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Horizontal Trajectories of Rotary-Drilled Holes

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	km	kilometer
°	degree	L/min	liter per minute
ft	foot	lb	pound
gal/min	gallon per minute	lb/ft	pound per foot
in	inch	m	meter
kg/m	kilogram per meter	rad	radian

HORIZONTAL TRAJECTORIES OF ROTARY-DRILLED HOLES

By Tobias W. Goodman[1] and Joseph Cervik[2]

ABSTRACT

This Bureau of Mines report investigates the horizontal trajectory of boreholes drilled in coalbeds using the rotary drilling technique. Test holes drilled in coalbeds showed that the path of a borehole in the horizontal plane depends on drilling assembly configuration, drill bit rotation, and coalbed geologic features. An assembly that contained an 18-ft (5.5-m) long drill collar and two centralizers had the best horizontal stability evidenced by trajectories that deviated less than 16 ft (4.9 m) from a target at 1,000 ft (305 m). Removal of one of the centralizers resulted in a loss of control of hole trajectory in the horizontal plane. Generally, holes tended to turn to the right, presumably because of right-hand rotation of the bit. Deviations from the original bearing line were as much as 200 ft (61 m) or more at a depth of 1,000 ft (305 m).

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INTRODUCTION

The Bureau of Mines experimentation with long hole drilling for coalbed degasification began in 1970 (1).[3] The Bureau's horizontal drilling technique is an adaption of the "packed hole" method used in vertical hole drilling by the petroleum industry (2). The primary objective in horizontal drilling is to maintain the vertical trajectory of the hole within the coalbed by varying the drill rotational speed and thrust parameters or by modifying the drilling assembly to prevent the bit from entering roof or floor rock, which could terminate the hole.

Horizontal trajectory, the course of the hole projected to the horizontal plane, is essentially uncontrollable in horizontal rotary drilling. However, the degree of deflection from a given path can be limited somewhat by choice of drilling assembly. A complete downhole drilling assembly, consisting of a bit, centralizer, 18-ft (5.5-m) long drill collar, and a second centralizer (fig. 1) (3-4), is a rigid assembly that can be deflected off course but does not drill in an arc. Experience shows that this assembly is vertically controllable in the Pittsburgh Coalbed by adjustments to bit rotational speed and thrust. Because of these factors, the complete assembly is preferred for use where possible in degasification drilling programs. Even minor modifications to this assembly, removal of a centralizer or use of a shorter collar, cause it to tend to drill in an arc. For instance, removal of the back centralizer, though useful in maneuvering the bit in the vertical plane, causes the back end of the drill collar to move off center and cock in the hole. Drill thrust tends to force the unsupported back end of the drill collar toward a side of the hole. The bit, then, begins to deflect away from the planned path in the horizontal plane. Continued drilling with this or other modified assembly causes deflection of the bit away from its original bearing line.

During drilling, the hole is routinely surveyed to measure bit inclination (4-5). Subsequently, changes are made in bit thrust and rotational speed to maintain bit trajectory parallel to the bedding plane. The objective during drilling is to maintain vertical control of the bit and prevent roof or floor interception, which slows drilling and increases drilling expense. The path of the bit in the horizontal plane is not measured during drilling because the horizontal trajectory of the hole cannot be controlled using the rotary drilling technique. In many cases where a hole is drilled to drain methane, horizontal deviation of the hole by 50 or more feet

[3]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

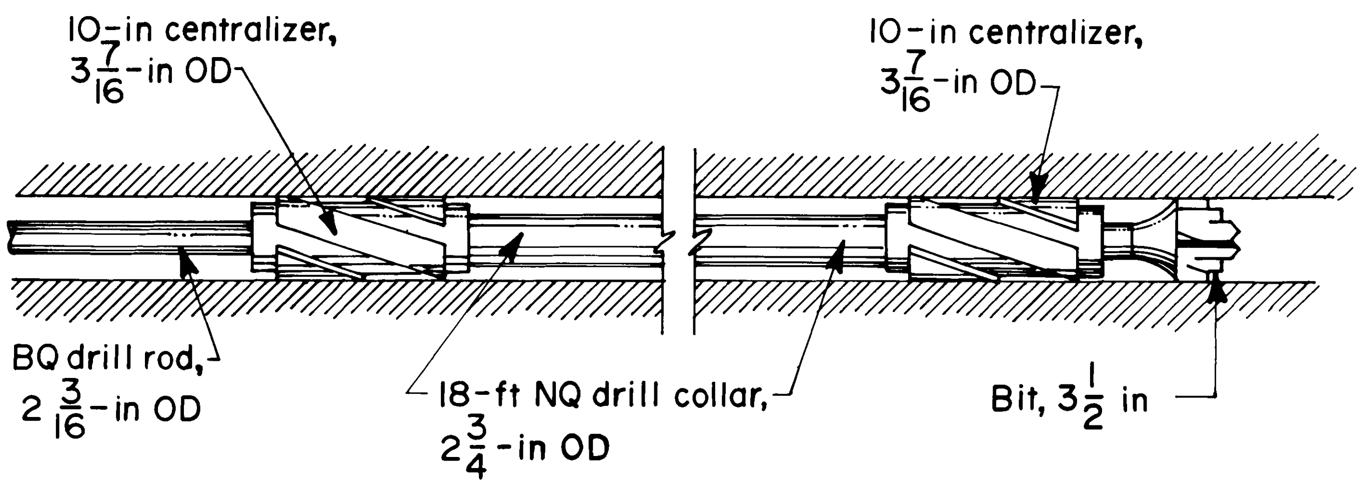

FIGURE 1.—Preferred assembly with 18-ft collar.

is not important. However, all holes should be surveyed after completion to determine the horizontal deviation from the programmed path and subsequently plotted on the mine map of the area. The exact location of the hole is important when the area is being mined because, as the mining machine is approaching the hole, mining advance rate must be reduced until after the hole is intercepted. If greater accuracy is required, the in-hole motor, which has been tried with success in coalbed drilling (6), is suggested.

The objective of this study is to review and analyze past Bureau horizontal drilling programs to determine the degree to which the various drilling assemblies deviated from the programmed bearing.

DRILLING PROCEDURES

The preferred assembly (fig. 1) for drilling horizontal holes in coalbeds includes a bit, centralizer, 18-ft (5.5-m) long 189-lb (85.9-kg) drill collar, and another centralizer followed by flush joint BQ rod (2-3/16-in OD, 1-13/16-in ID) (5.6-cm OD, 4.6-cm ID) in 10-ft (3-m) lengths. Bit diameters are 3-1/2 or 3-5/8 in (8.9 or 9.2 cm) and include three-blade drag bits and tricone roller bits (fig. 2). The roller bits are used mainly to drill through hard inclusions or shaley binders. The drag bit is preferred in coalbed drilling because the cutting blades are located both in front and on the side of the bit, which aids in making changes in vertical angle easier. The cones on the roller bit are oriented ahead of the bit and do not provide as much side-cutting action as the drag bit. Water is the required drilling fluid since the use of air is hazardous when mixed with coalbed methane. Water rates of 15 gal/min (57 L/min) or more are needed to adequately lubricate the path of the bit and flush the hole clear of cuttings during drilling (4).

The purpose of centralizers is to keep the assembly centered in the drill hole. The centralizers are 10 in (25.4 cm) long and 3-7/16 in (8.7 cm) OD. Drill collars are used to provide weight and rigidity to the drill string. Fourteen- and 18-ft (4.3- and 5.5-m) long NQ rod drill collars were used in this study. NQ rod is 2-11/16-in (6.8-cm) OD, 1-13/16-in (4.6-cm) ID and weighs about 10.5 lb/ft (15 kg/m).

In standard practice, vertical attitude of the assembly is controlled by varying the drilling parameters and/or removing one of the centralizers if needed. When the vertical angle is less than 2° (0.035 rad) out of alignment with the proposes trajectory, experience shows that small corrections may be obtained by

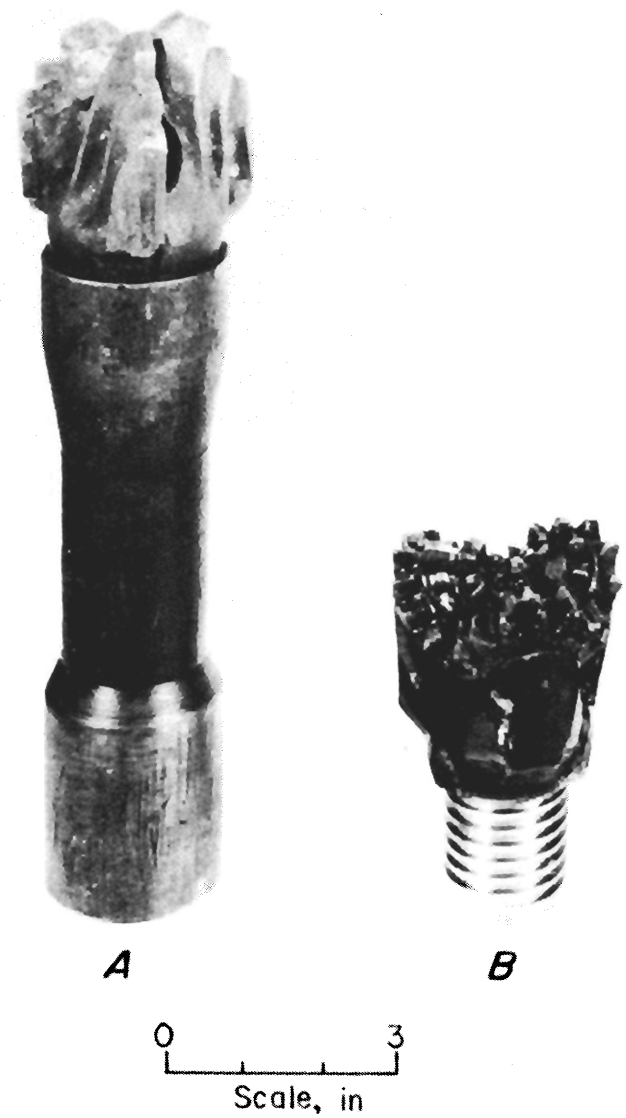

FIGURE 2.–Drill bits. *A*, **Three-blade drag bit;** *B*, **tricone roller bit.**

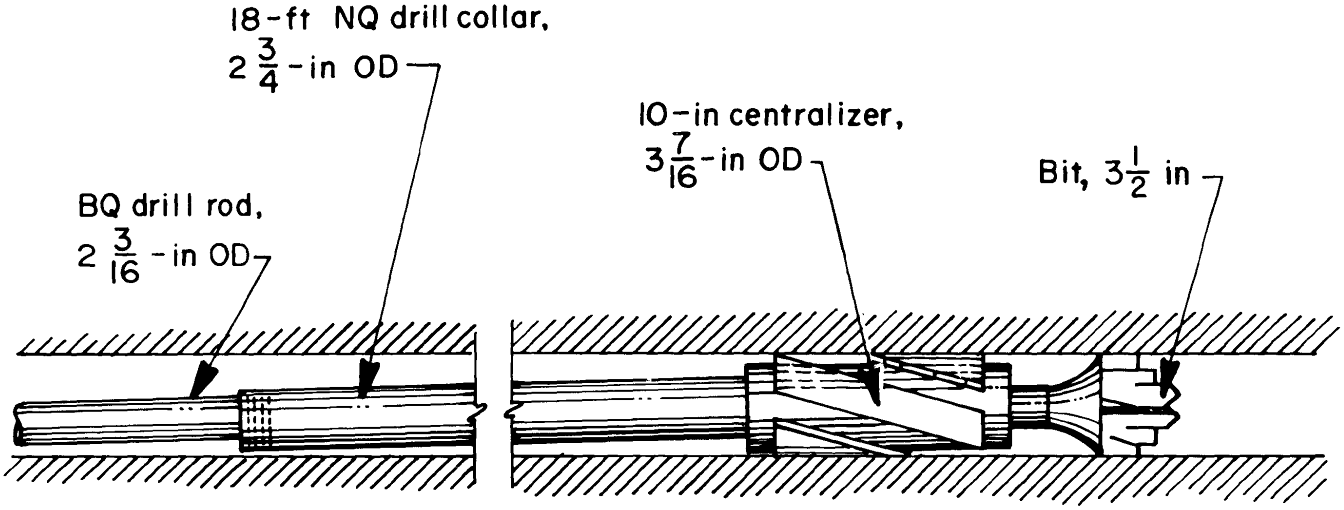

FIGURE 3.–Modified assembly–up drilling.

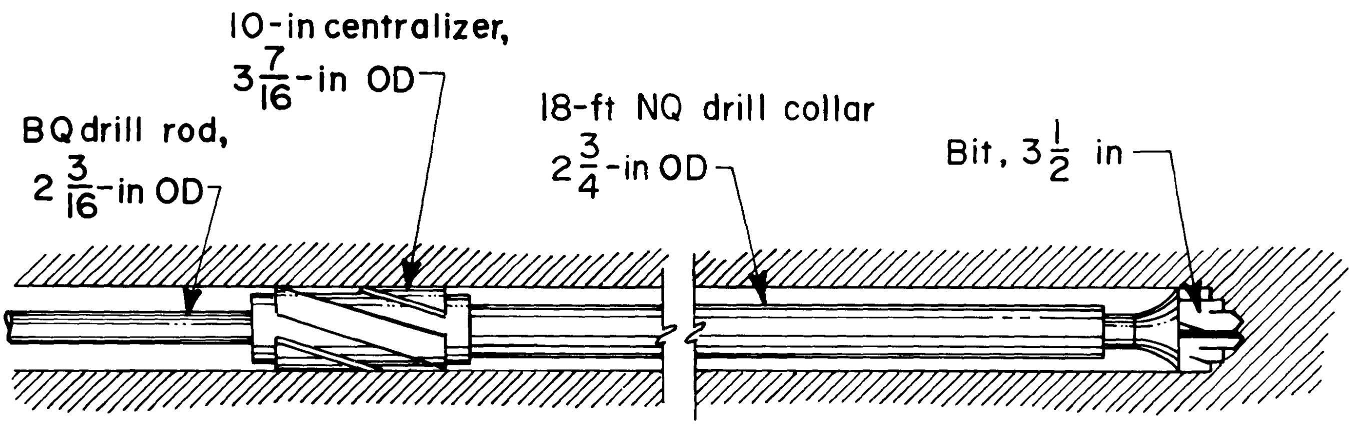

FIGURE 4.–Modified assembly–down drilling.

varying the drilling parameters with no alteration in the configuration of the preferred assembly. Higher thrust and lower bit rotational speed tend to raise the bit, and lower thrust and higher bit rotational speed tend to lower the bit. When the vertical angle is more than 2° (0.035 rad) out of alignment with the proposed trajectory, removal of the back centralizer cocks the drill collar, centralizer, and bit in the hole and turns the hole upward more rapidly than the use of drilling parameters (fig. 3). By removing the front centralizer (fig. 4) instead, the weight of the collar falls directly on the side-cutting blades of the bit, and the hole turns downward easily. These modified assemblies should be used only for short distances because of the tendency to lose control of the horizontal trajectory of the bit.

DATA ANALYSIS

A drilling strategy is developed for each site or coalbed. First, the preferred assembly (fig. 1), most readily controllable using drilling parameters, is used. Then modifications are made to this assembly as needed. If the preferred assembly can be used, drilling proceeds by altering drilling parameters to correct the vertical angle with occasional removal of one of the centralizers when larger adjustments are advisable. If, however, the preferred assembly cannot control the vertical angle, then the back centralizer may be removed and a 3-5/8-in (9.2-cm) bit substituted for the 3-1/2-in (8.9-cm) bit. The tendency of the cocked drill collar to drill upward is compensated by the tendency of the larger bit to overbreak the coal and drill downward. This modified assembly can be controlled in the vertical plane by varying bit thrust and rotational speed and was successfully used in the Pittsburgh and Sunnyside Coalbeds.

The longest interval drilled with the preferred assembly (fig. 1) occurred at a site in the Pittsburgh 8 Coalbed (3) that is relatively flat and blocky and similar to the Pittsburgh coalbed. Figure 5 shows the horizontal trajectory of the hole, which begins to bend abruptly to the left after the bit drilled into a band of pyrite at 350 ft (107 m). The bit never returned to its original bearing line though the total deviation was not extreme and the assembly was under control. At full depth of 1,034 ft (315 m), the hole was only 15.5 ft (4.7 m) to the left of the original bearing line.

Many coalbeds show a marked difference in the drilling characteristics in the upper and lower benches and may differ regionally as well. The upper portion may contain bands of pyrite compared with the lower half, which is relatively free of impurities and, hence, softer and easier to penetrate during drilling. As evidenced by penetration rates using comparable drilling parameters, the Pittsburgh Coalbed near Fairview, WV (4), was found to be much harder to drill than at Marianna, PA (7), located 30 miles (48 km) north, apparently owing to the difference in overburden thickness. As a result, the preferred assembly (fig. 1), which was very effective at the Fairview site, was not vertically controllable at the Marianna site. It repeatedly arced to the bottom. The preferred assembly was then modified by using a 3-5/8-in (9.2-cm) bit and removing the back centralizer (fig. 3). The penetration rate of the modified assembly was about twice that experienced using the preferred assembly. Figure 6 shows that the actual horizontal trajectory of the hole arced to the right. The deviation of the hole at 1,000 ft (305 m) from the original bearing line was 50 ft (15.2 m) but at 2,000 ft (610 m) measured along the

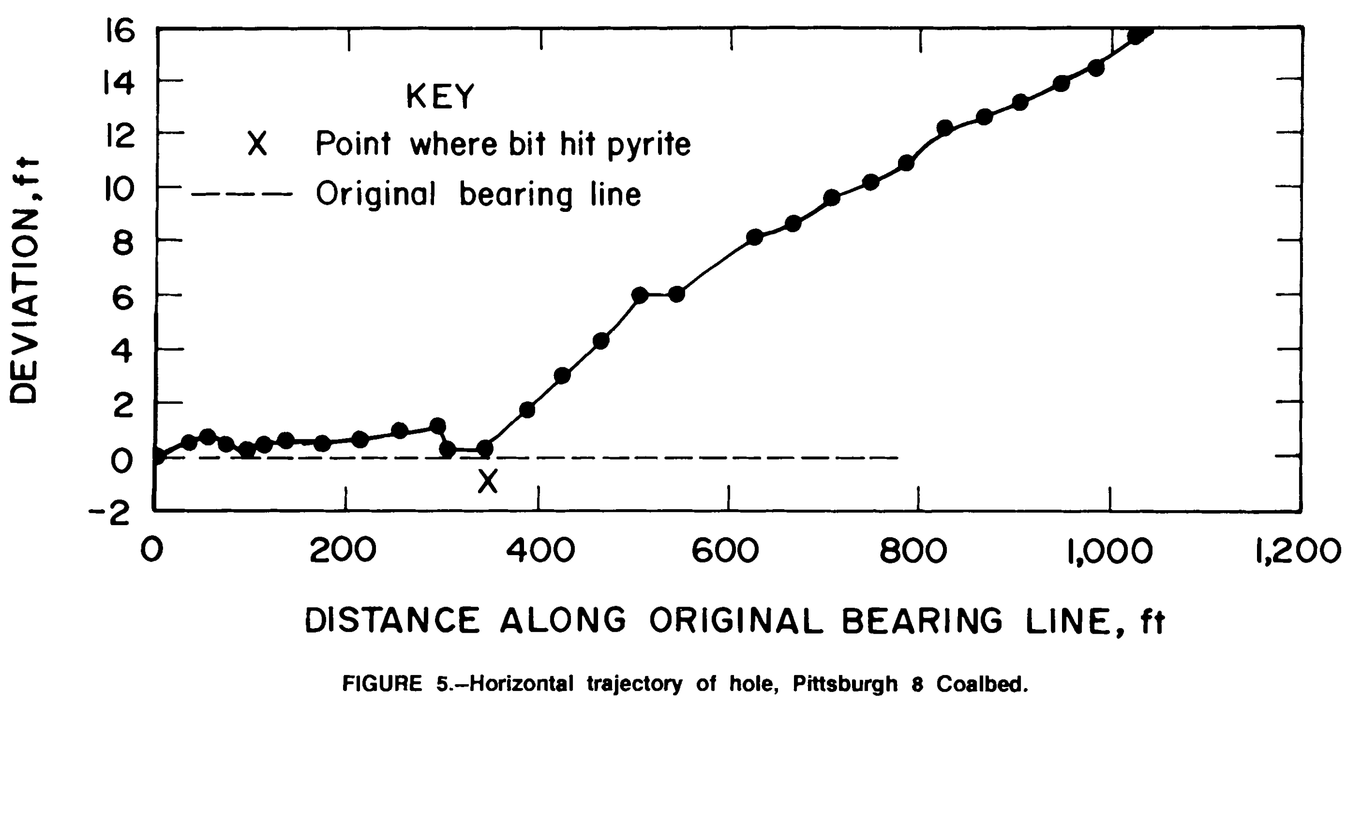

FIGURE 5.–Horizontal trajectory of hole, Pittsburgh 8 Coalbed.

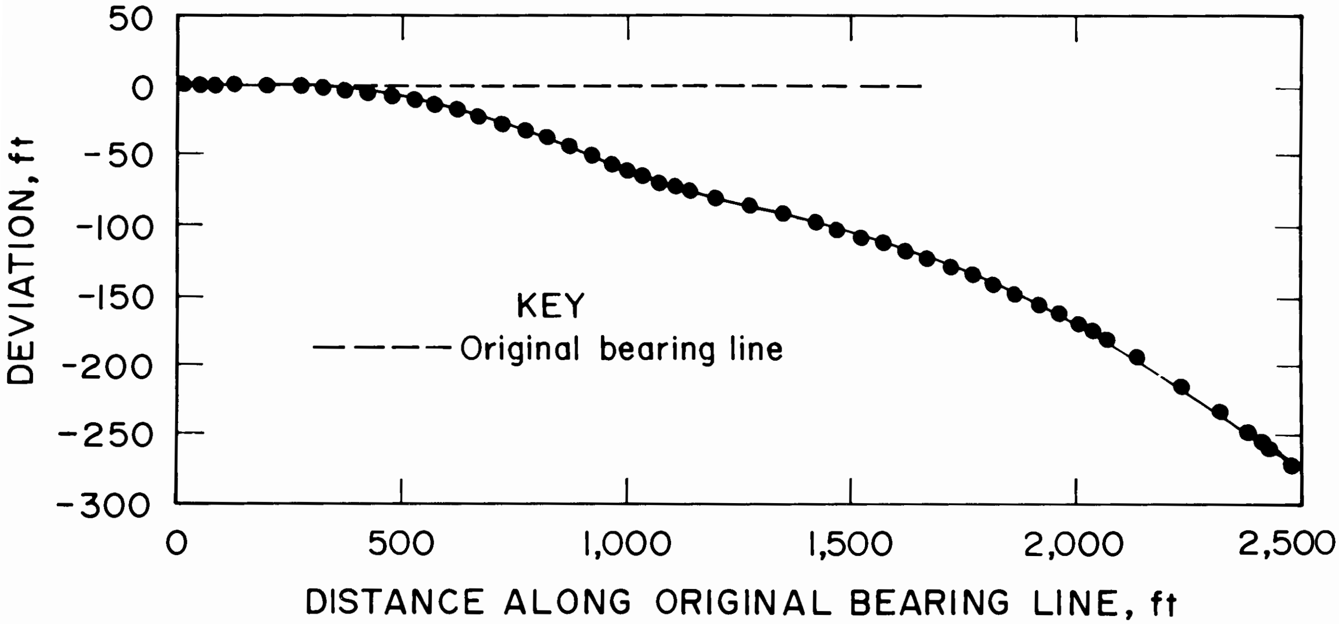

FIGURE 6.–Horizontal trajectory of hole, Pittsburgh Coalbed.

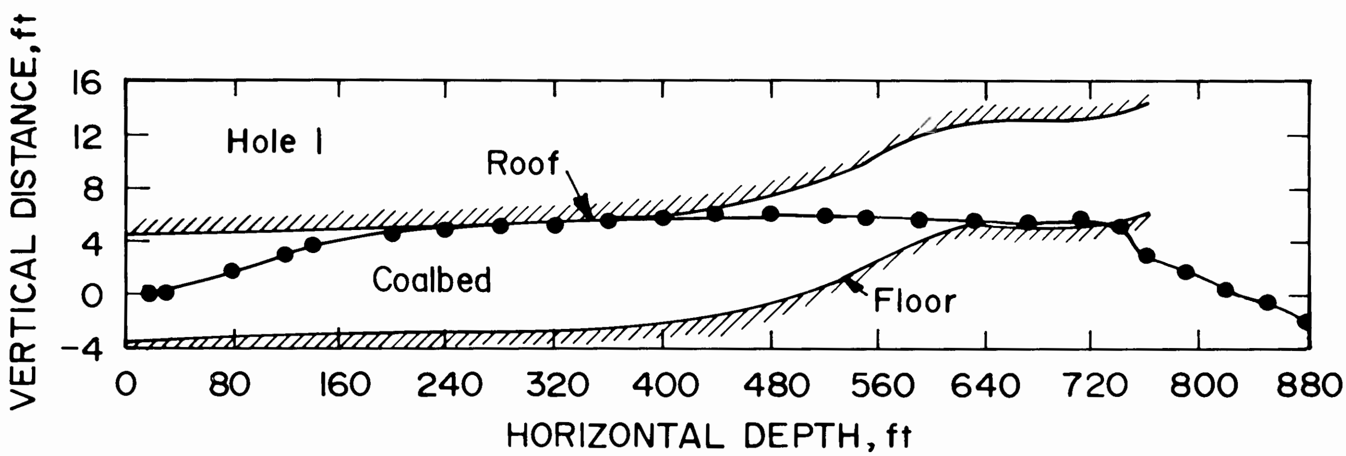

FIGURE 7.–Vertical trajectory of hole, Beckley Coalbed.

original bearing line, the deviation was about 160 ft (49 m). At the final depth of about 2,500 ft (762 m), the deviation from the original bearing line was about 270 ft (82 m). Initially, the hole was drilled to about 340 ft (104 m) with the preferred assembly (fig. 1). Figure 6 shows that there was very little horizontal deviation of the hole during this drilling interval. Deviation began shortly after the preferred assembly, which was unable to control vertical angle, was replaced by the modified assembly in the drill string.

Drilling difficulties were experienced in the Beckley Coalbed because of the soft, friable nature of the coalbed, particularly in the lower portion, which drilled differently than the top portion, and severe undulations of the coalbed, which were unknown and made location of the bit difficult to interpret. Even when properly interpreted, the hole trajectory could not be altered rapidly enough to follow the coalbed. Figure 7 shows the vertical trajectory of a hole drilled from the bottom of a ventilation shaft at Maple Meadow Mine (8) and why difficulties in interpretation occurred. The hole was started and drilled to 80 ft (24 m) with the modified assembly (fig. 3), which is cocked upward in the hole about 1° (0.02 rad). The smaller 3-1/2-in (8.9-cm) bit was chosen over the 3-5/8-in (9.2-cm) bit because of the extreme softness and friable nature of the coalbed. The assembly did not overbreak as expected, perhaps because of the small bit, and about a 2° (0.035 rad) upward vertical angle quickly developed that could not be decreased using drilling parameters. The back centralizer was reinstalled so that drilling parameters would be more effective in controlling vertical trajectory. The preferred assembly (fig. 1) leveled the hole near the roof, which it grazed occasionally between 240 and 370 ft (73 and 113 m) before hitting pyrite balls at about 390 ft (119 m). Drilling was continued until the bit hit the clay floor at 685 ft (209 m). The existence of the undulation beyond 400 ft (122 m) was unknown. Figure 8 shows that the hole deviated about 2 ft (0.6 m) at the 300-ft (91.5-m) depth. An abrupt change in deviation occurred after after the roof rock was intercepted by the bit at around that depth. Consequently the hole turned 18 ft (5.5 m) in the next 385 ft (118 m) of drilling. Thus, the total deviation of the hole was about 20 ft (6.1 m) at a depth of 685 ft (209 m). This example illustrates the impact of hard inclusions on hole trajectory. Vertical angle in this case was not affected. Figure 7 shows that the vertical angle remained horizontal after the bit intercepted the roof rock.

In the Mary Lee Coalbed in Alabama, drilling with the preferred assembly (fig. 1) was abandoned because the holes squeezed and collapsed, which locked the assembly in place. An alternative assembly consisting of a 3-in (7.6-cm) bit and BQ rod was used in this coalbed (fig. 9) (9) because, in many cases, this assembly could be rotated and backed out of the hole when collapse occurred. Figure 10 shows that this assembly arced to the right, and at a depth of 1,000 ft (305 m), the hole deviated over 200 ft (61 m) from the original bearing line. The first 120 ft (37 m) was drilled with the preferred assembly (fig. 1), and figure 10 shows that very little horizontal deviation occurred during the drilling interval. Attempts to control the trajectory in the vertical plane with the modified assembly by adjusting bit thrust and rotational speed were unsuccessful.

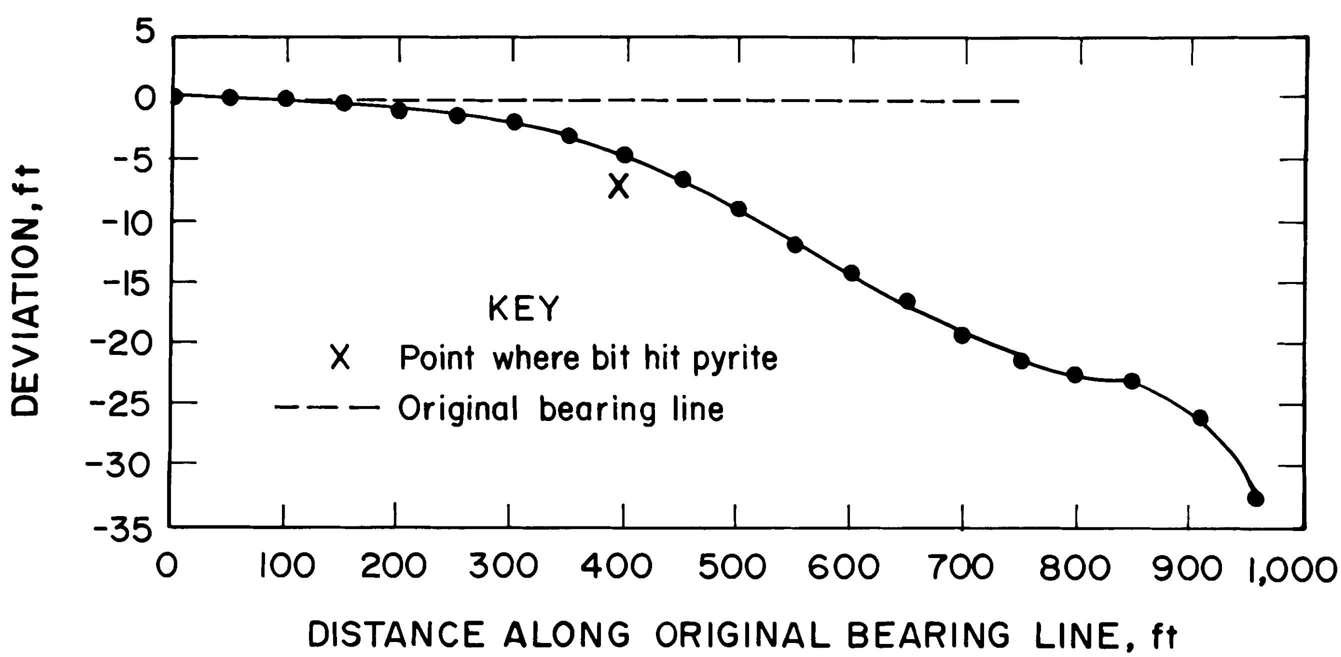

FIGURE 8.–Horizontal trajectory of hole, Beckley Coalbed.

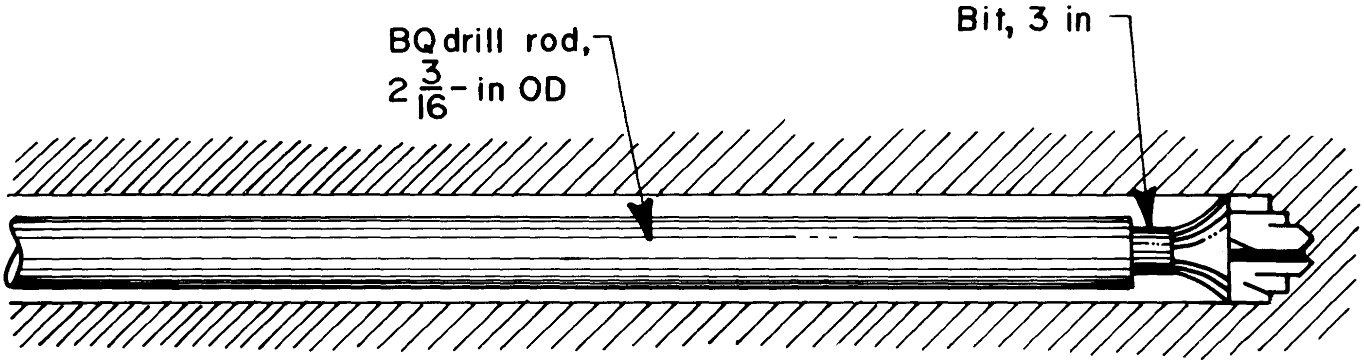

FIGURE 9.–Bit drilling assembly.

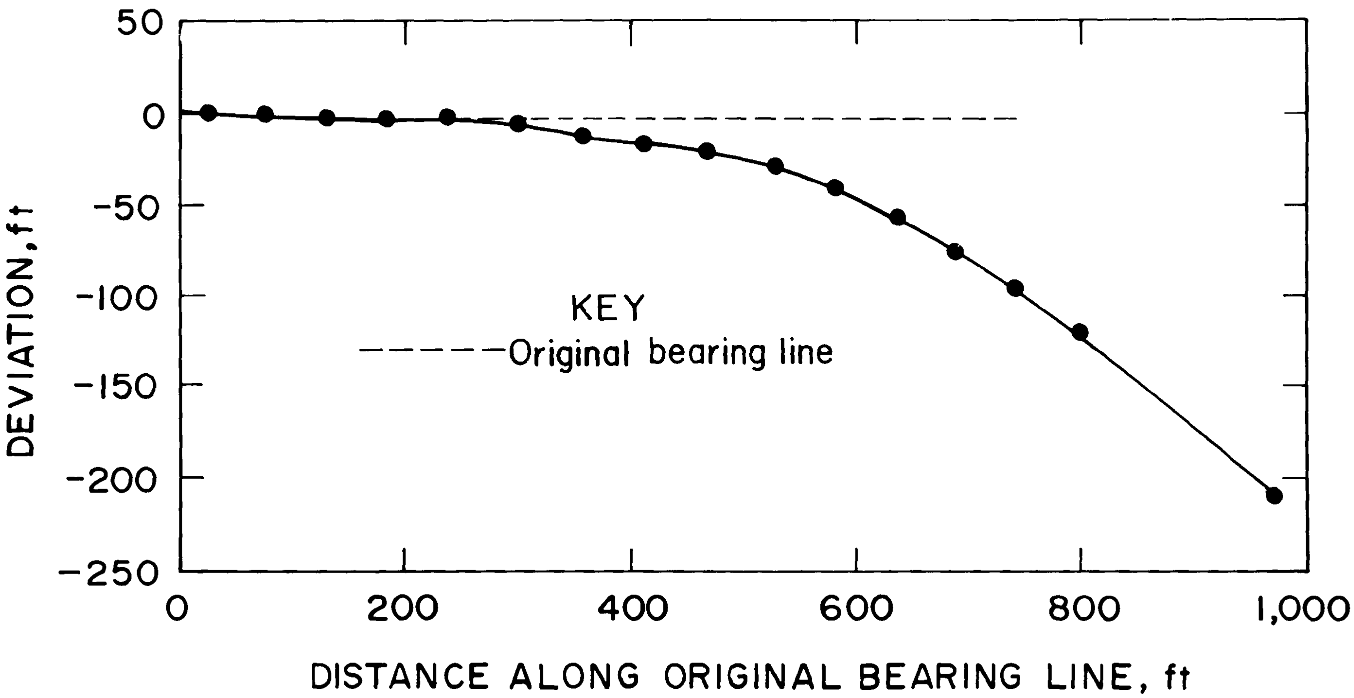

FIGURE 10.–Horizontal trajectory of hole, Mary Lee Coalbed.

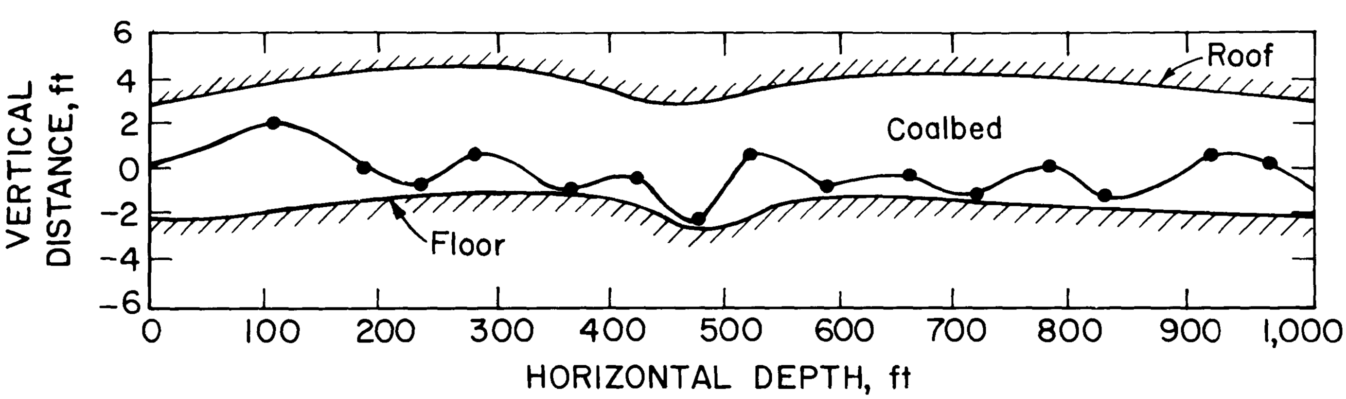

FIGURE 11.–Vertical trajectory of hole, Mary Lee Coalbed.

Figure 11 shows that the bit dropped to the bottom of the coalbed and followed the bottom, which was much harder than the soft coal.

The 18-ft (5.5-m) drill collar used in the preferred assembly (fig. 1) is difficult to handle underground because of its length and weight. Shorter drill collars are easier to handle but their effect on hole trajectory was unknown. Tests in the Beckley Coalbed using the preferred assembly configured with a 14-ft (4.3-m) collar (fig. 12) showed that the hole turned to the right. At 1,000 ft (305 m) measured along the projection of the original bearing line, the hole had deviated 320 ft (98 m) to the right, and at 1,600 ft (488 m), the hole trajectory was perpendicular to the original bearing line (fig. 13). Attempts to control the vertical trajectory of the drilling assembly by varying the drill bit thrust and rotational speed were ineffective. The assembly dropped to the bottom of the coalbed, deflected off floor rock, and drilled along the interface while staying in the coalbed. The total length of the hole drilled was 4,034 ft (1,230 m).

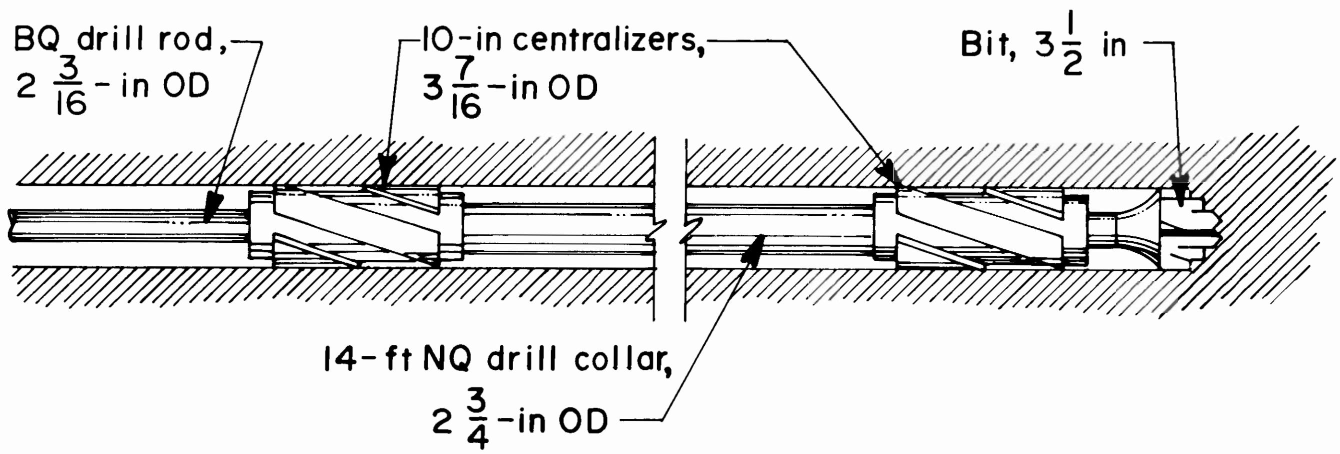

FIGURE 12.–Preferred assembly with 14-ft collar.

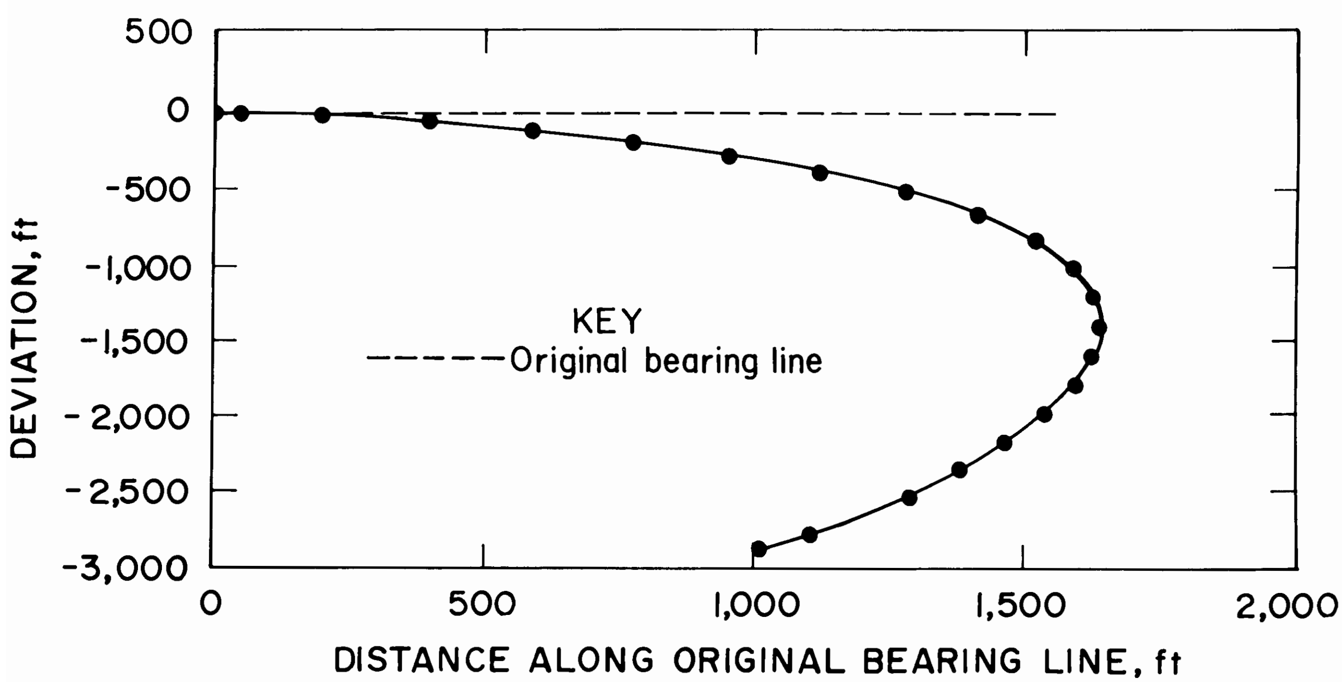

FIGURE 13.–Horizontal trajectory of hole, Beckley Coal Mine.

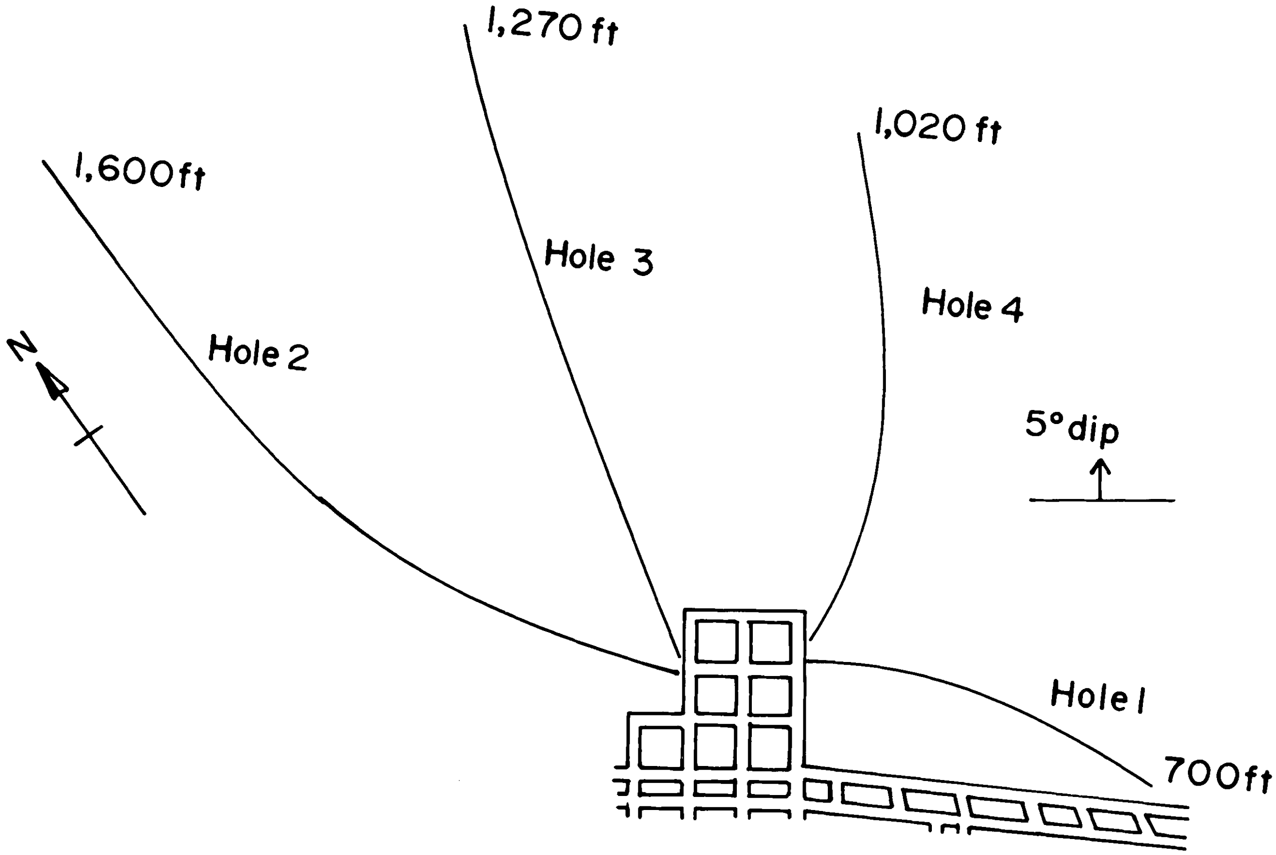

FIGURE 14.–Lower Sunnyside Coalbed (Utah) study.

Coalbed dip appears to be an important factor affecting the horizontal trajectory of holes in coalbeds. Studies in the lower Sunnyside Coalbed where the dip is 5° (0.09 rad) showed that the horizontal trajectory of the holes turned toward the maximum dip of the coalbed (fig. 14). All holes were drilled with the modified assembly (figs. 3-4). Hole 1, which was drilled along the strike, turned to the right as would be expected when using the modified assembly.

SUMMARY AND CONCLUSIONS

Analysis of the horizontal trajectory of holes drilled in coalbeds showed that the standard assembly (fig. 1), which includes an 18-ft (5.5-m) drill collar and two centralizers, had the best horizontal stability and missed a target at 1,000 ft (305 m) by only 15.5 ft (4.7 m).

In coalbeds where the standard assembly (fig. 1) is modified by removal of the rear centralizer to maintain control of the bit in the vertical plane, horizontal control of the hole trajectory is lost and the bit tends to arc to the right. At a depth of 1,000 ft (305 m), the deviation was as much as 50 ft (15.2 m) and was 160 ft (49 m) at the 2,000-ft (610-m) depth. Thus, once a hole begins to arc, the deviation becomes more severe with depth.

Short drill collars, though easier to handle in an underground environment, did not maintain control of hole trajectory in the horizontal plane. Deviations as much as 350 ft (107 m) occurred when hole depth measured along the original bearing line was 1,000 ft (305 m). At 1,600 ft (488 m) the trajectory of the hole in the horizontal plane was at a right angle to the original bearing line.

Holes drilled without a drill collar deviated over 200 ft (61 m) from the original bearing line at a depth of about

1,000 ft (305 m). In general, most holes tended to drill to the right, presumably because of the right-hand rotation of the bit. Hard inclusions in the coalbed, such as pyrite balls, can deflect a bit in any direction. In dipping coalbeds, the horizontal trajectory of holes appears to turn toward the direction of maximum dip.

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