[PS]XRF Chemostratigraphy for Characterizing Shale Reservoir along a Horizontal Well Track*

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Abstract

Chemostratigraphic correlations have been shown to be a reliable means of correlation within unconventional reservoirs. However, these analyses have focused on vertical wells rather than lateral wells. Tracing lateral chemostratigraphic variability back to a vertical section with a chemostratigraphic profile provides a means of targeting intervals of interest along the lateral well for subsequent hydraulic fracturing. Chemostratigraphic analysis uses elemental proxies for changing conditions within the environment of deposition. The principal elements used in this study to indicate detrital sedimentation are aluminum (Al), potassium (K), silicon (Si), titanium (Ti), zirconium (Zr). Declining trends in the detrital proxies indicate transgression while increasing trends indicate regression. The amount of quartz, both biogenic and detrital, is inferred using a Si/Al ratio. Biogenic quartz is inferred when detrital influx cannot account for the amount of quartz observed. Molybdenum (Mo) and vanadium (V) are indicators of basin restriction. The presence of V indicates anoxic conditions and Mo indicates euxinic conditions. This study utilizes Hand-Held XRF (HHXRF) data from cuttings within one horizontal well targeting the Woodford Shale in the Anadarko Basin. The cuttings were collected every 20-40 feet, revealing broad trends in lateral variability, brittleness; three potential high TOC concentration zone were identified for fracturing through from lower brittle zone within the Woodford Shale. These zones are located in the basal Woodford Shale during the onset of a transgressive systems tract (TST). The three separate targets along the lateral well appear to have been deposited in isolated mini-basins, resulting in euxinic conditions that allow for the preservation of organic matter. Chemostratigraphic analysis of the vertical section reveals the middle and lower portions of the Woodford record a declining trend in the detrital elemental proxies. This indicates a majority of the Woodford Shale in this area was deposited during a rise in stratigraphic base level associated with a TST. The maximum flooding surface (MFS) occurs at MD: 6884ft based on minimal detrital input. High Si/Al ratio section below the maximum flooding surface indicates the existence of biogenic quartz at the top of the TST and is part of the condensed section (CS). Above the MFS, the detrital proxies indicate a regression and are interpreted as the subsequent highstand systems tract (HST).

Reference Cited

Johnson, K.S., 2008, Geologic history of Oklahoma: Oklahoma Geological Survey, Educational Publication 9, Web Accessed January 28, 2017, http://www.ogs.ou.edu/pubsscanned/EP9_2-8geol.pdf

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XRF Chemostratigraphy For Characterizing Shale Reservoir Along a Horizontal Well Track

ABSTRACT

This study utilized the Hand-Held XRF (HHXRF) data from the drill cutting samples along one horizontal well that targeting the Woodford Shale near the Nemaha Uplift. The XRF profile along the horizontal well revealed lateral variability introduced by reservoir anisotropy. From the chemofacies defined by XRF data hierarchical cluster analysis, it is accessible to locate the horizontal section on the vertical scale and reconstruct the vertical chemostratigraphy profile of the target zone. Two high TOC zones were identified by high Mo and V for hydraulic fracturing, those to zones are interpreted as the sediment and crganic matter deposited in an isolated mini-basin, resulting the euxinic condition that allows for preserving the organic matter.

BACKGROUND

My study area locates in the Kingfisher county, OK (figure 1). Data utilized for this study include: one horizontal well with the cutting samples of 20 ft interval. One nearby vertical well with complete logs and cutting samples of 20 ft interval.

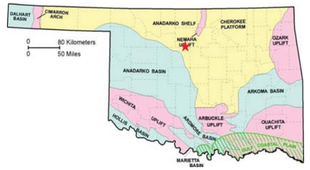
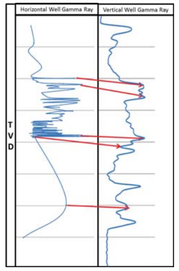


Fig 1: The study area highlighted with red star (modified Johnson, 2008)



One of the challenge for charactering the horizontal well is to correlate the horizontal well track with the vertical section because there are heterogeneity, dipping surfaces in the reservoir. Data is highly concentrated in landing depth interval but extreme less in the other section, this makes the correlation even harder.

Fig2. Vague correlation when using the true vertical depth scale gamma ray log between horizontal well and vertical well.

METHODOLOGY

Fig 3: HHXRF instrument for the cutting samples measurements.

XRF data of the 120 samples from the horizontal well and 23 samples from the vertical well is measured by Bruker HHXRF instrument, then the raw data is calibrated into the ppm unit (figure 4). The hierarchical cluster analysis was conducted to classify the data into 12 chemofacies base on the dissimilarity (figure 5). Chemofacies are interpreted base on sequence stratigraphy and sea level fluctuation (figure 6).

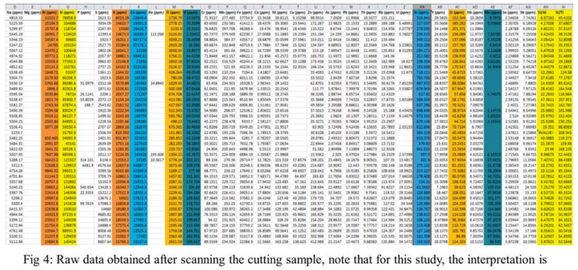


Fig 4: Raw data obtained after scanning the cutting sample, note that for this study, the interpretation is mainly using selected element: Al, K Si, Ca, Ti, V, Sr, Zr, Mo, Si/Al, Si/Ti.

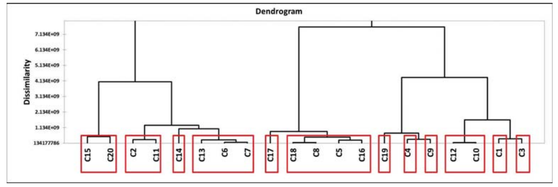
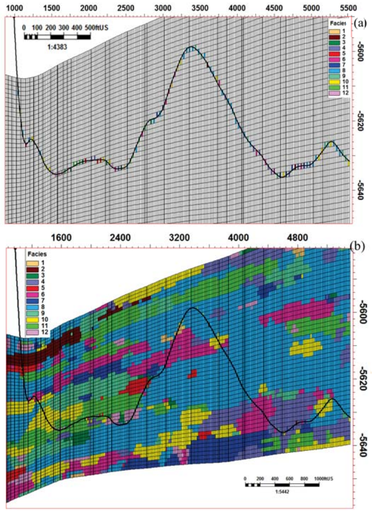


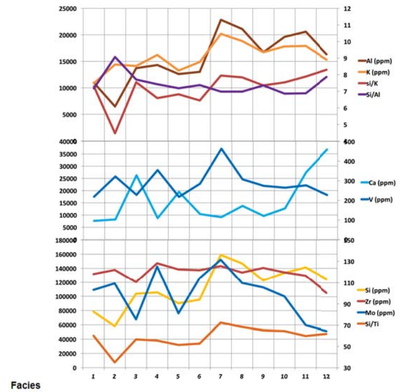
Fig 5: Hierarchal cluster analysis of the raw data initially separate the samples into 20 clusters, then base on the distribution, dissimilarity and average value of each group, manually grouping them into 12 clusters for further interpretation.



After classifying 12 chemofacies along the horizontal well track (figure 6a), a fine grid reservoir model was constructed base on the key surfaces (the Woodford top and base). The grid and layer help better trace the certain target chemofacies than simply comparing the value in true vertical depth scale. Sequential Gaussian Simulation method is utilized to estimate the chemofacies distribution within the entire model zone (figure 6b). Each chemoface has bigger I and J direction homogeneity than k direction. Along the same bed, chemofacies reflect the heterogeneity on both vertical and horizontal directions in the unconventional reservoir.
The model also helps reconstruct a high resolution vertical profile for the neighboring well (figure 8). From the vertical profile (the rightmost column) we can have a much higher resolution profile than the one we obtain from the 20ft interval sampling. The interpretation of the chemofacies also fits the sequence stratigraphy interpretation result based on the vertical well log (figure 7).

Fig 6: (a) Chemofacies along the horizontal well. (b) Fine grid chemofacies model generated by the SGS method.

RESULTS



Facies
1 Low clay and carbonate. Deep water shale with low detrital input.
2 Detrital input dominate shallow marine.
3 Less detrital input carbonate and biogenic quartz mixture, TST preferred.
4 Deepwater low circulation deposit, mudrock and biogenic quartz dominate.
5 Shallow water, medium detrital input, HST preferred.
6 Low circulation with medium detrital input, low carbonate. TST hyperpycnal flow.
7 Deepwater deposit low carbonate, high biogenic quartz and clay. TST preferred.
8 Medium to high constrain circulation, biogenic quartz and clay dominate.
9 Biogenic quartz and few clay dominate. More likely to be brittle. HST preferred.
10 Medium water depth and medium clay input. HST preferred.
11 High circulation water, high carbonate and clay concentration, HST preferred.
12 Low detrital input, high circulation level and carbonate dominate. HST preferred.

Fig 7: (Upper)12 chemofacies (each column) and their average value of the most important proxy elements. (Lower) Interpretation related to the sequence stratigraphy and depositional environments.

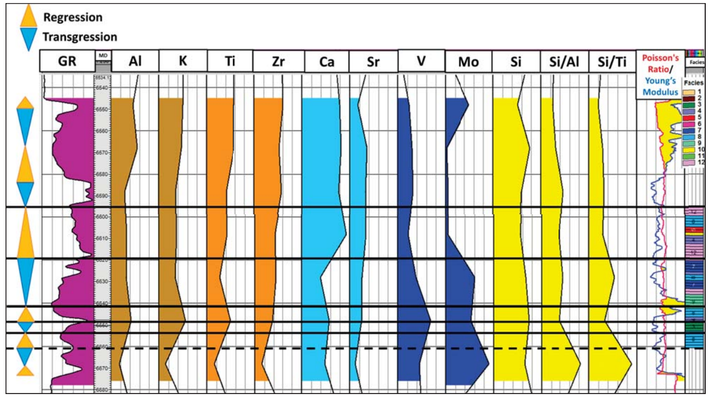


Fig 8: Chemofacies vertical profile after modeling, the interpretation of the chemofacies match the sequence stratigraphy interpretation result based on the well log and the chemofacies profile is much higher resolution than the original data from the vertical well.

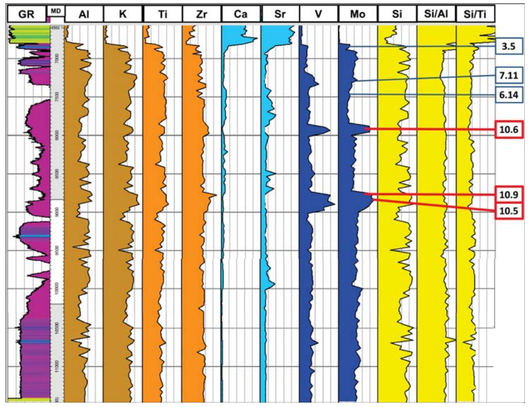


Fig 9: XRF data along the horizontal well, two abnormal high Mo and V zones are identified. And both zone are high TOC value which can be good reservoir targets.

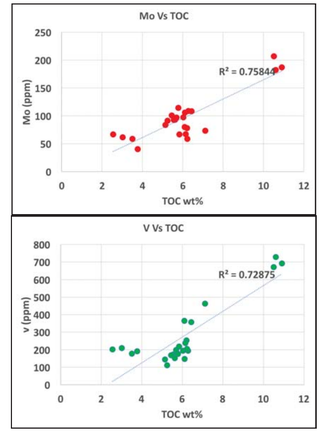


Fig 10: High correlation between Mo V and TOC value.

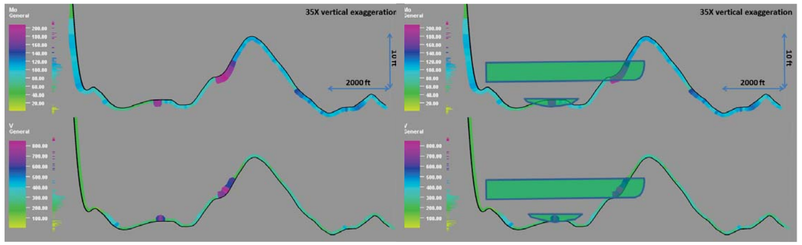


Fig 11: Two high Mo and V zones are obvious to observe, but these two zones are not GR high from the well log profile .

When analyzing the XRF data along the horizontal well, two abnormal high Mo and V zones are identified (figure 9&11), these two proxies usually stand for euxinic condition which benefits for preserving the organic matter. The RockEval data confirm this assumption, these two zones are with high TOC value up to 10.9. The RockEval data also confirm the high correlation between TOC and MO, V concentration (figure 10). The two abnormal high pockets of Mo and V are interpreted as discontinuous organic rich bedding that pinched in the middle part of the wellbore.

CONCLUSIONS

- XRF analysis is an economic tool for quick interpretation of the data along the horizontal well, since most horizontal wells have cutting samples and gamma ray log, it will help with locating the vertical section, finding organic rich zone, which can not be accurately locate by either regular cutting analysis or gamma ray log.
- Chemofacies analysis is an important tool assisting correlation the data, interpreting depositional environment, sequence stratigraphy and paleo water depth.
- Data along the horizontal well help to reveal the heterogeneity both in the horizontal direction and the vertical direction.
- Mo and V high is a quick tool to extrapolate the high TOC zone from cuttings or core samples.

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