AADE-05-NTCE-43

Comparison of Concentric Reamer Technology to Eliminate Wellbore Threading in Deepwater Wells

Chris Lenamond and Augusto Silva, Schlumberger D&M

Abstract

Improving hole quality is a major factor for accurate formation evaluation and reduced well construction costs in deepwater. Further optimization of the borehole quality using new generation drilling assemblies is now possible. Concurrent drilling and reaming techniques have been successfully used in many offshore wells and few examples of comparing these technologies in the same well have been done until now.

The effects of hole rugosity and wellbore threading caused by conventional steerable assemblies is well documented in the industry, and can lead to poor cement isolation, poor formation evaluation, high rotary torque, poor wireline conveyance success rates and high BHA shock-loading. Each of these conditions can have a significant impact on completion costs, reserves estimation, and drill string integrity. Integrating drilling mechanics results with an analysis of wireline and LWD data, the authors demonstrate a significant improvement in hole quality while drilling with a rotary steerable system in combination with concentric reaming devices, compared to conventional directional drilling and hole opening combinations in the same well. Multiple bottomhole assembly configurations were deployed to drill the various hole sections and the use of LWD imaging and wireline calipers provided a direct comparison of hole quality performance of each drilling system. A culmination of various drilling systems were evaluated in a single well while performing enlarging while drilling (EWD) of a 12 ¼" to 14 ¾" hole. Salt formations were drilled to fully compare each system in a common drilling environment without variations due to formation types.

Introduction

The effects of hole rugosity and wellbore threading caused by conventional steerable assemblies is well documented in the industry, and can lead to poor cement isolation, high friction factors, near wellbore formation evaluation risk, high rotary torque, poor wireline conveyance success rates and high bha shock-loading[1]. Each of these conditions can have a significant impact on completion costs, reserves estimation, and drill string integrity. Integrating drilling mechanics results with an analysis of wireline and LWD data, the authors demonstrate a significant improvement in hole quality while drilling with a new generation rotary steerable system in combination with concentric reaming devices, compared to conventional directional drilling and hole opening combinations. For this paper, hole quality refers to the final caliper hole size and shape from threading and not formation damage aspects of the final wellbore. Wellbore threading is the existence of uneven grooves inside the wellbore much like the threads on a bolt.

Theory

As the well designs and casing programs become more complicated in many deepwater applications, operators have looked for methods to reduce the maximum casing size required at the surface while still maintaining the production tubing size to meet project economics. One method of accomplishing this goal is to utilize hole enlarging-while-drilling (EWD) technology to drill the pilot hole and enlarge the hole size below the casing shoe simultaneously. This process allows for tighter tolerance casing pass-through in the existing casing strings and still have larger annulus clearances in the open hole sections to reduce operational issues such as swab/surge, wellbore stability and improved cementing programs. As shown in the case study that follows, the quality of the pilot hole section has a major influence on the final quality, size and shape, of the hole enlarged with the reamer tools.

While there are numerous options available to perform EWD operations successfully, hole quality issues vary significantly among the options and is the primary purpose of this paper. Some of the many EWD options available on the market today include:

1. Bi-centered bits
2. Eccentric reamers, and
3. Concentric reamers.

Typically, these devices can enlarge the pilot hole by approximately 20% while drilling.

Enlarge While Drilling Technology

Bi-centered Bits

Bi-centered bits are polycrystalline diamond cutter (PDC) drill bits with two centers of rotation. **Fig. 1**, the bicenter bit is essentially an integral PDC bit with reaming blades which will allow passing through casing but enlarges to an underreamed hole size. Normally the bit rotates around an offset center when inside casing and the pilot bit center when in open hole. The quality of the hole opening ability of the bi-centered bits is a direct function of the pilot bits ability to remain buried in the formation with sufficient force for the wings to enlarge the hole size. When the hole size for the pilot bit is larger than the pilot bit itself, the final enlarged hole size is compromised resulting in undergauge hole or egg-shaped hole. This can generally occur when:

1. the hydraulic jetting force of the bit causes washing out or enlargement of the pilot section while drilling,
2. the formation strength is inadequate to support the side forces exerted by the pilot bit portion of the bit while enlarging,
3. if the pilot bit design of the bit is insufficient to distribute side force loads generated by the enlarging blades of the bit, or
4. the penetration rates are significantly higher than the bit rotation speed.

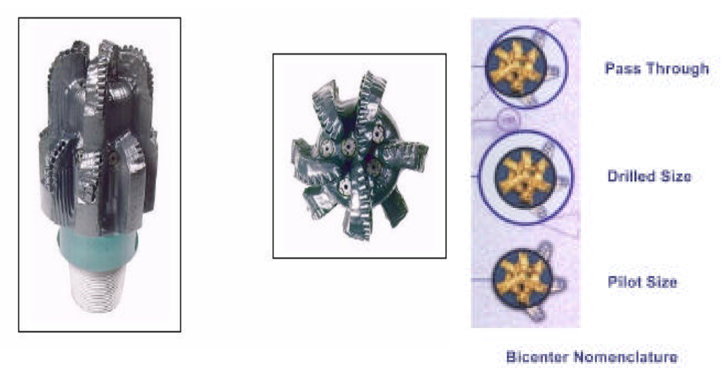

Figure 1. Bi-centered bit views and nomenclature

For these reasons, a bi-centered bit cannot open pre-existing hole larger than the pilot bit outside diameter (OD). It can also be deduced that if the rate of penetration (ROP) is excessively faster than the rate of bit rotation, within some guidelines, then the resulting hole size is compromised similarly. The enlargement blades do not fully enlarge the hole with sufficient blade rotations relative to the penetration rates achieved. Utilization of downhole mud motors to increase the bit speed can improve hole quality in fast drilling formations if the motor has a zero setting in the bent housing. The use of bent housing motors has been well documented in producing poor hole gauge conditions when rotated while drilling which is independent of the type of bit used. The bit offset produced by the bent housing produces an oversized hole that becomes exaggerated with bi-centered bits and reamer tools run below the motor[2]. Examples illustrating the effects of both bi-centered bits and mud motor with bent housings on hole shape and size are shown later in this paper.

Eccentric Enlarging While Drilling Tools

Eccentric EWD reamers include single and multiple-bladed subs that are placed somewhere in the bottom-hole assembly (BHA). **Fig. 2**, these tools act similarly to bi-centered bits when placed above the pilot bit with the addition of a force-balancing pad to offset the cutting blade forces on some designs[2]. When run above the pilot bit, the hole quality considerations and mechanics are similar to bi-centered bits

Figure 2. Eccentric reaming tools by various vendors which can be placed anywhere in the drillstring or above the pilot bit. The system on the right was used in this case study.

explained previously. When placing the eccentric EWD tools higher in the BHA, stabilization of the reamer section generally improves with the additional stabilization. The ability to open the pilot hole is again primarily a function of drillstring rotary speed, penetration rate and BHA flexibility adjacent to the reamer.

Concentric Reamers

Concentric reamer tools include expandable arm tools, which are mechanically or hydraulically activated, to enlarge the pilot hole during drilling. Due to the concentric principle of operation, these reamers are inherently more stable in design than eccentric reamers. **Fig. 3**, the concentric reamer used in this paper was a hydraulically expandable tool designed to enlarge the hole approximately 20% for improved casing running and cementing clearance. The tool body houses three equally spaced cutter blocks dressed with PDC inserts for both drilling and backreaming. Each cutter block has a stabilizer section in the middle of each blade to improve stabilization and centralization of the tool in the hole while drilling. This design feature enhances tool stability and improves hole quality by reducing downhole vibrations in much the same manner as a full-gauge, string stabilizer improves stabilization in the BHA.

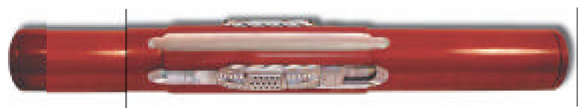

Figure 3. Concentric reamer designed with stabilization feature in center of each reaming blade that is used in this case study.

Fig.4, most other concentric reamer designs do not incorporate this stabilization feature. These reamer designs include drilling under-reamers and mechanical reamers with both fixed PDC and roller cone cutters. For the drill-off test in this paper, these designs are considered for testing due to lack of stabilization features. Wireline calipers of wells drilled with these tools have shown poor hole enlargement in many cases and higher downhole vibrations are often recorded.

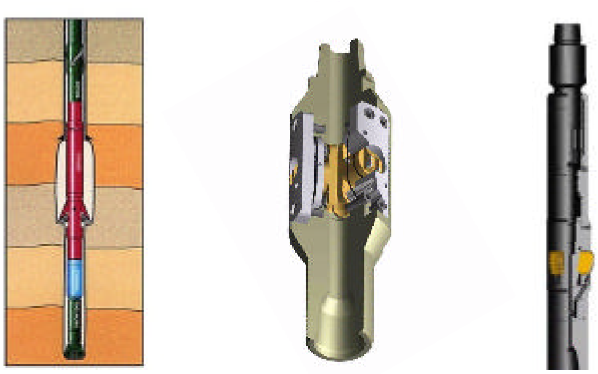

Figure 4. Other example of concentric reamer tools without built-in stabilization within the tool itself. Diagrams are of a conventional underreamer, hydraulically actuated piston-type reamer, and hydraulically actuated arm-type reamer.

Drilling Systems

During drilling operations with EWD tools, the mechanism to drive the EWD tools should be carefully considered to maximize hole quality of the enlarged hole section. The pilot bit, the EWD tool and the drive system for the bit are a "drilling system" and directly affect the produced hole quality. Typical drive choices include:

1. rotary BHA with rotation supplied from surface,
2. downhole mud motors that produce bit rotation with hydraulic energy from the mud, and
3. rotary steerable systems (RSS) which can use surface supplied rotary energy or a combination with downhole mud motors.

For directional control of vertical wells and in directionally drilled wells, EWD tools limit the choice of drive mechanism to maintain directional control. Bi-centered bits allow the use of conventional rotary BHAs or downhole mud motors for drilling, but without most rotary steerable systems. Only two RSS designs currently on the market can use bi-centered bit designs due to casing pass-through restrictions. Eccentric and concentric reamers prevent the use of mud motors for directional control due to the inability to drill without drillstring rotation called "sliding mode". While some eccentric and concentric reamers are below the mud motor, directional control and penetration rates become compromised. RSS allow maintaining directional control and penetration rates with both eccentric and concentric reamers in most cases. While downhole drillstring vibrations caused by EWD tools, such as stick-slip and BHA whirl, can compromise both penetration rates and hole quality, analysis of these drillstring motions are beyond the scope of this paper.

Rotary Steerable Systems (RSS)

Rotary steerable systems are a relatively new introduction to drilling. Many versions of rotary steerable systems are available and classified into two basic categories based on the method of deflection of the drill bit:

1. push-the-bit systems which exert a sideforce to the bit and
2. point-the-bit systems which utilize three points of contact to control the direction of the drill bit much like steerable mud motor systems.

These classifications are quite simplistic as the various RSS within push-the-bit category operate very differently. A majority of these systems have non-rotating or slowly rotating parts in the annulus that control the operation of the tools. When these parts are no longer able to remain stationary, directional control is compromised and by deduction that hole quality is also affected as the tool "steers" along different directions not intended. As is shown in the case study that follows, the quality of the pilot hole section has a major influence on the final quality, size and shape, of the hole enlarged with the concentric reamer tools.

The quality of the wellbores drilled with rotary steerable systems is superior to wells drilled with mud motors with conventional bits[3]. **Fig. 5**, the rotary steerable system used in this paper is a push-the-bit system with no external stationary parts referred to as a "fully-rotating" rotary steerable system. The tool applies a side-force to control the bit direction using mechanical pads near the bit that push against the borehole wall while drilling. Drillstring rotation is supplied from surface while the hydraulic force to the pads is furnished by the mud flow.

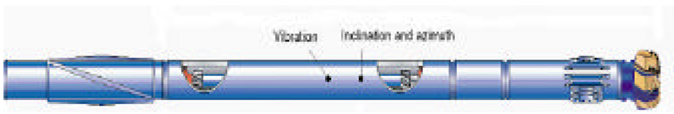

Figure 5. Fully-rotating rotary steerable system used in this case study. Features no external non-rotating parts and provides automated directional control in vertical well applications.

Case Study

Candidate Well Selection

The well in the BC-400 field was selected for the EWD drilling comparison tests. This well is in 1745m of water and was designed using intermediate casing strings to isolate salt formations before entering the reservoir. After the 13 3/8" intermediate string of casing was set at 3793m, a number of EWD combinations were utilized to open the 12 ¼" hole section to 14 ¾" while drilling. Afterwards, the 10 3/4" secondary intermediate casing string was set across the salt formation. The well selection for the EWD drilling comparisons was based on the following reasons:

1. client needed to enlarge the hole size the salt section to improve the cementing program,
2. utilization of a high-quality synthetic oil-based mud (SOBM) system would prevent cutters balling and formation instability issues and hole enlargement affecting the test results,
3. the well is vertical without directional needs affecting the results,
4. the salt formations are homogenous and remove any lithology variation influence in the test results, and
5. a 6-arm wireline caliper over the entire interval to fully evaluate the hole size and shape quality.

Hole Quality Determination

A wireline 6-arm caliper was logged at the end of the 12 ¼" x 14 ¾" hole section to evaluate the hole quality in terms of overall hole size and threading of the wellbore walls. Using the wireline data combined with the available MWD / LWD logging and drilling mechanics information for each BHA run, an analysis was performed to determine which hole opening BHA combination produced the best quality hole and drilling dynamics.

Drilling with Various EWD Tools

Utilization of three different enlarge while drilling (EWD) tools to drill the salt formations and enlarge the 12 ¼" pilot hole to 14 ¾" comprised the drilling comparison test. The depths of each section and the EWD drilling system is as follows:

1. Run #5 17 ½" rathole section below the 13 3/8"casing drilled with conventional mud motor with a 1.15 degree bent housing and PDC bit with no enlargement
2. Run #7 12 ¼" x 14 ¾" drill-out version of reaming while drilling (DORWD) tool consisting of a fixed-blade reamer in the BHA and 9 ½" pilot bit on a conventional rotary BHA,
3. Run #8 12 ¼"x 14 ¾" bi-center bit on conventional rotary BHA which inadvertently increased hole angle while drilling
4. Run #9 12 ¼" tri-cone bit with downhole mud motor with a 1.0 degree bent housing setting used to reduce inclination to near vertical
5. Run #10 12 ¼" x 14 ¾" stabilized-design, concentric reamer with fully-rotating rotary steerable system (RSS) used to open the previous Run #8 hole section before drilling ahead to section total depth.

Each bottomhole assembly utilized in the 12 ¼" x 14 ¾" is shown in **Fig. 6**. A summary table of depths, penetration rates and vibration results are shown in table 1 below.

Measurements While Drilling (MWD) tools recorded downhole vibrations due to lateral shocks and torsional

BHA's	Depth In	Depth Out	Lithology	Avg ROP	Shocks	StickSlip
5	3660	3887	Salt	7	No MWD shocks recorded	Some High level of Stick Slip
7	3887	3928	Salt	2	Little or no MWD shocks	Low level of Stick Slip
8	3928	4125	Salt	15	No MWD shocks recorded	Medium level of Stick Slip
9	4125	4275	Salt	7	No MWD shocks recorded	Very Low level of Stick Slip
10	4275	4529	Salt	10	Low levels of MWD shocks	Low level of Stick Slip

Table 1. Summary of each bottomhole assembly run in the case study well indicating depths of each run, formation type, penetration rates and levels of downhole shocks and torsional vibrations recorded by the MWD tools.

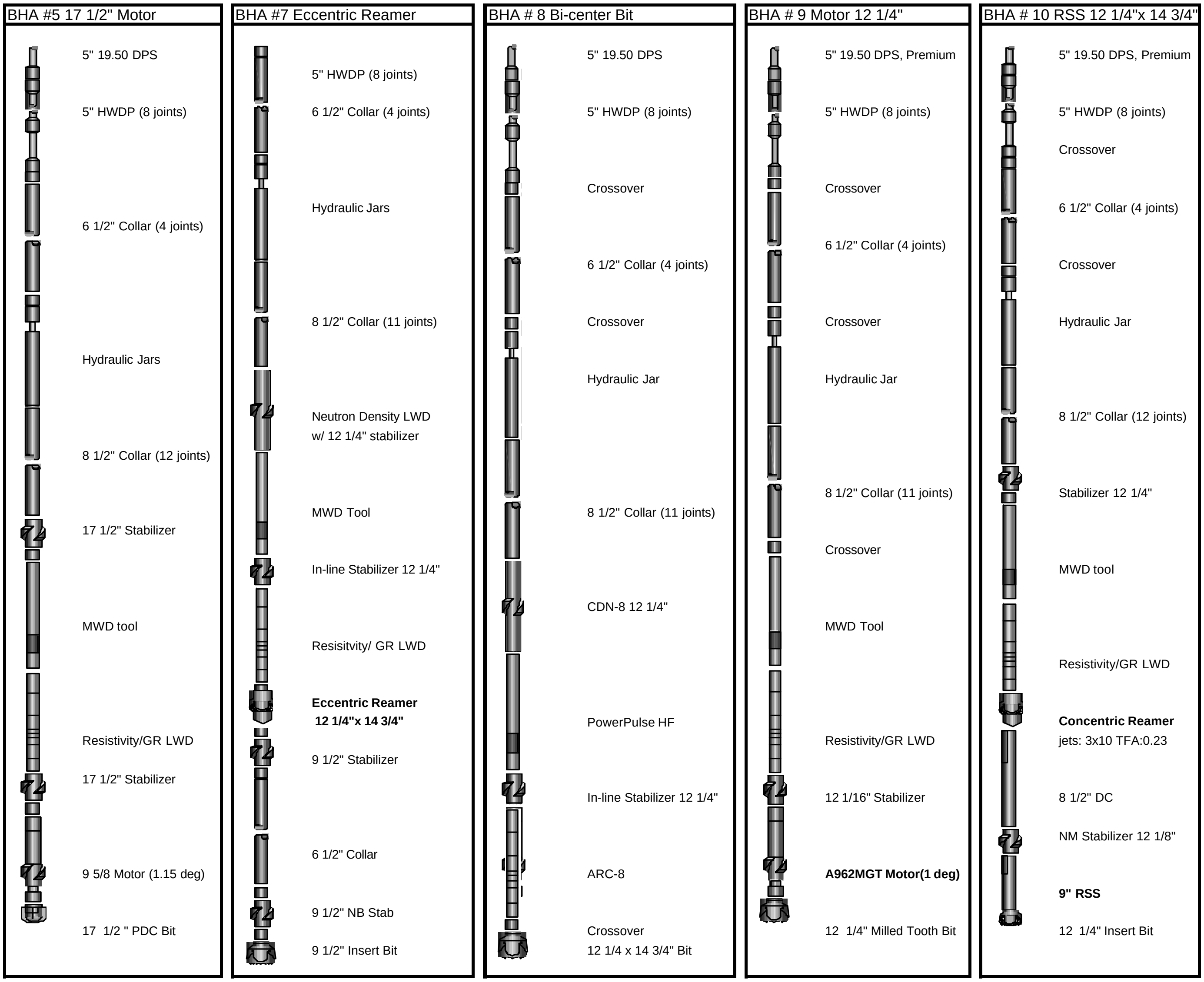

Figure 6. Diagrams of each BHA in 12 ¼" x 14 ¾" case study well.

vibrations called stick-slip. BHA reliability is function of limiting downhole vibrations and shocks. The highest levels of downhole vibrations were on runs #5 and #8 which were the 17 ½" PDC bit with mud motor run and the bi-center bit with mud motor runs, respectively. Run #10 with the rotary steerable and concentric reamer recorded MWD shocks, but these shocks occurred while opening the 12 ¼" section, that was drilled with mud motor. This results in an overgauge pilot hole section by physical design as explained previously.

Drilling Performance and Hole Quality Evaluation

From the caliper log in **Fig. 7**, the effects of hole rugosity and wellbore threading are clearly present. BHA Run #5 in the previous 17 ½" hole section which was drilled with a PDC bit and a steerable motor combination. This is indicative of the hole quality issues produced by mud motors with bent housing set more than zero degrees of bit offset. Each caliper curve represents one set of two caliper pairs in each track showing hole size. The caliper scales are set with the 14 ¾" expected hole size in the middle of each track. If the resulting final hole size is fully opened to 14 ¾" diameter, then the caliper curves should trace the middle of each track with little variation. Varying caliper curves indicate varying hole size and two caliper curves varying in different directions indicates threaded hole as well. The 17 ½" section shows a high degree of rugosity and enlarged hole. BHA #6 was a simple drill-out BHA for the casing shoe and is not shown above.

For Run #7, the caliper log shows the hole quality results for the 9 ½" bit and 12 ¼" x 14 ¾" eccentric reamer tool run on a rotary bottomhole assembly. While some wellbore threading is present, the hole rugosity is reduced. The hole appears to be reasonable gauge but from the drilling mechanics summary in Table 1, this BHA combination produced the lowest average ROP in the 12 ¼" x 14 ¾" hole section. The gamma ray (GR) curve on the left-side of Fig. 9 indicates the all the runs are in salt formations.

In Run #8, where a 12 ¼" x 14 ¾" bi-center bit on a rotary BHA was used, the caliper log distinctively showed the presence of hole rugosity and wellbore threading effects. The average ROP was 15 m/hr, but the BHA was pulled after only 197 m of formation were drilled due to poor directional control. The hole angle increased from 2 degrees to 6.7 degrees over the run. This run also presented the highest level of stick slip vibrations for any BHA run. The next run was a conventional mud motor with bent housing to correct the hole angle back to vertical.

In Run #9, a 12 ¼" tricone bit with a mud motor, and a 1.0 degree bent housing setting, was run to correct the hole inclination problems from the previous run. The hole was then opened to 14 ¾" during Run #10 using a 12 ¼" PDC bit, a fully-rotating RSS and a stabilized-design, concentric reamer assembly. Again the presence of hole rugosity and wellbore threading effects were present in the hole section drilled with a mud motor and was magnified during the under reaming operations. The poor quality and over gauge pilot hole drilled using the conventional steerable BHA configuration resulted in highly threaded or rugose hole section. This example illustrates the importance of a gauge pilot hole for any reamer tool to remain centralized in the pilot hole section and produce a quality enlarged hole. Once the old 12 ¼" pilot hole was enlarged to 14 ¾", BHA#10 then simultaneously drilled to the section total depth at 4529m while enlarging the hole to 14 ¾" size.

On BHA run #10, a localized washout section from 4290m to 4322m of up to 1" in diameter on the caliper logs exists where the BHA was circulated for a long period. Following this section of hole, the results clearly indicate that hole rugosity and wellbore threading were virtually eliminated by using this BHA combination. This was due to the improved pilot hole quality obtained with rotary steerable tools combined with the concentric reamer tool used. BHA #10 also produced the longest run for the section of 254m with an average ROP of 10 m/hr. The drilling mechanics data showed low levels of stick slip vibrations and MWD shocks. Additionally, the rotary steerable reduced the hole inclination from 2 degrees to less than 0.4 degrees for the entire run. The wireline caliper demonstrates that the fully-rotating RSS with a stabilized-design, concentric reamer combination produced the highest quality borehole and best overall drilling dynamics. The increase in hole quality and reduction of wellbore threading results in:

1. improved quality of logs as the pad-type logging tools have better borehole contact during the measurement,
2. improved hole cleaning in more uniform hole size,
3. less wellbore friction as the wellbore is smoother[1],
4. improved running of casing strings and completion strings in smoother wellbores[3], and
5. improved cementing with less channeling as casing centralization is improved in smoother, more uniform wellbore.

Conclusions

1. Fully-rotating rotary steerable system (RSS) with a stabilized-design, concentric reamer combination produced the highest quality borehole in terms of both reduction in oversized hole and threading effects.

2. Fully-rotating RSS and a stabilized-design concentric reamer combination produces fewer downhole vibrations over bi-center bit combination and longest run with the second best penetration rate.

3. Mud motors with bent housings set greater than 0.0 degrees produce highly threaded and oversize hole when rotary drilling.

4. Once the pilot hole is drilled poorly, the poor hole quality cannot be improved or removed with enlarging tools and the better stabilized designs would be expected to produce the best results.

5. Smoother and uniform boreholes should improve the quality of logs as the pad-type logging tools have better borehole contact during the measurement.

6. Reduced rugosity of the borehole reduces wellbore friction as the wellbore is smoother and cleaning is improved without wellbore threading and overgauge hole.

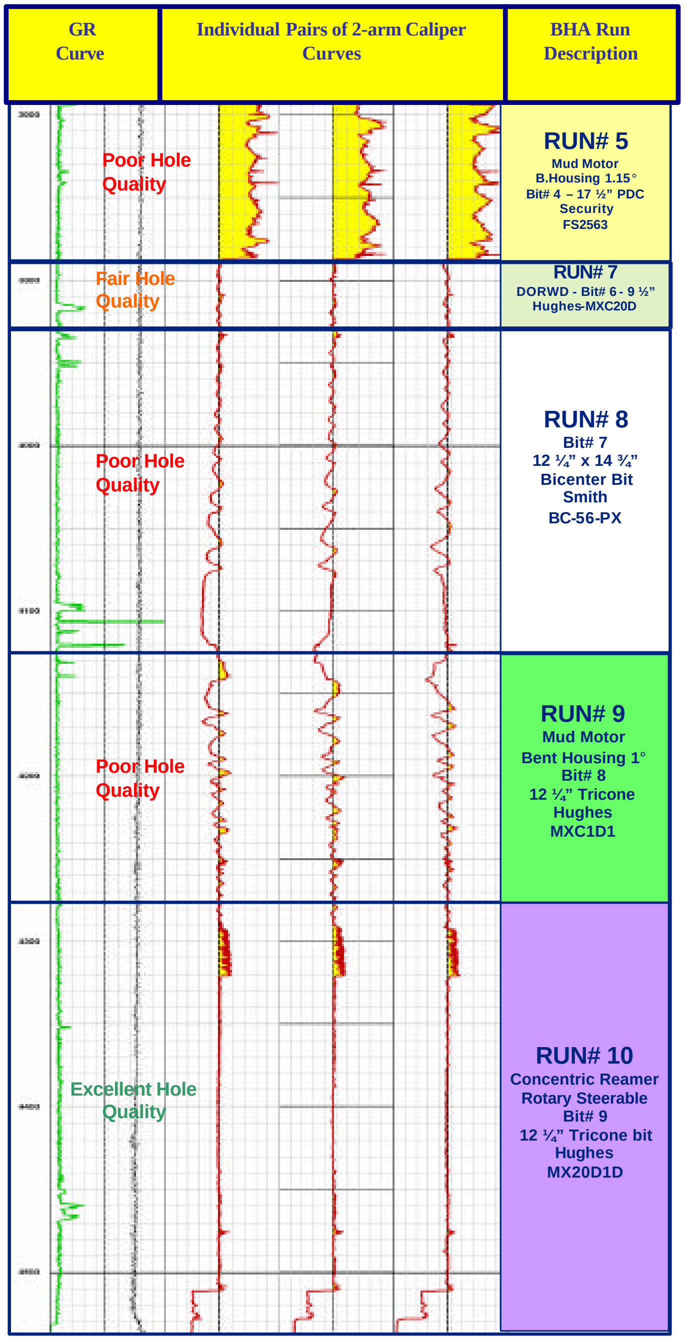

Figure 7. Wireline 6-arm caliper of 14 ¾" borehole drilled with various reamer combinations as shown in legend. Left track is gamma ray curve and description of hole quality from caliper results. Center track is each caliper set plotted as in each track to indicate both overgauge size and threading. Right track is BHA and bit descriptions.

Acknowledgements

The authors wish to thank Petrobras for permission to publish this paper and to Smith Services International for their assistance and support of our operations. Special thanks to Roger Goobie with Schlumberger and Raul Soares Felicissimo with Petrobras for their tireless efforts to support our operations.

Nomenclature

BHA - bottomhole assembly
EWD – enlarge while drilling
LWD - logging while drilling
MWD- measurements while drilling
OD – outside diameter
PDC – polycrystalline diamond cutter
ROP – rate of penetration
RSS – rotary steerable system

References

1. Chen, D.K., Gaynor, T. and Comeaux, B.: "Hole Quality: Why It Matters," paper SPE 74403 presented at the SPE International Petroleum Conference and Exhibition, Villahermosa, Mexico, 10-12 Feb 2002.
2. Cook, J., Doster, M., Dykstra, M.W. and McDonald, S.: "Development of Steerable Ream While Drilling Technology and Its Application in High Angle Wells in GOM," paper SPE 39326 presented at the IADC/SPE Drilling Conference and Exhibition, Dallas, TX, Mar. 3-6, 1998.
3. Johnstone, J.A., and Derek, A, "Realizing True Value From Rotary Steerable Drilling Systems," paper SPE 56958 presented at the 1999 Offshore Europe Conference held in Aberdeen, Scotland, 7-9 September.

SI Metric Conversion Factors

m x 3.280 840 E+00 = ft
m^3 x 3.785 412 E+03 = USgal
Pa x 6.894 757 E-03 = psi