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Rotary Steerable Systems in the Gulf of Mexico - A Step Change in Drilling Performance

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Abstract

For the last 10 years the majority of directional drilling work in the Gulf of Mexico has been undertaken using steerable positive displacement motors. While significant advances in motor design have been made during this period the basic steerable motor drilling technique has altered little.

Rotary steerable tools now provide an alternative drilling system for directional wells. The rotary steerable will eliminate many of the inefficiencies associated with steerable motor drilling. Wells can be drilled at a faster rate with no requirement to slide the BHA in order to steer. Hole quality is improved through drilling gage hole with no spiralling and a far less tortuous well path will be drilled with no micro dog-legs.

Through examples from Gulf of Mexico runs undertaken to date, this paper highlights the benefits of rotary steerable drilling. These benefits can be seen as a step change in drilling performance

Introduction

The use of rotary steerable systems for directional drilling in the Gulf of Mexico has been slower to develop than in other drilling provinces around the world such as The North Sea. Experience to date however has shown that the benefits of rotary steerable drilling can be highly significant for directional drilling operations under a wide variety of Gulf of Mexico well types and operational conditions.

The tangible benefits of a rotary steerable system when compared to a steerable motor assembly can be directly measured in the time saving achieved. This can be expected through elimination of sliding the BHA in order to steer the wellbore. At a basic level, therefore, the economics of using a rotary steerable system can be calculated based on the steering requirements of a given well trajectory. However, by providing improved hole quality, enhanced hole cleaning as well as optimized bit and drilling parameter selection the use of a rotary steerable will result in intangible benefits which can lead to a step change in drilling performance. Analysis of runs made with Schlumberger's PowerDrive system clearly illustrates these benefits in Gulf of Mexico operations.

Steerable Motor Drilling

Steerable motor drilling is inefficient. With a requirement to slide the bottom hole assembly in order to steer the well path drilling becomes slower and potentially more problematical. ROP is impacted as a result of wellbore friction and BHA components hanging up. Hole cleaning, without drillstring rotation, is adversely affected, as cuttings will drop out of suspension to the low side of the hole. As rotation is restarted after a steering interval these cuttings may be picked up as a mass with potential for hole pack off. This phenomenon is frequently observed when monitoring downhole pressure data from an MWD tool.

The transition from slide back to rotate requires rotating the motor bend through the section steered. This can result in hole spiraling.

Steering a steerable motor requires maintaining the orientation of the bend in the desired tool face setting. Reactive torque from the motor itself works against good tool face control with the force turning the string in a counterclockwise direction. The magnitude of reactive torque will depend on the torque being generated at the bit which itself is a function of bit aggressivity, motor torque output and the formation being drilled. Tool face control using a light set bit with large cutter diameter run on a low speed high torque motor can be extremely difficult. As a result a compromise on bit selection is frequently made for steerable motor drilling. It is not unusual for a roller cone bit to be run for a critical directional section of the well due to problems controlling toolface with a PDC bit and this frequently results in additional trips for that hole section. Orienting a PDC bit can be time consuming with frequent time spent off-bottom in order to control reactive torque.

The rotary sections with a steerable motor can also result in inefficient drilling. As with a rotary bottom hole assembly the directional behavior of a steerable motor assembly will be a function of stabilizer gauge and spacing as well as drilling parameters used. As a result the drilling parameters will be set to control the directional tendency of the assembly as opposed to maximizing ROP. Drilling an angle drop section of a well is a typical situation where efficiency is compromised through running low weight on bit to encourage angle drop in rotary mode.

Based on these inefficiencies the rotary steerable system should therefore be able to deliver:

- Increased ROP
  - no sliding intervals
  - more aggressive bits
  - optimized use of drilling parameters
- Reduce trip time through better hole quality
  - improved hole cleaning
  - reduced tortuosity
  - improved hole gage

Rotary Steerable System Overview

The PowerDrive design is contained in a short near-bit assembly. A 6 3/4" tool (PD675) is used for drilling 8 1/2" or 9 7/8" hole and a 9" (PD900) tool for 12 1/4" or 14 3/4" hole. These tools are 12.5 feet and 14.6 feet long respectively. A schematic of the tool is shown in fig 1. There are two principal components:

- The bias unit applies a lateral force to the bit while it constantly rotates at bit speed.
- The control unit is a roll-stabilized platform located within a nonmagnetic collar. It contains self-powered electronics and sensors that set the direction and magnitude of the force vector applied to the bit by the bias unit.

The bias unit is connected directly to the drill bit. Three exterior pads are kept in constant contact with the formation by internal, mud-powered actuators. A three-way disc valve controls the flow of mud to the actuators. When deviation is required, each actuator is extended in sequence, once each revolution of the bit, against the side of the hole opposite the intended bias direction. Fig 2 illustrates the steering principal. The pads are in constant contact with the wellbore, extending and retracting in a smooth, continuous action. When no deviation is required, the PowerDrive system is put in neutral mode by simply rotating the disc valve stator relative to the high side. This causes the pads to push in every direction and effectively cancel each other.

The control unit is mechanically linked to the bias unit and sets direction and deviation. It contains sensors and control electronics inside a cylindrical pressure case, which is mounted on bearings within the drill collar. The bearings allow the control unit to rotate or remain stationary, independent of drillstring rotation.

Power is generated through two turbine impellers that support the control unit's sensors and electronics.

PowerDrive directional programming can be altered from the surface without interrupting drilling using a sequence of flow generated mud pulses. Unlike a pressure activated command sequence, downlinking by flow rate change does not interfere with MWD/LWD signal transmission and therefore does not interrupt real-time log data. It is a highly robust system that has been succesful at hole depths of over 35,000 feet on ERD wells in Europe.

Steering commands are given as a tool face orientation (magnetic or gravity depending on hole inclination) and an operating percentage. The tool is normally programmed to operate on a 5 minute cycle and the percentage command will determine how much of the cycle is spent steering. At 100% the tool will steer continually in the programmed tool face and therefore drill at maximum dog-leg. At 50% setting the tool will steer for half the cycle time and drill with half the maximum dog-leg if the tool is stabilized to hold angle in the neutral mode. A total of 81 settings are available.

A key feature of the system is that all the external components of the tool rotate from surface. There are no stationary components to hinder hole cleaning or increase chance of pack off. This also means there is no limitation on the ability to backream as required. The tool creates a minimal shock environment promoting outstanding MWD/LWD reliability.

Drill Bit Requirements

When selecting a bit for rotary steerable drilling the cutting structure should be based on optimizing the ROP in the formations to be drilled. Bit design however should take into account a few basic requirements to insure good system steerability. The overall legth of the bit should be short. This is important because the side force applied to the bit depends on three points of contact: the top stabilizer is the end of the lever and the moveable pads are the fulcrum. The bit is the other end of the lever. The highest force is applied when the fulcrum is closest to the end where the reaction force is created (the bit). Thus, the shorter the distance from the pads to the bit face, the more responsive the system will be to the push of the PowerDrive pads. Secondly a flat profile will aid steering as the shallower the cone, the more readily the bit will change direction and side cutting can be enhanced by extending the full round cutters along the gauge line part of the bit profile. Products with a short gauge (1 ½") meet the criteria and work best with the PowerDrive system. Reed-Hycolog has a range of bits specifically designed for the PowerDrive system and the DS130 and DS163 are examples of bits that have provided excellent drilling performance in the Gulf of Mexico both in terms of system steerability and ROP.

Increasing ROP

PowerDrive runs in the Gulf of Mexico have shown significant improvements in ROP. Drilling an S shaped well through two tight targets in a Vioska Knoll well gave the opportunity to get a direct comparison between steerable motor and rotary steerable drilling. The PowerDrive rotary steerable system was selected to provide optimized penetration rates while managing the required drop and turn in the directional trajectory. Additionally the well required tight control on the ECD in order to prevent mud losses and insure efficient hole cleaning capability. Use of a rotary steerable system would ensure that cuttings could be kept in suspension at all times while drilling, eliminating ECD fluctuations and spikes associated with sliding.

The PowerDrive assembly was used to drill out the cement and shoe track. Formation was then drilled from 11,660 to 14427 ft a total of 2767 ft. This was achieved in 42 drilling hours at an average penetration rate of 66 feet per hour. By comparison a follow up motor run drilled 1303 feet in 48 hours with an average ROP of 27ft per hour. Fig3 shows a comparison of a ten-hour section from each run. Plotting depth against time as well as bit position clearly highlights the advantages of rotary steerable drilling. Each stand down with the rotary steerable plots as a straight line and at no time did the bit have to be picked off bottom. At each connection the pipe was worked while circulating cuttings away from the BHA. By contrast the steerable motor required constant picking off bottom as a result of the BHA hanging up and to keep the assembly in the right orientation.

On this well the PowerDrive provided the required directional response while drilling at nearly two and a half times the penetration rate of the steerable motor and insuring a wellbore in optimum condition through continuous rotation and allowable higher flow rates.

With increasing requirement to develop sub-salt reservoirs directional drilling in salt has become an increasingly important issue for the Gulf of Mexico. Bit selection for steerable motor work in salt has often been compromised in order to achieve tool face control with, for example, a roller cone bit being preferred over a PDC[1]. Average salt penetration rates have been reported at less than 30 ft/hr. Using PowerDrive for a 12 1/4" salt section in another Vioska Knoll block allowed optimum bit and drilling parameter selection and an average penetration rate of 116 feet per hour resulted.

The economics of drilling with such improvement in penetration rate can be clearly shown whether it be a jack-up operation on the shelf or a latest generation floater in deepwater. A Eugene Island well required a sidetrack in 9 7/8" hole after the initial well had failed to find economic hydrocarbons. Aligning the sidetracked wellpath on the new target required some 160 degrees of azimuth change. This necessitated dropping the well angle to below ten degrees inclination turning to the desired direction and building back up. Sliding a steerable motor in water based mud had been difficult through these formations first time round and drilling progress had been slow. Using a rotary steerable system and changing to oil based mud the drilling problems previously encountered. The PowerDrive assembly was run in the hole at 11467 feet and drilling proceeded with excellent steering response. The drop, turn and build required by the wellplan necessitated frequent downlinking of commands to the tool which were effected with minimal disruption to the drilling operation. At 12792 feet a top drive problem necessitated a trip to surface for repairs. With only 34.5 hours on the BHA and minimal wear seen on the bit or bias unit the same BHA was run back in the hole. Penetration rates averaged 90 ft/hr for the second run with some sections drilling at 120ft/hr and instantaneous rates over 200 ft/hr.

At 16363 feet the hole section was TD'd for a 7 3/4" liner to be run. At this point the well was lined up on both targets and the directional work essentially completed for the sidetrack. A total of 4894 feet had been drilled with PowerDrive 74.5 hours - an average ROP of 63.3 feet per hour. Even with nearly 3 days downtime for top drive repairs the hole section had been drilled in less than half the time for the equivalent footage on the original well.

Hole Quality

Hole quality resulting from a rotary steerable system should be as close to optimal as possible for a directional well. When drilling with PowerDrive tortuosity is kept to a minimum. Conventional surveying practices frequently hide the true profile of a directional well drilled with a steerable motor. Surveys taken every stand drilled will show an average of sliding and rotating over the length of the stand. Using continuous survey measurements from the MWD tool it is possible to gain a true picture of the tortuosity profile of the wellbore. Fig 4 shows such an example from a Gulf of Mexico well. The solid lines link the stationary survey inclination and azimuth measurements recorded each stand down and show that the planned 2.5 degree per 100 feet build up rate had been achieved. However the circles representing the continuous survey data paint a different picture. The build rate while sliding is at times over 8 degrees per 100 feet and additional sliding footage was required because the BHA was dropping angle in rotary mode due to the soft formation.

As a comparison fig 5 is from a hole section drilled with a PowerDrive rotary steerable tool. The continuous inclination data shows that a smooth predictable build and turn rate is achieved at each tool setting with no hidden or excess dog-legs. In this case the tool was being use for a secondary build and turn section in 12 1/4" hole. Keeping dog-legs to the plan can have a major impact on the success of a well. Unseen or micro dog-legs will increase forces on the drill pipe later in the well resulting in increased torque as well as potential tool joint or casing wear problems. They will also impact the ability to run wireline logs and casing into the wllbore.

Another indication of hole quality is the gauge or shape of the wellbore after drilling. The PowerDrive tool provides a gauge hole with no indication of hole spiraling. Schlumberger's Azimuthal Density Neutron tool (ADN) data can be used to provide qualitative indication of hole shape. Figure 6 is an example of such an image. In this consolidated reservoir a bit run was drilled with a mud motor followed by a run with PowerDrive. A 3D image is displayed where the BHA change was made. It is very clear from the images that the interval drilled with PowerDrive, exhibits a very smooth borehole. In contrast the interval drilled with the mud motor, exhibits enlargement and rugosity. The variations in borehole shape can be related to the sliding and rotating modes of the mud motor. In this case the largest borehole sizes are coincident with the zones of sliding and occur after rotation is re-started when the bend has to rotate through the steered section.

The intangible benefits of using a rotary steerable system are highly significant and should be taken into consideration when evaluating the potential for any particular well. Rotary steerable systems represent a step change in directional drilling costs for a well and as such must be justified through reducing the overall cost of a well. However, experience to date has fully justified the decisions to run PowerDrive. When a hole section with a best time of 11 days for steerable motor drilling can be drilled in less than 5 days with PowerDrive the economics are there for a win win scenario. With these time savings, even adding the cost of a rotary steerable system to an operating spread rate of $80,000 per day cost would result in considerable cost reduction.

Conclusions

This paper has given a brief highlight of the drilling improvements seen when drilling with the PowerDrive rotary steerable system in the Gulf of Mexico. However as more and more runs are made the theme remains the same. Well are drilled at a faster speed with improved hole quality insuring better trip times, a reduced need to wiper trip and easier logging and casing running operations.

While system availability will dictate that steerable motor drilling will remain the main directional drilling technique in the Gulf of Mexico for the near future experience to date is pointing to a bright future ahead for rotary steerable drilling.

Nomenclature

BHA = bottomhole assembly
BOP =blowout preventer
ECD = equivalent circulation density
EMW = equivalent mud weight
RKB=rig floor kelly bushing elevation
ROP = drilling rate of penetration
rpm = revolutions per minute
TD=total depth
TVD=true vertical depth
WOB = weight on bit

Acknowledgments

The authors thank the many people at

References

[1] J. R. Cromb,C.G. Pratten, M. Long, R.A. Walters, "Deepwater Subsalt Development: Directional Drilling Challenges and Solutions" IADC/SPE Paper No 59197 presented at the 2000 IADC/SPE Drilling Conference held in New Orleans, Louisiana, 23–25 February 2000.

Figures

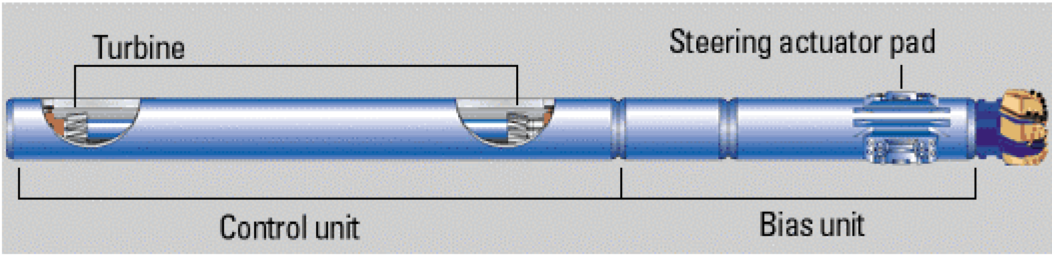

Fig. 1- Schematic of the PowerDrive rotary steerable tool.

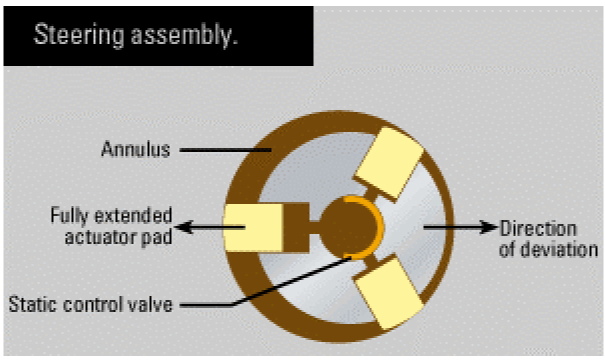

Fig. 2- PowerDrive steering principal.

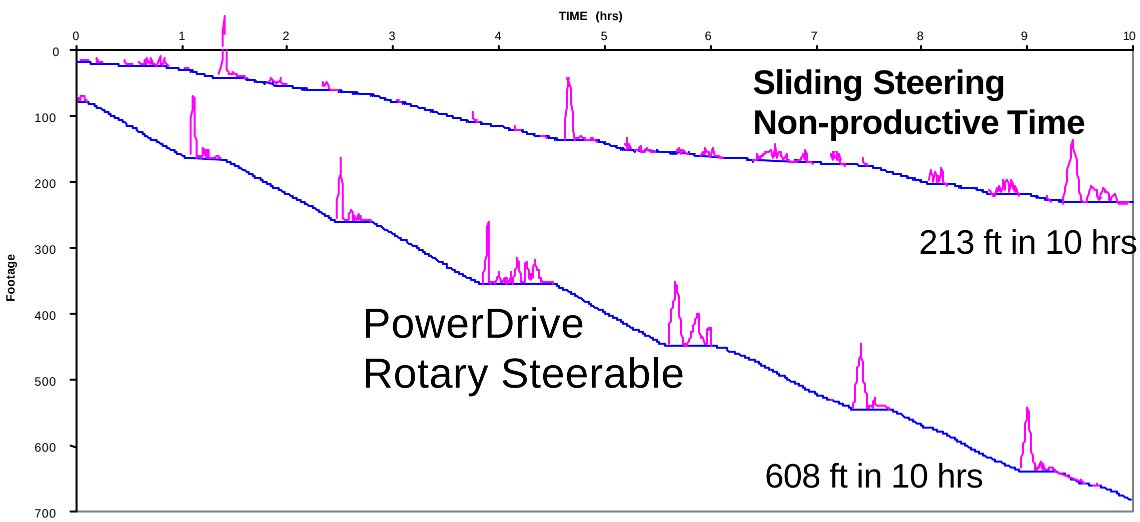

Fig. 3- Comparison between rotary steerable and steerable motor runs in the same well.

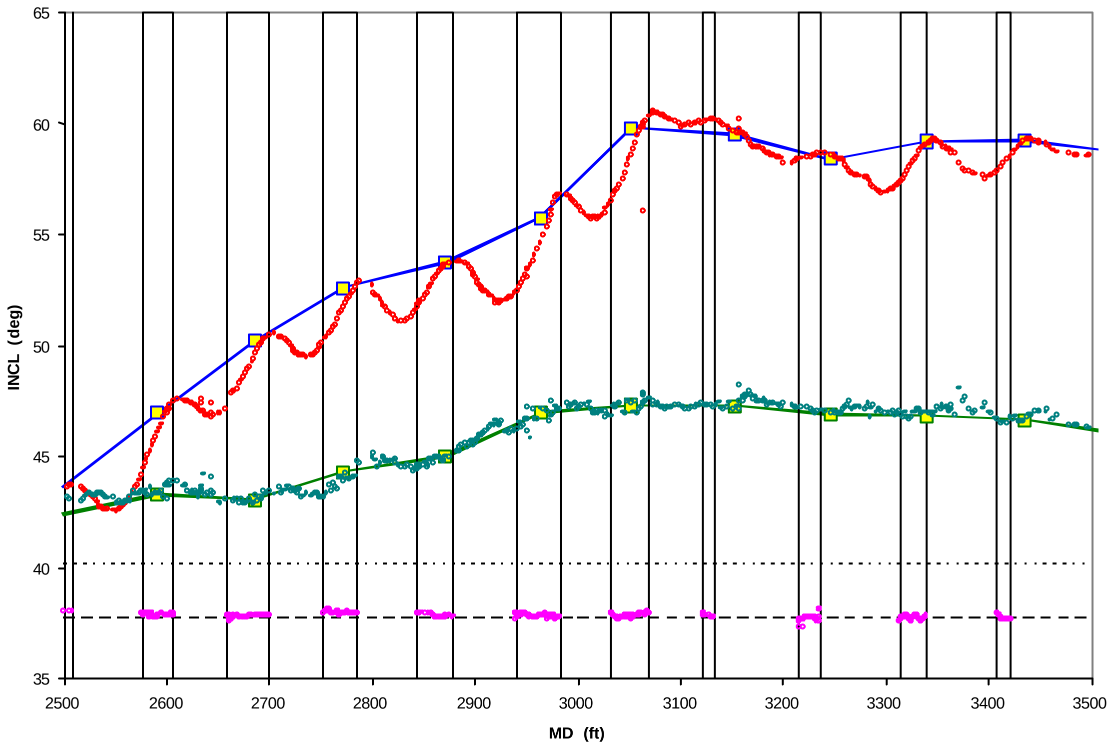

Fig. 4- Dog-leg and tortuosity from a steerable motor run as shown by continuous survey data

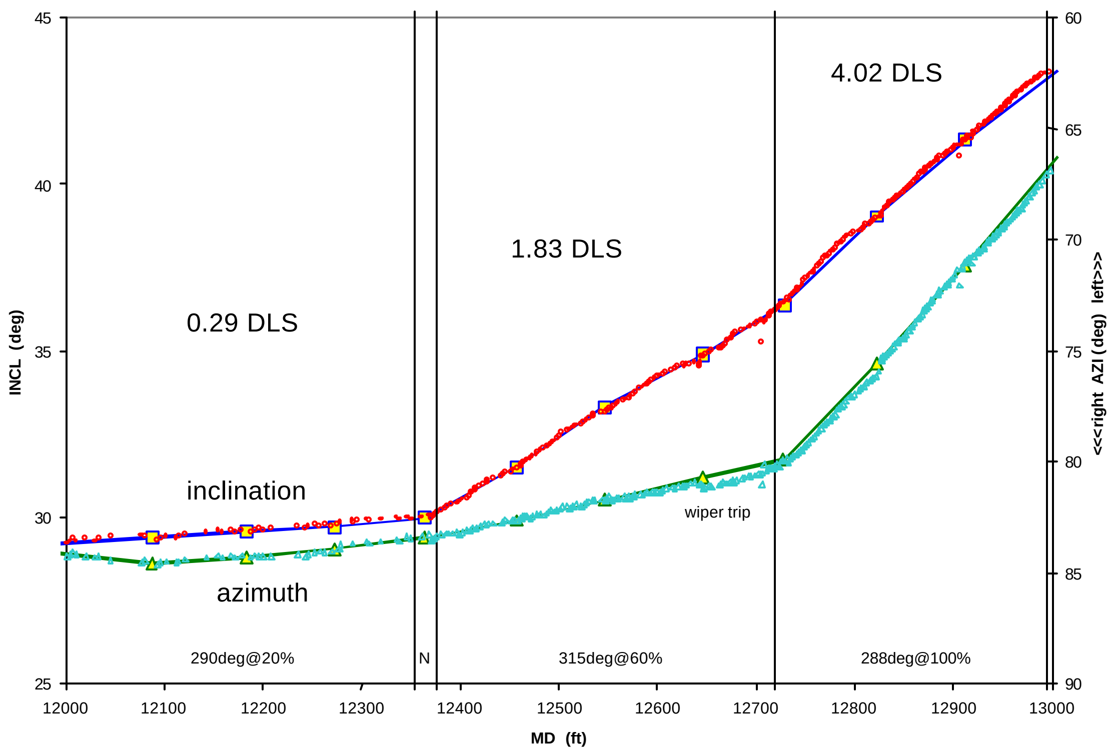

Fig. 5- Dog-leg and tortuosity from a PowerDrive run as shown by continuous survey data.

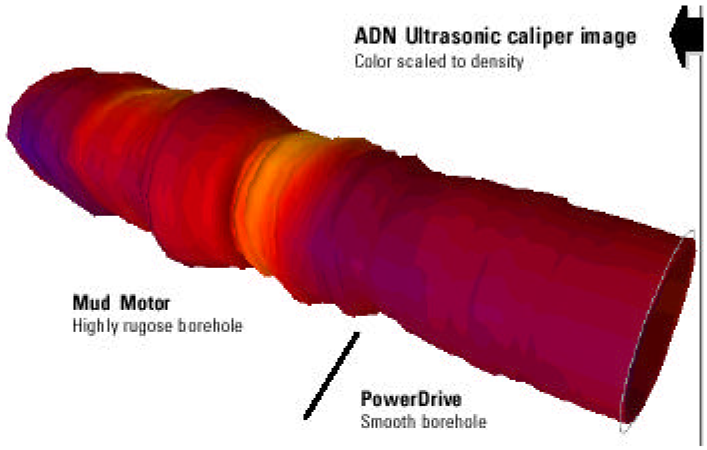

Fig. 6- Ultrasonic caliper images comaring borehole quality from PowerDrive with steerable motor