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Systematic Wellbore Spiraling from Stick Slip Induced Micro-Sliding

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Abstract

Stick Slip is a term that is often overused and commonly diagnosed from surface drilling parameters of torque and differential pressure, but the actual magnitude of the condition is rarely captured at the BHA level since the necessary measurements are seldom used. Deployment of an accurate stick slip measurement downhole has led to an interesting discovery that goes against long held traditional drilling lore. A divide has been identified between stick slip as independent bit and BHA conditions. This phenomenon in horizontal wells is common but few MWD systems have been able to capture it. Utilizing downhole measurements of rpm, weight on bit, torque, annulus pressure, bore pressure, high speed magnetometers, bending moment, and continuous inclination, the wellbore spiraling phenomenon is captured, quantified, and intimately tied back to effects of BHA stalling and resultant micro-sliding, thus increasing tortuosity and drag.

Introduction

Wellbore "spiraling", "porpoising", and "corkscrewing" are all terms used to describe what is commonly thought of as typical wellbore tendency when drilling with a bent housing mud motor. However, the phenomenon is rarely captured due to the low tech nature of the MWD systems that dominate the land market. Wellbore character of this scale typically is only revealed through caliper or acoustic measurements that are infrequently utilized due to high cost. High tortuosity wellbore profiles have numerous drilling and completions consequences: "A high quality wellbore is defined as having (1) an in gauge hole (2) a smooth wellbore (3) a wellbore with minimum tortuosity. Field data indicate that generating a straighter; high quality wellbore has improved almost every aspect of drilling. These improvements include lower vibration, better bit life, fewer tool failures, faster drilling, better hole cleaning, and better casing and cement jobs" [1].

Understanding the underlying source of unwanted wellbore tortuosity is critical to the successes of drilling, completions, and long term production.

Case study: A lateral well drilled in the Permian Basin showed high levels of stick slip for the first 6000' of a lateral trajectory, the severity of the stick slip was causing approximately two times higher RPM downhole. Indicators were transmitted from the MWD system; however, attempted changes in rotary and weight on bit failed to mitigate the problem. During the last 1500' of the lateral there was an abrupt change in the wellbore condition where stick slip levels doubled resulting in high top drive torque oscillations upwards of 6kft.lbs as seen in Figure A. Post inspection of the bit, mud motor, and MWD system showed no signs of violent conditions or excessive wear. Analysis of the downhole data retrieved from the MWD system's memory revealed that the torque oscillations seen on surface measurements were signs of severe stick slip events where the BHA would stall for 6-10 seconds and then unwind for 3-4 seconds at speeds greater than 300rpm. The evidence collected from the MWD system supports the theory that stick slip between the bit and BHA can be independent events, and are intimately tied to wellbore spiraling. All data presented has 60 – 80 top drive rpm input.

High Frequency Downhole Data Captures Drilling Dynamics Events

Deployed Equipment

Bit: 8.5" - 5 Blade PDC w/ 2.21in^2 TFA

Mud Motor: 6.75" 7/8 5.0 Stage 2.0° Bend

Bit to Bend: 54"

MWD: Nabors AccuSteer® Measurement Suite (Figure 1)

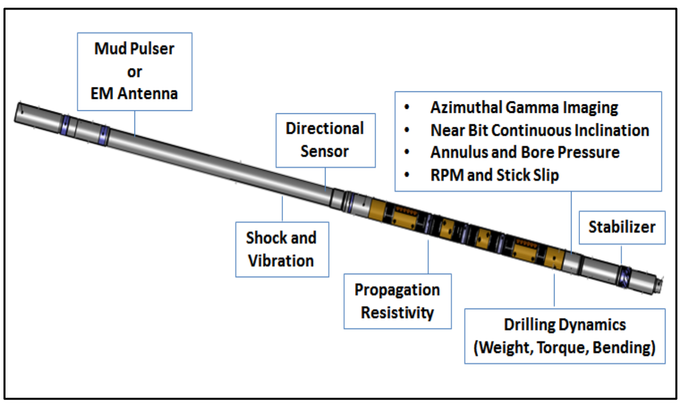

Figure 1 – Nabors AccuSteer® Measurement Suite incorporates a host of measurements in a 30-33' length.

Oscillations on Continuous Inclination and Bending Moment

Investigation of the continuous inclination measurement and dogleg severity calculated from bending moment showed cyclical patterning with a period of approx. 7'. Figure 2 illustrates that the oscillation shows a 0.2-0.3° change on the continuous inclination and ~1°/100' change in the DLS as calculated from bending moment. Tortuosity in terms of DLS is typically measured and calculated across distances of 30-90', thus the extent of the oscillations referenced in Figure 2 are seldom captured. It has been observed that approximation of wellbore DLS in micro-tortuous situations can be accurately captured using bending moment measurements [2,3] and continuous inclination data at sampling intervals in the range of 1-3' feet per point [3]. In the case of the data collected and analyzed from the MWD system on this well the sampling interval was less than 0.1 feet per point.

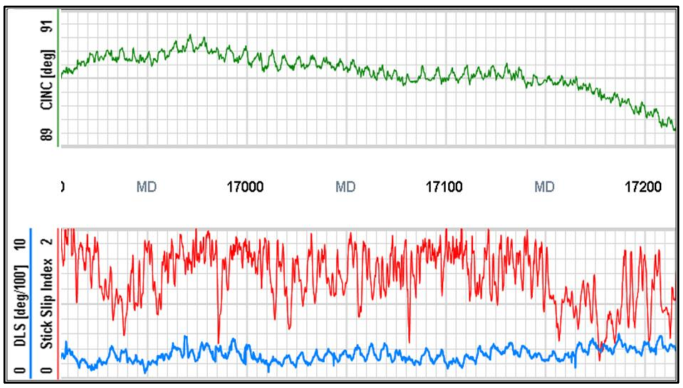

Figure 2 – Continuous inclination (green), DLS calculated from bending moment (blue), and stick slip index (red).

The continuous inclination and bending moment measurements in the MWD system are located at the same location as a configurable 7.25" OD x 4" long stabilizer on the lower end of the MWD system. This stabilizer acts as a guide that closely characterizes the borehole as the BHA moves forward. Interestingly, when stick slip subsides, the magnitude of the oscillations on the continuous inclination and bending moment subside also, raising the question of correlation between them.

High Speed RPM Measurements

Review of the downhole rpm/stick slip measurements brought visibility to the source of the torque oscillations seen at the top drive. Figure 3 shows the stick slip index for real-time transmission and the maximum, minimum, and average rpm readings as recorded downhole in memory. Stick slip index is calculated using the following formula.

$$\text{Stick Slip Index} = (RPM_{max} - RPM_{min}) / 2 \times RPM_{avg}$$

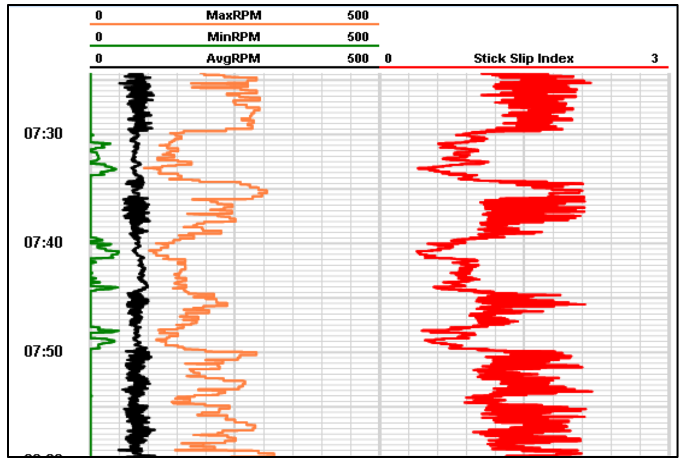

Figure 3 – Shows the range of rpm as measured downhole in a 16 second moving window.

The high levels of stick slip and rpm variance raised interest as to a possible explanation for the changes in continuous inclination and bending moment patterning. Investigation of the MWD system's high speed magnetometer data (500Hz), the basis for the rpm and stick slip measurements, showed that in lieu of the ~70rpm surface input by the top drive, the BHA would stall for 6-10 seconds and then unwind at speeds greater than 300rpm for 3-4 seconds as seen in Figure 4.

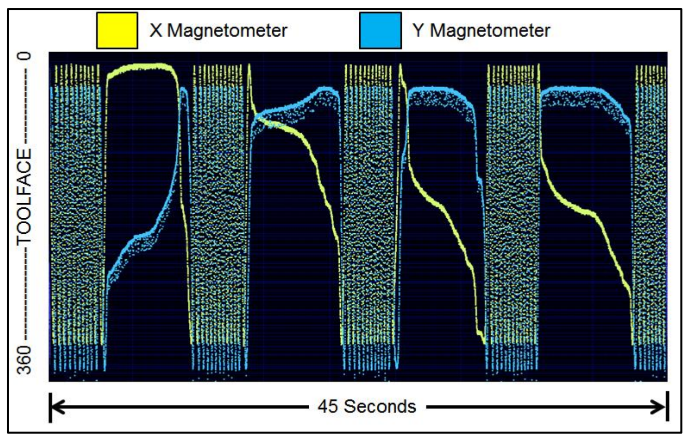

Figure 4 – Shows 500Hz magnetometer data (yellow and blue). A full period of the magnetometer data is 1 rotation.

Analysis of BHA Stall Toolface Position

It is hypothesized that the stick slip may be driving the cyclical pattern on the continuous inclination and bending moment. A non-referenced high-speed toolface position derived from the 500 Hz magnetometer data in Figure 5 validated said hypothesis. The instances of BHA stalling and thus low toolface variance are highlighted in white. A trend can be seen where the average toolface position during the stall moved ~10 degrees clockwise with a period of 7-10 minutes.

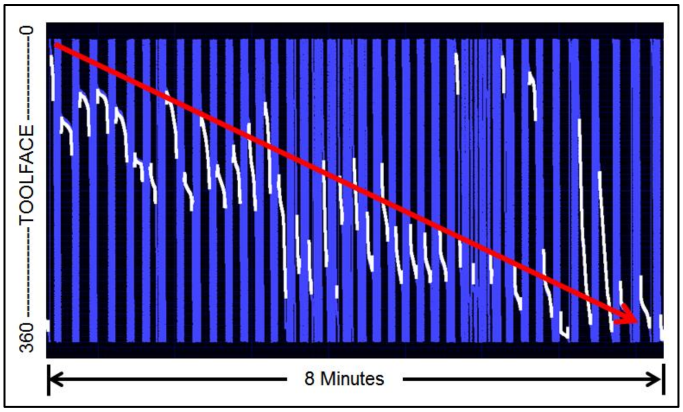

Figure 5 – High speed toolface (blue) calculated from 500Hz X&Y magnetometer data. The white curve represents the low variance slower moving toolface during the stall events. The red arrow shows the general trend in average toolface position.

Viewing 60 minutes of the stall/low variance toolface positon reveals a systematic clockwise movement as seen in Figure 6.

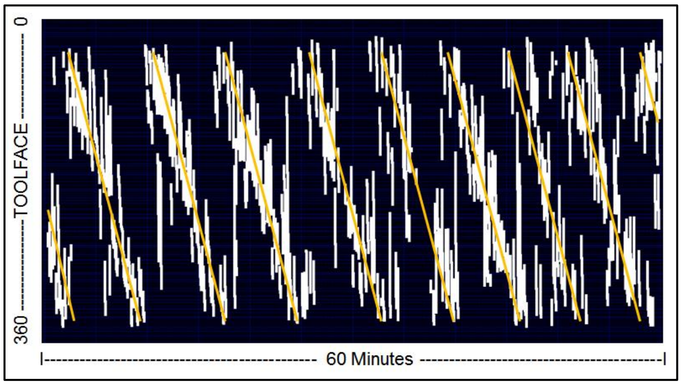

Figure 6 – Low variance toolface positon (white) overlain by a linear trendline (orange).

During the stall events, was the bit engaging the rock face and thus creating systematic wellbore spiraling from micro-sliding? The downhole differential pressure (bore pressure – annulus pressure) as seen in Figure 7 shows ~1200psi, which encompasses the sum of the bit pressure drop(50psi), the off bottom no load mud motor operating pressure drop(550psi), and the load pressure from drilling(600psi). To put the downhole differential pressure numbers in context, the bit pressure drop and off bottom no load pressure are effectively part of the standpipe pressure and are tared off of the surface differential pressure measurement prior to tagging bottom. The load pressure from drilling as seen downhole is equivalent to the surface differential pressure measurement given that ECD and flow rate remain constant since the last surface differential pressure tare point.

The bore pressure and downhole differential pressure measurements in the MWD system showed that during the BHA stalls there was ~150psi reduction in differential pressure across the mud motor. 150psi was only 25% of the 600psi loaded differential that the mud motor was producing from bit contact with the rock. Given that ~450psi of loaded pressure differential remained during the stall, it can be inferred that the bit was in fact engaging the rock and drilling continued during the BHA stalls. It's important to note that a slowing in bit rpm from BHA stalling results in a reduction of mud motor differential pressure due to reduced work at the bit. If the bit were to decrease speed relative to the BHA there would be an increase in differential pressure that would be seen on the bore pressure and downhole differential pressure measurements from the MWD system. Given the negative change in bore pressure and downhole differential pressure during the stall, without a decrease in downhole weight on bit, the data suggests that the bit relative to the mud motor housing was rotating at a constant speed dictated by flow rate and stator-rotor configuration in spite of the BHA stalling. The absence of variation in the downhole weight on bit measurement also supports drilling during the BHA stalling events.

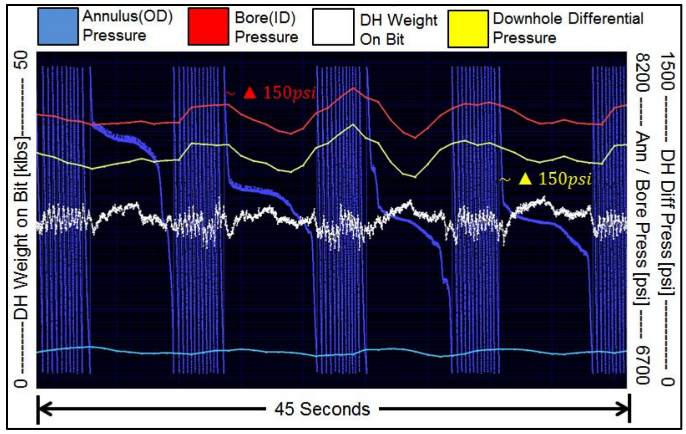

Figure 7 – Bore pressure (red) and downhole differential pressure (yellow) subsides ~150psi during the BHA stall events, indicating the bit was engaged and the mud motor was experiencing load. Downhole weight on bit (white) maintained at ~25klbs though the BHA stalls.

With the identification of major stick slip inefficiency, and resultant tortuosity from spiraling, the question remained…"How to mitigate the BHA stalling phenomenon to increase efficiency and reduce the resulting undesired wellbore profile?"

Analysis of Downhole Torque and Lithology

The downhole torque measurement in the MWD system as seen in Figure 8 shows that before the rapid unwinding at >300rpm, there is a significant build in downhole torque of sometimes greater than 6klbs.ft that releases when the BHA unwinds.

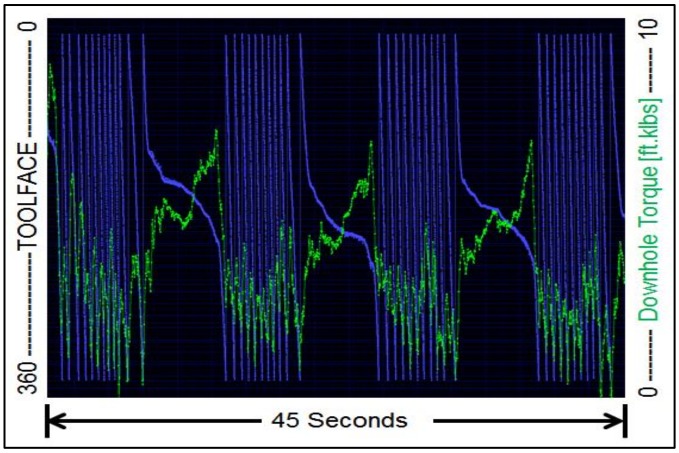

Figure 8 – Shows the downhole torque measurement (green) increasing prior to rapid BHA unwinding.

The data in Figure 8 suggests that the top drive torque input at the rig is transferring to the BHA and across the MWD system, but is building up at a high friction/wedging point between the MWD system and the bit. Given that the BHA below the MWD system is slick, the only logical high friction location would be the mud motor kick pad and resulting touch points from the mud motor's 2° bend.

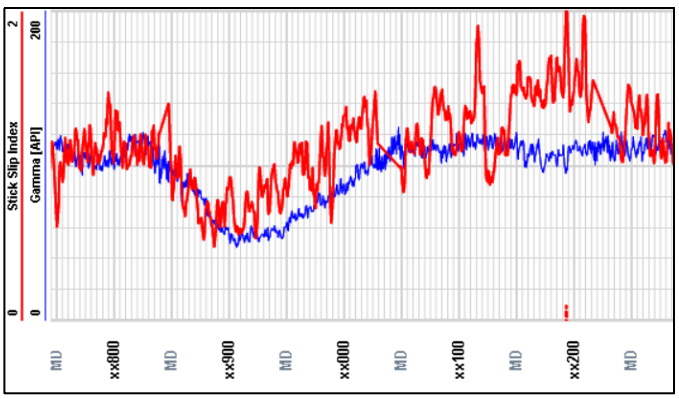

Figure 9 – Shows a correlation between gamma (blue) and stick slip (red).

Gamma and stick slip as seen in Figure 9 show a correlation of reduced stick slip levels with lower gamma readings. Rocks of lower radioactivity such as sands and carbonates have a tendency to be harder than more radioactive shales. Harder sands and carbonates generally show lower elasticity and reduced friction when compared to softer shales. This further supports that friction at the mud motor's kick pad and touch points are the source of stalling as seen in Figure 8.

Extent of Spiraling

Calculation of the spiraling extent showed that a 0.3° oscillation in the continuous inclination results in a spiral that has a 0.2" displacement from the wellbore axis. Drill collars and casing would sit between 2 peaks of the spiral resulting in an effective 0.4" displacement, thus reducing the borehole's diameter by nearly 5% as demonstrated in Figure 10.

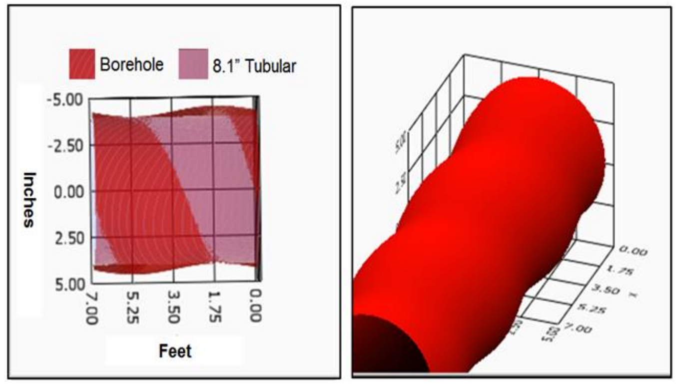

Figure 10 – (Right) An exaggerated illustration of the helical nature of the wellbore. (Left) A transparent model of the borehole with a straight tubular within demonstrating that the effective borehole diameter is no larger than 8.1" due to the spiraling. This assumes that the borehole is drilled to the 8.5" bit gauge.

It's important to note that the highest magnitude of spiraling that can be captured depends on the 7.25" stabilizer on the MWD system's lower end, as demonstrated in Figure 11. If the borehole spiraling feature is deeper than the stabilizer is proud, the full extent will not be captured. The flat sections on the continuous inclination support that the stabilizer is not able to fully characterize the full extent of the wellbore inclination.

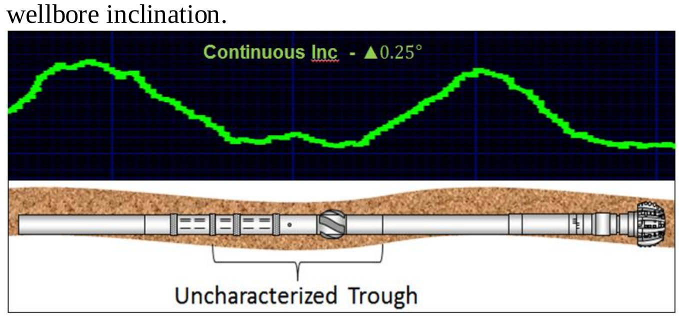

Figure 11 – Demonstrates the limits of the wellbore geometry characterization due to short spiraling period and stabilizer gauge.

Helical wellbore character of this nature has been identified as a source of increased friction that is difficult to account for during the wellbore planning and design phase [4]. Furthermore, micro-tortuosity within macro-tortuous wellbore character amplifies the effect resulting in higher friction and opportunities for interference with casing joints and hard banding on drill collars and drill pipe. "Recent evidence suggests that any torque and drag benefits derived from reducing doglegs as measured by survey data (macro-tortuosity) are likely to be completely overwhelmed by torque and drag generated by poor wellbore quality (micro-tortuosity)"[5].

Conclusions

The examples show that the phenomenon we refer to as “micro-sliding” can occur, which results in a spiraled or corkscrew borehole. In this well the micro-sliding is a result of BHA stick slip, not bit stick slip as indicated by the negative change in bore and downhole differential pressure during the BHA stall events. While it is clear that the wellbore spiraling and BHA stick slip are closely connected, it is difficult to determine if the spiral pattern in the wellbore is driving the stick slip, or if the stick slip is driving the wellbore spiraling. The downhole torque measurement shows a building of torque during the stall events, suggesting that the mud motor kick pad after an unwind event stops as a result of high friction/wedging. The next time that the BHA unwinds the kick pad stalls at its next position a few inches further forward and a number of degrees clockwise greater than the previous location, thus perpetuating creation of the spiral patterned wellbore. In order for the BHA to have downhole torque increase during the stall, it is most likely that the stick slip is a result of the binding activity and is therefore initiated and driven by wellbore character. Regardless of what occurred first, the evidence presented herein supports that the spiraling would likely not have occurred with a straight mud motor. Accordingly, the root cause has been determined as an aggressive mud motor bend coupled with an 8.5” bit diameter, thereby resulting in high deflection at the BHA touch points and excessive friction causing the assembly to bind.

Graphics

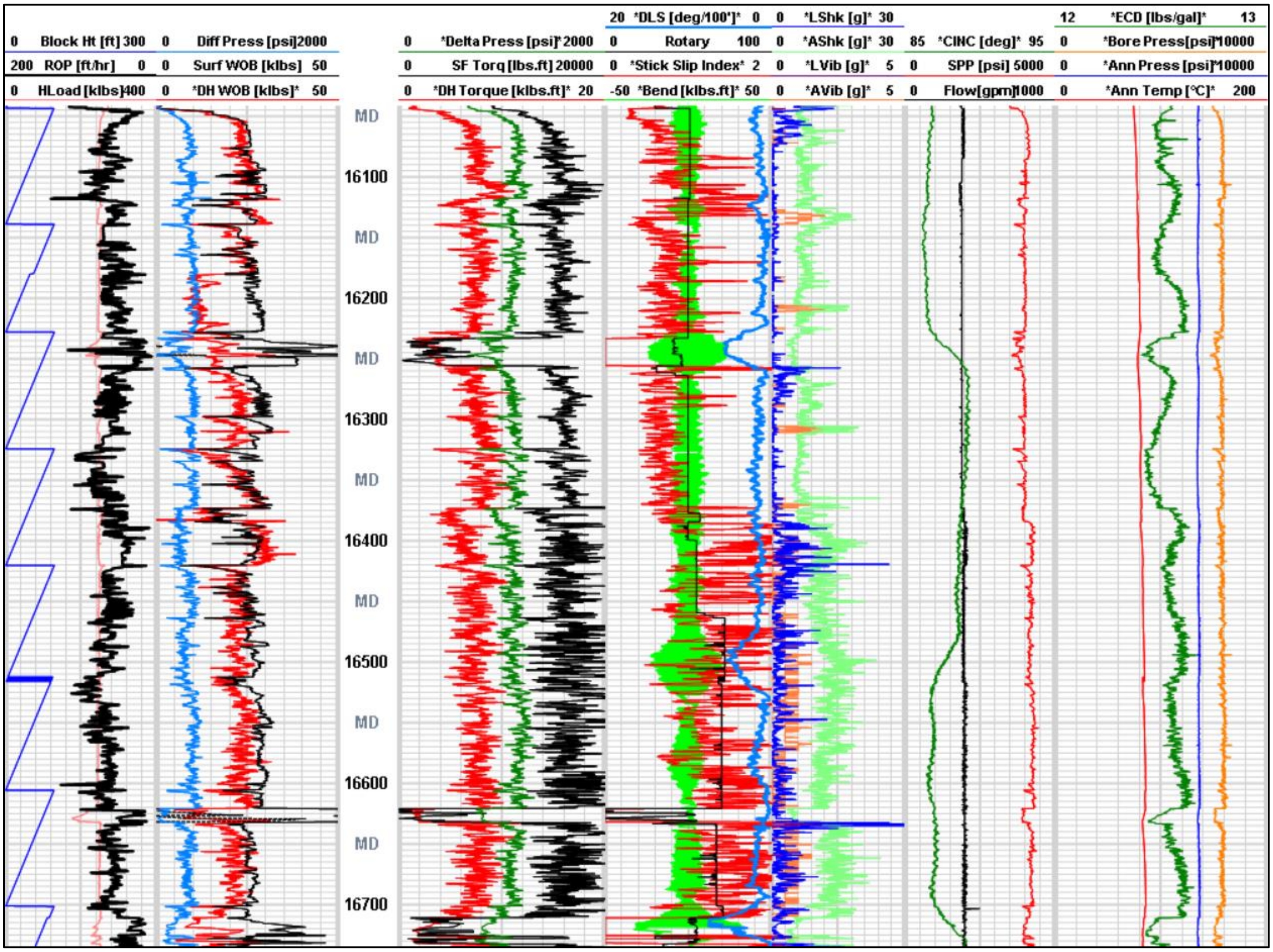

Figure A – Shows surface and downhole (*x*) measurements. From ~16,380 forward, stick slip and surface torque increased. Mitigation attempts through changes in rotary and weight on bit were not successful.

Acknowledgments

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Nomenclature

BHA = Bottomhole assembly

Micro-Toruosity = A term used to describe a helical wellbore

Macro-Tortuosity = A term used to describe the larger tortuosity able to be captured with conventional wellbore surveying

Bore Pressure = Pressure measured at the ID of the pipe

DLS = Dogleg Severity, commonly expressed in degrees per 100'

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