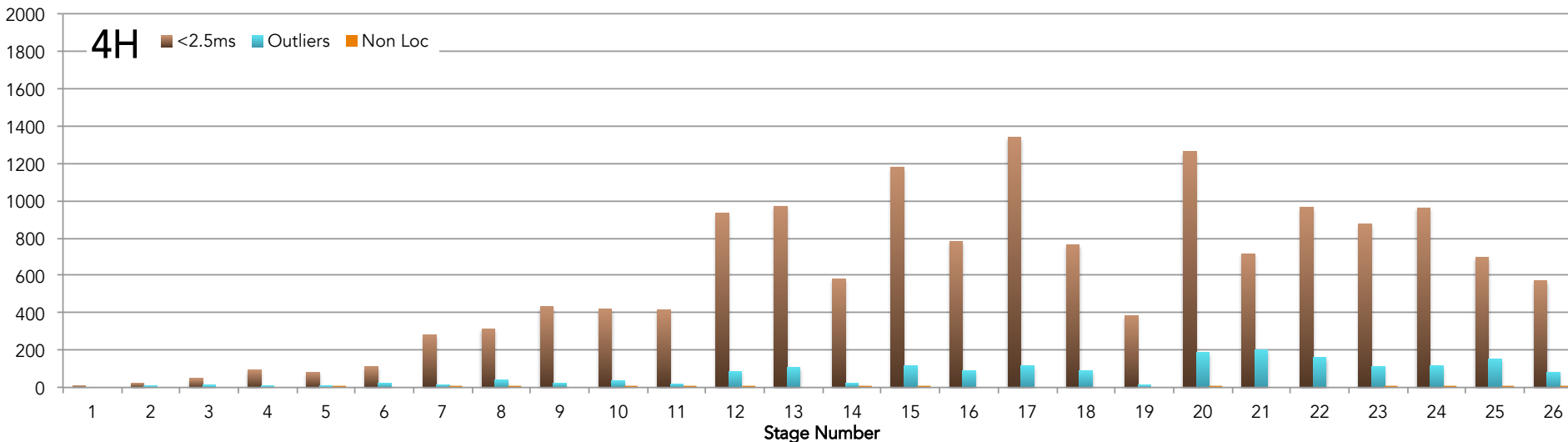
- TOTAL represent the total values for the 2H Treatment Well (2.5ms Misfit cut-off + Multi-well only).

Boxwood 4H Outliers Review Statistics

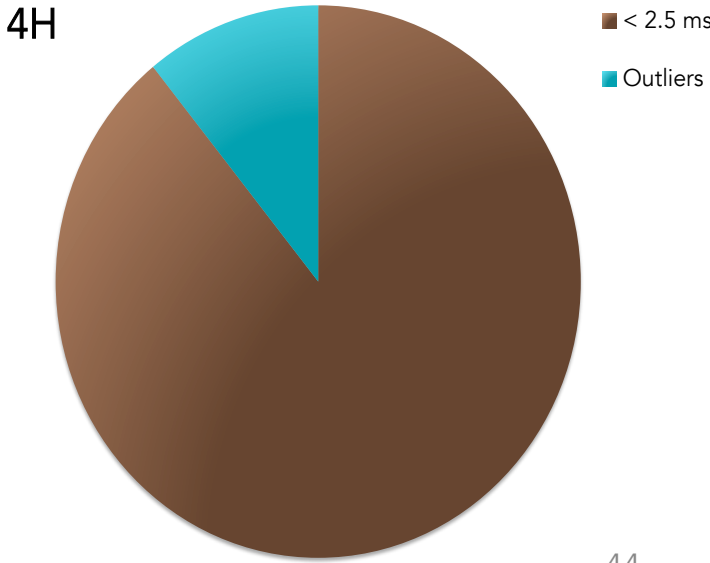
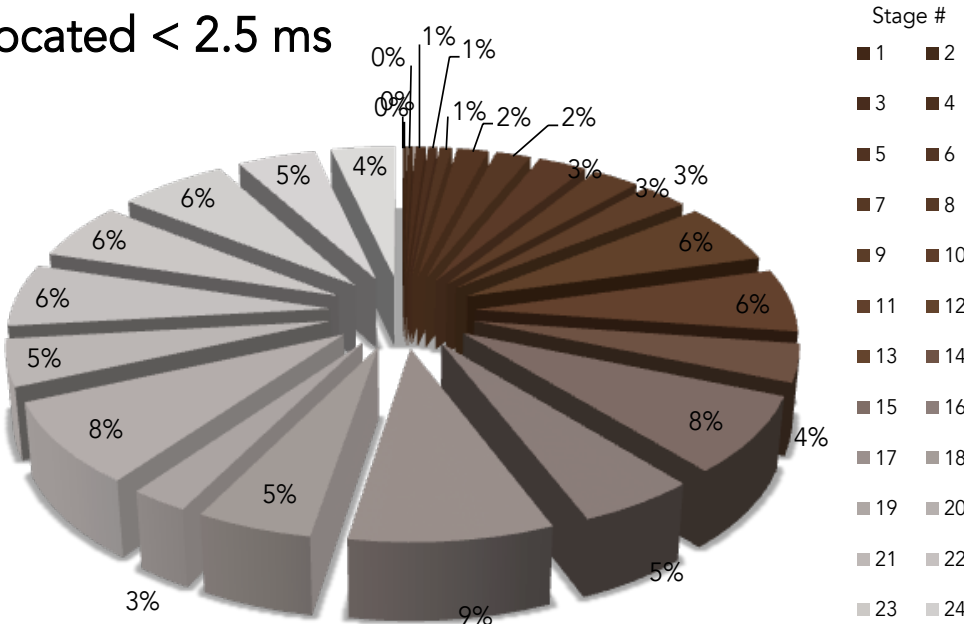
2.5ms Misfit cut-off + Multi-well only



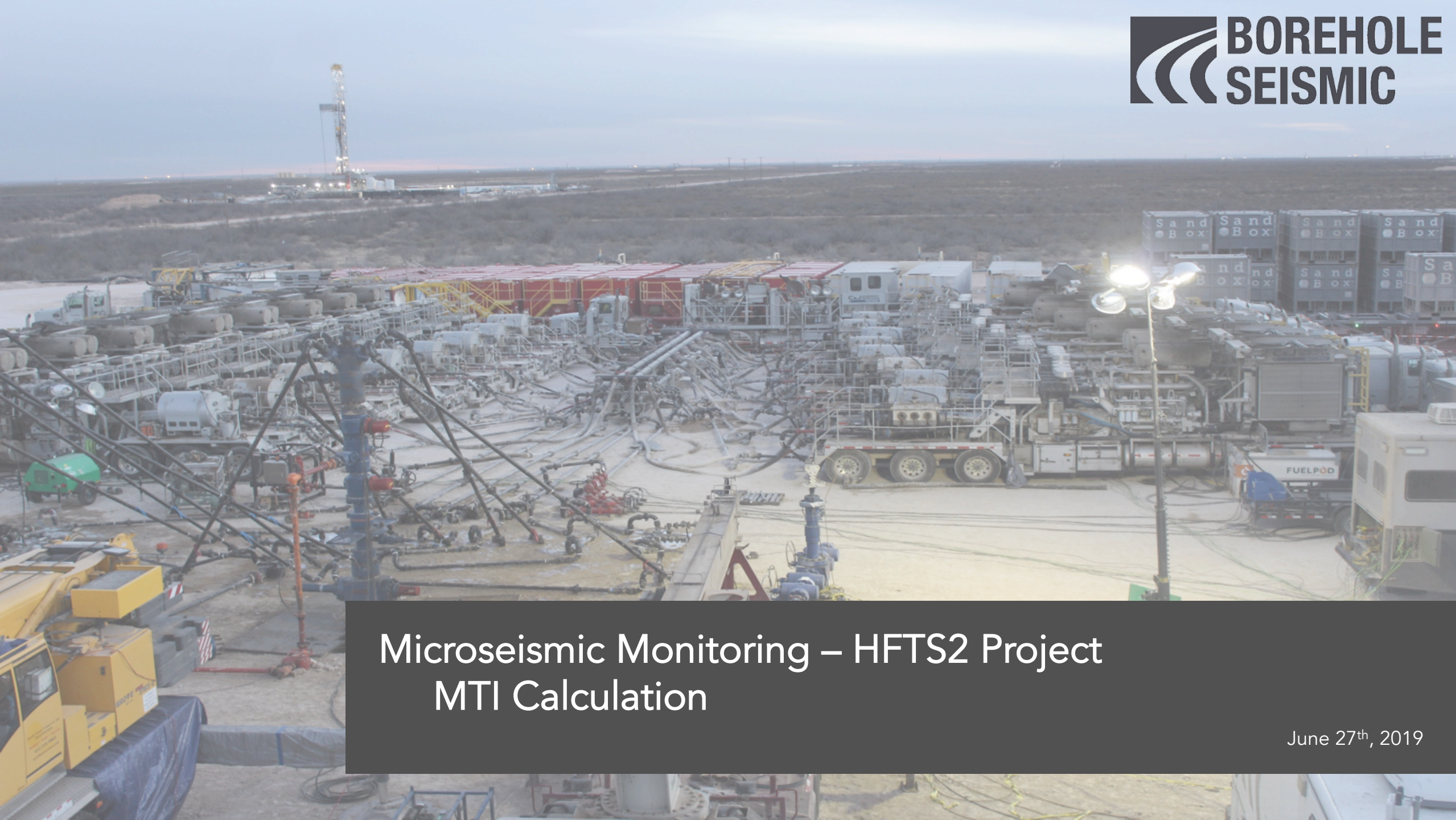
4H			
STAGE #	< 2.5 MS	OUTLIERS	NON-LOCATED
1	10	0	0
2	25	6	0
3	48	12	0
4	95	8	0
5	81	7	2
6	111	24	0
7	281	16	3
8	315	41	1
9	433	25	0
10	421	37	1
11	418	20	4
12	934	85	1
13	970	107	0
14	581	24	1
15	1178	117	3
16	783	89	0
17	1341	116	0
18	764	88	0
19	386	13	0
20	1263	186	4
21	716	202	0
22	963	160	0
23	876	114	2
24	962	117	1
25	699	152	6
26	572	83	12
27	-	-	-
28	-	-	-
29	-	-	-
30	-	-	-
31	-	-	-
32	-	-	-
33	-	-	-
TOTAL	15,226	1,849	41



Located < 2.5 ms



- TOTAL represent the total values for the 4H Treatment Well (2.5ms Misfit cut-off + Multi-well only).



Microseismic Monitoring – HFTS2 Project MTI Calculation

June 27th, 2019

- The amplitude is automatically picked by searching after the direct P- and S-wave arrivals within a window. The sample that give the largest indicator function $F(t)$ will be selected:

$$F(t) = \text{linearity of hodogram } (t) * \text{absolute amplitude } (t)$$

- The searching process utilize the 3-component data: hodogram is repeatedly calculated in between direct arrival and every points within the searching window, where highest linearity combined with the largest amplitude indicates the correct peak amplitude of direct arrivals.
- Once the amplitude of direct arrivals are obtained. The moment tensor is calculated by the least-square inversion:

$$m = G^{-1}d$$

- Where m is the moment tensor, G is the calculated amplitude from ray-tracing, and d is the picked amplitude. The same velocity model for locating events are used for MTI.



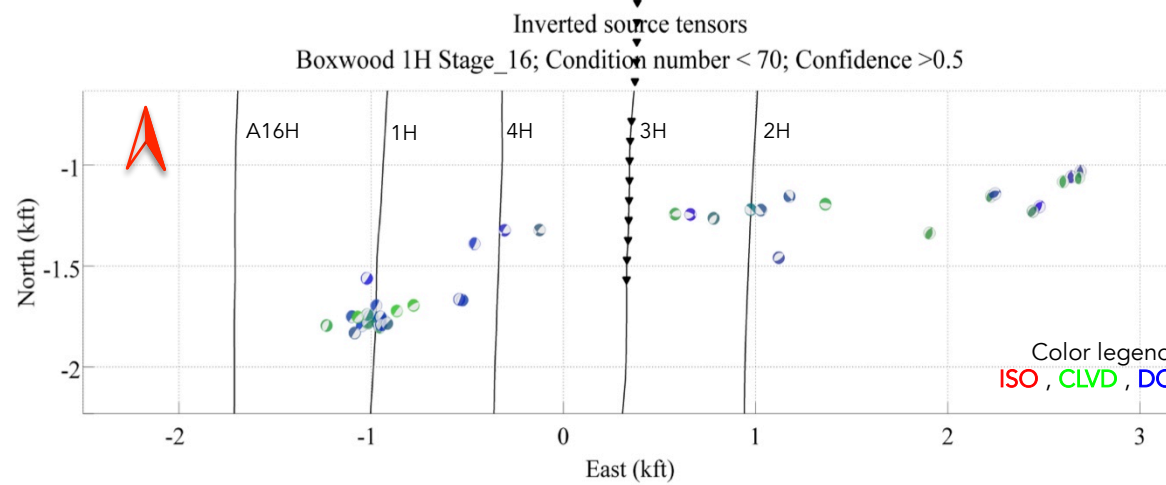
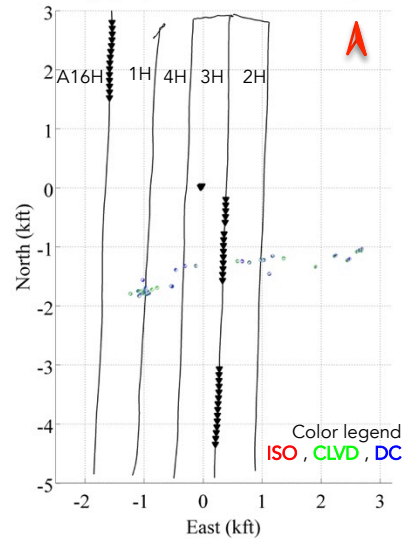
Microseismic Monitoring – HFTS2 Project MTI Report – Boxwood 1H – Stage 16

June 27th, 2019

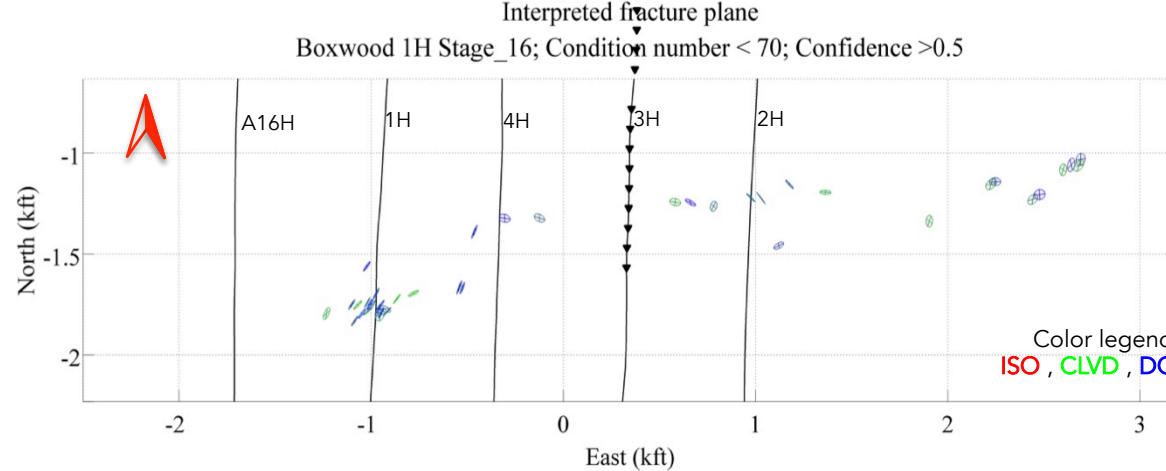
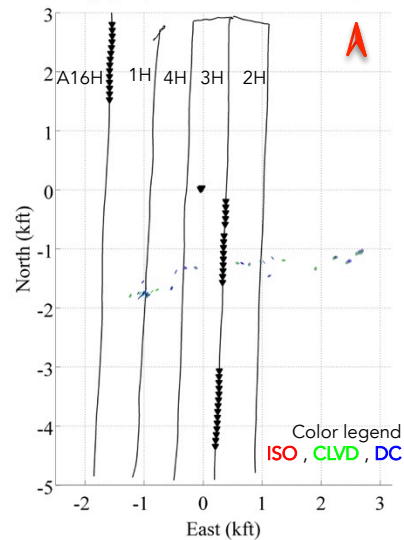
MTI Results Source Tensor – Boxwood 1H – Stage 16

Beach Ball, Crack Plots & Hudson Plot

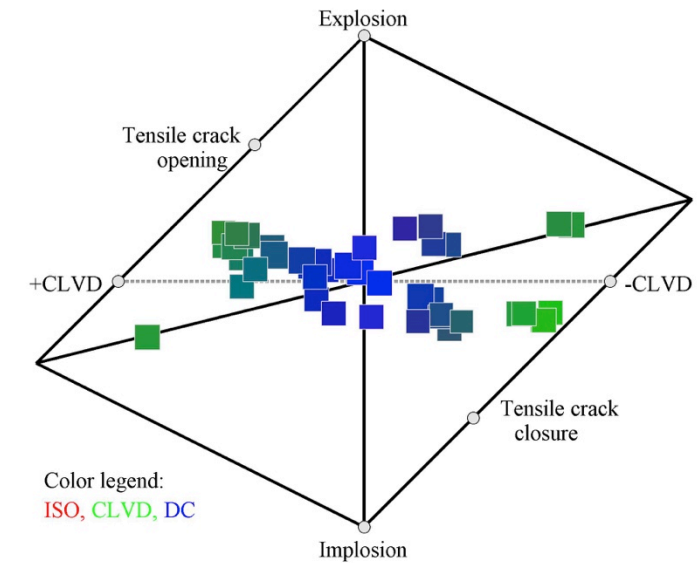
▼ Inverted source tensors
Boxwood 1H Stage_16; Condition number < 70; Confidence > 0.5



▼ Interpreted fracture plane
Boxwood 1H Stage_16; Condition number < 70; Confidence > 0.5

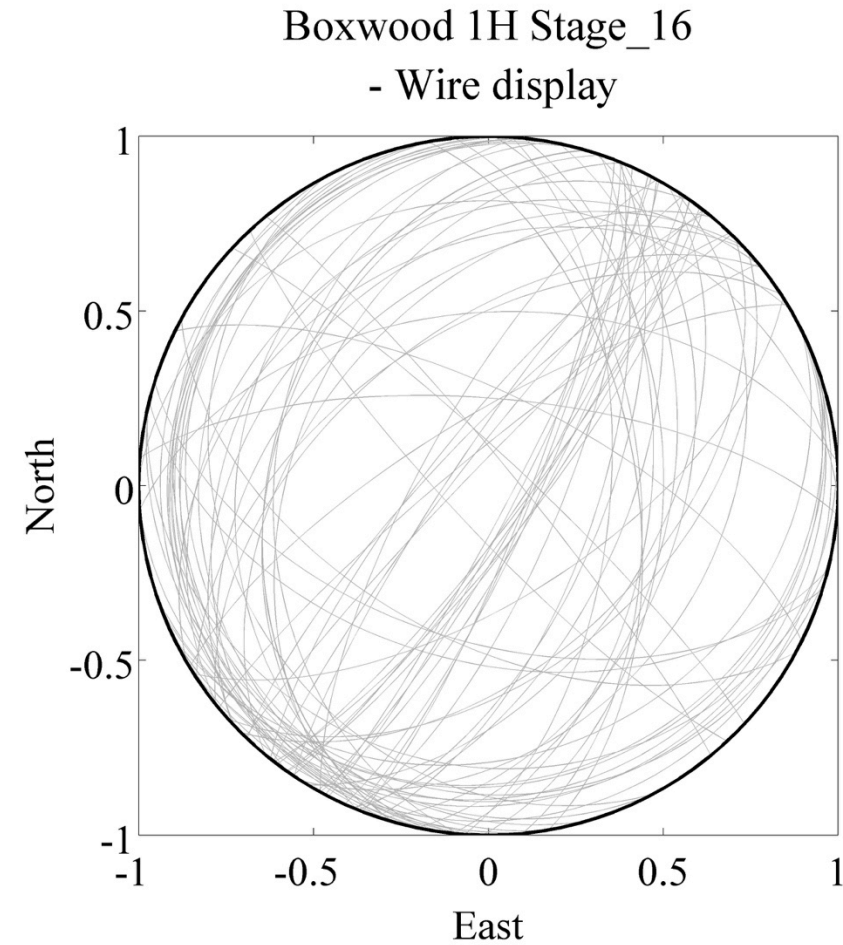
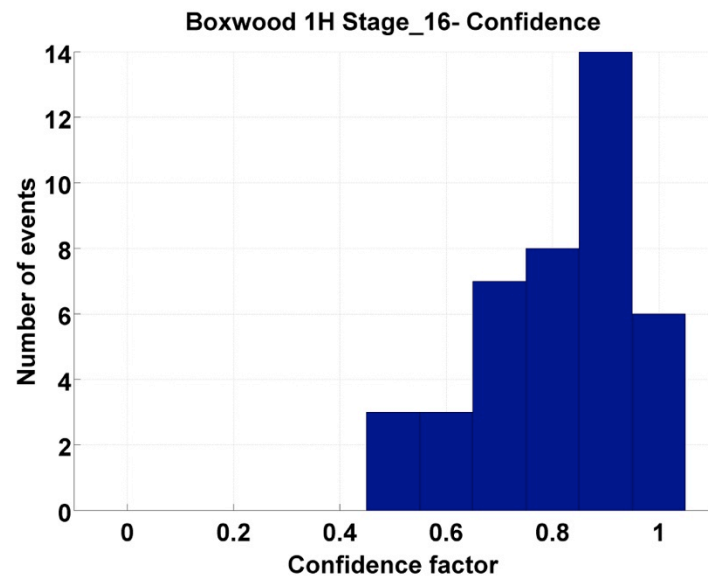
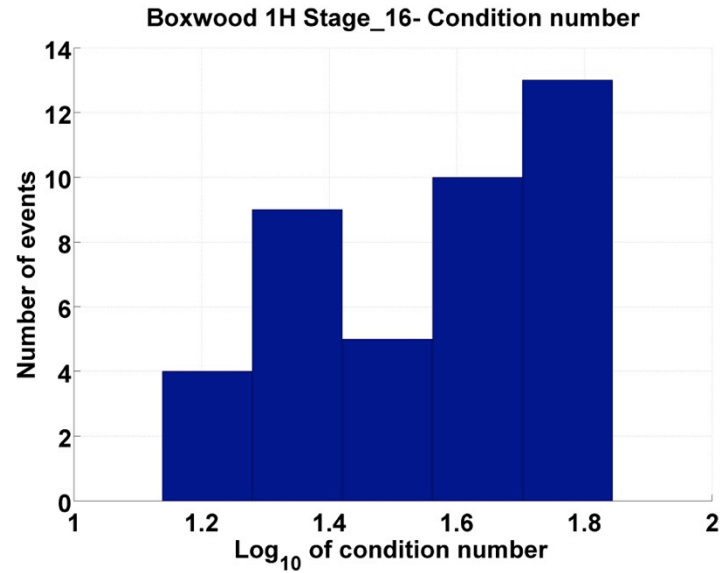


Source tensor Hudson plot -
Boxwood 1H Stage_16; Condition number < 70; Confidence > 0.5
Magnitude ranges from -2.87 to -1.46



MTI Results – Boxwood 1H – Stage 16

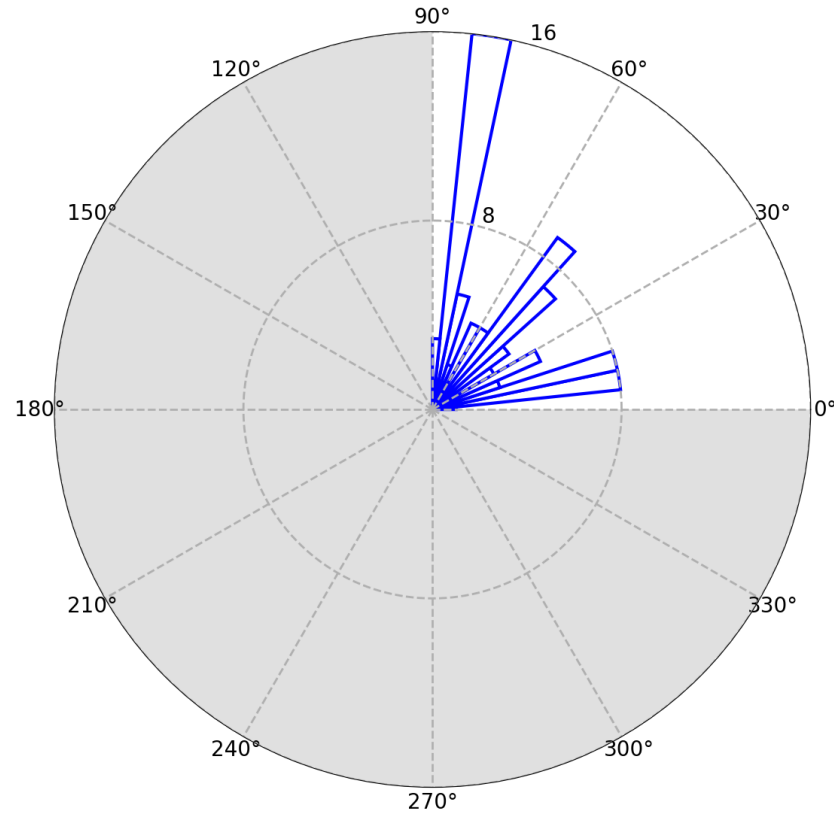
Condition Number, Confidence & Wire Display



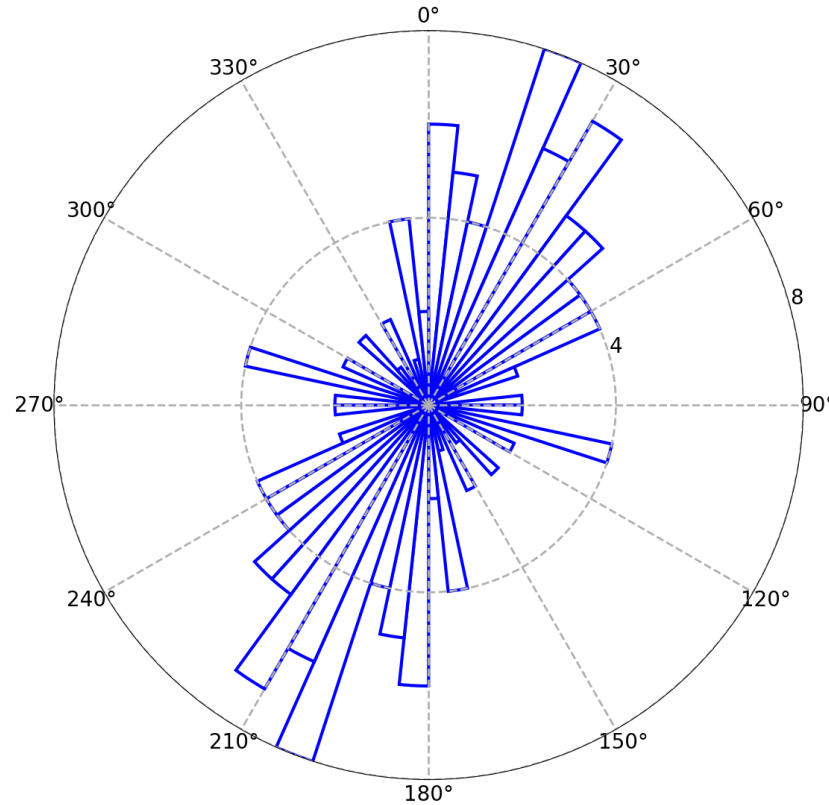
MTI Results – Boxwood 1H – Stage 16

Strike-Slip Fault Properties

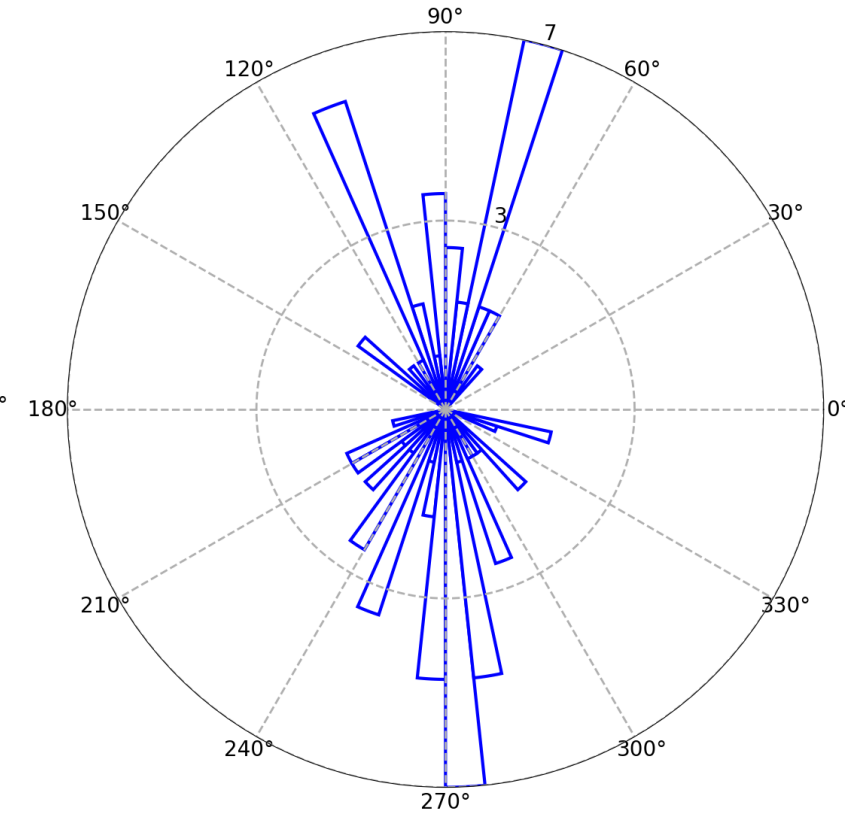
Dip - Boxwood 1H Stage 16
Condition number < 70; Confidence > 0.5
Mean DC percentage: 52.4099%



Strike - Boxwood 1H Stage 16
Condition number < 70; Confidence > 0.5
Mean DC percentage: 52.4099%



Slip - Boxwood 1H Stage 16
Condition number < 70; Confidence > 0.5
Mean DC percentage: 52.4099%





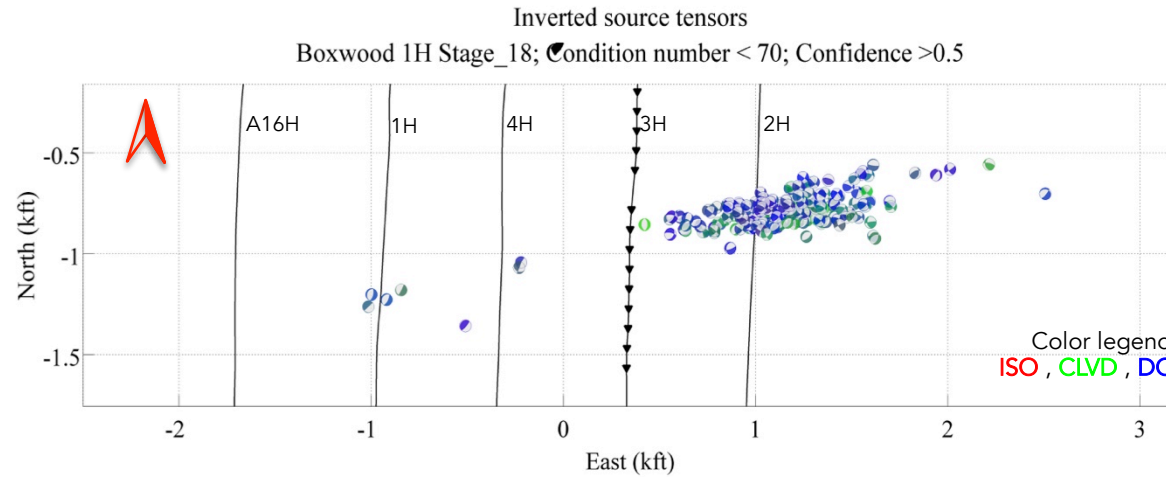
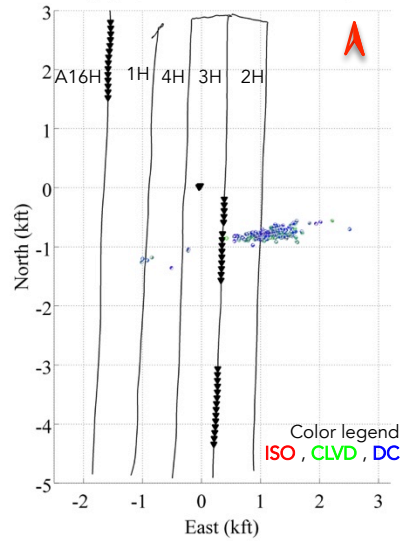
Microseismic Monitoring – HFTS2 Project MTI Report – Boxwood 1H – Stage 18

June 27th, 2019

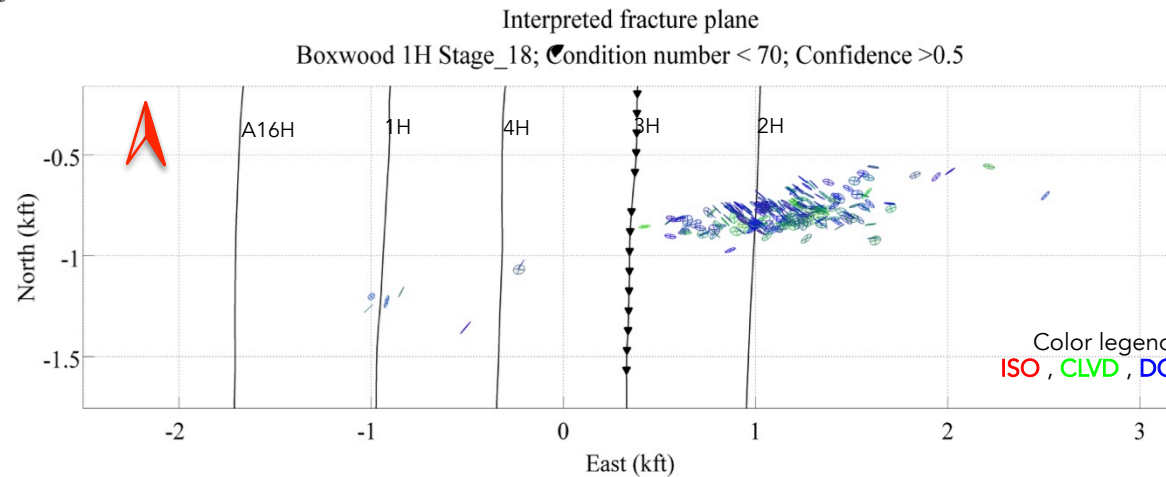
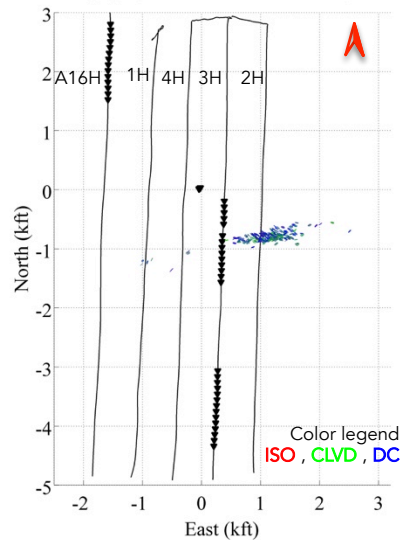
MTI Results Source Tensor – Boxwood 1H – Stage 18

Beach Ball, Crack Plots & Hudson Plot

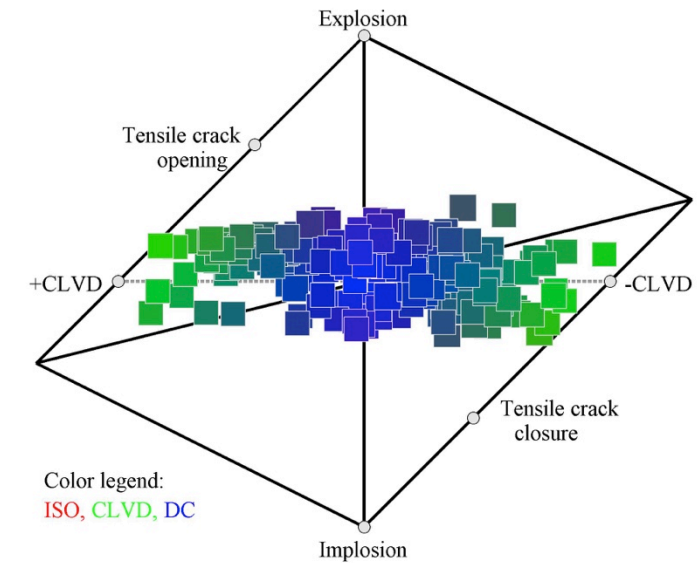
▼ Inverted source tensors
Boxwood 1H Stage_18; Condition number < 70; Confidence > 0.5



▼ Interpreted fracture plane
Boxwood 1H Stage_18; Condition number < 70; Confidence > 0.5

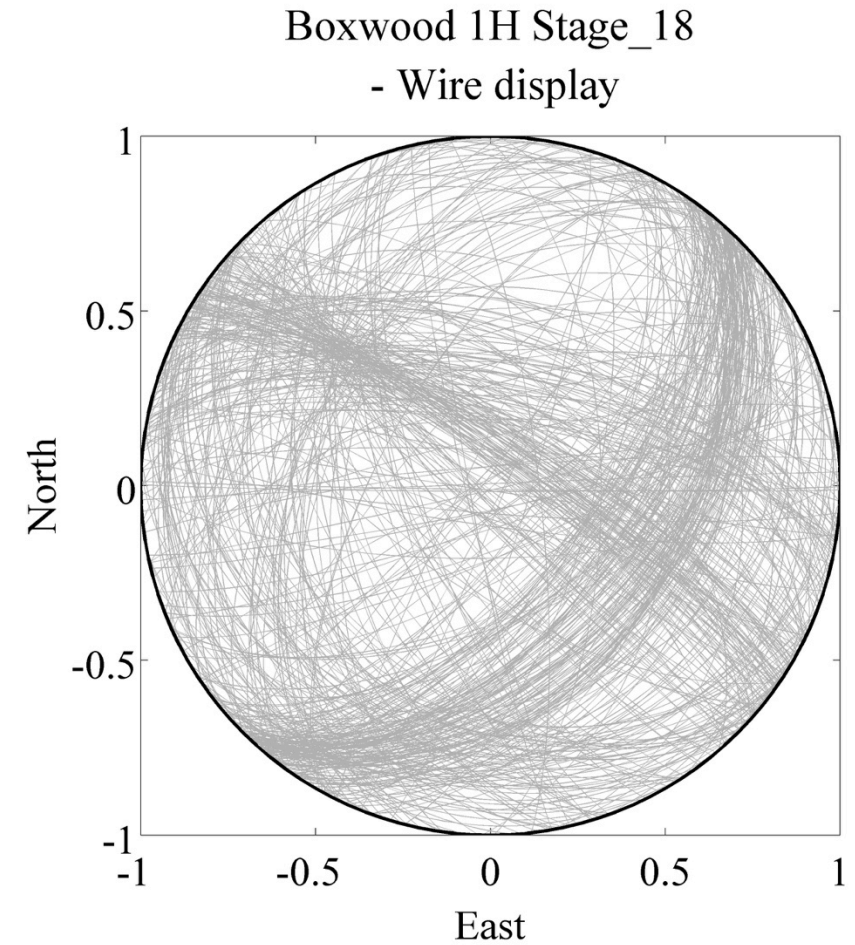
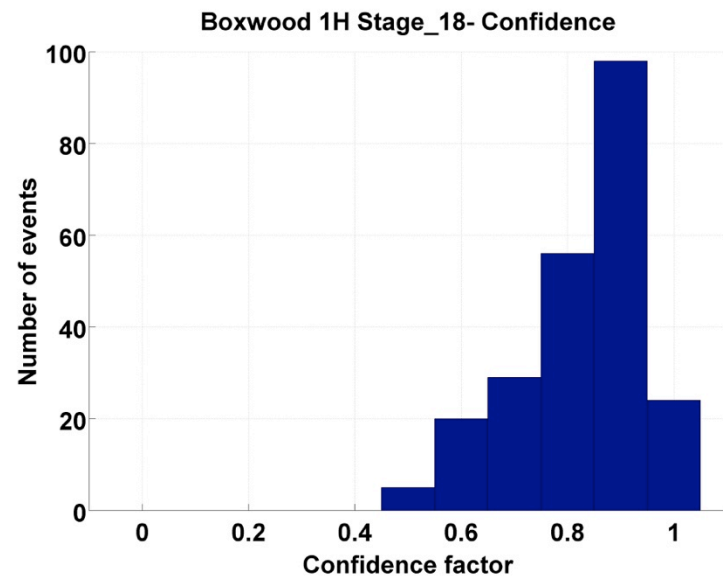
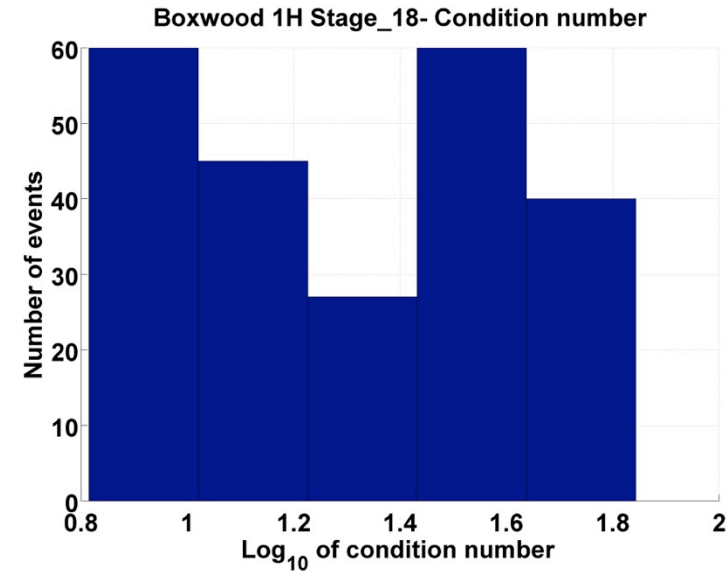


Source tensor Hudson plot -
Boxwood 1H Stage_18; Condition number < 70; Confidence > 0.5
Magnitude ranges from -3.16 to -1.63



MTI Results – Boxwood 1H – Stage 18

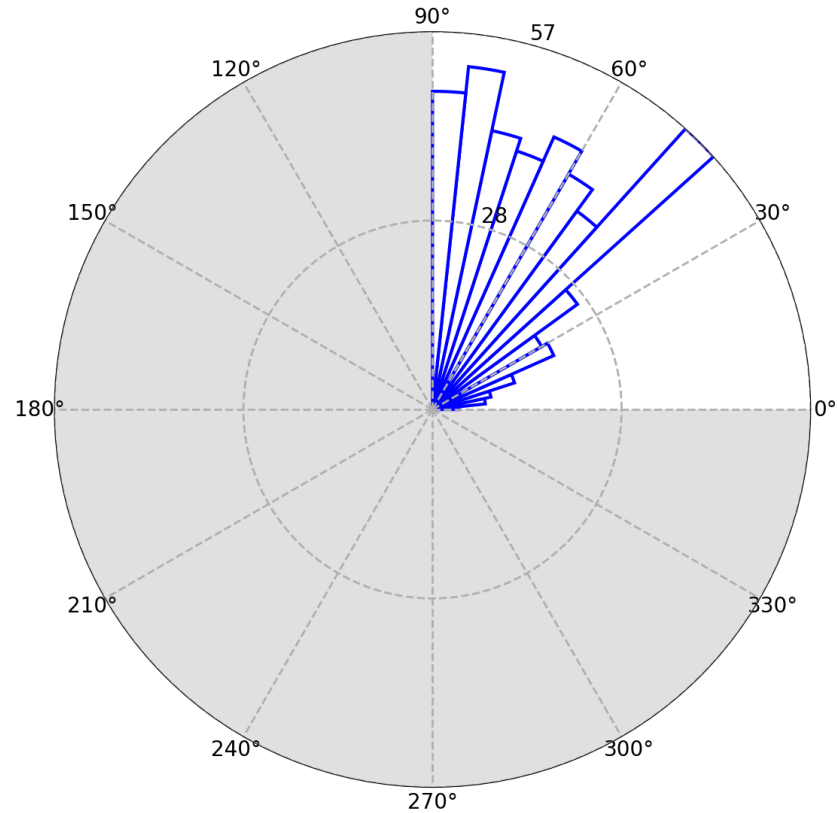
Condition Number, Confidence & Wire Display



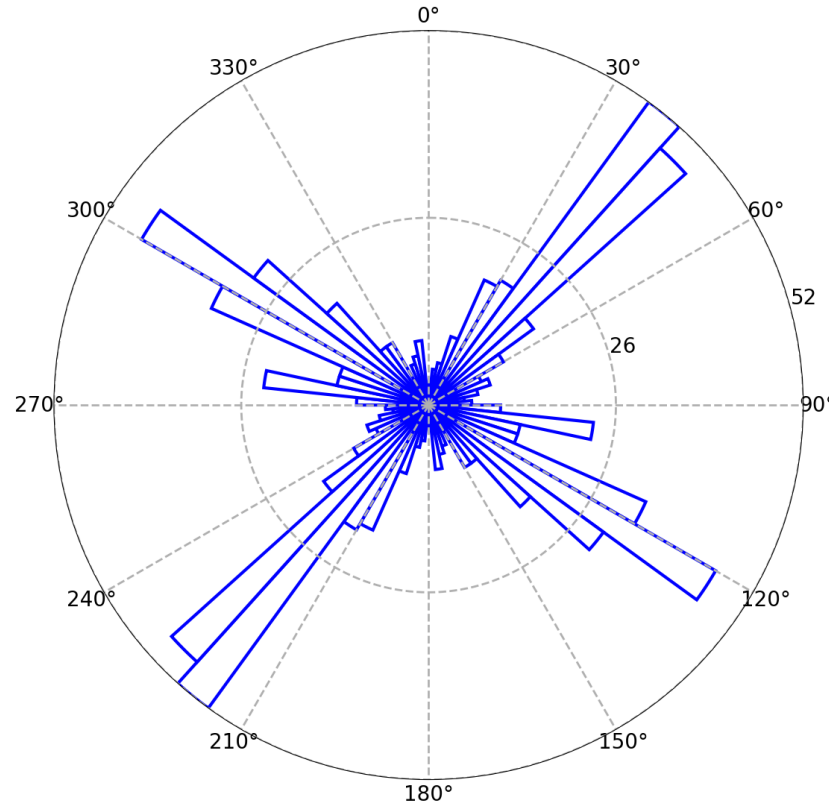
MTI Results – Boxwood 1H – Stage 18

Strike-Slip Fault Properties

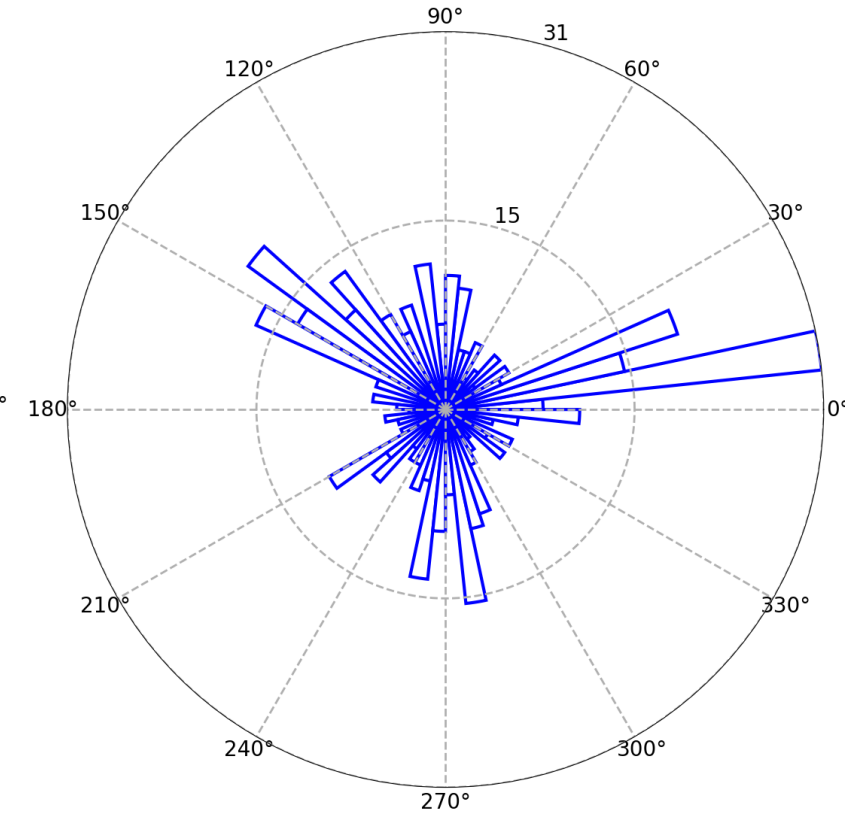
Dip - Boxwood 1H Stage 18
Condition number < 70; Confidence > 0.5
Mean DC percentage: 58.7054%



Strike - Boxwood 1H Stage 18
Condition number < 70; Confidence > 0.5
Mean DC percentage: 58.7054%



Slip - Boxwood 1H Stage 18
Condition number < 70; Confidence > 0.5
Mean DC percentage: 58.7054%





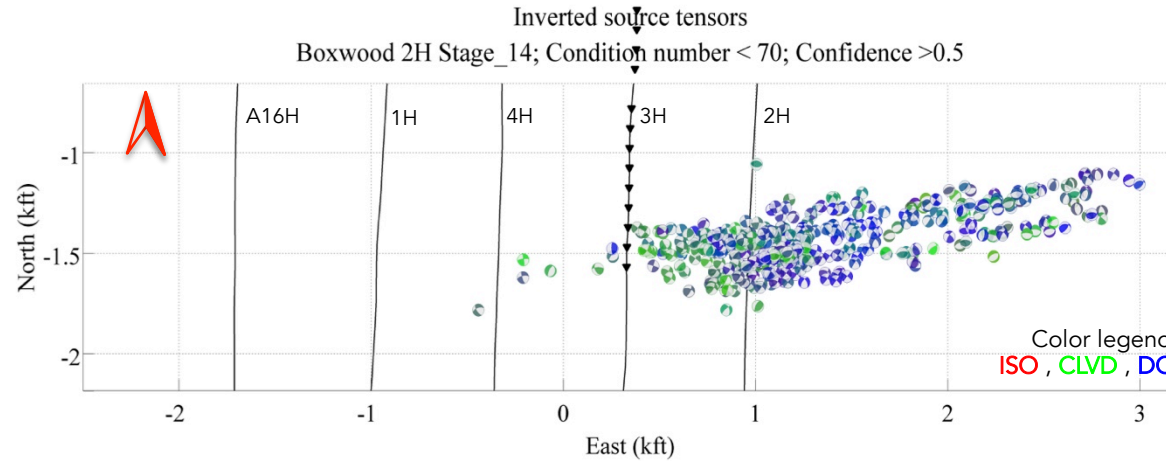
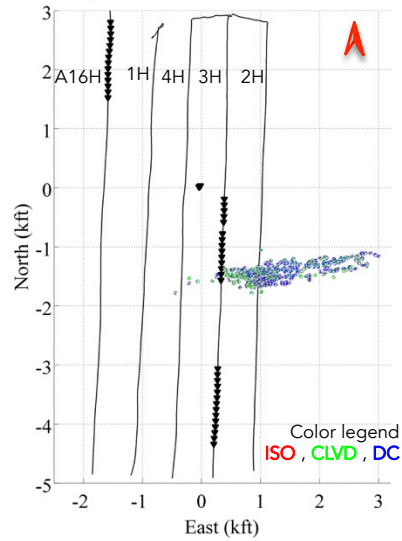
Microseismic Monitoring – HFTS2 Project MTI Report – Boxwood 2H – Stage 14

June 27th, 2019

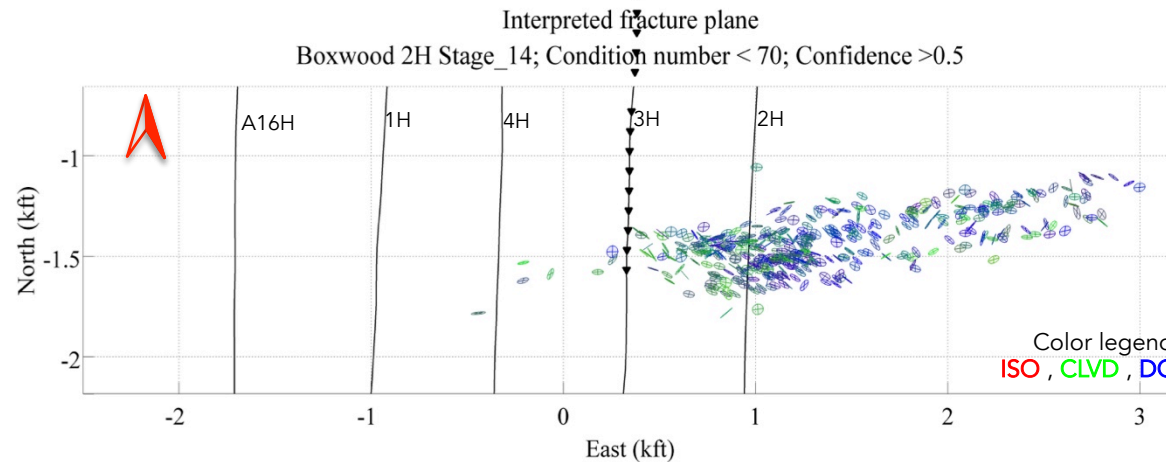
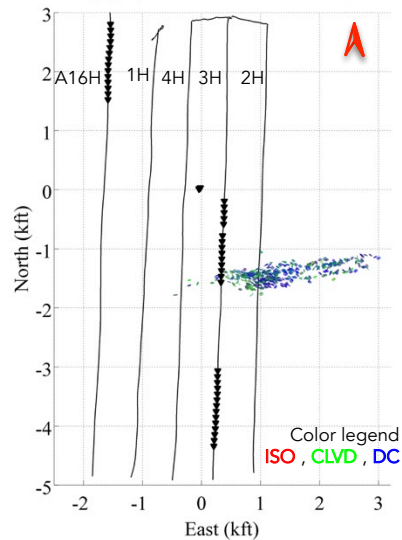
MTI Results Source Tensor – Boxwood 2H – Stage 14

Beach Ball, Crack Plots & Hudson Plot

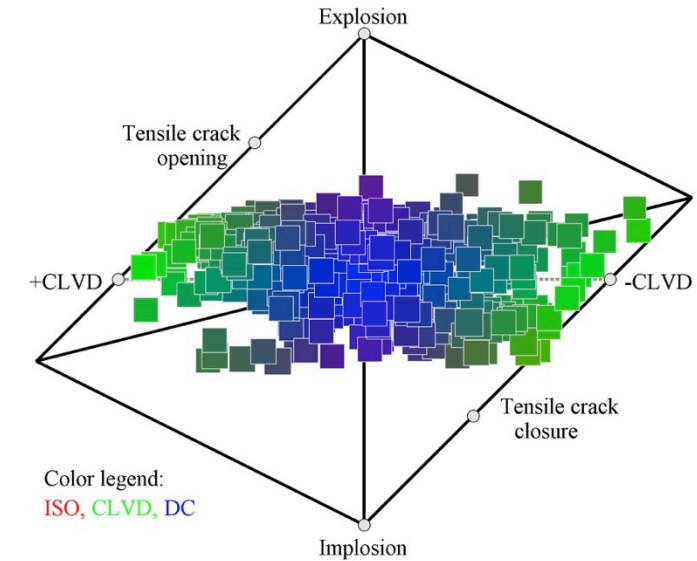
▼ Inverted source tensors
Boxwood 2H Stage_14; Condition number < 70; Confidence > 0.5



▼ Interpreted fracture plane
Boxwood 2H Stage_14; Condition number < 70; Confidence > 0.5

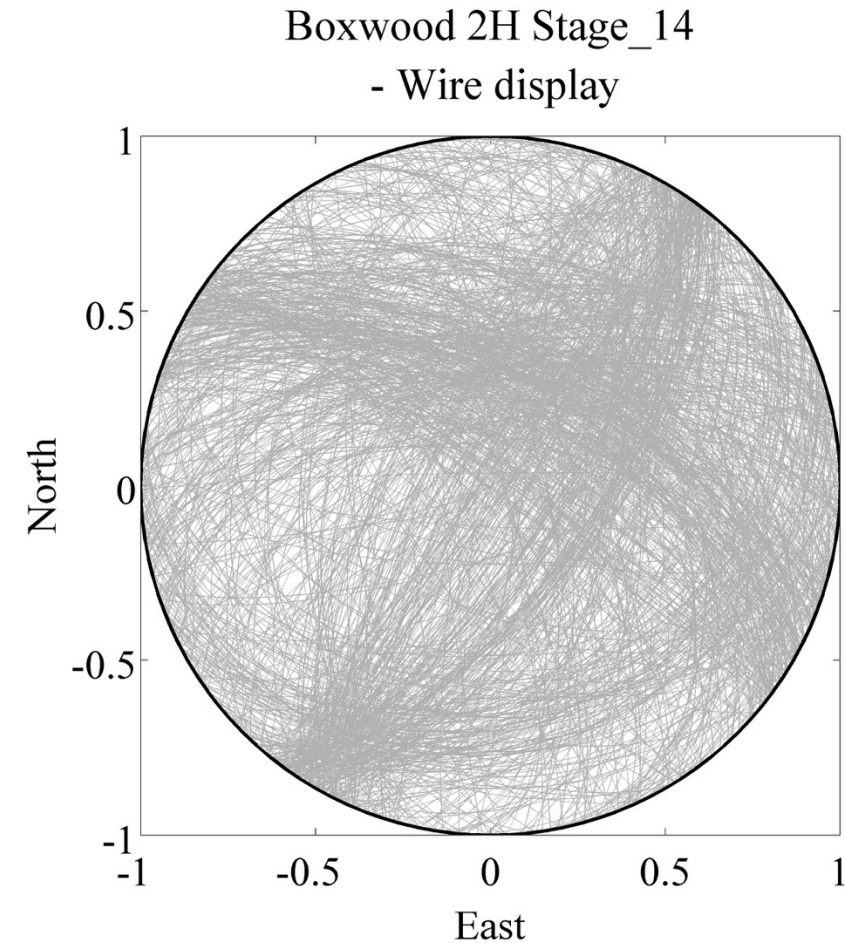
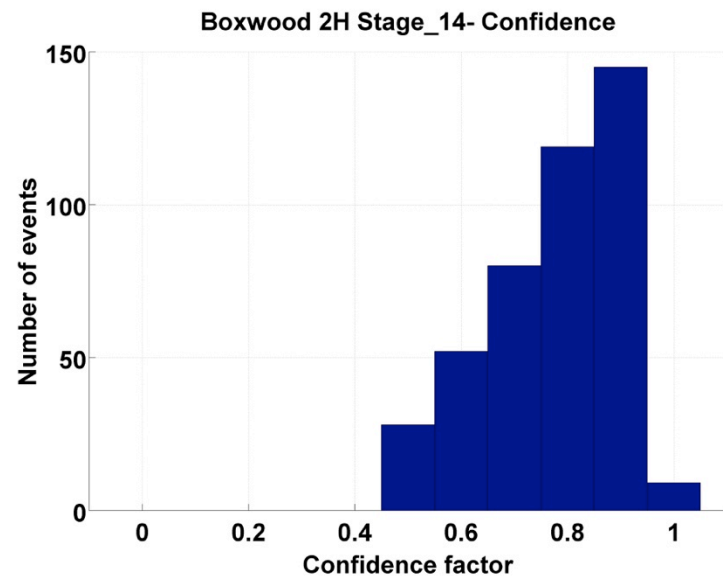
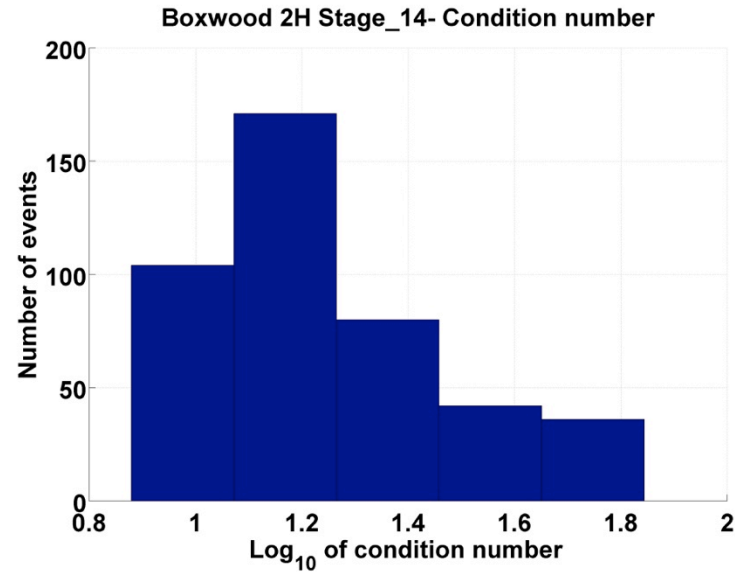


Source tensor Hudson plot -
Boxwood 2H Stage_14; Condition number < 70; Confidence > 0.5
Magnitude ranges from -2.92 to -0.64



MTI Results – Boxwood 2H – Stage 14

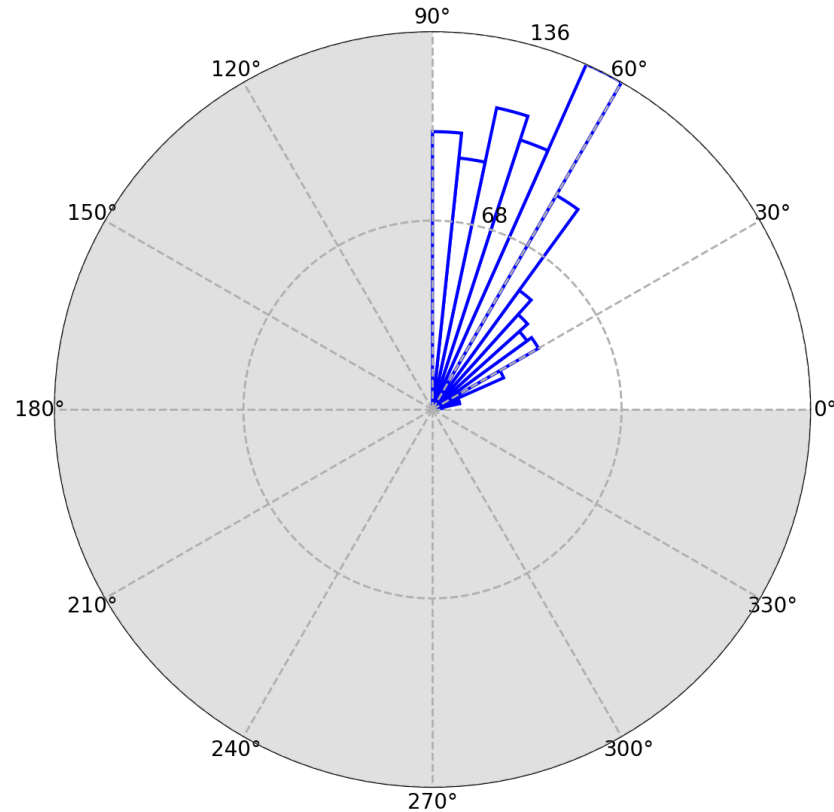
Condition Number, Confidence & Wire Display



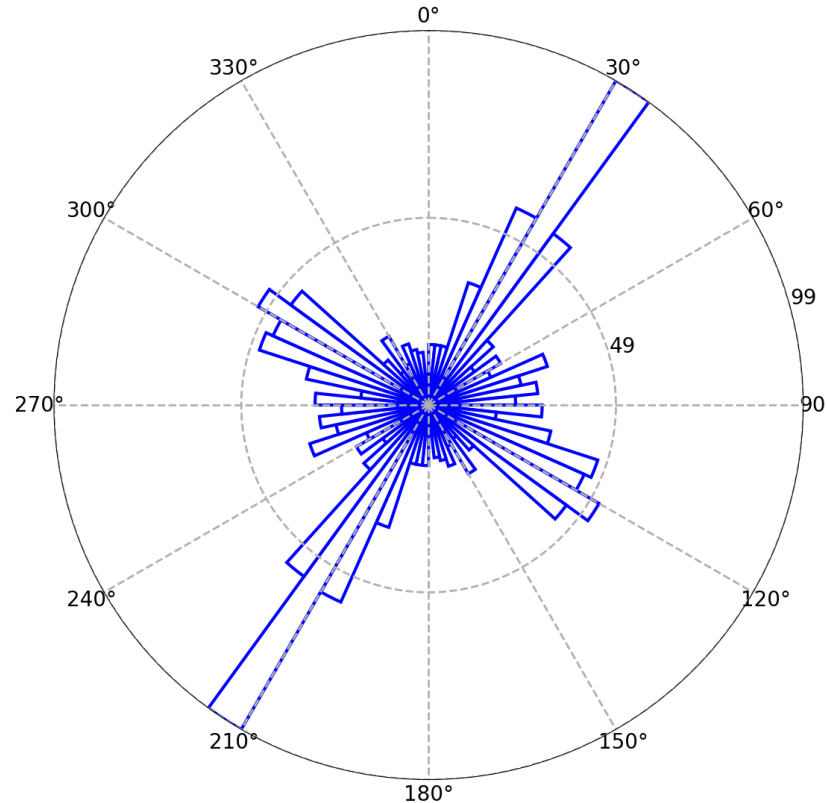
MTI Results – Boxwood 2H – Stage 14

Strike-Slip Fault Properties

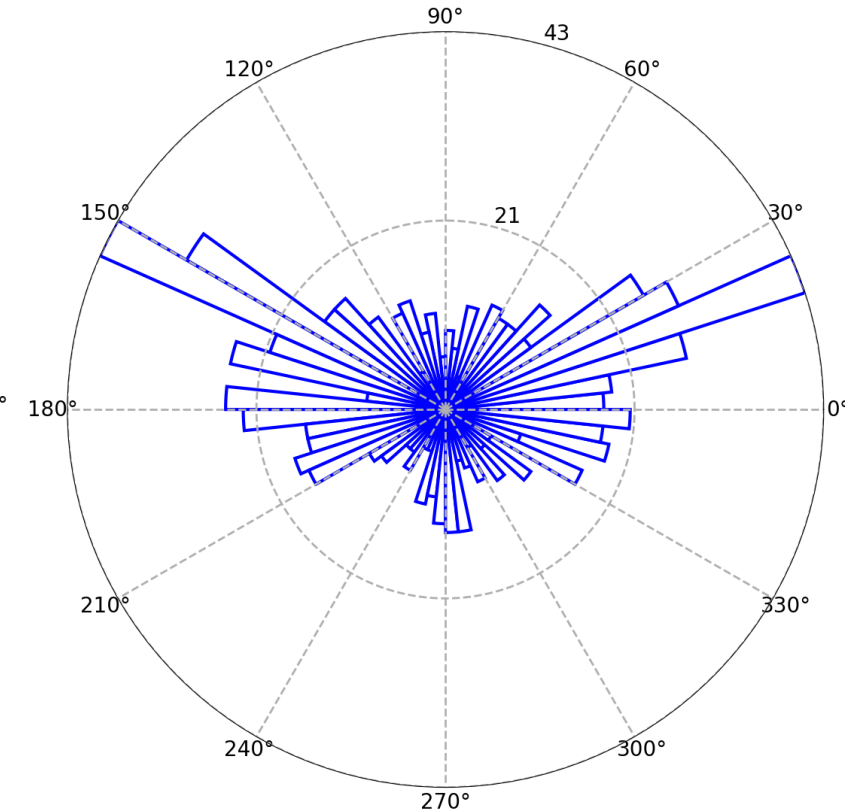
Dip - Boxwood 2H Stage 14
Condition number < 70; Confidence > 0.5
Mean DC percentage: 51.4265%

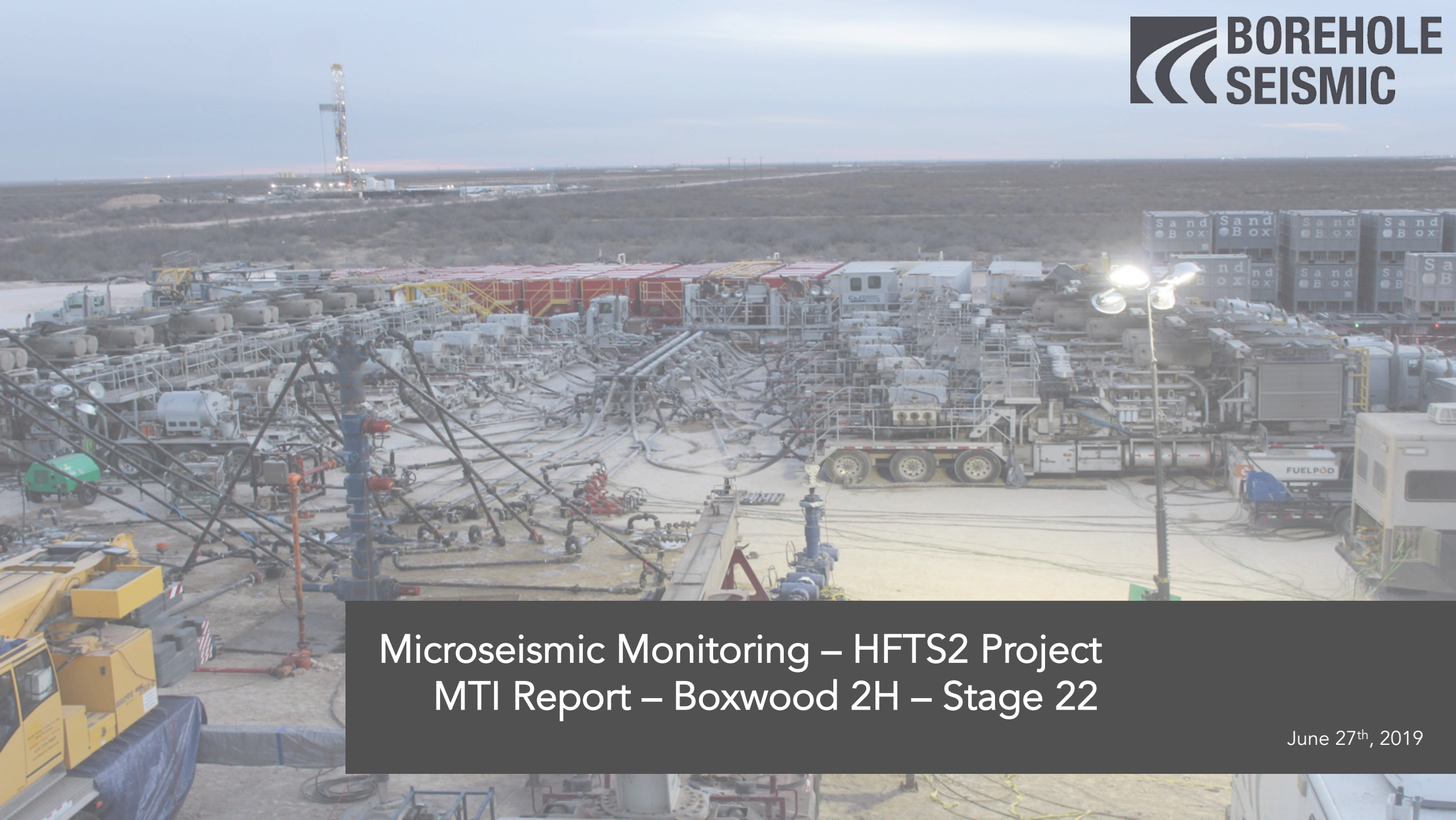


Strike - Boxwood 2H Stage 14
Condition number < 70; Confidence > 0.5
Mean DC percentage: 51.4265%



Slip - Boxwood 2H Stage 14
Condition number < 70; Confidence > 0.5
Mean DC percentage: 51.4265%





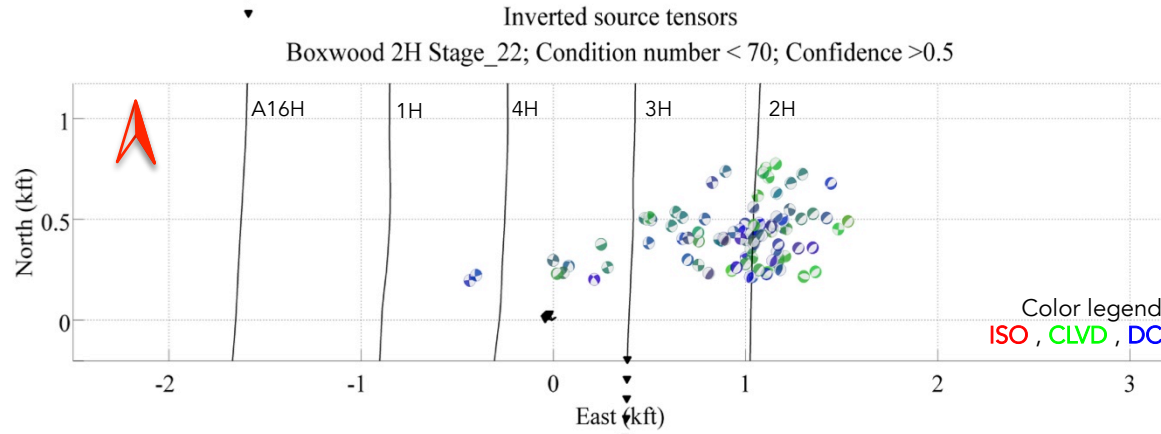
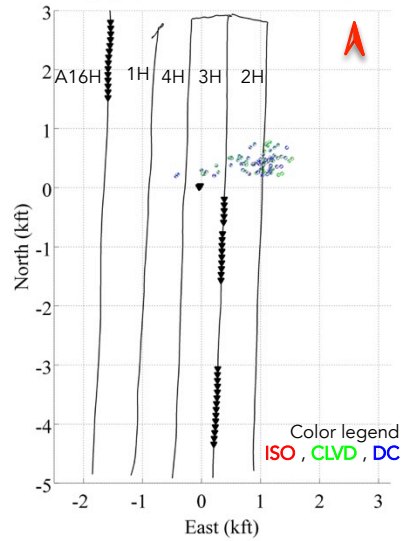
Microseismic Monitoring – HFTS2 Project MTI Report – Boxwood 2H – Stage 22

June 27th, 2019

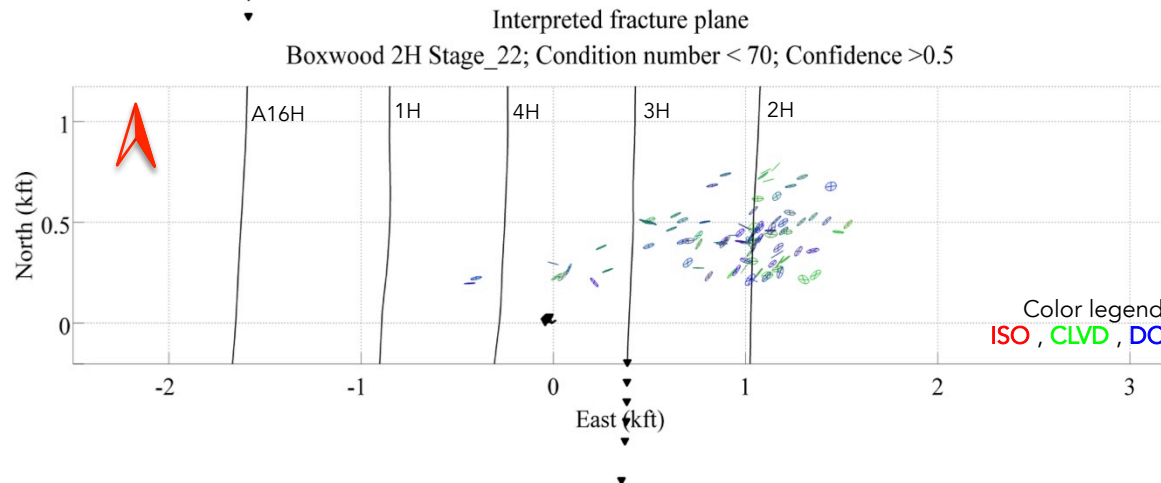
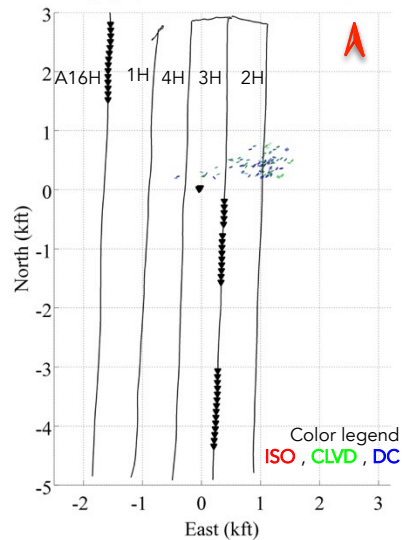
MTI Results Source Tensor – Boxwood 2H – Stage 22

Beach Ball, Crack Plots & Hudson Plot

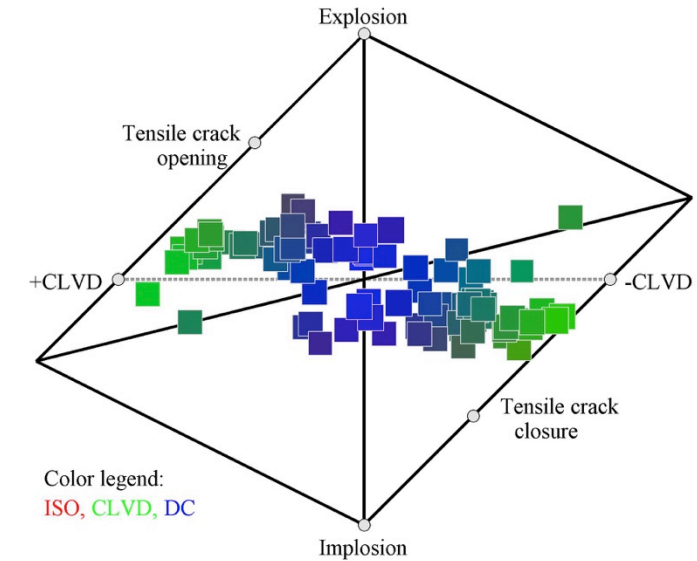
▼ Inverted source tensors
Boxwood 2H Stage_22; Condition number < 70; Confidence > 0.5



▼ Interpreted fracture plane
Boxwood 2H Stage_22; Condition number < 70; Confidence > 0.5

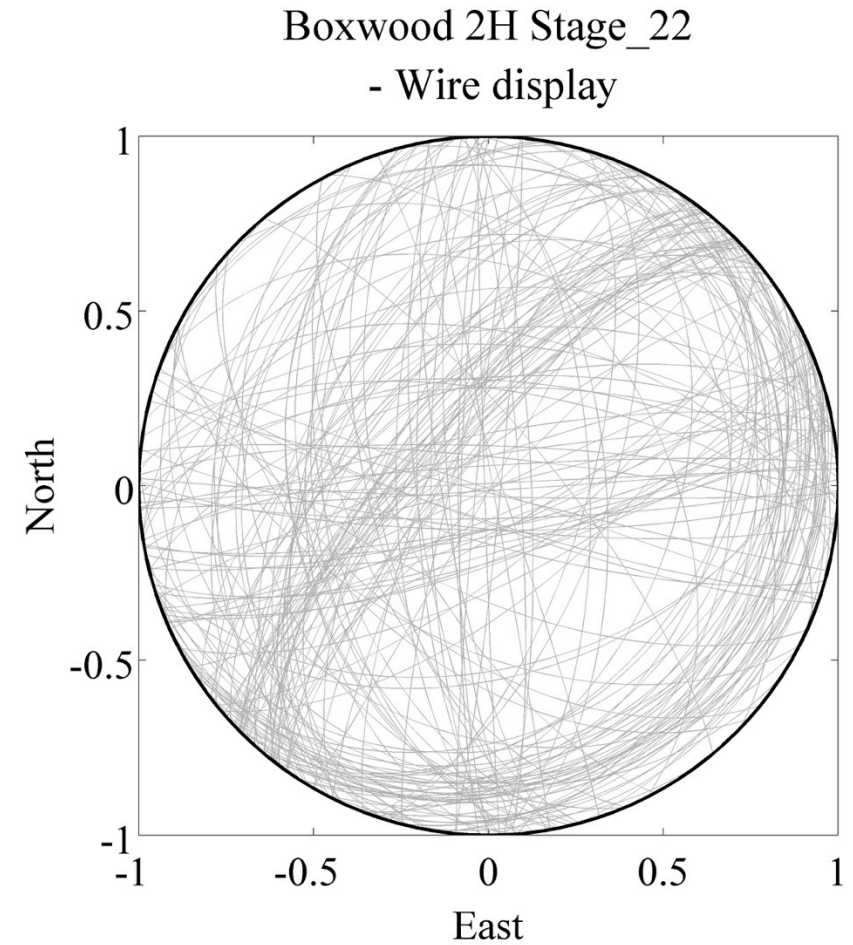
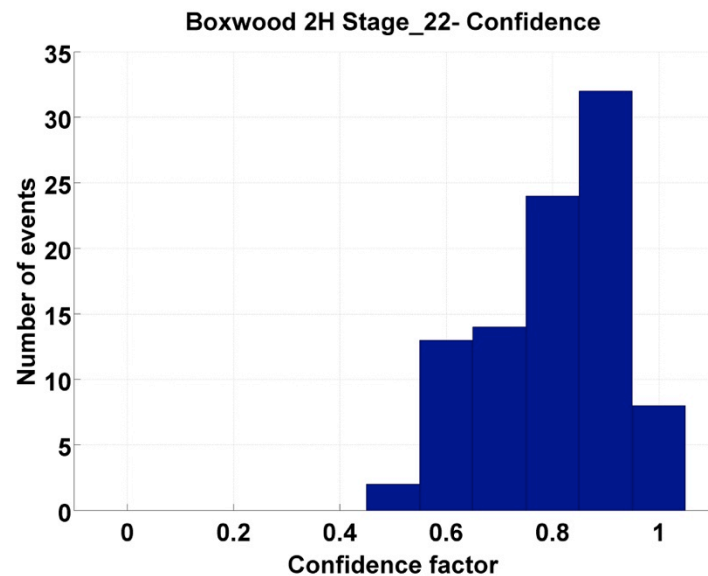
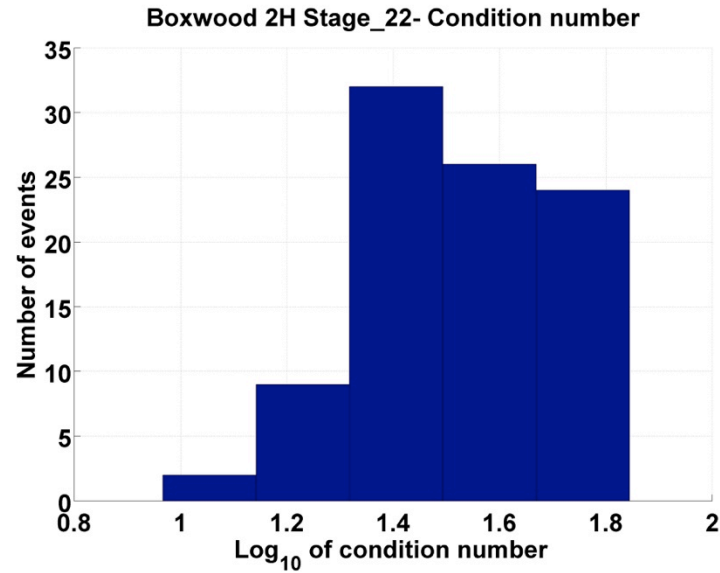


Source tensor Hudson plot -
Boxwood 2H Stage_22; Condition number < 70; Confidence > 0.5
Magnitude ranges from -2.94 to -1.53



MTI Results – Boxwood 2H – Stage 22

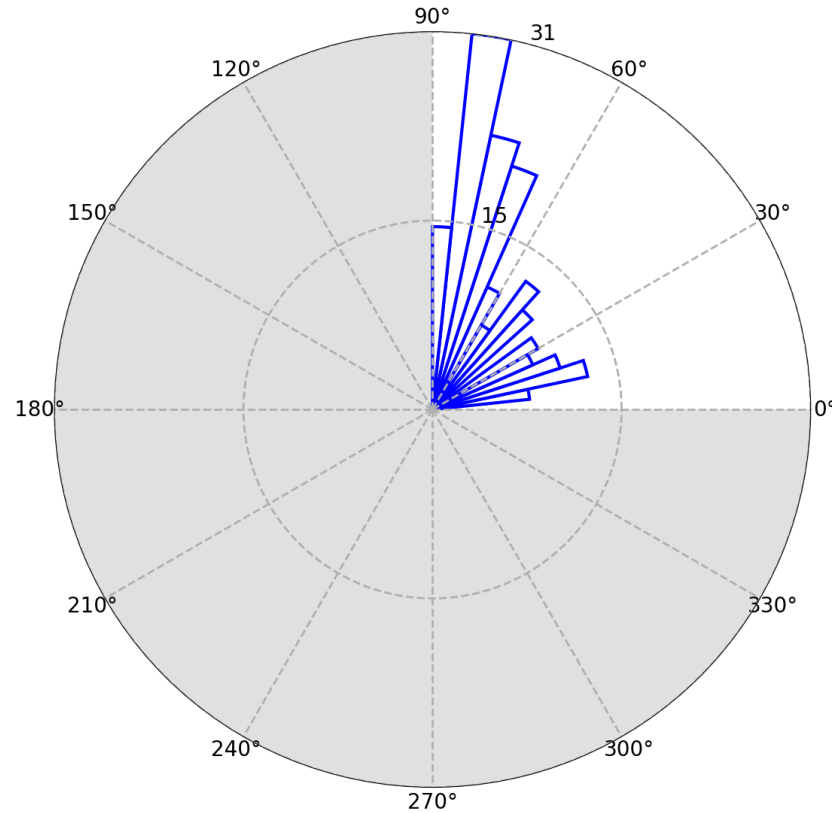
Condition Number, Confidence & Wire Display



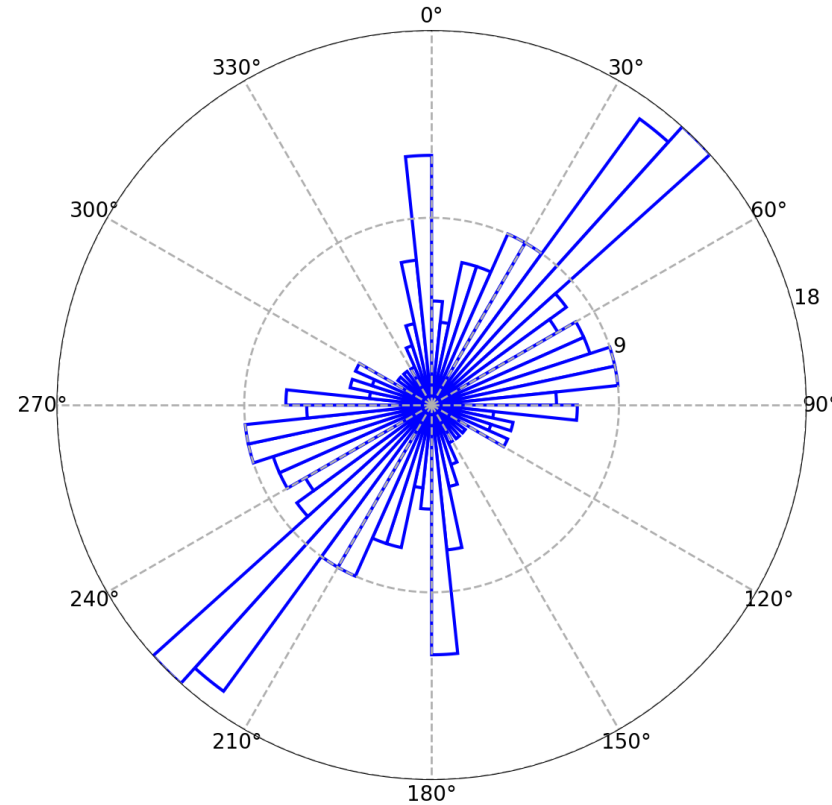
MTI Results – Boxwood 2H – Stage 22

Strike-Slip Fault Properties

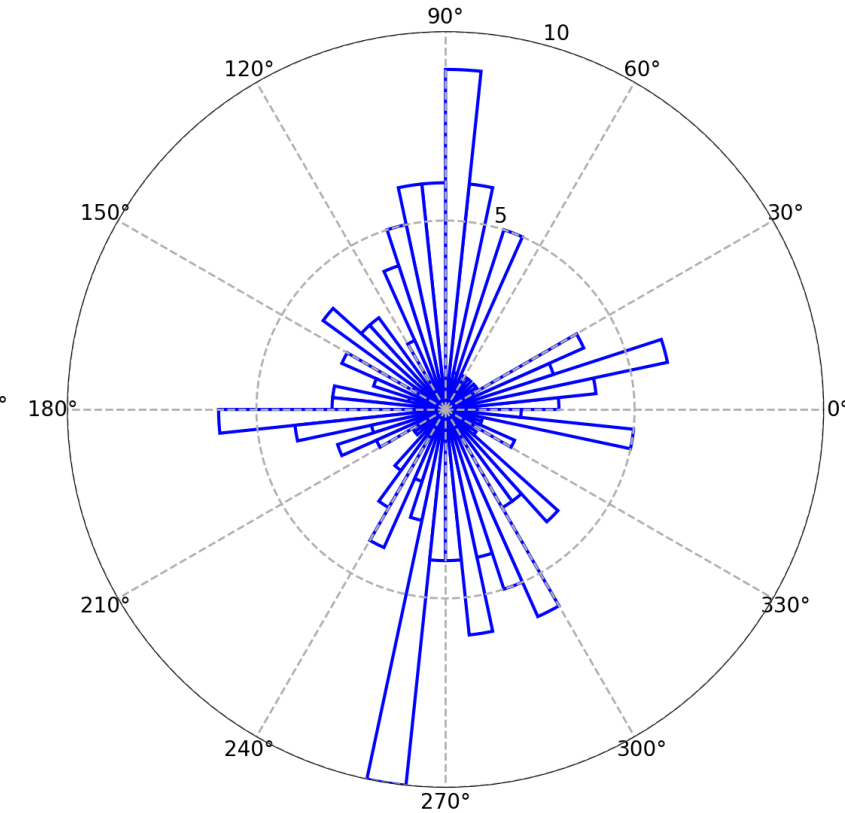
Dip - Boxwood 2H Stage 22
Condition number < 70; Confidence > 0.5
Mean DC percentage: 47.3851%

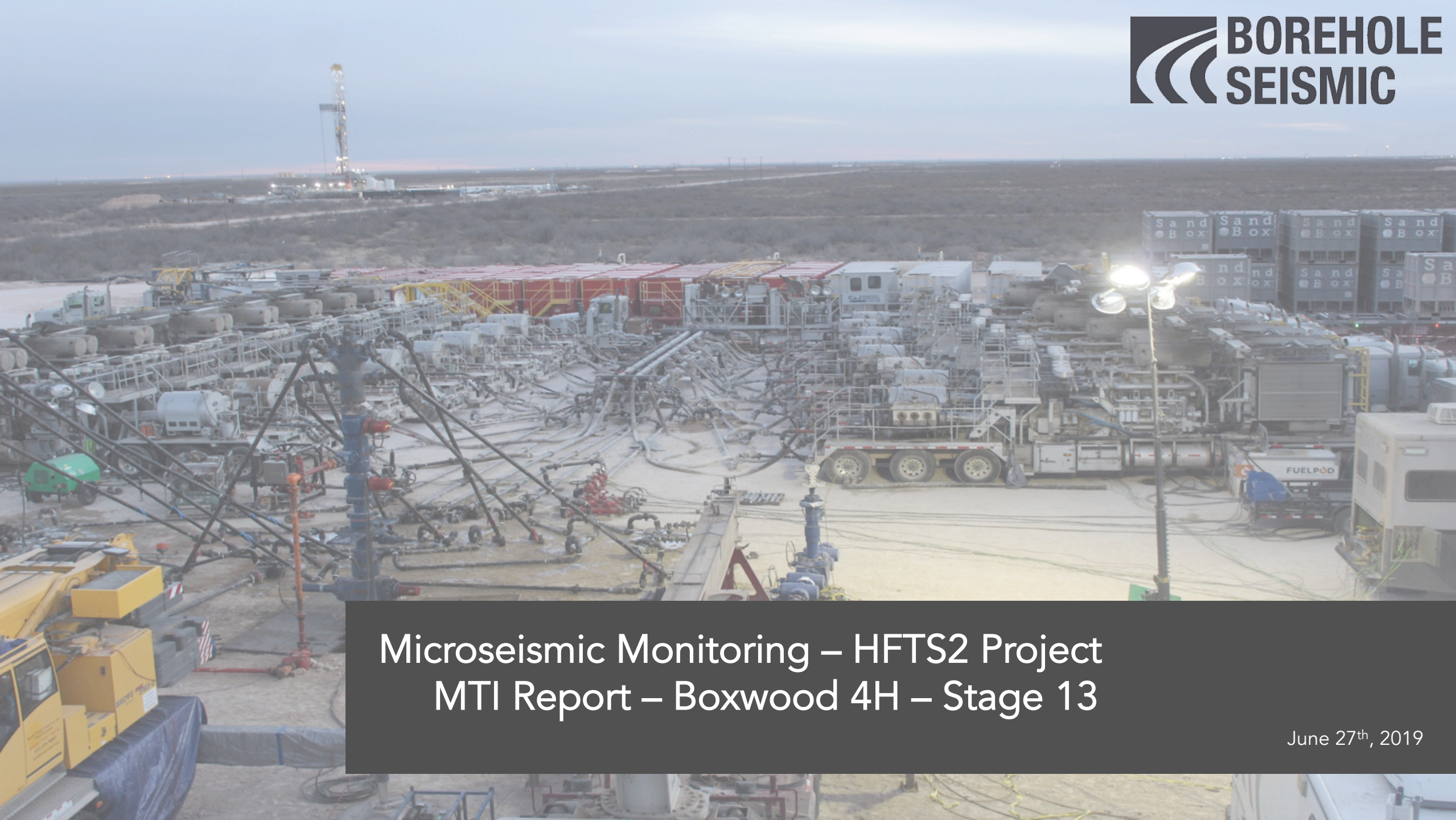


Strike - Boxwood 2H Stage 22
Condition number < 70; Confidence > 0.5
Mean DC percentage: 47.3851%



Slip - Boxwood 2H Stage 22
Condition number < 70; Confidence > 0.5
Mean DC percentage: 47.3851%





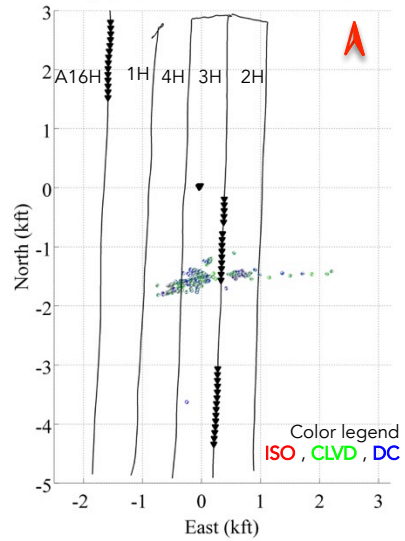
Microseismic Monitoring – HFTS2 Project MTI Report – Boxwood 4H – Stage 13

June 27th, 2019

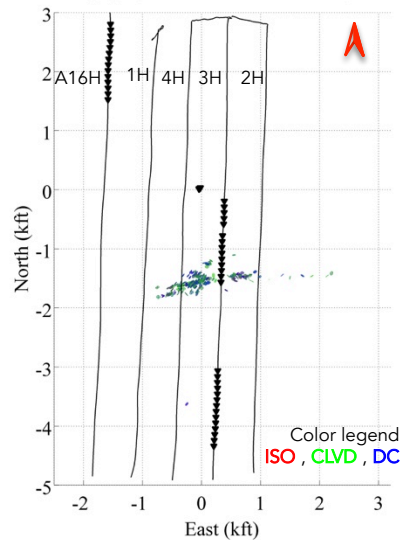
MTI Results Source Tensor – Boxwood 4H – Stage 13

Beach Ball, Crack Plots & Hudson Plot

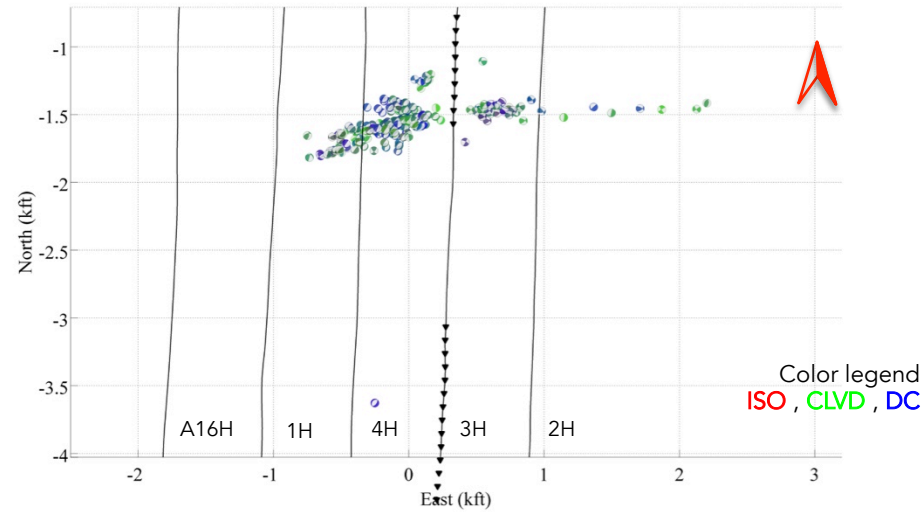
▼ Inverted source tensors
Boxwood 4H Stage_13; Condition number < 70; Confidence > 0.5



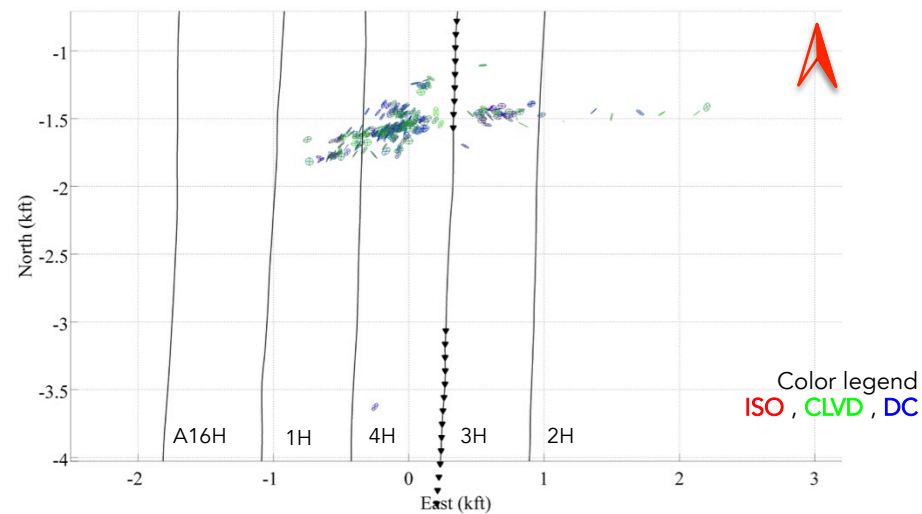
▼ Interpreted fracture plane
Boxwood 4H Stage_13; Condition number < 70; Confidence > 0.5



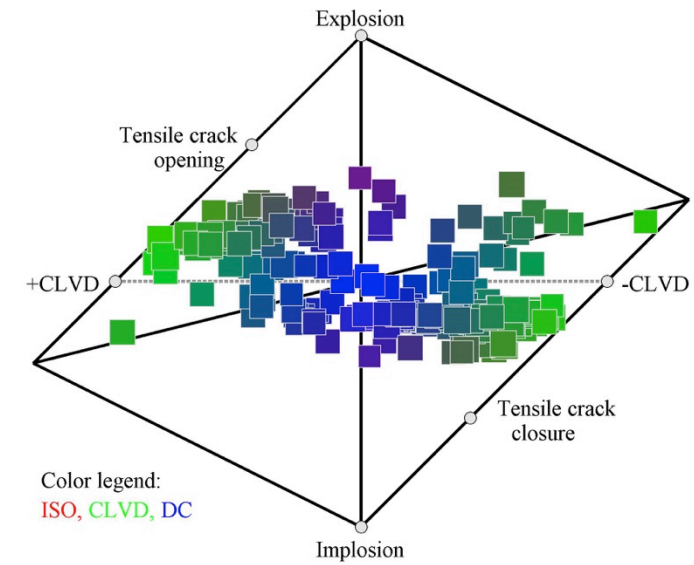
▼ Inverted source tensors
Boxwood 4H Stage_13; Condition number < 70; Confidence > 0.5



▼ Interpreted fracture plane
Boxwood 4H Stage_13; Condition number < 70; Confidence > 0.5

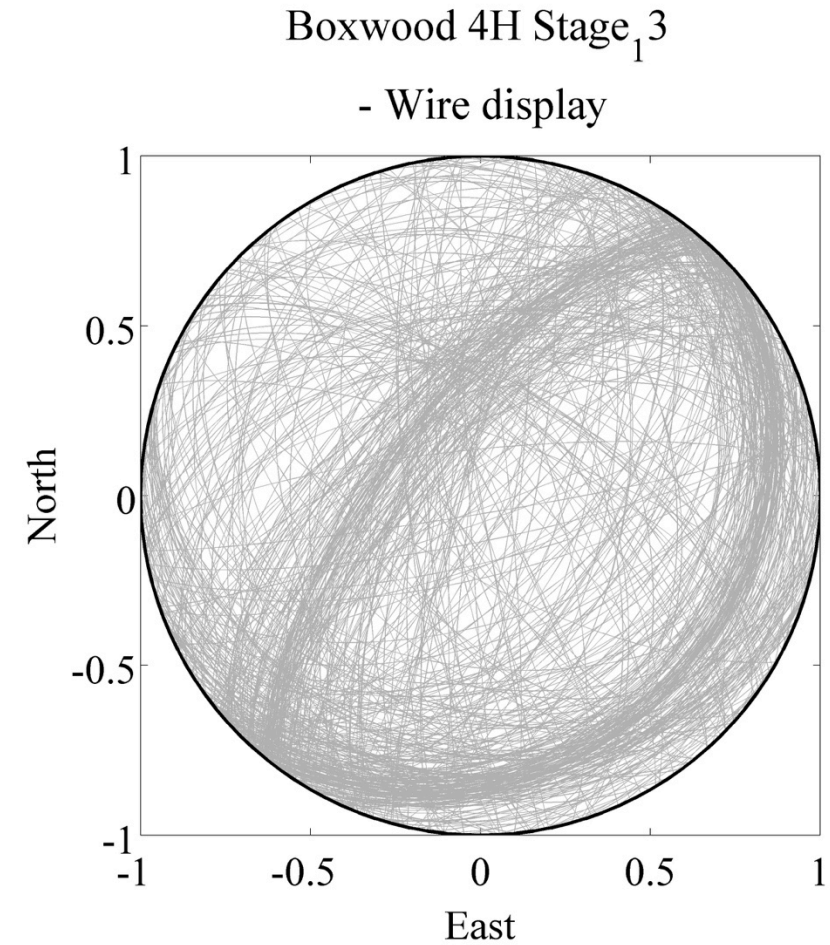
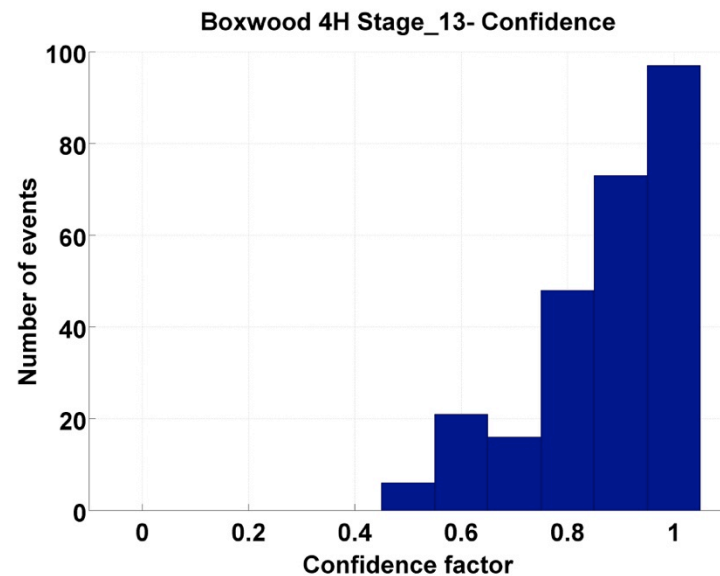
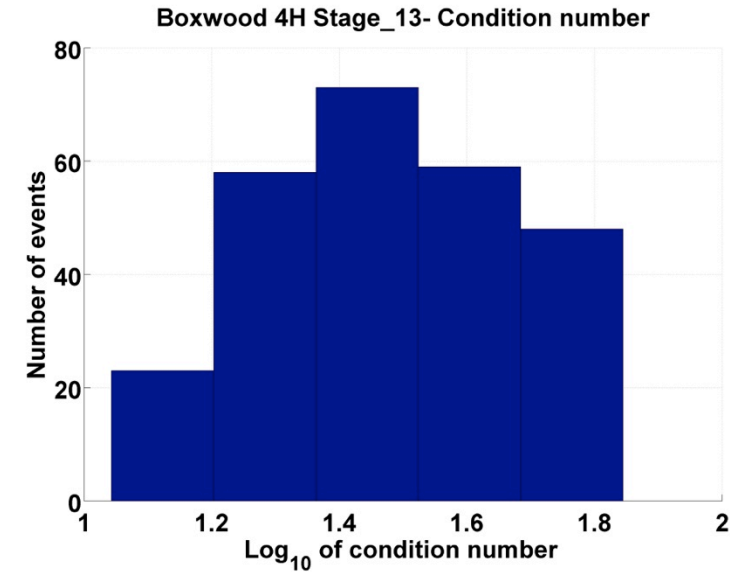


Source tensor Hudson plot -
Boxwood 4H Stage_13; Condition number < 70; Confidence > 0.5
Magnitude ranges from -2.62 to -0.83



MTI Results – Boxwood 4H – Stage 13

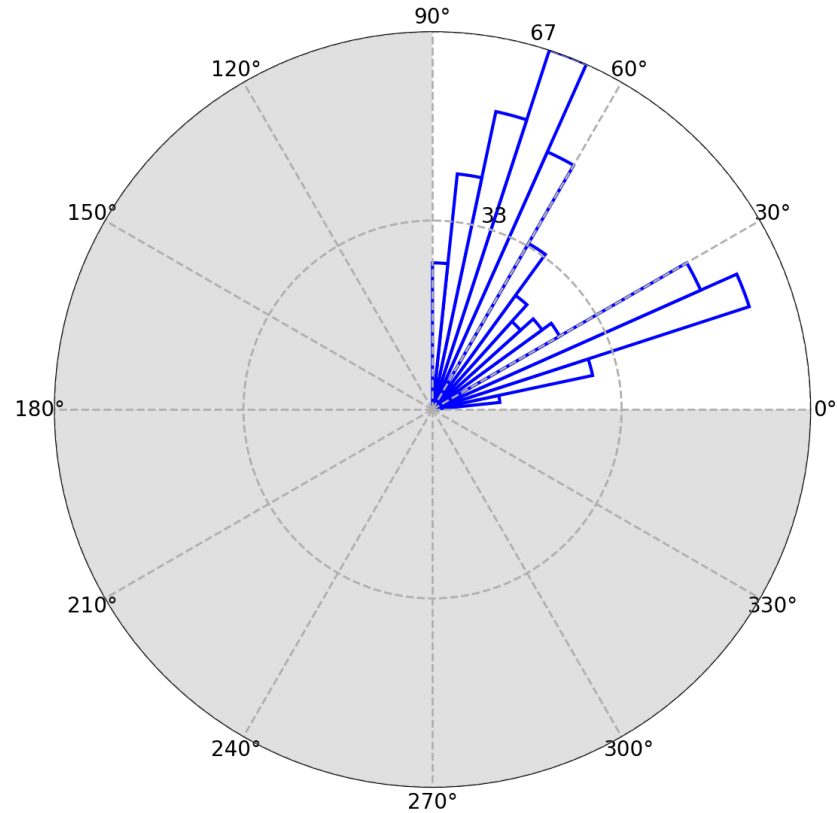
Condition Number, Confidence & Wire Display



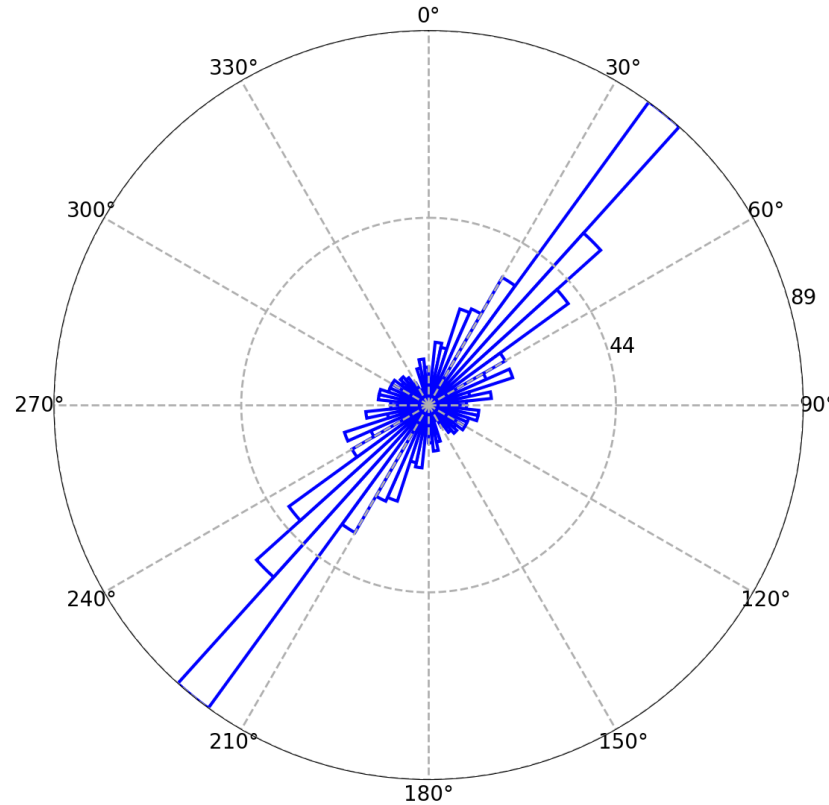
MTI Results – Boxwood 2H – Stage 22

Strike-Slip Fault Properties

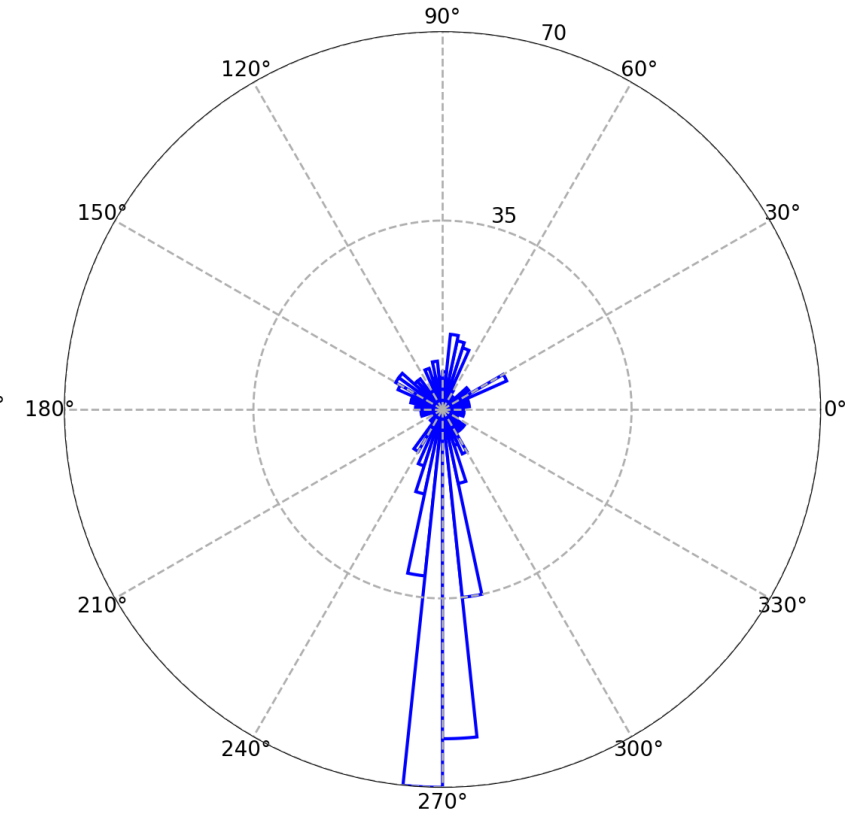
Dip - Boxwood 4H Stage 13
Condition number < 70; Confidence > 0.5
Mean DC percentage: 42.6999%

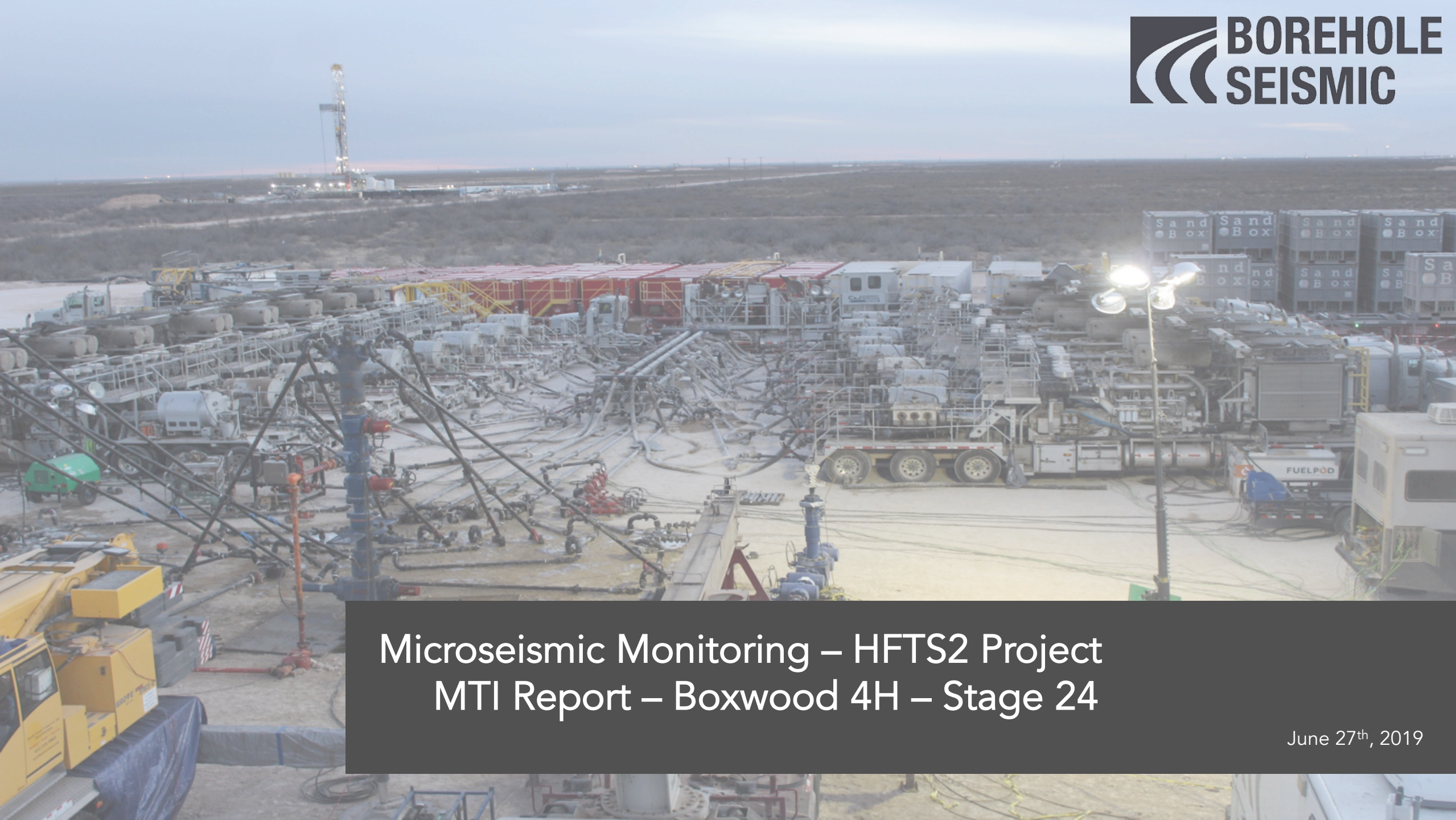


Strike - Boxwood 4H Stage 13
Condition number < 70; Confidence > 0.5
Mean DC percentage: 42.6999%



Slip - Boxwood 4H Stage 13
Condition number < 70; Confidence > 0.5
Mean DC percentage: 42.6999%





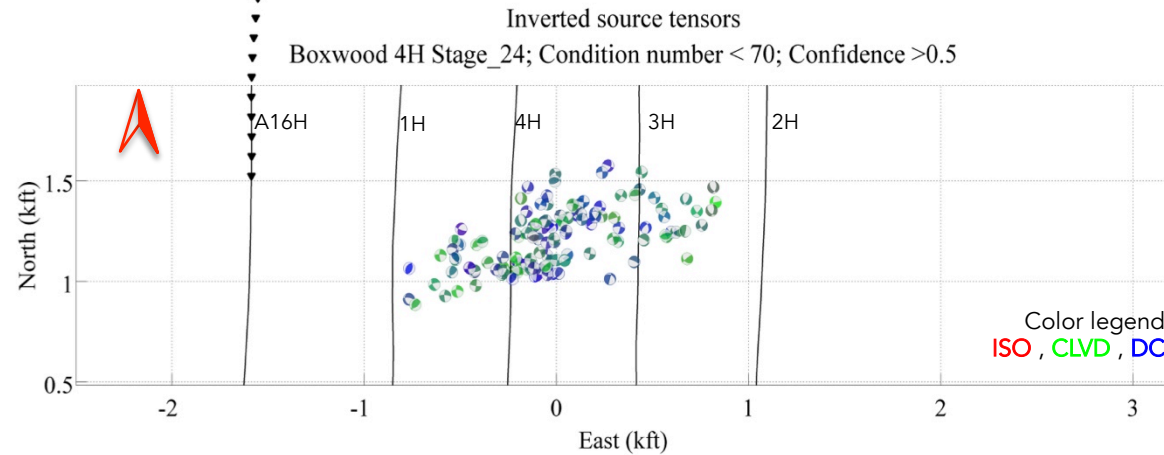
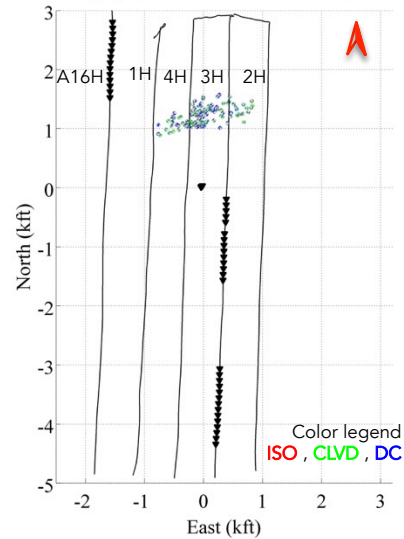
Microseismic Monitoring – HFTS2 Project MTI Report – Boxwood 4H – Stage 24

June 27th, 2019

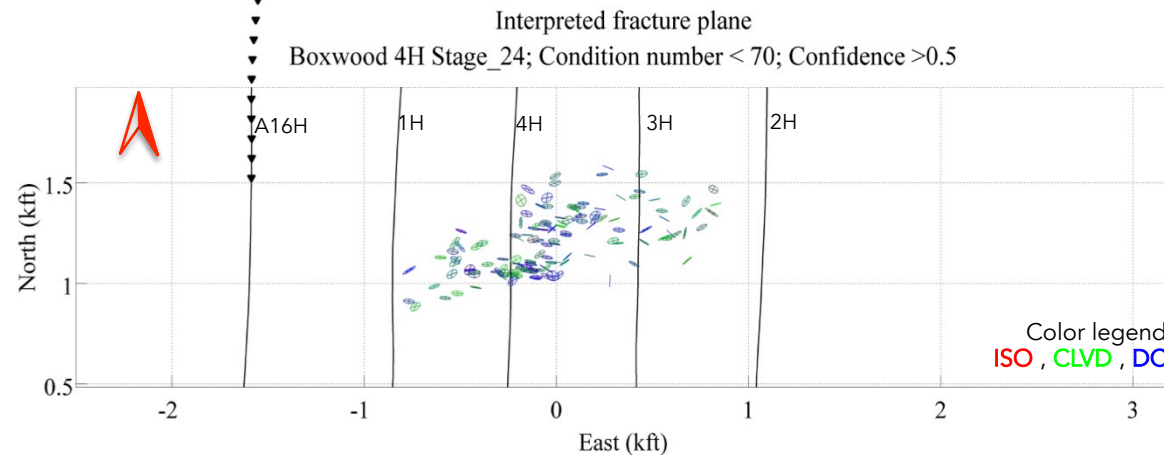
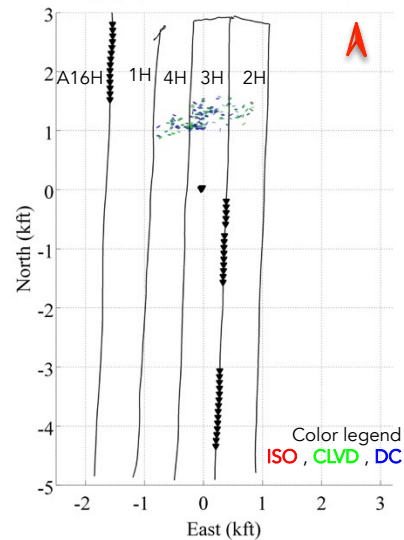
MTI Results Source Tensor – Boxwood 4H – Stage 24

Beach Ball, Crack Plots & Hudson Plot

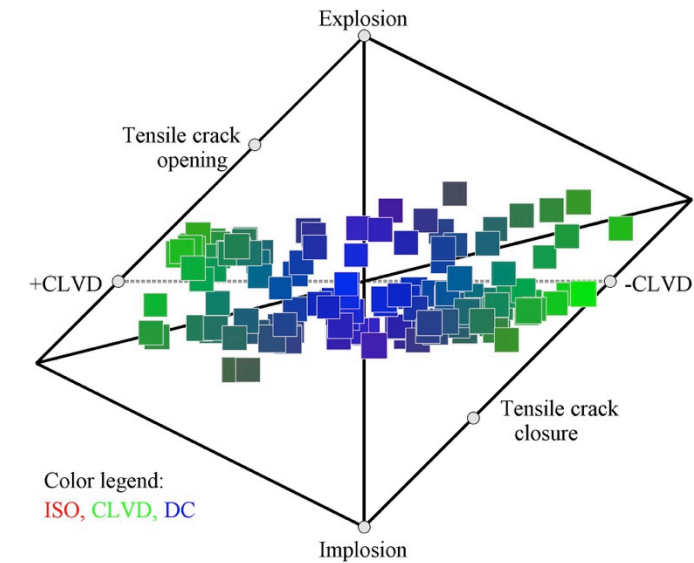
▼ Inverted source tensors
Boxwood 4H Stage_24; Condition number < 70; Confidence > 0.5



▼ Interpreted fracture plane
Boxwood 4H Stage_24; Condition number < 70; Confidence > 0.5

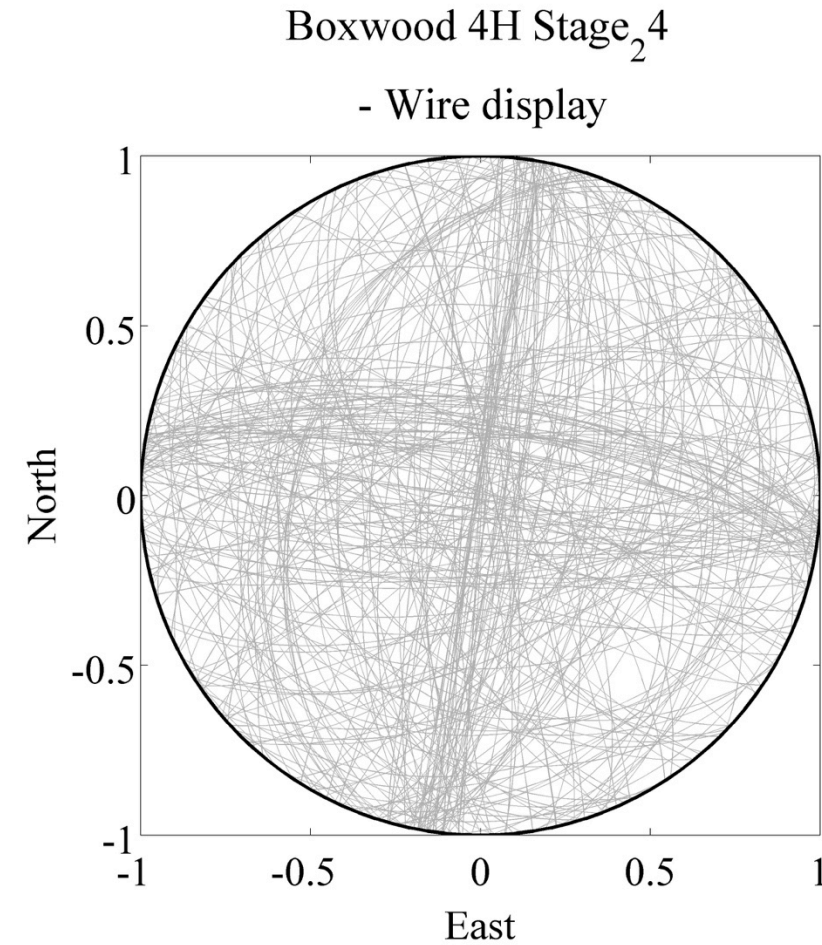
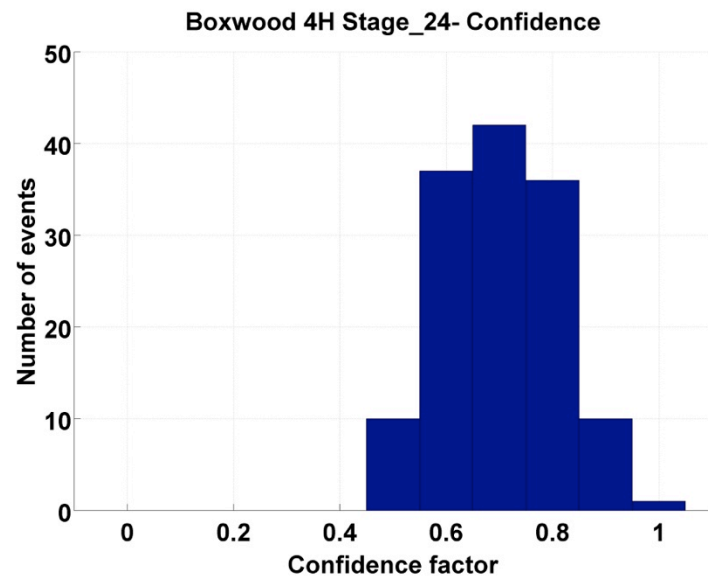
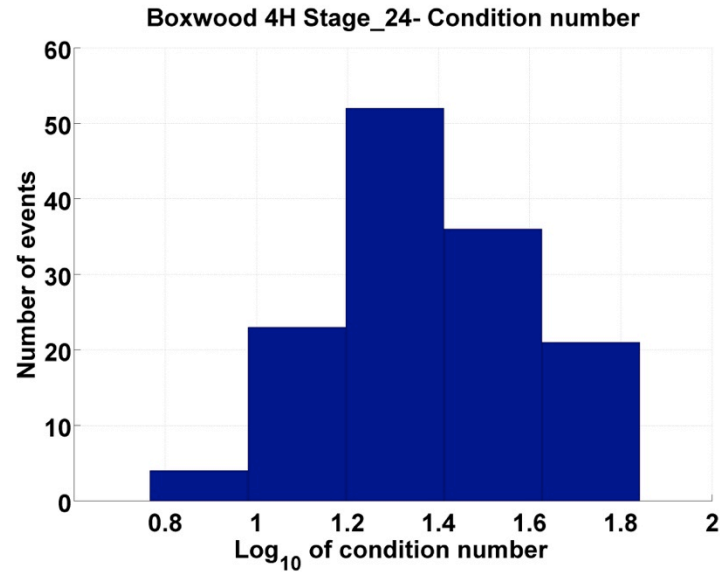


Source tensor Hudson plot -
Boxwood 4H Stage_24; Condition number < 70; Confidence > 0.5
Magnitude ranges from -2.95 to -1.39



MTI Results – Boxwood 4H – Stage 24

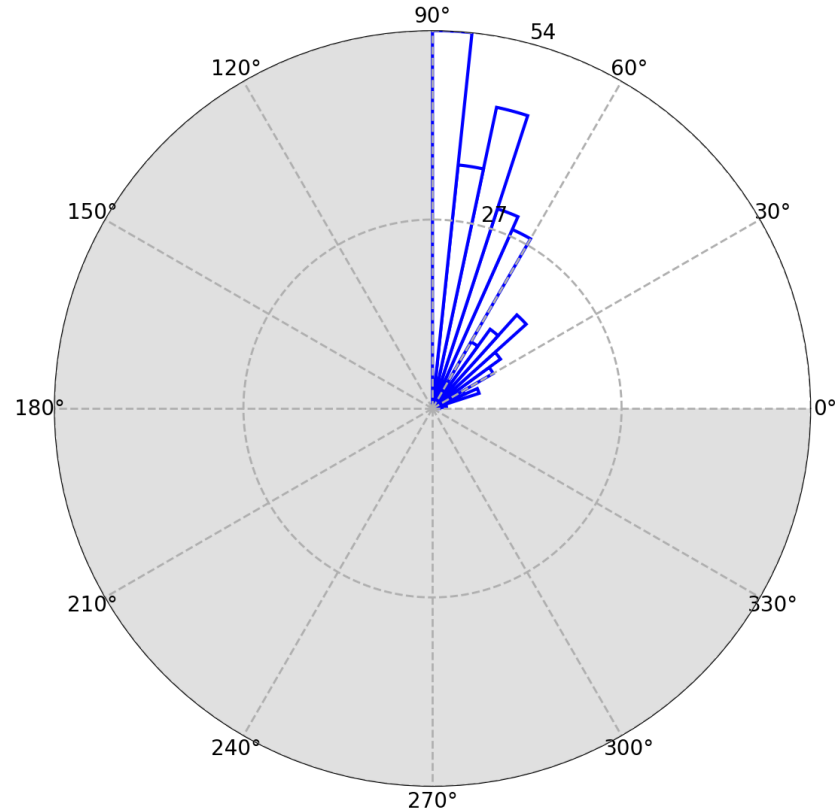
Condition Number, Confidence & Wire Display



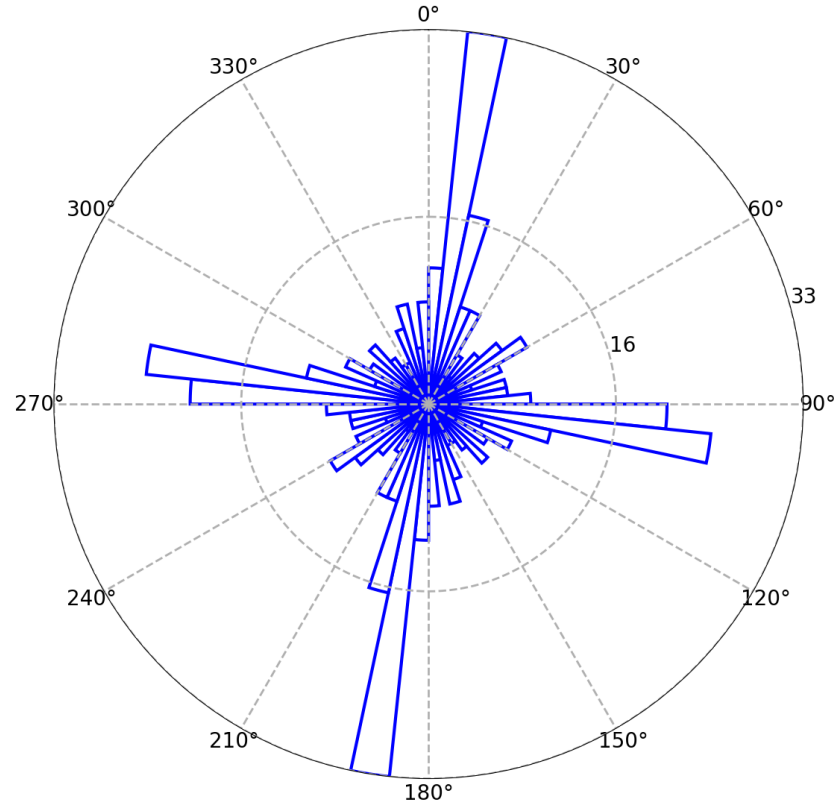
MTI Results – Boxwood 4H – Stage 24

Strike-Slip Fault Properties

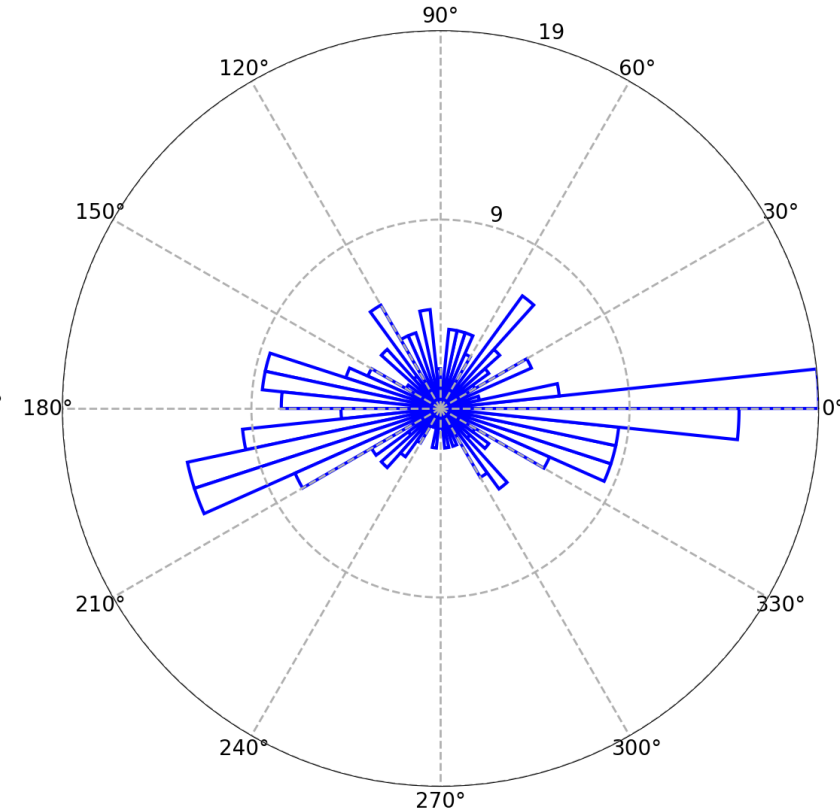
Dip - Boxwood 4H Stage 24
Condition number < 70; Confidence > 0.5
Mean DC percentage: 47.4474%



Strike - Boxwood 4H Stage 24
Condition number < 70; Confidence > 0.5
Mean DC percentage: 47.4474%



Slip - Boxwood 4H Stage 24
Condition number < 70; Confidence > 0.5
Mean DC percentage: 47.4474%



Deliverables List

- ✓ Continuous Raw data (SEGY file)
- ✓ Interferometry Data (SEGY file) (if applicable)
- ✓ VSP Data (SEGY file) (if applicable)
- ✓ Real-time Results
 - ✓ Reports
 - ✓ Catalogues – with times derived from Microseismic Data
 - ✓ Field Acquisition Observation Notes
- ✓ Geometry
 - ✓ Toolstring Diagram (Instrument make and Model)
 - ✓ Geophone Locations & Orientations
 - ✓ Well Paths
 - ✓ Perforation Shots Catalogues
 - ✓ Planned Location
 - ✓ True Location
 - ✓ Real-time Relocations (with times derived from Microseismic Data)
 - ✓ Final Relocation (with times derived from Microseismic Data)
- ✓ Formation Tops
- ✓ Processing Log
- ✓ Well-logs
- ✓ Perforation Shots Records (date, time & Measured Depth)
- ✓ Velocity Model
 - ✓ Post-Processed
 - ✓ Initial
 - ✓ Real-time
- ✓ Post-Processing
 - ✓ Final Event Catalogues (with p and s-waves picks and final event locations)
 - ✓ MTI Catalogues
 - ✓ Final Microseismic Reports
 - ✓ Transform Deployer
 - ✓ Gyration Movies
 - ✓ Triggered Data Trace Gathers (SEGY file)
 - ✓ Inversion results Trace Gathers (SEGY file)
 - ✓ Perforation Shots Trace Gathers (SEGY file)

- Option 1:
 - Provide Borehole Seismic with 16TB of External Hard-Drive storage (please add Company Label) and we will copy and delivery to you;
 - Deliver to: Denise Furtado
10500 Northwest Freeway suite 224
Houston, TX – 77092-8224
- Option 2:
 - Notify Borehole to please provide the 16TB of storage and invoice for data transfer;
 - \$2,500.00 for data storage and related services
- Option 3:
 - Collect and copy from GTI;

- Stimulated rock volume (SRV) is computed by summing the piecewise volume of the tetrahedron, which is formed by every four microseismic events. The complete set of the tetrahedron is determined by the method of Delaunay triangulation, which guarantees that tetrahedrons are non-overlapping and the union of all tetrahedron is the convex hull of the given points (microseismic events).
- In order to avoid significantly overestimating the SRV, the outliers have to be removed during the calculation. This goal is fulfilled by the algorithm called "Alpha-Shape" method, where the "large" tetrahedrons (whose circumcircle's radius exceed a threshold) will be excluded from the volume calculation. The threshold of filtering is adjusted manually for each stage based on the distribution of hypocenters.

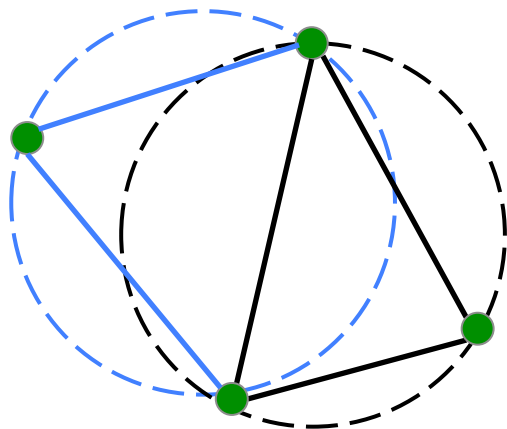
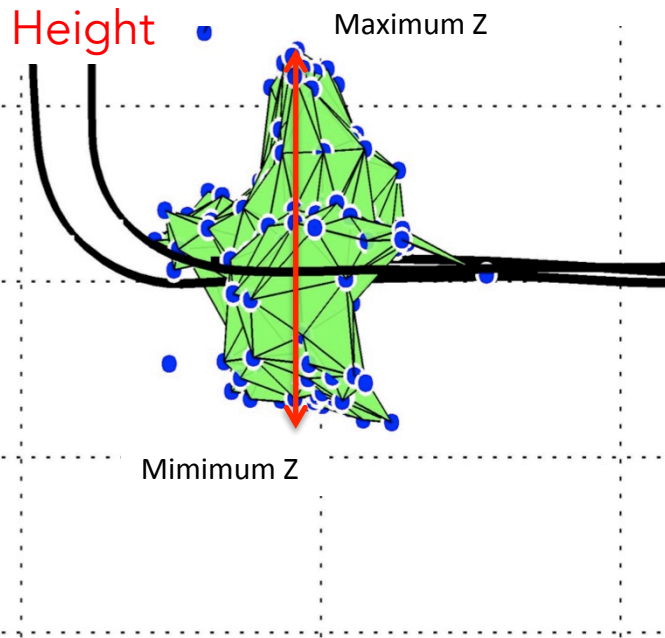


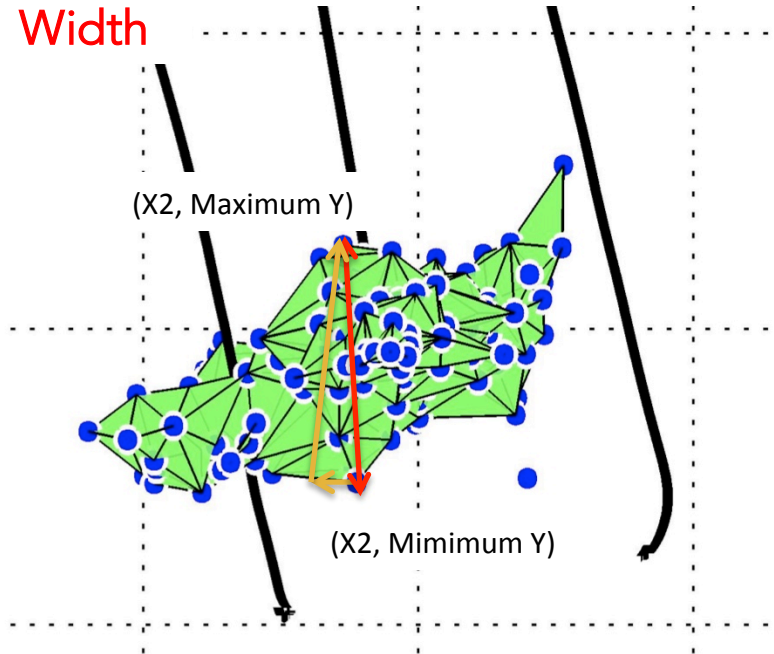
Figure: 2D view of Delaunay triangulation. Green dots indicate the microseismic events. Solid lines indicate the determined triangle, which will be used for area/volume calculation. Dash lines indicate the circumcircles, whose radius will be the parameter used to filter outliers.

Fracture Growth Calculation Procedure



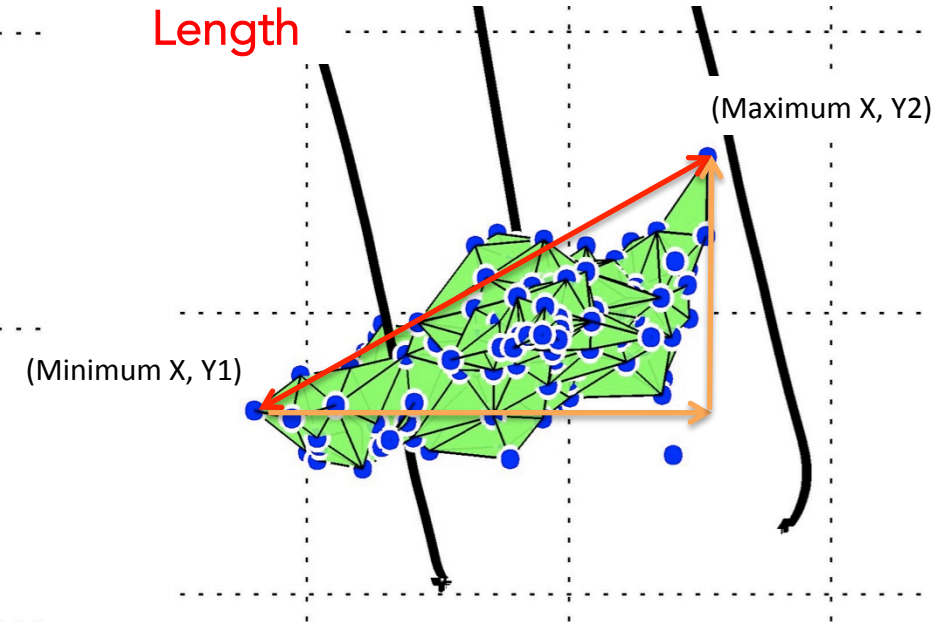
Height is calculated taking minimum and maximum depth (z) points:

$$d = Z_2 - Z_1$$



Width is calculated taking minimum and maximum northing (y) points with corresponding easting (x) coordinates with distance equation:

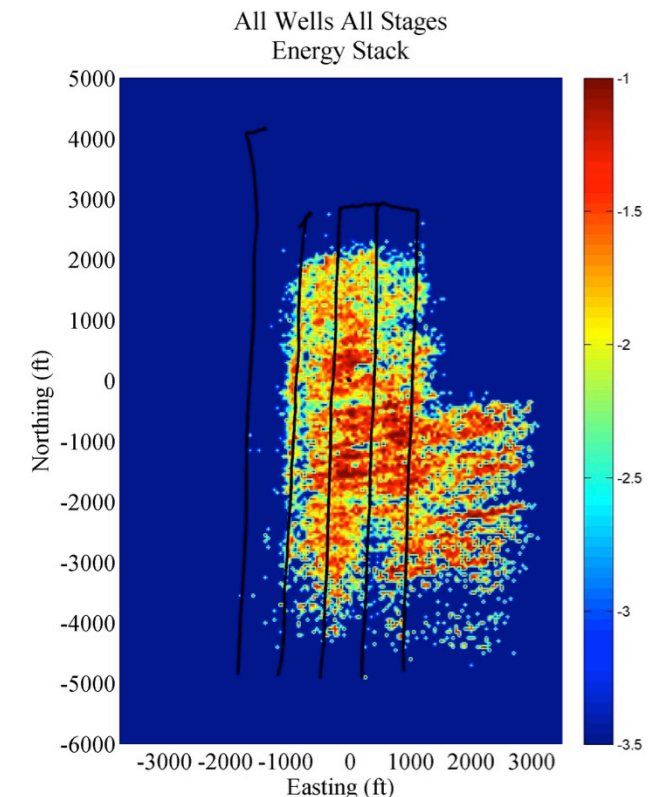
$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$



Length is calculated taking minimum and maximum easting (x) points with corresponding northing (y) coordinates with distance equation:

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

- The energy stack figure displays the density distribution of seismic energy. It is created by adding the logarithm of each event's seismic moment to the discrete grid at the hypocenter.
- It involves the following steps:
 - Discretize the region of interests into grids.
 - Determine the grid that the event is located within.
 - Add the logarithm of event's seismic moment to this grid.
 - Repeat the above steps for all events.



Maximum Fracture Height, Width and Length Displays

- The figure shows two attributes, the maximum fracture length/height derived from the SRV method and are represented by the bars length/height. The second attribute is events density and it involves the following steps:
 - Discretize the region of interests into grids.
Here we used 50 ft grid size.
 - Determine the number of events occurred in each grid.
 - Find the grid with maximum number of events for the well
 - Normalize the values with maximum events count in log scale (maximum=1, minimum~0)
 - Plot the grid values using Violin shapes

