

Utah Forge

Monitored Well: 16B(78)-32



Hydraulic Fracture Monitoring of Well 16A FRAC From 16B Cross well Fiber Measurements 16A(78)-32 **Frac Stages 3R through 10**

Field Operations: Apr 2024

Neubrex Energy Services (US), LLC

Dana Jurick | COO, Neubrex Energy Services (US), LLC

Dr. Artur Guzik | Software Engineering and Services, Neubrex Infra AG

Last update: November 1, 2024

Acknowledgements



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During field operations, Neubrex worked with many operational experts and received critical assistance from many people, including Alan Reynolds, Leroy Swearingen, Kevin England, John McLennan, Joe Morris, Garth Larson, Monty Keown, Dr. Mukul Sharma, Ben Dyer, Dr. Peter Meier, and Neubrex Ops Chief Wayne Fishback. Working frac, drilling, water management crews and HSE managers were instrumental in getting the surface and downhole work accomplished in a safe and effective manner.

Technical Report and Contact Information

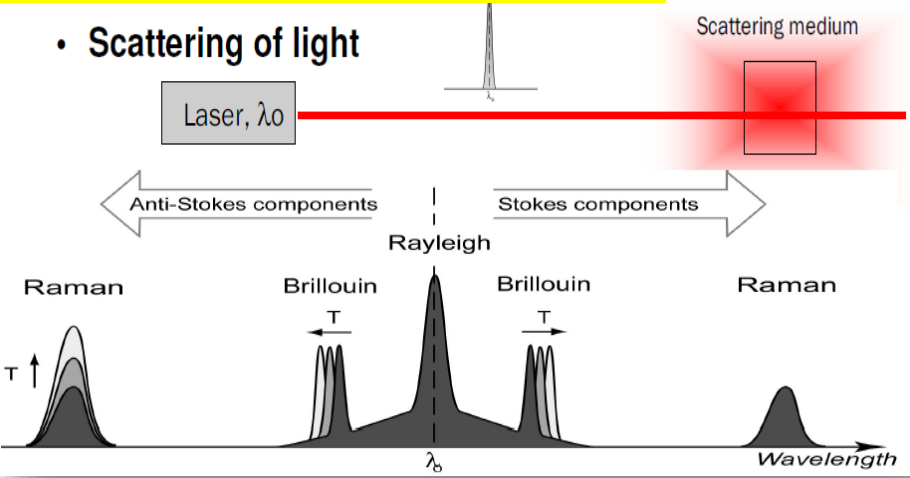


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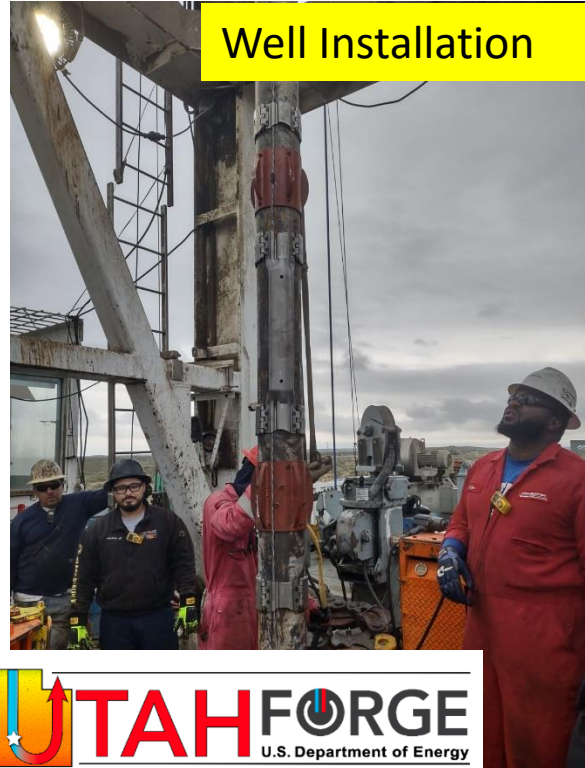
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First Principles – Optical Physics

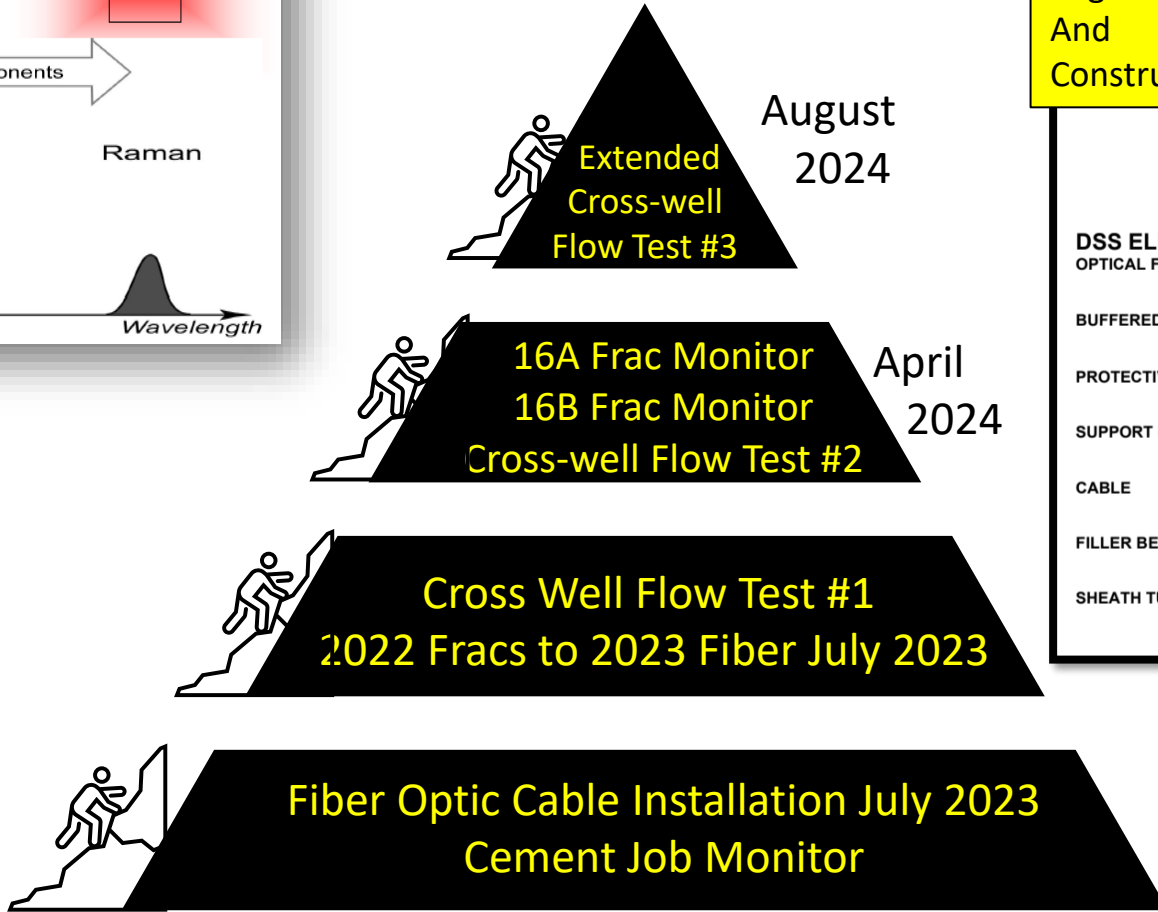
Scattering of light



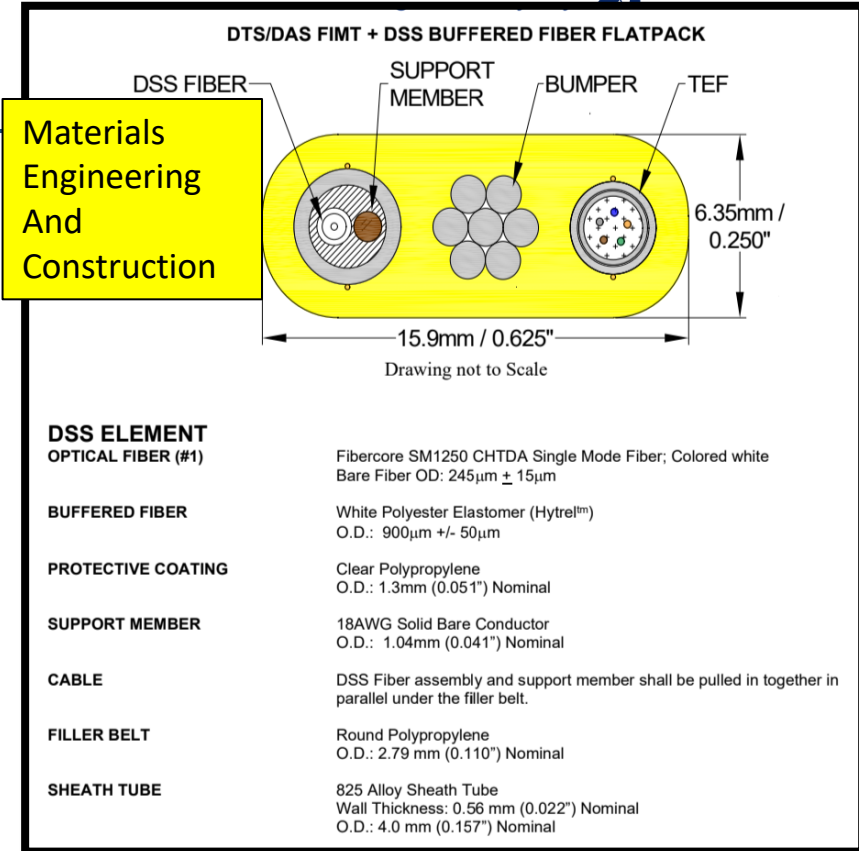
Distributed Fiber Optic Sensing Applications at FORGE



Well Installation



Materials Engineering And Construction



FORGE Site Operations



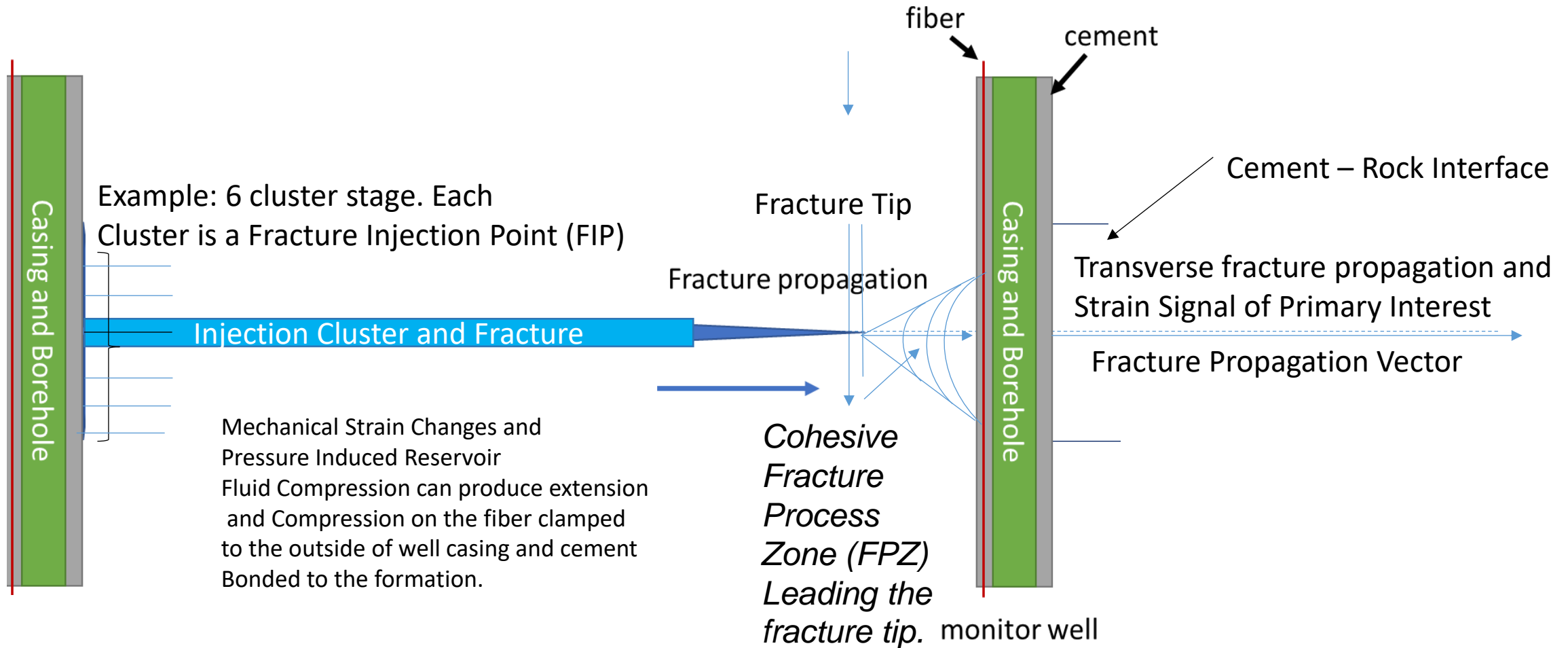
NEUBREX ENERGY SERVICES (US), LLC and UTAH FORGE

Conceptual Schematic of Far Field Strain Creating Fracture Driven Interaction Signal on Fiber Optic Strain Detection System



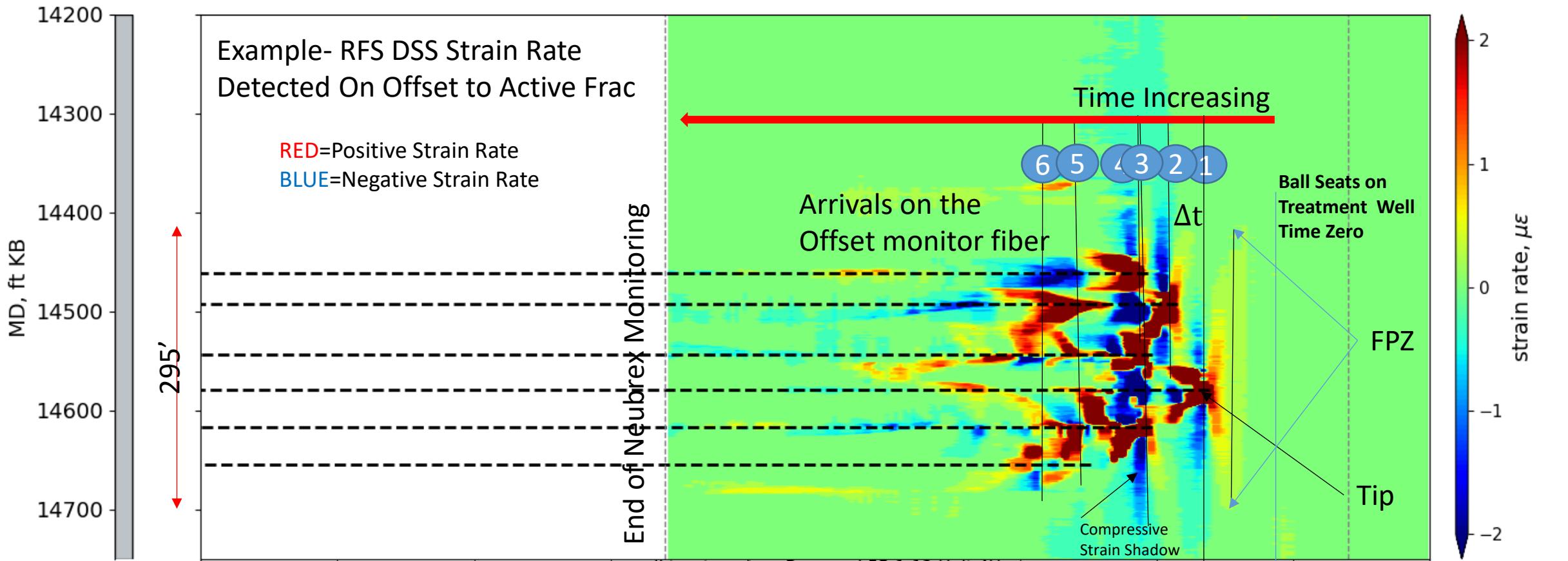
Treatment Well

Monitor Well

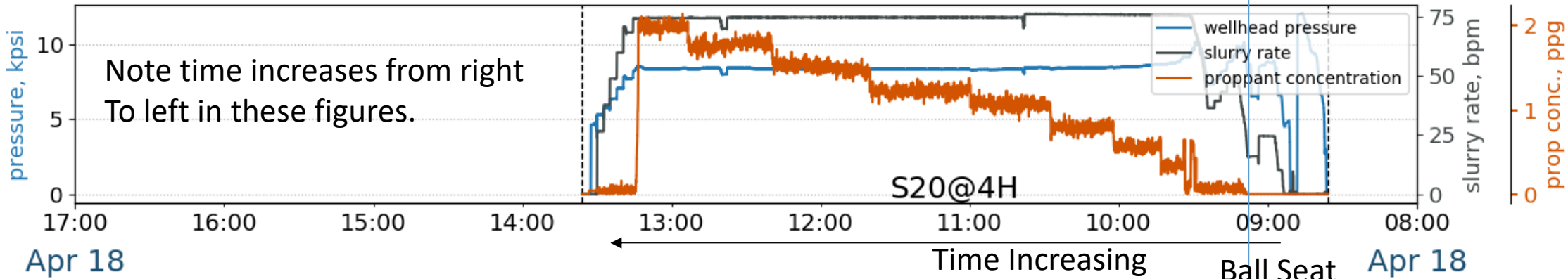


Boxwood 55-1-12 Unit 3H: strain rate - stage 20

Start



well treatment on Boxwood 55-1-12 Unit 4H




S20@4H

Timeline – This report Covers “Evolution 2” of FORGE Project



Project timeline and acquisition settings

Name	Target	Neubrex acquisition	
		start	end
Evolution 0	Cementing	Jul 13, 2023, 04:39	Jul 14, 2023, 11:14
Evolution 1	Post-cementing monitoring	Jul 15, 2023, 12:18	Jul 20, 2023, 15:40
 Evolution 2	Interaction with stimulation on well 16A	Apr 1, 2024, 12:00	Apr 7, 2024, 16:00

This report covers the fiber optic monitoring of frac stimulation
On Wells 16A at the Crosswell 16B Monitor Well using Fiber optics in 16B.

Primary method of monitoring is Distributed Fiber Optic Sensing using
Rayleigh Frequency Shift - Distributed Strain Sensing Method. DAS was also
Used for Micro seismic monitoring and DTS was used for Temperature Monitoring

Stim 16A Well (Green) and Monitor Well 16B (Red)

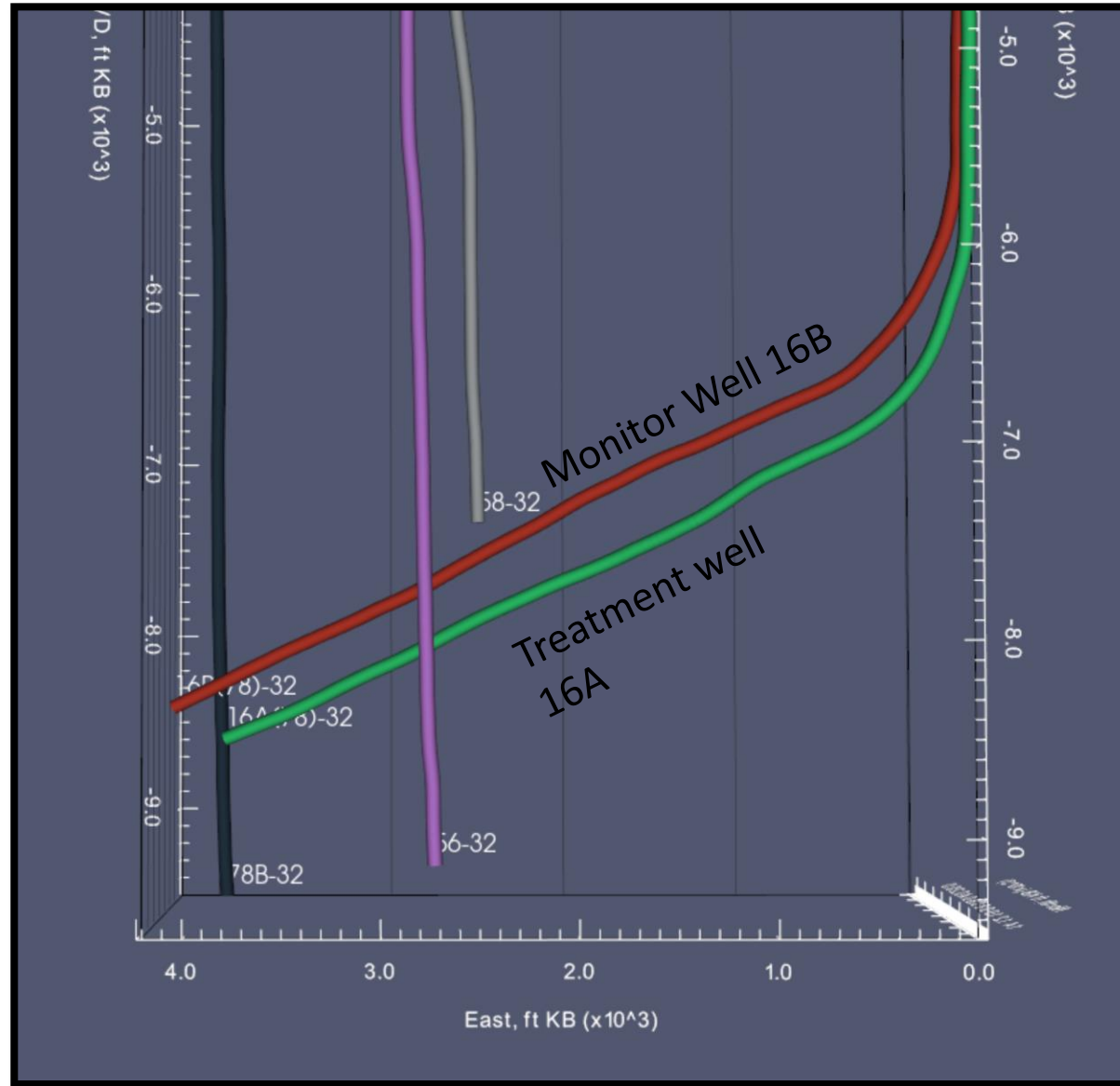


VIEW LOOKING SOUTH

The 16B well is instrumented With a fiber optic cable That contains 2 single mode Fibers and one multi mode Fiber.


Green is the treatment Well.

Red is the monitor well.



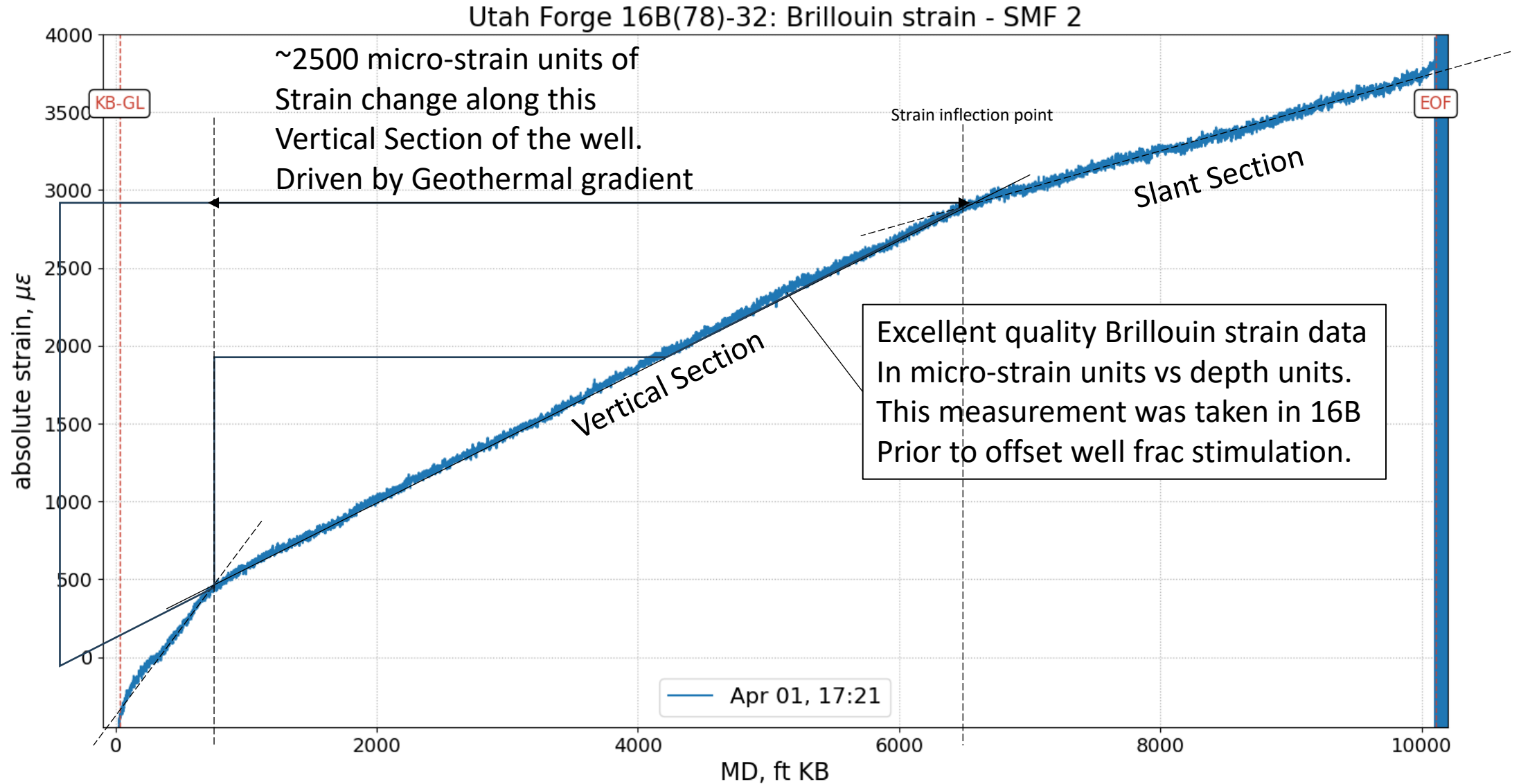
Well 16B(78)-32 Well Header File Information



	<h2>Daily Completion Report</h2>					
	Well ID: FORGE 16B(78)-32 Job ID: 16B(78)-32STIM1		Well:			
Field: FORGE		Sect: 32 Town: 26S Rng: 9W				
Report No: 8				Report		
Operator:	Utah FORGE	Rig:	UDES WOR105	Wellbore:	Original Wellbore	Daily Cos
Measured Depth (ft):	10947.0	Completion Days (act.):	8	Orig RKB Elev(ft):	30.5	AFE No.
Vertical Depth (ft):	8357.0	Last BOP Test:	16-Mar-24	---	---	---

65° Slant Section

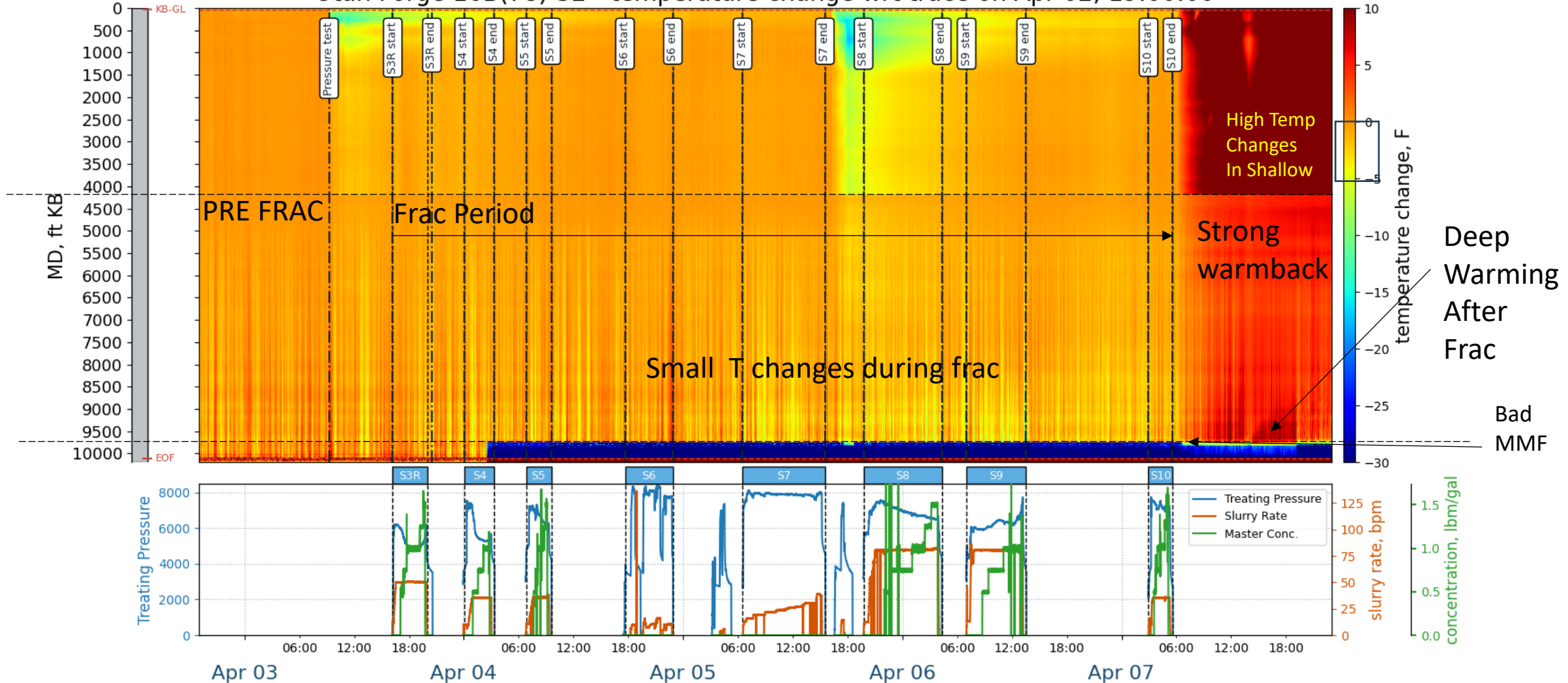
Well 16B – Brillouin Absolute Total Strain prior to frac ops



Well 16B – DTS temperature change wrt baseline April 02



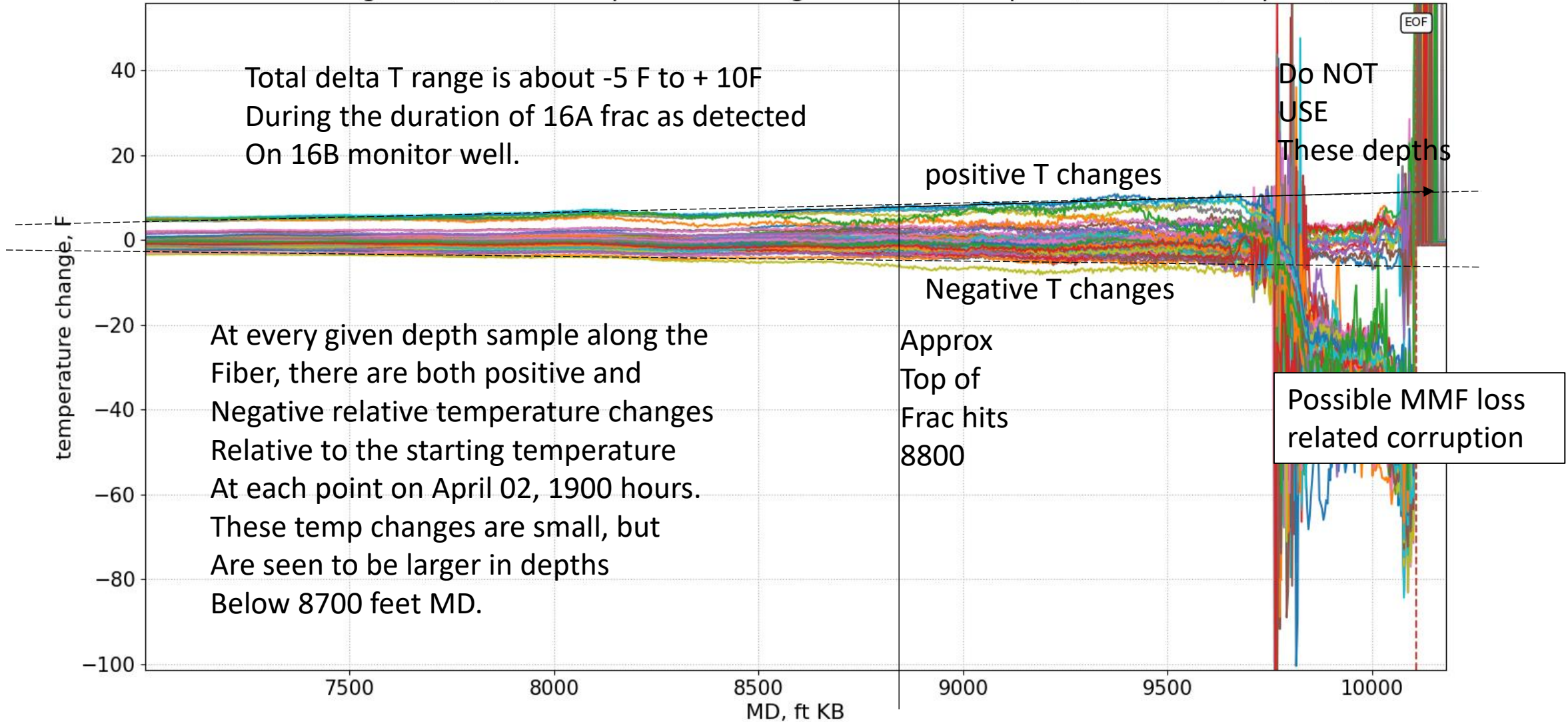
Utah Forge 16B(78)-32 - temperature change wrt trace on Apr 02, 19:00:00



Well 16B – DTS temperature changes small during frac



Utah Forge 16B(78)-32: Temperature change wrt trace on Apr 02, 19:00:00 (step 2 h)





16A Cluster and Plug Depths & Pressure Pumping Schedules

As received from Operator.

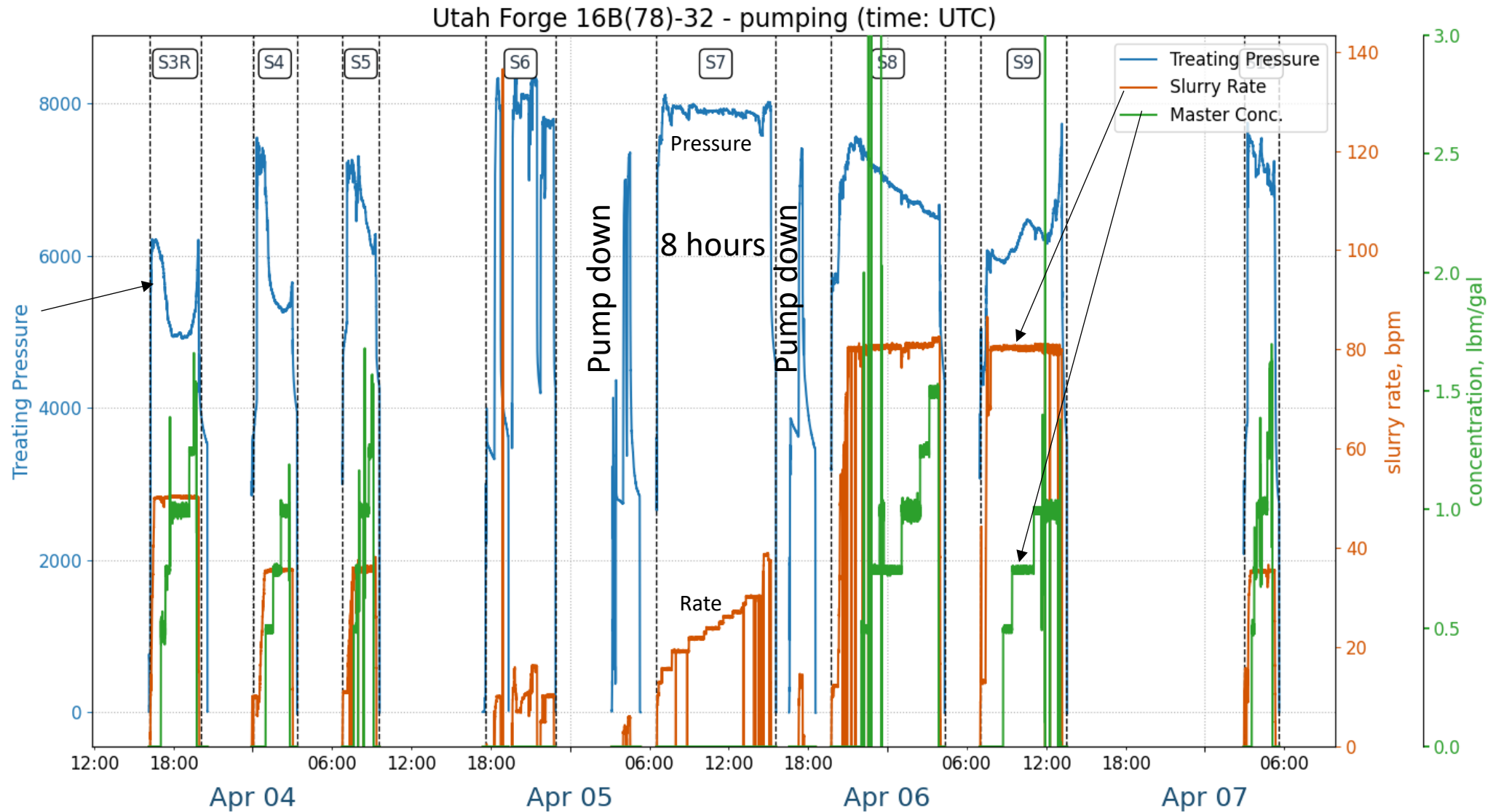
Well 16A Stages, Plugs and Perf Cluster Depths in MD RKB



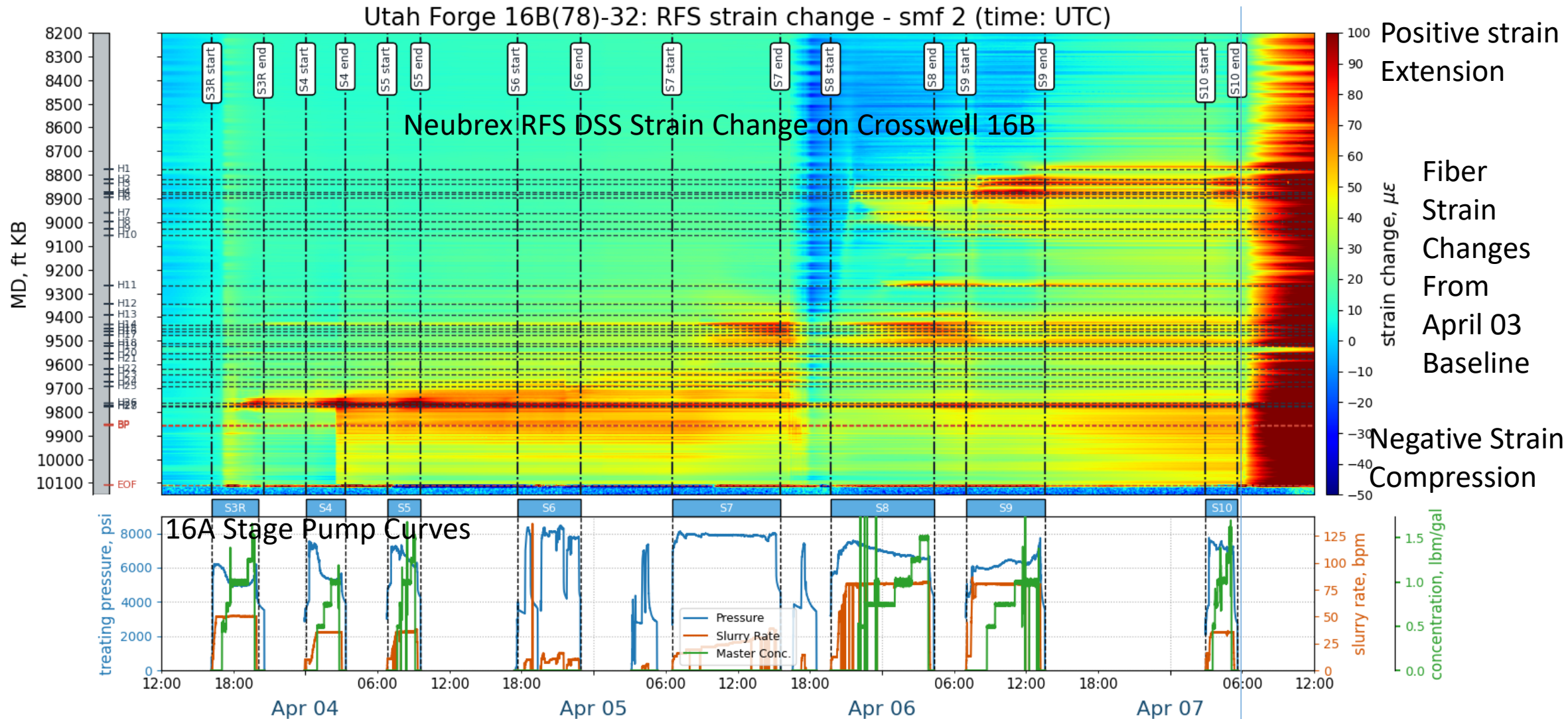
Measured Depth (Referenced to KB = 32 ft)

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8	Frac Plug
Stage 3R (16A)	Open-hole	10,560 - 10,580	10,120 - 10,140						
Frac Plug #1									10,095
Stage 4 (16A)	10,070 - 10,076								
Frac Plug #2									10,045
Stage 5 (16A)	10,020 - 10,026								
Frac Plug #3									9,995
Stage 6 (16A)	9,970 - 9,976	9,959 - 9,962 ¹							
Frac Plug #4									9,945
Stage 7 (16A)	9,898 - 9,901	9,850 - 9,853	9,798 - 9,801						
Frac Plug #4									9,745
Stage 8 (16A)	9,720 - 9,723	9,695 - 9,698	9,670 - 9,673	9,645 - 9,648	9,620 - 9,623	9,595 - 9,598	9,570 - 9,573	9,545 - 9,548	
Frac Plug #5									9,520
Stage 9 (16A)	9,490 - 9,493	9,470 - 9,473	9,445 - 9,448	9,420 - 9,423	9,395 - 9,398	9,370 - 9,373	9,345 - 9,348	9,320 - 9,323	
Frac Plug #6									9,295

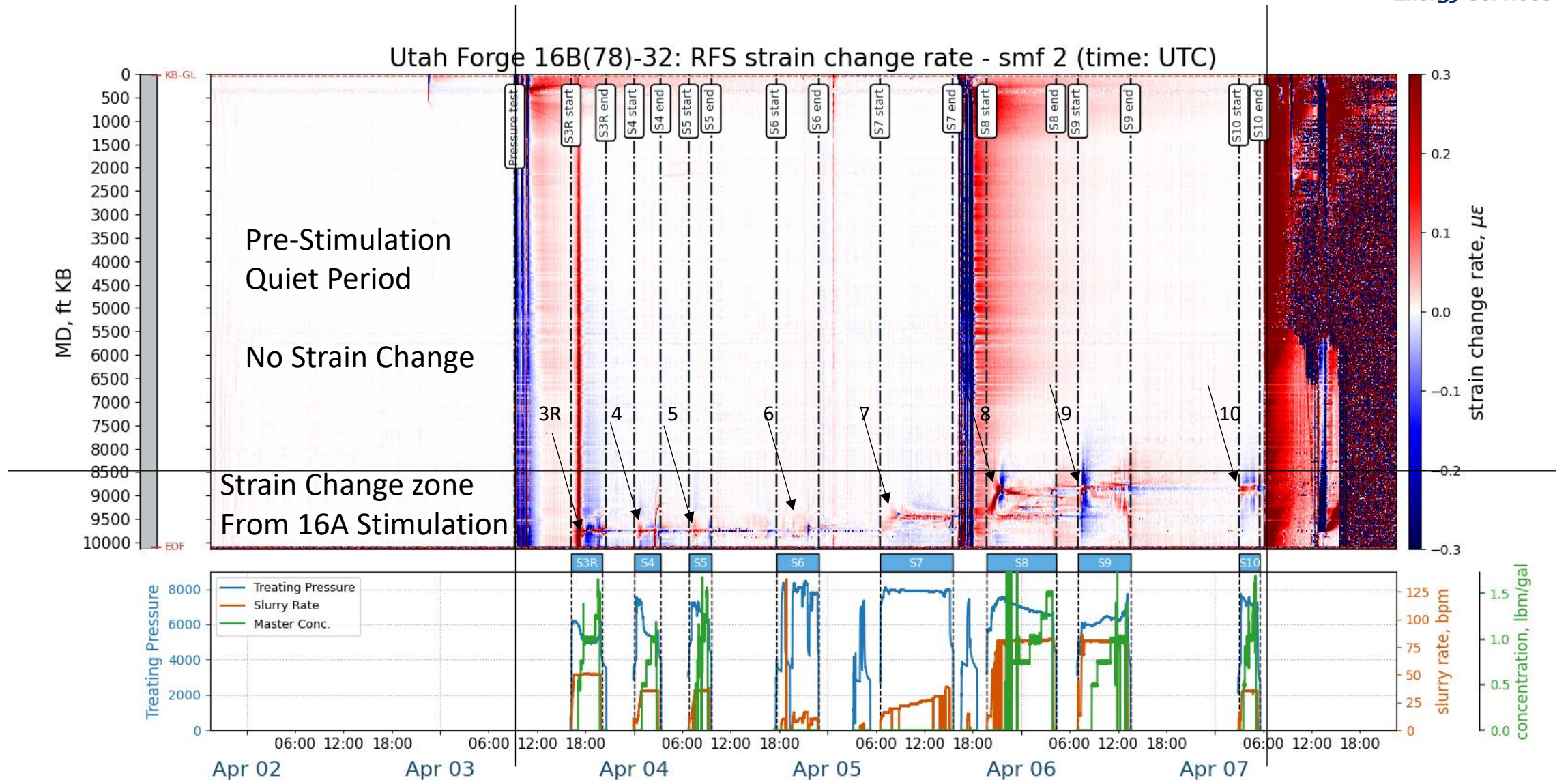
Well 16A – pressure pumping data – Frac Stages 3R to 10



On Well 16B – RFS DSS strain change from baseline - Interpreted Fracture Driven Interactions



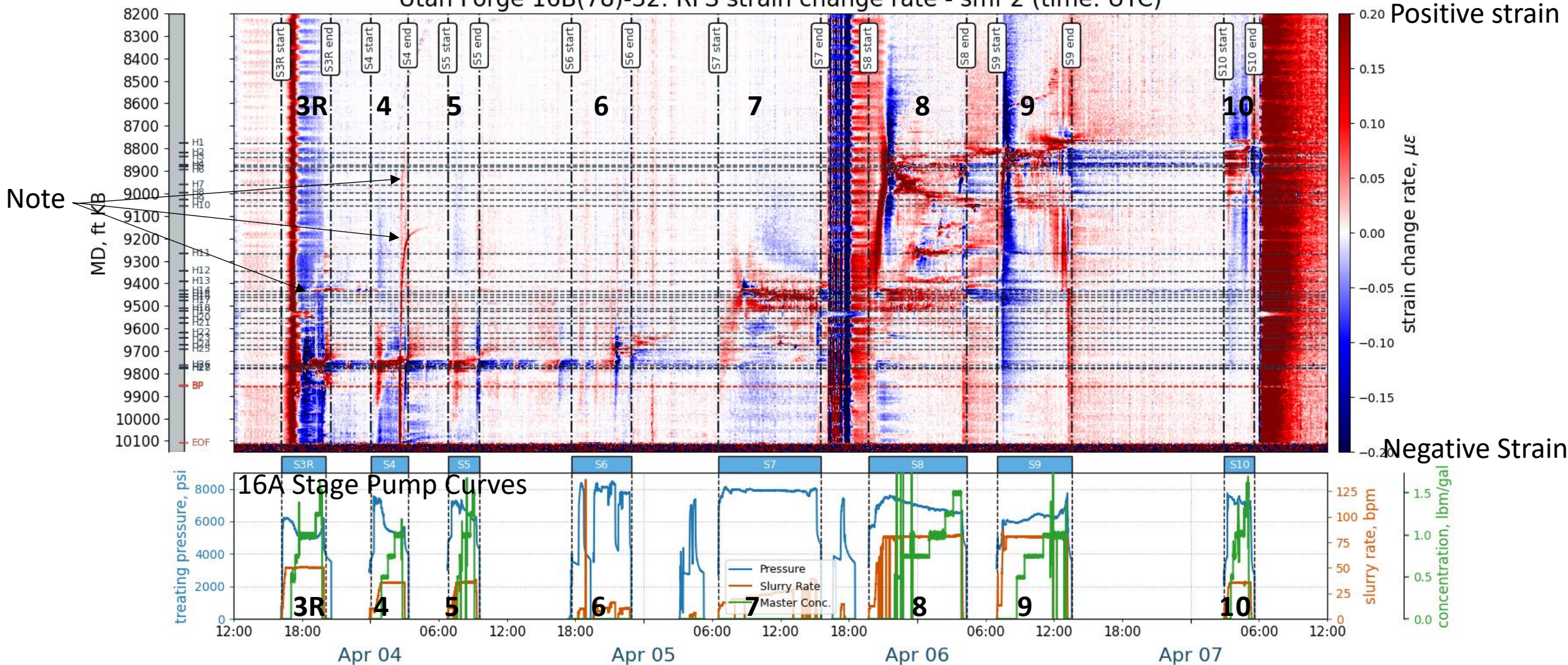
Well 16B – RFS DSS strain change rate – Overview Full Waterfall



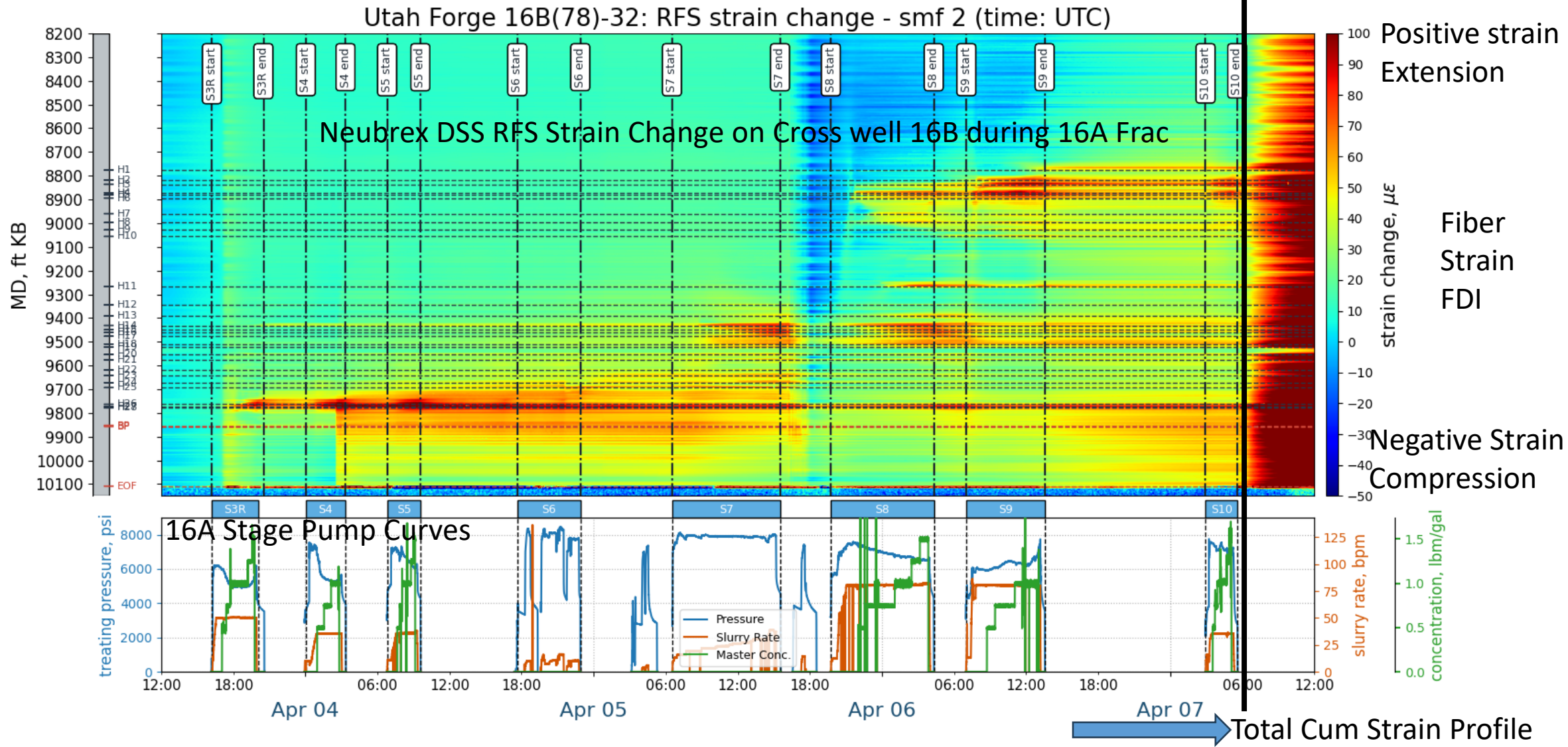
On Well 16B – RFS DSS strain change RATE (time differential for rate calculation of 30 S) produced from 16A frac with Interpreted Fracture Driven Interactions (FDI) on 16B



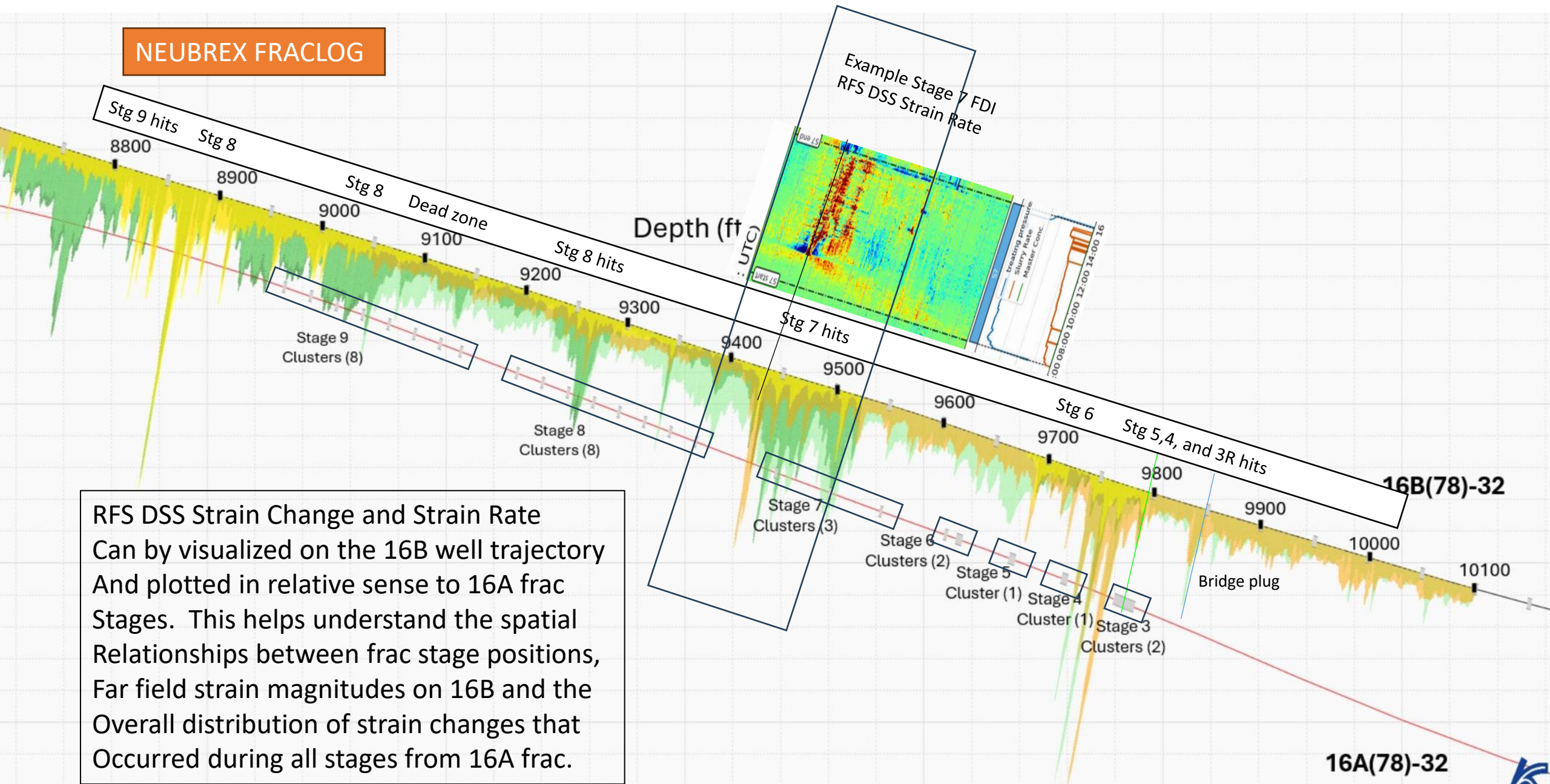
Utah Forge 16B(78)-32: RFS strain change rate - smf 2 (time: UTC)



On Well 16B – RFS DSS strain change from 16A - Interpreted Fracture Driven Interactions (FDI)



NEUBREX FRACLOG



RFS DSS Strain Change and Strain Rate Can be visualized on the 16B well trajectory And plotted in relative sense to 16A frac Stages. This helps understand the spatial Relationships between frac stage positions, Far field strain magnitudes on 16B and the Overall distribution of strain changes that Occurred during all stages from 16A frac.

16A(78)-32

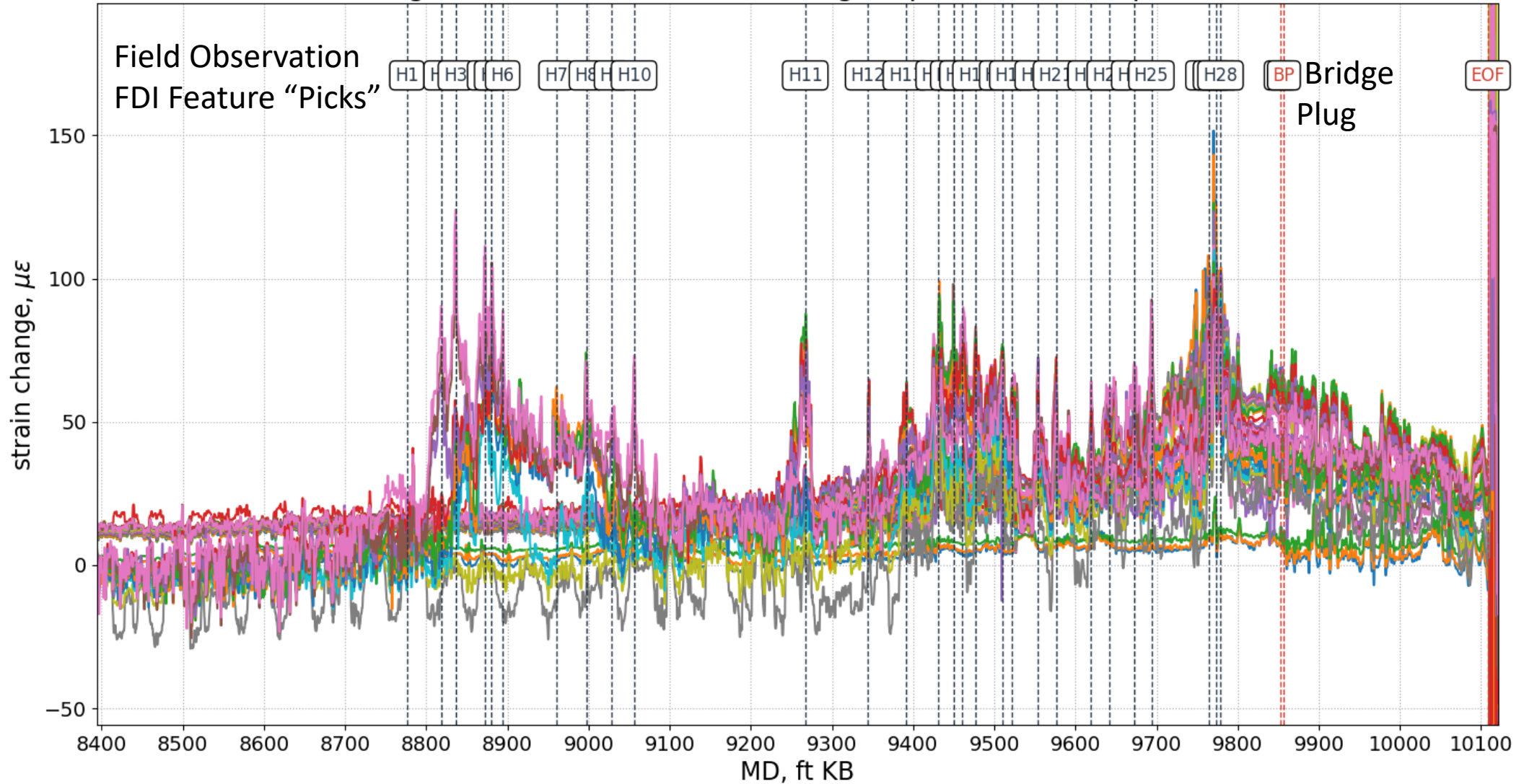
16B(78)-32



Well 16B – RFS DSS Cumulative Strain Change Profiles at Specific Profile Times over Depth Domain



Utah Forge 16B(78)-32: RFS strain change (Apr 03 12:00 to Apr 06 12:00)



Selected FDI MD Depths on 16B from 16A Frac Stimulation

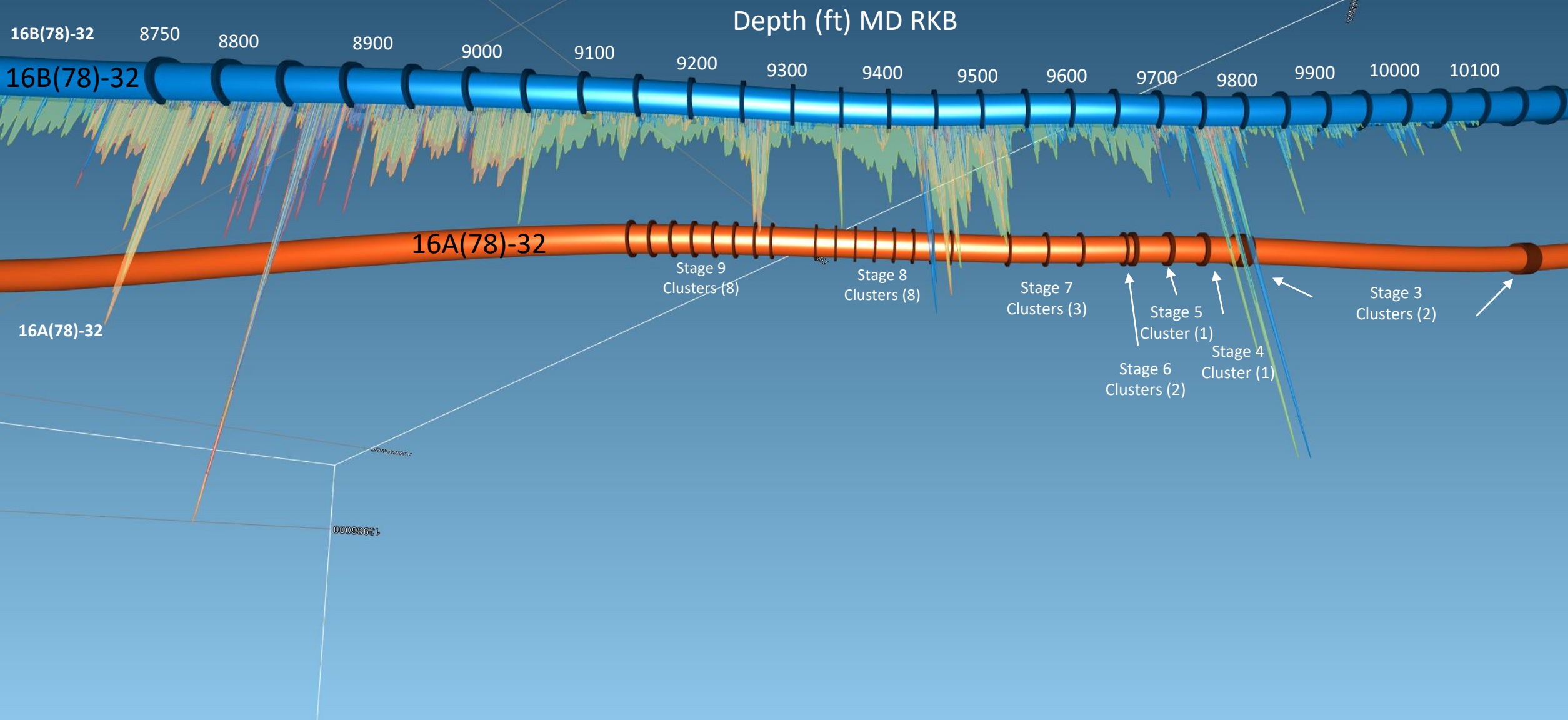


- The following locations were selected for potential frac perf locations on future 16B frac
- Total of 28 FDI picks were made
- These were picked on site location during field operations

Label	Depth, MD ft KB
H1	8776.265
H2	8818.477
H3	8836.065
H4	8872.024
H5	8880.622
H6	8894.151
H7	8959.965
H8	8997.487
H9	9028.365
H10	9056.115
H11	9267.093
H12	9344.577
H13	9391.146
H14	9431.453
H15	9449.455
H16	9460.804
H17	9476.848
H18	9509.721
H19	9522.243
H20	9553.550
H21	9576.247
H22	9618.903
H23	9642.383
H24	9672.516
H25	9693.648
H26	9763.903
H27	9773.289
H28	9778.827

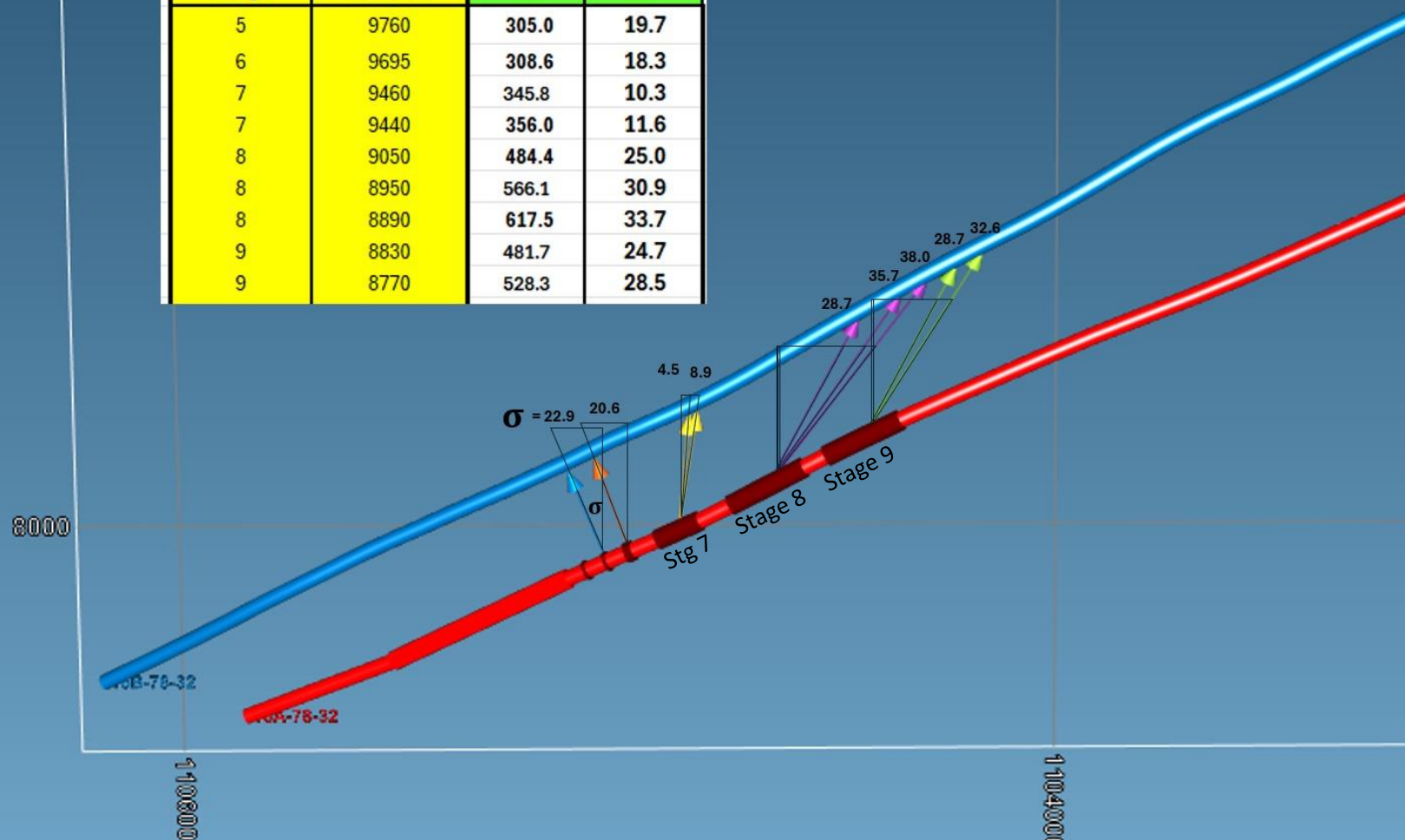
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16B Cumulative Strain relative to 16A Cluster Locations used during Stimulation



Possible Propagation Directions and Angles 16A to 16B

16A Stage	16B Hit MD		
Stage	16B MD	d	σ
5	9760	305.0	19.7
6	9695	308.6	18.3
7	9460	345.8	10.3
7	9440	356.0	11.6
8	9050	484.4	25.0
8	8950	566.1	30.9
8	8890	617.5	33.7
9	8830	481.7	24.7
9	8770	528.3	28.5



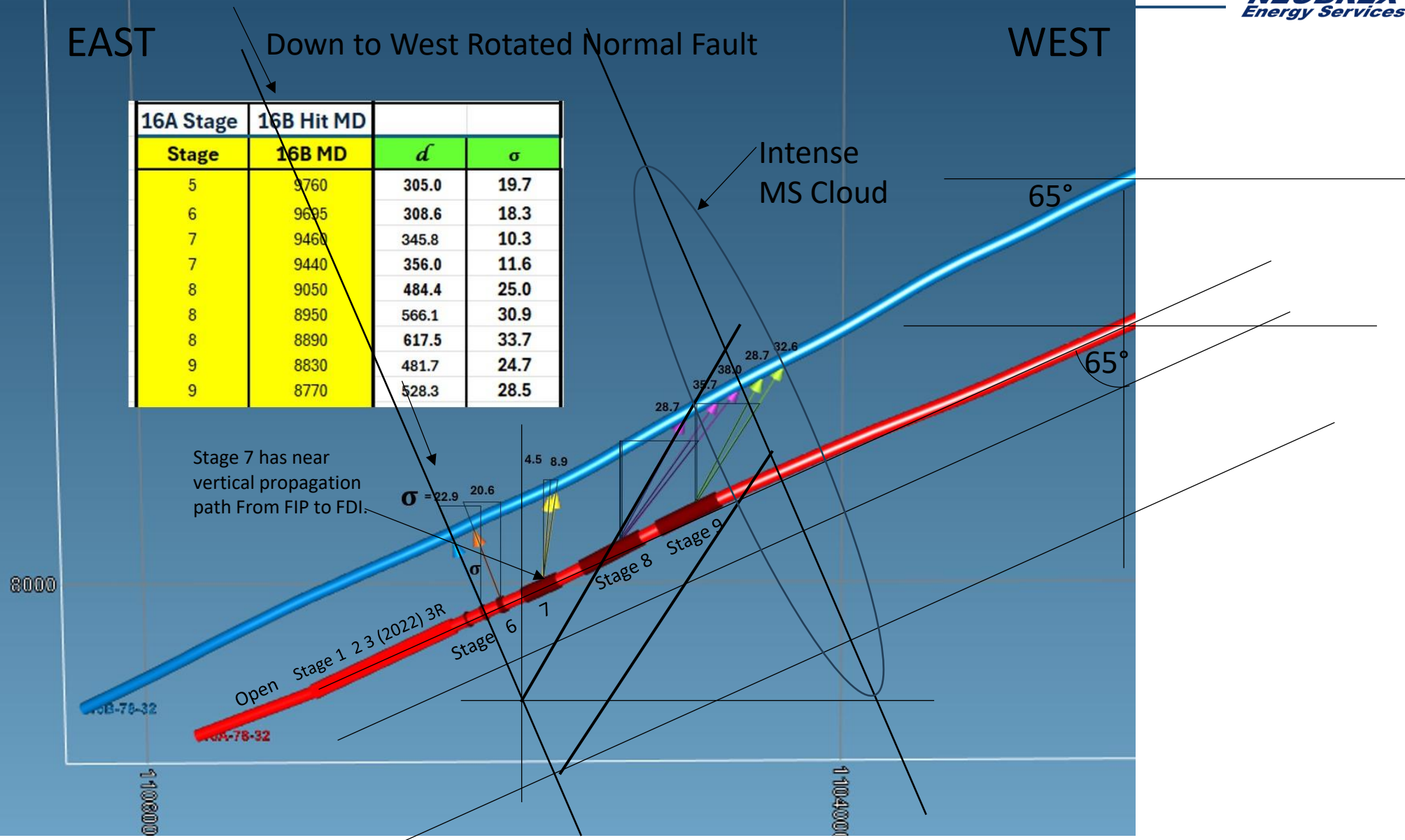
Possible Preexisting Structures to Explain Frac Propagation Angles

EAST

Down to West Rotated Normal Fault

WEST

16A Stage	16B Hit MD		
Stage	16B MD	d	σ
5	9760	305.0	19.7
6	9695	308.6	18.3
7	9460	345.8	10.3
7	9440	356.0	11.6
8	9050	484.4	25.0
8	8950	566.1	30.9
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Utah FORGE

16A Frac

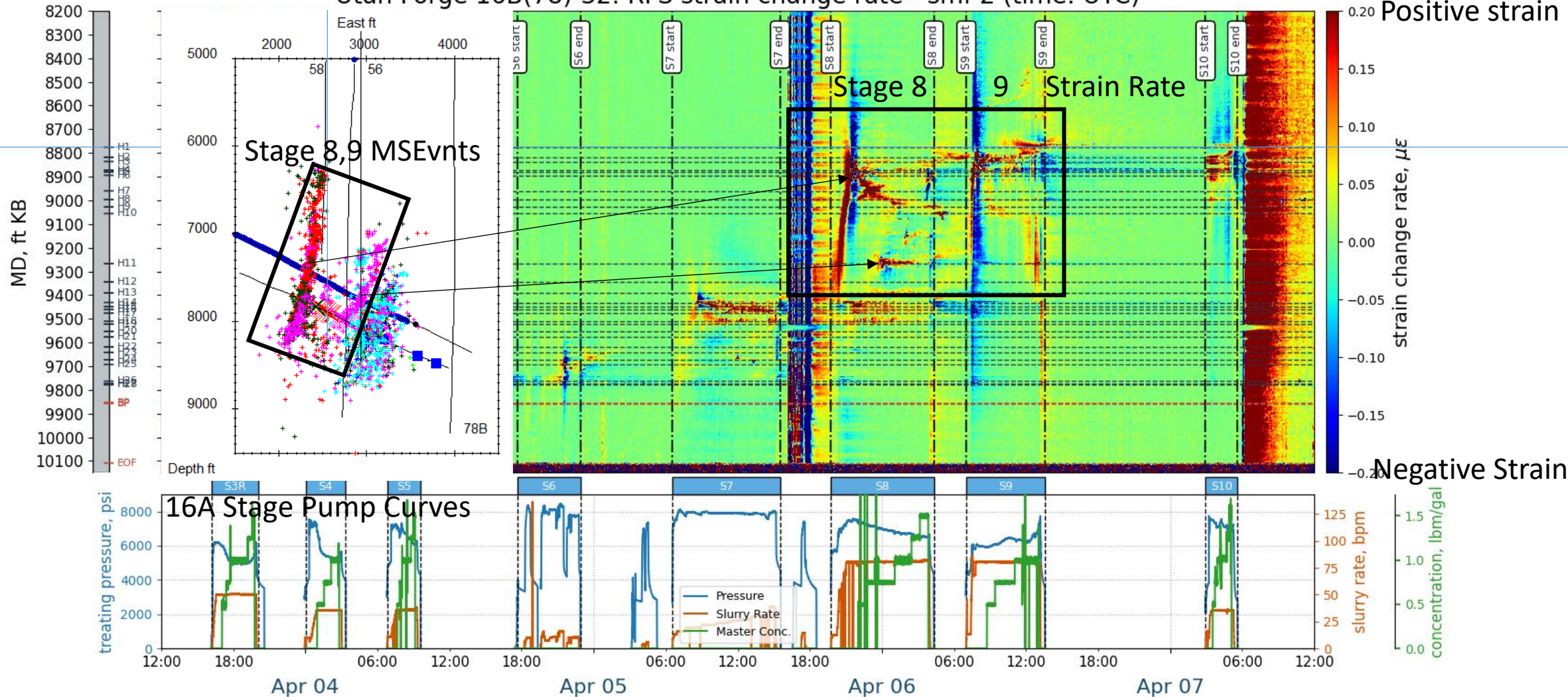
Stages 3R-10

Micro seismic Location Analysis (GES Solution) with RFS DSS Strain
Profile Shown on 16B

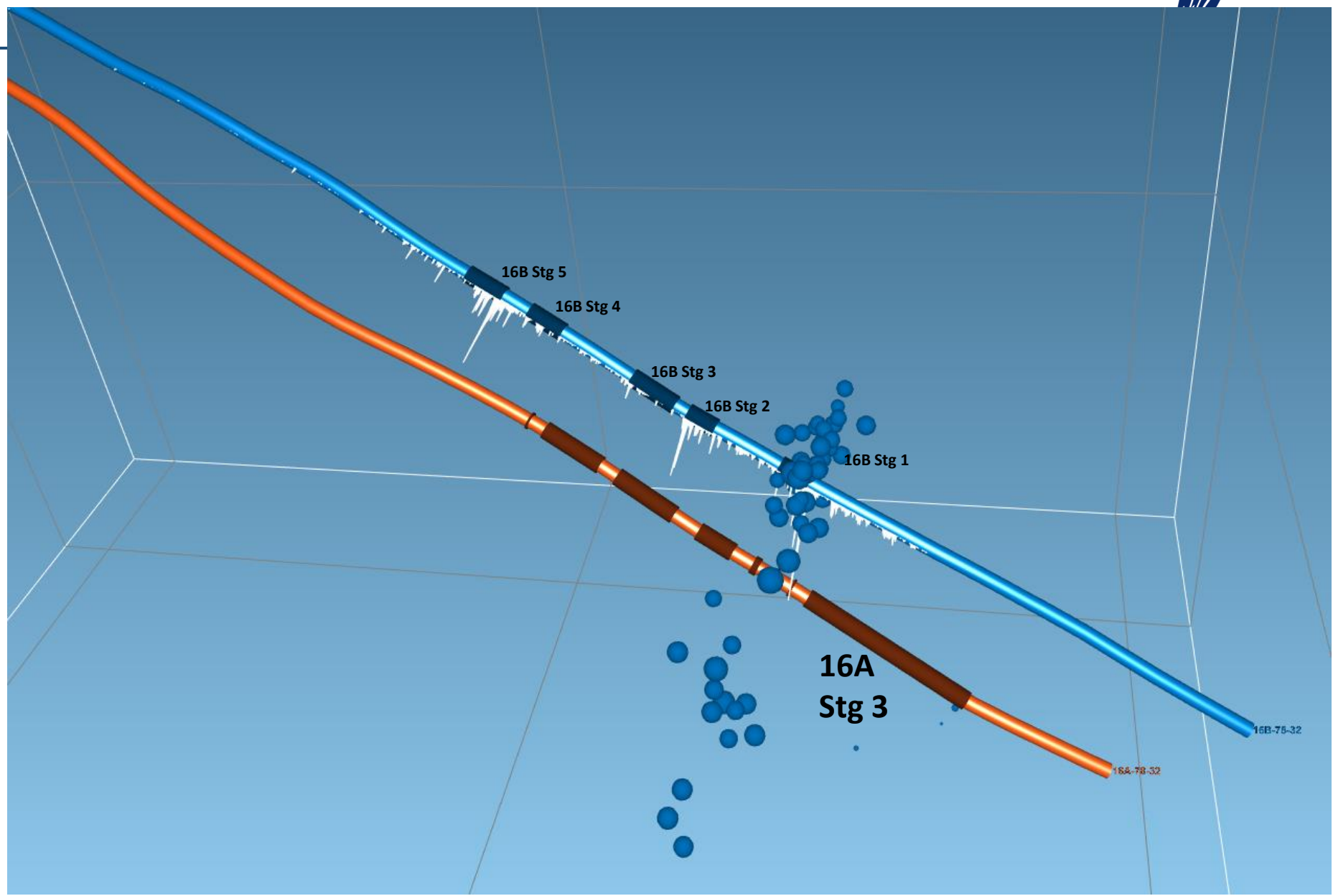
Example: Correlation of DAS Micro seismic with 16B RFS DSS strain change rate



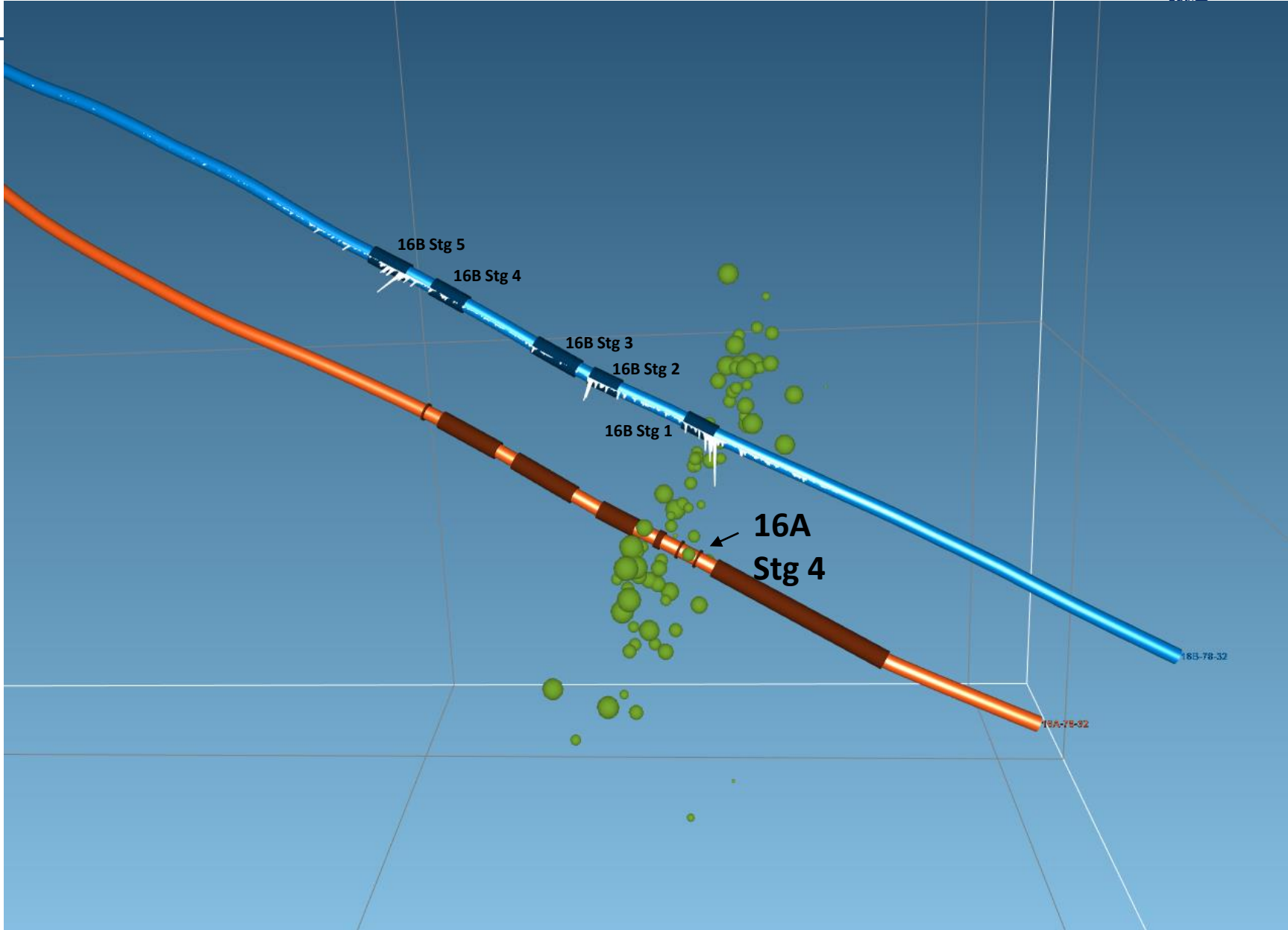
Utah Forge 16B(78)-32: RFS strain change rate - smf 2 (time: UTC)



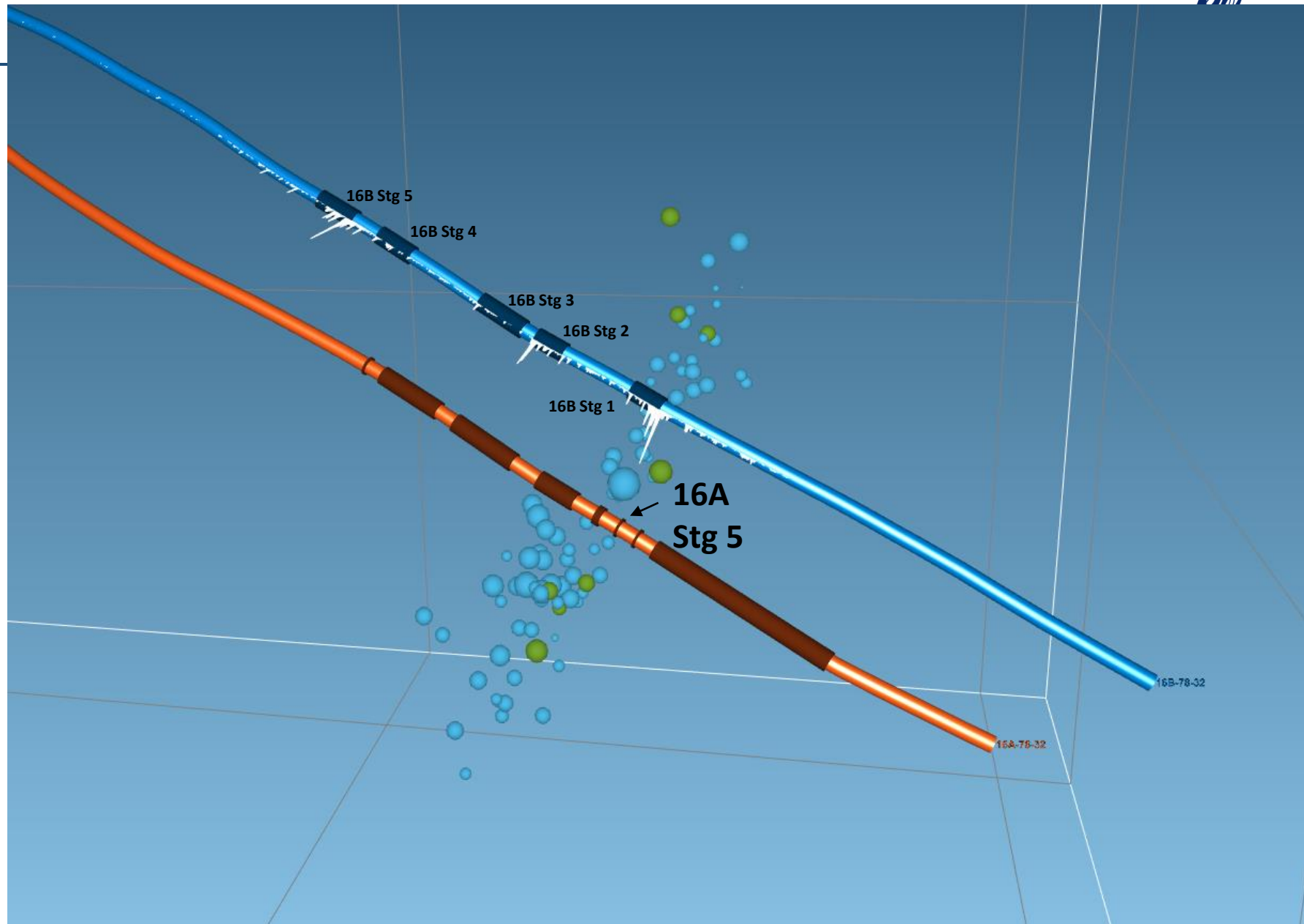
16A Stage 3R



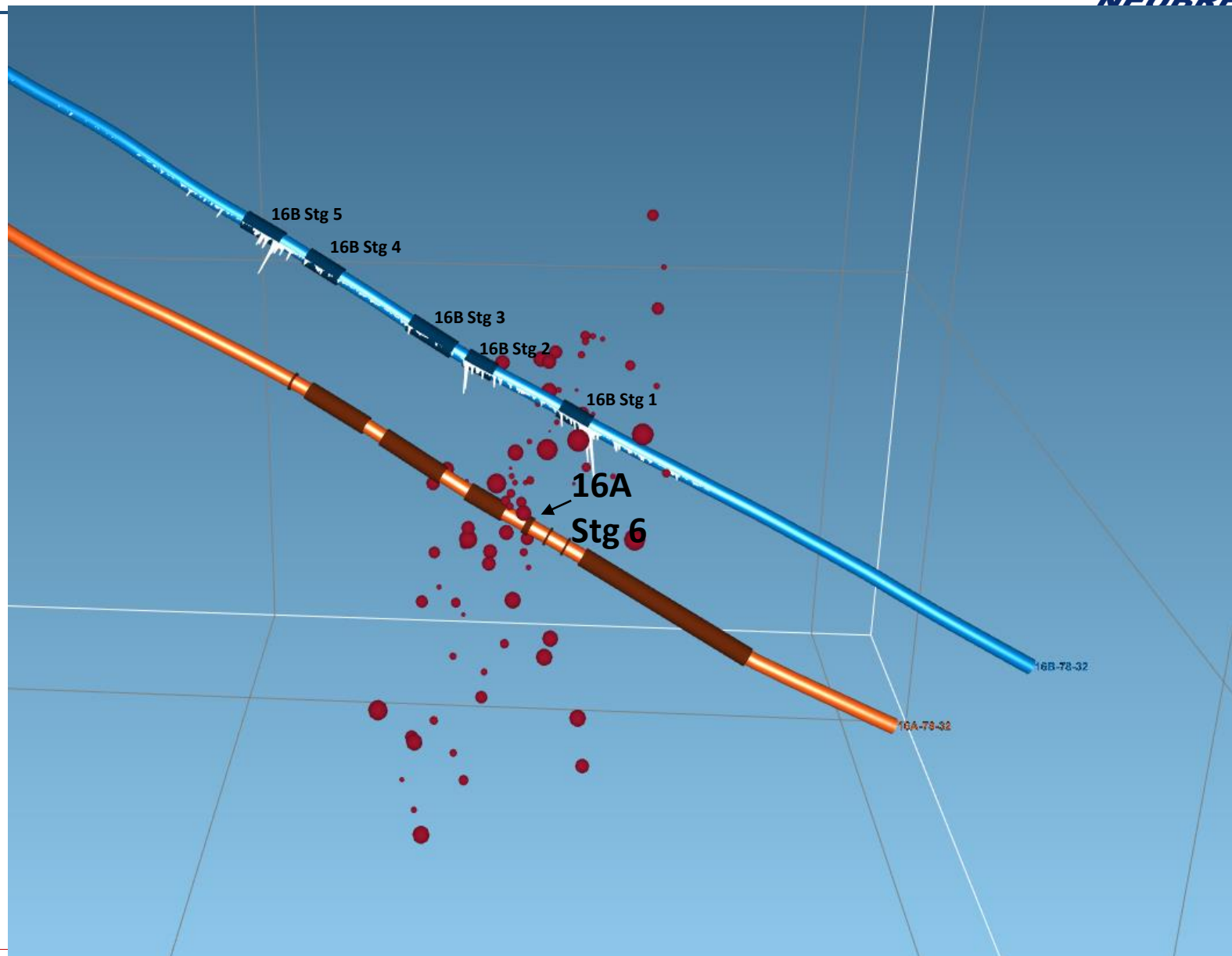
16A Stage 4



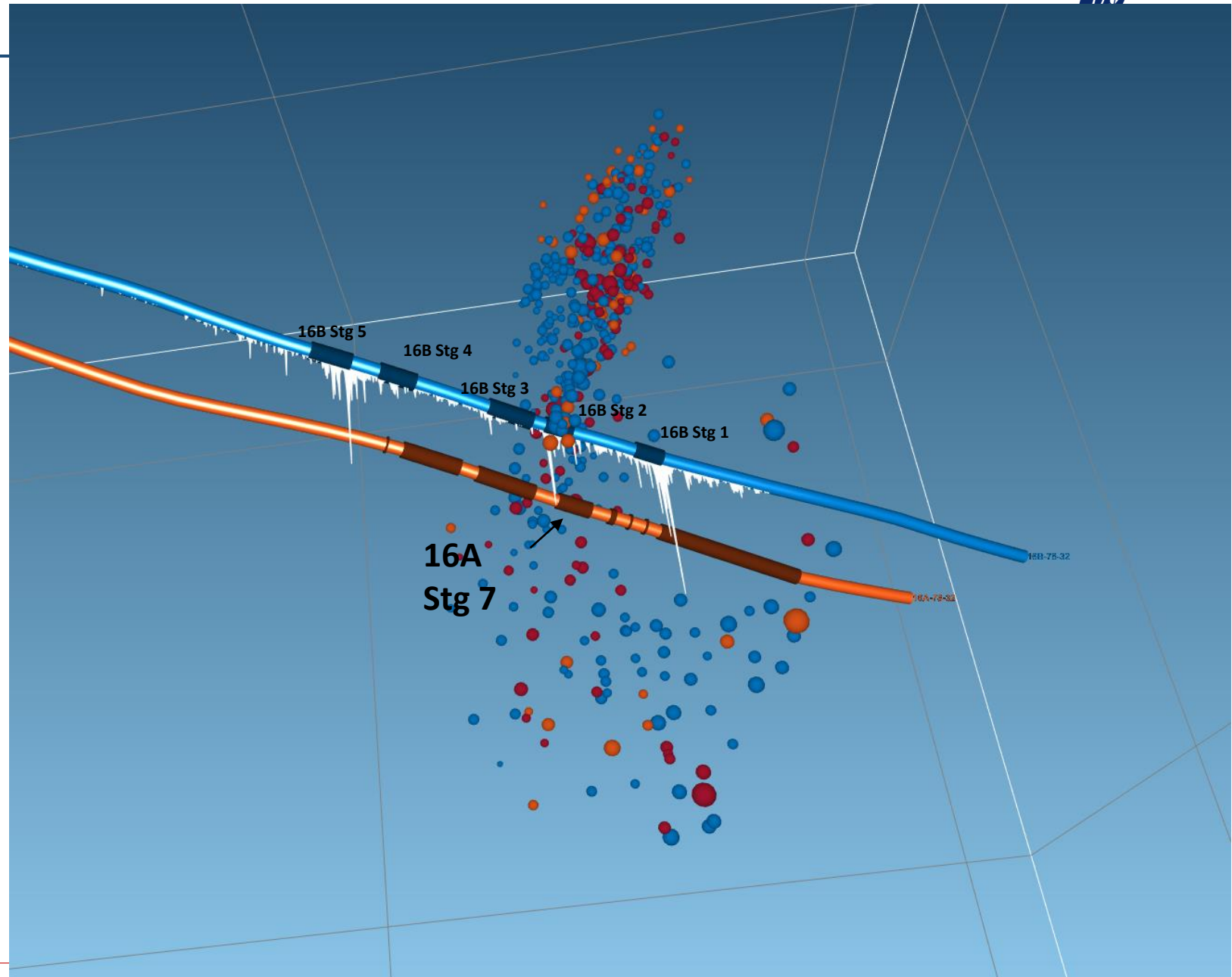
16A Stage 5



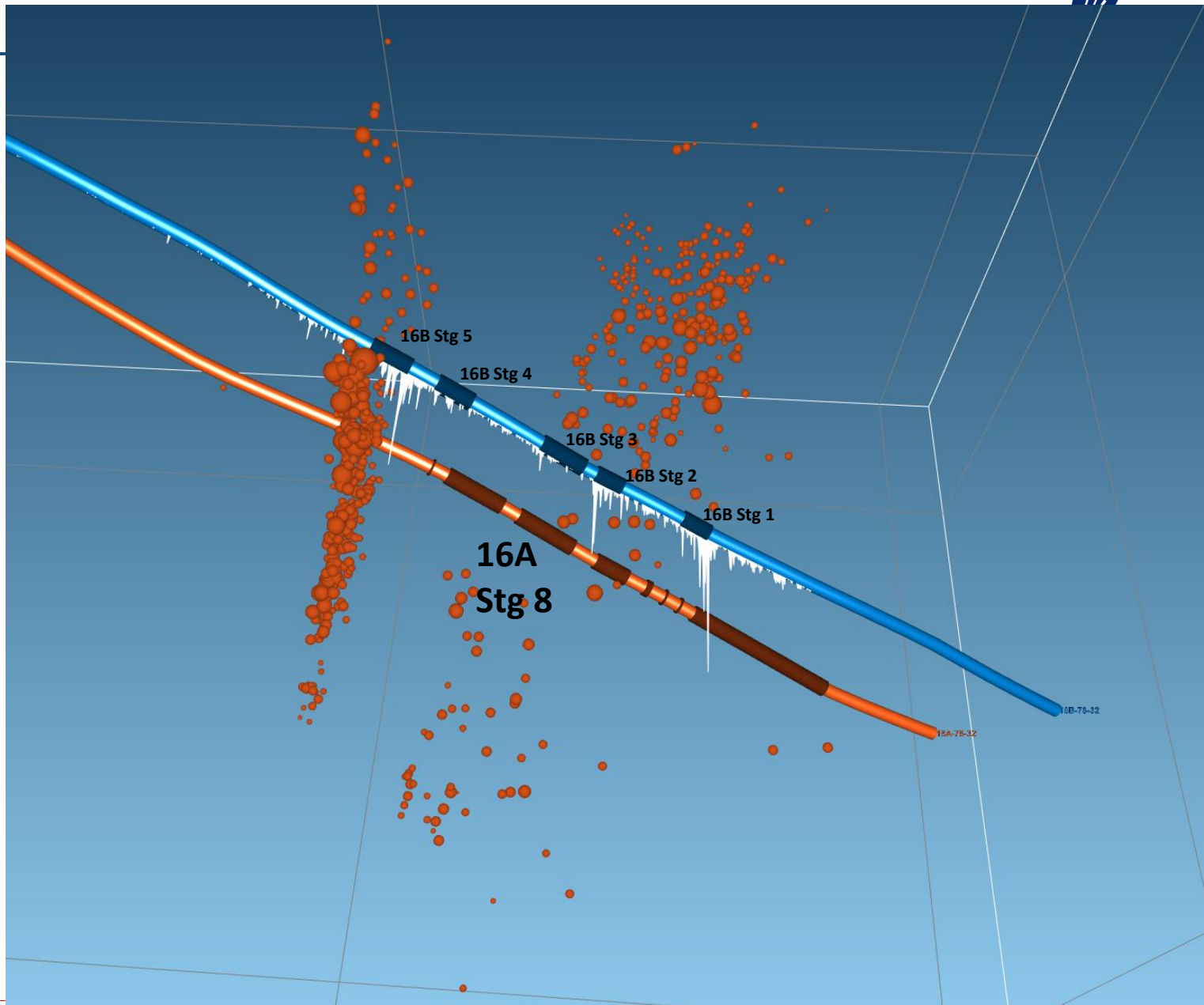
16A Stage 6



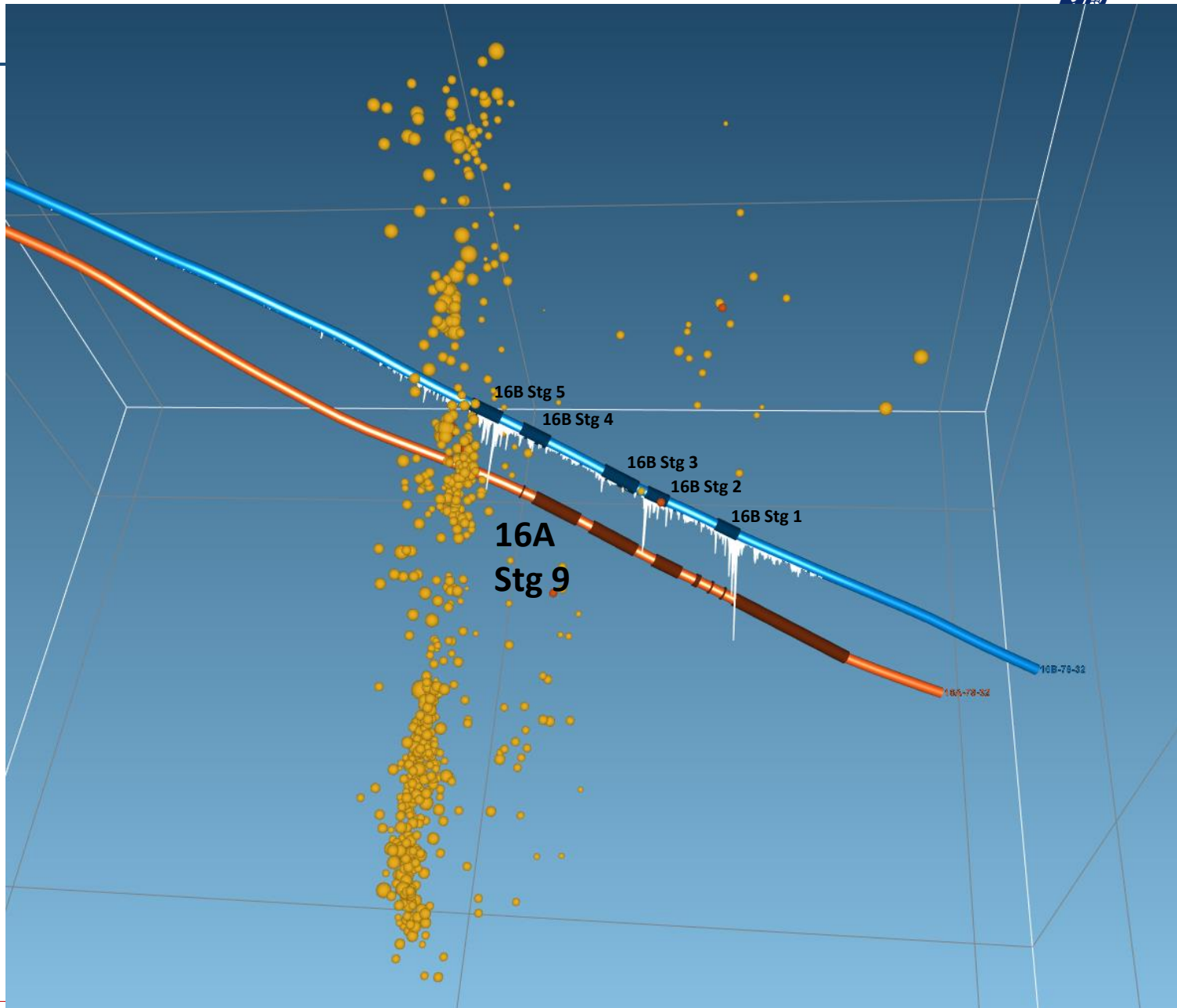
16A Stage 7



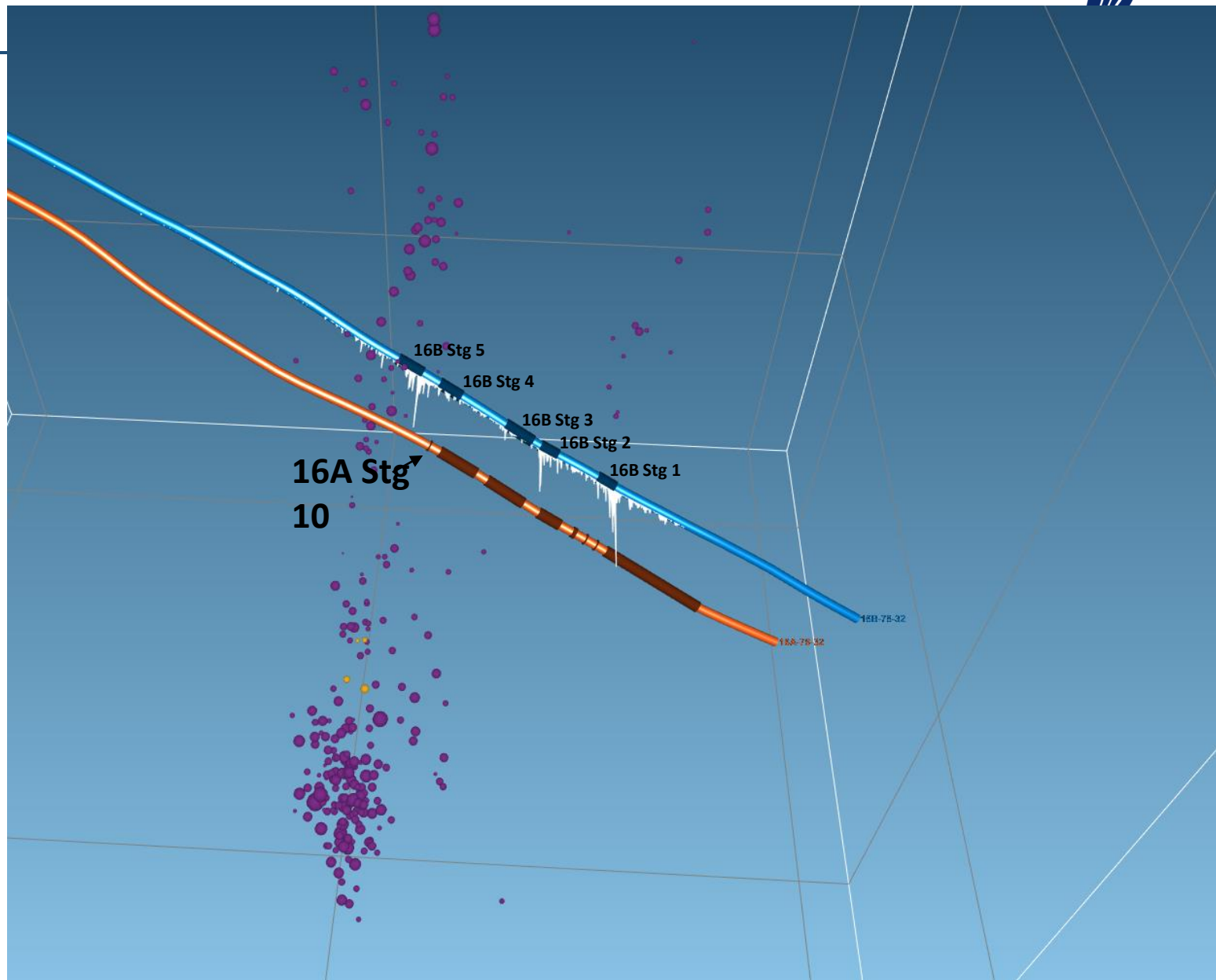
16A Stage 8



16A Stage 9



16A Stage 10

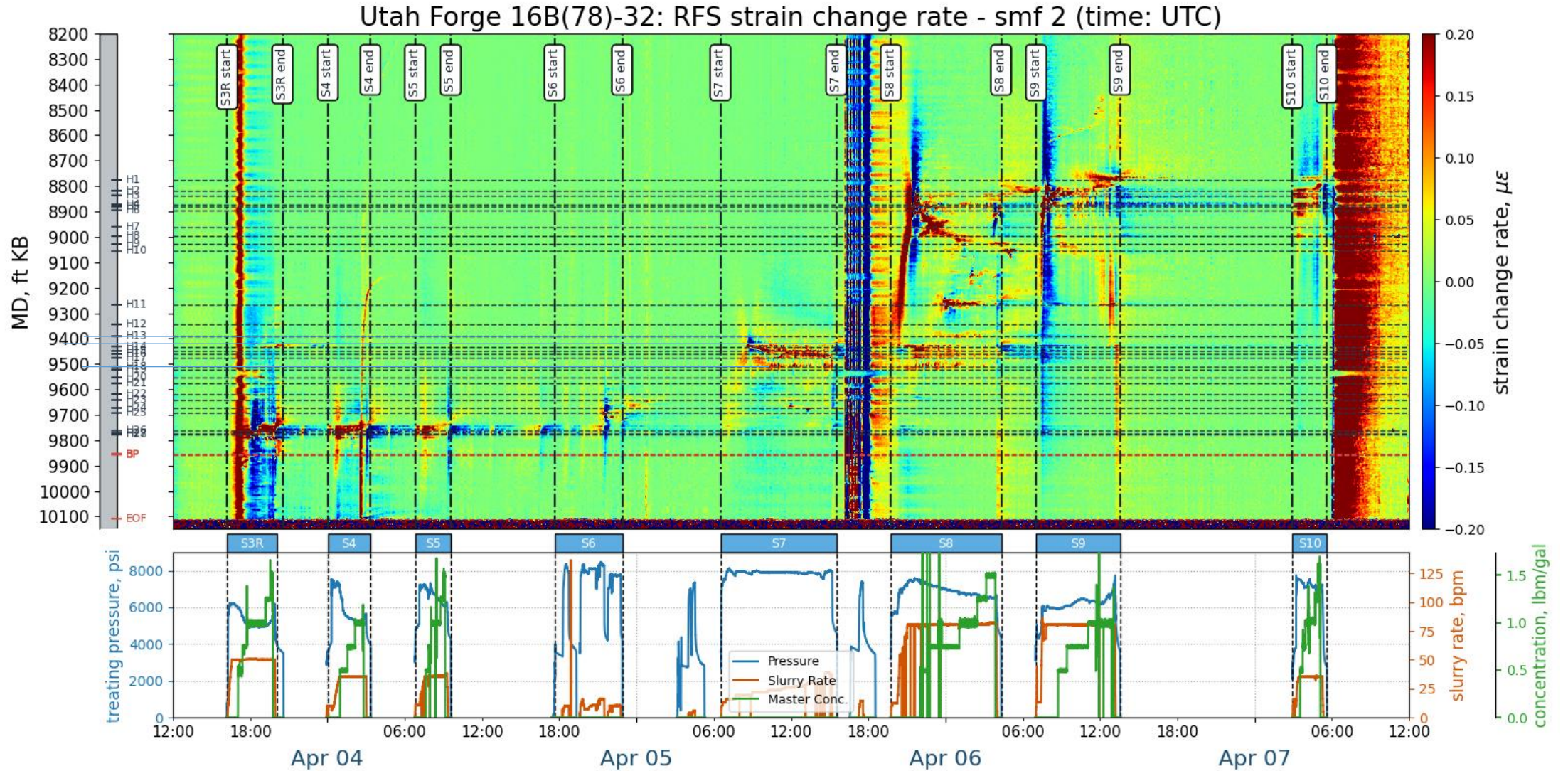




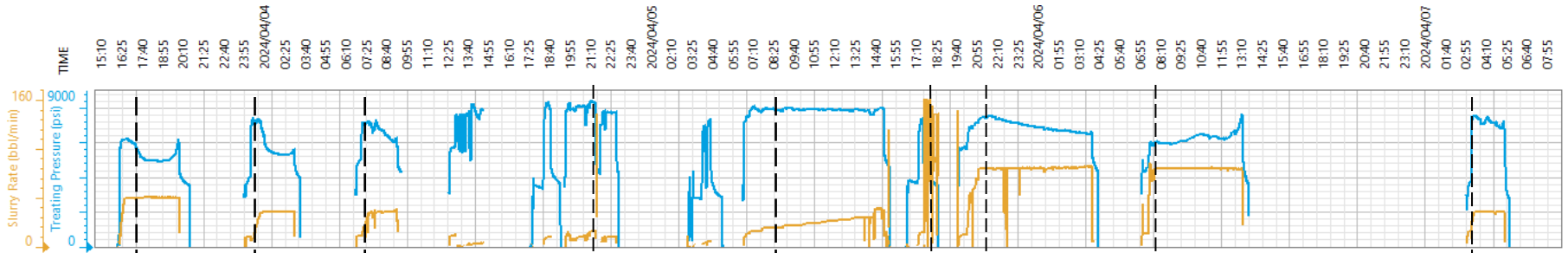
Selected Interpretations of FDI frac hits interpreted by Neubrex

Interpreted by Neubrex (D Jurick)

Well 16B – RFS DSS strain rate – overlay selected locations

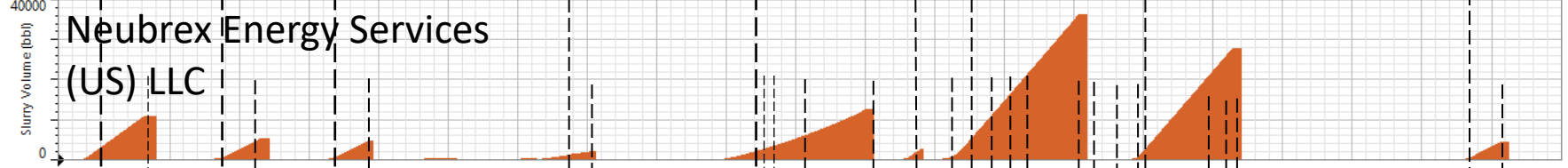


Rate & Pressure Curves



— Treating Pressure (psi)
— Blender Slurry Rate (bbl/min)

Cum Volume Of Slurry

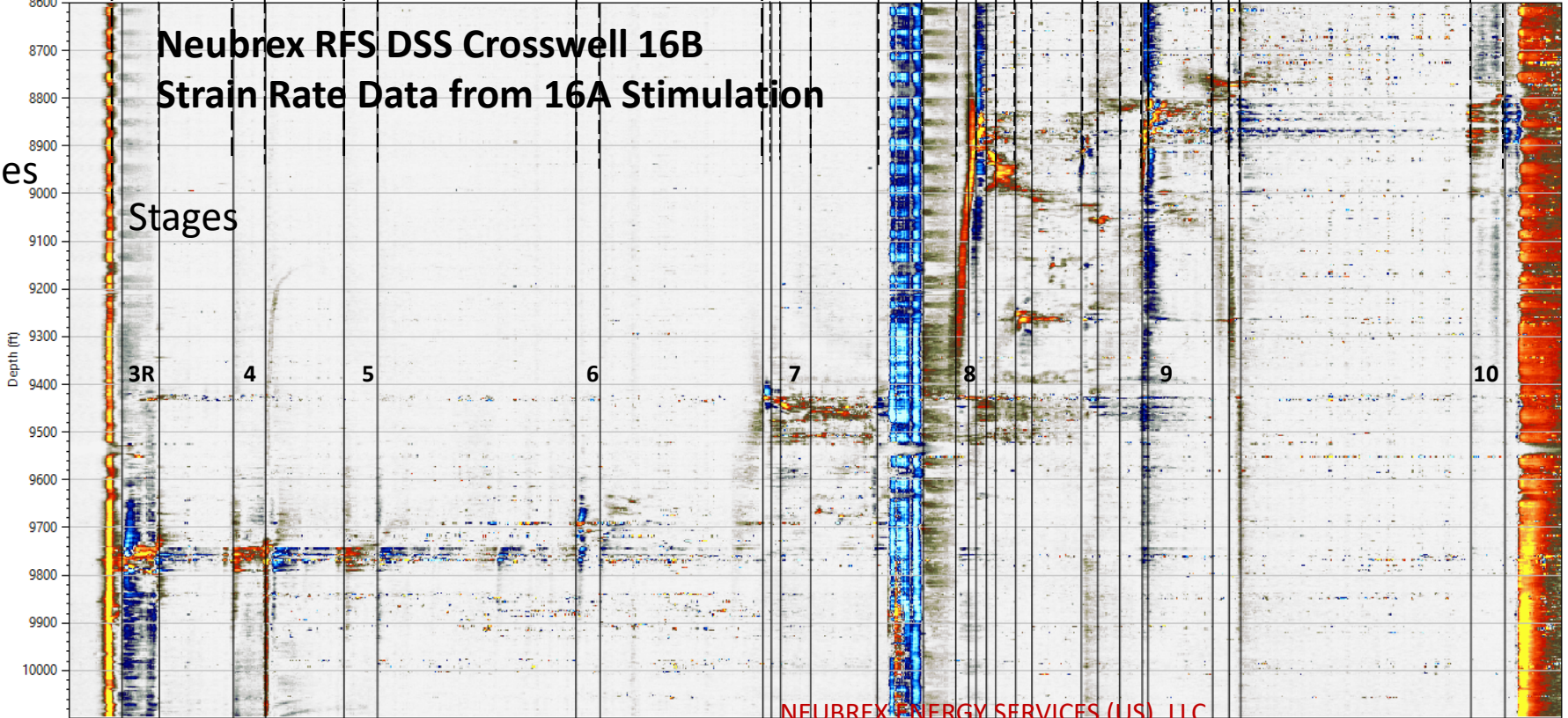


— Slurry Volume (bbl)

Event ID



16A Stages



Neubrex RFS DSS Crosswell 16B
Strain Rate Data from 16A Stimulation

Stages

3R 4 5 6 7 8 9 10

Pump Metrics



Ref	DateTime	Treating Pressure (psi)	Slurry Rate (bbl/min)	Slurry Volume (bbl)
1	4/3/2024 17:55:00	4958	50.3	4608.0
2	4/3/2024 20:09:30	3837	0.0	10687.6
3	4/4/2024 0:37:30	7151	19.3	397.3
4	4/4/2024 2:34:00	5286	35.7	4391.3
5	4/4/2024 7:18:00	7048	21.4	377.9
6	4/4/2024 9:19:00	5742	26.1	4511.7
7	4/4/2024 21:17:30	8314	16.0	1051.2
8	4/4/2024 22:45:00	7784	10.1	1977.0
9	4/5/2024 8:34:30	7871	19.2	1982.7
10	4/5/2024 9:05:00	7963	21.8	2581.8
11	4/5/2024 9:38:30	7883	22.0	3312.1
12	4/5/2024 11:27:00	7899	24.9	5842.4
13	4/5/2024 15:28:00	4682	3.1	12514.8
14	4/5/2024 18:15:30	3651	95.0	2037.8
15	4/5/2024 20:12:30	5653	12.3	419.8
16	4/5/2024 20:59:00	7143	68.6	2676.8
17	4/5/2024 21:26:00	7399	80.1	4817.7
18	4/5/2024 22:03:30	7371	80.3	7800.3
19	4/5/2024 22:37:00	7267	35.0	10455.1
20	4/5/2024 23:49:30	7040	80.6	16213.0
21	4/6/2024 0:48:00	6863	80.3	20925.2
22	4/6/2024 3:47:00	6495	82.0	35382.5
23	4/6/2024 4:46:30	0	0.0	0.0
24	4/6/2024 6:06:00	0	0.0	0.0
25	4/6/2024 7:27:30	5103	48.3	450.5
26	4/6/2024 7:48:30	5933	76.4	1947.1
27	4/6/2024 11:42:30	6288	79.7	20739.5
28	4/6/2024 12:42:00	6727	80.3	25488.0
29	4/6/2024 13:24:00	4020	0.0	27854.2
30	4/7/2024 3:17:30	7297	24.8	279.4
31	4/7/2024 5:20:30	4653	5.0	4507.6

Crosswell FDI events detected during 46A Frac



	A	B	C	D	E	
1	Ref	DateTime	Treating Pressue (psi)	Slurry Rate (bbl/min)	Slurry Volume (bbl)	Note
2	1	4/3/2024 17:55	4958	50	4608	Stage 3R first arrival
3	2	4/3/2024 20:09	3837	0	10688	
4	3	4/4/2024 0:37	7151	19	397	Stage 4 first arrival
5	4	4/4/2024 2:34	5286	36	4391	
6	5	4/4/2024 7:18	7048	21	378	Stage 5 first arrival
7	6	4/4/2024 9:19	5742	26	4512	
8	7	4/4/2024 21:17	8314	16	1051	Stage 6 first arrival
9	8	4/4/2024 22:45	7784	10	1977	
10	9	4/5/2024 8:34	7871	19	1983	Stage 7 arrival
11	10	4/5/2024 9:05	7963	22	2582	Stage 7, 2nd arrival
12	11	4/5/2024 9:38	7883	22	3312	Stage 7,3
13	12	4/5/2024 11:27	7899	25	5842	Stage 7,4
14	13	4/5/2024 15:28	4682	3	12515	
15	14	4/5/2024 18:15	3651	95	2038	
16	15	4/5/2024 20:12	5653	12	420	
17	16	4/5/2024 20:59	7143	69	2677	
18	17	4/5/2024 21:26	7399	80	4818	Stage 8 first arrival
19	18	4/5/2024 22:03	7371	80	7800	
20	19	4/5/2024 22:37	7267	35	10455	Stage 8, 2nd arrival
21	20	4/5/2024 23:49	7040	81	16213	Stage 8, 3
22	21	4/6/2024 0:48	6863	80	20925	Stage 8,4
23	22	4/6/2024 3:47	6495	82	35383	Stage 8, 5
24	23	4/6/2024 4:46	0	0	0	
25	24	4/6/2024 6:06	0	0	0	
26	25	4/6/2024 7:27	5103	48	451	Stage 9
27	26	4/6/2024 7:48	5933	76	1947	Stage 9 first arrival
28	27	4/6/2024 11:42	6288	80	20740	Stage 9, 2
29	28	4/6/2024 12:42	6727	80	25488	
30	29	4/6/2024 13:24	4020	0	27854	
31	30	4/7/2024 3:17	7297	25	279	Stage 10
32	31	4/7/2024 5:20	4653	5	4508	
33						

Was strong strain response prior to isolated FDI

Very little volume prior to first arrival at same location

Very little volume prior to first arrival at same location

Weak first arrival. Clear strain shadows around hit

Very well-developed Fracture process zone ahead Of frac tip of first arrival. Followed by multiple clear FDI strain rate events after first arrival

A 600-foot MD long Fracture Process zone moved from the location of the Stage 7 FDI up the well to the first Arrival of the Stage 8 FDI. Some "leakage" of strain rate response Was detected in Stage 7 cross well strain zone, early in Stage 8. The first strain rate arrival on Stage 8 was very Clear and strong with strain shadows around it. Subsequent FDI hits occurred below the initial hit Location and then some hits occurred above the initial location

The initial FDI hit occurred in close depth proximity to the upper Frac hits that were detected as the upper frac hits of stage 8. Second FDI hit was strong and occurred above the initial hit depth

Stage 10 FDI hits followed the same depths as the stage 8 upper and Stage 9 FDI hit depths. They did not show any evidence of fracture Process zone morphology and look different than other stage responses

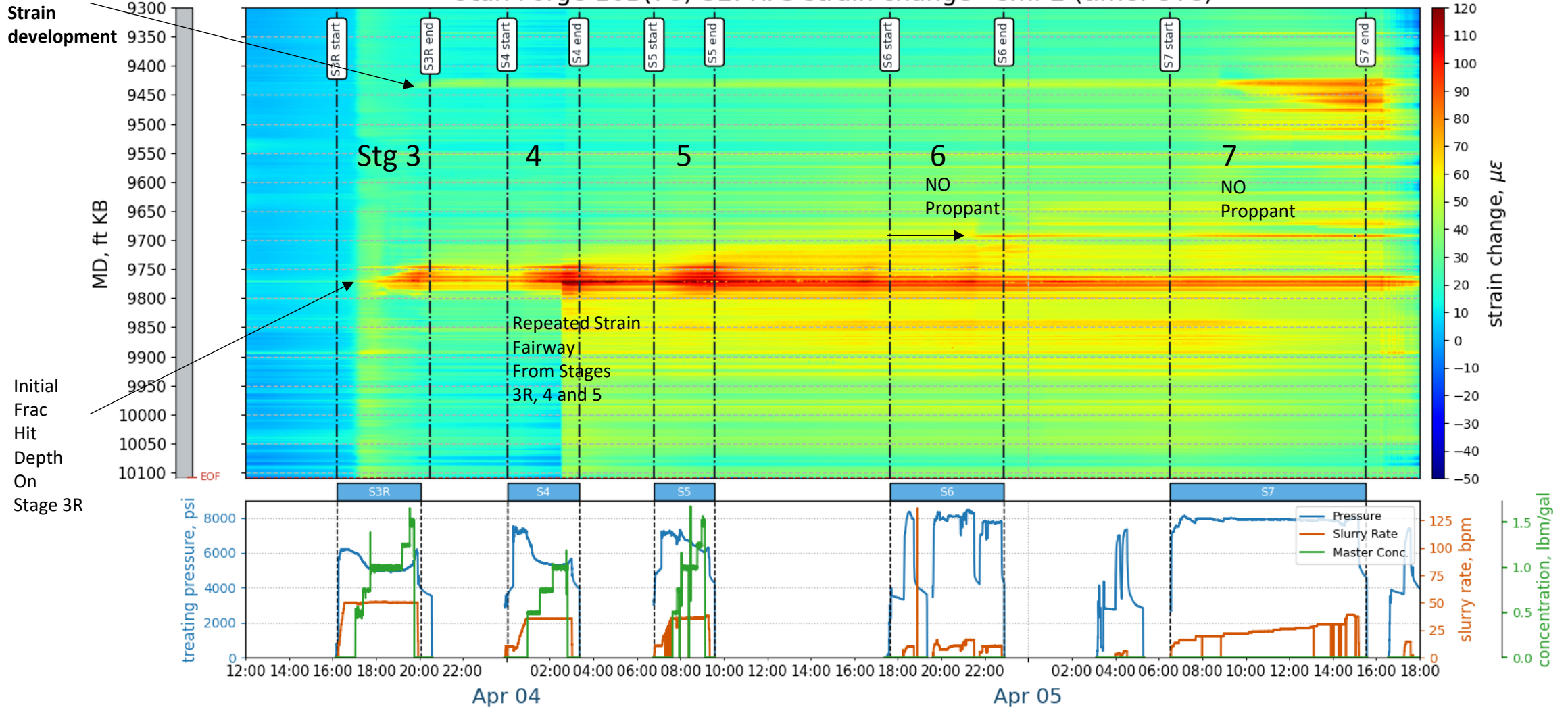
Neubrex

Well 16B – RFS DSS Strain Change – stim 16A stg 3R thru 7

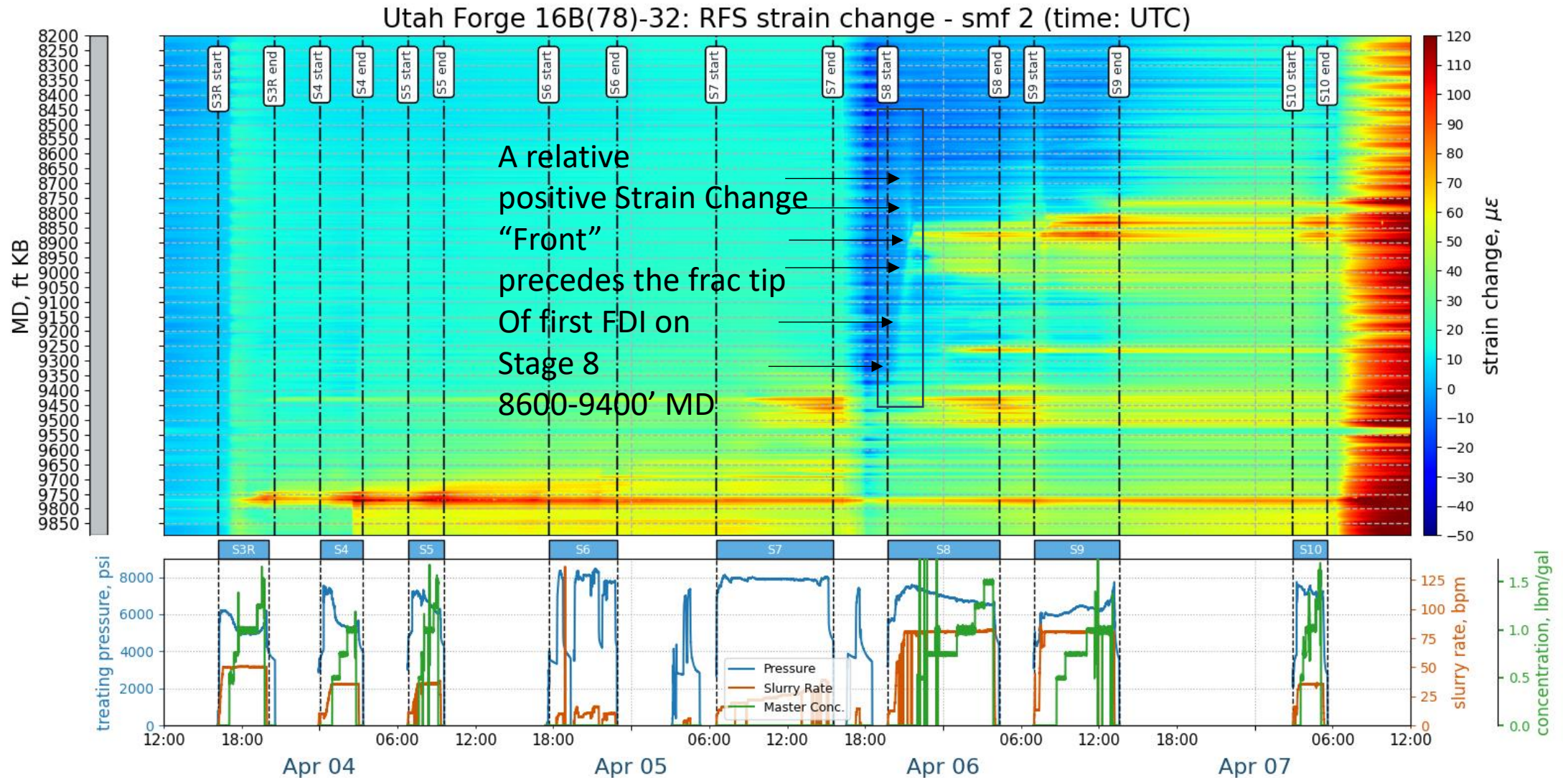


Note this
Early uphole
Strain
development

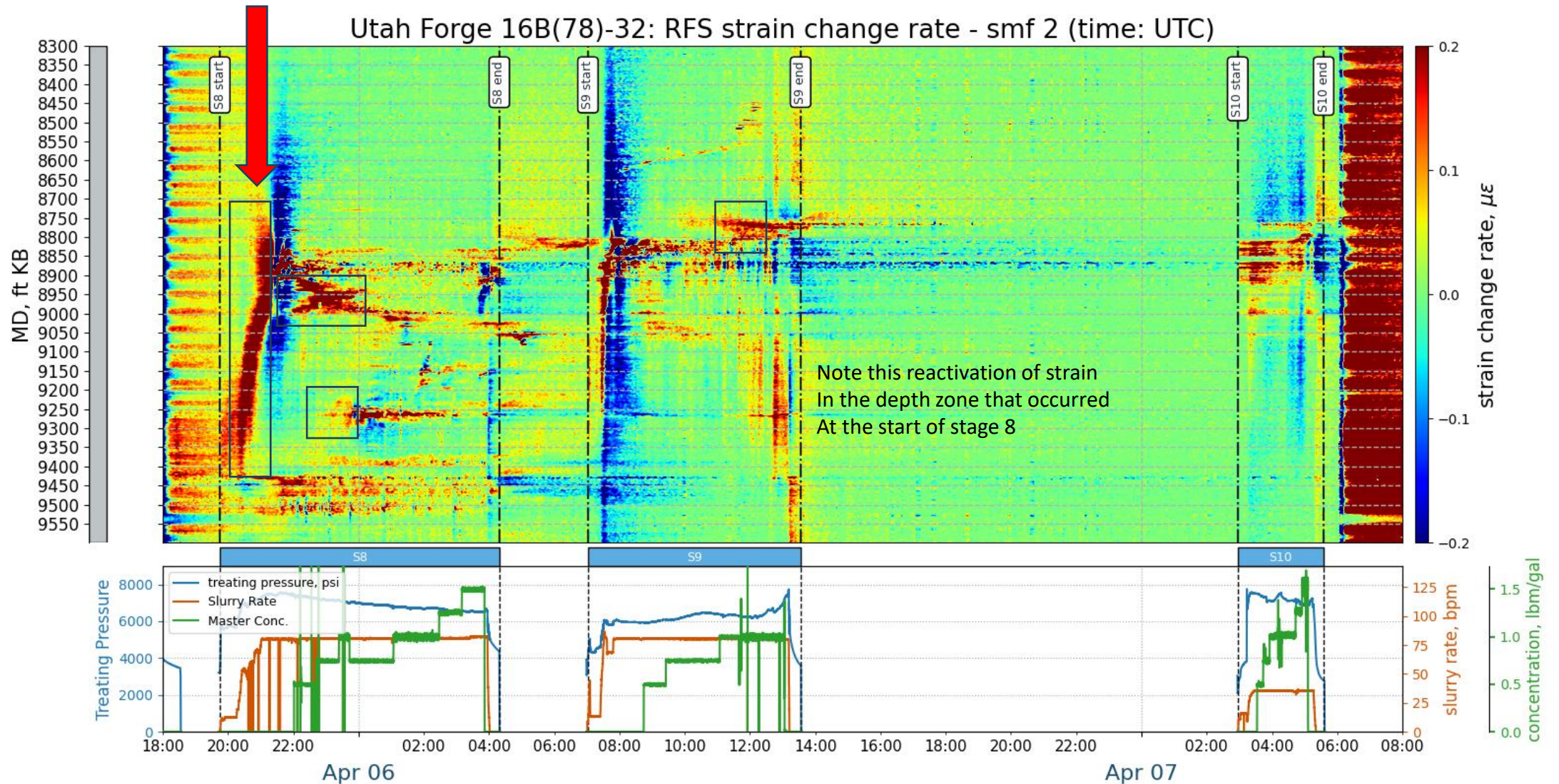
Utah Forge 16B(78)-32: RFS strain change - smf 2 (time: UTC)



Well 16B – RFS DSS strain change – stimulated stages 3-10 on 16A



Well 16B – RFS DSS strain rate –stages 8-10 Heart Shaped Features



Chronological Development of Hydraulic Fractures from 16A



- **Stg 3R** – a positive strain response was observed on 16B as the treating pressure “turned over” on the 16A well. There is a very high temporal correlation between this pressure change and a positive strain change response from end of fiber to 8600 MD (possibly longer in length).
- **3R** - After 1h55m, and after the treating pressure “ramped down” to a steady pressure after breakdown, the first arrival strain rate response was detected on 16B. This is a clear FDI with definitive hit point and surround by compressive strain shadows.
- **3R**- Active positive strain rate changes occurred in a “frac corridor” on 16B for 2h15m, until pumping ended and immediate relaxation (negative strain change) was detected in the frac corridor of 16B.
- **3R** - 3 distinct strain rate features interpreted as fractures detected.

- **Stage 4 and 5** – Very little volume was pumped from 16A before immediate positive strain rate response were detected from both of these stages. The cross well DFI features appear in the same place on 16B as seen to be present from Stage 3R. These are interpreted to be fracture “reoccupations”.
- Post pumping relaxation or closure features on both of these stages align with the relaxation closure features from Stage 3R.
- During the end of Stage 4, a different type of strain rate response was seen to move from the DFI location, up the wellbore about 600 feet. At the top of this feature is a “hook” morphology that means that the strain anomaly climbed a certain distance up the 16B well and then stopped. That depth was 9160 MD RKB in 16B.

Chronological Development Hydraulic Fractures from 16A



- **Stage 6** produced a small strain rate DFI feature during the last 2 hours of treating. No proppant was able to be pumped in this stage.
- There is a positive strain features surrounded by negative strain shadows, so this looks like a legitimate FDI fracture feature. It is very thin in depth domain.
- Only 1000 bbls were pumped when this event arrived at 16B, which is $\frac{1}{4}$ of the volume pumped when the 3R stage FDI arrived at 16B.

Chronological Development Hydraulic Fractures from 16A



- **Stage 7** – 2000 bbls pumped before the first arrival occurred on 16B.
- No proppant was pumped on Stage 7.
- The depth of first arrival was clearly different and distinctive and up hole on 16B from stages 3R, 4, 5 and 6.
- This feature occurred in depth where a strain feature was first observed up hole for the 3R stage FDI main event.
- 4 FDI features are seen during Stage 7 pumping covering a distance of 100 feet on the 16B well.
- The first arrival feature has a clear fracture process zone strain rate morphology ahead of the first arrival FDI frac hit.
- **Stage 7** cross well strain rate response has the most classic cross well strain response morphology seen in modeling and other field areas where sedimentary rocks are being stimulated with HF processes.
- The Positive FDI features relax or close upon pumping stop on 16A.

Chronological Development Hydraulic Fractures from 16A



- **Stage 8** has a complex and unexpected chronological and spatial development at the 16B well.
- Some pumping operations occurred between end of stage 7 and start of stage 8. These ops produced some strange strain rate responses on the length of 16B that should be investigated because they precede further observations on Stage 8.
- Stage 8 saw a large positive strain feature, like a strain front that climbed up 16B for over 500 feet before a fracture process zone strain rate morphology feature was seen.
- Then, the initial fracture point developed 500 feet above the top most fracture from stage 7 in 16B. This is a well defined strong FDI feature.
- After this, up to 7 additional FDI fracture type features are seen above and below the initial FDI initiation point.
- These FDI's cover a depth range of 450 feet on the 16B well.
- Strain rate relaxation, negative strain rate, responses are not well detected.
- This stage pumped largest volume of slurry at fastest rate of injection. And a clear rollover in the treating pressure curve is seen in the data. The time of the pressure rollover is closely aligned with the First Arrival FDI event on 16B data.

Chronological Development Hydraulic Fractures from 16A



- **Stage 9** – FDI features appear in the same depth range on 16B as the upper FDI created during Stage 8.
- There are good relaxation features during pump stop that clearly show at least 5 independent FDI “planes”.
- There is one FDI feature from stage 9 that is present in a depth region above those created from stage 8 and this seems to be a separate and independent FDI feature.
- This “high” feature may be a unique and new frac plane that intersects 16B at the shallowest point in 16B from this Frac Operation.

- **Stage 10** – also known in the field as Stage 6R.
- This stage did not create any new fracture fairway and seems to be a reoccupation of the features produced by Stages 8 (upper) and 9.
- No fracture process zones are seen to proceed the positive strain rate features and no strain shadows are detected around each of these features.
- The morphology of the features in stage 10 indicate that there are NOT new fracture driven features, but rather, reoccupation of pre existing fracture planes created by earlier stage processes.

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