AADE-05-NTCE-44

Borehole Quality Analysis Comparing Rotary Steerable Tools to Conventional Directional Drilling Assemblies.

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Abstract

A new rotary steerable drilling system (RSS) was introduced in 2004. This tool incorporates a rotating drive shaft through the center of the tool and a non-rotating housing supported by large bearings. This non-rotating part holds three extension blades which are independently operated to provide the steering forces for the tool. Each of the three blades incorporates a measuring device to provide an exact measurement of the blade extension. With three of these measurements a real-time caliper is obtained. This caliper measurement is situated approximately eight feet behind the bit.

Data from one well are analyzed where consecutive sections were drilled with the RSS, a packed hole assembly and a motor. The caliper data (wireline and RSS caliper) show dramatic differences in borehole quality. Whereas the RSS drilled section shows a smooth borehole, albeit enlarged by the time the wireline logs were run, the motor drilled section show a rapid changing caliper with a period of about three feet, indicating a spiraling borehole. This spiraling borehole caused problems when completing the well during the casing run. It also affected the quality of the wireline log measurements. The density/neutron data are rendered invalid for quantitative analysis. The resistivity logs are not affected.

Data from another well compare the borehole quality from an RSS run in point-the-bit and push-the-bit mode. Drilling in point-the-bit mode generally produces a smoother, more regular borehole caliper profile, as a result of greater bit and lower bottom-hole-assembly stability.

Introduction

During the field testing and initial commercial deployment of the Rotary Steerable System (RSS) described by Moody et al. 2004, borehole quality was evaluated using the tool's caliper measurement and when available, using other LWD and/or wireline logs. Earlier work has indicated that RSS's drill smoother boreholes and provide better hole cleaning (Grini et al, 2001) resulting in reduced torque and drag. Gaynor et al. (2001) comment on tortuosity generated by bent-housing motors and its effects on running tubulars into wells. One of the conclusions was that point-the-bit rotary steerable tools eliminate hole spiraling.

Maintaining an in-gauge borehole is also essential for RSS tools to obtain appropriate doglegs and to control the wellpath (Stroud et al, 2004). This is especially significant with respect to push-the-bit tools.

This paper focuses on caliper measurements and on the influence of borehole quality on data from logging tools. It is shown that good borehole quality improves the quality of the log data.

The Rotary Steerable System

The RSS used in this comparison is described in detail by Moody et al, 2004. **Figure 1** shows the RSS in push-bit-bit mode. **Figure 2** shows the tool in its point-the-bit configuration. A drive shaft runs through the center of the tool. A non-rotating housing supported by large bearings holds three blades which are independently operated to provide the steering forces for the tool. A stabilizer can be mounted below the tool to operate in point-the-bit configuration. With a drill bit connected directly to the rotating shaft, the tool is converted to push-the-bit configuration.

Real-Time Caliper Measurement

The RSS tool provides a real-time caliper based on the individual blade extension measurements. Because three of these data points are available both a caliper and a tool eccentricity value can be computed (Birchak et al, 1993). **Figure 3a** shows a cross section through the rotary steerable system. Each of the three steering blades is individually controlled by hydraulics. Each of the three blades incorporates a measuring device to provide an exact measurement of blade extension.

Figure 3b shows a real-time caliper log. The red, blue and green curves are the individual blade extensions on a 5 to 7 inch scale. The magenta curve is the resulting caliper log. The floating blade indicator shown as the orange bar on the left hand side of track 1 indicates which of the three blades acts as the floating blade (see Moody et al, 2003 for an explanation of the floating blade concept). A change in floating blade indicates that the essentially non-rotating housing did in fact rotate 120 degrees. The narrow track with the DD insert, shows the data density, as in standard LWD logs. The third track shows the time and date stamp, again typical for real-time LWD information before the time-to-depth conversion is performed. The black curve in this track shows the block position up to down from left to right of the track.

The caliper measurement has two major functions: RSS effectiveness indicator and drilling parameter quality indicator.

The real-time caliper information is used to gauge the effectiveness of the RSS and its ability to maintain the wellpath that it has been programmed to run. When the wellbore is enlarged and the moving pads are unable to keep tight borehole wall contact the tool will not drill effectively in its programmed direction.

The caliper is also a good indicator of general drilling parameter quality. It is understood that borehole break-out or borehole wash-out doesn't necessarily happen at the bit. Borehole deterioration in fact happens over a certain time period spanning from closely behind the bit to as long as the borehole remains uncased. But if borehole wash-out occurs during the drilling process, it is an indicator of poor drilling parameter selection. With this caliper information available in real-time, immediate action can be taken to correct the problem.

Well #1

This Gulf Coast well required a 10,320 ft long, 12¼ -in. section with a build at the beginning, and a long tangent to TD. The well was drilled using an oil base mud. Three BHA's were used in this section: first the rotary steerable system, then a fully stabilized assembly and finally a conventional directional performance motor. Details of these assemblies can be found in Table 1.

The rotary steerable system drilled 6,114 ft at an average of 97 ft/hr. WOB was maintained at 12,000 to 15,000 lbs. This penetration rate compared very favorably to the ROP of 46 ft/hr in an offset well. The difference in rig time was 85 hours or $106,000 in savings.

The packed hole assembly drilled 1,133 ft of the tangent section. This assembly achieved 41 ft/hr with WOB similar to the rotary steerable system run. Increasing the WOB to 30,000 lbs was necessary to increase the ROP to be comparable to the RSS achievement. This increased WOB caused the assembly to build angle and the WOB had to be reduced to 15,000 lbs, with resulting lower ROP's. Using the RSS would have resulted in savings totaling about $19,275.

The third BHA used a conventional performance motor. ROP's cannot be compared reliably because of formation changes and different drilling conditions. The motor, however, achieved 16 ft/hr while sliding and an average of 27 ft/hr while rotating. Even if the RSS would have not improved on the rotary ROP, it still would have saved at least 18.7 hours in this part of the well by eliminating sliding.

Borehole Quality Analysis

As shown above, it is quite easy to quantify the advantages of using an RSS in terms of ROP and the resulting rig time savings and hence a dollar figure can be attributed to these advantages. As we will show, we can identify borehole quality improvements when drilling with an RSS over conventional drilling assemblies. It is however a lot more challenging to express improved borehole quality in dollar terms. In the best case the quality of the borehole has no influence on the well completion cost. However, one casing that can not be set properly or one extra wiper trip can have quite an impact on the drilling cost. Trying to assess the cost of poor quality formation evaluation log data is beyond the scope of this paper, although it is recognized that this cost could be extremely high.

Figures 4 to 7 show wireline caliper logs for sections drilled with the three different BHA's. The logs show the gamma ray curve in green in track 1. The caliper is represented as mirror images in track 2. The caliper is shaded red from bit size (12.25-in) to indicated borehole enlargement. All figures display 200 feet of data.

The section represented in **Figure 4** was drilled with the RSS. The lithology changes from shale and shaly sands at the top into sandstone (xx125 ft) and shale again at the bottom of this section (xx225 ft). The borehole is in good condition although the shales are slightly washed out.

The section shown in **Figure 5** was drilled with the packed assembly. The sandstone section below xx740 ft appears to be in good condition whereas the shales above this depth are slightly washed-out.

Figures 6 and 7 show sections drilled with the motor assembly. Both figures show that the borehole is cork-screwed. In figure 6 the minimum measurement is about 12.5-in, the maximum about 14.5-in. The cycle is about 4 ft long between two low readings. Figure 7 shows the same cyclic behavior but superimposed on wash-outs. The caliper ranges from about 13.5-in to 16-in.

Log Data Quality

Figures 8 to 10 each show 200 ft sections of well log data to indicate the effect of the borehole quality and hence the effect of the choice of drilling system on the quality of the wireline logs. The caliper is plotted in track 1 and the red shaded area represents the difference between bit size and the caliper measurement and thus borehole enlargement. Track 2 contains the gamma ray in green (solid). Track 3 contains the resistivity data from an array induction type of tool. Track 4 has the density – neutron overlay with density in black (solid) and neutron porosity in blue (dashed). The crossover is shaded red. The density correction is the dotted black curve. Track 5 contains the compressional slowness from the sonic tool.

Figure 8 shows an interval of good borehole condition across some shales and a water sand. All the log curves respond accordingly. The data are valid and usable for formation evaluation.

Figure 9 shows another 200 foot section drilled this time with the packed hole assembly. As seen before, the shales are slightly washed out and display a more rugose borehole, whereas the borehole across the sandstone section seems to be in good condition. The data appear to be valid although spikes have appeared on the sonic curve and the neutron porosity seems to have been affected for instance from xx910 ft to xx917 ft. The density correction indicates larger and less smooth correction applied above xx975 ft than below this depth in the sandstone section.

Figure 10 shows an interval of spiraling borehole across some shales and another water sand. The borehole deterioration is obvious from the caliper response. The gamma ray and resistivity measurements don't seem to be affected by the borehole conditions. These two measurements don't rely on borehole wall contact to make a valid measurement. The density sources and detectors are built in to a movable pad that is pushed against the borehole wall to ensure good contact with the formation. The neutron tool is typically pushed against the wall using a bow spring. Both measurements cycle with the caliper, indicating repeating and cycling instances of loss of contact with the borehole wall. This renders the measurement invalid for quantitative formation evaluation. The density correction is large and again cyclic with the caliper. The sonic log is also affected. Although the measurement doesn't rely on wall contact, it is affected by borehole washout and rapidly changing borehole diameter. This can be seen from the spiky and irregular nature of the curve. Compare the nature of sonic response in the sandstone in **Figure 10** (xx300 ft to xx375 ft) to the sandstone in **Figure 8** (x130 ft to x225 ft).

Real-time and Wireline Caliper

Figure 11 shows a comparison between the real-time caliper measured by the RSS and the wireline caliper. The gamma ray is plotted in track 1 (green curve). Track 2 has the wireline caliper in blue and the RSS caliper in red.

It is interesting to observe that the shale sections predominantly wash-out after the RSS measurement. When and where the sandstone sections wash out we see this happening in the real-time caliper measurement. By the time the wireline caliper is measured typically the borehole deterioration is worse, but generally the borehole has the same washed-out shape as the measured by the RSS tool. This would indicate a mechanical wellbore instability situation during drilling in some of the sandstones.

Well #2.

The RSS tool has been run on 11 occasions at the GTI facility in Catoosa Oklahoma. The tool has been run in both push-the-bit and point-the-bit-hole configurations as shown by Figure 1 and Figure 2.

In addition to the fundamental changes to the steering method, a variety of bit types and styles have been run, and the spacing between bit-to-stabilizer and bit-to-blade-to-stabilizer have been tested.

In the push-the-bit configuration the tool exhibits a greater sensitivity of bit type to maximum dogleg and steering sensitivity. The position of the stabilizer has also had a large influence over the dogleg capability.

While the tools have achieved the same maximum dogleg in both configurations, the point-the-bit configuration has reduced the influence of the bit selection, and has produced reliable high quality boreholes.

The borehole quality assessed by the amount of drag, or additional force needed to move the BHA in the drilled hole, has been considerably worse in push-the-bit mode. A poor choice of bit type in addition to an incorrect bit-to-stabilizer spacing can cause sufficient drag to considerably reduce the ROP. It is assumed that the wellbore tortuosity is caused by the poor support for the bit exhibited by the push-the-bit configuration.

Conclusions

Caliper logs indicate that a rotary steerable system drilled a better quality borehole than a packed assembly and especially better than a motor/bent sub assembly. It's the author's opinion that this result should be expected in general, although extensive statistics are not yet available.

It has been shown that the improved borehole quality of a well drilled by an RSS (as opposed a motor assembly) can lead to more accurate and interpretable well logs. While the electric and natural gamma ray logs are relatively tolerant to borehole quality variability, the sonic and density-neutron logs can be affected much more severely. In examples shown here, the density-neutron and sonic logs could not be used for quantitative formation analysis.

The financial effects of poor borehole quality can be very large indeed, both to the hydrocarbon bearing wellbore and to the 'dry' hole. As the paper shows the accuracy of the LWD data is considerably reduced and in cases the data are invalid this directly reduced the accuracy and validity of the hydrocarbon in place calculations and can therefore call into question the financial viability of the well.

The added tortuosity of the wellbore considerably increases the problems running the casing, and in the worst case can result in the casing not reaching bottom, or sticking off bottom.

The point-the-bit configuration gave a better quality borehole than the same tool run in push-the-bit configuration in the cases considered here. While the push-the-bit configuration can make a good quality borehole, it has proven sensitive to bit type and tool spacing.

Acknowledgments

The authors would like to thank the different operating companies for their willingness to field test the Pathmaker™ rotary steering tool and to allow us to use the data presented here. We are grateful to PathFinder Energy Services and especially Peter Leonard and Steve Jones for their help.

Nomenclature

BHA = *bottom hole assembly*
ROP = *drilling rate of penetration*
WOB = *weight on bit*

References

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Table 1 – Well 1 Bottom Hole Assemblies

		RSS	Packed Hole Assembly		Motor Assembly
Footage	ft	6114	1133		3073
WOB	lbs	12,000 – 15,000	12,000 – 15,000	30,000	
ROP Rotating	ft/hr	97	41	90	27
ROP Sliding	ft/hr	N/A	N/A	N/A	16

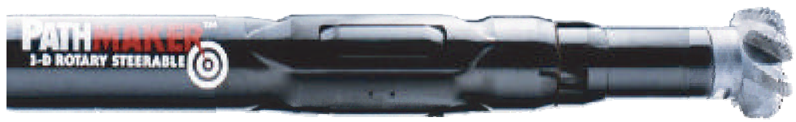

Figure 1 – Rotary Steering System in Push-the-Bit Configuration

Figure 2 – Rotary Steering System in Point-the-Bit Configuration

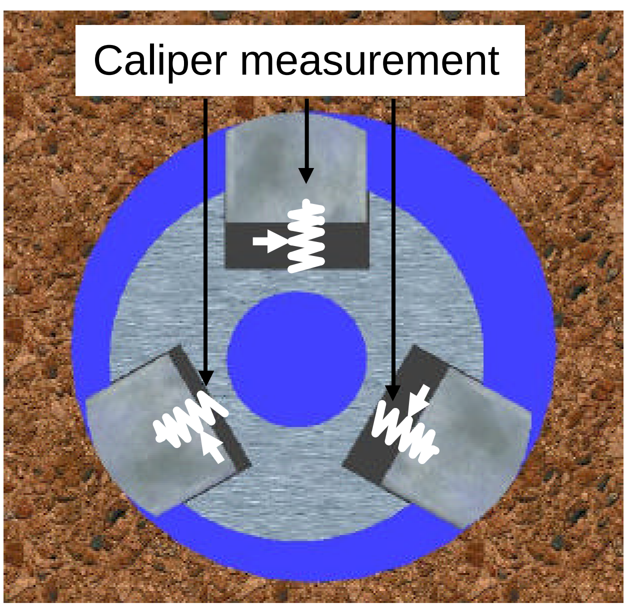

Figure 3–a. Caliper Measurement

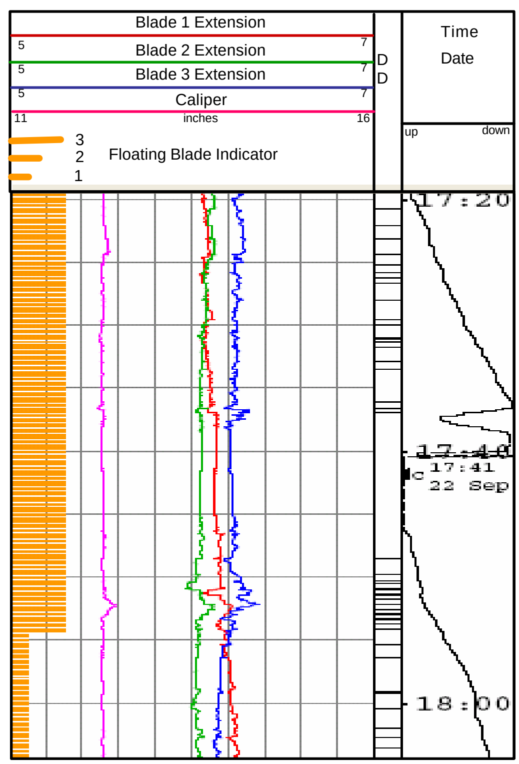

Figure 3-b. Real-time Log

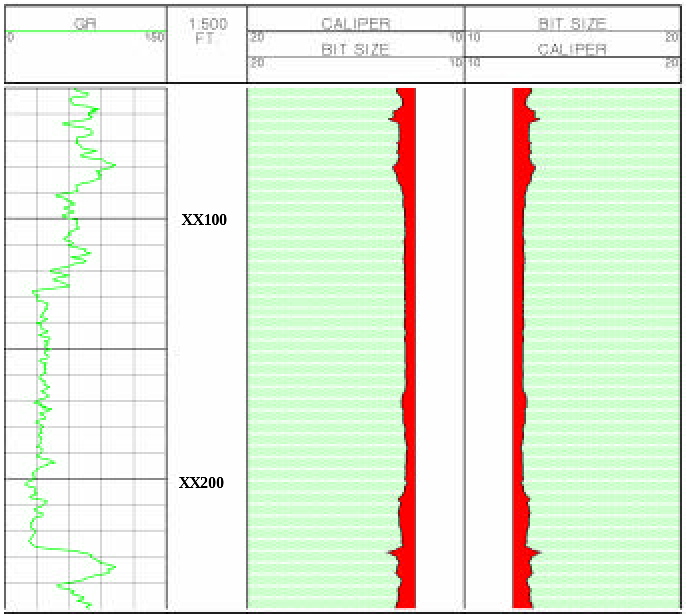

Figure 4 – Section drilled with RSS

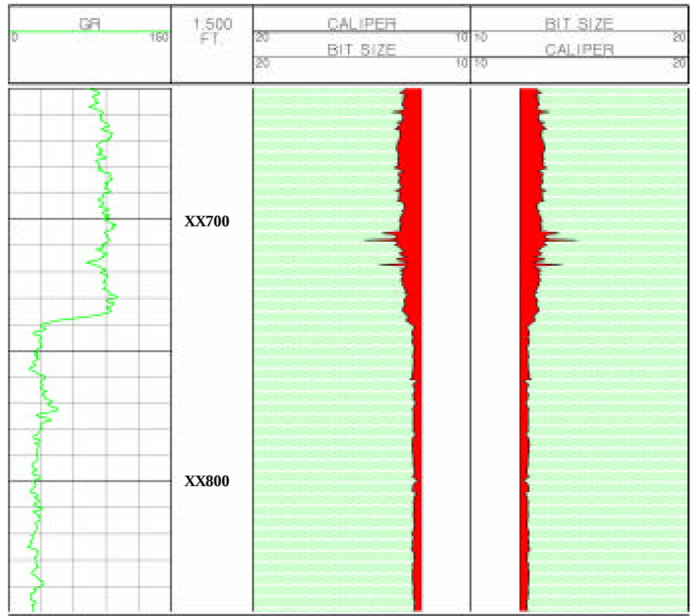

Figure 5 – Section drilled with packed assembly

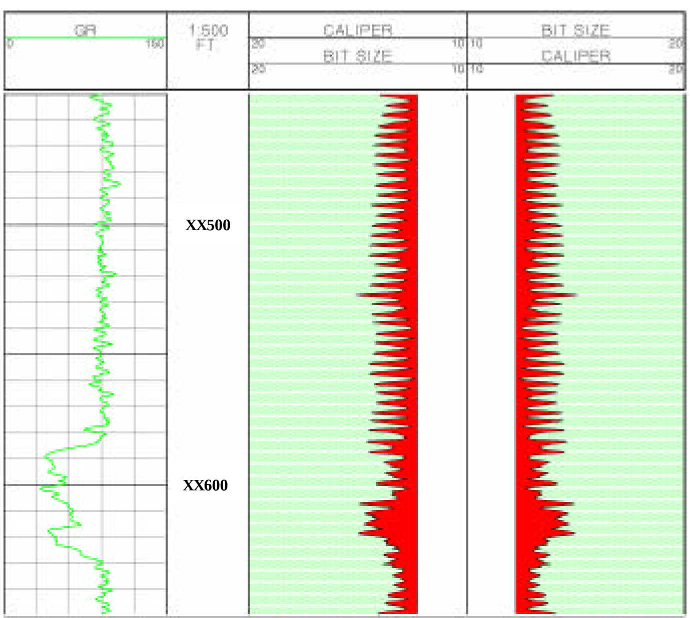

Figure 6 – Section drilled with motor assembly

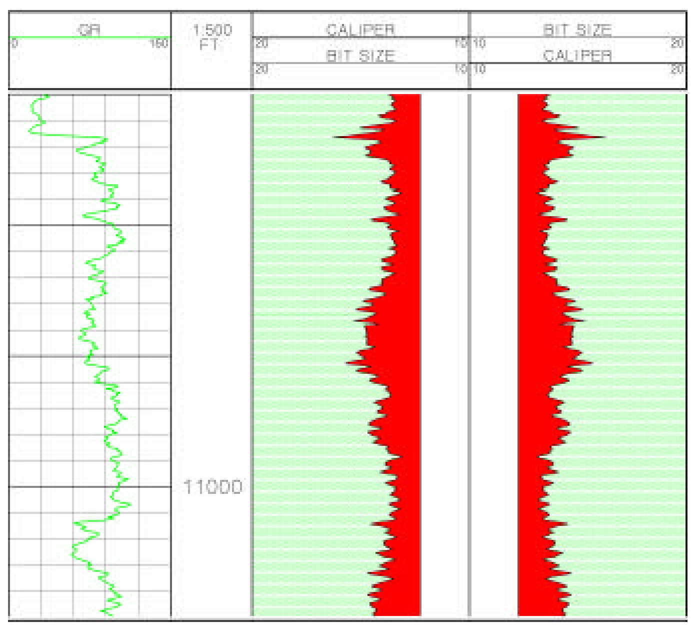

Figure 7 – Section drilled with motor assembly

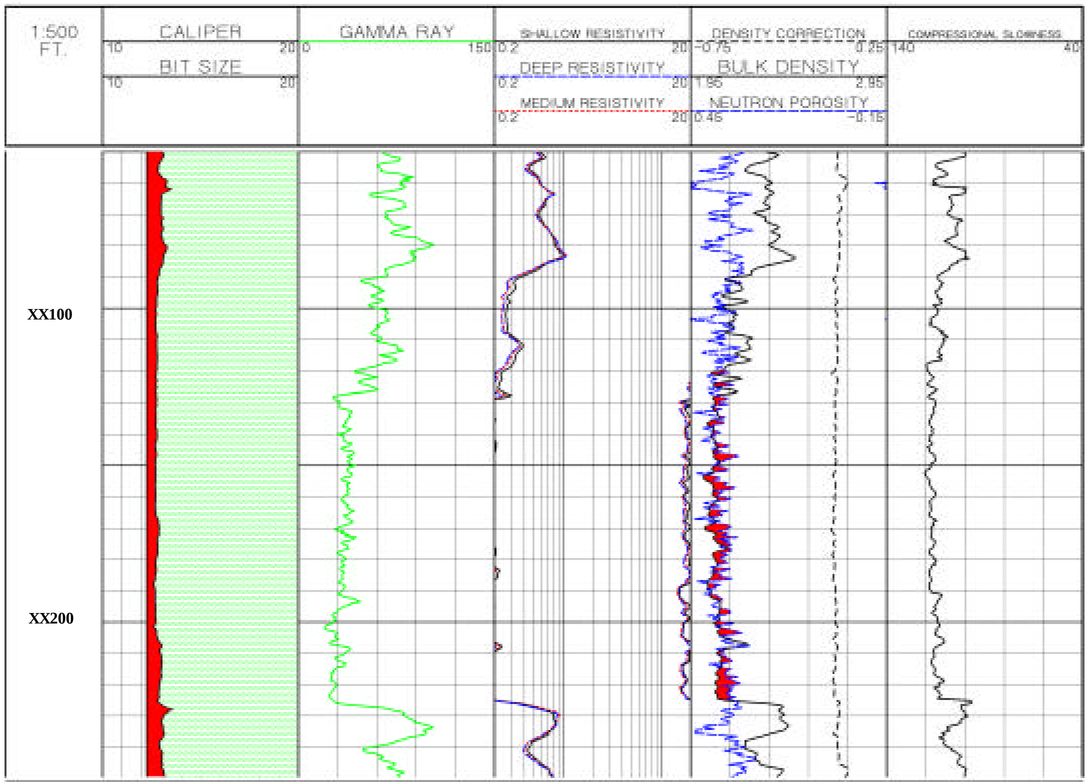

Figure 8 – Log Data Quality in Section Drilled with RSS

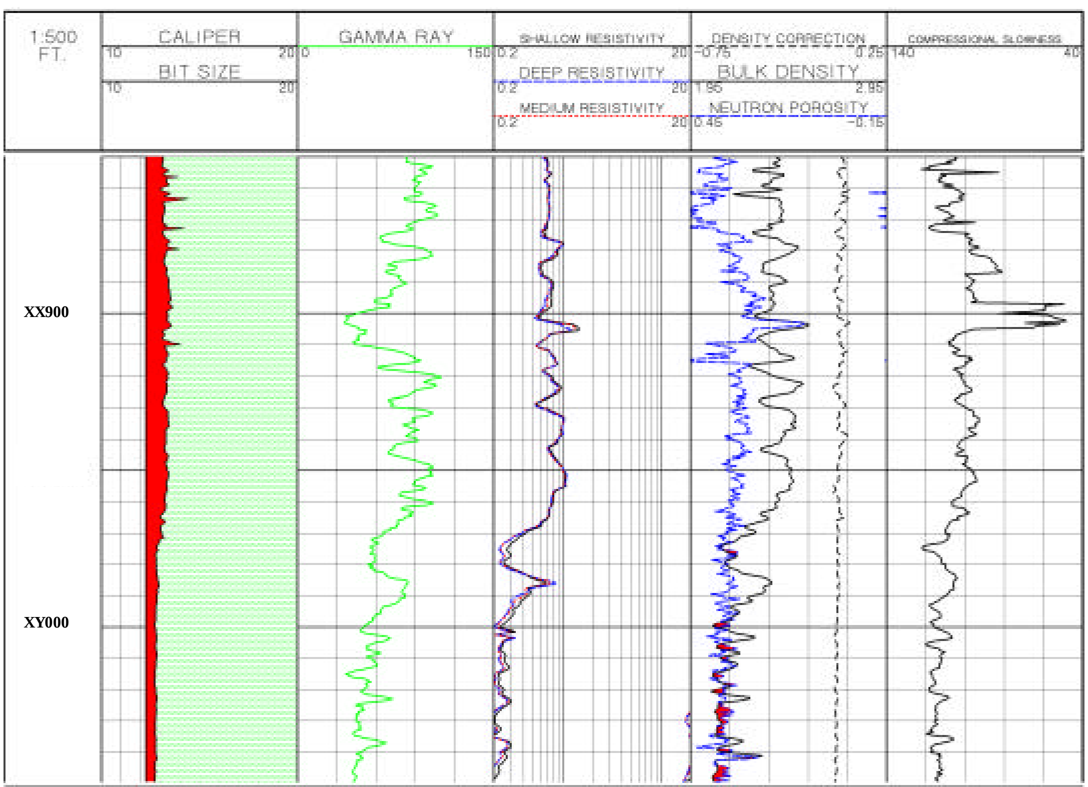

Figure 9 – Log Data Quality in Section Drilled with Packed Hole Assembly

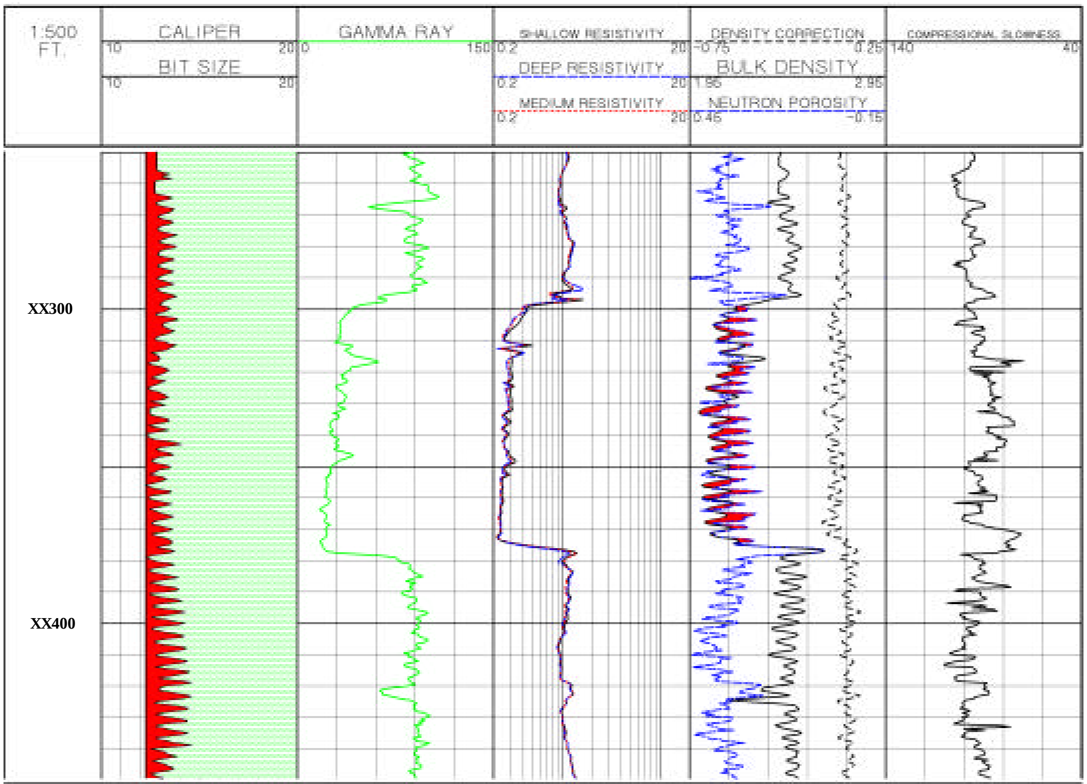

Figure 10 – Log Data Quality in Section Drilled with Motor Assembly

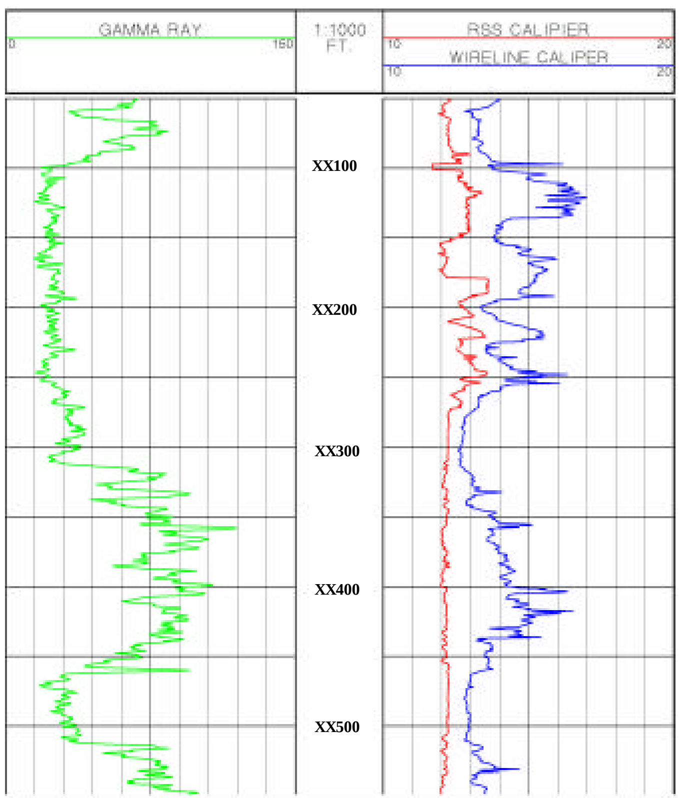

Figure 11 – RSS Caliper and Wireline Caliper