PS Microseismic Tool Utilization in Helping Characterize the Woodford Shale, North Oklahoma*

Jing Zhang[1], Jennifer Scott[2], Roger Slatt[3], and Bryan Turner[3]

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[1]University of Oklahoma, Norman, OK
[2]Longfellow Energy, LP, Addison, TX
[3]University of Oklahoma, Norman, OK

Abstract

Microseismic study has been playing an important role in widening our view to explore unconventional reservoirs, characterize fracture networks, brittle ductile couplets, and well space scale heterogeneities. This study is focused on comparing the relationship between microseismic interpretation results from brittle ductile couplets identified from cuttings and stratigraphic framework. Interpretation of seismic alone could lead to a huge bias especially in unconventional reservoirs that are affected by high potential VTI and HTI (vertical and horizontal transverse isotropy). Correlation between microseismic and geologic data of the reservoir could strengthen the interpretation of results and filter out the pseudo-events displayed within the microseismic data. The cuttings obtained from the microseismic treatment well can be a good indicator of lithology change and geomechanical properties at certain depths. With fluctuations a horizontal well trace in the target window, the cuttings correspond with alternations of brittle and ductile couplets indicated by well log trends. Considering the microseismic event distribution, which mirrors the induced fracture network around the well bore, the identification of brittle and ductile zones improves. The results of interpretation helps to locate the desirable zone with brittle properties and determines the future horizontal well drilling and fracturing scenario in the Woodford Shale.

The UNIVERSITY of OKLAHOMA
Mewbourne College of Earth and Energy
ConocoPhillips School of Geology and Geophysics
ConocoPhillips

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1. University of Oklahoma 2. Longfellow Energy, LP

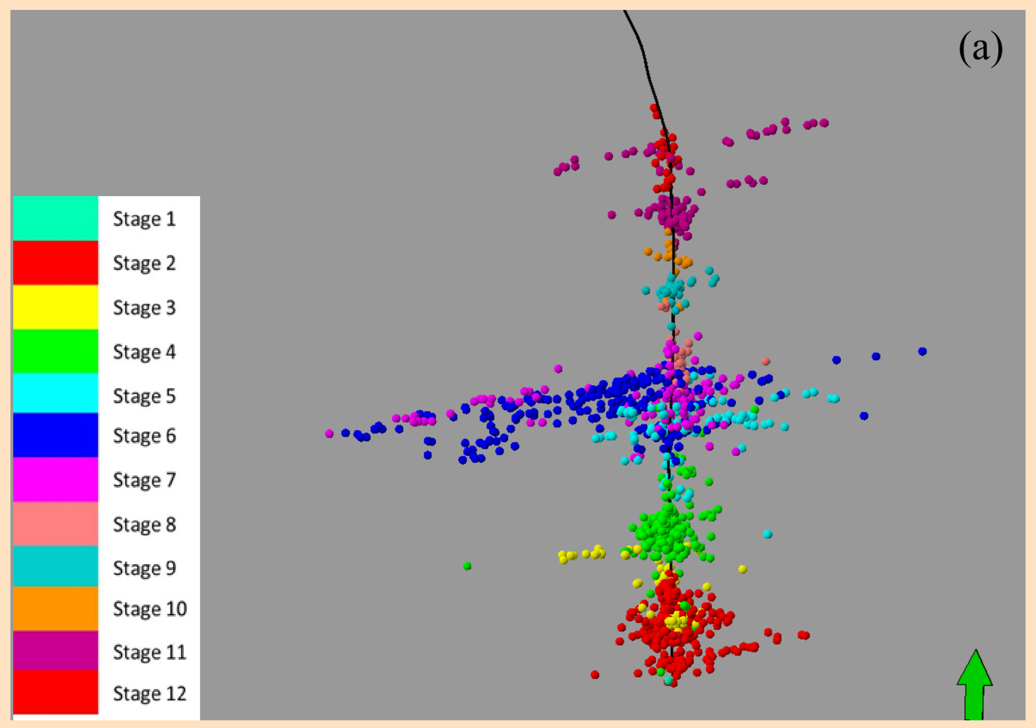
LONGFELLOW ENERGY, LP

Motivation:

Microseismic interpretation is a study utilized to evaluate the efficiency of hydraulic fracturing. How the activities distributed are affected by geomechanic properties of the reservoir. Tying fine scale sequence stratigraphic knowledge with engineering stimulation activity can enhance confidence of characterizing and predicting the preferential fracture growth pattern and ultimately optimize the future hydraulic fracturing job (Cabarcas et al., 2014).

Available Data:

The data available for this study includes 1552 microseismic events location data separated by 12 stages along a horizontal well. The locations are obtained by surface array survey. Well logs and cuttings are available from one nearby vertical well and the treatment well, which landed within the Woodford Shale. XRF (X-Ray Fluorescence) data of the cuttings are measured and calibrated.



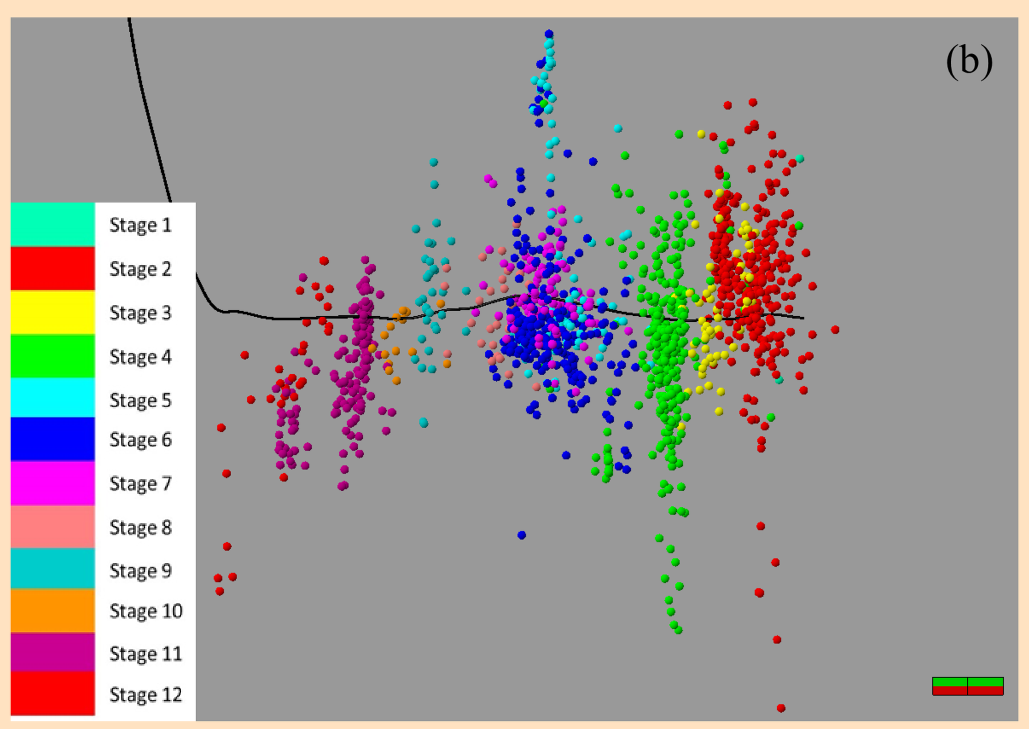
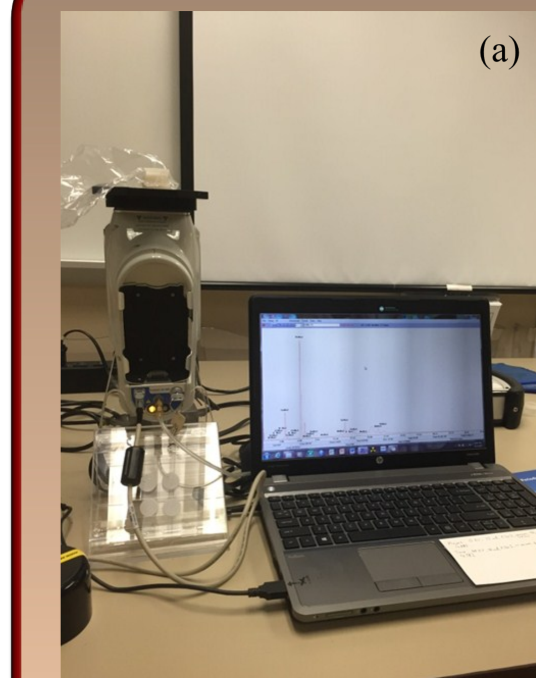
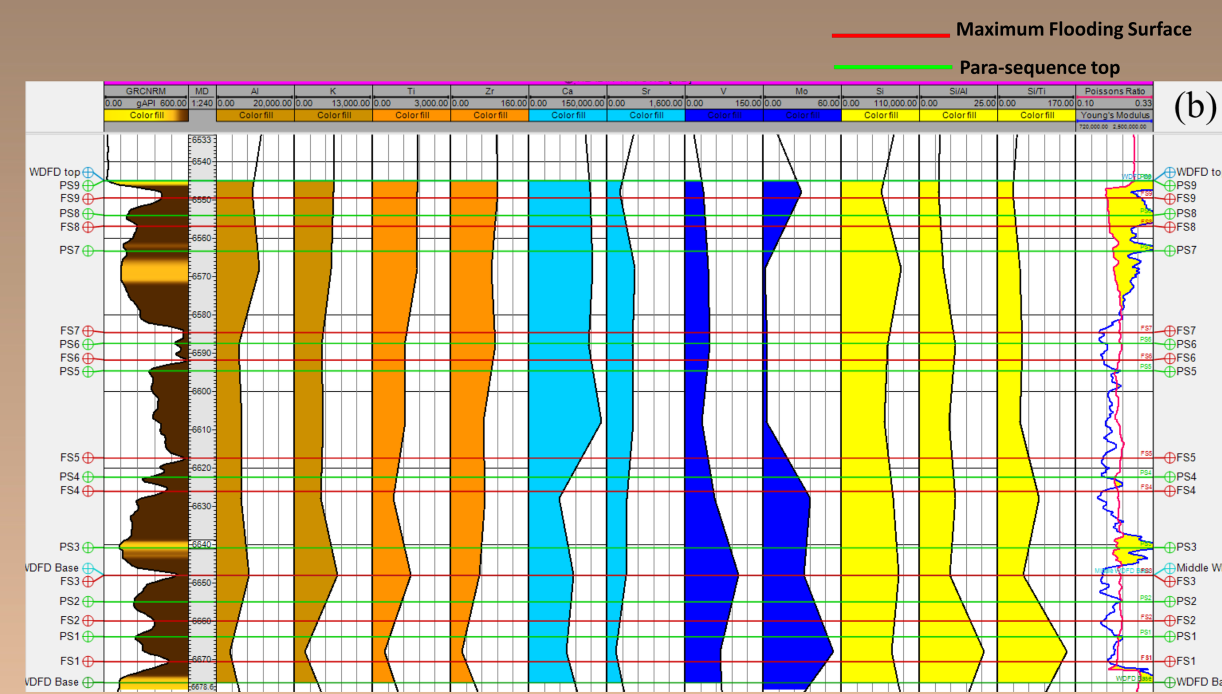


Figure 1. Microseismic events in (a) map view and (b) west view with horizontal well track. Events are colored by stages.

Methods:

In order to correlate the microseismic events with the regional geologic framework, a stratigraphic model was built based on the well logs and XRF profiles from both horizontal and vertical wells. A brittle-ductile model also defined based on the stratigraphic framework and Young's modulus/ Poisson's ratio (Slatt and Abousleiman, 2011). The number and magnitude of the microseismic were upscaled for both models to analyze the distribution pattern.





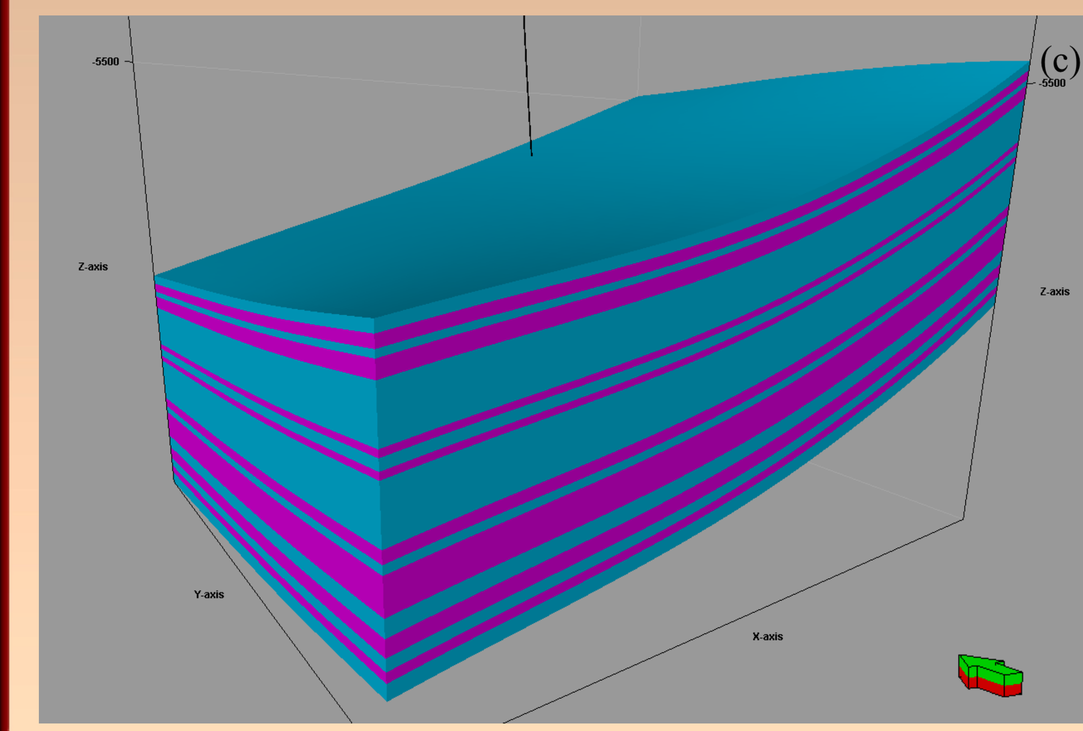
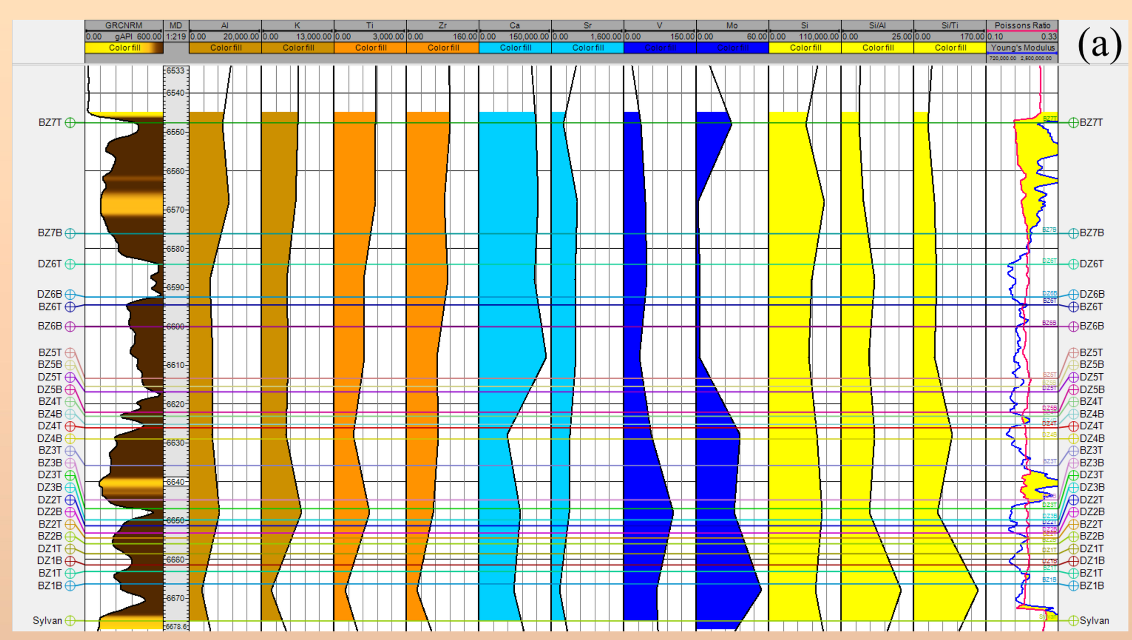


Figure 2. (a) HHXRF instrument used for measuring elemental profiles for the both wells. (b) Para-sequence sets of the vertical well, green lines are tops of para-sequence sets, red lines are flooding surfaces. (c) Regional stratigraphic model built based on key surfaces and dipping trend from the top Woodford surface with 20X vertical exaggeration scale.



BZ------Brittle Zone

DZ------Ductile Zone

Clay Proxies

Continental Proxies

Carbonate Proxies

Anoxia Proxies

Quartz/Sand Proxies

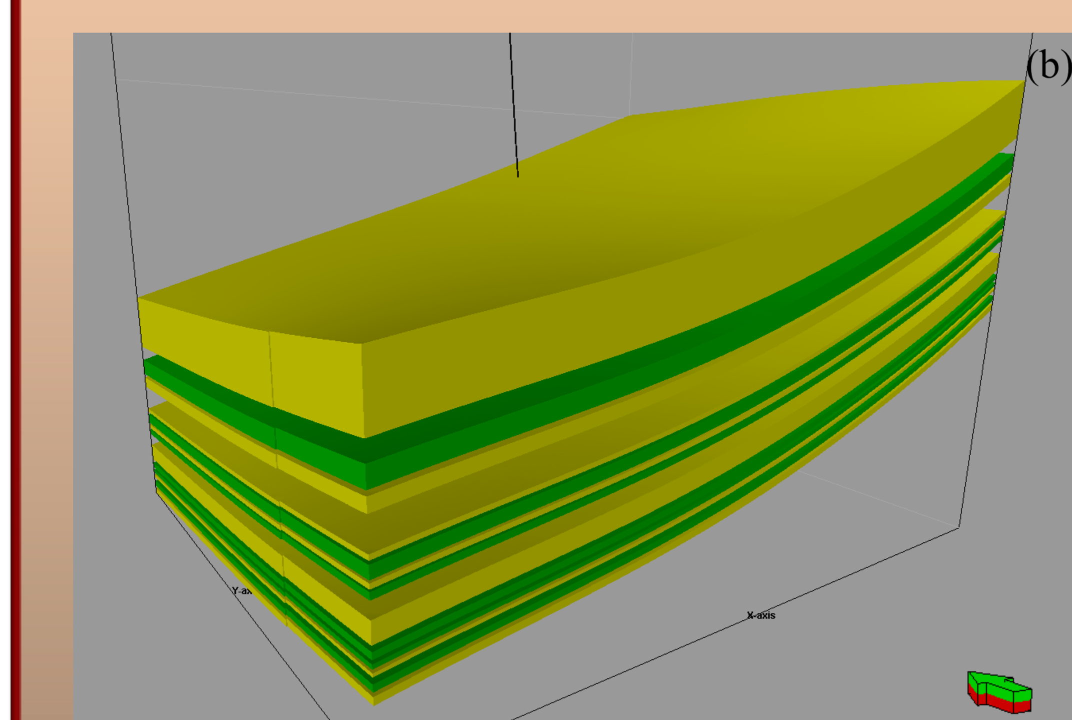


Figure 3. (a) Brittle and ductile zones identified based on para-sequence sets, Young's Modulus/ Poisson's Ratio. (b) Brittle-ductile couplets model built based on the key surfaces and dipping trend of the Woodford top, brittle zones in yellow and ductile zones in green. 20X vertical exaggeration

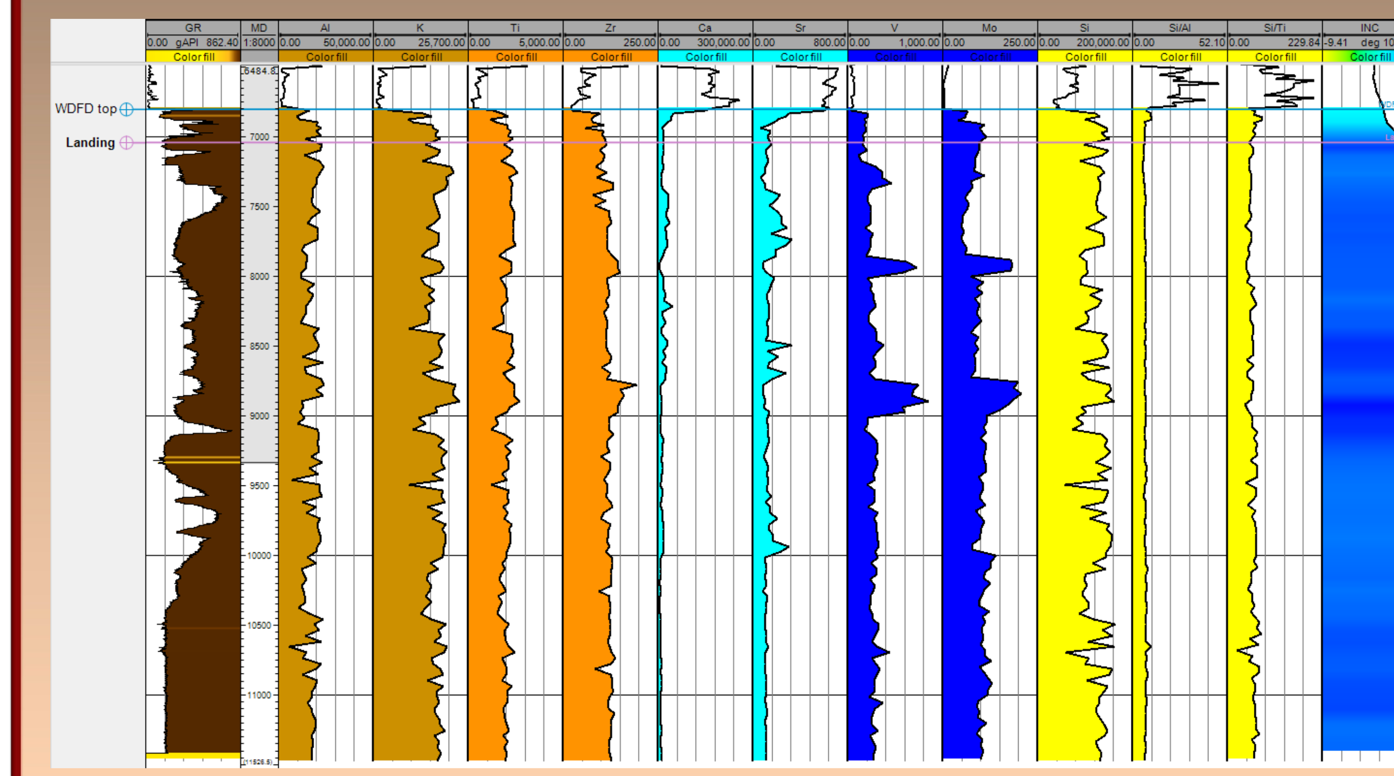
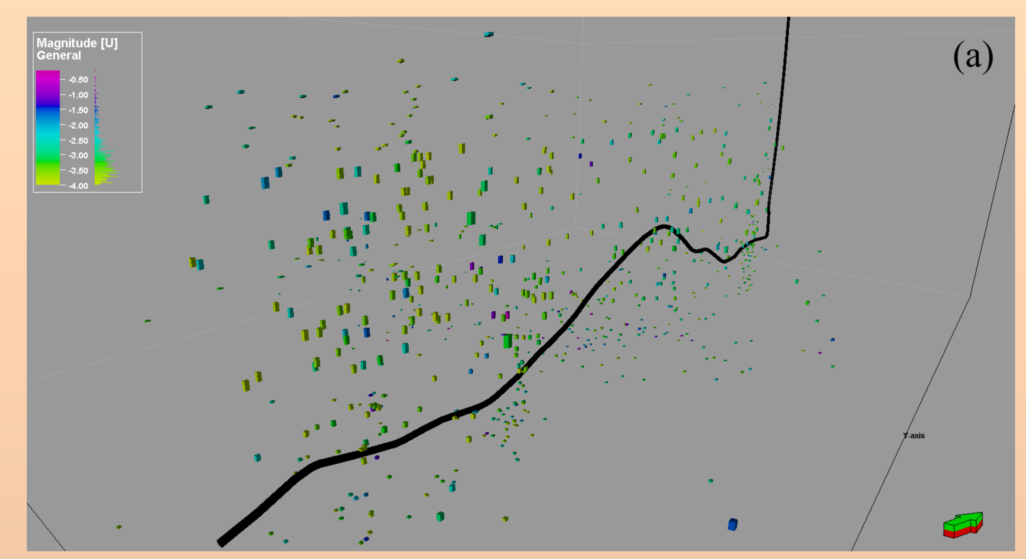
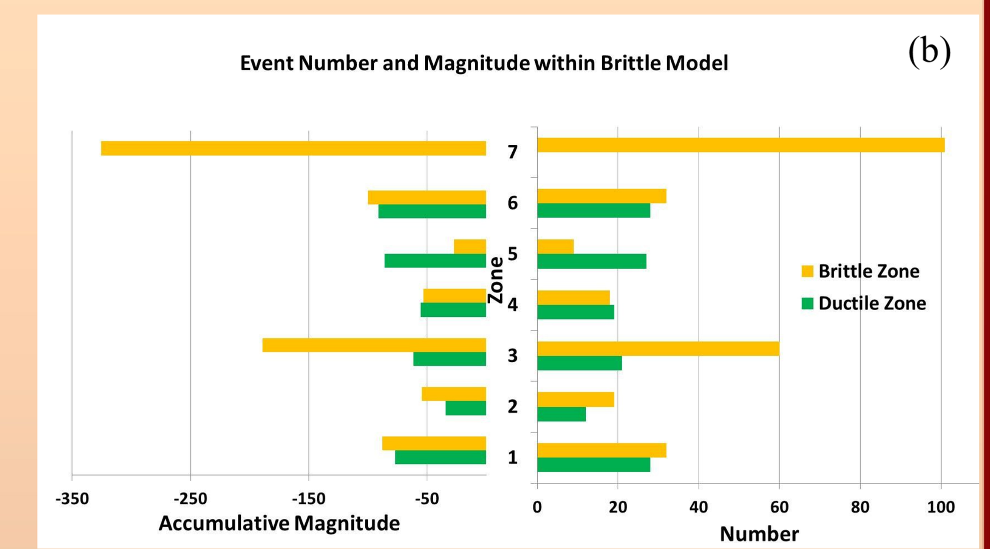
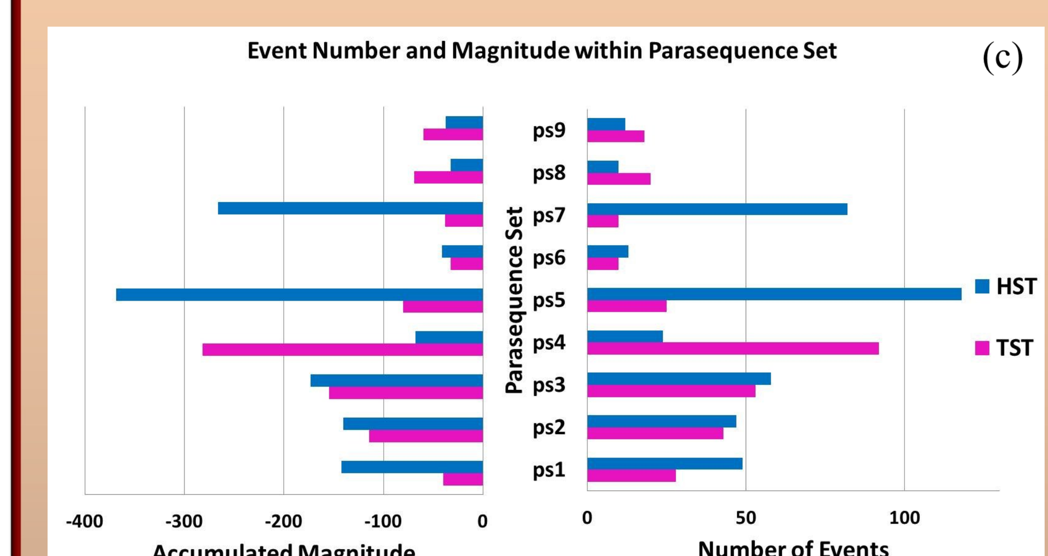


Figure 4. XRF and gamma ray profiles of the horizontal well, landed section marked with the pink line. Horizontal profile can be used as correlation tool to examine the uncertainties and horizontal anisotropy. Above the landing surface, there is a maximum flooding surface identified by decreasing in continental proxies (Al, K, Ti, Zr) and increasing in anoxia environment proxies (V, Mo). Most sections along the horizontal track correspond with certain parts of the vertical section.

Interpretation Results:







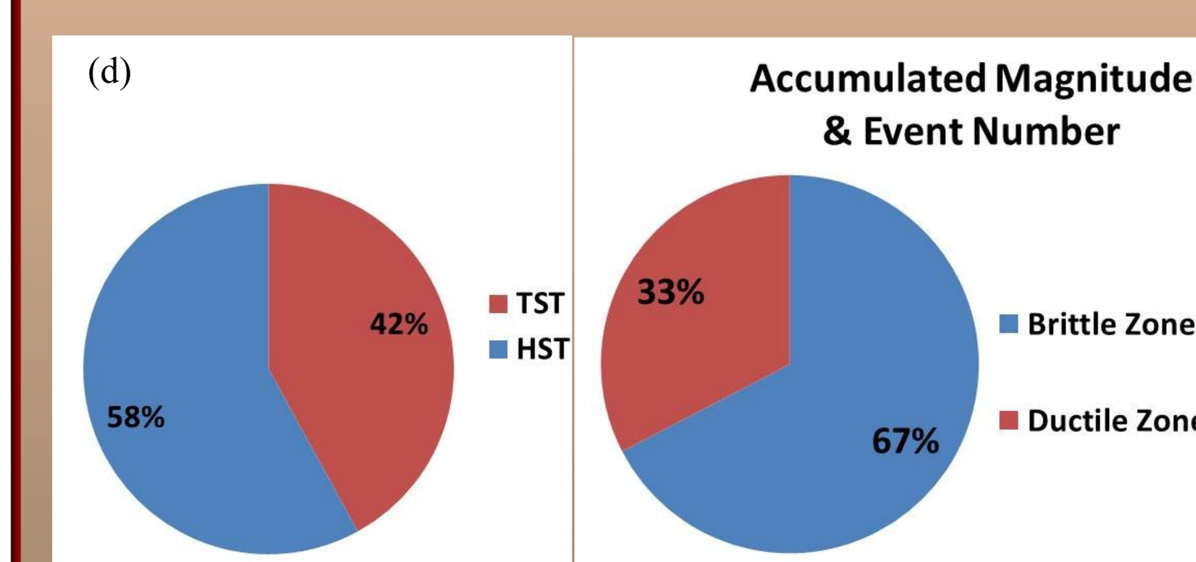


Figure 5. Upscaled magnitudes of all events within the Woodford, as shown in (a), the total magnitudes and number of events within each zone of the two models are counted and compared. For sequence stratigraphic model, the number and accumulated magnitudes have same trend in each zone, as shown in (d), overall 58% events locates within HST (Highstand System Tract). Parasequence set 4 has more events in TST because of the low gamma ray, high brittleness at the base. In the brittle-ductile model, overall 67% events locate within the brittle zones, as shown in (d). Brittle zone 5, which located above the ductile zone 5 has fewer events due to the difference in thickness between the two zones.

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Efficiency of Hydraulic Fracturing:

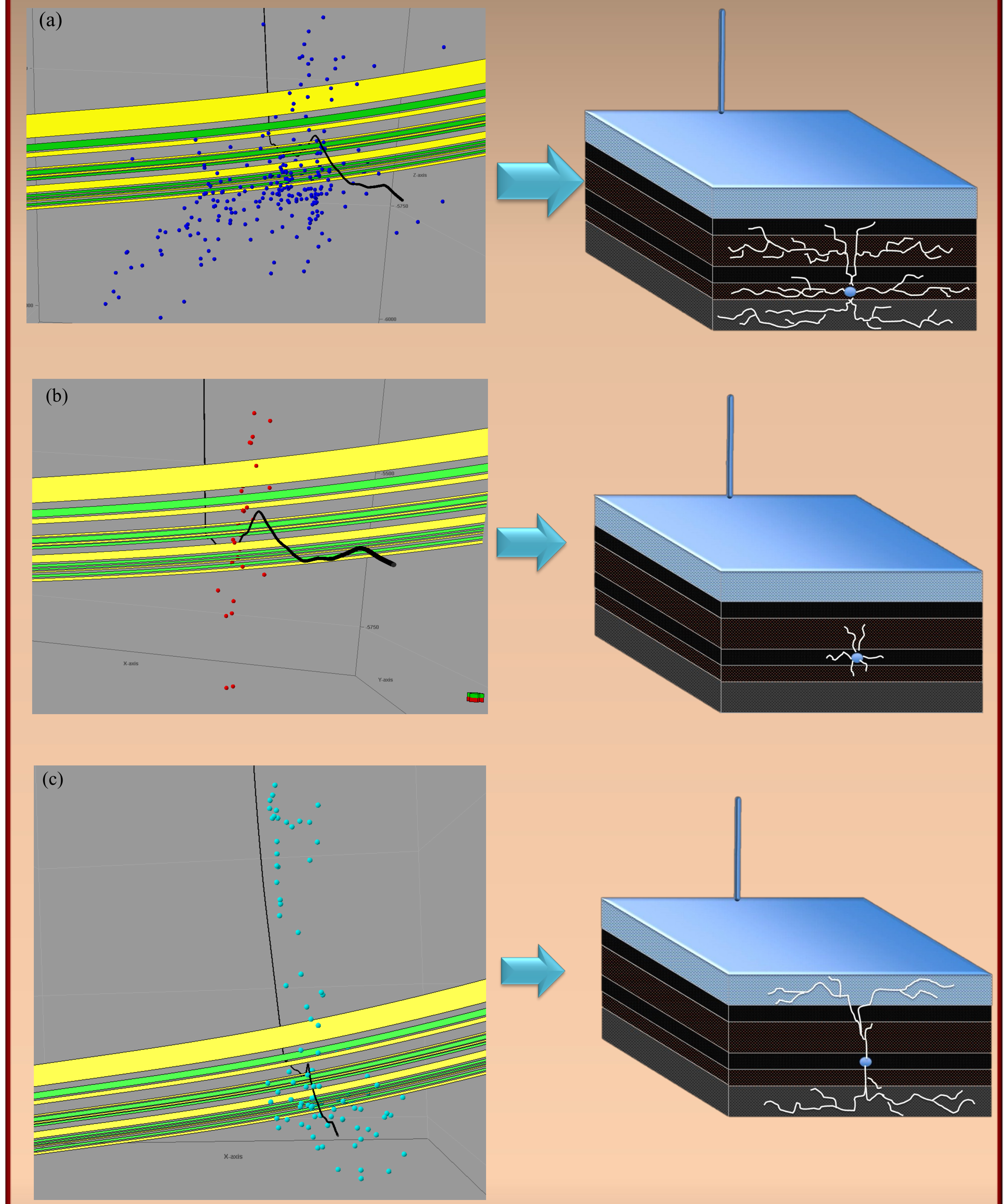
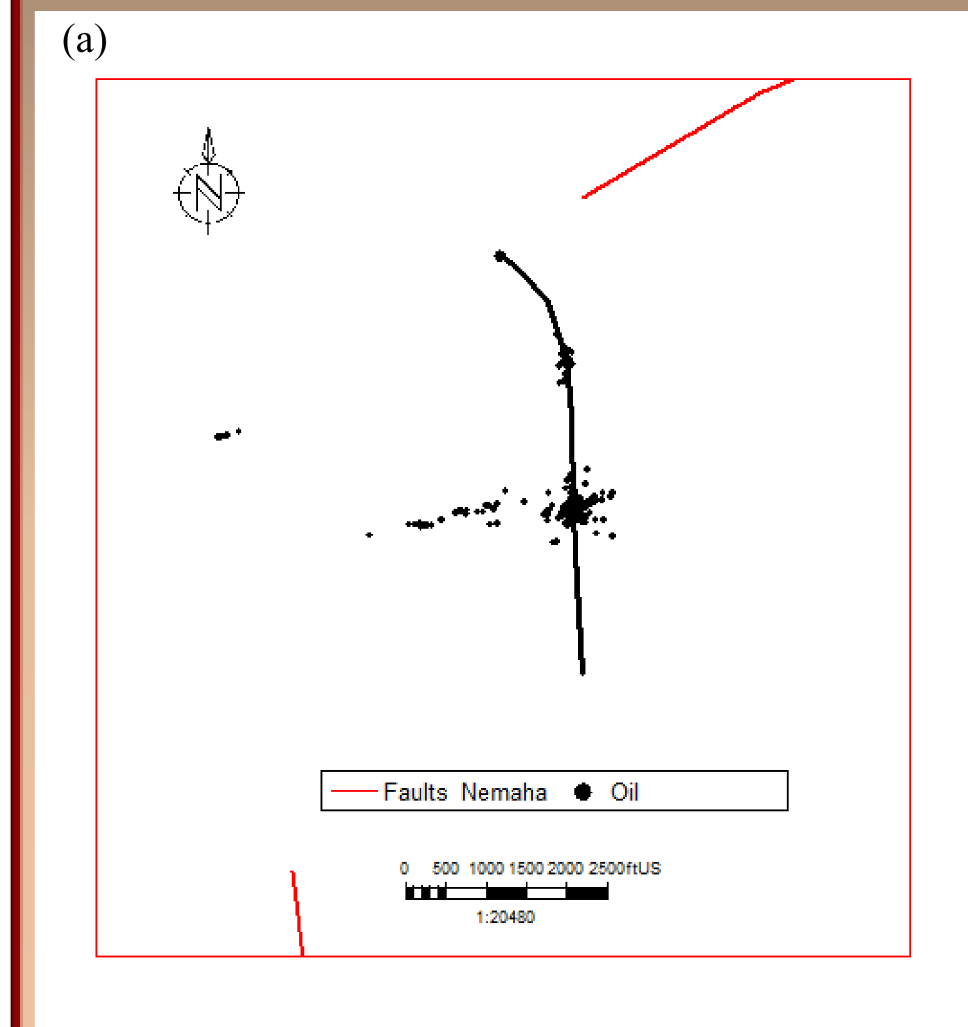


Figure 6. Schematic diagrams showing three types of hydraulic fracturing job. When the well tract located at significantly low gamma ray (a), it is interpreted as local continental deposit influx event. Perforation in brittle zone makes hydraulic fracturing more efficient also in the other adjacent zones. (b) showing ineffective fracturing job when the well tract located in ductile zone 4, perforation energy was absorbed so fewer fracture network grows horizontally along the bed but only perforates vertically (c) shows another ineffective hydraulic fracturing job, the well tract located in a ductile zone, increasing in perforation pressure penetrate upper and lower brittle non-reservoir formations and grow within those formations.

Stress Analysis:



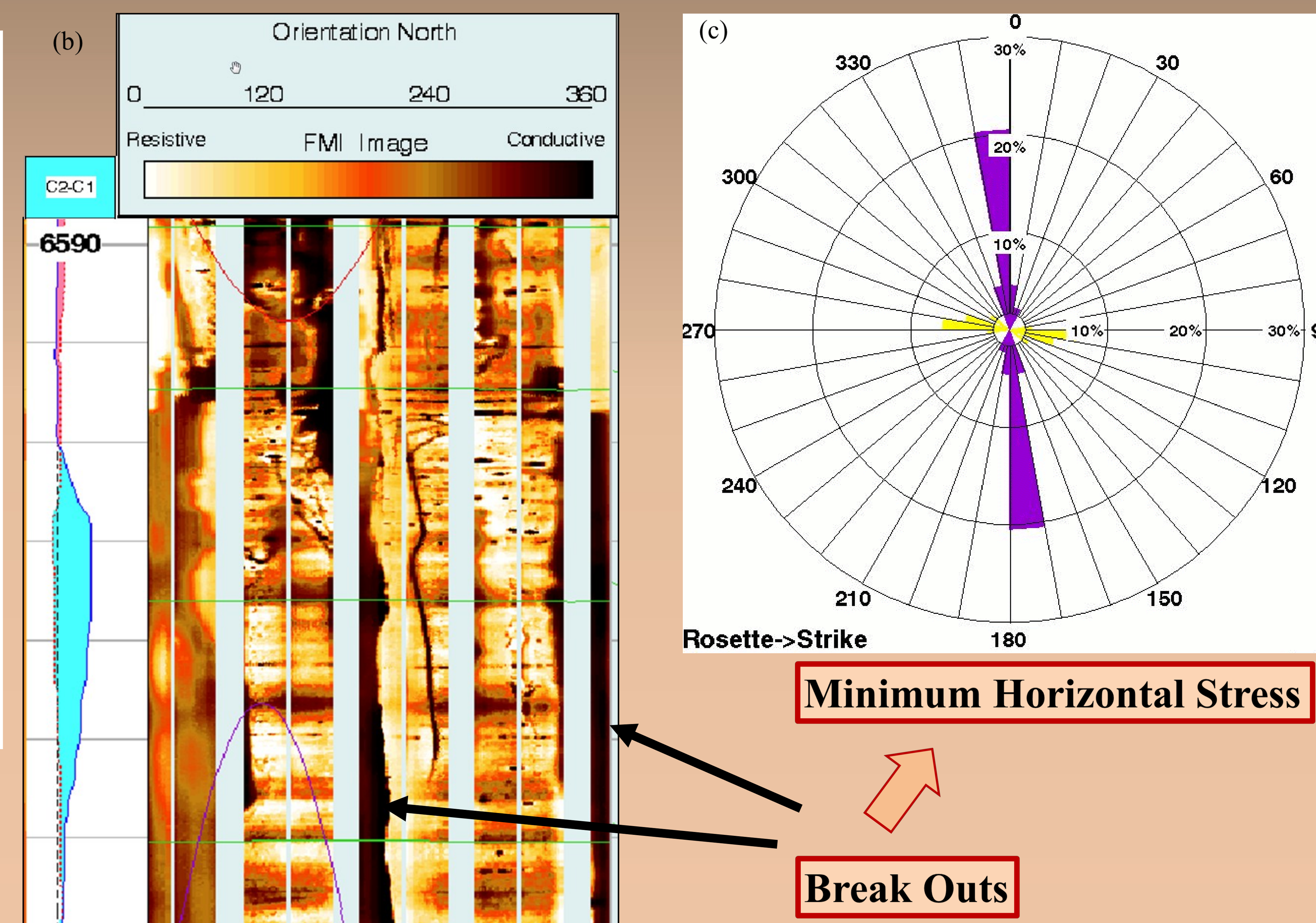


Figure 8. (a) Near vertical faults around the study area also have impacts on growth pattern of the induced fractures. There are two stages with obvious asymmetrical bi-wing geometry, the northern stage has discontinuous events distribution was interpreted as either respond of subsurface fault activation or pre-existing natural fractures response along the fault strike direction. Another southern stage's asymmetrical shape also proves that there is a pressure relieve zone near the fault area. Most stages have microseismic events extend along the direction of N78°E, also interpreted as S_{hmax} orientation. (c) From the FMI image log we observe break out within the wellbore. The orientation of the break out can be interpreted as S_{hmin} direction, which is perpendicular to the S_{hmax} (b).

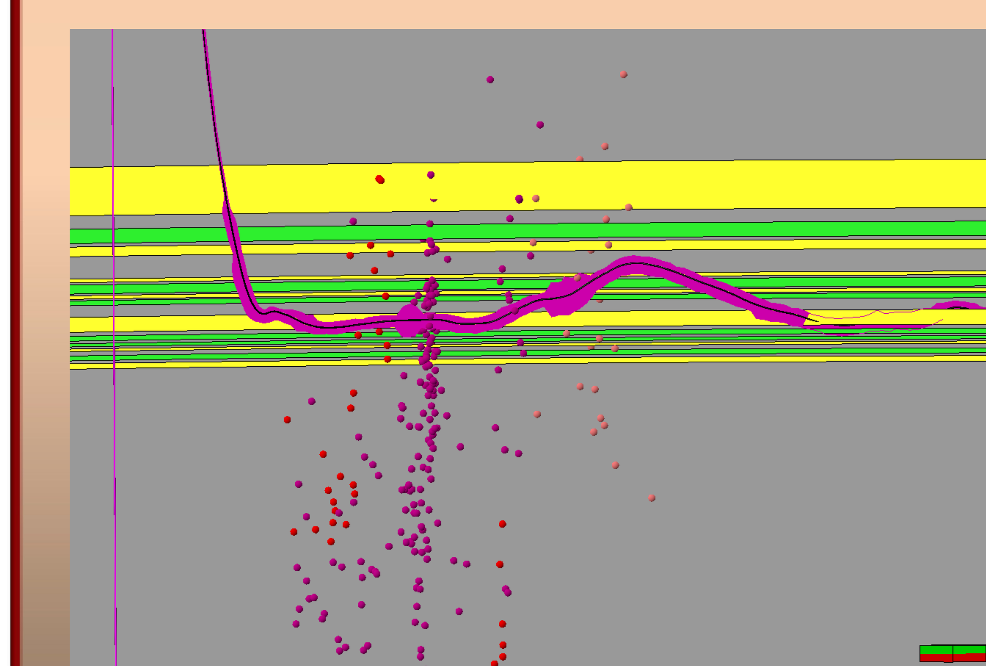


Figure 7. Three stages of microseismic events and brittle-ductile model intersect with V (above well track), Mo (below well track) logs along the horizontal track. Note that there are three sections with high Mo and V value are interpreted as potential high TOC ductile zones, all three stages events develop around those ductile zones . The blue stage events are dipping towards south (left direction on this diagram) is interpreted as due to the pressure depletion from the nearby vertical well (purple line on the left). (Maxwell, 2014)

Conclusions and Suggestions:

- Hydraulic fracturing jobs are more efficient when perforated in brittle zones, fractures grow along brittle bed easier than the ductile beds. Ductile zone dissipates energy and fractures grow vertically.
- XRF and sequence stratigraphic models are helpful for interpreting and predicting the microseismic distribution pattern.
- Hydraulic fracture growth patterns are highly impacted by reservoir anisotropy and local stress fields.
- S_{hmax} is oriented N78°E, future neighboring horizontal wells are suggested to drill along the direction perpendicular to S_{hmax} in order to optimize the hydraulic fracturing job.

References:

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Acknowledgement:

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