Real-Time Advanced Mud Returns Flow Analysis Combined with Advanced Mud Gas and Elemental Analysis on Drill Cuttings Aids Fracture Detection and Interpretation in Unconventional Reservoirs: A Case Study*

Barzin Chiniwala[1], Isaac Easow[1], Alberto Martocchia[2], and Eliana Russo[2]

Search and Discovery Article #42307 (2018)**
Posted October 29, 2018

*Adapted from extended abstract based on oral presentation given at 2018 AAPG Annual Convention & Exhibition, Salt Lake City, Utah, May 20-23, 2018
**Datapages © 2018 Serial rights given by author. For all other rights contact author directly. DOI:10.1306/42307Chiniwala2018

[1]Geolog Americas Inc, Houston, Texas, United States (b.chiniwala@geolog.com)
[2]Geolog, San Giuliano Milanes, Milan, Italy

Abstract

Identifying and interpreting the presence of fractures while drilling has always been a challenge. In conventional reservoirs, open fractures could infer higher porosity, permeability and accumulation of hydrocarbons which are beneficial to higher production but also point to potential drilling hazards by possibly causing lost circulation or potential influx. In unconventional reservoirs, the presence of open fractures could enhance the effectiveness of hydraulic stimulation and hydrocarbon production. However, they could also indicate connectivity of fracture networks to potential water producing zones, along with oil or gas.

Fracture detection while drilling has been an evolving subject of discussion in recent years. Operators have been relying on conventional methodology of running downhole wireline logging tools to detect and interpret fractures to characterize the reservoir, which could be expensive, intrusive and very challenging in long lateral well bores. Fracture detection while drilling by means of surface measurement is now possible with the help of advanced flow monitoring sensors installed strategically on the drilling rig mud returns flow line. These flow sensors operate with high sensitivity and accuracy, which aid in detecting micro-losses of the drilling fluid that could be identified as open fractures, micro-fractures or permeable intervals.

By applying an interpretational model in this case study, we were able to infer three different types of fractures, occurring with different apertures and densities. This interpretation was further enhanced by correlating the real-time drilling parameter variations to lithology, advanced mud-gas analysis and X-ray fluorescence (XRF) analysis on drill cuttings in near real-time. The results of this integrated analysis acquired while drilling, showed good correlation with the interpreted fractures from open-hole image logs.

This case study explains the details of the integrated analysis and the relationships observed between various data sets collected while drilling. A localized interpretation model can be generated which could be utilized for reservoir characterization and completions optimization. The objective of this technique is to obtain a fracture analysis data set at a fraction of the typical well cost.

Introduction

In the west and north Oklahoma Anadarko Basin (Figure 1), Mississippian strata have traditionally been separated into four units, in ascending order, termed Kinderhookian, Osagean, Meramecian, and Chesterian, based on lithologic and electric log characteristics of rock sections in wells (Jordan, 1959). The Osage and Meramec (Figure 2) have been the focus within the Anadarko Basin for the evaluation of the Mississippian strata for potential hydrocarbon accumulations. The detection of fracture systems and porous/permeable zones within these formations is crucial for optimizing completions and determining the hydraulic fracturing efficiency.

As stated by K. S. Johnson et al. (2000), Mississippian carbonates have varied depositional and diagenetic histories that have led to reservoir development and hydrocarbon entrapment; diagenesis of the Osage rocks, fracturing of Meramec limestones, and deposition of Chester bioclastic packstones, wackestones, and oolitic grainstones are typical examples. The Meramec Formation was deposited in a shallow shelf environment in Oklahoma, and is characterized by a prevalent oolitic and quartz-sandy carbonates with minor detrital material deposited locally during the mid-Meramecian regression. Mississippian reservoirs of the Midcontinent are primarily chert-rich Osagean and Meramecian carbonate strata below the basal Pennsylvanian unconformity. These units have been prolific oil and gas producers in north central Oklahoma and southern Kansas (Watney et al., 2001). Over 278 million bbl. of oil and 2.4 TCF of gas in Kansas (Watney et al., 2001), and 105 million bbl. of oil and 1 TCF of gas in Oklahoma (Rogers, 2001) have been produced. There are conventional and unconventional targets within the Mississippian section. The unconventional reservoirs produce from less porous autoclastic chert and fractured lime mudstone (Rottmann, 2011).

The top of the “Osage” is commonly picked at the top of the first carbonate (high-resistivity) sequence below the “Meramec” siltstone/shale. The Osagean interval is almost 500 feet thick in Dewey County and thins southeastward to less than 50 feet thick in eastern Blaine County, to less than 10 feet in Kingfisher County (Figure 2). This cherty carbonate section is distinctive and correlatable across much of the northern Anadarko Basin shelf. The Osagean section can be divided into lower and upper intervals with similar lithologies. The lower interval is mostly cherty, occasionally dolomitic and sometimes capped by limestone. The upper interval shallows upward from siliceous, cherty, to calci-sponge dominated limestone sometimes capped by grainstone or packstone. It is common to encounter tectonically fractured zones as identified in cores and image logs. Some of the best producing wells are in the moderately to highly fractured cherty zones, at the base of the upper and the lower Osagean section.

Interpretation Methodology

Using advanced flow meters (Figure 3) with Electromagnetic technology for water based mud or Coriolis technology for oil based mud, provides accurate data sets for advanced flow analysis while drilling. The meter installation design is critical and needs to be adapted to the rig configuration in order to gather accurate data suitable for the interpretation. The difference in volume of the drilling fluid pumped versus the returns, also referred to as ‘Delta Flow’, is monitored for formation fracture identification and further analysis. Fractures encountered while drilling provides an instantaneous signature at the surface by means of changes in the returns of mud-flow readings when drilling in over-balanced conditions. The appropriately installed, highly sensitive meters detect micro-variations of the flow-out readings on surface in real-time.

Flow analysis is performed using the real-time flow-out data to identify the fracture patterns in the drilled formation. An interpretational model based on the “fingerprint” of the Delta Flow has been used (Figure 4). This interpretation model has been previously published by Alvarez et al. (2015).

1) In the case of a ‘Natural Open Fracture’, the mud invades the fracture and a sudden decrease of Delta Flow volume is recorded on surface by the flow-out sensor; the solid particles of the mud gradually plug the fracture and delta flow return to the base line.

2) On the contrary, a hydraulically ‘Induced Fracture’ by the action of the bit / bottom hole assembly (BHA) shows a reduction in Delta Flow volume when the fracture is generated and the fluid invades, with an immediate recovery of the invaded fluid.

3) The response of the Delta Flow in case of ‘Micro-Fractures’ zone or ‘Matrix Permeability’ shows a gradual decrease in delta flow volume due to the invasion of the mud into the pores or micro-fractures, until it reaches the end of the permeable zone.

4) In a large aperture/cavernous zones, the mud losses occur suddenly at high-rates, with no return to surface.

The interpretation of the events is not exclusively based on the analysis of the delta flow but also considers a set of drilling parameters such as Stand Pipe Pressure (SPP), Torque (TRQ), Weight on Bit (WOB), and Rotations per Minute (RPM) of the drill string to eliminate the flow variations caused by surface drilling parameters.

Figure 5 and Figure 6 show examples of fractures detection that uses the advanced flow analysis technique to highlight the characteristic shape of the delta flow. The advanced flow analysis results are integrated with formation hydrocarbon gas acquired while drilling, extracted from the drilling fluid under constant volume, temperature and mud flow conditions, and analysed with a proprietary advanced gas analyser capable of detecting hydrocarbons from C1 up to C8. The gas is extracted from drilling fluid flowing out of the well arriving at the shale shaker, representing the ‘Gas Out’ or liberated gas, as well as in the mud pits before the drilling fluid is pumped back into the well, representing the ‘Gas In’ or ‘mud-background recycled gas’ from the well. The difference between Gas Out and Gas In helps us to eliminate the re-cycled hydrocarbons and derive the actual quantity of formation gas per depth. The hydrocarbon readings are then normalised against ROP and synchronized with bit position, before being plotted with real-time flow-out readings. The correlation between the flow out and formation hydrocarbon gas helps to register any changes in hydrocarbon quantity associated with fractures, if present.

Further information is derived from on-site geochemical lab analysis, where geochemical composition of cuttings was measured using X-ray fluorescence (XRF) equipment. Elemental analysis from XRF on cuttings aid to ascertain major elements from the rock sample, which, depending on the geological settings, can be used as markers to help determine existing relationship with fractures.

Fractured reservoirs all over the world have varying uncertainties. Oil companies gather data from different sources and integrate them together to improve reservoir characterization. Advanced Flow Analysis while drilling, provides an additional data set for fracture identification and characterization of the reservoir.

For this project, the operator chose to run a full suite of open-hole wireline petrophysical logs. Data from the wireline image and neutron porosity logs were plotted along with Delta Flow measurements, advanced formation gas readings and XRF analysis from drill cuttings. It should be noted that the surface data measurements recorded while drilling are dynamic compared to acquisition methodology of the image logs which are run after drilling, in a static well environment. Depending on the type of reservoir drilled, the results are likely to vary, as both these techniques are meant to have different applications and outputs. Integrating the analysis and interpretation with fracture detection, formation gas and geochemical composition from XRF, provide an additional data set to improve the source rock characterization and the completion program.

Field Application

The fracture detection service was deployed for the first time to log and evaluate the tight rock targets within the Anadarko Basin. The case-studies focus on two wells which were drilled using Advanced Flow Analysis along-side advanced mud gas and geochemical logging. Surface logging data were acquired in real-time and recorded on-site while drilling. The fracture detection was performed in quasi real-time and synchronized and integrated with the advanced mud-gas analysis and the elemental analysis on drilled cuttings. A suite of wireline (WL) logs containing image logs, neutron magnetic resonance (NMR) porosity and neutron-density were run in the open hole to acquire petrophysical properties of the target formation. As a part of the post drill analysis, wireline data was shared by the operator to perform an integrated petrophysical and geochemical evaluation to characterize the reservoir.

A composite log integrating data sets coming from multiple sources was plotted to enhance the evaluation.

Case I - Well A

The first case study refers to a ~5000 feet lateral Well A, drilled with an 8¾” bit through the reservoir section in the Anadarko Basin. The main lithology of this section is tight limestones (carbonates) with intermediate cherty and dolomitic bands with occasional traces of silty sandstone. Using the Delta Flow the interpretational model, different types of fractures are detected and displayed using ‘red’ color flags for natural open fractures and ‘green’ color flags for matrix permeability zones on a depth-based log. An integrated approach has been adopted combining:

1) Surface logging data.

2) Advanced formation gas (C1-C8, delta gas).

3) Fracture detection from Advanced Flow data.

4) Elemental data on drilled cuttings, where Strontium (Sr) and Magnesium (Mg) were picked as proxy elements to study the structural and lithologic heterogeneity.

5) Conductive and Resistive fractures interpreted using WL image log data, NMR porosity, resistivity and gamma ray data.

In Figure 8 the blue bands in the lithology column refer to limestone and the white bands indicate cherty layers along with traces greenish-blue silty sandstone layers. The integrated data set shows open fractures (red) and micro-fractures zones (green) using flow detection on surface (track 11), conductive and resistive fractures from image log (tracks 10, 13), C_1-C_8 Gas vs. ROP (track 6), XRF Sr, Mg, Pb (Lead) (tracks 8, 9, 12) and Porosity from wireline (track 7). Open fracture flags are plotted with a density increment from left to right of track 11, on a scale of 1 to 5, at a given depth interval.

Open Fractures interpreted through surface logging are correlated with conductive fractures interpreted through open-hole wireline log; Matrix permeability/micro-fractures zones are correlated with the NMR porosity log. The intervals with higher Mg (Track 9) content indicates an increase in dolomitization and correlates with matrix permeability zones detected by Advanced Flow analysis. High Sr content in carbonate sequences can be considered a proxy of hydrothermal fluids circulation, therefore an increase in open fractures density and conductive fractures is observed together with the reduction in Sr content.

The Figure 9 showcases an example, where total losses were detected at 10,100 feet in real-time from the advanced flow meters, which correlate with low resistivity readings due to mud invasion and validated by large aperture fractures interpreted by image log. The operator also correlated it with the sonic log which confirmed the presence of a large aperture fracture with a propagation of 110 feet from the borehole.

Case II - Well B

Figure 10 illustrates an integrated data set of open fractures (red flag track 12) and matrix permeability zones (green flag track 12), conductive and resistive fractures (tracks 10, 11), C1-C7 advanced gas data and TGAS vs. ROP (tracks 6, 7), Silica (Si), Zirconium (Zr), Sulphur (S) and Strontium (Sr) (tracks 5, 9, 10, 11) and Porosity (track 8).

The matrix permeability zone has a direct correlation with gas analysis, NMR porosity, the elemental content of Zr and S, and inverse correlation with Sr due to the dolomitization process. Increasing density of open fractures correlate with detection of conductive fractures from WL image logs. The WL resistive fractures match with the increase of Sr content (picked as a limestone proxy), which confirms the presence of carbonate cement healing the fractures.

Conclusion

The Advanced Flow Analysis technique is the only method to identify fractures while drilling. This article demonstrates that by accurately monitoring the micro-losses associated with the presence of fractures in the open hole, it is possible to provide valuable data to identify and characterize the reservoir. A local interpretational model can be used for reservoir characterization and potentially completion optimization. Whenever wireline logs are not available or their results are affected by a high degree of uncertainty, mainly because of difficult borehole conditions, fractures identification done by advanced flow analysis becomes an integral solution to better understand a naturally fractured reservoir and unconventional players.

Additional benefits of utilizing this technique are:

- Early kick/loss detection using advanced flow meters improve safety at the wellsite.
- Reservoir damage due to drilling fluid invasion can be promptly detected and consequently reduced by drilling fluid conditioning while drilling.
- Being a surface solution, there are no risks related to downhole tools.

Acknowledgements

Geolog would like to thank the operator, who would like to remain anonymous, for giving permission to use their data for this study.

References Cited

Al-Adwani, T., S. Singh, B. Khan, J. Dashti, A. Martocchia, G. Ferroni, and J. Estarabadi, 2012, Real time advanced flow analysis for detection of open fractures: EAGE Annual Conference & Exhibition incorporating SPE Europec, Copenhagen, Denmark, June 4-7.

Alvarez, S.F., and G.V. Cazuriaga, O.C. Mealla, and A. Martocchia, 2015, Evaluation of a fractured tight reservoir in real-time: The importance of detecting open fractures while drilling with accurate mud flow measurement: AAPG Annual Convention & Exhibition, Denver, Colorado, May 31-June 3, AAPG Search and Discovery Article #41632 (2015). Website accessed October 19, 2018.

Beda, C.E., 2001, Use of mud microloss analysis while drilling to improve the formation evaluation in fractured reservoir: SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, September 30 - October 3.

Cordova, J., and S. Fontenla, 2013, Geological modeling for naturally fractured reservoirs in a fold and thrust belt: An example from Margarita Field, Bolivia: E&P Technical Congress, Madrid, Spain, December 9-11.

Druckmann, C.H., 1981, Burial diagenesis and porosity evaluation, Upper Jurassic Smackover, Arkansas and Louisiana: AAPG Bulletin, v. 65, p. 597-628.

Pozzi, A., I. Easow, and M. Ruggiero, 2017, Wellsite chemostratigraphy in the petroleum province of Anadarko Basin: How thermal pulses, deposition and diagenesis influence hydrocarbon accumulation: URTeC Conference, Austin, Texas, July 24-26.

Sanfilippo, M.B., 1997, Characterization of conductive fractures while drilling: SPE European Formation Damage Conference, The Hague, The Netherlands, June 2-3.

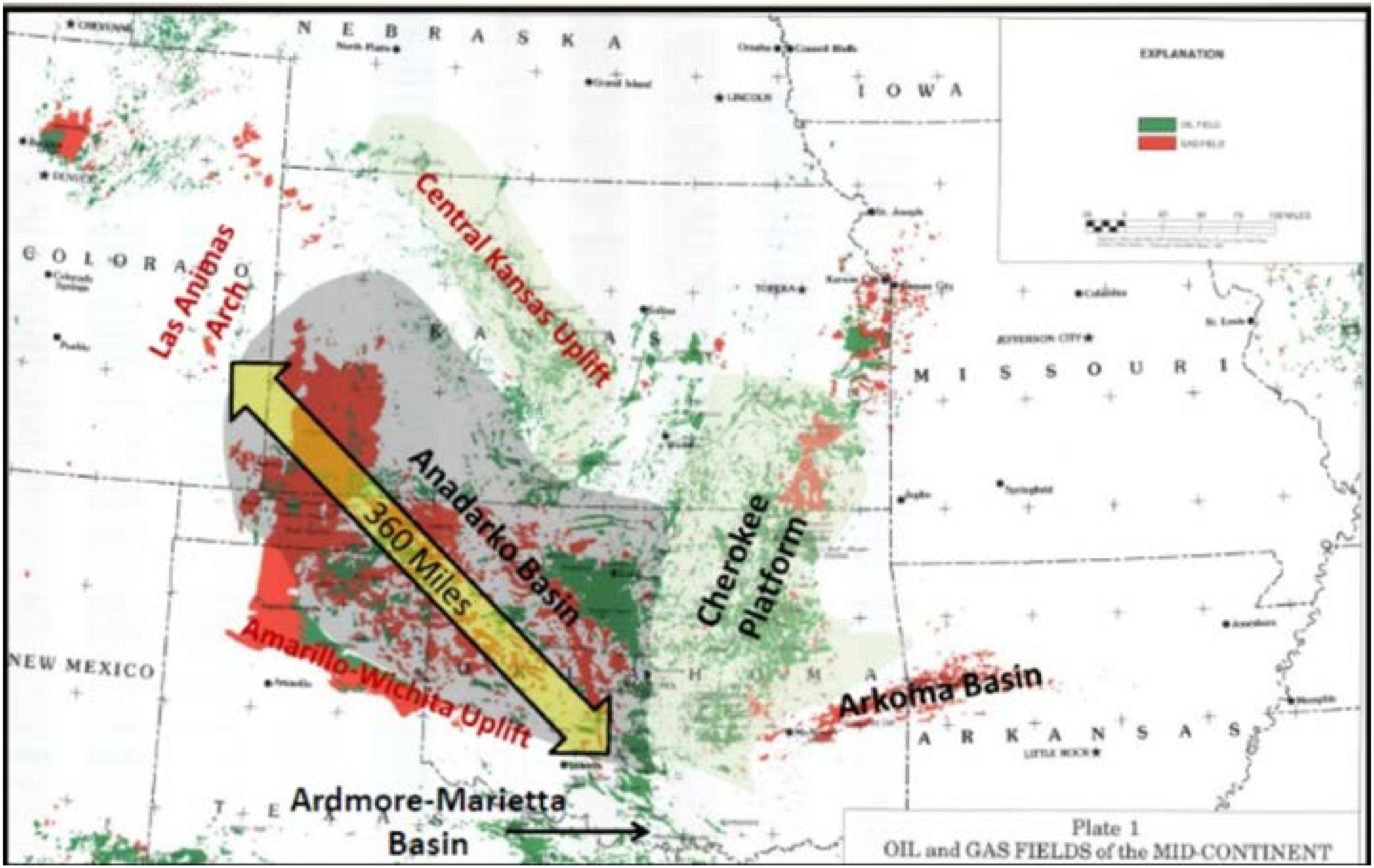

Figure 1. Map showing location of the Anadarko Basin.

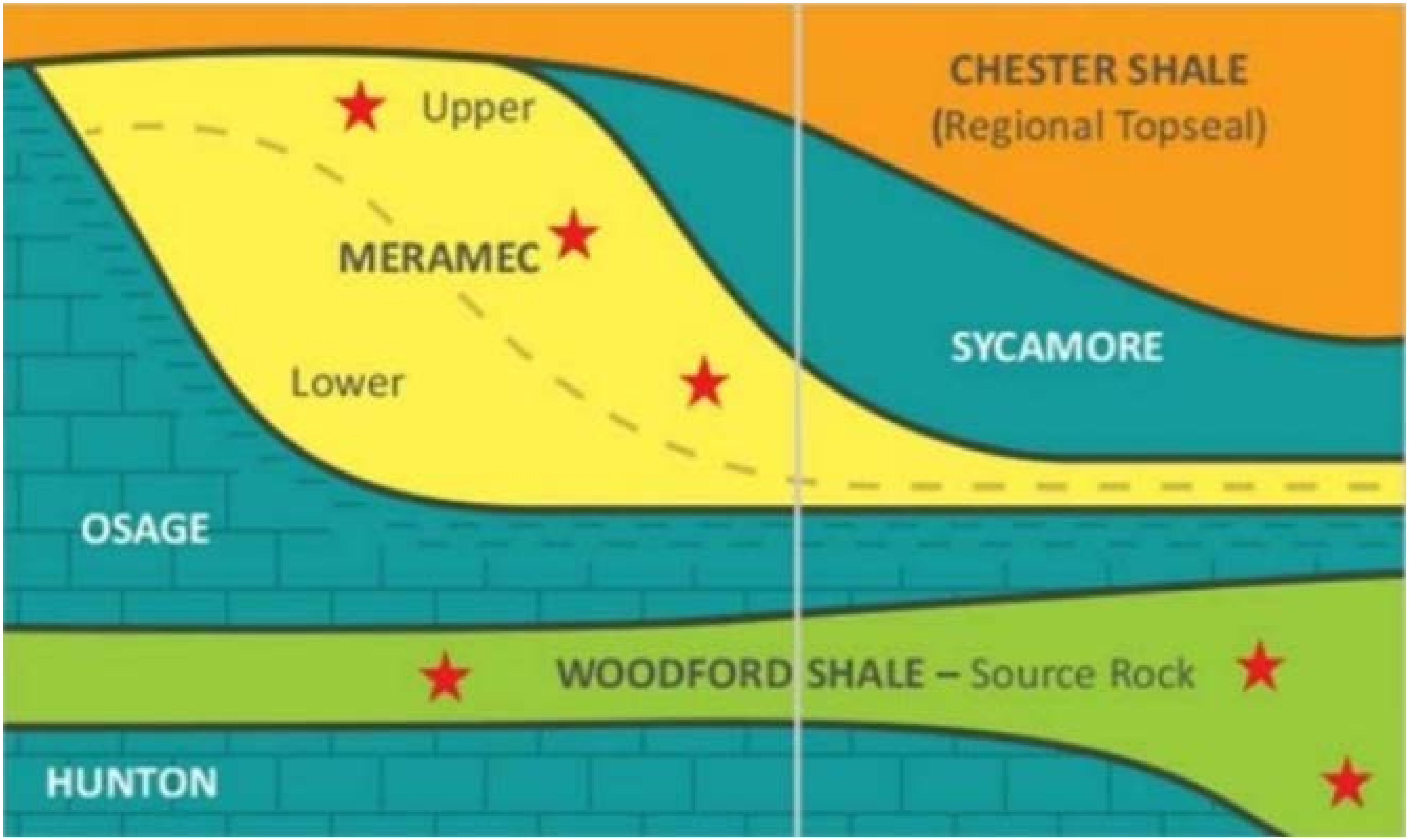

Figure 2. Stratigraphic section showing Osage and Meramec strata north to south across the Anadarko Basin.

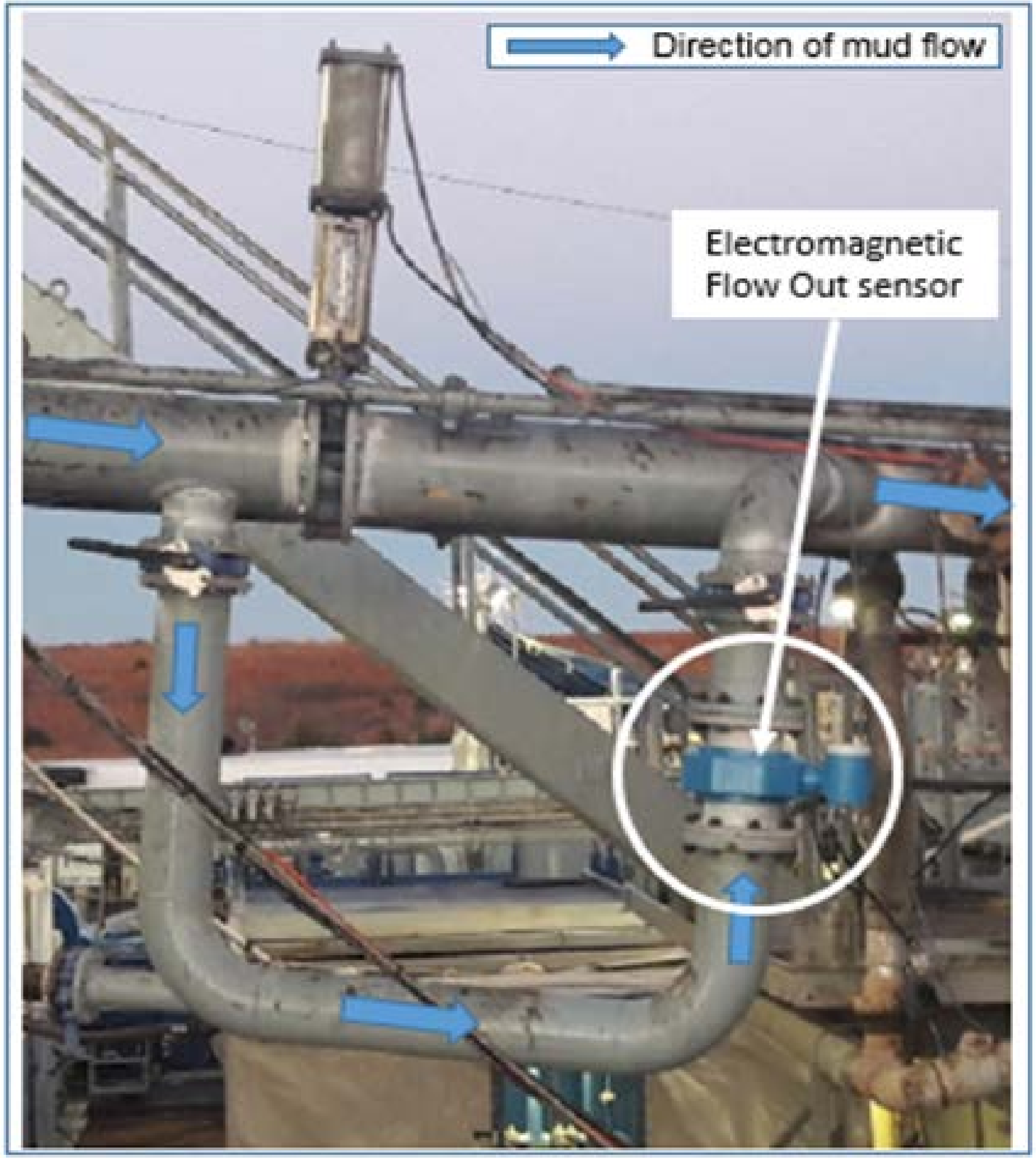

Figure 3. Electromagnetic Flow Out sensor installation, in a bypass line.

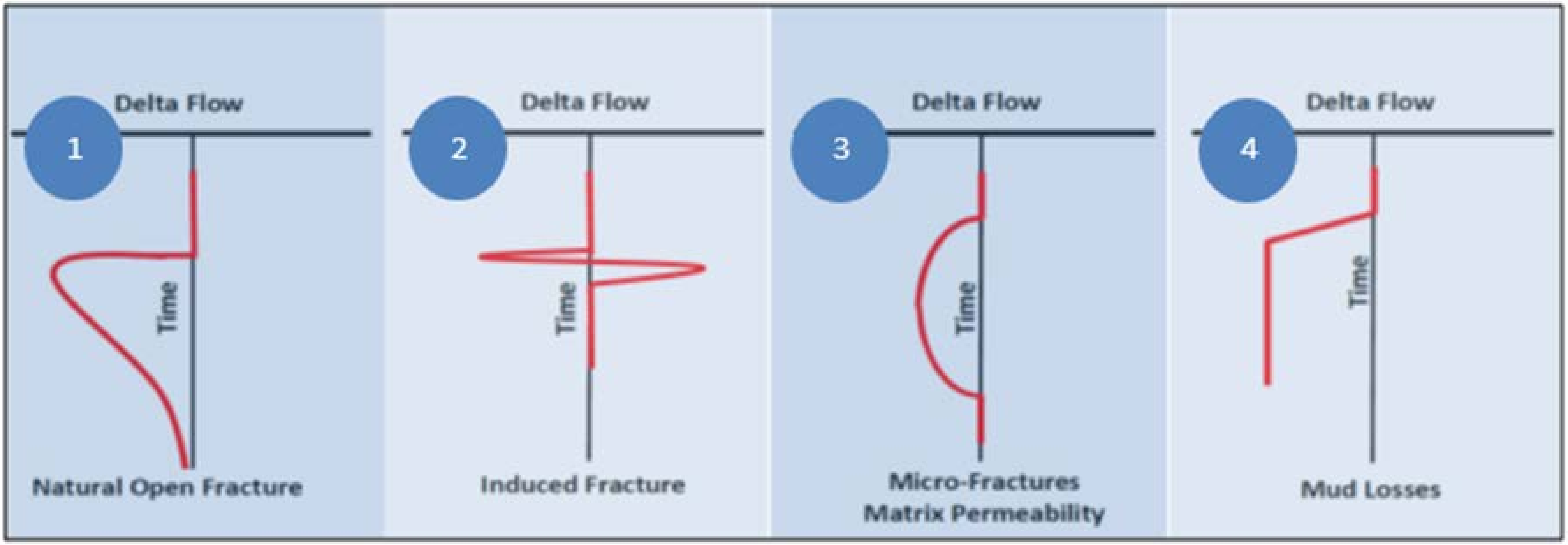

Figure 4. Characterization of Delta Flow trends to corresponding downhole fracture events.

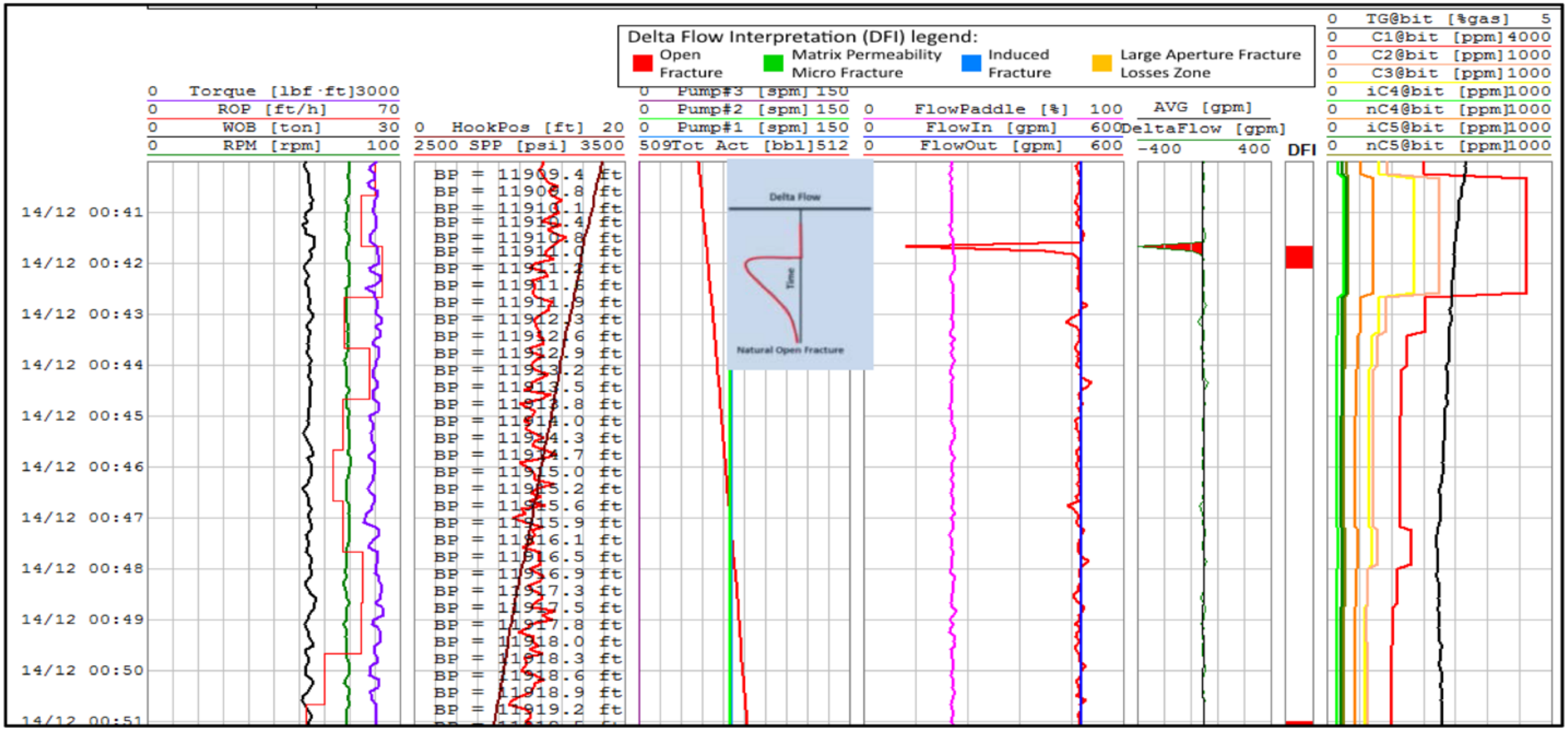

Figure 5. Natural open fracture detected by Advanced Flow Monitoring.

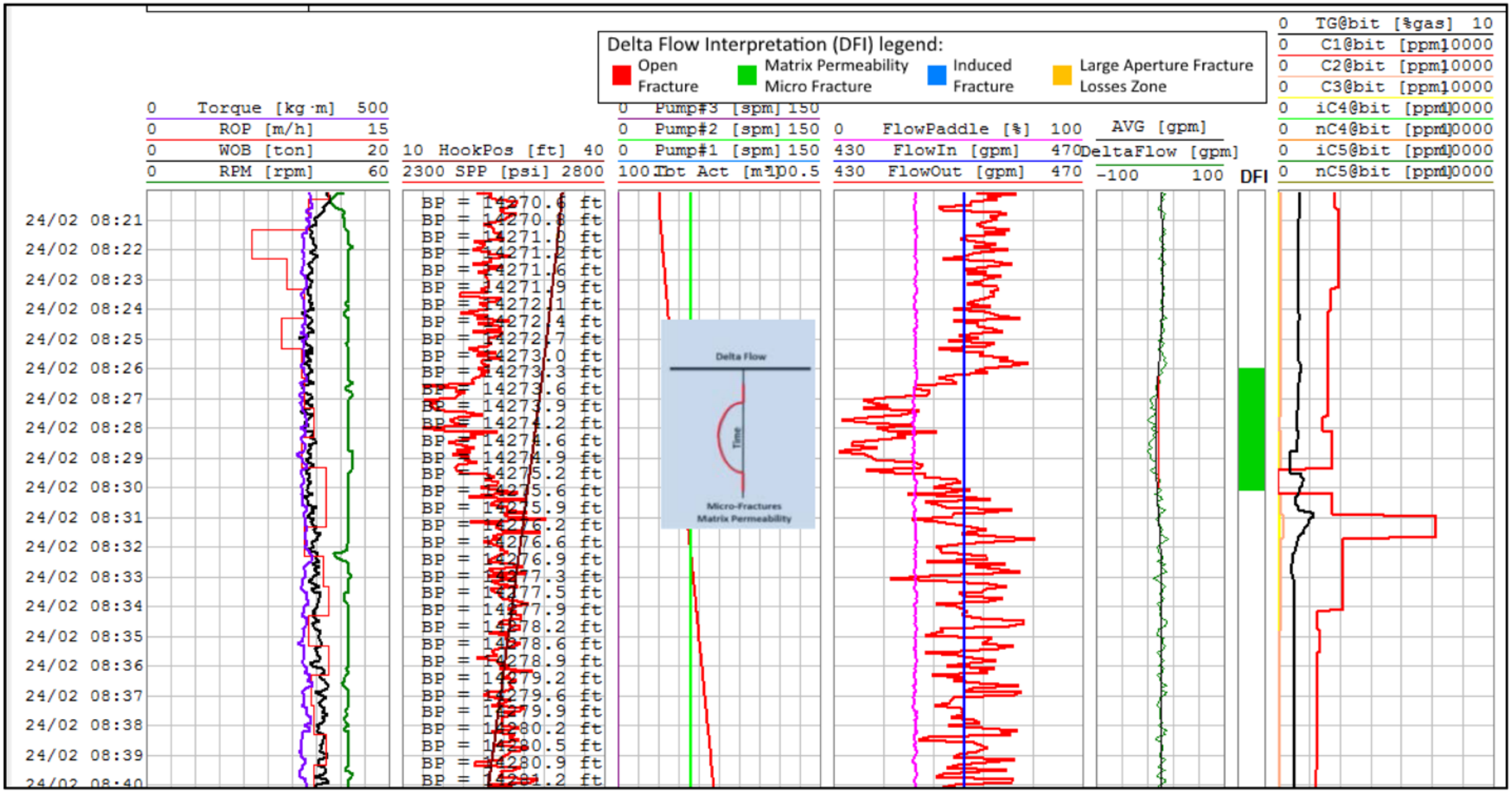

Figure 6. Micro-fractured zone/matrix permeability detected by Advanced Flow Monitoring.

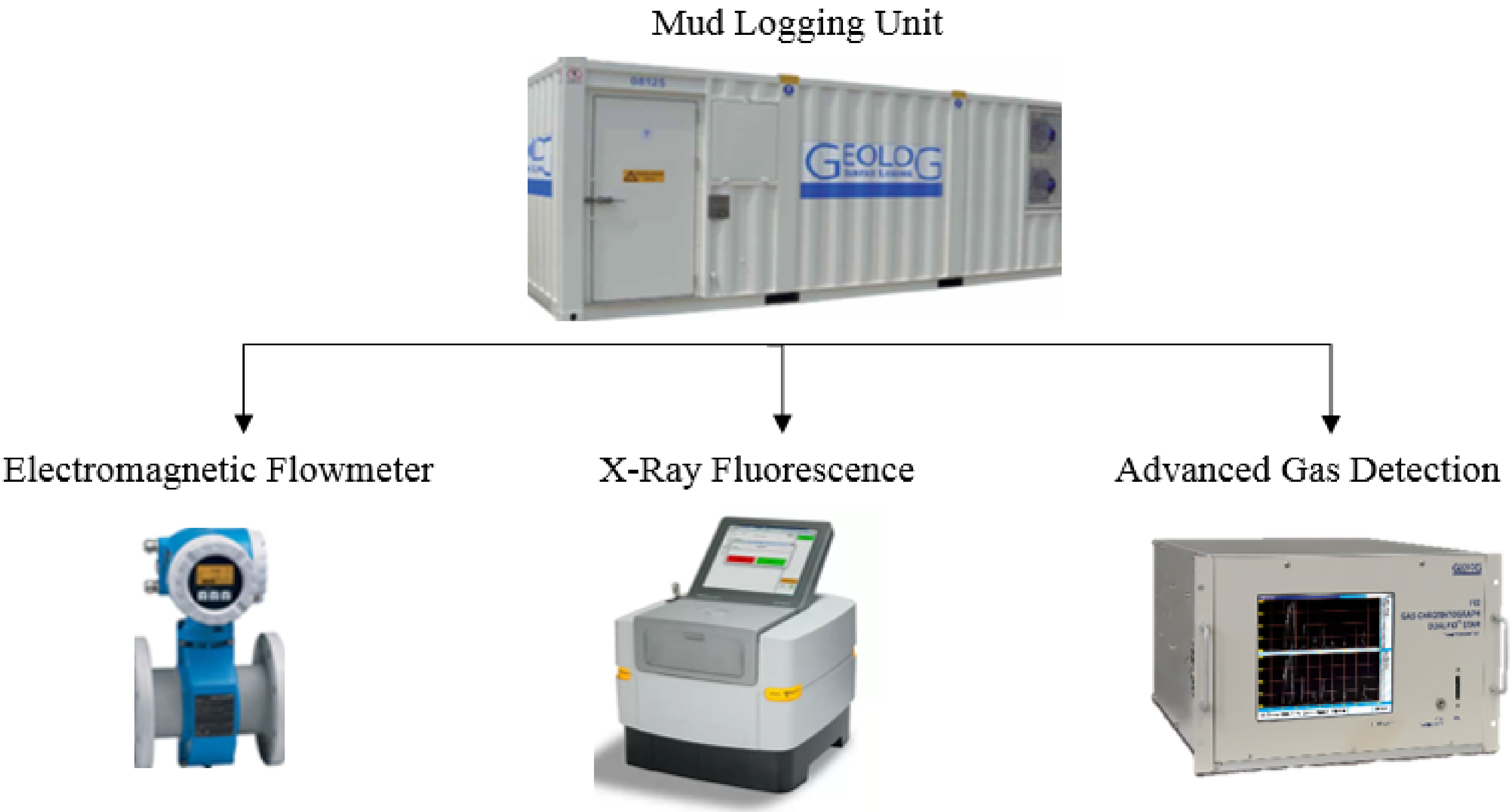

Figure 7. Mobile Surface Logging Unit deployed with Advanced Logging Services at well site. (Below) An onsite geochemical laboratory with X-ray fluorescence and formation gas analysis equipment.

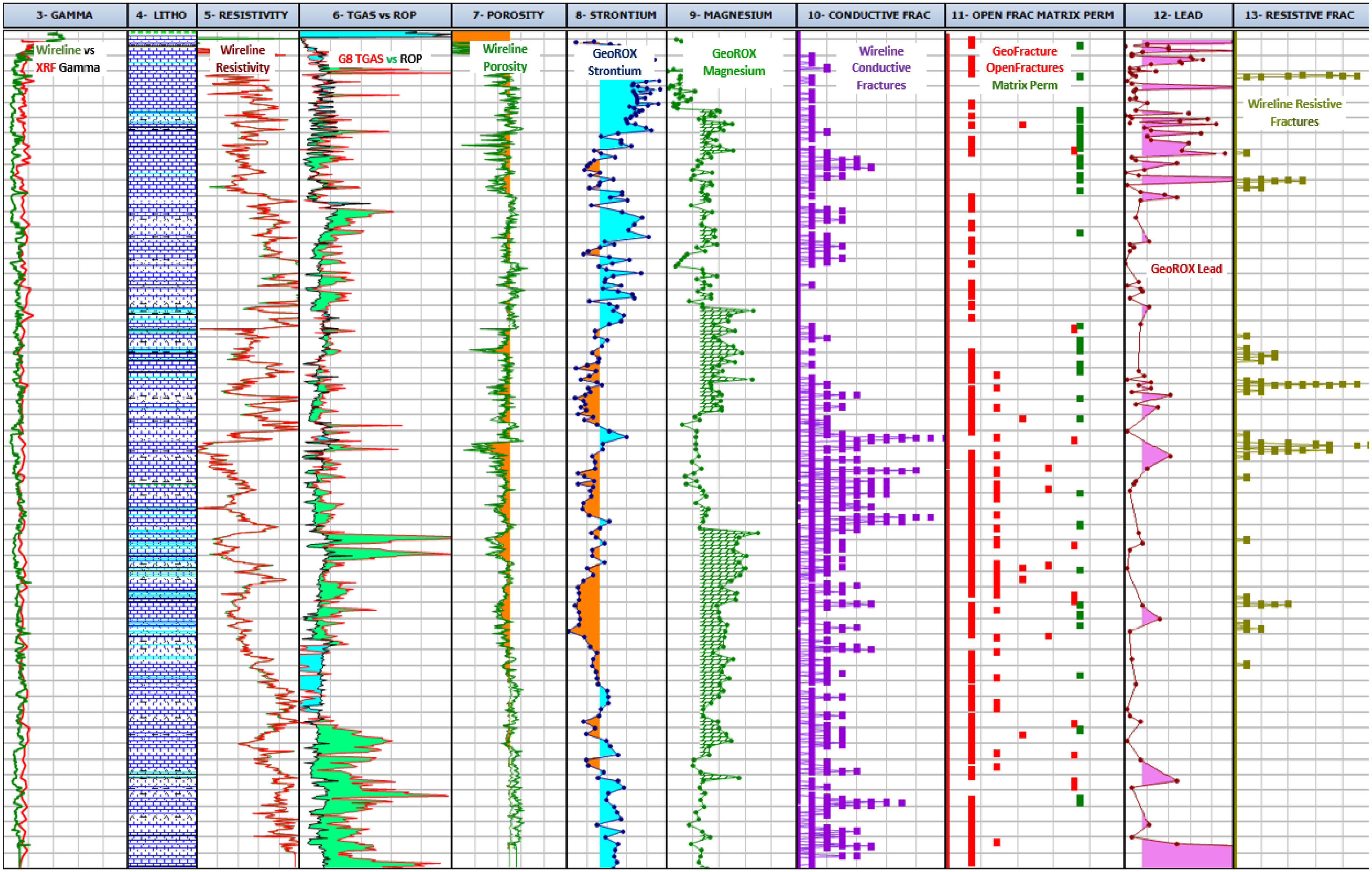

Figure 8. Integrated data set for Well A (5000 feet in lateral section).

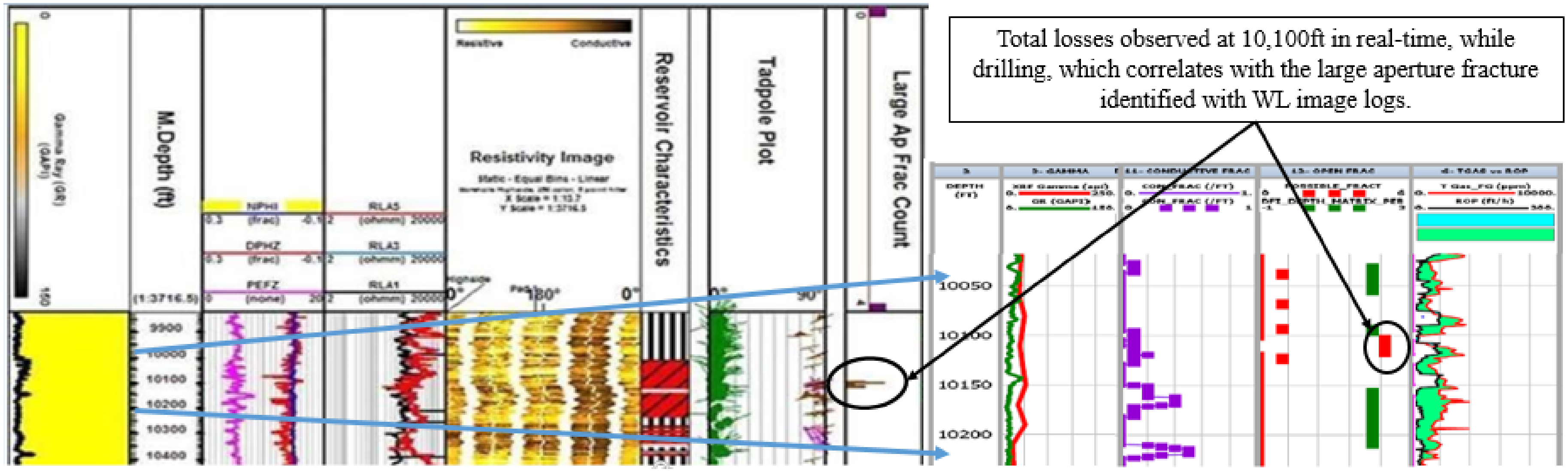

Figure 9. Example of an event detected in Well A with total losses observed while drilling using advanced flow sensor and confirmed with a large aperture fracture interpreted with Image Logs.

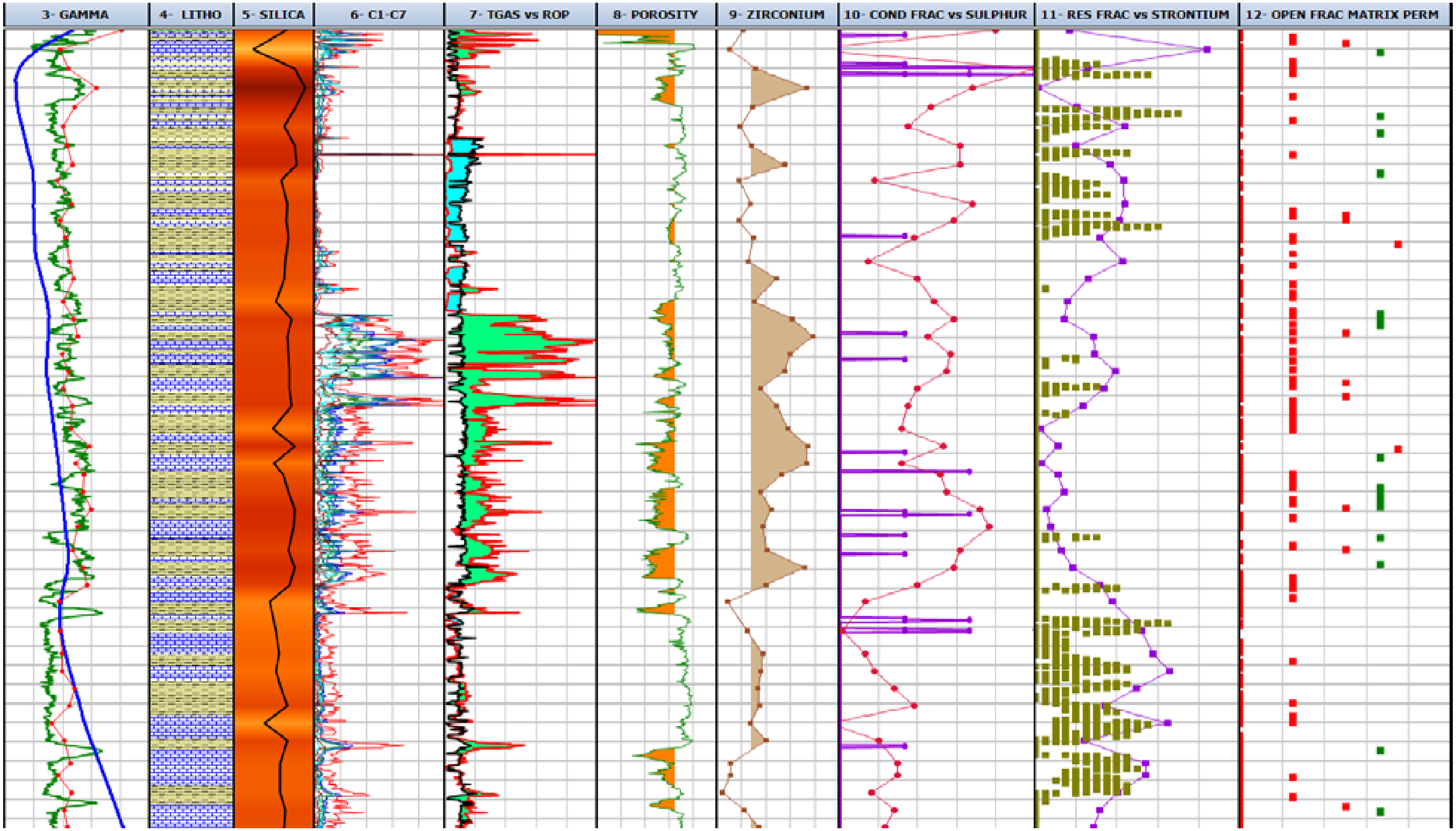

Figure 10. Integrated data set for Well B (5700 feet in lateral section).