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Real-time Alkene Detection and XRF while drilling to monitor the efficiency of PDC Drill Bits in US Land Tight Rocks: A Case Study.

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Abstract

Drilling optimally in organic tight rocks has been a challenge as even modern designs of polycrystalline diamond compact (PDC) bits can be susceptible to premature wear resulting in unexpected decline in ROP (Rate of Penetration) in abrasive formations. However, reduction in ROP may not only be related to bit wear, but could also be due to lithological factors; it is important to know in real-time which causal factors predominate, to determine the most effective way to optimize drilling.

Real-time detection of alkenes – gases generated from the thermal breakdown of drilling fluid due to high at-bit temperatures resulting from the friction of a worn bit with abrasive rock - has been proven to be extremely valuable in tracking bit performance. As drilling inefficiency increases with deteriorating bit condition, the quantity of alkenes generated also increases, typically accompanied by reduced reactive torque and consequent loss of ROP.

However, although alkene presence is diagnostic of worn PDC bit, it is not diagnostic of the *cause* of wear. Subtle changes in lithology composition can be quantitatively tracked at the rig-site by analyzing drill cuttings using real-time elemental analysis with XRF (X-Ray Fluorescence) measurements; this technique also aids in optimal well placement by proactive geosteering within known problematic formations.

This paper will illustrate how the holistic approach of alkenes detection and XRF, in conjunction with drilling parameters, provides complimentary solution to real-time analysis of the cause *and* effect of worn bits, enabling both improved drilling efficiency and commercially-timely decisions for POOH, thereby mitigating invisible lost time (ILT).

Introduction

Predicting and monitoring premature bit wear is one of the biggest challenges faced by the drilling community. Drill bit selection is one of the toughest decisions taken by the drilling engineer as an inappropriate bit can produce disappointing results and can put the drilling schedule in jeopardy. Conversely, appropriate bit selection can play a big role in the positive outcome of the drilling program and reducing ILT (Invisible Lost Time) due to low ROP and so saving money. Irrespective of the bit selected, the chances of encountering an unexpected lithology can be fairly likely, especially while drilling long laterals, which makes drilling performance unpredictable.

There are many aspects of drilling parameters which have to be considered and analyzed before the bit selection process is completed. Often the bit can be over run, resulting in excessive damage beyond repair (DBR) or continuing to drill with a dull bit, consequently resulting in ILT (invisible lost time) while drilling. Conventional ways to assess the drilling efficiency include comparing the actual performance statistics of offset bit run data, completed in the same drilling environment. Other process also involves monitoring Mechanical Specific Energy (MSE) at the drill floor, which may need to be further complemented with data acquired from expensive down-hole data from logging while drilling (LWD) which can then be compared with the field offsets. Nevertheless, progress towards recognizing early bit wear which would aid in objective decision-making driving timely trip out of hole and subsequently resulting in savings, has been minimal.

Intermittent abrasive rock lithologies, as are found in wells drilled in the Delaware basin, West Texas and Anadarko basin, and Oklahoma areas, are found to be very tough to drill. These rocks prematurely dull the bit cutters and are directly responsible for slowing down the rate of penetration (ROP). The toughness of the rock is likely to make the bit work harder and increase the at-bit temperature during this interaction. In case of PDC drill bits, the cutters start to naturally deteriorate and get worn, in-turn increasing the rotational friction contact area (‘wear-flat’) at the contact points. These wear-flats generate considerable friction when they come in contact with formation and consequently, extreme heat at the bit-face of close to 1450°F (800°C).

This extreme heat thermally cracks the hydrocarbon content in the oil based mud (OBM) or synthetic based drilling fluids or even hydrocarbon based additive in the water based mud (WBM) as they pass through the high temperature and high pressure environment. Cracking is a process by which heavy hydrocarbon molecules are broken down in to lighter molecules by means of heat. The thermal cracking of the drilling fluids generates alkenes gases in sufficient quantities that can be measured on arrival at surface, via specially designed surface logging gas chromatograph.

Oil–based drilling fluid are often based on diesel. An example of a typical complex alkane found in diesel breaking down under thermal cracking is illustrated below:

$$C_{15}H_{32} \rightarrow 2C_2H_4 + C_3H_6 + C_8H_{18}$$

Simple alkenes such as ethylene C_2H_4 and propylene C_3H_6 rarely originate from natural degradation of formation hydrocarbons. Hence, the presence of alkenes is directly related to the proportion of thermal cracking taking place primarily at-bit or potentially at any other high-friction interaction along the drill-string such as stabilizers, giving rise to a phenomenon often referred to as 'drill bit metamorphism'. By tracking the amount of alkenes generated, the operator can qualitatively infer a degree of wear of the bit in real-time and so, by managing drilling parameters, maximize the useful life of the bit, potentially prolonging the bit run.

Technique

By having the ability to track and monitor the trends of the alkenes generated, one has an indication of the condition of the drill bit down-hole. To achieve this, standard mud logging equipment is used to extract gas samples using continuous mud flow at constant volume from the shale shakers. (Ref. Fig.01.) The extracted gas is then sent to a dedicated alkenes analyzer located inside the surface logging unit onsite. In standard drilling operations, artificially-generated alkenes are considered as contaminant as they affect the measurement and analysis of naturally-occurring formation gas. Chromatographic response of alkene peaks appear very close to those of natural alkanes, potentially skewing the outcome of alkane analysis.

Fig.01. Advanced gas extraction and gas chain distribution system.

A specially designed chromatograph with the ability to quantify alkenes is installed in parallel to the standard gas chromatograph, to overcome this challenge. Ref. Fig.02.

Fig.02. Alkenes Analyzer.

The chromatograph contains modified columns that allow full separation of the alkenes from the alkanes; the molecules are detected by a FID (Flame Ionization Detector). The limit of detection for the ethene is 5 ppm. As shown in Ref. Fig 03, the alkenes peak elutes slightly earlier compared to the alkanes peaks. A complete cycle of methane to propane is conducted every 240secs, allowing real-time tracking of the gas component and subsequent correlation with drilling parameters.

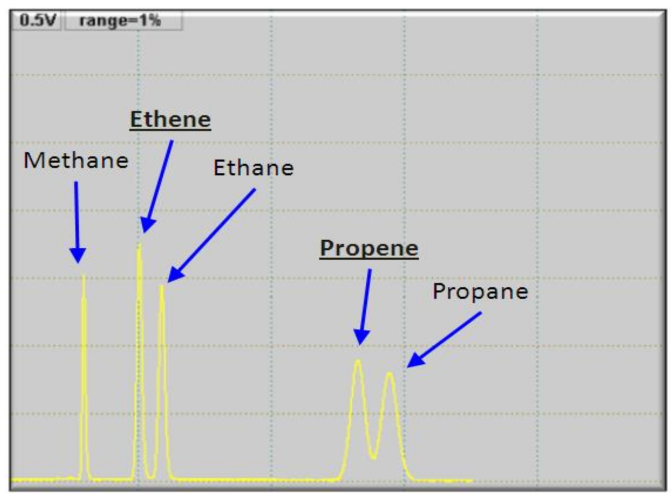

Fig.03. Alkenes chromatographic distribution

In parallel to bit wear monitoring, unconventional reservoir analyses can be optimized by gathering precise information on its rock properties. The analytical breakdown of rock composition aid in identifying the properties of brittle intervals of the formation to optimize hydraulic stimulation. The content of quartz and calcite, in addition to minerology, petrophysics and rock mechanics, govern the brittleness property in shale formations. X-Ray Fluorescence (XRF) technique is used to analyze the rock properties in drill cuttings. (Ref. Fig.04.) High precision bench-top instruments were utilized on-site to generate XRF logs displaying mineralogical composition of drilled cuttings. The cuttings analysis identified calcium and silica to be the two major elements which can be considered as proxies aiding to geo-steer in the most suitable layers of the formation.

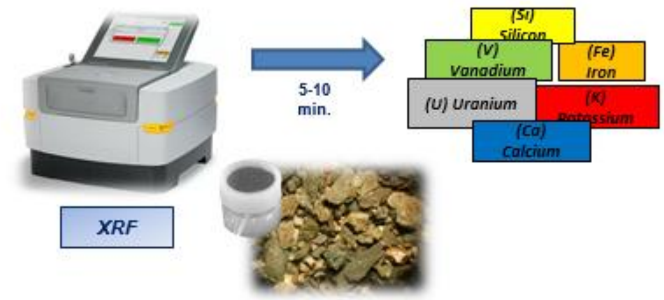

Fig.04. High precision X-Ray Fluorescence technique used on-site to track the elemental composition of the drilled cuttings.

After the synchronization of all the mud-gas and cuttings data, a composite log is generated consisting of the drilling parameters including ROP, RPM (rotations per minute), torque and WOB (weight on bit), and cuttings lithological column. The lithological information is derived from examination of drill cuttings under the field microscope. XRF analysis complements the cuttings descriptions and aids in confirming any heterogeneity in the mineral content of the drill cuttings, which would be under evaluated with a typical field microscopic examination.

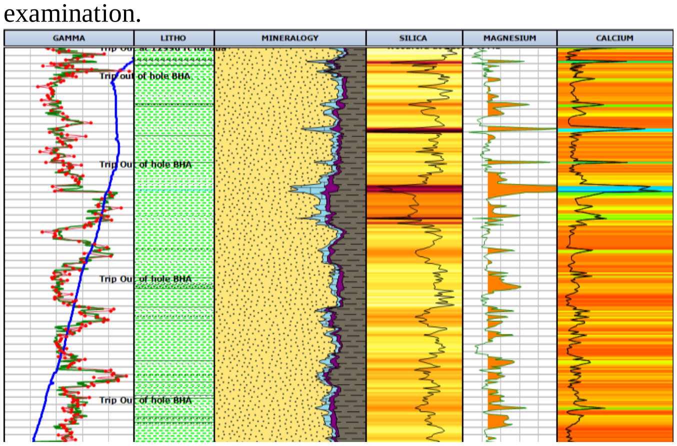

Fig.05: Example of a typical XRF log which is generated using the results of the drill cuttings analysis on-site in near real-time.

The first sign of bit wear comes from the advent of alkenes mixed with the liberated gas while drilling, resulting from the inefficient drilling and potentially dysfunctional bit behavior and consequent reduction in ROP. The outcome is primarily dependent on the type of lithology and so the chemical composition of the rock types drilled. The presence of silica, for example, in the form of chert or arenaceous lithology such as sandstone, is primarily responsible for the abrasive nature of the rock. With timely recognition of changes to the rock properties complemented with real-time alkenes detection, the drilling parameters can be altered to efficiently negotiate the progress and avoid premature bit wear.

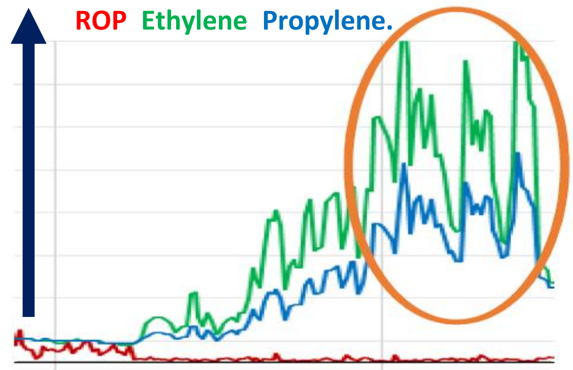

Fig.06. Illustration of alkenes detection in real-time and the corresponding reduction in the ROP curve.

This work-flow is developed on the rig-site to overcome the following challenges:

1. To be able to optimise the bit run and then aid in making an informed and objective decision about when could be the right time to change the drill bit, based on operational and economic circumstances
2. Utilize the real-time information to optimize drilling parameters as well as geo-steering towards preferred rock formation layers within the target zone that would facilitate better drilling. This could help prolong the life of the drill bit and avoid any premature wear as well as aid in correct well placement in a tight unconventional reservoir.
3. Worn out bits can leave behind junk in the hole such as broken or displaced cutters, adversely affecting the subsequent bit runs and adding to non-productive time (NPT).
4. Persevering with severely dulled bits can also induce other secondary drilling dysfunction such as excessive vibration leading to BHA failure and related damaged tool and repair costs, supplemental to the project NPT.

Aid in minimizing under-gauge hole and associated bit gauge wear caused from excessing reaming All the above issues have the potential to severely impact the overall drilling performance of the project. The case studies that follow, demonstrate the objective of this technique and illustrate how surface logging data collected on the wellsite is leveraged to eliminate potential ILT or NPT thereby optimizing bit runs.

Case History #1

A fresh 7-bladed PDC bit was deployed to drill the lateral section of the reservoir. The formation was predominantly organic rich shale interspersed with abrasive chert and silica rich layers. The lateral cut across several layers within the upper, middle and lower part of the selected target. The content of silica was determined by measuring the elemental composition of the drilled cuttings using XRF. Light color bands on the silica track (the last track on the right in Fig.07) indicates higher silica content, interpreted as a relatively more abrasive rock. Drilling with this new bit commenced in predominantly silica-rich rock and is reflected in slightly higher background alkenes (ethylene) trend from the very beginning of this run. (Ref. Fig.07.)

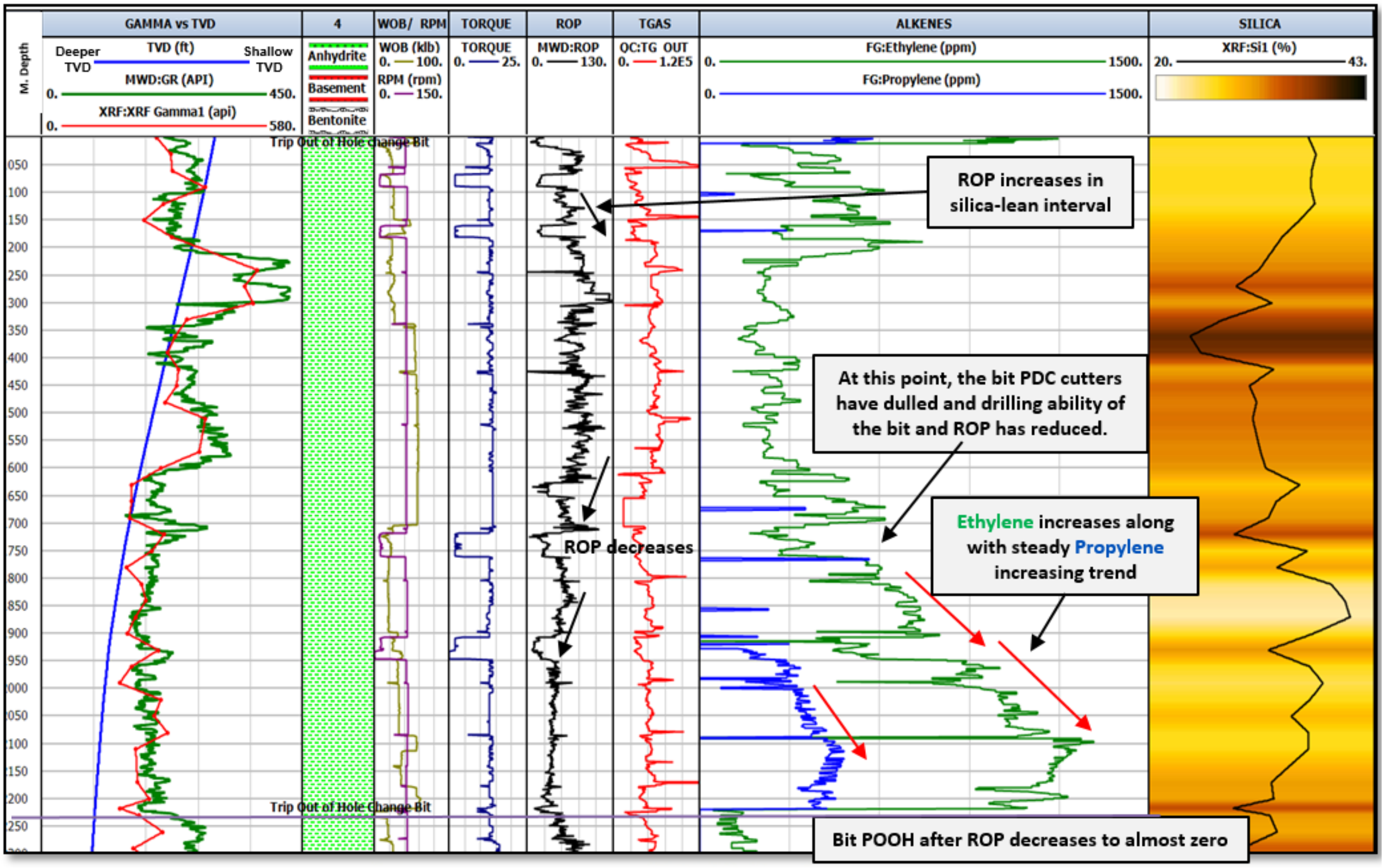

Fig.07: Composite log indicating the increasing alkenes trend and corresponding slow-down of ROP, indicating potential bit wear.

As the bit cut though silica-lean rock, the ROP increased and the bit appeared to drill more effectively. The bit drilled for 900ft, when a drop in ROP was recorded as indicated by the arrow in the ROP track. This drop in ROP correlated with an increase in the alkenes gases (ethylene and propylene) recorded at surface. Both these occurrences could be correlated to the increase in the silica content, as found in the drill cuttings analysis using XRF. The indication for the bit inefficiency were noted, however the operator decided to persevere with the same bit for another 200ft, before it was decided to POOH (Pull Out of Hole) for a bit change. The used bit was found to be damaged beyond repair (DBR) with lost cutters, bit body on the shoulder and gauge completely under-gauged, and substantially rung-out. Ref. Fig 08.

Fig.08: Worn PDC cutters on the shoulder and gauge area of this hybrid drill bit when examined at surface after POOH.

Case History #2

While drilling the 8¾" curve section, using OBM, targeting an unconventional reservoir in the Woodford formation, Delaware basin, US Land, the operator was expecting to encounter tough abrasive rocks which would make it challenging to drill efficiently. A hybrid bit was chosen to maximize the ROP. The objective of the bit run was to efficiently drill the curve and land the well in the target zone and be able to continue drilling the lateral.

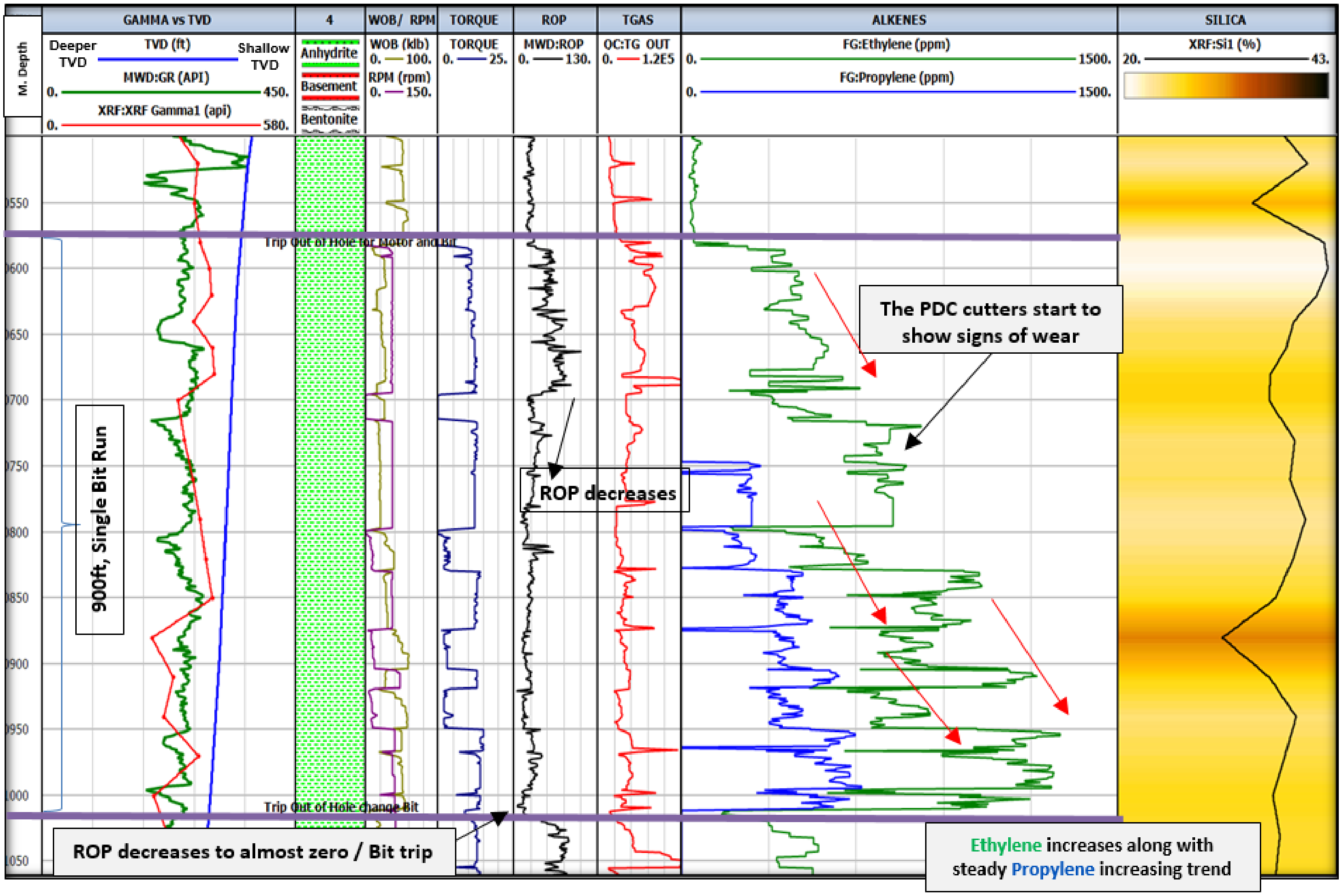

Fig.09: Composite log indicating the increasing alkenes trend and corresponding slow-down of ROP, indicating potential bit wear.

The lack of efficient progress would have a huge impact on the overall well expenditure and would threaten to cut their campaign short. Alkenes detection at the well-site was deployed to track the health of the bit while drilling. The intention was to correlate the increase in the alkenes to the drilling response. When the bit started drilling the lateral section, the ROP was consistent and the bit made good progress (Ref. Fig 09). As the bit drilled farther through sandy shales, the cutters naturally wore and the ROP started to see a decline, correlated with the rise of alkene levels. as measured by the dedicated alkenes analyzer in real-time. The gradual increase in alkenes were consistent with the high amounts of silica recorded in the XRF analysis of the drill cuttings. The high silica content was observed due to the presence of abrasive sandstones as well as traces of chert. As the dulled bit progressed further, the alkenes trend continued to rise until the ROP reduced to lower single digits. By this time both ethylene and propylene levels were sufficiently elevated to give the drillers enough confidence to make the call on the bit. The driller continued to persevere for a few feet more, before deciding to POOH. Once the bit was on surface, it was observed to be worn out on the shoulder and the gauge (Ref. Fig.10). This log provides the composite view of the drilling situation. This bit drilled a total of 600ft before it was POOH for a bit change.

Fig.10: Worn PDC cutters on the shoulder and gauge area of this hybrid drill bit when examined at surface after POOH.

Case History #3

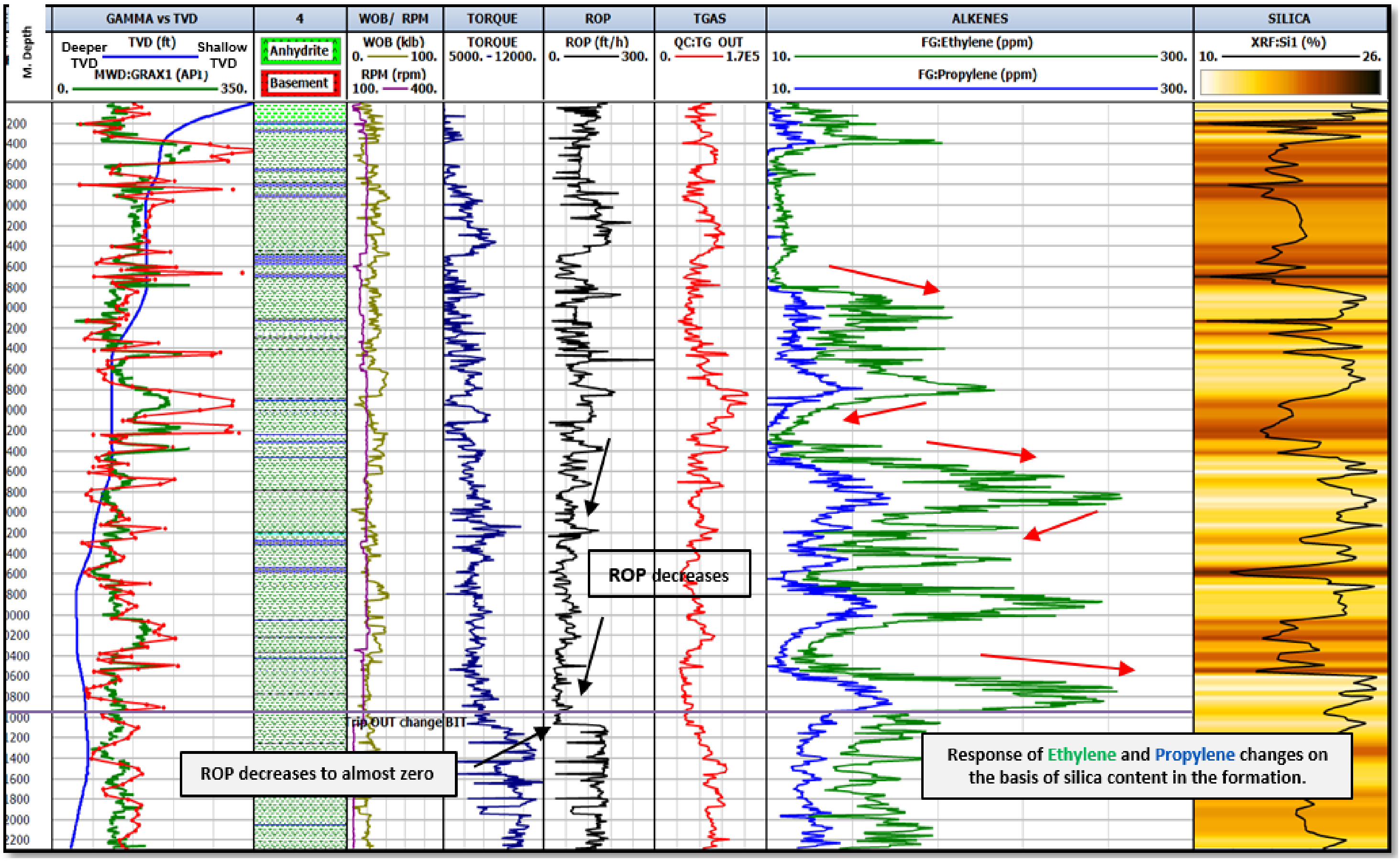

Fig.11: Propylene and ethylene (alkenes) readings seen to respond to the changes correlating to the silica content, indicating the bit's response to tougher rock properties.

Drilling commenced in the 8¾" lateral section of a well in the Arkoma basin. The objective of the bit run was to maximize the footage drilled with optimal drilling parameters, as well as staying in the target, avoiding silica-rich intervals which would be detrimental to the life of the PDC cutters. The PDC bit encounters numerous chert and dolomitic carbonate stringers, as well as organic shales which was confirmed by the elemental composition from drilled cuttings, measured using the XRF in quasi real-time. The increase in silica correlated well with the increase in alkenes and the intermittent slowing down of the ROP simultaneously. (Ref Fig.11.) These trends were frequently communicated to the Geo-steering team enabling prompt correction and adjustments to aid in steering-away from potentially abrasive rock layers, resulting in prolonging the life of the bit. As a result, the alkenes would drop to minimal values indicating a positive change in the type of formation and effective progress to make hole. The bit continued to drill for 5,900ft until the ROP slowed down considerably and the alkenes showed a progressive increase in an interval rich in silica (as proven by XRF), prompting pulling out of hole for a bit trip. The bit came out of the hole in a repairable condition, with worn cutters as expected for a normal bit run, but showing no indications of excess bit wear or high temperature. (Ref. Fig. 12.) During this run the alkenes detection service potentially saved the operator at least one bit trip by proactively communicating bit life condition status with Geo-steering team, resulting in prolonging the life of the BHA and the drill bit.

Fig.12. Used bit POOH with worn cutters mainly in the shoulder area indicating a good run for this bit.

Case History #4

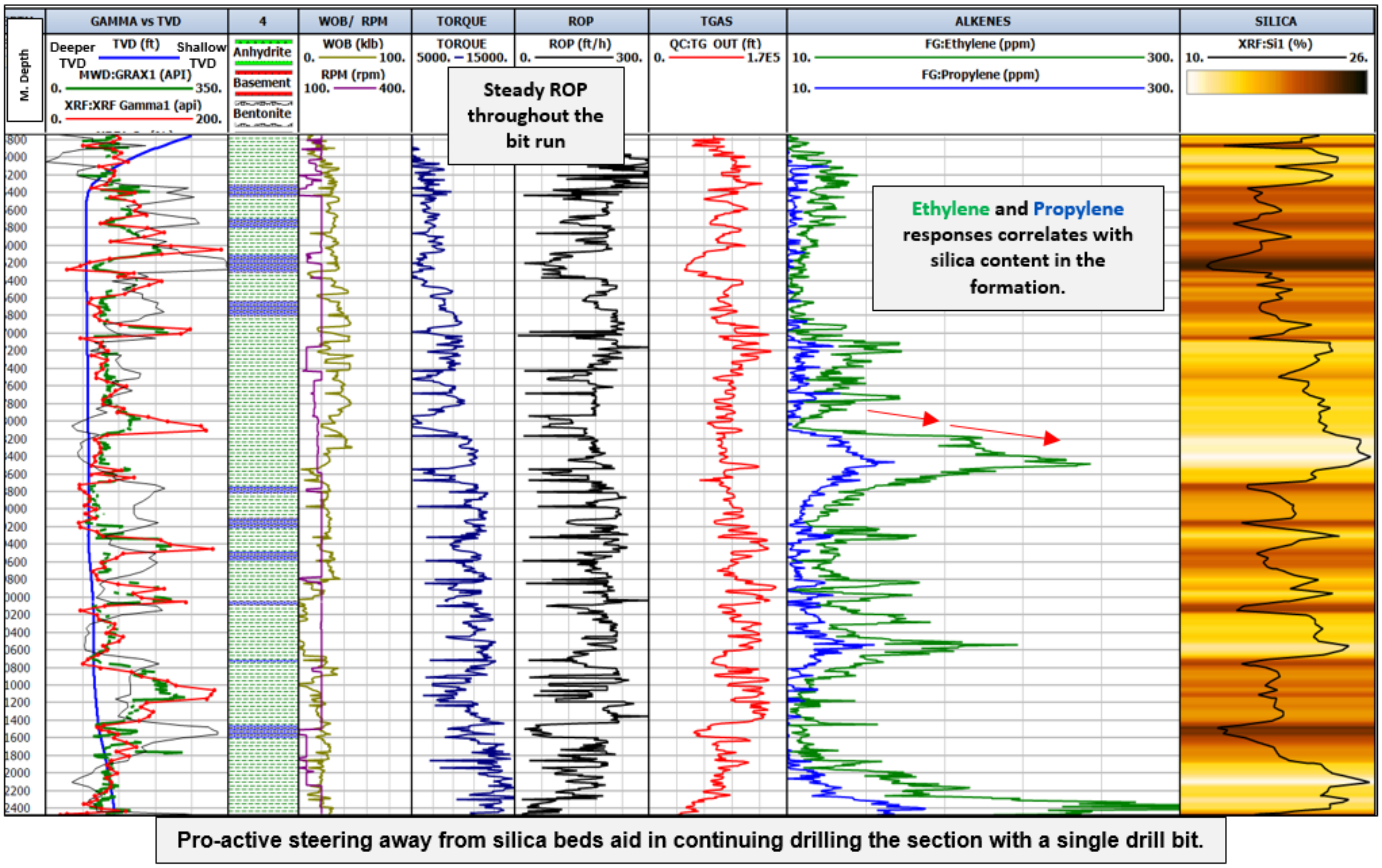

Fig.13. Alkenes trend closely follow the abrasive behavior of the formation. The silica content reduces as the bit steers away intentionally out of the abrasive zone.

A 6-bladed bit was deployed to drill a lateral section of a well in predominantly silica rich formation. The objective of this bit run was similar to the case history #3 discussed earlier. The bit was tasked to reach well TD in this lateral section, which was approximately 7,600ft. The lithology was expected to be comprising mainly of shale with inter-bedded abrasive chert beds and occasional dolomitic stringers. The bit drilled very efficiently through the initial 3,500ft of rock until the cutters started to show some fatigue. Presence of chert is highly detrimental to the life of the cutters. ROP reduction became evident when the bit encountered cherty silica rich beds, where the alkenes reading rose sharply. (Ref. Fig.13.) Geo-steering team was notified of this event and prompt action was taken to steer away from the silica rich layers. Such pro-active responses aided to continue drilling at a constant effective pace. Alkenes trend and the silica content was continuously tracked to help remain in the 'safe-zone' in order to keep the cutters from suffering premature wear. As a result the operator successfully reached well TD in a single bit run as intended and the bit was also pulled out in good condition. (Ref. Fig.14.) The cutters showed normal, evenly-distributed wear on the shoulder and gauge and was in a condition to continue drilling farther, if needed to.

Fig.14. PDC pulled out of the hole after drilling 7,600ft of formation was in a good, repairable condition.

Conclusion

The cases discussed in this paper provide objective and empirical validation that alkenes detection in real-time, having established a reference baseline, and when correlated with trending changes observed in drilling parameters, enables identification of early and/or excessive bit wear. When these observations are complemented by elemental analysis of drilled cuttings, using the XRF technique, it enhances the diagnosis further.

To overcome the challenges of premature bit-wear, a robust and integrated workflow combining alkenes detection in real-time with drill cuttings identification alongside XRF analysis is extremely helpful to the operators. When this holistic technique is used effectively, it aids in drilling optimization by enabling timely and proactive mitigating actions, potentially eliminating NPT which could be associated with severely worn bits, under-gauged hole, unplanned reaming of the open hole and associated ILT. Prolonged use of this technique in similar conditions could potentially lead to effectively improving the overall drilling performance, assigning standard operating practices, and optimizing bit selection for future wells.

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References

1. Wenger, L.M., Pottorf, R.J., Macleod, G., Dreyfus, S., and Justwan, H. 2009 Drill-Bit Metamorphism: Recognition and Impact on Show Evaluation. Annual Technical Conference and Exhibition, New Orleans, Louisiana, USA, 4–7 October 2009. SPE 125218.
2. Regan M., Carcione E., Martocchia A., 2018. Near Real-time Monitoring of PDC Bit Condition and Associated NPT Mitigation Using Alkene Detection. IADC/SPE Asia Pacific Drilling Technology Conference, Bangkok, Thailand, 27-29 Oct 2018. IADC/SPE-190997.
3. Carcione, E., Easow, I., and Chiniwala, B. 2017. Alkenes Detection from Drill Bit Metamorphism and Real-Time Geochemical Elemental Analysis on Drill Cuttings Aids Drilling Optimization and Geo-Steering in Tight Unconventional Laterals. Unconventional Resources Technology Conference, Austin, Texas, USA, 24-26 July 2017. URTeC: 2697162.
4. Perez R., Marfurt K., Calibration of Brittleness to Elastic Rock Properties via Mineralogy Logs in Unconventional Reservoirs. Oklahoma (2013).