AADE 01-NC-HO-25

Implementation of a Next Generation Rotary Steerable System

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This paper was prepared for presentation at the AADE 2001 National Drilling Conference, "Drilling Technology- The Next 100 years", held at the Omni in Houston, Texas, March 27 - 29, 2001. This conference was hosted by the Houston Chapter of the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individuals listed as author/s of this work.

Abstract
This paper will present a second generation rotary steerable system that utilizes "point-the-bit" technology as opposed to "push-the-bit" concepts employed on first generation systems. The point-the-bit technique and the differences between point-the-bit and push-the-bit systems will be discussed. The system has accumulated 25 runs at the time of the writing of this paper (2/01). Results for several selected case histories will be presented. The paper will discuss the issue of borehole quality and why point-the-bit concepts deliver on this promise of rotary steerable technology.

Introduction

Rotary steerable technology promises to enable greater extended reach, more complex 3-D well geometry, and greater drilling efficiency by eliminating the slow ROP associated with oriented drilling. In addition, hole cleaning is generally improved due to the constant agitation with full-time rotation of the drill string. Weight transfer is also improved due to the elimination of sliding friction. The ability to manipulate the directional behavior downhole has also reduced the need for trips to change the BHA.

Early systems utilize a deflection method that relies on exerting side forces on the wellbore to cause the bit to drill in the opposite direction. While these systems have proven to work under many circumstances, the concept relies on external moving parts that are subject to reliability problems. Contrary to claims of reducing wellbore spiraling, these systems actually create an environment that encourages wellbore spiraling by the very nature of the bit deviation technique.

A new second-generation rotary steerable system has been introduced which does not rely on reacting against the well bore with external moving parts for deviation. (See Figure 1) Instead of using external pads to push the bit sideways, an internal rotating driveshaft is deflected off-center to create a deviation of the bit axis relative to the rotary steerable tool axis. Perhaps even more significant than the inherent reliability of the technique is the impact this concept will have on wellbore quality, specifically the elimination of wellbore spiraling.

History of Development

The new Geo-Pilot™ rotary steerable system is the result of a collaboration between Japan National Oil Corporation (JNOC) and Sperry-Sun Drilling Services. The heart of the system originated with JNOC's "Remote Controlled Dynamic Orienting System", ("RCDOS"), the details and development of which are described in SPE 56443[1]. RCDOS included a highly refined compact biasing unit, drawing on technology from the robotics and automation industries. The collaboration was initiated in August of 1997 and proceeded through 1999. The development team included members of Sperry-Sun's three technology centers (Nisku, Canada; Houston, Texas; Cheltenham, England), and included contributions from JNOC and JNOC subcontractor technical professionals. Under the collaboration, the RCDOS bias unit was integrated with Sperry-Sun's LWD and drilling tool elements and expertise, resulting in a complete rotary steerable system. Following successful field trials in 1999, Sperry-Sun, with its global drilling services market presence and infrastructure, was granted patent and technology licenses by JNOC to bring this technology to market.

System Description

The system consists of several major components. A driveshaft with bearings mounted at each end is driven by drill string rotation from surface. The bearings in turn support a rotation-resistant housing, which slides down the borehole maintaining contact so as to provide a reference orientation. Rotary seals on both ends of the housing allow the driveshaft to rotate while containing the oil that lubricates all internal parts. The housing has an inclinometer package for establishing a highside reference (which way is "up"). Midway between the bearings is the compact bias unit. The bias unit is comprised of two eccentric cams and the control mechanism for rotating each cam independently. (see Figure 2). The eccentric cams can be moved to opposite positions relative to each other such that the offsets cancel and the shaft remains straight. By orienting the cams in the same direction, the driveshaft can be moved to full deflection. This deflection can be oriented up, down, left, right, or in any other desired toolface simply by rotating the cams together. Intermediate levels of deflection are possible by rotating the cams to any desired position between fully aligned and opposed.

The result is that by bowing the driveshaft in the middle, the end of the shaft is tilted relative to the axis of the tool. (See Figure 3) The bit is made up to the driveshaft, translating tilt directly to the bit, thereby creating a deflection of the bit axis relative to the tool axis, hence "pointing the bit". The lower bearing, which acts as the pivot point, is located only 2 feet from the end of the tool, thus creating a high degree of tilt for a relatively small deflection of the driveshaft.

Reliability

Reliability is crucial to achieving a viable commercial system and becomes more critical on extended reach wells, where the cost of a trip is considerably higher than for a typical well. From its inception, one of the most critical design goals for the Geo-Pilot™ system has been to achieve extremely high reliability. Design decisions in this regard included the incorporation of the extremely robust JNOC bias unit, the containment of all moving parts within an oil environment, and the use of many proven design features from other drilling and MWD tools.

In addition, four of the five electronics boards were already in use in existing LWD tools or other proven equipment and had gone through significant refinement before being incorporated into the Geo-Pilot system. Therefore the expectations of reliability are very high, and early indications are that these expectations will likely be realized.

Numerous field trials were conducted, prior to commercial launch, that revealed various shortcomings, and improvements were engineered and implemented. The system was then launched commercially. To date, February 2001, the system has been run 25 times on a commercial basis. Out of these 25 runs, five failures have been experienced, all in the first 16 runs, with no failures in the last nine runs. Statistically this data is not sufficient to draw any firm conclusions, but it is an early indication of excellent potential reliability. Also significant is that the last five jobs have each been completed in a single run with a single tool. The current mean time between failures is approximately 250 hours. Another statistic of interest is that, in 25 runs, there has never been an LWD failure. This success rate is attributed to the low vibration levels resulting from the use of long gauge bits, as discussed in the next section.

Point-the-Bit Technology and Borehole Quality

Several papers have been published[2,3,4] which discuss the significant impact of borehole quality on overall drilling efficiency. Wellbore quality really means drilling straighter boreholes and eliminating borehole spiraling. Better quality is achieved primarily by use of long gauge bits, combined with either specially designed positive displacement motors or point-the-bit rotary steerable technology. These references reflect experience with over 300 wells (primarily utilizing motors) demonstrating the following improvements:

- Significantly lower friction, thus extending directional reach capability, allowing more complex 3-D well trajectories, and making for easier casing/logging runs
- Improved hole cleaning and fewer short trips, hence less time spent circulating and tripping, especially in high angle wells
- Longer bit life due to the stabilizing effect of the extended gauge length
- Better overall rate of penetration due to the improved bit life, resulting in higher overall ROP for a greater percentage of the interval
- Reduced incidence of MWD/LWD failures as a result of the vibration dampening action of the long gauge bit
- Higher quality logs due to the absence of spiraling and hence the elimination of a constantly changing borehole effect

A long gauge bit (See Figure 1) imposes certain requirements on the drilling system, whether used with a conventional positive displacement motor or with a rotary steerable system. The rotary steerable concept for bit deflection must allow for the use of long gauge bits. A point-the-bit concept allows for the use of long gauge bits because the bit is tilted. In order for a push-the-bit tool to deviate, the bit must have sidecutting structure in order that side loads created by the tool result in deviating the hole. Once the bit has the ability to cut away the side support of the formation, and has minimal gauge length to constrain it, the bit will move laterally off center. Due to the centrifugal forces of the rotating drill string, a short gauge bit with cutting structure on the gauge will naturally begin to cut a helical path rather than a straight path.

By utilizing a deflection technique that does not rely on side forces but rather a change in bit axis relative to tool axis, no sidecutting action is required of the bit, and extending the gauge length is not an issue. All of the improvements in drilling efficiency listed above are realized, greatly enhancing the tremendous value already achieved by utilizing a rotary steerable device.

Case Histories

As mentioned before, the Geo-Pilot system has been run 25 times as of the writing of this paper. All but one of these runs was in the North Sea. Most of these wells are true rotary steerable applications, in that, for the most part, the wells could not have been drilled without rotary steerable technology. A few projects have been selected for discussion.

Well 1

This well was drilled in the Norwegian Sector of the North Sea. The extremely challenging well profile is shown in Figure 4. The upper 12-1/4-in. hole section was considered a serious challenge for conventional technology and actually qualified as a rotary steerable application. The final 8-1/2-in. hole section was definitely a rotary steerable application.

In the 12-1/4-in. hole interval, a 2-D rotary steerable system made up of the SlickBore™ system and the TRACS™ (Telemetry Regulated Angle Control System) adjustable gauge stabilizer was utilized. The SlickBore™ system matches SecurityDBS long gauge PDC bits with specially designed SperryDrill™ extended power section mud motors. The SlickBore™ system has drilled some of the lowest friction wellbores on record. The TRACS™ adjustable gauge stabilizer allows the stabilizer diameter to be manipulated downhole via commands from surface so as to alter the build or drop tendency of a rotary BHA. By utilizing an adjustable gauge stabilizer, the majority of the well is drilled in rotary mode, with only infrequent corrections required by the steerable motor.

The well was successfully drilled with ROP's in the 12-1/4-in. section ranging from 29-48 m/hr, very solid for this area. ROP in the 8-1/2-in. hole section reached 50 m/hr. The reservoir was steered using a real-time data acquisition and distribution system that fed data directly into the customer's office for updating the seismic earth model based on logging data acquired from the LWD tool. Real-time data was also made available to the customer's entire team via the customer's secure intranet.

On these extremely challenging hole intervals, casing went easily to bottom and rig personnel commented about the high wellbore quality. The entire 8-1/2-in. interval of 1366m (4482 ft) was drilled in a single run with no tool failures. The bit grade upon pulling the BHA was 1-1-NO-AX-I-NO-TD, indicating excellent condition with minimal wear.

Well 2

This well was drilled in the Danish Sector of the North Sea. The well plan called for drilling a long horizontal section with water based mud. The Geo-Pilot system was run when oriented drilling was no longer possible due to excessive sliding friction. At this point, 7200 ft of horizontal had been drilled with the SlickBore system and the Adjustable Gauge Stabilizer (AGS™), a slightly different adjustable stabilizer concept. Target dimensions in the vertical and horizontal planes required precise inclination and azimuth control. The Geo-Pilot drilled from 4596 m (15080 ft) to 5628 m (18463 ft), a distance of 1031 m (3383 ft) in 41 on-bottom hours, averaging 25 m/hr (82.5 ft/hr). The inclination was carefully controlled to remain within the 1 m (3.3 ft) thick porosity layer. The tool completed the entire interval in a single run and was in good condition when tripped out of the hole.

Well 3

This well was also drilled in the Norwegian Sector of the North Sea. The Geo-Pilot system achieved the longest single run on the tool to date, drilling for 2187 m (7175 ft). The tool performed flawlessly, but a third party downhole component in the BHA failed and the assembly was pulled. The remaining 363 m (1190 ft) was drilled on a subsequent run with the same Geo-Pilot tool and Security DBS long gauge bit to complete the planned section. The bit was graded 1-1-WT-A-X-1-ER-TD, again indicating very low wear and damage after drilling 2550 m (8366 ft) containing abrasive formations. Casing strings went easily to bottom, and a total of 10 days were saved on the project.

Conclusions

1. A new, second-generation rotary steerable system has been introduced based on a point-the-bit concept. This concept allows the use of long gauge bits for superior wellbore quality.

2. Other systems that rely on a push-the-bit concept cannot function with long gauge bits. Due to the sidecutting action and short gauge required for these systems to drill directional wells, these systems remain prone to borehole spiraling which tends to increase torque and drag while reducing ROP.

3. By focusing on wellbore quality, even greater improvements in drilling efficiency have been realized on wells that have utilized the new

system.

4. The stabilizing effect of the long gauge bit has resulted in impressive bit life and no failures of the LWD system in 25 runs.

Acknowledgements

The author would like to thank the management of Sperry-Sun Drilling Services and Halliburton Energy Services for permission to publish the paper. We further acknowledge and thank our collaboration partner Japan National Oil Corporation. Thanks also to Rick Hay, Tom Gaynor, David Chen, Dan Gleitman, and Chris Maranuk, all with Sperry-Sun Drilling Services, for their editorial review.

Nomenclature

BHA = bottomhole assembly
ROP = drilling rate of penetration
TD=total depth

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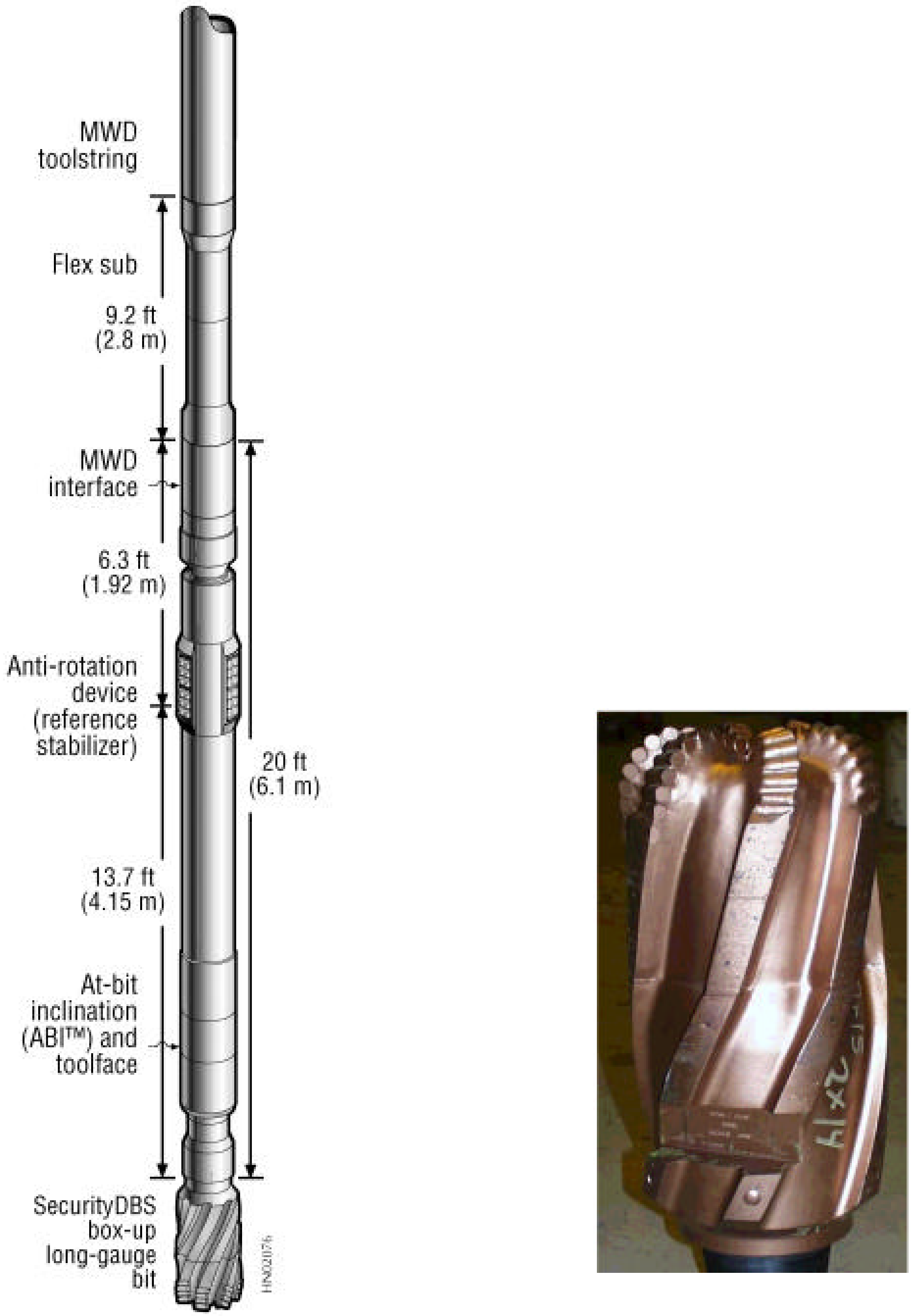

Figure 1 – The Geo-Pilot Rotary Steerable System. The system contains an inclination sensor three feet from the end of the tool for near-bit surveying. The system makes use of long gauge bits for dramatic improvements in wellbore quality. The bit is considered part of the Geo-Pilot system.

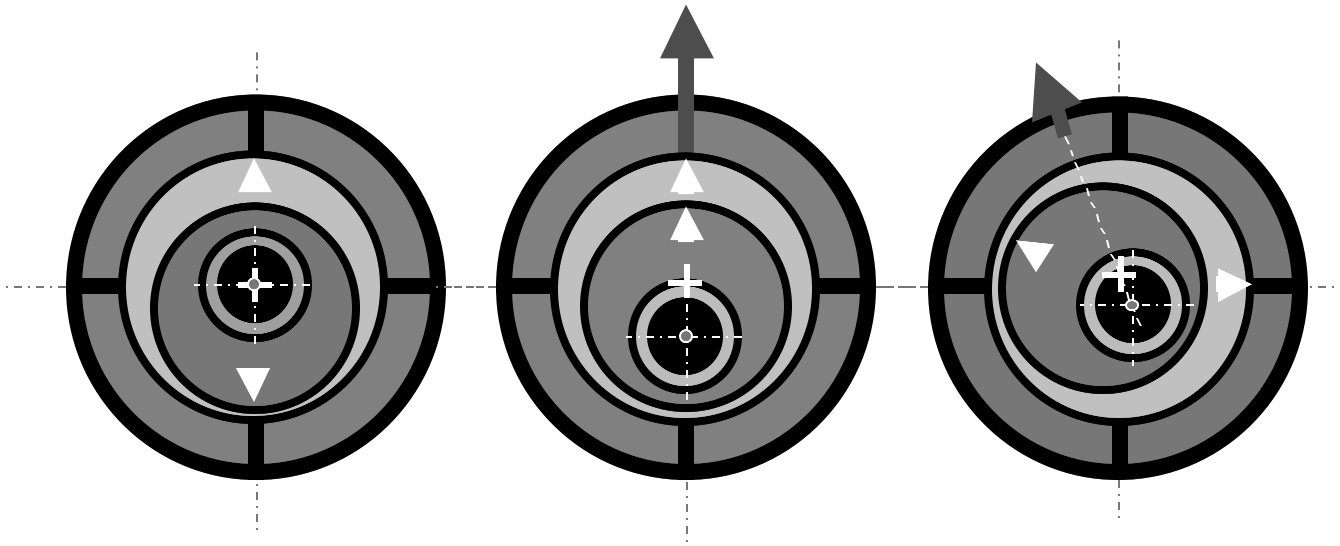

Figure 2 – Deflection of the driveshaft by selective orientation of the internal and external eccentric rings. In the first diagram (A), the eccentric rings or cams are positioned opposite each other, thus cancelling out the eccentricities and keeping the shaft straight. In the second diagram (B), the cams are completely aligned, generating the maximum amount of deflection and hence build rate. This orientation can be rotated around to deflect the wellbore in any direction. The cams can be positioned to an intermediate position for less than 100% build rate, as shown in the third diagram (C).

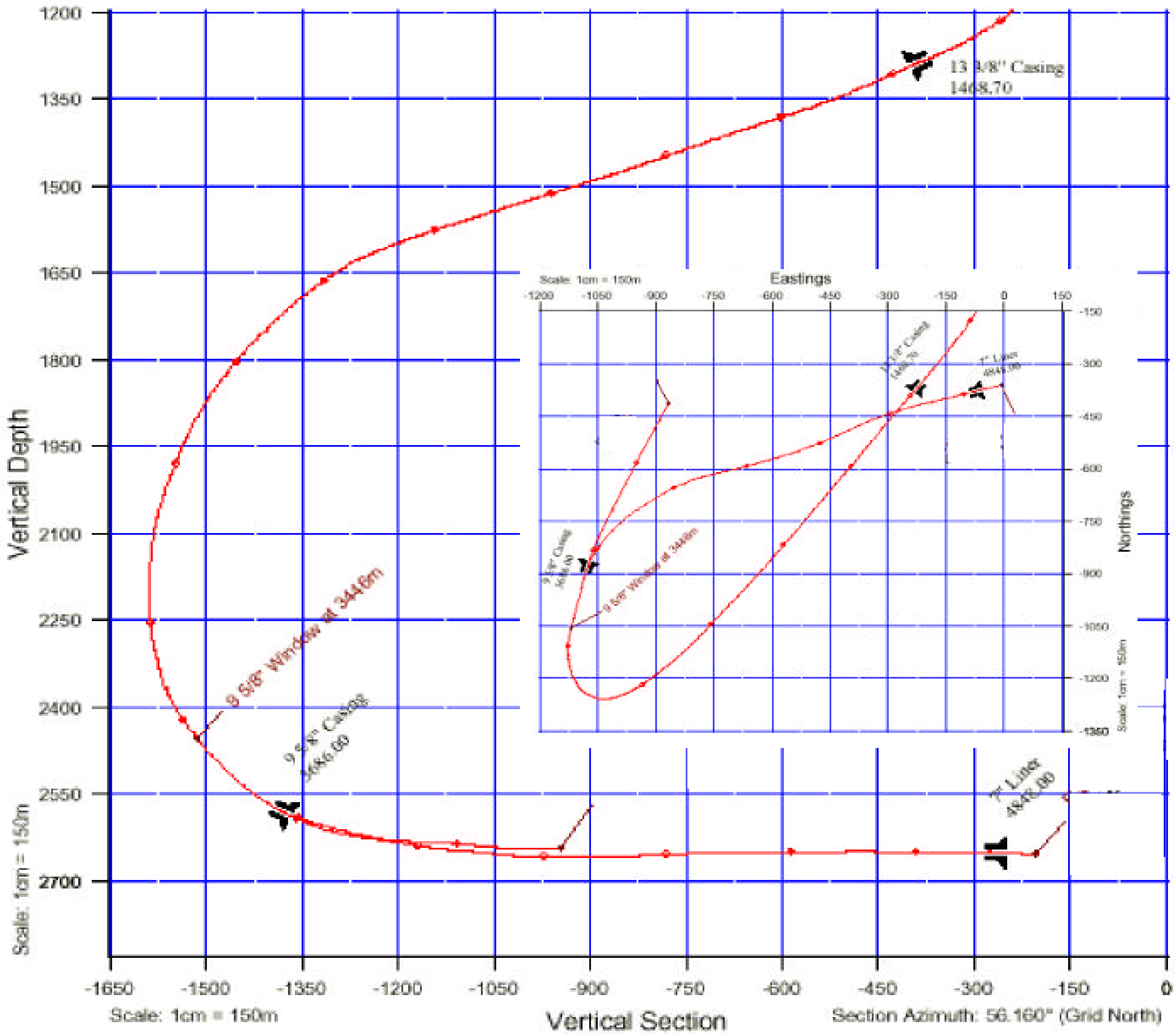

Figure 4 – Well plan for well in Norwegian Sector of the North Sea. The 12-1/4-in. interval was drilled with the SlickBore™ system combined with a TRACS™ adjustable gauge stabilizer, while the long horizontal 8-1/2-in. interval was done in a single run with the Geo-Pilot.