

Microseismic Event Location Trends and Their Relationship with Sequence Stratigraphy*

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Abstract

Microseismic event distribution is commonly interpreted as the geometry of a fracture network growth due to hydraulic fracturing. The event number, distribution pattern, and events cloud geometry are keys to evaluate the efficiency of the fracturing job. For this study, the interpretation of the relationship between microseismic event and sequence stratigraphy is based on the microseismic location data obtained by a ground survey while hydraulic fracturing of one horizontal well targeting the Woodford Shale (Devonian-L Mississippian, Oklahoma). The microseismic data has already been processed as 12 stages 1,552 events in total with reliable signal-to-noise ratio. A four square mile sequence stratigraphic framework was built by gamma ray log and scanned-cutting's XRF (X-ray fluorescence) profiles from a nearby vertical well and the hydraulic fracturing treatment well. Brittle and ductile zones were identified based on stratigraphic framework and Young's modulus/Poisson ratio. After filtering out the events outside of the Woodford interval, the distribution of microseismic events reveals that the events, which represent growth patterns of fractures preferentially, develop along the bed dipping trend and SHmax (maximum horizontal stress) direction of N78°E. About 60 percent of events or accumulated magnitude (calculated magnitude 3D model) are located within a Highstand System Tract and the number of events within brittle zones is twice the number as those within the ductile zones. This result indicates that there is a relationship between microseismic events location and regional stratigraphic framework of the Woodford Shale; fractures extend further horizontally and with higher density vertically within brittle zones and the Highstand System Tract. Asymmetric bi-wing event clouds at stage 5 and stage 6 of the horizontal well prove anisotropy exists on both sides of the wellbore. Future horizontal drilling is recommended to extend along SHmin that is S12°E and landing at the lower section of the TST.

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Microseismic Event Location Trends and Their Relationship With Sequence Stratigraphy

By: Jing Zhang*, Roger Slatt
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Guideline

- Case Study Location
- Data Available
- Model Analysis
- Stage Analysis
- Fracture Efficiency
- Stress Analysis
- Conclusion

Case Study Geological Background

Age, Ma	System	Series	AU names	
318.1 ±1.3	Permian	Cheslerian		Northern Anadarko Basin
				Cunningham sand
				Britt sand
				Manning zone
333	Mississippian	Meramec	Mississippian	St. Genevieve Limestone
				St. Louis Limestone
340				Salem Limestone
				Warsaw Limestone
348				Mississippi chert
				Cowley Formation
				Mississippi solid
359.2 ±2.5	Devonian	Chautauquan	Woodford Shale	Kinderhook Shale
			Gas, Oil	
365				
374				
379				
416.0 ±2.8	Silurian	Utahian	Hunton Group	Frisco Formation
				Bois d'Arc Formation
				Haragan Formation
				Henryhouse Formation
421				
432				Chimneyhill Limestone
443.7 ±1.5	Ordovician	Cincinnatian	Viola Group	Sylvan Shale
				Fernvale Limestone
				Trenton Limestone
452				
				Bromide Formation
				(Simpson de rose, Wilcox sands)
				Tulip Creek Formation
				McLish Formation
				Oil Creek Formation
472				Joins Formation

Modified from Higley, 2014



Early Mississippian



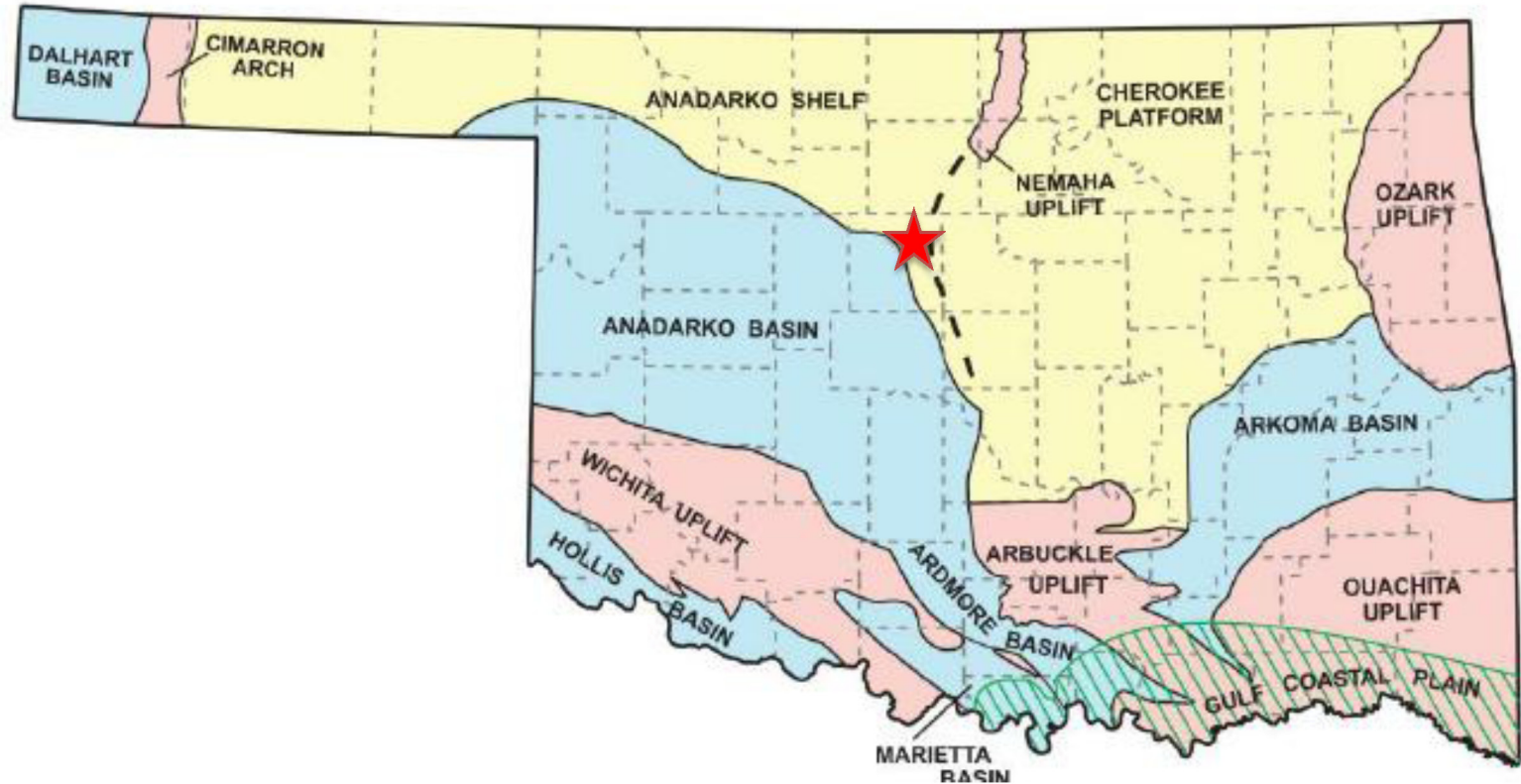
Late Devonian



Modified from Blakey, 2012

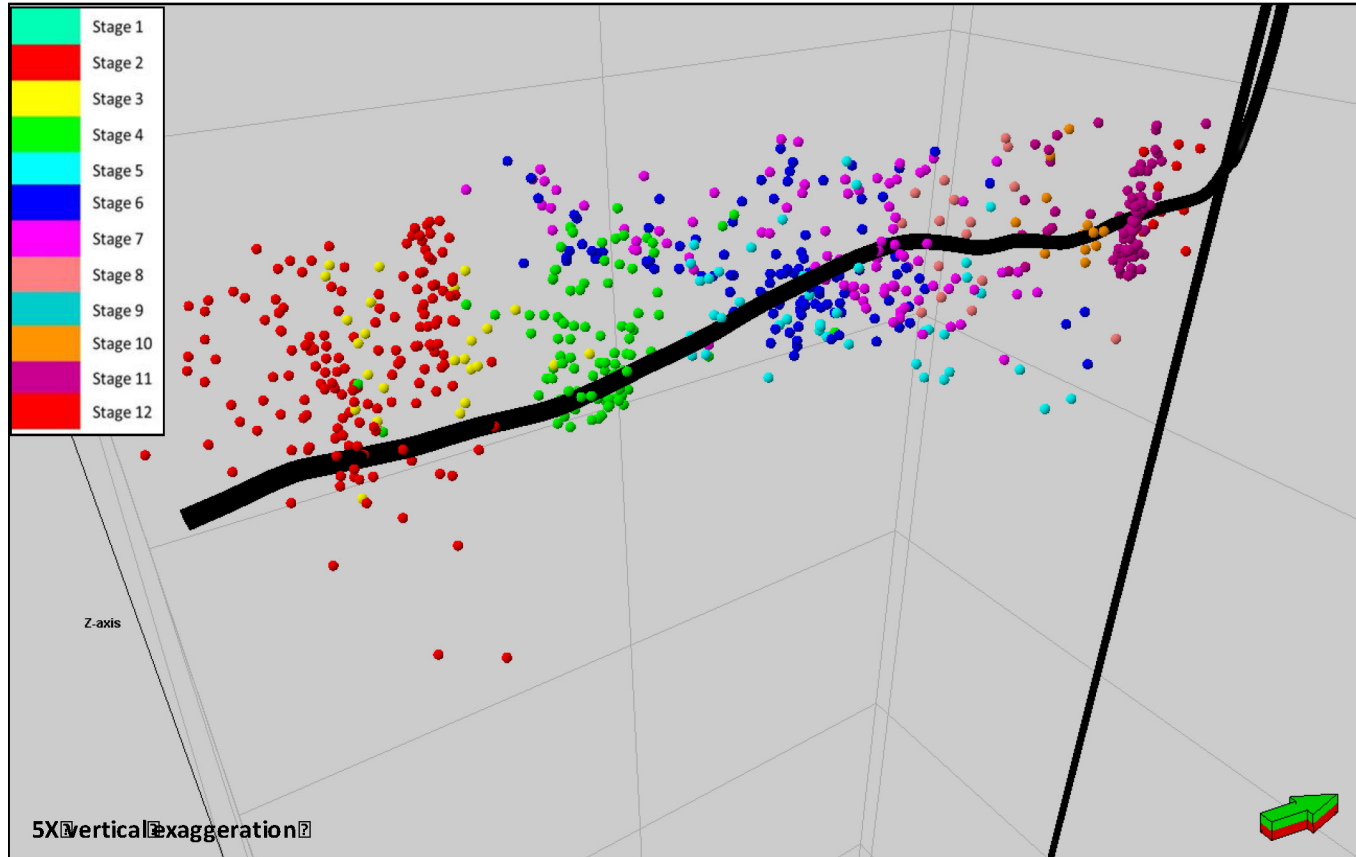
Presenter's notes: Our target formation is the Woodford shale, an organic rich shale formation deposited from late Devonian to early Mississippian, there is a transgression trend starts from the beginning of the Woodford deposition age. In my area, there is no Hunton limestone beneath the Woodford shale, just Sylvan shale, an organic lean shale, below and Mississippian limestone above.

Case Study Location



(Johnson, 2008)

Data Available

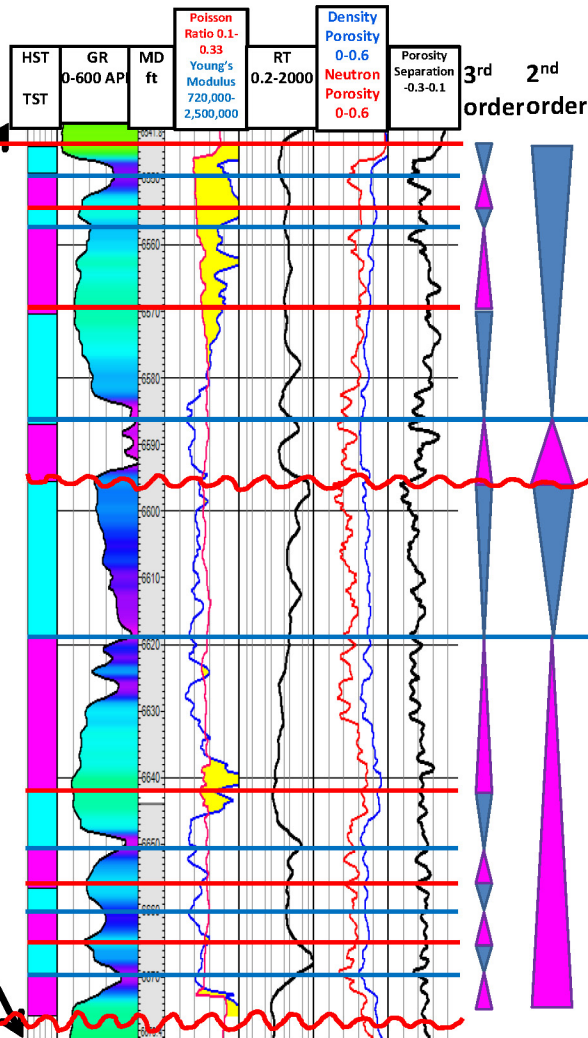


- Surface microseismic survey for one horizontal well.
- 20 ft interval cutting samples for the SWD well and the horizontal well.
- Well logs for the SWD well.
- 28 nearby wells with well logs for sequence stratigraphic framework correlation.

Model Analysis

Woodford Top

Woodford Base

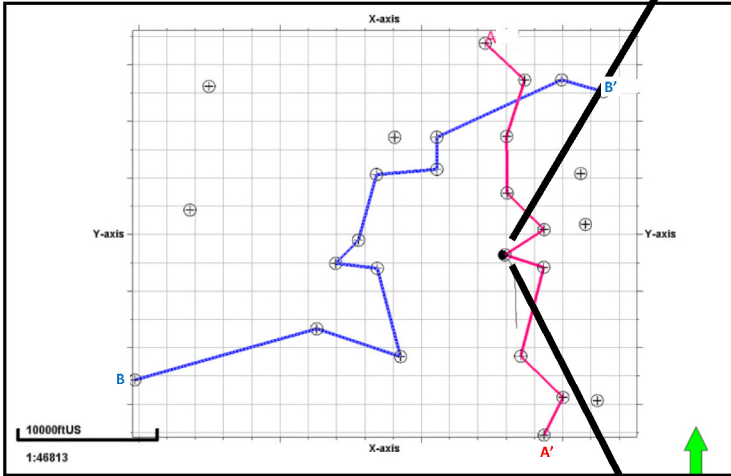


Two cross sections A-A' and B-B' were defined to construct the sequence stratigraphic framework. The stimulated well and the vertical reference well are on A-A'.

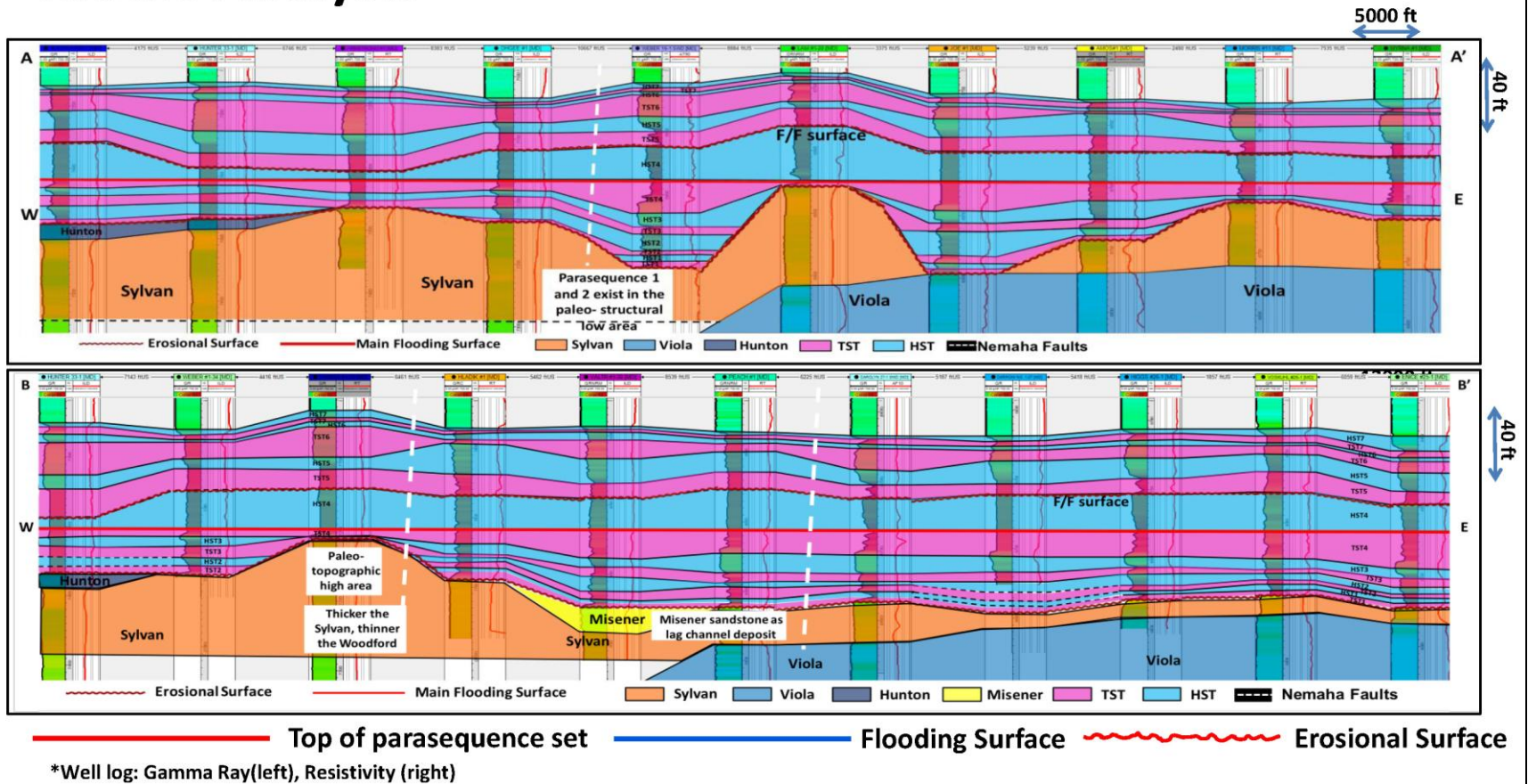
Gamma ray, resistivity, neutron, density porosity, are the well logs mainly used for correlation.

Two MFS in the Woodford separate the formation into two 2nd order sequence sets, the 3rd order parasequence sets are identified from the well log.

Since the fracability is directly related to the brittleness of the shale, the brittle-ductile couplet model also made based on the existing parasequence set surface and the well with sonic log available.

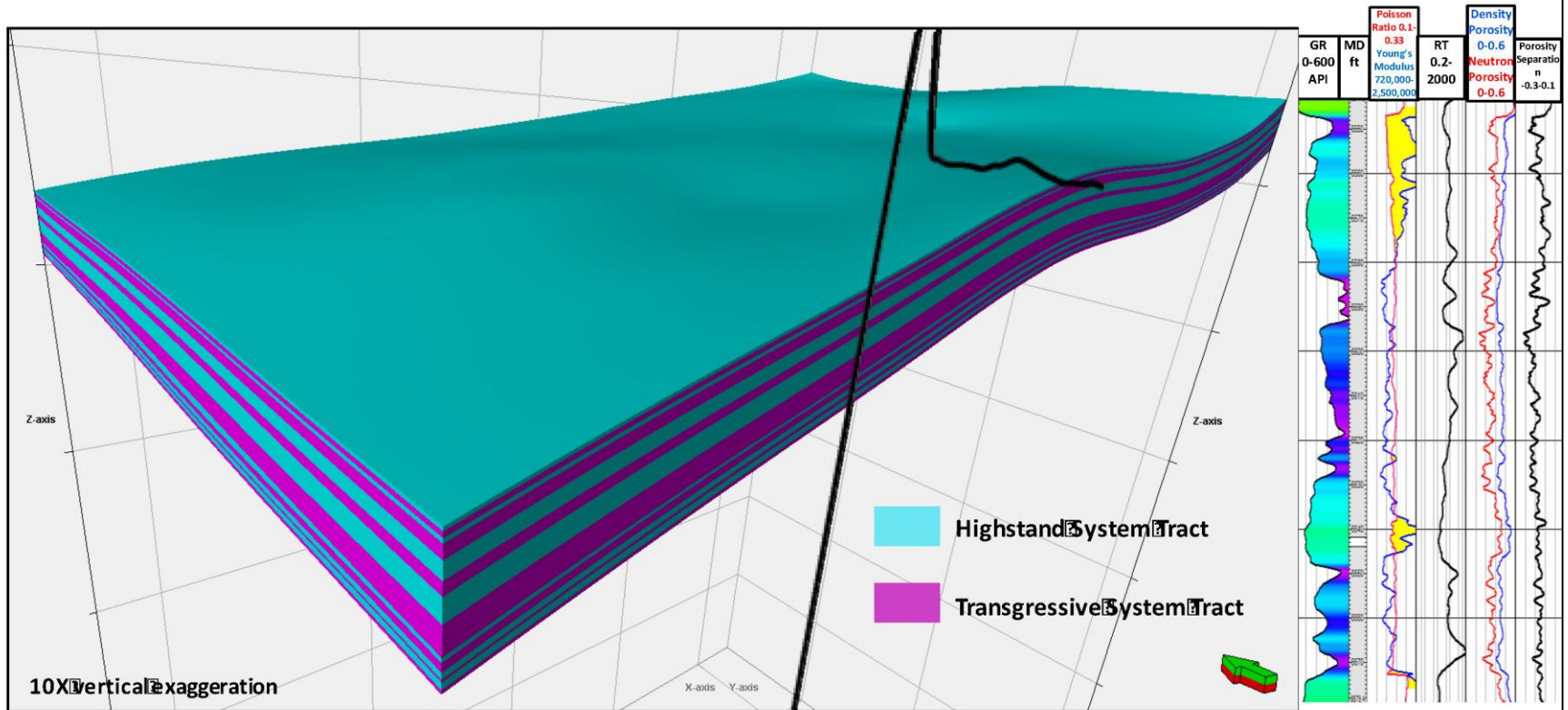


Model Analysis



Presenter's notes: Two cross sections, AA' and BB'; the red line indicates the top of each parasequence set and the blue line stands for the flooding surface.

Model Analysis (Sequence Stratigraphy Model)



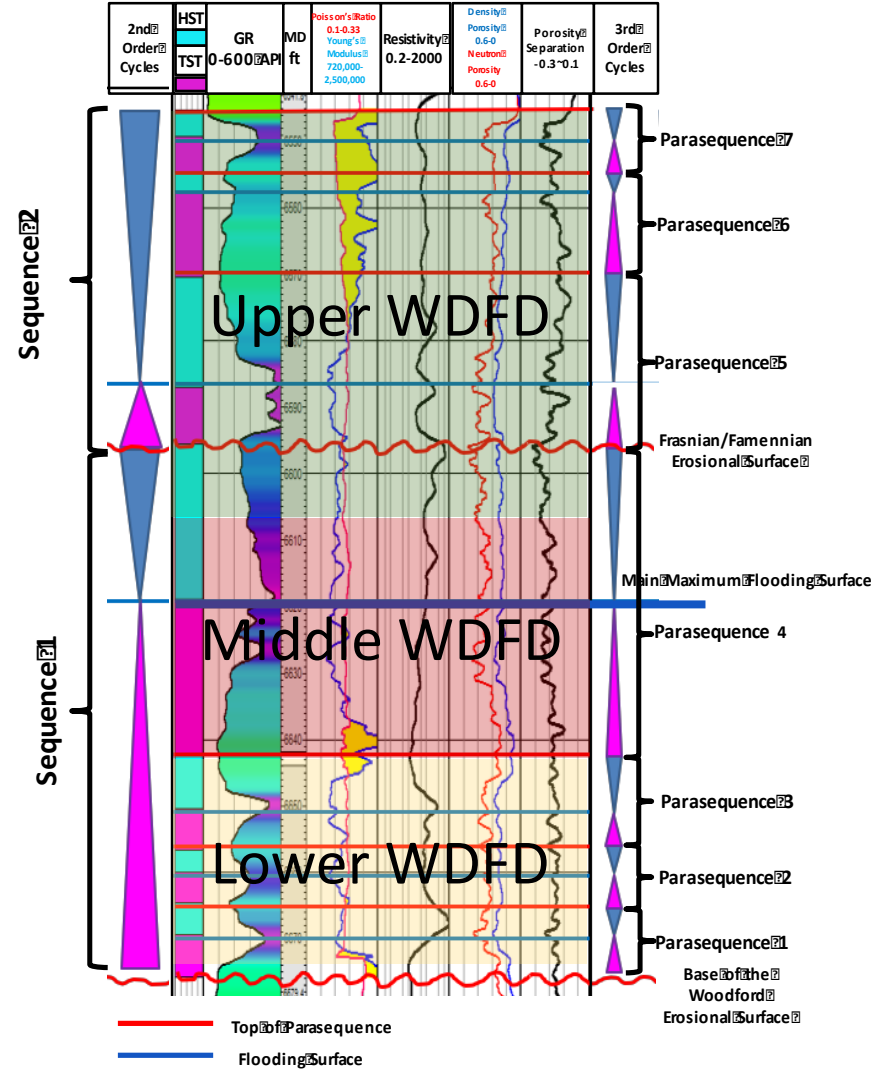
Presenter's notes: The sequence stratigraphic model constructed based on the correlation with 10X vertical exaggeration, giving a view of the well location.

In Nature

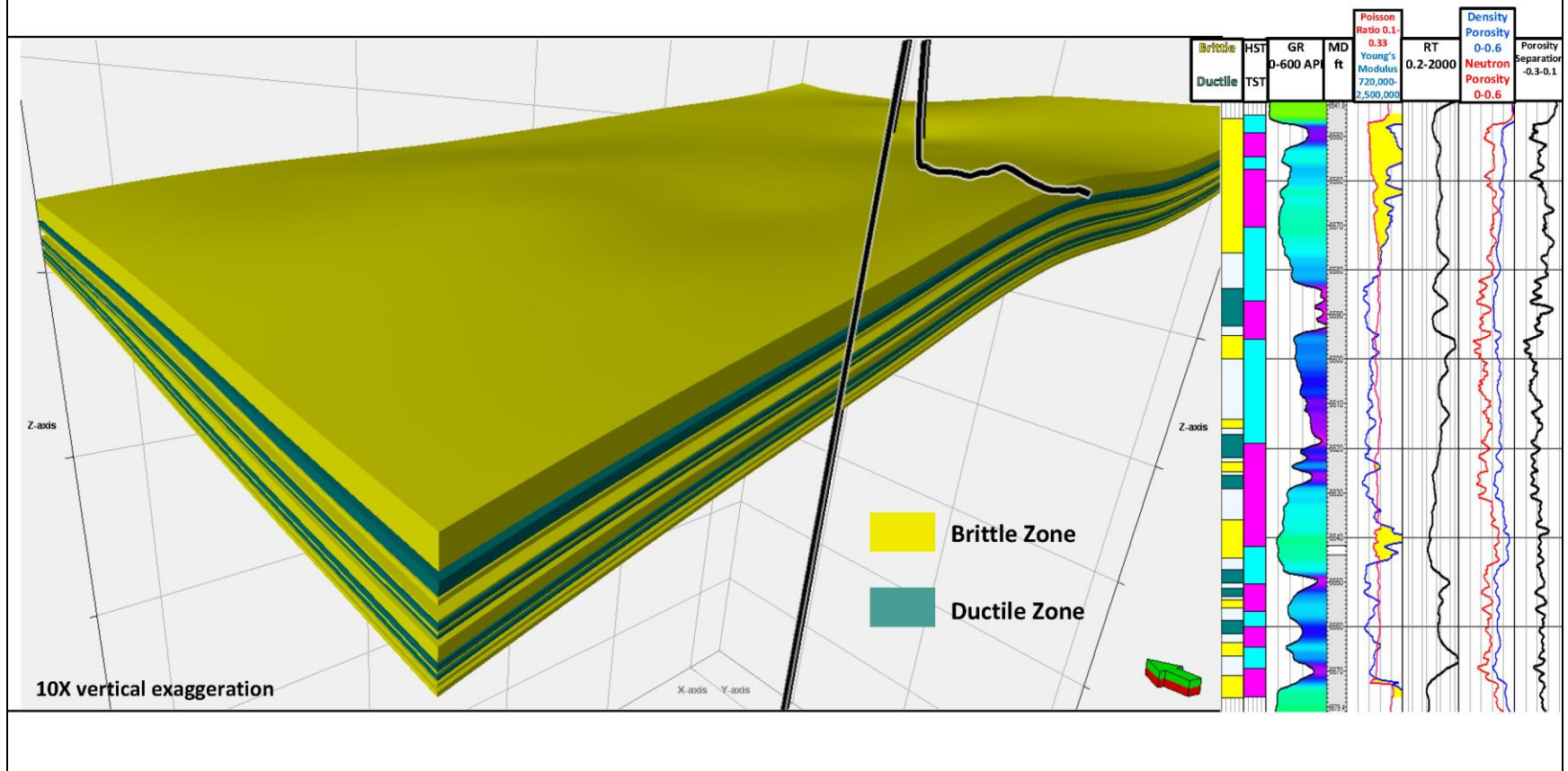


Brittle-Ductile Couplet on the Woodford Outcrop

(Badra, 2008)

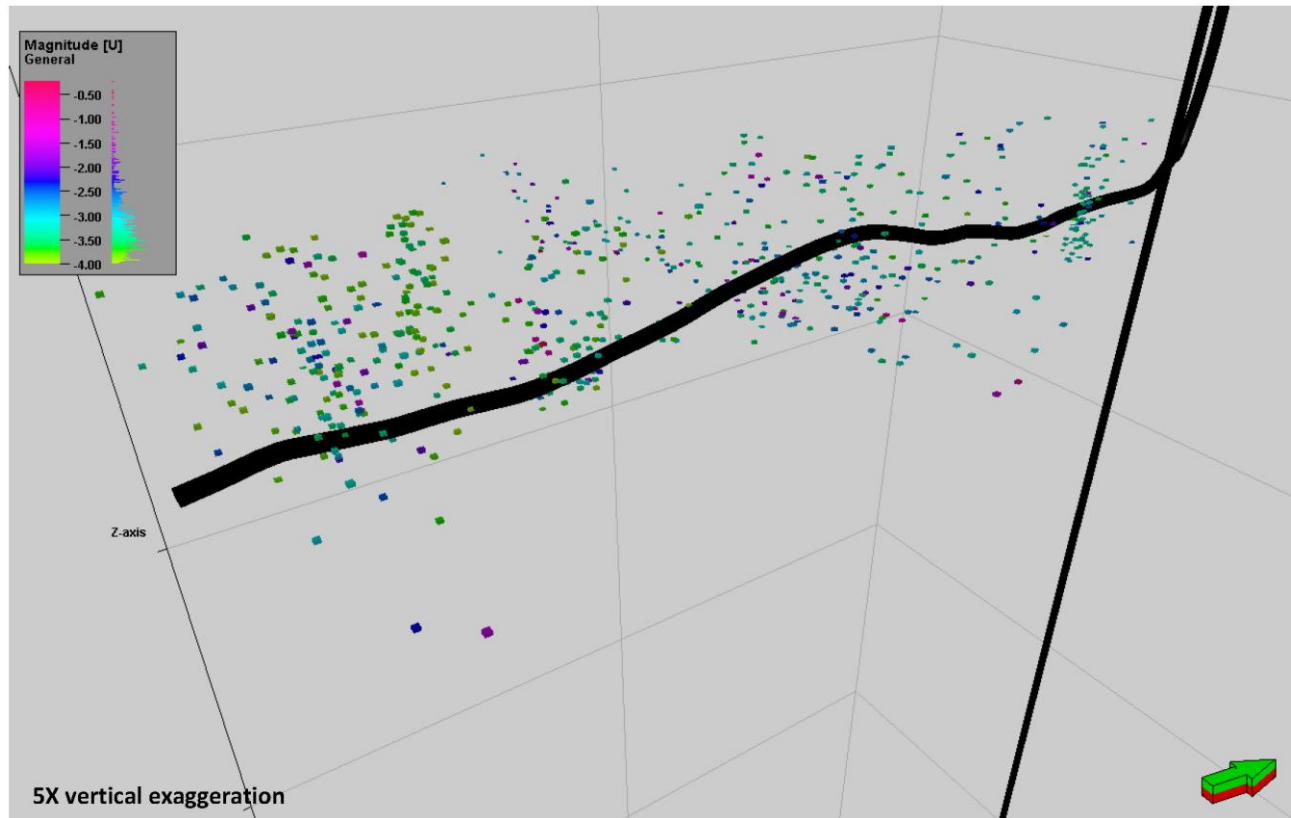


Model Analysis (Brittle-Ductile Model)



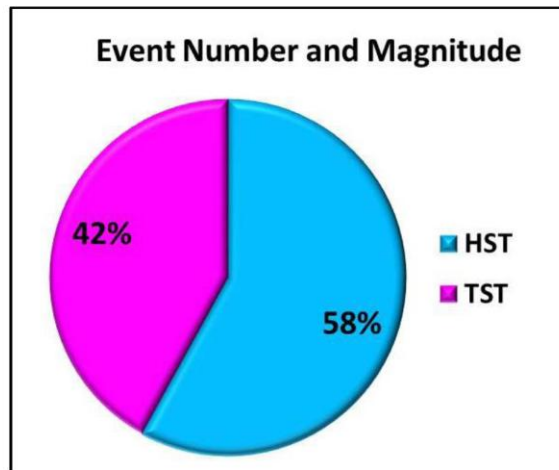
Presenter's notes: The brittle ductile couplet model we constructed. Gaps do exist between zones because they are not brittle or ductile.

Model Analysis (Upscale the Microseismic)

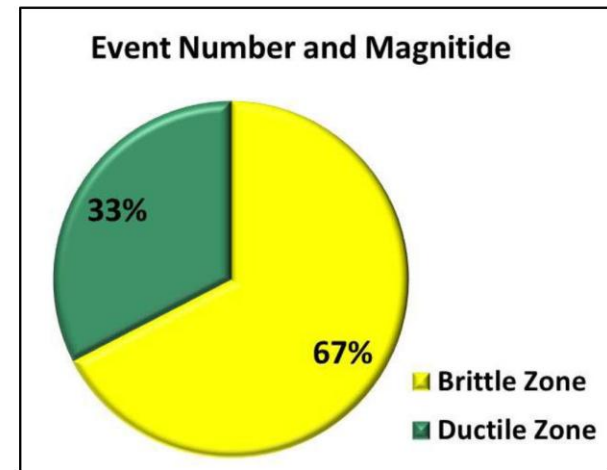


Presenter's notes: For the model analysis, first step is to upscale the microseismic event into the model, magnitude of each event are upscaled into a small grid for both model for overall distribution analysis.

Model Analysis



- From the sequence stratigraphic model, there is slightly more microseismic events and accumulated magnitude are located within the highstand system tract (HST).



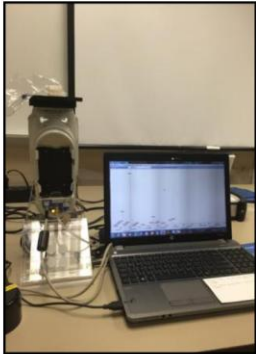
- From the brittle-ductile couplet model, the contrast gets bigger, 67% of the microseismic events and accumulated magnitude are located within the brittle zone.

Why?

- At the beginning of the highstand system tract, the sediment inputs are still clay dominant and less silicious content in the deposit. At the beginning of transgressive system tract, low gamma ray reading indicates less clay content in the sediments.
- For the model analysis, overall distribution pattern is observed, but for evaluating the fracturing performance and their relationship with the framework, each stage needs to be observed individually.

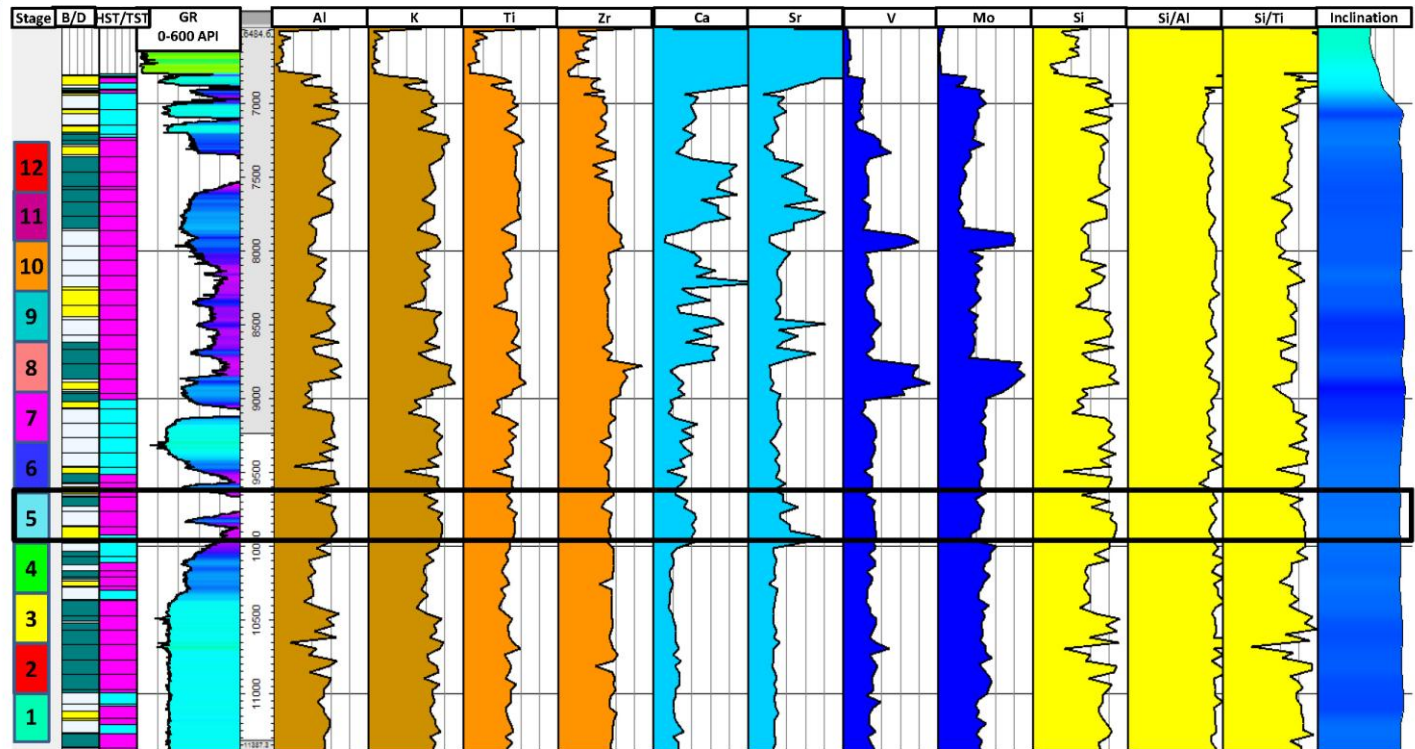
Presenter's notes: For the overall trend analysis, we add the event number and magnitude in different zones. In both models, there are a slightly higher number of magnitudes and the microseismic event locates within the HST. The contrast is getting bigger in the brittle ductile model, as 67% of the events and magnitude are located within the brittle zone. We interpret the cause of this contraction is because at the beginning of the HST, the sediment inputs are still clay dominant and less siliceous content in the deposit. At the beginning of TST, low gamma ray readings indicate less clay content in the sediments. For fracturing performance evaluation and their relationship with the framework, each stage needs to be observed individually.

Stage Analysis



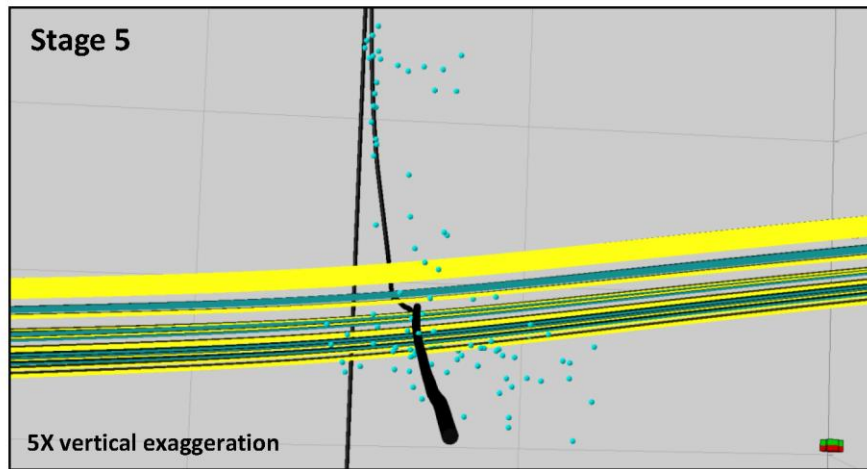
Stage 5: Locates in the transgressive system tract and mixing brittle and ductile zone. High gamma ray reading, XRF profile indicates high clay content with low TOC (high Al, K, low in Si/Al, Mo, V).

Horizontal Well XRF (X-Ray Fluorescence) Profile from the Cutting Samples

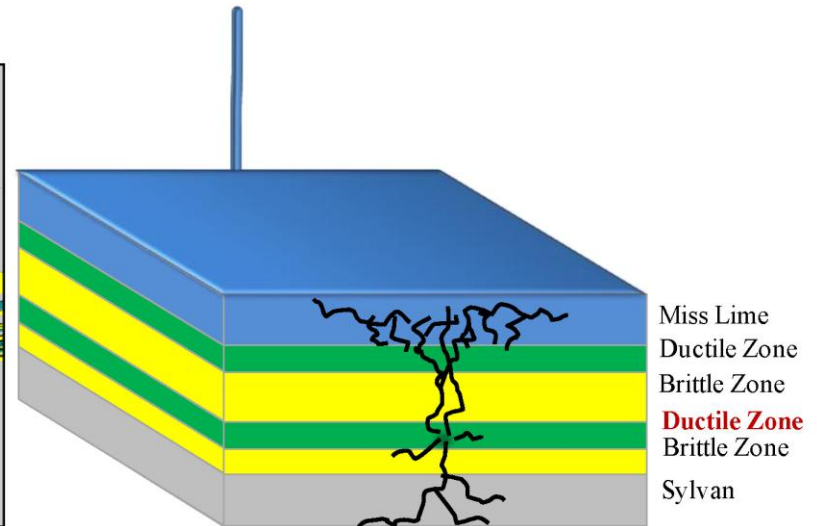


Presenter's notes: We have cutting samples for the horizontal well to build up the x-ray fluorescence profile by using our Bruker HHXRF instrument; these elements listed above are used for interpretation. Four stages are picked for evaluation demonstration to save the time. Starting with stage five, it locates within the TST from our model, high gamma ray and Al K reading indicates there is high clay content, which makes this section more the ductile.

Stage Analysis



Stage 5: Most of the events occur outside of the Woodford shale, extended width is limited within the Woodford because the perforation shots located in the high gamma ray, ductile zone. Notice the fractures grow all the way up through the Mississippian Limestone.



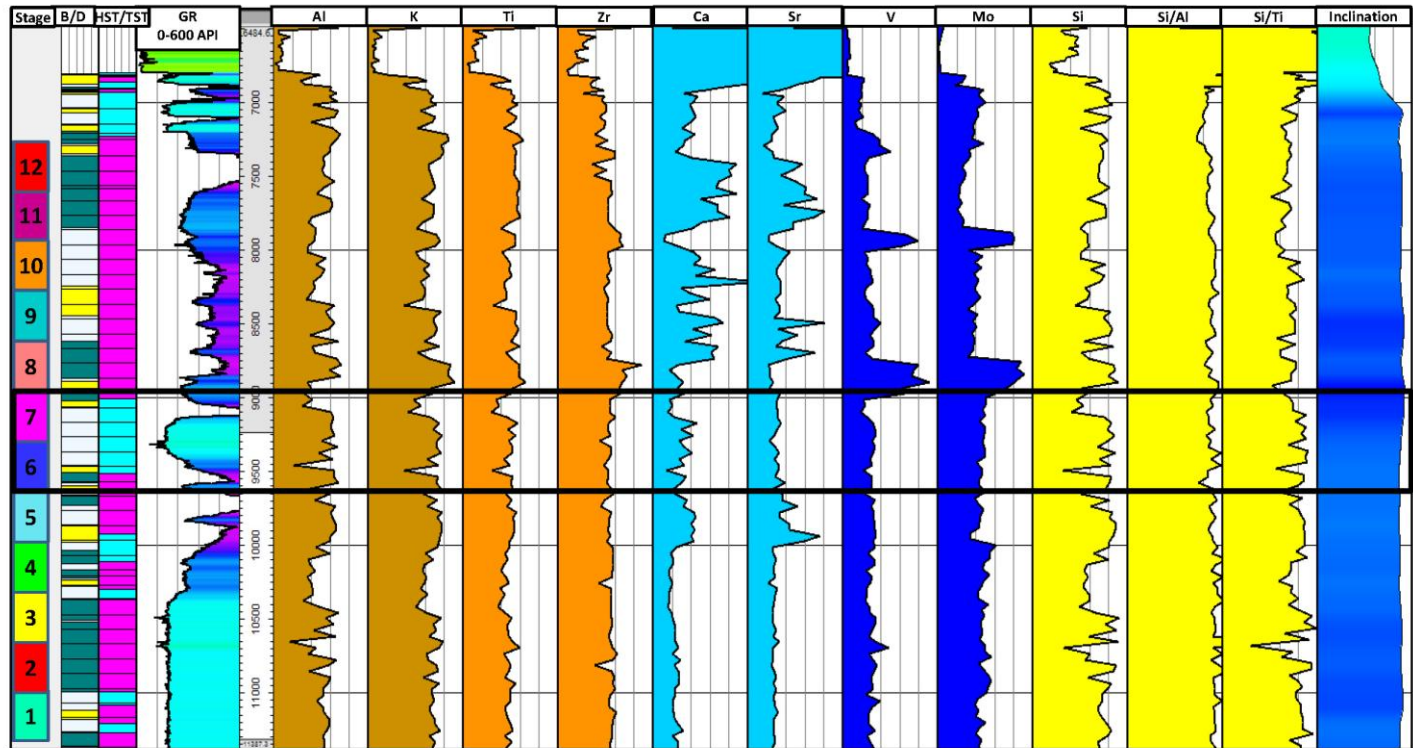
Fracturing type 1: The preexisting fracture in the upper limestone formation, when the stimulation goes up to the formation boundary, most of the energy extend further up instead of stays in the target formation. Also, when stimulation locates in a ductile zone the width growth is constrained which leads to low fracturing efficiency.

Presenter's notes: This is stage five with a nearby slice of brittle and ductile model, which labels the Woodford shale formation location. The microseismic events locate mostly outside of the formation, and go all the way up to the Mississippian limestone and downwards to Sylvan shale. Our interpretation is when there is preexisting fractures in the upper limestone formation. It will no longer act as a fracture barrier, instead when perforation shots hit the formation boundary it touches the weak point and extends further upward. Fewer events located within the target formation lead to low fracturing efficiency.

Stage Analysis

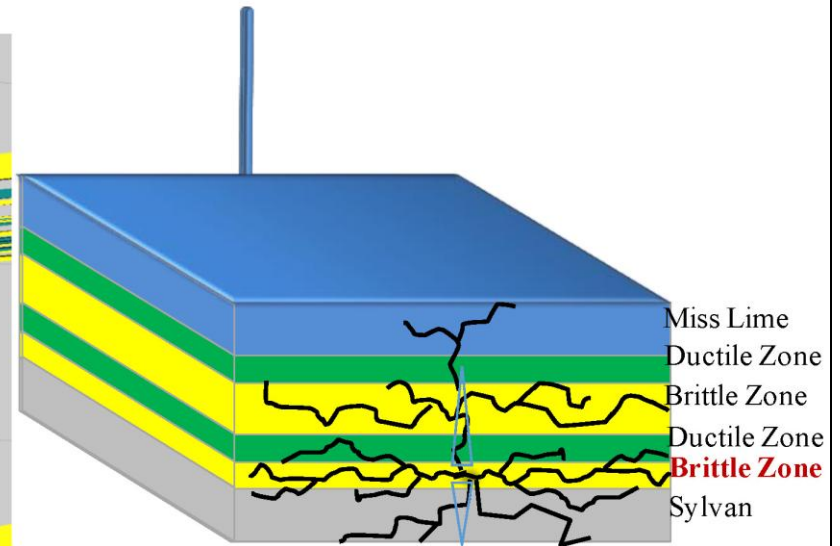
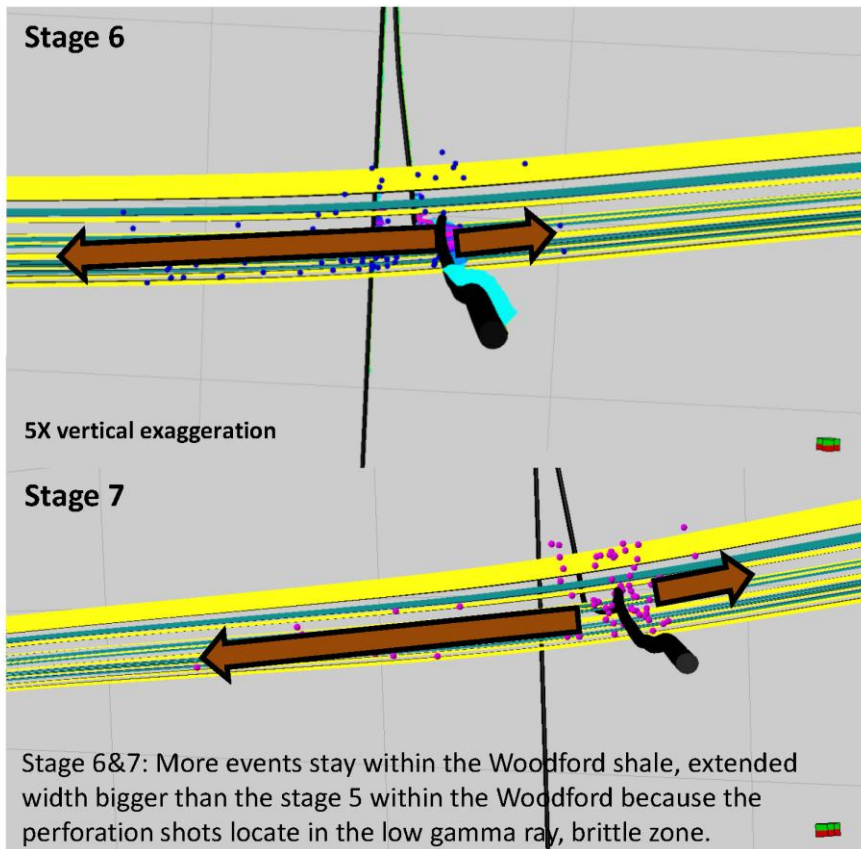
Horizontal Well XRF (X-Ray Fluorescence) Profile from the Cutting Samples

Stage 6 and 7:
Locate in the
highstand system
tract. Very low
gamma ray,
brittleness not
defined due to
the lateral error
of the model. The
XRF profile
indicates high
biogenic quartz
content and low
TOC (low Mo, V
high Si/Ti).



Presenter's notes: For stage 6 and 7, even though the model does not predict it as brittle zone due to the error. The low gamma ray, high Si/Ti ratio indicates this is a biogenic quartz rich section, which increases the brittleness.

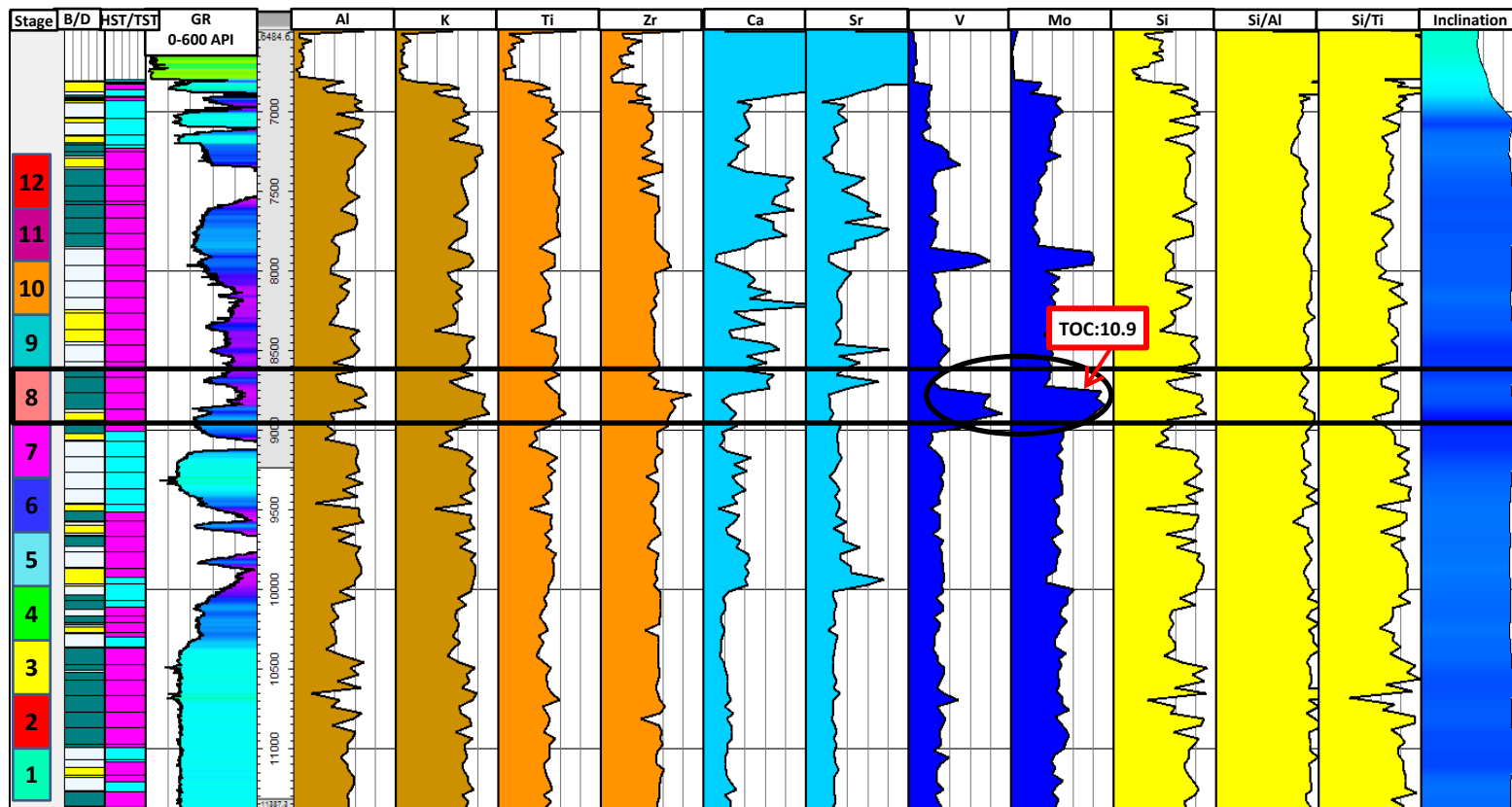
Stage Analysis



Fracturing type 2: When stimulation starts from the brittle zone in the formation, the fracture will be more prone to stay within the target formation and grow laterally then ultimately leads to high fracturing efficiency.

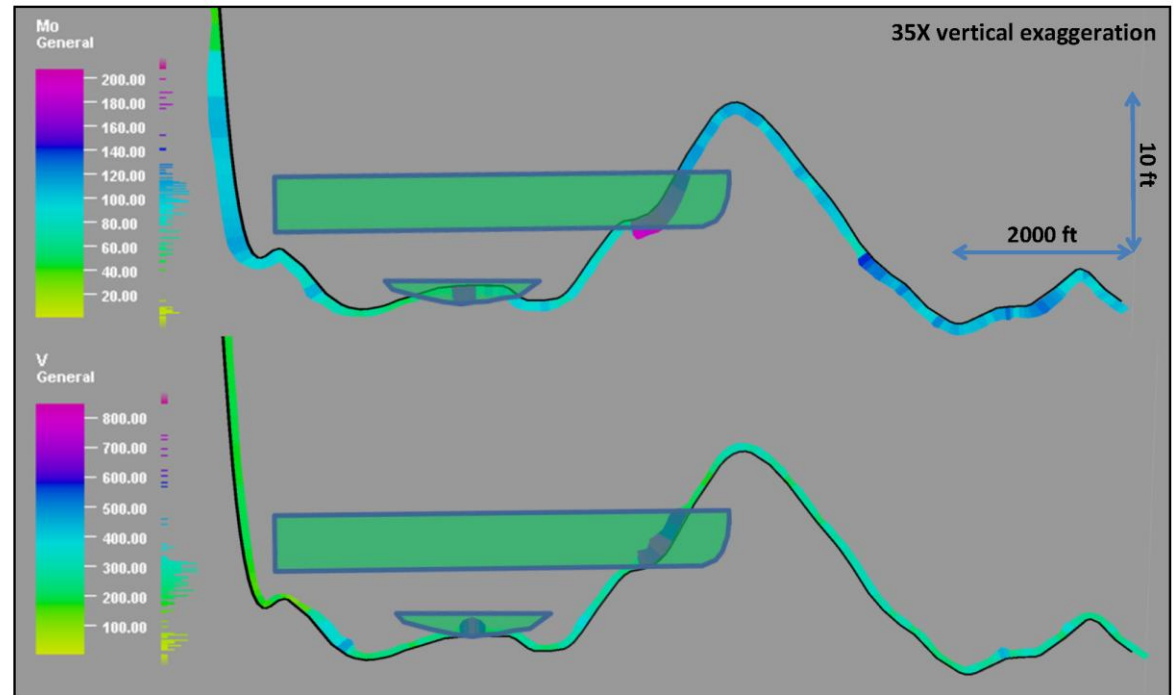
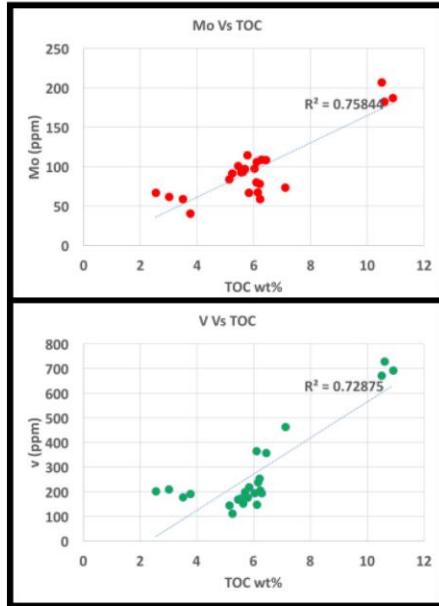
Presenter's notes: Here you can see there are more events located within the Woodford formation that extend further laterally. The trend is more obvious when we screen out the outside points. As you can see many event are following the bed dipping direction and stay within the Woodford shale. We interpret this as when the perforation shot within the brittle zone, the fracture does not extend vertically in either direction. When it encountered a brittle zone, the fracture will grow along the bed and ultimately enhance the fracturing efficiency.

Horizontal Well XRF (X-Ray Fluorescence) Profile from the Cutting Samples



Stage 8: Locates within the transgressive system tract and ductile zone. High gamma ray. The XRF profile has abnormal high Mo and V pocket indicate high TOC content.

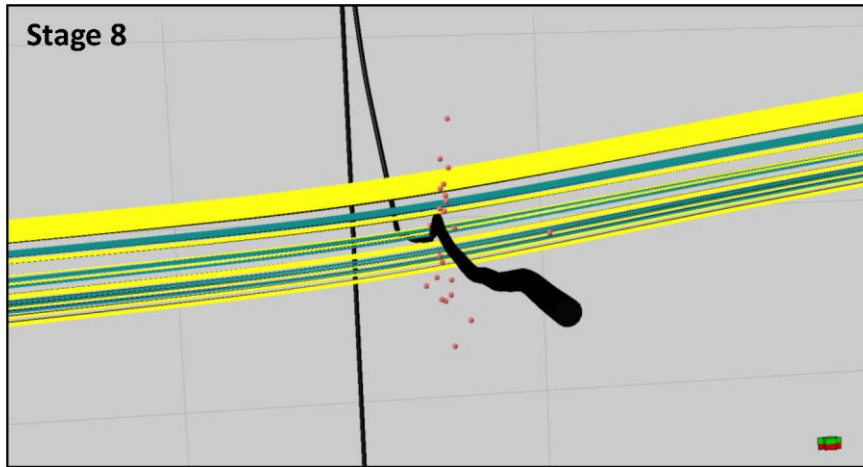
Stage Analysis



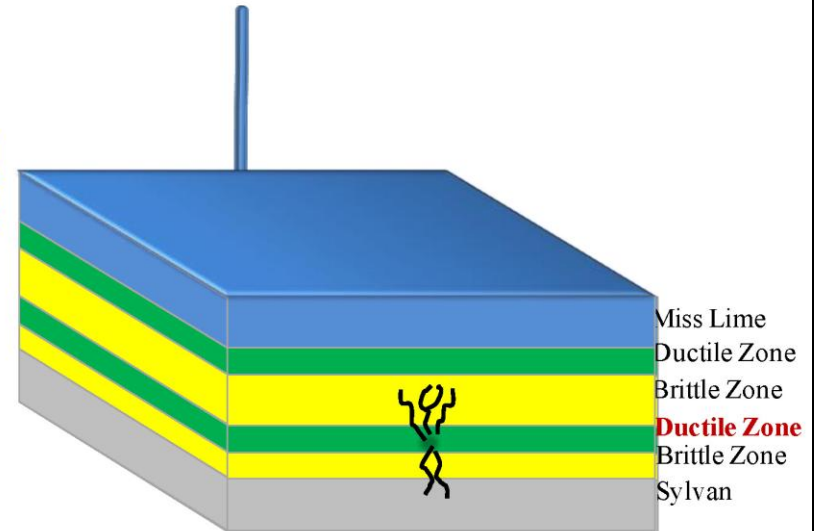
Stage 8: The two high Mo and V pockets are shown in the horizontal well section, the interpretation of these two pockets are laterally pinched out organic-rich bedding.

Presenter's notes: We summarized all of the Mo V point with rock eval data and found there is high correlation between Mo V and TOC value. From the side view of this high vertical exaggerated well, we interpreted this pocket as laterally pinched out organic-rich bed.

Stage Analysis



Stage 8: Less amount of microseismic events occur during this stage. Height and width all constrained close to the wellbore.



Fracturing type 3: When stimulation starts from the ductile zone in the formation, the fracture will be constrained close to the wellbore and the energy absorbed by the formation which leads to low fracturing efficiency.

Presenter's notes: For stage 8, as you can see much fewer microseismic events occurred during this stage. We interpret this stage as when stimulation locates within a ductile zone, the fracture will be constrained close to the wellbore and the energy absorbed by the formation, which leads to low fracturing efficiency.

Fracture Efficiency

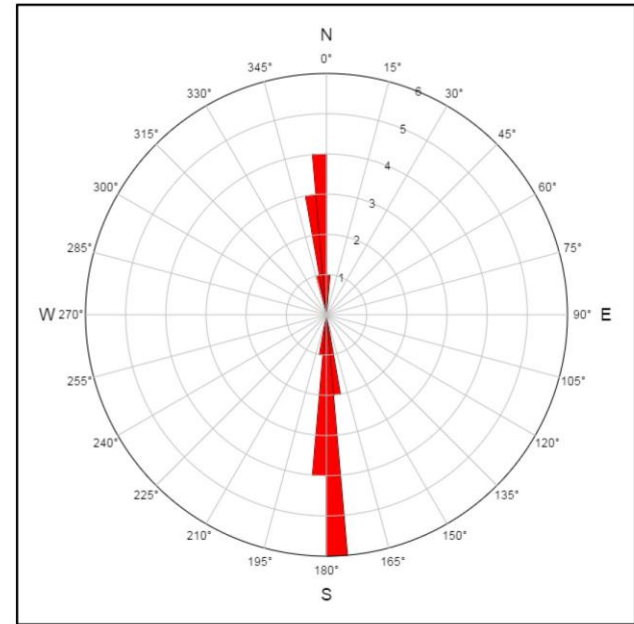
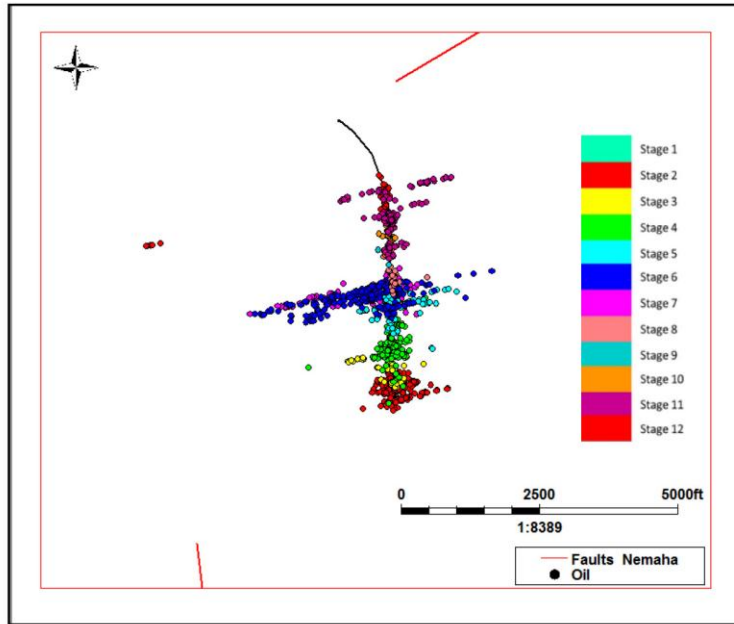
Summary of each stage (stage 1 skipped)

Stage	Width	Width in WDFD	Height	In WDFD	Accumulated Magnitude (in Woodford)	Number of Event (in Woodford)
2	1572	1365.84	914	49.8%	-537.44	160
3	1359.2	680	460	37.5%	-72.62	24
4	745	551	788	23.6%	-247.82	78
5	1785.5	1386	509	27.3%	-83.35	27
6	4345.99	2884	725	35.4%	-266.86	93
7	3064.31	2548	316	75.9%	-242.59	85
8	710	710	249	61.5%	-55.43	16
9	515	377	390	60%	-64.73	21
10	230	230	294	53.8%	-40.78	14
11	2022	126	481	35.7%	-251.71	65
12	158	106	325	27%	-26.86	9

- The fracturing efficiency is evaluated considering microseismic event cloud width, height, the percentage of the event within the target formation, accumulated magnitude and event number.
- Overall speaking, stage 2, 6 and 7 is considered as high efficiency fracturing stage.
- Stage 3 seems has high width value but the accumulated magnitude within the Woodford is way too low.
- Stage 5 seems has high width and well extended within the Woodford but the percentage of events and accumulate magnitude stay within the Woodford is not good enough.
- Stage 11 seems to have high width for the entire stage but the width within the Woodford is small (extended within the other non-target formation).

Presenter's notes: All the stages are evaluated comprehensively by width, width in the Woodford, height, percentage of event in the Woodford, accumulate magnitude and event number in the Woodford shale. Overall, stage 2, 6, and 7 are high efficiency fracturing jobs, some of the stages are not considered as good performance jobs because of low accumulated magnitudes in the Woodford. For stage 3, the low percentage of events in the Woodford for stage 5 and small width extension within formation for stage 11 even though other parameters seem optimistic.

Stress Analysis



- (Left) The map view of the stimulated well and the Nemaha faults, the faults are almost vertical (red solid line). Stage 12 has an abnormal set of points away from the wellbore, can be the response of the subsurface fault. The events are all oriented around NE80, which reveals the maximum horizontal stress direction. The future nearby well can be drilled perpendicular to this direction.
- (Right) The maximum horizontal stress direction is also confirmed by the vertical well image log, the wellbore breakouts indicate the minimum horizontal stress direction with NNW-SSE.

Presenter's notes: This is the map view of all the stage. The red line represents two vertical Nemaha faults. Most stages are oriented N80E which indicates the maximum horizontal stress direction,. Minimum horizontal stress direction is also confirmed by SWD well image log borehole breakouts.

Conclusions

- The distribution pattern of the microseismic event is related to the sequence stratigraphic framework, HST is relatively brittle than TST, thus more prone to have more microseismic events.
- Perforation better located within a brittle section of the horizontal well to get a higher efficiency fracturing job.
- XRF profile and sequence stratigraphic framework are the quick helpful tools to identify the better target zones before planning for the fracturing job.
- Fracturing efficiency can be evaluated by integrating the width, height, accumulated magnitude, event number especially considering the case within the target formation.

References

- Badra, H. (2012, October 23-26). *Fracture Characterization and Analog Modeling of the Woodford Shale in the Arbuckle Mountains, Oklahoma*,. Retrieved from AAPG Search and Discovery :
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- Johnson, K. (2008). Geologic history of Oklahoma, Oklahoma Geological Survey. Educational Publication 9.

The background features a white canvas with a series of horizontal, wavy bands in bright cyan and magenta. A thick black line starts at the top left, curves down, and then follows a path across the middle of the image. Scattered throughout the scene are numerous small, semi-transparent dots in various colors: red, green, blue, yellow, orange, and purple. Some of these dots are clustered together, forming vertical or diagonal streaks, while others are isolated.

Thank you!