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ADVANCED TECHNIQUES FOR DRILLING 1,000-FT SMALL DIAMETER HORIZONTAL HOLES IN A COAL SEAM

Volume 1

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USBM CONTRACT REPORT HO111355
March 1973

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DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
Washington, D.C.

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FOREWORD

This report was prepared by Fenix and Scisson, Inc., Tulsa, Oklahoma, under USBM Contract No. H0111355. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of PM&SRC, with Joseph Cervik acting as the technical project officer. Albert G. Young was the contract administrator for the Bureau of Mines.

This is the final report of the project to investigate, test, and evaluate horizontal drilling control techniques for the U.S. Bureau of Mines. It is a summary of the work recently completed as part of this contract during the period June 1971 to October 1972. This report was submitted by the authors in March 1973.

This technical report has been reviewed and approved.

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The authors wish to acknowledge the assistance and cooperation of those who aided in this project during the field testing and writing of the final report manuscript. We would particularly like to thank Charles S. Dunn, project director, and A. J. Christensen, project manager during the initial phases of this project.

In addition, we want to thank the following personnel of the Continental Oil Company and the Hanna Coal Company, a division of Consolidation Coal Company, who provided us with a test drilling site in Ohio and considerable material assistance and time. They include Ralph Hatch, president of the Hanna Coal Company, Cadiz, Ohio; Joseph Hickle, Hanna's chief strip mine engineer; and H. Douglas Dahl, supervisor of the Mining Systems Group, Central Research Division of Continental Oil Company, Ponca City, Oklahoma.

We also wish to thank the following Fenix and Scisson, Inc., personnel for their advice and assistance in preparing the manuscript. They include Harry Forshaw, administrative assistant; Tom Young, senior drilling engineer; Edward Sessions, senior drilling engineer; William Grovenburg, senior drilling engineer; and Carol Hare, technical editor.

SECTION 1

INTRODUCTION

Deeper mines (1,500 to 2,500 ft) are the current trend in the coal industry today, and with increased depth has come increased hazards. One significant problem is the elimination of uncontrolled methane emissions, which increase with depth. The U.S. Bureau of Mines Methane Research Program has made the elimination of these emissions one of its major objectives. The Bureau's immediate effort is toward the prevention of disastrous explosions, but the ultimate goal is to provide the technology needed to predrain the methane far in advance of active mining.

One possible solution to the problem is the use of boreholes drilled vertically from the surface or horizontally parallel to the bedding, and the Bureau has done considerable research on this method of degasification.

The use of horizontal holes is more attractive because more coal is exposed with fewer holes. However, two factors must be met to make the use of horizontal holes for degasification in high production-rate mines practical.

1. Reasonably precise directional control of long holes, possibly 1,000 to 2,000 ft.
2. Maintenance of practical economic cost limits.

The width of a section in a coal mine is usually about 500 ft; therefore, to control methane flows from the face areas of the section, horizontal holes at least 500 ft in length are required. The length of the hole determines the application frequency of a methane control technique, such as natural drainage, and, also, a longer hole will degasify a larger area of virgin coal.

Before the contract was let for this work, the longest horizontal hole known to have been drilled in coal was drilled by the U.S. Bureau of Mines to 503 ft. A longer hole could probably have been drilled, but time factors prevented this.

Equipment and methods have been virtually nonexistent for drilling long holes in coal with reasonable directional control in the space and time limitations applicable to underground coal mining. Prior experimental work had been concerned with using horizontal holes to determine how gassy a coal was, how much gas could be readily drained from it, or where high methane concentrations were found. However, progress made in the Bureau of Mines methane control program now makes it possible to design a practical system of degasification, using long, horizontal holes.

To develop more scientific precision in drilling long, horizontal holes, the U.S. Bureau of Mines contracted with Fenix & Scisson, Inc., to investigate, test, and evaluate horizontal drilling control techniques. The contract goal was to demonstrate in the field the control devices and techniques

applicable to drilling 3-inch diameter, horizontal holes with enough accuracy to stay within a coal seam and come within 30 ft of a designated point at a depth of 1,000 ft. Volume 1 of this report presents the work accomplished and the results achieved in the research program conducted by F&S. Volume 2 contains the final report of the major subcontractor in this work, Telcom, Inc., who was responsible for the development of the "wireless-continuous use" survey system.

SECTION 2

SUMMARY

To reach the ultimate objective of this project, the study was divided into four phases.

Phase I--A comprehensive investigation of the natural factors affecting the directional control of horizontal holes and the mechanical factors needed to overcome these natural problems. The results of this investigation were used to select the devices for testing and to establish detailed test procedures.

Phase II--A field test model of a telemetry survey system was designed, fabricated, and tested. Telcom, Inc., developed this system under sub-contract to F&S.

Phase III--Field testing and demonstration of the various control devices and techniques was done in coal strip pits in Oklahoma and Ohio.

Phase IV--The various techniques and devices available or developed during this project were evaluated.

PHASE I

The Phase I study indicated that the natural factors with the most significant impact are the thickness of the coal seam, undulations in the coal seam, and hard inclusions within the seam itself. This was verified by field testing. The equipment developed during the testing program was designed to overcome these problems.

The state-of-the-art investigation in Phase I determined that directional control of the hole is the major mechanical problem. Lateral and vertical hole direction must be controlled if the hole is to remain in the thin coal seam for its entire length and still hit a target at 1,000 ft. Vertical deviation is the biggest problem. In previous attempts to drill long holes in coal, the hole usually bottomed out in the rock above or below the coal seam, and subsequent field testing substantiated this.

A significant influence often overlooked is the human factor involved. In drilling long, horizontal holes the driller as well as the engineer is a principal investigator in any field-test operation, and the driller's ability and skill can often mean the difference between success and failure.

Tools and devices chosen during Phase I for the field test included deflection devices such as the Dyna-Drill with bent sub, whipstock, spade bit, reaming collar, and jet bit. A 3-inch jet bit was unavailable, but the directional jet bit showed such promise that approval was received from the Bureau of Mines to test this equipment in the laboratory.

Bit selection for testing was made after a survey of bit manufacturers and drilling contractors revealed the most popular bit types. In addition to these bits, 2- and 3-blade drag bits were designed and fabricated with a combination of face and blade rake angle. We had hoped to find not only a directionally stable bit, but a bit or bits that would consistently drill in a particular direction.

The stabilizers were selected to be short enough for use in various drill string combinations to determine their capability of controlling hole direction.

PHASE II

Experience in drilling rock other than coal had shown that for maximum directional control a survey must be taken every 30 to 40 ft. The use of survey instruments previously available was time-consuming and significantly affected the cost of drilling. Drilling had to be stopped while a survey instrument was pumped to bottom, and lost drilling time amounted to from 1 to 2 hours per survey in a 500-ft deep hole.

Electronic survey instruments have now become available. Such units include an instrument mounted near the bit that rapidly telemeters survey data to a surface unit by electrical cable. However, the time improvement rendered by this unit is overshadowed by the limitations that the cable puts on the use of the drill.

To avoid the cable limitations of existing survey systems, Telcom developed a unique cableless system. For this unit, the drill pipe acts as one conductor and the earth as the other conductor, constituting the complete electrical circuit. With no cable to interfere, drilling can be continued while the telemetry survey system is in operation.

PHASE III

The field testing and evaluation of tools and devices was separated into three parts. First was bit-configuration testing using 25 different types of rotary drill bits. These included 2-, 3-, and 4-blade drag bits, concave and convex plug bits, and 3-cone roller bits. We hoped to find a bit that would consistently drill in a particular direction; however, bit

testing indicated that design has no significant impact on drilling direction. Therefore, a directionally stable bit¹ with a high rate of penetration appeared to be best for long-hole, horizontal drilling in coal. Although most bits tested were directionally stable, the 4-blade drag bits have the most potential for high penetration rate. Design changes have been suggested to make this bit even more directionally stable.

The testing of deflection tools was disappointing. Only the Dyna-Drill could turn the hole in any direction. All other tools tested either had no effect at all, had only minimal effect, or were too complicated to use.

The most successful portion of the field testing was drill string stabilization. As a result of this investigation, we now have available the stabilization and drilling techniques that can be used to change the vertical direction of a horizontal hole at will. In addition, the long-hole stabilization developed can be used to drill a reasonably straight hole laterally.

After testing the various tools, devices, and techniques in strip pits in Oklahoma and Ohio in 125 holes up to 1,102 ft deep, a final demonstration hole was drilled in the 5-ft Ohio seam to a depth of 1,034 ft. According to both the telemetry survey and the multishot survey, the hole was within 30-ft of the original bearing line. For a short 40-ft section, the bit was allowed to drop into the shale below the coal seam to establish the coal-shale contact points.

The horizontal drill rig, designed and fabricated to F&S specifications by E.J. Longyear Company, was satisfactory for the test drilling. However, for underground horizontal drilling, a light-weight unitized drill rig that can be easily moved by a two-man crew would work better.

PHASE IV

Sections 3 and 4 summarize the evaluation of the devices and techniques tested for this project.

¹A directionally stable bit is one that did not tend to wander, was not easily deflected by natural factors, and did not tend to build up angle laterally or vertically.

SECTION 3

CONCLUSIONS

1. This study has resulted in the development of devices and techniques that can be used to consistently drill horizontal holes in a coal seam to 1,000 ft and within 30 ft of the original bearing line.
2. Proper drill-string stabilization is the key to lateral control in drilling a horizontal long hole in coal. All other techniques of lateral control are either ineffective or too expensive for consistent use in long-hole drilling. Thrust and revolutions-per-minute changes cannot be used to control lateral bit deviation.
3. The only reliable hole deflecting device that deflects a horizontal hole in coal both laterally and vertically is the slim-hole Dyna-Drill. Laboratory testing of the directional jet bit indicates that it may be potentially the most economical tool for lateral hole-direction change.
4. A deflection tool is not required to change the vertical direction of the bit in a long horizontal hole in coal. Vertical bit direction can be controlled by the correct use of thrust, revolutions per minute, and stabilization.
5. Bit design did not have a significant influence on hole deviation when used with proper stabilization. Therefore, bit selection for long-hole drilling can be based on bit cost and expected penetration rate. Four-blade drag bits have the most potential for low cost, straight, long-hole drilling in coal.
6. A downhole survey is not required to drill a reasonably straight long hole if proper stabilization is used to control lateral bit deviation and if the driller can differentiate between the roof rock and floor rock by the rock hardness or the color of the cuttings or return water. Otherwise, a simple but accurate inclinometer is all that is required for the driller to decide which technique to use to change vertical hole direction.
7. The telemetry survey system is a valuable aid in drilling experimental long, horizontal holes in coal. However, the initial cost and sophistication of the tool in its current form will prevent its wide use in most methane control programs.
8. The judgment and skill of the driller is of significant importance to the success of a long-hole drilling program. How the driller uses the tools, devices, and special drilling techniques can be the deciding factor in the consistency with which reasonably straight, economical, long holes are drilled in coal.

SECTION 4

RECOMMENDATIONS

1. Future development work in long-hole drilling in coal should be centered around the four basic problems that still remain:
 - a. Development of an economical method for changing lateral hole direction. (The directional jet bit appears to have the most potential for this use.)
 - b. Development of a simple, inexpensive, and accurate inclinometer and downhole tool orientation device that can be quickly pumped down and retrieved on a wireline.
 - c. Development of a light-weight, sectionalized drill capable of drilling 3- to 4-inch diameter holes to a minimum depth of 1,000 ft for underground use.
 - d. Development of an inexpensive remote sensing device that indicates the vertical distance from the bit to the rock above or below the coal seam.
2. A drill string assembly with even more vertical control than those tested should be developed.
3. All long-hole, horizontal drilling should be done with the drill rig fully instrumented to record thrust, revolutions per minute, and torque on the bit.
4. Horizontal drill rig accessory equipment should include a semi-automatic rod handling system.
5. Because of the volume of water required for effective long-hole drilling, an in-mine method should be developed to reuse the circulating water after the rock cuttings and, if necessary, the methane is removed.

SECTION 5

NATURE OF THE PROBLEM

NATURAL FACTORS

Natural factors have a direct influence on drilling time and the vertical and lateral deviation of a long, horizontal hole. The major natural factors involved are discussed briefly to point out the problems. Some of these natural factors are illustrated in figure 1.

ROCK PROPERTIES

HARDNESS

Rock hardness is one of the most important natural factors to be

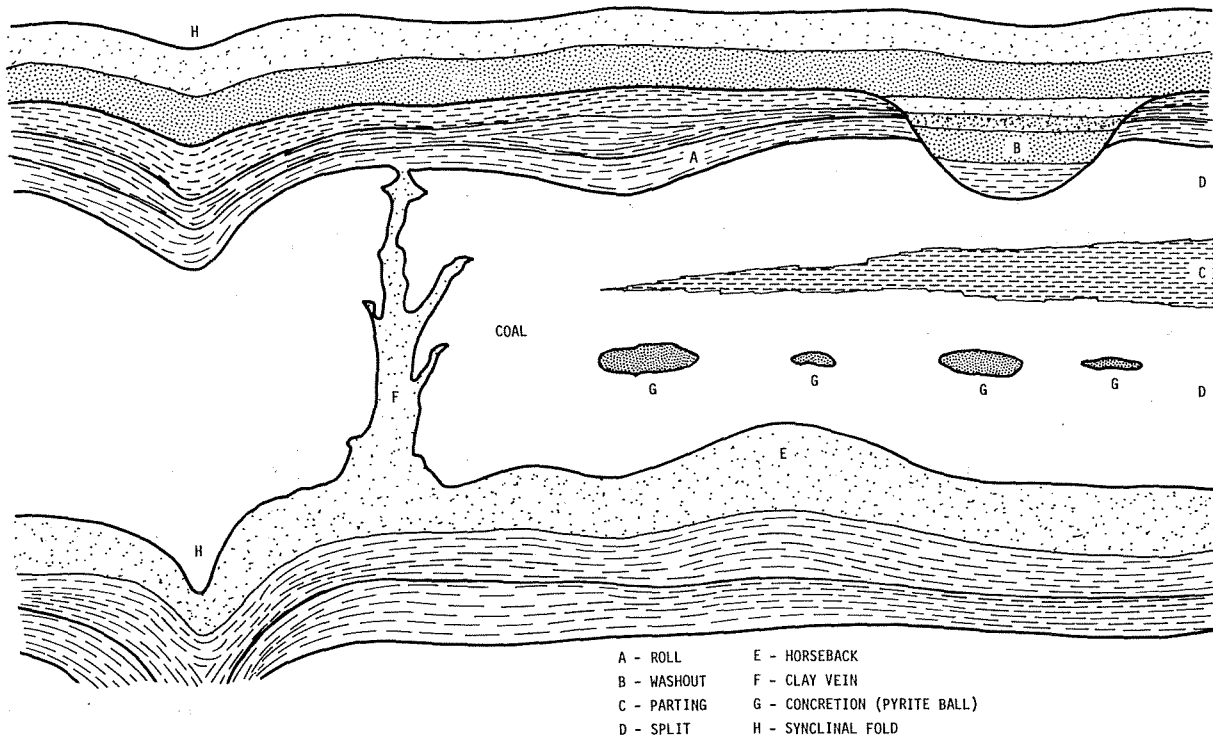


Figure 1. Lithology of a generalized coal seam.

considered in straight-hole, horizontal drilling. As the rock drilled becomes harder, problems of directional control intensify, and time needed for drilling and replacement of worn bits increases.

Coal is a soft rock so drilling in coal presents little problem except for minor hole deviation caused by variations of hardness within the coal.

Rock hardness is a problem in coal drilling when the drill bit encounters roof and floor rocks. Hard inclusions within the coal also cause bit deflection and premature bit wear.

Coal softness is a factor in anchoring downhole tools, such as a deflecting wedge. In soft coal, drilling activity may break away the rock to which a downhole tool is anchored.

MECHANICAL STRUCTURE

Coal is brittle and usually breaks with a blocky or cubical fracture. The brittle nature and fracture characteristics of coal greatly improve drillability and, based on field testing results, do not adversely affect horizontal or vertical deviation of a hole. However, the blocky fracture can cause coal chunks to build up in the hole, thus disrupting drilling activities.

CRUSHING STRENGTH

If the crushing strength of the coal being drilled varies considerably, the drill hole may have some tendency to deviate when it hits coal of a different strength.

ROCK STRUCTURE

BEDDING

A drill bit tends to follow the bedding plane if the angle of intersection between the drill hole and the bedding plane is small. This is due to wedges of coal, broken off as the hole is drilled, that act like a deflecting wedge and force the bit to follow the bedding plane.

JOINTING

If the angle of intersection between the drill hole and the major joints in a coal seam is relatively small (less than 45°), the bit will tend to turn and follow the joint system.

If the angle of intersection is greater than 45° , the bit will tend to cut across the joints, finally achieving an angle perpendicular to the joints.

DIP AND STRIKE

The apparent dip and strike of the coal seam should be known so the drill rig can be set up initially at the dip angle. If the rig's angle of inclination differs greatly from the apparent dip of the coal, the drill bit will hit rock above or below the coal, resulting in time lost deflecting the hole back into the coal seam.

ROLLS, HORSEBACKS, WASHOUTS, PARTINGS

Rolls, horsebacks, washouts, and partings thin the coal seam, giving less seam thickness in which to drill. If the rock filling the roll, horseback, washout, or parting is harder than the coal, it will tend to deflect the drill bit.

Thin partings of relatively soft material will have little or no effect on drilling. However, slower penetration rates are necessary in denser, soft partings because this material will tend to plug the bit.

FOLDS

In a folded coal seam, the drill bit may encounter the rock above or below the coal and cause hole deviation.

FOREIGN INCLUSIONS

CONCRETIONS

Hard concretions in coal may cause tight spots and will tend to deviate the hole, reduce penetration rates, and dull the bit.

INTRUSIONS

A drill bit encountering an intrusive dike or clay vein could be deflected, or the bit could become plugged, causing a stuck drill string.

NATURAL FORCES

GRAVITY

When drilling long holes in coal, gravity tends to pull the drill string down in an arc from its horizontal course.

LOCAL MAGNETIC INCLUSIONS

Presently, the tools used to survey horizontal holes rely on the earth's

magnetic field to determine horizontal direction.² Because these tools depend on magnetic attraction, they are susceptible to nearby ferrous objects. Underground items, such as rails, pipes, and power cables, could cause erratic instrument readings. Large concentrations of magnetite although uncommon, may be encountered in the rock above or below the coal and could affect survey results.

ROCK PRESSURE

Sometimes a coal seam is overstressed due to excessive overburden pressure or weight redistribution caused by mining. This can cause a tight hole and, when drilling, result in a stuck drill string.

MECHANICAL FACTORS

The mechanical factors to be considered in designing a drilling system to economically and consistently drill long straight holes in coal are discussed in this section. These mechanical factors must be adapted to overcome the problems caused by the natural factors previously discussed and other natural factors found in the mine environment.

COAL DRILL

The coal drill is one of the most important factors to consider when developing a long-hole drilling system. The drill must (1) be low profile, (2) be light weight so it can be easily moved by a two-man crew, (3) have adequate reserve power to drill a 3-inch hole to 1,000 ft, and (4) be fully instrumented to record thrust, torque, and revolutions per minute. This last requirement cannot be overstressed. Drilling parameters must be recorded so that hole direction changes caused by different combinations of thrust, revolutions per minute, and torque are known and can be duplicated when required.

DRILL ROD

The drill rod should not be too small in diameter or too flexible

²Some of these instruments are so accurate that they require a correction factor of the earth's magnetic field known as the magnetic dip angle. This magnetic dip angle for a given point on the earth's surface is the angle at which the earth's magnetic field reenters the earth. This angle, when applied to the result of the downhole instrument survey, allows the operator to know precisely the horizontal and vertical angles from which the instrument is transmitting.

because excess rod whip, especially at high revolutions per minute, could have a possible adverse effect on hole direction. The rod outer diameter must be small enough to allow for the return of cuttings and drilling fluid between the rod and hole wall. The rod inner diameter must be large enough for passage of a pump-down survey instrument to periodically determine bearing, inclination angle, and axial orientation.

The rod tool joint must have an adequate cross sectional area to safely transmit the drilling forces to the bit. The tool joint must also form a watertight seal under relatively high pressures so that hole deflection devices such as a Dyna-Drill or jet bit can be used.

CIRCULATING FLUID

The circulating fluid should be water. Using air as a circulating medium could cause an explosive mixture in the methane environment, and drilling mud is expensive and difficult to handle. The annular velocity and volume of the circulating fluid must be great enough to keep the cuttings in suspension, otherwise penetration rate is seriously impeded and the drill string may become stuck in the hole. Insufficient fluid volume could also contribute to adverse hole direction.

DRILL BITS

Bit selection for long-hole drilling depends on (1) the bit's directional stability over a wide range of conditions, (2) expected penetration rate, (3) cuttings size produced, (4) expected bit life, and (5) relative cost.

STABILIZERS

Drill rod stabilizers properly used, can aid in controlling the lateral and vertical direction of a horizontal hole. Previous studies indicate that a bit will tend to climb in a horizontal hole when one 8- to 12-inch stabilizer is used directly behind the bit. Conversely, the bit can be made to drop by placing a stabilizer one rod joint behind the bit.

Although lateral hole deviation can be minimized, theoretically, by making the downhole drilling assembly as rigid and tight-fitting in the hole as possible, other problems can develop. For example, an extremely rigid assembly is not compatible with a drilling technique that uses drilling parameters to control vertical hole direction.

DEFLECTION DEVICES

Downhole deflection tools are required when the trajectory of the drill

hole must be deviated. Hole deviation may be needed to keep the bit in the coal seam or to deviate a hole back on target.

A deflection tool should have a low initial cost, should not require specialists to operate, should need only minimal time downhole, and should be able to deviate holes in soft rock.

Special equipment and techniques to correct hole deviation in vertically drilled holes are available. The two deflection tools used most often and most successfully are the Dyna-Drill and the deflection wedge or whipstock device. The jet or "big eye" bit is also used to change hole direction. Another deflection tool that has been used with some limited success is the spade or curlew bit.

A Dyna-Drill, steel deflecting wedge, reaming collar, and spade bit were selected for testing in this program. A jet bit was not field tested because none is currently available for a 3-inch hole and also funds were not available for the high pressure pumping equipment required. However, a directional jet bit was tested in the laboratory. The knuckle joint, also not selected for testing, is not made small enough for a 3-inch hole, and special design and fabrication costs exceeded the available funds.

HUMAN FACTORS

Of all the factors that must be considered in the drilling of a long, horizontal hole in coal, human factors will be more difficult to control in the present state of the art than will natural or mechanical factors. The drill crew must be selected for their potential to learn how to consistently drill long holes because few people have drilled long holes in coal.

Preferably the driller should have had some exploratory drilling experience. He should be intelligent, mechanically inclined, and inquisitive. The successful drilling of long horizontal holes in coal is dependent upon the skill, experience, and attitude of the driller and his immediate supervisor.

The driller must be familiar with the drilling tools, devices, and techniques required for successful long-hole drilling and be able to select and use the proper tools. He must be prepared to cope with the problems and changing conditions encountered. In addition, the driller will have to develop the ability to determine when and for how long a particular drilling tool and/or technique should be used. Proper timing in the use of the drilling tools and techniques can only be achieved after successfully drilling several long holes.

An experienced driller can forestall problems and expedite drilling by observing the sound and vibrations of the drill rig. For example, when the bit encounters a hard spot, an experienced driller can tell by the rod chatter that corrective action must be taken.

The drill crew selected will first have to become familiar with the drill rig, drilling tools, survey equipment, and the drilling techniques that have been most effective in drilling long holes. Then, once long-hole drilling has begun, the crew should expect the first few 1,000-ft holes to take a relatively long time to drill. The crew will also need time to establish a procedure for long-hole drilling in a particular coal seam. Drilling will go faster once the crew has become familiar with the equipment and techniques required.

The drill crew must maintain an accurate drilling record so that, among other things, successful procedures can be duplicated. An accurate record of the drilling tools in the downhole string is also important if a twist-off and subsequent fishing job is needed.

Drilling both vertical and horizontal holes is, after all, still an art, and as such is dependent on the skill and adaptability of the drilling personnel.

SECTION 6

STATE OF THE ART

DRILLING LONG HORIZONTAL HOLES

The purpose of this project is to develop more scientific precision in drilling long, horizontal holes in coal and to establish definitive techniques that can be duplicated in future drilling programs. Until now, the state of the art of drilling long, horizontal holes in coal was inadequate for consistently drilling to 1,000 ft. Most of these earlier holes had been drilled for a specific purpose, with little regard for establishing basic techniques.

The state of the art of drilling 3- to 36-inch diameter horizontal holes has been reported in Bureau of Mines Information Circular 8392.²⁵ An additional report dealing more specifically with the drilling of small diameter horizontal holes in coal is Jacobs Associates report to the Bureau of Mines.³⁶ These reports document the state of the art through July 1970. Information in these reports can be divided into two categories: equipment available and drilling methods used. The information on equipment is comprehensive but that on drilling methods is sketchy.

The following brief information is provided to acquaint the reader with the equipment and methods previously used in drilling horizontal holes. This information was the basis for selecting the drilling tools, devices, and techniques for testing in this project.

EQUIPMENT

The basic equipment required for drilling horizontal holes is the rig, drill rods, bit, deflection devices, stabilizers, and surveying instruments.

DRILL RIG

The Jacob's report concludes that the rotary drill has the best potential for drilling long, horizontal holes. However, it adds that currently available rotary rigs "were not built to operate in the confined vertical space found in most coal mines or were not designed for handling extremely long drill stems required for deep methane drainage."

DRILL RODS

Numerous types of drill rods are available for horizontal drilling. No information is available on the torque requirements for drilling long, horizontal holes; therefore, rod selection is normally based on personal preference.

BITS

Many types of bits have been used for drilling horizontal holes, and selection seems to be based on the contractor's preference or on economic considerations. The following bits are generally used.

DRAG BITS

Drag or blade bits are used extensively for blast hole and exploratory drilling in the mining industry. The drag bit is said to require more torque than other bit types and is primarily used for drilling in soft rock. In 1968 the Bureau of Mines stated, "specific knowledge is lacking on long horizontal holes drilled with drag bits."²⁵ After further Bureau research, a report published in 1969 stated that a drag bit (Blue Demon MP-200) "gave the most satisfactory combination of factors needed to drill a long 2-inch diameter horizontal hole."¹⁴

PLUG BITS

Plug or full face bits have been successfully used in drilling rock other than coal. These bits are not considered effective for long-hole drilling in coal because they provide slower drilling rates than other bits. However, plug bit manufacturers are making efforts to improve the bits' performance in softer materials.

ROLLER CONE BITS

Roller cone bits are used for all types of rock and have been the standard in oil well drilling for many years. These bits are reported to require more thrust but less torque than other bits. Jacobs reported that "roller cone bits in diameters of much less than 4 3/4-inch have never been made with very good life capabilities (*therefore*) the roller cone bit does not seem to be a good candidate for research in small diameter (*hole*) methane drainage."

DEFLECTION TOOLS

Devices such as whipstocks, knuckle joints, jet bits, spade bits, and the Dyna-Drill with bent sub are available for redirecting small diameter horizontal holes.

1. The whipstock has been successful in changing horizontal hole direction in tuff at the Atomic Energy Commission's Nevada Test Site, but directional change in deep holes has often been difficult due to the soft volcanic rock.
2. The 4 1/2-inch knuckle joint is the smallest available.
3. Jet bits require the use of high-pressure pumps to be effective and, therefore, have not been used for small-hole drilling.
4. The spade bit has had limited use in horizontal drilling, and, consequently, little information is available on its use.
5. Bent subs with a Dyna-Drill have been used in Japan to change hole direction in a horizontal hole.

STABILIZERS

Studies have shown that by placing two stabilizers on the drill string, one near the bit and one 10 to 30 ft away, the bit will tend to drill straight holes. Drilling with no stabilization causes the bit to fall, and if only one stabilizer is placed at the bit, the bit will rise.

SURVEYING INSTRUMENTS

Many survey instruments are available for determining the position of a borehole. These include the etch tube, manometer device, mechanical gimbal-mounted devices, magnetic singleshot, and magnetic and gyro multishot survey instruments.

ETCH TUBE

The etch tube inclination device relies on the fact that the free surface of a liquid at rest will always remain level or horizontal by force of gravity. The etch tube is partially filled with hydrofluoric acid that etches a line at the surface level of the liquid. This small tube is lowered into a drill hole, and after 15 to 20 minutes of etching time, the device is removed from the hole. The resulting angle between the wall of the bottle and the top of the etched line is determined as the hole deviation from the horizontal. This method is slow and is accurate only to within several degrees.

MANOMETER DEVICE

This method of surveying long, rising, horizontal holes measures the pressure head of water within the drill rods on a manometer or other pressure

gauge. It can be done quickly and is sensitive enough to give an accurate profile of the hole as it is drilled. When a reading is required, the drilling operation stops for only a few moments while the reading is made. This method is currently used during drilling operations in coal seams, and where applicable, is simple, inexpensive, and rapid. The main disadvantage is that the manometer gives no indication of the position of the borehole relative to the roof or floor of the coal seam, and the pressure will cease to rise as soon as the hole begins to drop. It is only accurate for a constantly rising hole.

GIMBAL-MOUNTED DEVICES

Due to its unlimited swing mountings, a gimbal-mounted plumb bob will remain fixed due to gravity. Determination of inclination requires a scale to indicate the angular difference between the fixed gravity reference and the gimbal mount. One such device is the Tro-Pari instrument (Trotter-Pavari Instruments, Sudbury, Ontario), characterized by a unit mounted in gimbals and provided with a clockwork mechanism that clamps a compass to indicate azimuthal direction and simultaneously clamps the unit in plumb (gravity-related upright) position to indicate hole inclination. The inclination is accurate to the nearest $1/2^{\circ}$, and this singleshot device is fast and inexpensive to use. The device is reliable anywhere except in the presence of ferromagnetic material where the directional compass becomes unreliable.

SINGLESHOT AND MULTISHOT SURVEY TOOLS

The singleshot is a magnetic or gyroscopic survey instrument. It offers compass-angle units in a variety of ranges capable of reading angles from 0° to 135° . This instrument provides the vertical inclination and horizontal direction at any given point in the drilled hole, and at the same time, the film records are easily interpreted and permanent, making filing possible. However, it is capable of making only single records of vertical inclination and horizontal direction at one loading. A less expensive, simpler modification of this tool may be used to record inclination only. The compass-angle unit is replaced with an inclination unit available in ranges capable of reading 0° to 135° .

The multishot operates in the same way as the singleshot, but it is capable of taking a picture every 20 seconds for about 4 hours.

DISCUSSION

The etch tube, manometer, gimbal-mounted devices, and pendulum are inclination devices and are not considered to have the versatility required for research projects. The gyro compass instruments can only be rented from survey companies and must be accompanied by trained company service personnel. Use of the singleshot survey tool in testing is limited because the instrument can take only one reading per loading, thus providing only spot checking. The magnetic multishot survey tool offers the best advantages for continuously surveying a long, horizontal hole in coal.

DRILLING METHODS

The horizontal drilling methods presented in the literature reviewed are not definitive. Accomplishments rather than detailed analytical information are stressed. The Jacobs report states that "there is little reliable published information on the effects of thrust and rotary speed or bit configuration. Naturally there is even less known about the change in combinations of these parameters....There is very little knowledge available on the thrust requirements needed to propel, or advance, a long horizontal smooth-wall drill stem with different diameter ratios to the wall of the hole, or in different kinds of rock and at different rotary speeds." Because thrust, revolutions per minute, torque, and drill string configurations are the basic parameters available to the driller, information on these parameters is of significant importance.

Horizontal drilling projects completed to date have had varying degrees of success (success being defined in terms of total depth reached). The English were the first to drill horizontal holes in coal, and their longest hole has been to 450 ft. Up to July 1970, the most successfully drilled hole in coal was one to 503 ft drilled by the U.S. Bureau of Mines; however, in Spring 1972, Sprague & Henwood, Inc., under contract to F&S, drilled holes in coal to 850 ft. The projects outlined below are representative of horizontal drilling to date.

HORIZONTAL DRILLING IN THE U.S.

A 3-inch diameter horizontal hole was drilled to 503 ft in the 50-inch thick Pocahontas No. 3 Coal Seam at the Beatrice-Pocahontas Mine by the U.S. Bureau of Mines.

As recorded in the Jacobs report, "the air drill used at Beatrice-Pocahontas was a Thor 56 pound, 8 horsepower, Model 09609A, Code BL... The drill is a straight (non-percussive) rotary, turning the bit at 500 rpm, under no load, and about 425 to 450 rpm under load." A swivel just ahead of the drill transmitted approximately 10 gallons per minute (gpm) of mine water from a 1-inch hose into the 10-ft long EW diamond drill casing.

Drilling commenced at the rib 14 to 16 inches from the floor, and at 160 ft the bit went into the roof. Two 3-inch x 12-inch long stabilizers with four straight ribs were used, one on each end of the first drill rod. They were taken off at 160 ft, and apparently the bit deflected back into the coal. The bit stayed in the coal until the total depth of 503 ft was reached.

Thrust was applied for the first 80 ft of drilling by two men pushing on the drill. At 80 ft, pushing became difficult and a 1-ton come-along was attached; the come-along and two men provided thrust for the rest of

the drilling. "Probably 2,000 pounds thrust was needed toward the end of the drilling and some of this was to propel the pipe rather than need by the bit...."

Sprague & Henwood, Inc., under subcontract to F&S, drilled several horizontal NX-size degasification holes in excess of 500 ft deep. The holes were drilled (during 1972) in coal from the bottom of a 4-ft diameter, 830-ft deep cased shaft for the U.S. Bureau of Mines at a site near the Federal No. 2 Mine near Blacksville, West Virginia. The hole depths were 500, 549, 556, 608, 616, 646, and 850 ft.

The equipment used consisted of a Sprague & Henwood skid-mounted, 40 CL, rotary drill with an "N" swivelhead, having a 30-inch stroke. Power was supplied by an air motor delivering 20 horsepower (hp). The drill rods used were NX wire-line rods in 5-ft lengths. Drilling water was recirculated underground by an air driven triplex pump. The first 55 ft of the 850-ft hole was drilled with an NX diamond-set coring bit. The remainder of the hole was drilled with a Hughes NX-size, insert-type, replaceable blade drag bit. While drilling the 850-ft horizontal hole, vertical control was achieved by changing the stabilization and varying thrust and revolutions per minute. The angle of inclination was determined first by taking hydrostatic water level readings and later by surveying with a Tro-Pari compass. The stabilization configuration that caused the hole to slowly drop consisted of a bit, 10-ft stabilizer, 10-ft drill rod, and 5-ft stabilizer. The climbing configuration consisted of a bit, 5-ft stabilizer, and 5-ft, 2 1/4-inch OD drill collar.

HORIZONTAL DRILLING IN ENGLAND

Extensive testing in England, using an electric-hydraulic drill rig with flexibility of thrust and revolutions per minute, was done in the late 1950's to determine the most practical method of drilling long, horizontal holes in coal for degasification. This work was conducted under the direction of the National Coal Board at the Newman Spinney Mine.^{3,39} The project was discontinued in June 1959.

Two basic drilling techniques were tested. They were straight-line drilling where stabilization was used to keep the hole straight, and deflection drilling where changes in drill string configuration, thrust, and revolutions per minute were used to induce vertical hole deviation.

Straight holes were drilled to depths of 200 ft by using a packed hole assembly consisting of a 3- to 3 1/2-ft long stabilizer immediately behind the bit. The stabilizer had about .0020 inch of clearance between it and the hole wall. With this stabilizer, vertical angle build-up or reduction was held to a minimum.

During deflection drilling testing, the holes were made to rise or fall by changing the position of stabilizers and varying thrust and revolu-

tions per minute. The holes could be induced to slowly fall by using a slotting collar behind the bit to wear away the bottom of the hole. The slotting collar consisted of a heavy sub about 1-ft long with carbide buttons around its circumference. Holes could be made to rise by using a "rose" or pointed-nose bit. A second method was developed using a flat-nose bit with a 9-inch stabilizer directly behind it.

Several methods of hole surveying were considered, and those instruments that recorded through cables were discarded. The survey methods tried were a manometer, a tiltmeter, a magnetic system developed by the Admiralty Compass Observatory, and a "coal sensing" device using an iridium source. A sink-and-float gravity method of sampling cuttings returns was also used to determine the location of the hole in the coal seam.

To drill a hole to 450 ft, the operator had to make a number of trips in and out of the hole to change bit types or stabilization in order to control vertical deviation. Frequent manometer surveys indicated when this was necessary.

OTHER DRILLING PROJECTS

Drilling horizontal holes in rock other than coal has been quite successful at the U.S. Atomic Energy Commission's Nevada Test Site. Holes have been drilled as deep as 3,600 ft using core drilling techniques, with water as the circulating media. The core holes were drilled with a Long-year 44 diamond drill rig and an NA drill rod. The core barrel was a standard 20-ft long NX barrel with a 3.032-inch OD, oversize, piloted coring bit. As the holes were being drilled, the NX wire-line core barrel was pulled every 20 ft. Hole direction was checked with a singleshot survey each 20 ft. A Sperry-Sun multishot survey was run every 500 ft to check the singleshot survey.

The Japanese have developed and used the rotary drill machinery, equipment, and methods for drilling long, horizontal, directionally-controlled probe and grout holes ahead of the long tunnels being constructed to join the Islands of Japan.

The Seikan Tunnel in Japan was the site of a major drilling effort. A horizontal drill rig with 4 1/2-inch drill string and a 7 5/8-inch 3-cone bit was used to drill a 1,340-ft hole in a pilot boring ahead of the tunnel face. The Dyna-Drill was used successfully by the Japanese as a directional control tool in this drilling operation.

SECTION 7

FIELD TEST AND DEMONSTRATION

GOALS AND GUIDELINES

Drilling long, horizontal holes into virgin coal may become the most effective method for predevelopment methane drainage. Long-hole horizontal drilling can become a practical application by (1) developing a drilling system that can reliably be used to drill 1,000-ft holes in coal rapidly at least cost and (2) developing techniques that, in combination with the drilling system selected, will help control hole direction. Prior to this study neither of these conditions were met.

The purpose of this present work is to investigate, test, and evaluate methods of controlling bit deviation and to develop methods of surveying the direction of small-diameter long holes drilled horizontally into a coal seam. The Bureau's Request for Proposal for this work required the ability to maintain the course of a long hole within the coal seam laterally within 30 ft of the original bearing line to a depth of 1,000 ft.

Although drilling devices to maintain or change hole direction were available, their usefulness in coal drilling had to be evaluated. Therefore, testing primarily involved evaluating the usefulness of currently available or quickly converted drilling devices in the coal environment. One of the major goals of this project, however, was also the development of an in-hole, cableless, survey system.

PREDEMONSTRATION TESTS

TEST SITES

For economy, field testing was conducted in coal strip pits rather than underground. Two sites were used: one in the friable coal of eastern Oklahoma and one in the blocky coal of eastern Ohio.

The Oklahoma test site was an abandoned bituminous coal strip mine near Henryetta, Oklahoma. The coal averaged about 39 inches thick and had an apparent dip from 3° to 7° in the direction of drilling. No hard inclusions in the coal were encountered during drilling. However, the relatively soft bituminous coal seam contained short-amplitude undulations that made it difficult to keep the bit in the coal.

The Oklahoma tests were concerned primarily with bit testing and evaluation. A total of 25 different bits were tested under as nearly the same conditions as possible. At the Oklahoma site, 93 holes from 50 to 420 ft deep were drilled with a total footage of 8,057 ft.

The Ohio test site was in the Hanna Coal Company's West Farmfield "D" pit area in eastern Ohio. The drilling was in the Pittsburgh No. 8 bituminous coal seam at the base of an old high wall in an active strip mine.

The coal seam was nearly horizontal and about 58 inches thick. The main seam was overlain by about 11 inches of soft shale, in turn overlain by 1 to 2 ft of coal. An occasional hard pyrite "ball" was encountered while drilling. The pyrite balls varied from about 6 to 18 inches long, were lens shaped, and laid flat and parallel to the bedding. The coal had an apparent dip of about 0° 50' opposite the direction of drilling.

Selected bits from the Oklahoma testing were used for more extensive testing and evaluation in the somewhat harder bituminous coal to more completely evaluate their directional drilling characteristics.

The Ohio bit testing was similar to that in Oklahoma. That is, in each case, the same drill string stabilization was used for each hole drilled, and the same drill fluid volume was used.

The Ohio test series consisted of 32 holes, ranging in depth from 45 to 1,102 ft. Total footage drilled was 7,040 ft.

Table 1 is an example of the drilling record maintained on all holes drilled at each test site. Figure 2 shows columnar sections of the coal seams tested in Oklahoma and Ohio.

EQUIPMENT

DRILL RIG AND ACCESSORY EQUIPMENT

Drilling equipment manufacturers were requested to quote on a low-profile drilling rig capable of drilling 3- to 3 1/2-inch diameter horizontal holes to a minimum depth of 1,000 ft. Rig specifications called for a minimum of 500 foot-pounds (ft-lb) of torque at 500 revolutions per minute (rpm) and a minimum thrust of 10,000 lb.

The drill rig eventually selected and used for this work was fabricated by E.J. Longyear Company. The rig was powered by a gasoline engine coupled to a hydraulic pump that drives a hydraulic N-type motor on the drill. A gasoline engine was used for economy in the testing program, but the rig can be converted to electric power. The feed is hydraulic and capable of 10,000 lb positive thrust and 20,000 lb retractive force. The rig, illustrated in figure 3, is 18.25 ft long, 5 ft wide, and 3.5 ft high.

Table 1. Example of drilling record kept on all test holes.



DRILLING RECORD

DATE 7/4/72 SHEET 3 OF 4
3 1/2" Williams
 BIT NO. 3 cone Roller
 HOLE NO. P-2
 DATE COLLARED 6/30/72
 DATE COMPLETED 7/6/72

DATE	DEPTH FT	THRUST LB	THRUST REQUIRED TO MOVE STRING	ROTATION RPM	FLUID VOL. GPM PUMPING	WATER PRESSURE PSI	TORQUE ON STRING PSI*	TORQUE REQUIRED TO BEGIN TURNING	TIME DRILLING			PENETRATION RATE in/sec.	REMARKS
									START	STOP	ELAPSED		
7/4/72	779.5 789.5	1500		400	40	35	900	Nil	12:08:15	12:11:45	210 sec.	0.57	At 1215 hr return dark black with considerable fine powder coal. Return dark black
	789.5 799.5	1500	Make 3 reaming passes at end of 10 ft. run. slightly. Smooth drilling	400	40	35	900		12:17:45	12:22:15	270 sec.	0.44	Drilling somewhat harder. At 1225 hr return dark black.
	799.5 809.5	1500	Attempting to hold vertical angle.	400	40	35	950		12:28:45	12:34:30	345 sec.	0.35	Harder drilling, soft zone about 805 ft. At 1237 hr water somewhat clear.
	809.5 819.5	1500	At 1238 hr start getting dark return. Therefore takes about 9 minutes to return dark black.	400	40	35	950		12:41:30	12:46:00	270 sec.	0.44	At 1244 hr water return had slight shaley color. Hard drilling 1st 5 ft. Last 5 ft easier drilling. Could be center shale parting. At 1246 and 1257 hr return dark black.
	819.5 829.5	1500		400	40	35	950		12:52:30				Nine min. to get cuttings return. Return black. Smooth drilling.
	829.5 839.5	1500		400	40	35	950		13:02:30	13:09:30	420 sec.	0.29	Return dark black. Drilling in coal. Smooth drilling. Made 3 reaming passes in attempt to slightly reduce vertical angle.
	839.5 849.5	1500		400	40	35	950		13:16:00	13:25:00	540 sec.	0.22	Hard drilling all the way. Could be in upper 2 ft of harder coal. Return dark black. Smooth drilling. Made 3 reaming passes.
	849.5 859.5	1500		500	40	35	2100 psi 2:1 gr. rto		13:33:30	13:41:00	450 sec.	0.27	Harder drilling all the way. Increase rpm to 500 in attempt to reduce tendency to climb. In addition, made 3 reaming passes at end of 10 ft run. Return dark black.
	Note: With rods stationary takes 1000 lb thrust to just move rods and negligible torque. All above measurements made with bit 2 ft off bottom.												

FORM T014

* 6:1 Gear Ratio

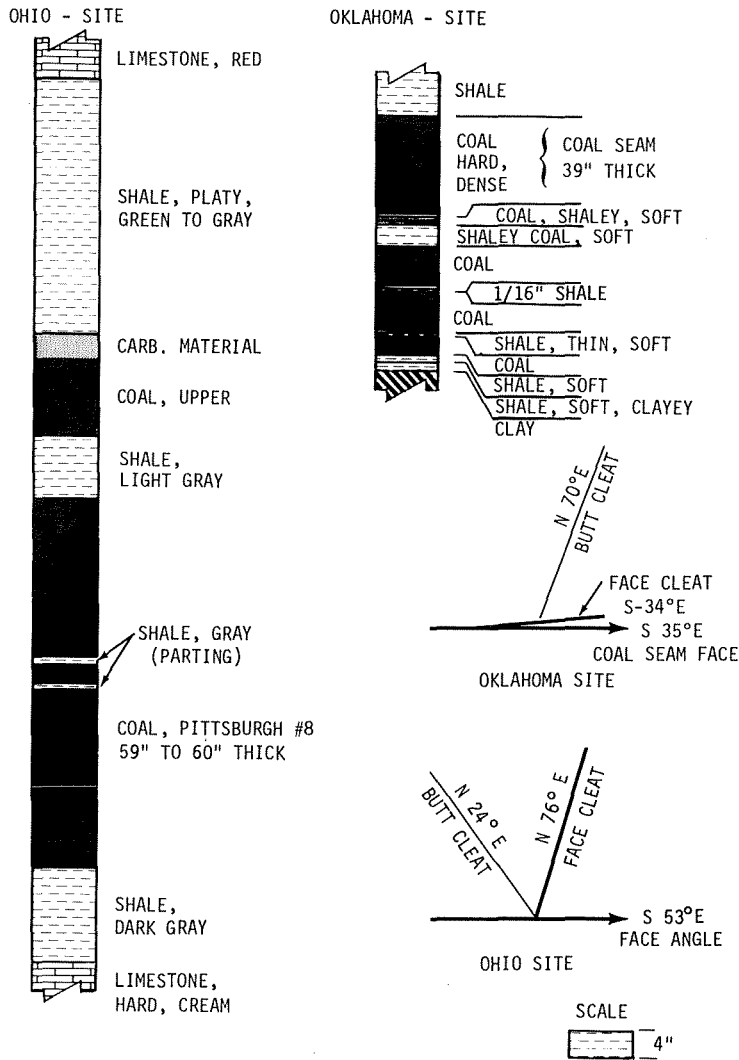


Figure 2. Columnar sections of the Oklahoma and Ohio coal seams.

The circulating fluid pumping unit consisted of a triplex plunger pump with 2-inch plungers rated at 500 pounds per square inch (psi) at 25 gpm and powered by a 2-cylinder, air-cooled, gasoline engine. The unit was mounted on a heavy-duty structural steel skid.

A hydraulic-feed pressure gauge on the driller's control panel was used to determine the thrust on the bit in total pounds of force. The pressure indicated on the gauge in pounds per square inch was converted to pounds of force on the bit with the aid of a chart furnished by Long-year.

Another hydraulic pressure gauge on the driller's control panel was

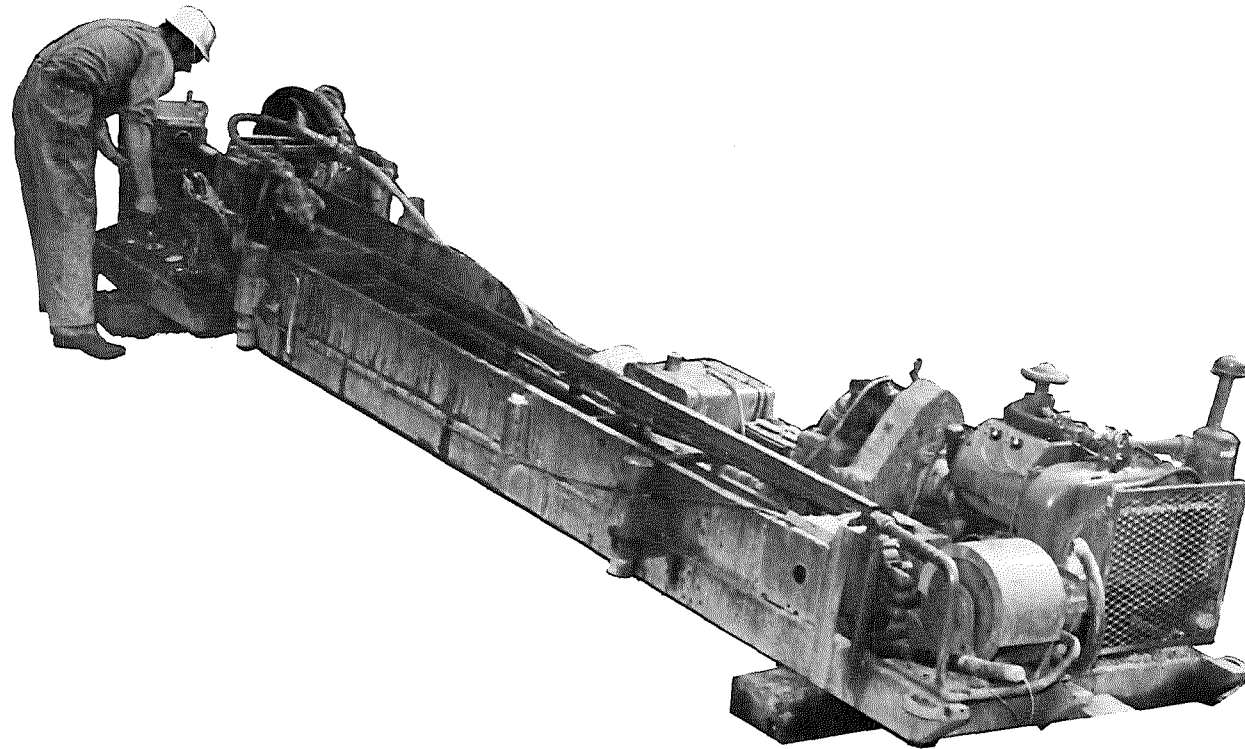


Figure 3. Coal drill used for horizontal holes.

used to determine the torque on the drilling assembly. The hydraulic pressure reading, indicated in pounds per square inch, was converted into foot-pounds of torque.

Revolutions per minute of the drilling assembly were indicated by an electronically operated meter located next to the driller's console. A water pressure gauge, also next to the driller's console, was used to determine water pressure applied to the drilling system at the rig. Water volume was measured directly in gallons per minute with a direct-reading flowmeter mounted on the triplex pump.

DRILL ROD

The drill rod selected for this work was a BQ flush joint. The wedge-lock joint wire-line rods have tapered threads for fast stabbing and quick coupling and uncoupling. The following specifications apply:

OD	2 3/16 inches
ID	1 13/16 inches
Threads/inch	3
Weight	40 lbs/10-ft rod

The box end of the 10-ft long rods have hard chrome plating. The tapered threads form rigid joints that should give good performance under high compressive loads.

CIRCULATING FLUID FLOW RATES

Initial test drilling at the Oklahoma site was used to try out the drill rig and to establish optimum circulating water-flow rates. The purpose of the flow-rate tests was to determine the best hole-cleaning fluid volume. Based on test results, a drilling fluid volume of 25 gpm was used. At this flow rate, the penetration rate was nearly maximum and hole cleaning was good.

The flow tests were conducted with a 3-inch diameter, Hughes DB-400, 3-blade drag bit with tungsten carbide inserts. Thrust on the bit varied between 1,000 and 5,000 lb, and the flow rates used were 10, 20, 25, and 30 gpm. A constant 150 rpm was maintained at each combination of thrust and flow rate.

Forty to fifty feet of hole was drilled at each combination of thrust and flow rate. Figure 4 presents test results in a plot of penetration rate vs. thrust as a function of water-flow rate.

Coal cuttings produced by the bits tested ranged from 1/2 x 1/4 x 1/8 inch at the shallower depths to finely ground cuttings (about the size of ground black pepper) at greater depths. The cuttings size was not only

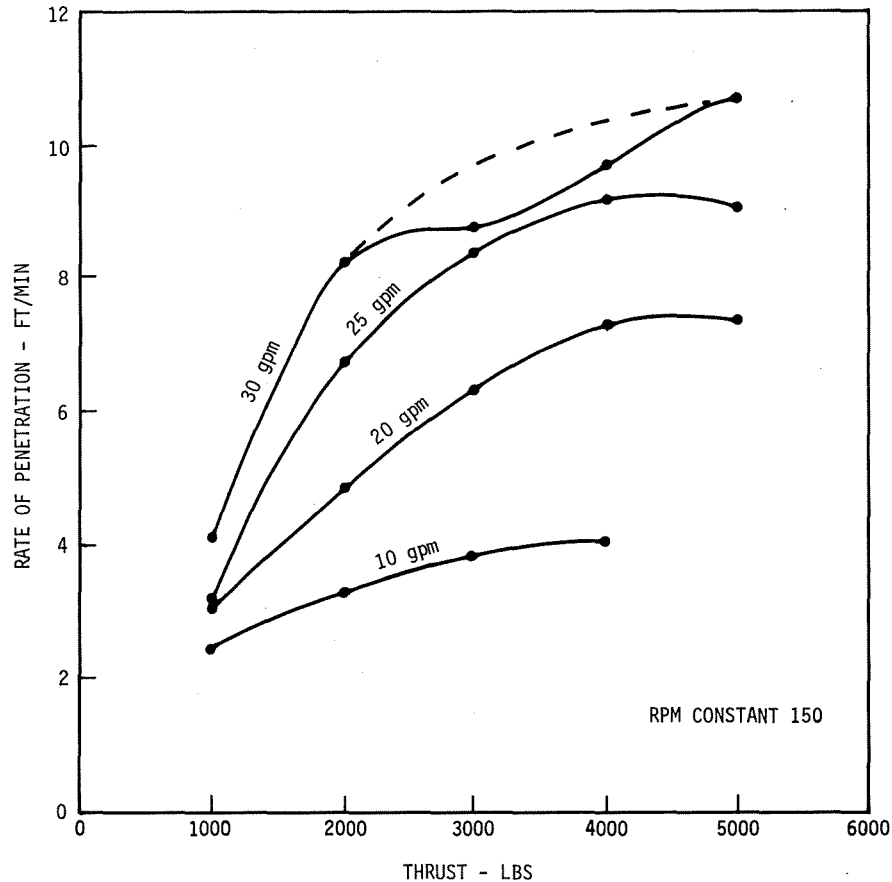


Figure 4. Plot determining optimum drilling fluid volume.

related to the depth of the hole but to the type of bit used. The plug-type bit produced the smallest cuttings, while the drag-type produced the largest in the shallower (0-200 ft) portion of the hole. As the hole deepened, all cuttings became progressively smaller due to the beating action of the drill rods. In the later field test we found that as long as the fluid return rate remained at 25 gpm or above, efficient cuttings removal was obtained even with penetration rates as great as 19 feet per minute (fpm).

BITS

The bit testing program was designed to (1) determine what bit types

were the most directionally stable, (2) evaluate the effect on hole direction of changing thrust and revolutions per minute, and (3) identify bit types that have a good penetration rate and produce a minimum amount of overbreak in coal. The number of bit types tested are presented in the following list:

<u>Type</u>	<u>Number</u>
2-Blade	4
3-Blade	13
4-Blade	3
3-Cone	2
Convex	2
Concave	<u>1</u>
Total Types Tested	25

This selection was made from a study of the rotary bits and possible new bit designs available.

A survey of rock bit manufacturers and drilling contractors was made to determine in advance what the rotary drilling parameters should be for the different bit types (see appendix A). The major rock bit manufacturers vary in their recommendations as to how the bits should be used to obtain optimum performance. Most point out that they just do not know and that the information they provide is only an estimate. They suggest field testing as the best way to establish definitive data.

Each bit type was tested under similar conditions. In Oklahoma the bit testing assembly consisted of the bit, one 10-inch stabilizer, and the BQ drill string. In Ohio the assembly consisted of the bit, a 10-inch stabilizer, 20 ft of BQ rod, a second 10-inch stabilizer, and the BQ drill string.

The drilling parameters selected for bit testing were based on an evaluation of manufacturers' suggestions and field results. As testing progressed, the better performing bits were more extensively tested.

Table 2 shows an evaluation of the directional stability of the various bits tested and the relationship between thrust, revolutions per minute, and penetration rates. (See appendix B for more detailed descriptions of the bits and their wear record.)

Drag Bits--Drag bits tested in this work are pictured in figures 5, 6, and 7. They include:

2-Blade

Servco 16, 17, 18
EDECO Flycutter

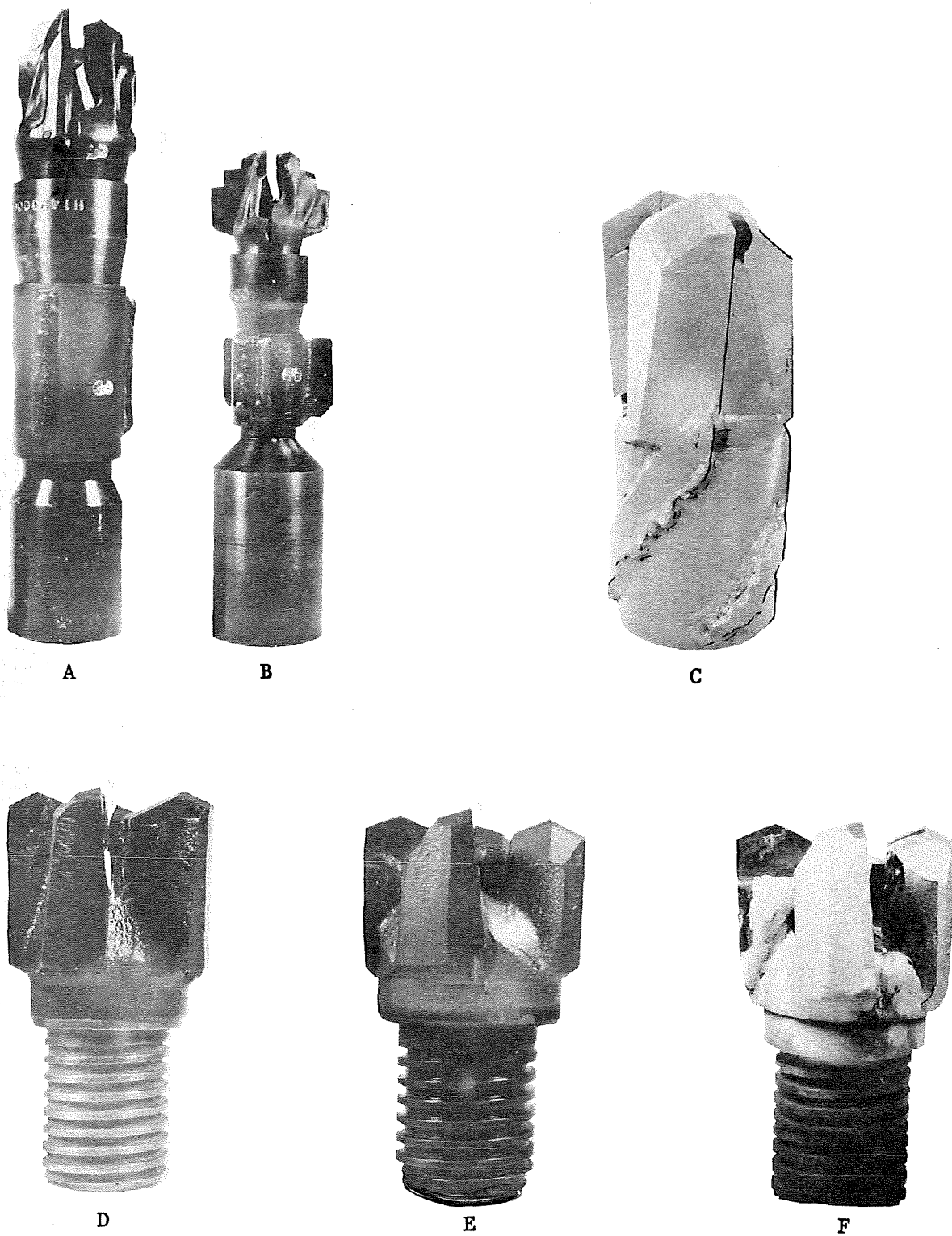


Figure 5. Drag bits tested: A--Hughes DB-400 three-blade, B--Hughes MP-200 three-blade, C--Servco 21 mill three-blade, D--Varel four-blade, E--Gault four-blade, and F--Walker-McDonald four-blade.

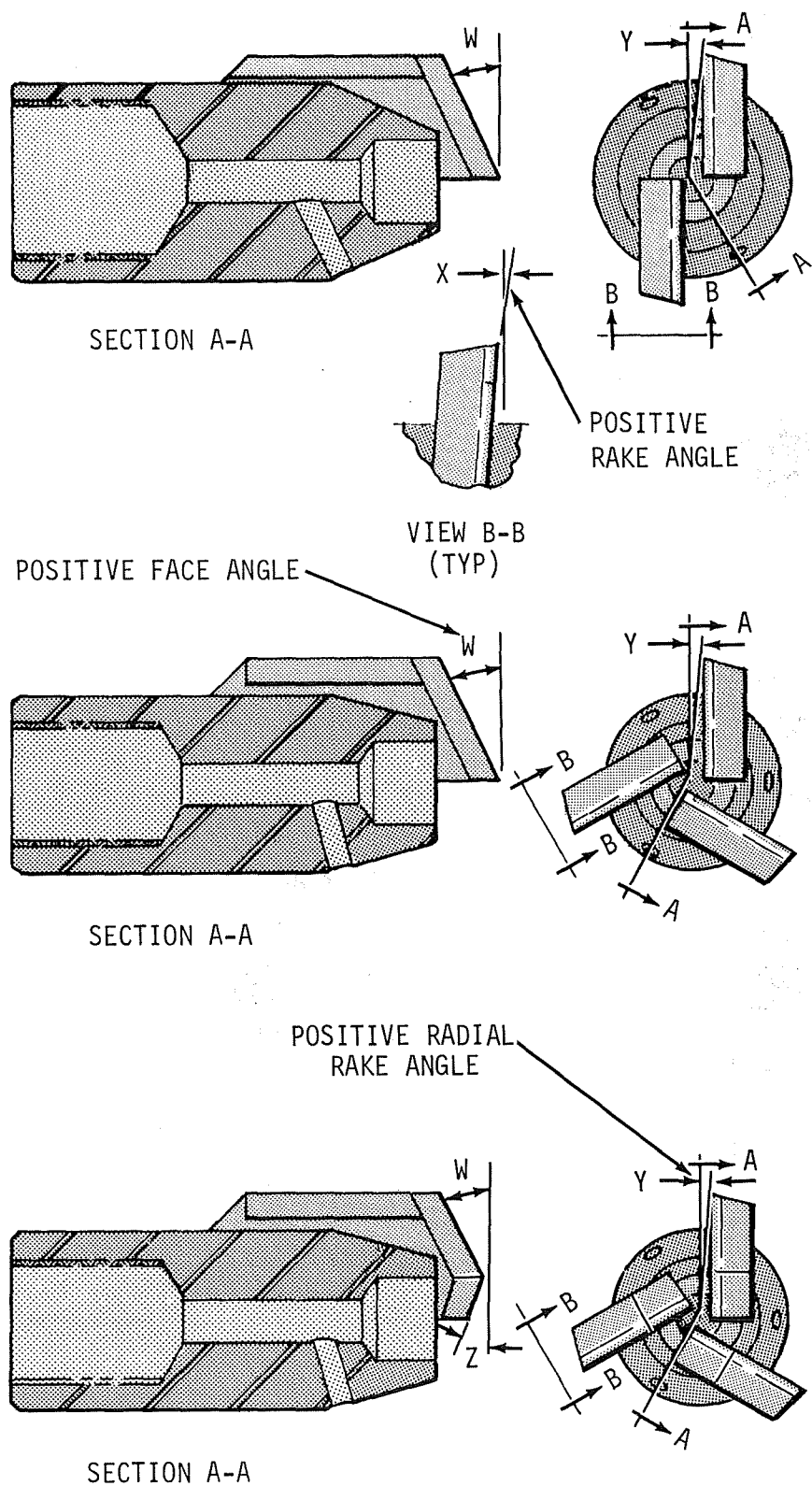
Table 2. Directional stability and relation between thrust, revolutions per minute, torque, and penetration rates.

Bit Class	Bit Type	Hole ¹ No.	Depth (ft)	Thrust		Torque (ft/lbs)	Penetration Rate (fpm)	Directional Stability ²	
				(lbs)	RPM			Horizontal	Vertical
Two-Blade									
Drag	Servco 16	33	20 - 50	4000	200	290 - 330	7.1 - 9.1	G	F to G
	Servco 17	37	9 - 59	3000	200	100 - 120	6.2 - 8.0	G	F to G
	Servco 18	38	49 - 109	3000	200	100 - 120	4.7 - 5.1	G	F to G
	EDECO Flycutter ³	A-1	108 - 158	3000	200	220 - 320	1.5 - 1.9	F	F to G
Three-Blade									
Drag	Hughes DB-400	12	20 - 50	4000	200	290 - 330	7.1 - 9.1	VG	G
		9	60 - 80	3000	200	220 -	11.1 - 11.8		
C-1		109 - 159	2500	150	90 - 110	4.9 - 8.0			
	Hughes MP-200	Not tested as individual bit - tested only with Dyna-Drill							
	Servco 2	21	106 - 156	3000	200	140 - 150	5.0 - 7.2	G	G
	Servco 3	24	87 - 137	3000	200	130	3.9 - 5.9	F to G	G
	Servco 5	26	0 - 56	3000	200	110	6.7 - 9.4	F to G	G
		26	106 - 156	3000	200	150	8.5 - 11.1		
	Servco 8	26	166 - 206	3000	200	160 - 180	5.4 - 8.2	G to VG	G to VG
	Servco 9	19	0 - 60	3000	200	150	6.0 - 6.7	G	G to VG
	Servco 10	26	306 - 356	3000	200	130 - 150	1.7 - 2.2	G to VG	G to VG
	Servco 11	28	6 - 46	3000	200	90 - 110	2.2 - 2.8	G to VG	G to VG
	Servco 14	30	7 - 67	3000	200	110	3.1 - 5.0	F to G	G to VG
		33	7 - 47	3000	200	110 - 130	4.7 - 6.3		
	Servco 19	41	79 - 129	3000	200	130	4.6 - 5.0	G	G
	Servco 20	42	7 - 57	3000	200	150	4.4 - 4.7	G	G
	Servco Mill 21	68	36 - 86	3000	200	130	5.4 - 5.9	VG	G to VG
		E-3	7 - 108	2500	200	110	4.8 - 7.0		
	EDECO Stratabit ³	B-1	111 - 141	3000	200	150 - 210	N/A	VG	G to VG
Four-Blade									
Drag	Gault	49	65 - 125	3000	200	170 - 250	6.6 - 10.9	G	G to VG
	Varel	51	76 - 126	3000	200	150 - 230	7.9 - 14.6	G	G to VG
	Walker-McDonald	53	96 - 146	3000	200	290 - 330	9.1 - 15.0	G	G to VG
Three-Cone									
Roller	Williams 3"	53	100 - 150	4000	200	180	3.0 - 3.5		
		55	46 - 96	3000	200	130 - 150	2.8 - 3.1	G to VG	G to VG
		D-1	99 - 169	3000	200	130 - 150	3.0 - 3.4	G to VG	G to VG
	Williams 3 1/2"	P-1	226 - 307	3000	200	150	3.3 - 3.8	G to VG	G to VG
		P-1	319 - 419	3000	200	150	2.2 - 5.7		
		P-1	669 - 749	3000	200	150 - 180	2.5 - 4.0		
		P-2	609 - 669	3000	200	150	2.2 - 4.6		
		P-2	959 - 1089	3000	200	160 - 220	1.2 - 3.1		
	R-1	494 - 514	3000	200	180	3.4			
	Gruner	13	10 - 40	4000	400	150	5.7 - 6.2	G to VG	G to VG
	Plug Bits								
	Carbonado	18	70 - 100	3000	200	130 - 150	4.5 - 5.0	G to VG	VG
	Amer. Coldset Concave	57	6 - 56	2000	800	100	2.3 - 3.0	G to VG	VG
		59	26 - 46	3000	200	150	1.9 - 3.0		
	Amer. Coldset Convex	60	6 - 56	2000	800	100	1.9 - 4.3	G to VG	G to VG

¹Those holes numbered with a letter followed by a number (i.e., R-1, M-1) were drilled in Ohio. All other holes were drilled in Oklahoma.

²The directional stability indicated is based on the entire drilling program and is not necessarily limited to the data included in this table. Symbols: VG, very good; G, good; F, fair. Cases where increased thrust resulted in reduced penetration rates must have been due to harder coal.

³After drilling with the two English bits, both were found to be slightly undersize to a 3-inch gauge. This caused the stabilizer following the bit to be involved in drilling the hole, thus reducing the penetration rate and causing excessive torque.



BIT TYPE	BIT NO.	ANGLE, DEGREES			
		W FACE	X RAKE	Y RADIAL	Z COMPOUND
2 BLADE	16	25	5	0	-
	17	0	5	0	-
	18	25	5	5	-
3 BLADE	2	25	5	0	-
	3	25	0	0	-
	5	-10	5	0	-
	8	0	5	0	-
	9	0	0	0	-
	10	25	-5	5	-
	11	25	5	5	-
14	0	5	5	-	
3 BLADE COMPOUND	19	30	0	0	-15
	20	30	5	0	-15
	21	30	5	0	-15

Figure 6. Servco drag bits tested.

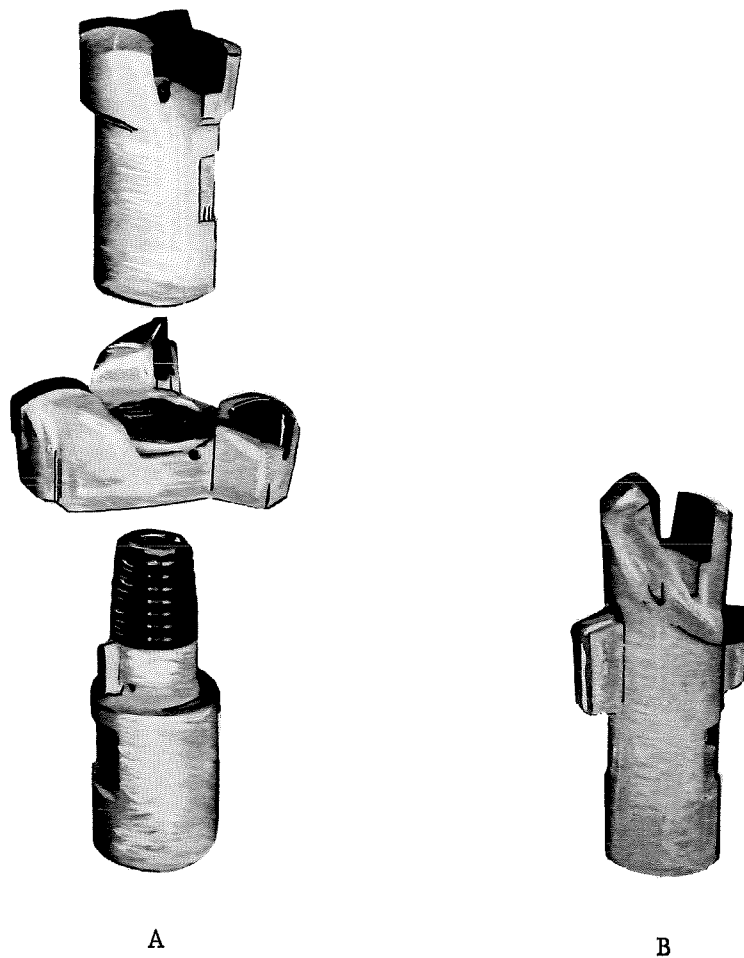


Figure 7. Staged bits tested: A--EDECO three-blade multi-stage Stratabit and B--EDECO two-blade multi-stage Flycutter.

3-Blade

Servco 2, 3, 5, 8, 9, 10, 11, 14,
19, 20 and 21 Mill

Hughes DB-40
EDECO Stratabit

4-Blade

Gault
Varel
Walker-McDonald

The use of manufacturer's names is for identification purposes only. No endorsement is implied or intended. The Servco numbers represent bits that were designed and made especially for this work. The missing numbers represent bit designs that were eliminated during the device evaluation stage.

Drag bit testing was performed under the following conditions:

Thrust:	varied in 1,000-lb increments between 1,000 and 5,000 lb.
Revolutions per Minute:	varied in 50-rpm increments from 100 to 500 rpm at each increment of thrust
Fluid Volume:	25 gpm
Pump Pressure:	40 to 75 psi

About 40 to 50 ft of hole was drilled with each drag bit at different combinations of thrust and revolutions per minute. The holes were surveyed with a multishot survey instrument and the course of each hole plotted in the vertical and horizontal plane for evaluation.

The penetration rate of most of the drag bits was good, even at lower ranges of thrusts and revolutions per minute. The DB-400 had a penetration rate of 18 fpm at 5,000-lb thrust and 200 rpm. However, this amount of thrust was not practical for drilling a controlled hole, and no extensive testing was done in this thrust range.

At a thrust of 3,000 lb and 200 rpm, highest penetration rate for each bit in the short test hole was:

<u>Bit</u>	<u>Penetration Rate (ft/min)</u>	<u>Maximum Torque (ft/lb)</u>
Flycutter	1.9 (bit was under gauge)	320
Servco 10	2.2	150

<u>Bit</u>	<u>Penetration Rate (ft/min)</u>	<u>Maximum Torque (ft/lb)</u>
Servco 11	2.8	110
Servco 20	4.7	150
Servco 19	5.0	130
Servco 18	5.1	120
Servco 3	5.9	130
Servco 21	5.9	130
Servco 14	6.3	110
Servco 9	6.7	150
Servco 21	7.0 (2500-1b thrust)	110
Servco 2	7.2	150
Servco 17	8.0	120
Servco 8	8.2	180
Servco 16	9.1 (4000-1b thrust)	330
Gault	10.9	250
Servco 5	11.1	150
DB-400	11.8	220
Vare1	14.6	230
Walker-McDonald	15.0	330

In the directional stability test, 16 of the 20 drag bits were stable. Nearly all drilled relatively straight laterally; vertical deviation was more pronounced than lateral deviation.

When lateral deviation occurred, it was confined to a short hole interval of 10 to 30 ft, producing a lateral "kink" or dogleg in the hole with the section of hole before and after the dogleg being relatively straight. The doglegs apparently resulted from bit deflection by structural changes or hard inclusions in the coal seam.

Drag bits that showed the slightest lateral deviation at 3,000 lb thrust and 200 rpm were the Hughes DB-400, Servco 8, 10, 11, and 21, the English Stratabit, and all the 4-blade bits. For example, during Oklahoma testing, with only one stabilizer behind the bit, the lateral deviation of the DB-400 varied from 0 ft in 70 ft to 3 ft right in 250 ft. The Servco bits mentioned above had little or no lateral deviation for distances up to 120 ft. With the 4-blade drag bits, the greatest lateral deviation was 2 ft right in 100 ft of hole.

The bits that had the greatest tendency to deviate laterally were the Servco 3, 5, and 14 and the English Flycutter. Servco 3 and 5 deviated 4 to 6 ft right in 150 ft. The remainder of the drag bits (Servco 2, 9, and 16 through 20) were reasonably stable laterally.

The tendency of the drag bits to climb or build up angle with only one stabilizer behind the bit was more pronounced as the thrust was increased. Invariably, with one stabilizer behind the bit, the hole tended to build up angle as thrust was increased and revolutions per minute decreased. The drag bits tested that appeared to have the least tendency to build up

vertical angle were the DB-400; the Servco 8, 9, 10, 11, 14, and 21; the 4-blade drag bits; and the EDECO Stratabit. The bits that have the most potential for vertical control were the DB-400; Servco 8, 10, 21; the 4-blade drag bits; and the Stratabit.

The drag bits that had the most tendency to build up vertical angle at 3,000 lb thrust and 200 rpm were the Servco 5 and 14 and the EDECO Fly-cutter.

The rest of the drag bits (Servco 2, 3, and 16 through 20) were reasonably stable vertically in the tests.

Structural changes in the coal seam affect the vertical deviation of the bit as they do the lateral deviation. In several holes the vertical plot indicates a relatively sharp build-up or decrease in vertical angle that could only be attributed to a structural change in the coal such as a hard or soft spot.

The limited drag bit testing has not conclusively proved that bit blade angle has any effect on bit direction. However, a common characteristic of some of the more stable bits (Servco 8, 10, and 11) are blades with positive rake angle, positive radial rake angle, zero to positive face angle, and lower drilling rates.

The fastest drilling Servco bits (Servco 2, 3, 5, 16, and 17) had a zero to positive rake angle and a zero radial rake angle.

Bits with long gage cutting blades, such as the Servco and DB-400, tend to drill straight probably due to the stabilizing effect of the longer bit blades.

Coal cuttings produced by the cutting action of the DB-400 averaged $1/8 \times 1/8 \times 1/4$ inches in Oklahoma and $1/8 \times 1/4 \times 1/4$ inches in Ohio. The smaller Oklahoma cuttings were probably a result of the softer and more friable coal. The largest DB-400 cuttings observed were about $1/4 \times 1/4 \times 1/2$ inches. Cuttings size was determined visually; however, cuttings were frequently measured to confirm visual determinations. An estimate was made, while drilling, of the average size of the large fraction. No screen analysis was made to determine the percentage of fine and coarse cuttings.

Coal cuttings produced by most of the Servco bits averaged $1/8 \times 1/8 \times 1/8$ inches. Exceptions were the Servco 5, 8, and 14 that produced smaller cuttings averaging $1/16 \times 1/16 \times 1/8$ inches. The 4-blade drag bits produced cuttings averaging $1/8 \times 1/8 \times 1/4$ inches.

Plug Bits--Three different plug bits were tested:

1. Carbonado concave diamond bit
2. American Coldset concave carbide chip bit
3. American Coldset convex carbide chip bit

These bits are illustrated in figure 8.

Drilling Parameters--The plug bits were only tested with one stabilizer behind the bit. Other parameters were:

Thrust: varied in 1,000-lb increments from 2,000 to 4,000 lb

Revolutions per Minute: varied in 100-rpm increments from 200 to 800 rpm for each increment of thrust

Flow Rate: 25 gpm

Pump Pressure: up to 220 psi for the Carbonado;
up to 110 psi for the carbide chip bits

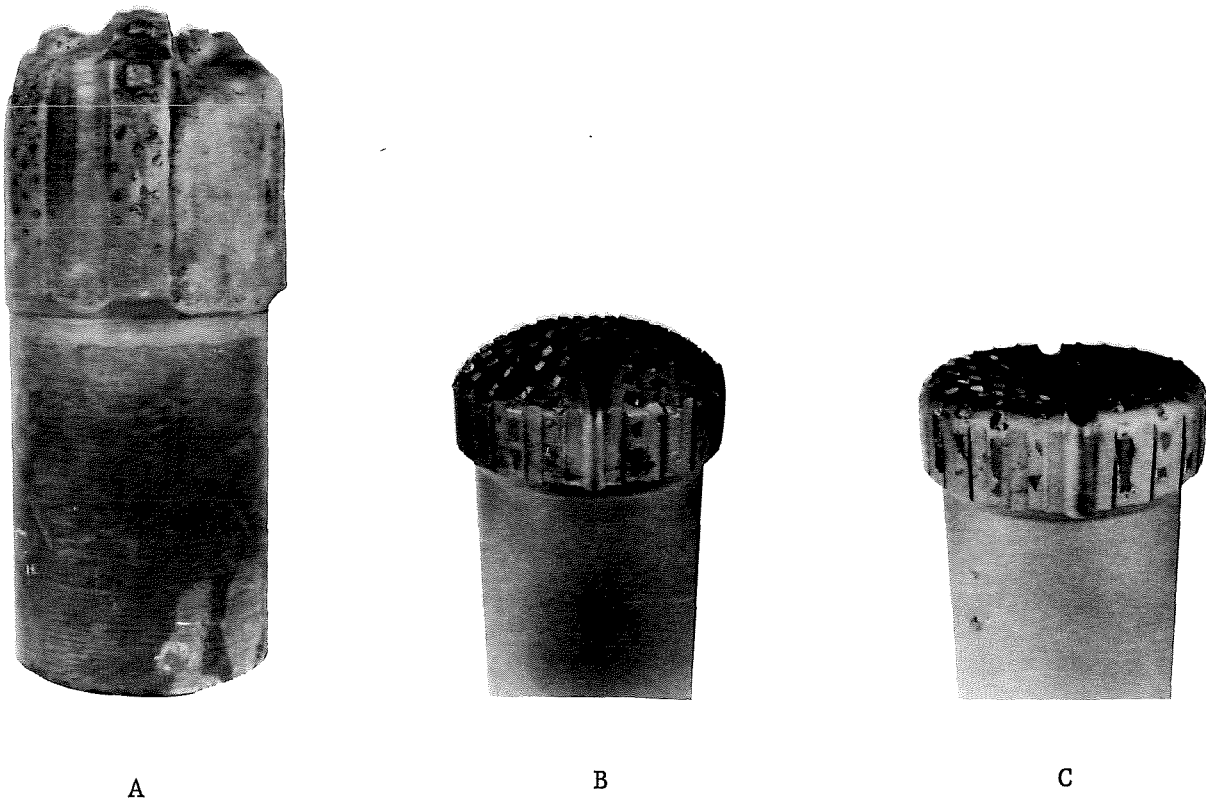


Figure 8. Full face or plug bits tested: A--Carbonado diamond, B--Convex carbide chip set, and C--Concave carbide chip set.

Water pressure could be reduced by increasing the size of the bit's water courses.

The penetration rate for the Carbonado was good, averaging 4.5 to 5 fpm at 3,000 lb thrust and 200 rpm.

The torque indicated while drilling with the Carbonado bit in a hole less than 100 feet deep was 140 ft-lb at 2,000 lb thrust and 200 rpm and 230 ft-lb at 4,000 lb thrust and 400 rpm.

This bit showed no noticeable wear after drilling 160 ft of coal and 145 ft of shale and should be capable of drilling considerable footage in coal. The initial cost is about 6 to 8 times greater than that of the roller-cone bits and about 4 times greater than the highest cost drag bit tested.

The American Coldset concave carbide chip set bit had a relatively slow penetration rate of 2.3 to 3 fpm at 2,000 lb thrust and 800 rpm. The convex bit drilled up to 4.3 fpm at 2,000 lb thrust and 800 rpm. The torque indicated while drilling with the carbide chip bits was 100 ft-lb at 1,000 lb thrust and 500 rpm and 200 ft-lb at 3,000 lb thrust and 800 rpm.

The concave carbide chip set plug bit showed noticeable wear, especially on the outer edge of the face. The concave bit drilled 340 ft of coal and the convex bit drilled 130 ft of coal. Bit wear could possibly be reduced by redesign, including the use of larger carbide chips.

During the directional stability test, the plug bits climbed less than the drag or roller cone bits drilling at the same thrust and revolutions per minute. This is probably due to the plug bit's design and relatively slow penetration rates; the gage cutting surface of the plug bit has more time to wear away the bottom of the hole.

The Carbonado concave diamond bit deviated least both laterally and vertically. It also had good response vertically to changes in thrust and revolutions per minute.

The American concave had good lateral and vertical stability over a range from 1,000 lb thrust and 500 rpm to 4,000 lb thrust and 500 rpm. The American concave appears to be a good straight-hole drilling bit, but it may not respond well vertically to changes in drilling parameters.

The American convex bit was not as directionally stable as the concave bits. This was most noticeable in the climb tendency of the bit in the vertical plane. The convex bit also had a greater tendency to wander laterally.

The Carbonado bit deviated laterally from 1 ft right in 50 ft to 1 ft left in 30 ft. The American concave bit deviated a maximum of 1/2 ft right in 70 ft. The American convex bit tended to wander both right and left and eventually deviated 1.5 ft left in 60 ft of hole.

The cuttings size was considerably smaller than that produced by the

drag bits and the roller cone bits. The Carbonado diamond bit produced the largest cuttings of the 3-plug bits tested, with an average size of 1/16 x 1/16 x 1/8 inches and maximum observed size of about 1/8 x 1/8 x 1/8 inches. The American concave and convex carbide chip bits produced the finest cuttings of all bits evaluated, averaging 1/16 x 1/16 x 1/16 inches or less.

Three-Cone Roller Bit--The types of 3-cone roller bits tested are shown in figure 9. One was a K-2 type, purchased from Williams Rock Bit Company, and one a "Frio" type purchased from Gruner and Company. The bits appeared to be identical. For the Ohio testing, a 3 1/2-inch bit was used to overcome the drill string sticking problem caused by lost circulation.

In the bit testing series the following drilling parameters were used to test the 3-cone bit.

Thrust:	varied in 1,000-lb increments from 1,000 and 4,000 lb
Revolutions per Minute:	varied in 100-rpm increments from 100 and 400 rpm at each increment of thrust
Flow Rate:	26 gpm in Oklahoma 40 gpm in Ohio
Pump Pressure:	40 to 50 psi

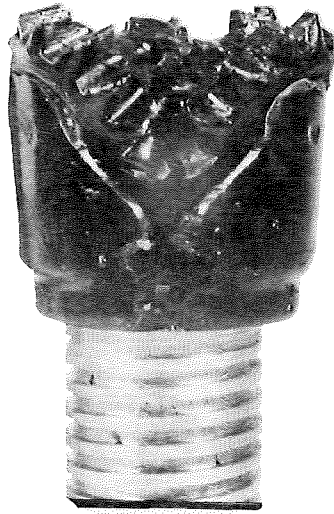


Figure 9. Williams three-cone roller bit tested.

Approximately 40 to 80 ft of hole was drilled with each combination of thrust and revolutions per minute.

The penetration rate was fair to good, ranging from 2.5 to 5.5 fpm at 3,000 lb thrust and 200 rpm at 1,400 lb thrust and 400 rpm, the penetration rate averaged 2 to 4 fpm. Maximum penetration rate for the 3 1/2-inch bit was 6.2 fpm at 4,000 lb thrust and 400 rpm.

Bit life was good. The 3-inch and 3 1/2-inch bits tested had a predicted life of 1,500 ft or more for coal drilling.

The directional stability of the 3-cone roller bits was relatively good. They had little tendency to deviate laterally especially when two stabilizers were used. Vertical deviation was much more pronounced. The bit tended to build up angle rapidly as the thrust was increased with both types of stabilization used. However, this type of bit responded reasonably well vertically to drilling parameter changes.

At lower thrusts and higher revolutions per minute in the range of 1,500 to 2,000 lb and 300 to 400 rpm, when used in conjunction with a 20-ft drill collar, the bit is stable in the vertical plane. The measured lateral deviation of the roller cone bits varied from 1/2 to 4 ft right in 100 ft.

Coal cuttings chip size is smaller than those produced by most of the drag bits and larger than those produced by the plug bits. The average size of the large fraction of cuttings ranged from about 1/8 x 1/8 x 1/8 inches to 1/8 x 1/8 x 1/4 inches. No attempt was made to determine the percentage of fines.

STABILIZATION TECHNIQUES

In Oklahoma testing, a series of stabilization evaluation tests were conducted using the Servco 21 Mill bit and various combinations of drill rod stabilization. The Servco 21 was used because of its directional stability. The stabilizers used in this test series are described in table 3. In the slightly harder Ohio coal, a similar series of stabilization tests were conducted with the 3-cone roller bits.

Table 3. Stabilizers tested.

Type	Size		No. of Ribs	Rib Depth (inches)
	OD (inches)	ID (inches)		
Nonrotating Sleeve (8-inch sleeve, 20-inch body)	2 15/16	1 3/8	4	-
Rotating Spiral Rib (8-inch rib, 10-inch body)				
Counterclockwise	2 31/32	NW 1 3/8 BQ 1 13/16	4	11/64

<u>Type</u>	<u>Size</u>		<u>No. of Ribs</u>	<u>Rib Depth (inches)</u>
	<u>OD (inches)</u>	<u>ID (inches)</u>		
Clockwise	2 31/32	NW 1 3/8 BQ 1 13/16	4	11/64
Clockwise	2 15/16	BQ 1 13/16	3	3/8
Clockwise	3 7/16	BQ 1 3/8 BQ 1 13/16	3	5/8

The nonrotating sleeve-type stabilizer, although it was as effective as the rotating stabilizer, was not extensively tested, because it could present a problem when drilling with a bit that produces large cuttings. Large cuttings would tend to build up ahead of the stationary sleeve, slowing penetration and causing a stuck string when drilling in lost circulation zones.

Initial tests of the rotating stabilizers indicated no difference between the clockwise and counterclockwise spiral ribs; therefore, to assist cuttings removal, the clockwise spiral was used for the most of the stabilization test. (Both nonrotating and rotating stabilizers are shown in fig. 10.)

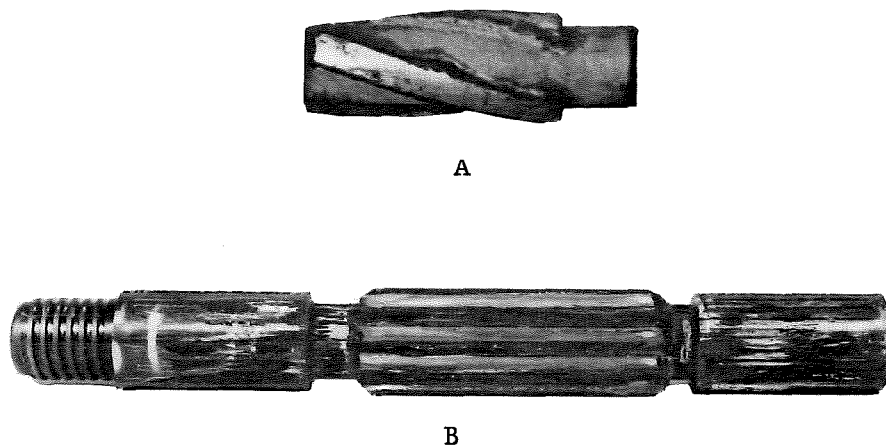


Figure 10. Nonrotating and rotating stabilizers tested: A--Longyear three-rib clockwise spiral rotating stabilizer and B--Drilco non-rotating sleeve stabilizer.

A separate hole was drilled with each different stabilization assembly. The test hole was drilled at different combinations of thrust and revolutions per minute to develop the overall tendency of the assembly to change hole direction. The combined effect of the stabilization assembly and drilling parameters on hole direction was determined through an analysis of multishot directional survey results.

During the Ohio stabilization testing and long-hole drilling, a heavy drill collar was used. The drill collar was made from a 20-ft length of NW drill rod. The collar was 1 3/4-inch ID, 2 5/8-inch OD, and weighed 10.23 lb/ft for a total of 204.6 lb. In contrast, a 20-ft length of BQ erill rod weighs 80 lb. The drill collar was used to stiffen and drilling assembly, thus increasing lateral stability, and to add weight to the bottom side of the bit.

Table 4 is a summary of the stabilization test results. Of all assemblies tested, the stabilization assembly with the heavy drill collar had the best response vertically to changes in drilling parameters, and lateral stability was excellent. However, changes in drilling parameters were only effective in changing vertical hole direction, not horizontal hole direction.

Stabilization assembly 9 had the best lateral stability. Significant changes in thrust and revolutions per minute did not cause adverse lateral deviation. Control of vertical deviation was good when making the hole climb (building angle) or holding vertical angle. Deflecting the hole down (dropping angle) with this assembly was difficult. With the roller-cone bit, this assembly can be made to climb with 4,000 lb thrust and 100 to 150 rpm. The same response should be obtainable with a 3- or 4-blade drag bit. The inclination or vertical hole angle can be kept reasonably constant by holding the thrust near 1,500 lb and the rate between 400 and 500 rpm.

Table 4. Stabilization test results.

<u>Test Assembly</u>	<u>Lateral Deviation</u>	<u>Vertical Deviation</u>
No. 1 Bit, no stabilizer	Slight tendency to wander right and left with 3-cone bit. Drifted 1 ft right in 170 ft with Servco 21. No deviation in 90 ft. Can be easily deflected by natural factors.	Slight tendency to drop at 2,000 lb thrust and 300 rpm with 3-cone bit. Dropped 2 ft in 140 ft. Servco 21 tends to hold angle well at 2,000 lb thrust and 200 rpm. Dropped 1 ft in 50 ft at 2,500 lb thrust and 300 rpm.
No. 2 Bit, one stabilizer	Essentially no deviation in 100 ft with 3-cone bit. With Servco 21, slight right drift up to 1 1/2 ft in 75 ft.	3-cone bit climbed 3 ft, in 100 ft, at 2,000 lb thrust and 300 rpm. Servco 21 tends to slowly build vertical angle at 2,000 lb thrust and 200 rpm to 2,500 lb thrust and 300 rpm.
No. 3 Bit, 1st stabilizer, 5 ft BQ rod, 2nd stabilizer	In 325-ft hole with 3-cone bit had slight tendency to wander right and left 2 to 3 ft both directions.	3-cone bit held angle well at 1,000 lb thrust and 400 rpm and 2,000 lb thrust and 300 rpm but would not climb at higher thrust.
No. 4 Bit, 10-ft BQ rod, one stabilizer	With Servco 21 bit drifted 3 ft right in 150 ft at 2,000 lb thrust and 200 rpm.	Tendency to slowly climb but rate of climb at 2,000 thrust and 200 rpm not steady - tends to wander.
No. 5 Bit, 1st stabilizer, 10 ft BQ rod, 2nd stabilizer	No deviation in holes up to 210 ft with 3-cone bit. Also drilled straight with Servco 21.	Dropped 2.2 ft in 210 ft. Tendency to drop at 2,000 lb thrust and 300 rpm with 3-cone bit. Servco 21 held angle for 50 ft at 2,000 lb and 300 rpm.
No. 6 Bit, 1st stabilizer, 20 ft BQ rod, 2nd stabilizer	No deviation in holes up to 150 ft deep with 3-cone bit over wide range of thrust and rpm. With Servco 21 drifted 1 ft right in 140 ft.	Strong tendency to climb with 3-cone bit, especially at higher thrusts. Climbed 6 ft in 150 ft at 4,000 lb thrust and 200 rpm. Much slower increase in vertical angle at 2,000 lb thrust and 300 rpm. Servco 21 climbed at rate of 4 ft in 140 ft at 2,000 lb thrust and 200 rpm.

Test Assembly

Lateral Deviation

Vertical Deviation

No. 7
Bit, 20 ft collar,
stabilizer

Drilled straight over wide range of thrust and rpm with 3-cone bit. Slight tendency to wander left and right along bearing line.

Dropped at all combinations of thrust and rpm. Drops faster when thrust is reduced and rpm increased. Recommended for dropping angle during long-hole drilling.

No. 8
Bit, one stabilizer,
20 ft collar

Slight deviation over wide range of thrust and rpm with 3-cone bit.

Climbed at all combinations of thrust and rpm tested. Recommended for building angle during long-hole drilling.

No. 9
Bit, 1st stabilizer
20 ft collar, 2nd
stabilizer

Best stability of all assemblies tested at all combinations of thrust and rpm with 3-cone bit.

Slight tendency to climb at 2,000 lb thrust and 200 rpm. (0.6 ft in 80 ft.) Climbs more rapidly at 4,000 lb thrust and 200 rpm. (1.7 ft in 70 ft.) Can be made to hold angle at about 1,500 lb thrust and 400 rpm.

DEFLECTING TOOLS

Deflecting devices selected for testing in the field were:

1. Dyna-Drill with Bent Sub
2. Whipstock
3. Reaming Collar
4. Spade Bit

In addition, laboratory tests were conducted to determine if a jet bit could be used to change hole direction in coal.

Dyna-Drill and Bent Sub--The micro-slim Dyna-Drill tools are presently available in 1 3/4-inch, 2 3/4-inch, and 3 3/4-inch sizes. The 1 3/4-inch diameter Dyna-Drill was used in this test program and was tested in both Oklahoma and Ohio.

Basically the Dyna-Drill, shown in figure 11, is a positive displacement motor used as a downhole drilling machine. Drilling fluid is pumped under pressure into the tool and directed through a cavity between a rotor and a rubber lined stator. Flow occurs when the rotor is displaced and rotated by the pressure of the fluid column. Fluid pressure in turn rotates the connecting rod, a hollow drive shaft, and finally the drill bit.

The Dyna-Drill, however, must be used in conjunction with a bent deflecting/orienting sub in a controlled direction program. Two types of bent sub were tested for this project. The predominant type was an AW- or BQ-size sub bent to a prescribed angle, while the other type had one tool joint machined to a predetermined offset angle. Both were designed to give the desired amount of "kick" and could be oriented to obtain the desired hole direction. A bent connecting rod housing is used instead of a bent sub for specific drilling problems when orientation is difficult.

After the tool is run in the hole, orientation is maintained by locking the drill pipe at the collar. As the hole is drilled, the tool and bent sub should create a smooth curve along the planned course. Additional corrective settings can be made while the tool is in the hole by reorienting the tool direction. Accurate checks on tool direction can be made by running a survey instrument in the hole.

In the Oklahoma Dyna-Drill testing, 1° and 1 1/2° AW-rod bent subs were used. The bent sub was attached directly to the uphole end of the 8-ft long, 48-lb Dyna-Drill. The bent sub was connected to the BQ drill string by 5 ft of AW drill rod. Bits used at this test site with the Dyna-Drill were a Hughes MP-200 3-blade drag bit and a Varel 4-blade drag bit. The Dyna-Drill was oriented by marking the drill rods as the Dyna-Drill was run into the hole. This method was sufficiently accurate for the Oklahoma test because the Dyna-Drill test holes were less than 150 ft deep.

In Ohio, 1° and 1 1/2° BQ-rod bent subs were used with the Dyna-Drill. Because the Oklahoma test results with bent subs were unsatisfactory, a



DUMP VALVE ASSEMBLY

3 STAGE MOTOR ASSEMBLY

CONNECTING ASSEMBLY

BEARING AND
DRIVE SHAFT ASSEMBLY

ROTATING BIT SUB

Figure 11. Dyna-Drill with straight housing (photo courtesy Dyna-Drill Company, Long Beach, California).

0° 57' Dyna-Drill bent housing was also used. The Dyna-Drill assembly was connected to the BQ drill string with 9-ft of AW rod. The flexibility of AW rod allowed the uphole end of the Dyna-Drill to come in contact with the hole, thus aiding bit deflection. The bits for this test were the Hughes MP-200 three-blade bit and a 3-cone roller bit. The Dyna-Drill was oriented by marking the drill rods in holes less than 150 ft deep. It was oriented with the multishot survey instrument in deeper holes.

All test holes in Oklahoma and Ohio were surveyed full length on 10-ft stations with a multishot survey instrument.

The manufacturer recommends that the slim-hole Dyna-Drill be operated with a fluid volume between 18 and 20 gpm. At 18 gpm, the rate is 760 rpm; at 20 gpm, 900 rpm.

The 18-gpm fluid volume was used to operate the Dyna-Drill in Oklahoma, and the 20 gpm was used in Ohio. Pump pressure averaged between 350 and 400 psi in Oklahoma and between 250 and 300 psi in Ohio. A different Dyna-Drill was used in Ohio, which may account for the lower pressure.

The thrust exerted on the bit with the Dyna-Drill in the drill string was held at maximum while drilling (maximum meaning the thrust held on the bit without the Dyna-Drill stalling). Maximum Oklahoma thrust was between 500 and 600 lb; maximum Ohio thrust was between 600 and 1,100 lb.

The Dyna-Drill was the most effective deflecting tool tested. With this tool, hole direction was easiest to deviate to the right or down and most difficult to deviate up and to the left. When oriented due left or due right the Dyna-Drill dropped rapidly, due to the high revolutions per minute and low thrust at the bit. To hold existing vertical angle and at the same time turn the hole laterally, the Dyna-Drill had to be oriented left or right and up to prevent or minimize hole drop-off. The limited testing done on this problem indicated the equilibrium angle required to hold vertical angle was between 40° and 60° left or right of top center.

Although the Dyna-Drill with BQ bent sub was effective in turning the hole in all directions, the most effective Dyna-Drill assembly was the Dyna-Drill with bent housing. The AW-size bent sub was not effective. This may have been due to the flexibility of the AW rod.

The 3-blade drag bit was slightly more effective than the roller-cone bit in sidetracking the hole with Dyna-Drill and bent sub. It was found that the distance between the bit face and the rotating bit sub should be as short as possible to reduce wear on the Dyna-Drill and assist in turning the hole.

Figure 12 is a horizontal plot of test hole 0-1. The Dyna-Drill with 1 1/2° bent sub was quite effective in turning this hole to the left. From 14 ft to 84 ft, the orientation was up and slightly to the left, and the hole slowly deviated to the left. Between 84 and 114 ft, the Dyna-Drill was

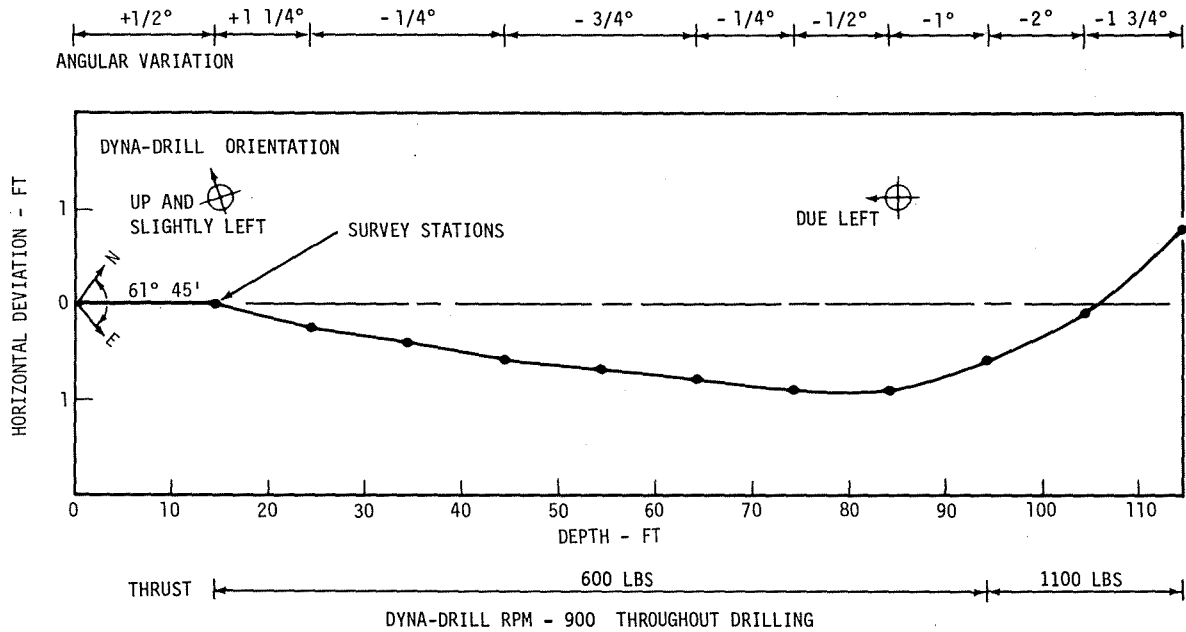


Figure 12. Plot of horizontal directional control with a 1 3/4-inch Dyna-Drill in hole 0-1.

oriented due left, and the left deviation greatly increased, while simultaneously the hole dropped 1.2 ft in 20 ft due to the dropping tendency of the Dyna-Drill. Hole 0-1 was drilled with a 3 1/2-inch diameter 3-cone roller bit.

Figure 13 is a vertical plot of test hole L-1 drilled with the Dyna-Drill oriented in the vertical plane. The Dyna-Drill assembly in L-1 consisted of a 3-inch Hughes MP-200 drag bit, the Dyna-Drill with bent housing, 10 ft of AW rod, a mule shoe sub, 20 ft of nonmagnetic rod, a locking sub, and the BQ drill string. Between 17 and 67 ft, the Dyna-Drill was oriented up, and the bit ran into the top shale at 67 ft. The bit was then pulled back 20 ft and oriented down. A side-track hole, started beneath the original hole, rapidly dropped between 47 and 94 ft. The Dyna-Drill was then oriented up at 94 ft, and the hole slowly began to build up vertical angle. Between 94 ft and 134 ft the hole climbed 0.4 ft.

The degree of vertical angle build up was small and therefore not readily apparent. Between about 104 and 124 ft, the angle built up $+1/4^\circ$. Between 124 and 134 ft, the angle built up to $+1/2^\circ$, thus showing an increase in rate of change.

The most extensive testing done in any one hole with the Dyna-Drill was a hole designated P-1 and drilled in Ohio to 748 ft. In the first application

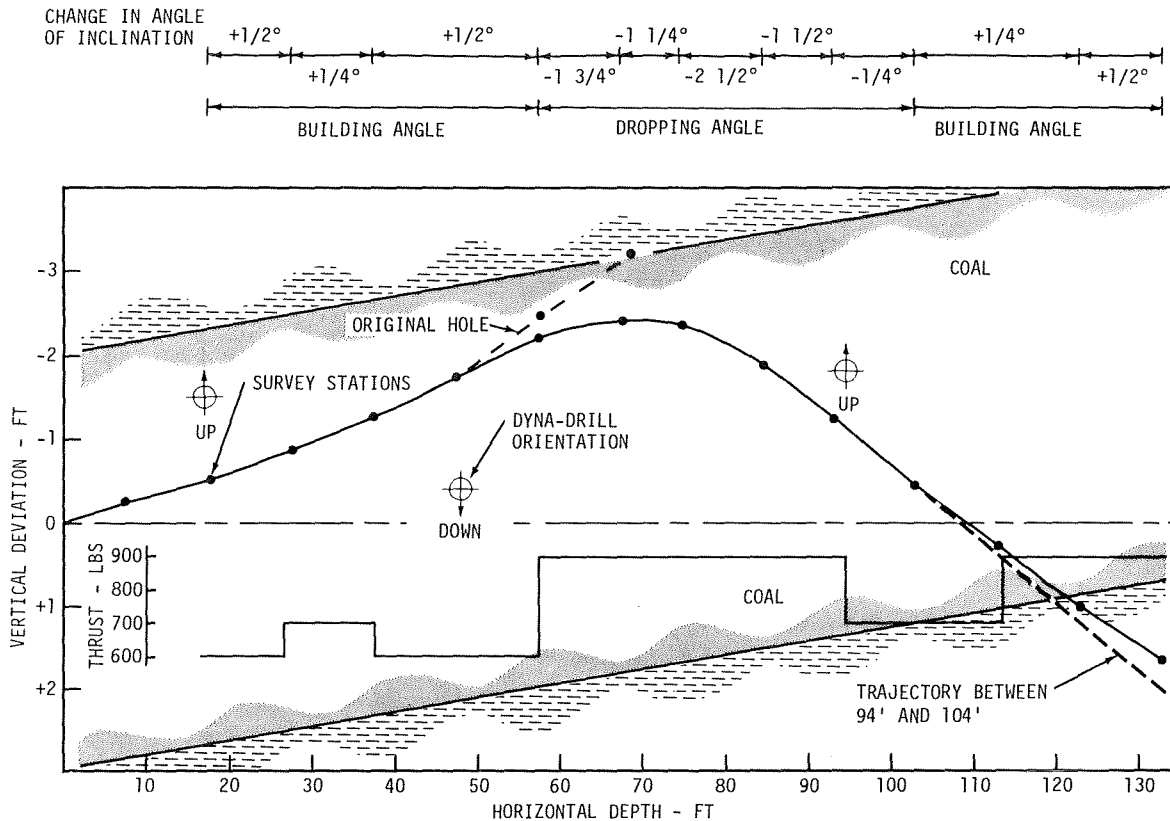


Figure 13. Vertical plot of hole L-1 drilled with a 1 3/4-inch Dyna-Drill.

in P-1, the Dyna-Drill with the 1° bent sub was used to turn the hole down out of the shale above the coal at 107 ft.

In the second application in P-1, the Dyna-Drill with bent housing was used to try and turn the hole up out of the shale below the coal and slightly to the left between 538 and 562 ft. Vertical deviation in this second application was good, but no left deviation was apparent.

The Dyna-Drill with bent housing was also used in P-1 to turn the hole left between 598 and 625 ft. For this application the tool was oriented 60° left of vertical. The result was a slight horizontal dogleg that produced a total of 8 ft of left horizontal deviation between 598 and 730 ft.

In each test in P-1, the bit used with the Dyna-Drill was a 3-cone roller bit. The Dyna-Drill was oriented by marking the rods during the first application. In the second and third applications, the tool was oriented with a multishot survey pump-down instrument.

Retrievable Whipstock--The whipstock is essentially a steel wedge used as a deflecting tool. Permanent whipstocks are cemented or otherwise secured

to the surrounding rock, but they often cause trouble later on by falling over in the hole when they are placed in a soft rock such as coal. Retrievable whipstocks, the type used in this investigation, commonly have a chisel point that is spudded into the bottom of the hole, and the subsequent application of additional thrust shears two steel pins so that the bit can drill ahead for a few feet while the whipstock remains in position. A heavy collar at the top of the whipstock provides for its withdrawal when the drill bit is pulled from the hole.

Three-inch retrievable whipstocks, the type used in this investigation, commonly have a chisel point that is spudded into the bottom of the hole, and the subsequent application of additional thrust shears two steel pins so that the bit can drill ahead for a few feet while the whipstock remains in position. A heavy collar at the top of the whipstock provides for its withdrawal when the drill bit is pulled from the hole.

Three-inch retrievable whipstocks with $1\ 1/2^\circ$ wedges, as shown in figure 14, were tested in six holes in Oklahoma. Each hole was drilled 25 to 35 ft deep before the first whipstock was set. Whipstocks were set to turn the holes right, left, up, and down. One to four whipstocks were set in series from 10 to 20 ft apart.

The whipstock was run into the hole on the end of a BQ drill string connected to 10 ft of AW rod and 9 ft of A rod. The whipstock was oriented by marking the rods as it was run into the relatively shallow holes. After the whipstock was set, an 8-ft deep pilot hole was drilled with an AW plug bit. The whipstock was then pulled from the hole and a pilot reaming bit run to bottom to enlarge the AW hole to 3 inches in diameter. The pilot reaming bit was removed and replaced with a conventional bit.

Test results indicated the whipstock was ineffective for changing hole direction in coal. The hole could not be deviated to the left or down, and deviating the hole to the right was only slightly effective. Deviation up was only effective in maintaining the existing vertical angle for a short distance. In most cases, the hole tended to straighten out or return to its original bearing 5 to 15 ft beyond a whipstock setting point. The softness of the coal evidently caused the whipstock's inability to effectively change hole direction in the coal seam.



Figure 14. Retrievable deflecting wedge tested.

Reaming Collar--A reaming collar was used to ream the bottom of a test hole to evaluate the effectiveness of this device in reducing the vertical angle. The reaming collar used was heavy, cylindrical, 1 ft long, and studded with tungsten carbide insert buttons (see fig. 15).

In the test, the bit was removed and the reaming collar attached to the BQ drill string with 10 ft of flexible AW drill rod. The collar was run to hole bottom, where it was slowly moved in and out with 10-ft strokes. Rotary speed was held at 400 rpm and flow rate at 40 gpm. A considerable amount of fine coal was washed from the hole while reaming took place, indicating coal was being removed. After reaming, the collar was pulled and replaced with a 3-blade drag bit.

In the limited test carried out, the reaming collar was found to be less effective in making the hole drop than a technique developed in the long-hole test described later. (One stabilizer is used 20-ft behind a quick drilling bit with low thrust and high revolutions per minute.)

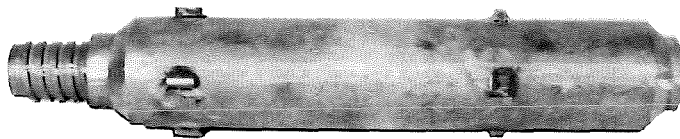


Figure 15. Reaming collar tested.

Spade Bit--The spade bit is a hole deflecting tool used to sidetrack a hole by jetting and spudding, without rotation, in soft rock. Figure 16 is a drawing of the spade bit used in the field test.

In the test, the spade bit was run in a short hole and oriented to the left. With up to 6,000 lb of thrust on the bit and a water-flow rate of 40 gpm at 500 psi, the bit failed to penetrate the coal.

Directional Jet Bit--Laboratory tests were conducted at the University of Tulsa Drilling Laboratory to determine the pressure and fluid volume necessary to wash a sidetrack hole in the bottom of a 3-inch hole in bituminous coal with a jet bit. Data developed can be used in the further design and development of a jet bit for use in drilling long, horizontal holes in coal.

It has been determined from the laboratory tests that a sidetrack can be jetted out of a 3-inch drilled hole in coal by increased water pressure to the point that the force of the jetted stream exceeds the compressive strength of the coal. This potential might lead to developing a bit that can be used to drill a hole conventionally, and, when needed, the same bit could be used to

cause sidetracking or deviation of the drilled hole. All this could be accomplished without removing the drill string from the hole.

The water courses in a conventional bit are positioned so that the water-flow jets are directed at the bottom of the hole to wash away the cuttings. Directional jet bits are made with one large nozzle and with the other jets either blanked off or with small nozzles. Deflection is accomplished by orienting the large nozzle in the desired direction and then circulating water at a high pressure and flow rate without rotating the bit. Field testing with a jet bit was not conducted in this test program because a high-pressure pump is required.

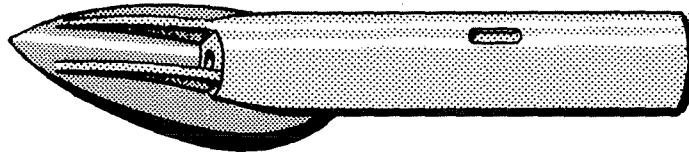


Figure 16. Spade bit tested.

Coal samples for the lab test were obtained from a Consolidation Coal Company strip mine in the Waynesburg Formation near Waynesburg, Pennsylvania. Fifteen of the coal samples were placed in 10-inch diameter x 9-inch high cylindrical sheet metal containers. The samples were cemented into the containers with the bedding planes parallel to the cylinder axis, one face being even with the top of the container. A hole, 3 inches in diameter by 1 1/2 inches deep, was then prepared in the center of the exposed sample face.

The test system was arranged as shown in figure 17. The system was capable of establishing test-flow conditions through a nozzle and bypassing the test cell until the desired test conditions were reached. The flow could then be switched by the diverter valve to the nozzle over the sample within the test cell. The test assembly is illustrated in figure 18.

Test variables measured were pressure-drop across the nozzle, flow rate, and elapsed time. Water was the testing liquid and was supplied from a Haliburton T-10 pump driven by an AGMC diesel engine. Flow control was by engine throttle and gear box. The nozzle holder in the test cell was in a fixed position so that the nozzle exit and centerline were 1/2 inch from the center, 15° from vertical, and 1/4 inch from the bottom of the 3-inch sample hole. The nozzle centerline crossed the sample centerline above the surface of the sample. Similar test runs were made on all 15 samples.

Apparent cutting with the 1/2-inch nozzle seemed to occur at about 7 to 9 horsepower (hp), fluid pressure being 750 to 900 psi. Corresponding fluid flow was about 14 gpm. All tests with the 3/16- and 5/32-inch nozzles produced cutting. However, on all samples, the jetting action tended to deflect along the bedding planes, independent of the jet nozzle direction.

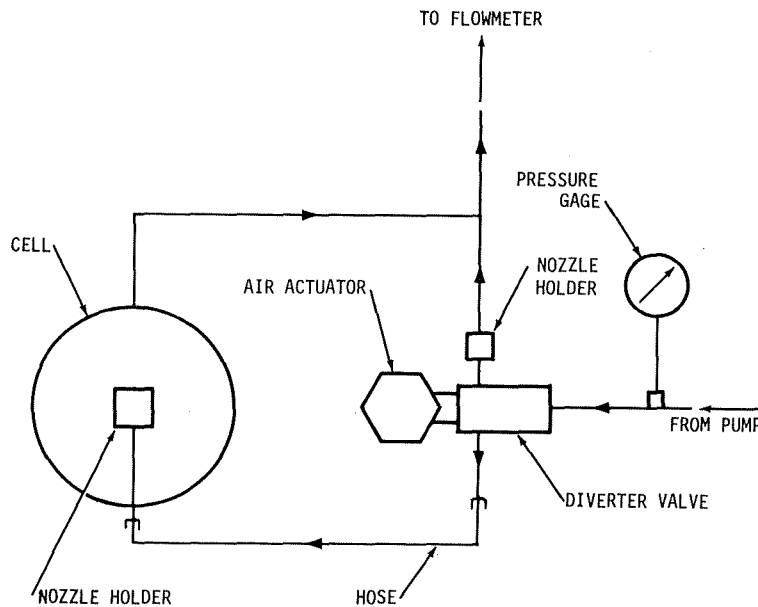


Figure 17. Schematic of jet-bit testing system.

Graphic analysis of the laboratory data (fig. 19) has shown that either a pair of 1/8-inch nozzles or a single 5/32-inch nozzle would be best suited for additional laboratory and/or field testing. As shown in figure 19, the 1/8-inch nozzle could pass 11 to 14 gpm of water at pressures of 600 to 980 psi without resultant cutting. In the laboratory, cutting action apparently began at a pressure of about 1,000 psi, resultant flow being about 14.5 gpm. Although not confirmed by laboratory tests, the 3/16-inch nozzle apparently could pass as much as 20-25 gpm, with attendant pressure of 350-720 psi, without producing a useful cutting action. However, pressures of 1,000 psi or more, with attendant flow of 30+ gpm, did produce cutting action. The 5/32-inch nozzle probably would not cut below 450 psi, flowing 18 gpm, but this has not been confirmed by laboratory tests. All testing done in the laboratory with the 5/32-inch nozzle produced a cutting action.

Not considered in this program of testing was cutting size produced by the jetting action. Jetting could produce large particles, which could cause problems of removal from the hole at depth. These cuttings would have to be reduced to a size that would readily pass by the stabilizers. A bit with a long, fluted skirt or a fluted stabilizer could be developed that would grind the cuttings (on rotation of the drill string) down to a size more easily discharged from the hole.

Future fluid testing should be centered around either a pair of 1/8-inch

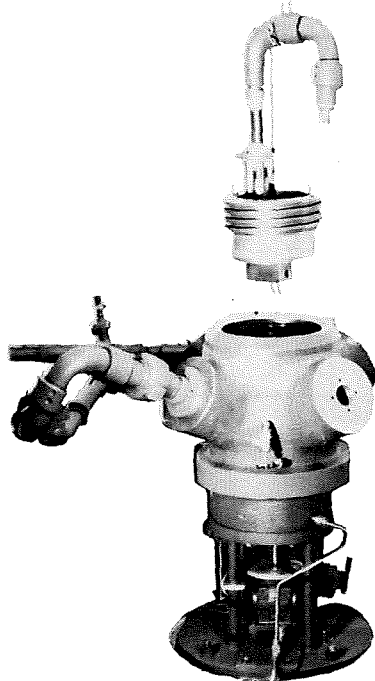


Figure 18. Jet-bit test assembly.

nozzles or a single 5/32-inch nozzle. Also, lab testing should be done on samples with top as well as side overburden pressures, to better simulate in situ conditions.

The analysis of the lab test results must be taken as an indicator, not a firm rule. Only a limited number of runs were made, and no data were recorded regarding the actual size or orientation of the generated cavity in relation to the sample on the jet nozzle.

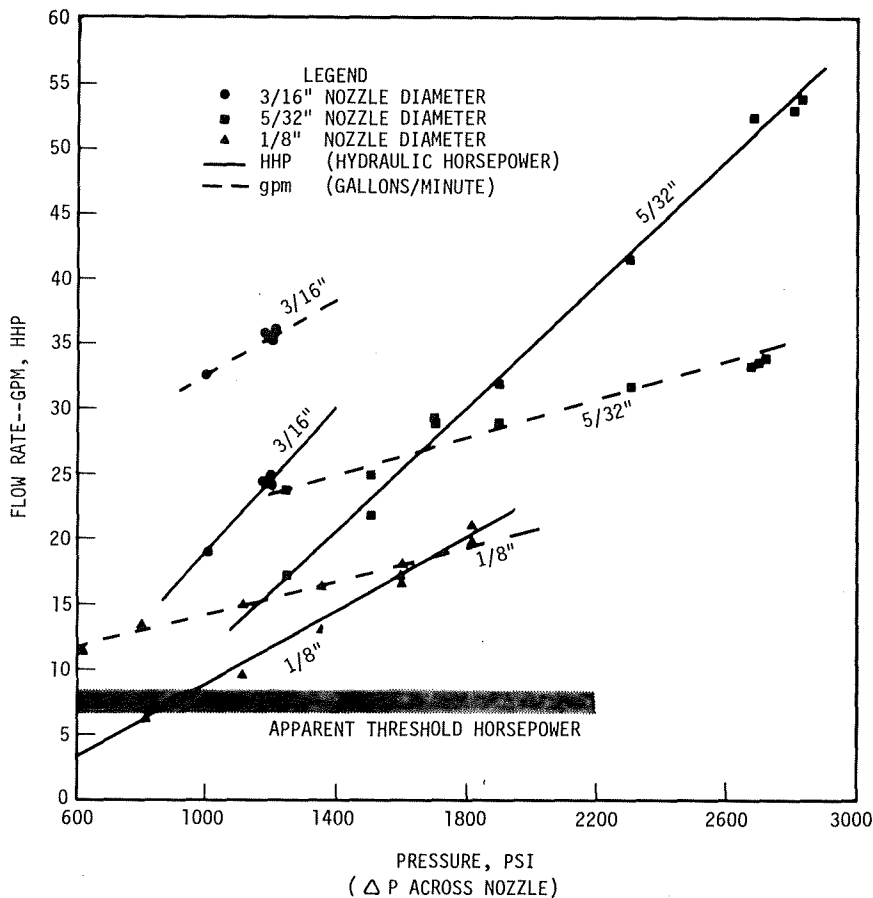


Figure 19. Plot of horsepower and flow rate vs pressure for 1/8-inch, 5/32-inch, and 3/16-inch diameter nozzles.

SURVEY INSTRUMENTS

Multishot Directional Survey--A multishot directional survey instrument (hereafter called a multishot) was used to directionally survey the boreholes during or after drilling. Figure 20 is an illustration of the multishot used in this test.

Two methods of running the multishot into the borehole were used, depending on hole depth. In short holes, the multishot in its protective outer casing was attached to wooden rods. The 10-ft wooden rods had a special quick disconnect coupling on each end. The multishot was put into the hole and wooden rods added to push it to the desired depth. This method was used to make directional surveys to a depth of 250 ft.

For holes over 250 ft deep, a pump-down multishot assembly was used inside the drill string. For this application a special string assembly, consisting of a mule shoe sub with centering key, 20 ft of K-monel rods, and a locking sub, was placed in the drill string directly behind the bit. When the operator was

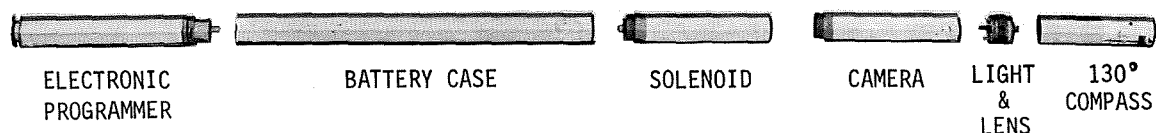


Figure 20. Magnetic multishot survey instrument tested (photo courtesy of Sperry-Sun Well Surveying Company, Houston, Texas).

ready to survey, the multishot was locked in its protective casing and placed in a pump-down assembly, consisting of mule shoe, several spacer bars, the multishot casing, additional spacer bars, and the locking device. The spacer bars centered the multishot in the K-monel collar to minimize the influence of the ferrous material in the drill string.

The assembly was pumped down inside the drill string. At the bottom of the hole, the pump-down assembly homed into the mule shoe sub, and the locking device latched into the locking sub. This held the tool in place near the bit to insure the most deflection-free readings.

Survey was made by removing the drill string from the hole one joint at a time to allow time for the camera to take several pictures at each station. Each hole drilled was surveyed at least once, and many holes were surveyed more than once. When only a short section near the bottom of the hole had to be surveyed, the multishot was retrieved by pumping down an overshot device that latched onto a stinger on the multishot locking mechanism. The multishot was pulled from the hole with a 1/8-inch stainless steel wireline attached to the overshot device.

The multishot was also used to orient the downhole deflecting devices. The mule shoe key in the sub was lined up with the downhole device, and a multishot photo was taken in place. If necessary, the drill string was then turned to correctly orient the downhole device. A check was then made with the multishot to verify orientation.

The multishot survey procedure was found to be accurate, and repeat surveys in the same hole usually matched. Hole P-1 was drilled 748 ft through the other side of a hill, and a transit and tape traverse was made from the drill collar to the exit point of the hole. These results compared horizontally within 6.5 ft and vertically within 0.5 ft of the multishot survey results.

The magnetic compass unit of the multishot was calibrated often on a specially built calibration stand. If the compass calibration did not meet acceptable standards, the compass was exchanged for another one. Two compass units were on hand at all times. Each filmstrip, including one or more downhole surveys, also had a compass calibration to verify compass accuracy.

Telemetry Survey System--The telemetry survey system developed as a part of this project by Telcom, Inc., McLean, Virginia, was designed to become an integral part of the drilling assembly. The telemetry survey system is a

unique, cableless, directional drilling guidance survey method that indicates the position of the bit without being pulled from the hole. The system performs four basic functions: down-hole directional sensing, transfer and processing of the telemetry information, display of information on the driller's console and by teletype, and directionally guiding the drill hole to the target.

The survey device and its housing is approximately 24 ft long, 2 11/16 inches in diameter, and weighs 240 lb. The electronics section, containing the vertical and horizontal sensors and the rechargeable batteries, is in a waterproof protective canister. The canister fits inside the outer survey collar, which is the main structural member. During drilling, water passes between the outer wall of the canister and the inner wall of the outer survey collar. The outer survey collar and all metal parts are made of nonmagnetic material.

The telemetry system has two basic components, the downhole and the uphole. The downhole component contains the sensors and the transmitter. The sensors are the triaxial magnetometer, which senses horizontal bearings, and the accelerometers, which sense the inclination angle. The transmitter sends the telemetry data signal to the uphole component through the drill string.

Outside the collar of the hole, the telemetry signal is picked up by a receiving transducer mounted on the drill rig and transmitted to a receiver. The receiver feeds the signal to a minicomputer that calculates, as a minimum, the corrected bearing, true inclination, true depth, distance above or below the target, distance left or right of the target, and the latitude and departure of the end of the hole. Therefore, the true position of the bit and the deviation from the projected target can be constantly known and can be plotted as drilling progresses. The calculated results are displayed on a control panel. In addition, a permanent record is made by a teletypewriter.

For detailed information on the design, fabrication, and testing of the telemetry survey system, see volume 2 of this report.

Caliper Log--A hole caliper device was run in a representative group of test holes to determine if drilling tools or parameters seriously affected hole configuration. This was important in determining the best tools and drilling parameters to use in a demethanation program that requires downhole packers.

A tabulation of the drilling parameter values and equipment used in several of the holes, both in Oklahoma and Ohio, and the observations drawn from a study of the caliper logs are shown in table 5.

A study of the caliper logs produced the following conclusions:

1. Roller bits produce the roughest wall surface due to the

Table 5. Caliper Survey Results.

Hole No.	Thrust (lbs)	Rotating Speed (rpm)	Fluid Volume (gpm)	Bit Size	Bit Type	Special Equip.	Remarks
OKLAHOMA							
49	2000	300	27	3"	3-Blade Drag		Average hole size for both bits - 3½". No enlargement due to bit or change in drilling parameters. Good hole for setting packers.
	2500-3000	150 - 300	27	3"	4-Blade Drag		
52	2500-3500	150 - 300	27	3"	4-Blade Drag		Good gage hole - 3½". No enlargement due to bit.
58	1000-3000	500 - 800	27	3"	Concave Plug		Hole size 3-1/8" except for 10' washed out zone. Smoothest caliper trace of any bit type.
65	1000-3000	100 - 300	15-27	3"	4-Blade Drag	Whip- stock	In soft material 0'-84' whipstock tended to cause slight enlargement. In harder material 84'-T.D. no enlargement was seen due to either bit or whipstock.
OHIO							
C-1	2000-2500	150 - 250	27-42	3"	4-Blade Drag		Fair caliper trace in upper portion of hole, rough in bottom. No hole enlargement attributable to change in drilling parameters. Several washed out zones believed due to more friable formation.
J-3	1000-2000	300 - 500	40-42	3"	3-cone Roller		Hole reamed 10' to change direction - slight enlargement. No apparent enlargement due to change in drilling parameters. Several washed out zones believed to be soft zones. Rough caliper trace.
L-1	600 - 900	900	20	3"	3-cone Roller	Bent Dyna- Drill	No apparent enlargement due to Dyna-Drill or change in drilling parameters. Dyna-Drill oriented both up & down with no enlargement. Several soft zones washed out. Rough caliper trace.
P-1	500-2000	300 - 900	20-50	3½"	3-cone Roller	Str. Dyna- Drill & Bent Sub	Most irregular caliper trace of any of holes. Good packer seats do exist throughout total length of hole. No specific zones of enlargement due to equipment or change in drilling parameters. Several washed out zones.
Q-1	1500-4000	150 - 400	20-40	3½"	3-cone Roller	Telcom Tool	No enlargement due to equipment or change in drilling parameters. Rough caliper trace but good packer seats exist. Several washed out zones.
R-1	1000-4000	200 - 400	38	3½"	3-cone Roller	Telcom Tool	Fairly rough caliper trace. One 7' zone enlarged but not believed to be due to equipment or change in drilling parameters. Good packer seats throughout length of hole surveyed.

chipping action of the bit teeth. However, a good packer seat can still be obtained in a hole drilled with a roller bit.

2. Plug bits produced the smoothest wall surface.
3. The special deflecting tools did not cause excessive hole enlargement. The whipstock had the greatest tendency to increase hole size.
4. Drilling parameter changes (thrust, bit speed, and circulating rate) did not cause hole enlargement.

LONG-HOLE DRILLING

The long-hole drilling phase of the test program took place in Ohio. The most promising techniques and devices initially developed and tested were used in this phase to evaluate their effectiveness in drilling relatively straight 1,000-ft holes in coal. Four holes were drilled: J-3 to 278 ft, P-1 to 748 ft, P-2 to 1,102 ft, and Q-1 to 356 ft.

The holes were surveyed frequently with the multishot during drilling to evaluate the effectiveness of the thrust, revolutions per minute, and stabilization being used to control hole direction.

LONG-HOLE DRILLING ASSEMBLY

The 3-cone roller bit was used in long-hole testing, because it produced smaller cuttings than the faster drilling drag bits. Small cuttings were necessary because the lost circulation zones encountered at the Ohio site reduced the return flow from the hole. In earlier Ohio tests the drill string became stuck because large coal cuttings piled up in front of the stabilizers. This problem was overcome by using a bit that produced smaller cuttings and increasing the flow rate from 25 gpm to 40 gpm.

The drill string stabilization selected for long-hole drilling consisted of the bit, a 10-inch long clockwise spiral-rib stabilizer, a 20-ft long heavy drill collar, and a second 10-inch stabilizer directly behind the drill collar (see fig. 21). Tests had shown that this stabilization assembly produced a laterally straight holes. Also, the assembly was similar to the final assembly that would be used to drill the demonstration hole. The telemetry survey collar was approximately the same length, diameter, and weight as the heavy drill collar.

Drilling parameters selected for the long hole drilling were based on prior test results. Thrust, revolutions per minute, and stabilization were changed as necessary to change the vertical direction of the hole.

Hole J-3

The first long hole, J-3, was drilled with a 3-inch bit to a total depth

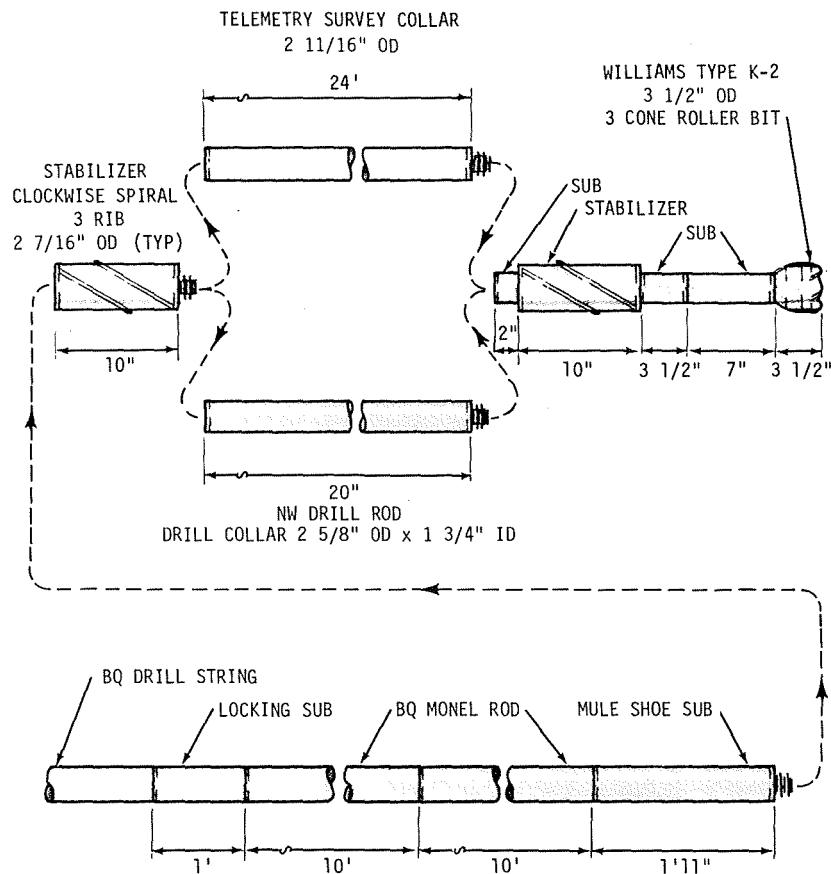


Figure 21. Long-hole drilling assembly tested.

of 278 ft. The bit remained near the center of the 5-ft coal seam most of this distance. Drilling parameters proved to be quite effective in maintaining vertical control, and lateral deviation was no problem. The hole was only 1.5 ft right of the initial bearing line at total depth.

J-3 was terminated at 278 ft so the Ohio Dyna-Drill tests could begin.

HOLE P-1

P-1 was drilled with a 3 1/2-inch diameter bit to a total depth of 748 ft. Total drilling time was 8 1/2, 8-hour days. At total depth, the bit came out the opposite side of the hill, and the exit point was used to check the accuracy of the multishot survey.

The bit entered the top shale at 100 ft, and the Dyna-Drill with a 1° BQ bent sub was used to drop the bit back into the coal at 135 ft. At 428 ft the bit neared the top shale again, and this time a slotting technique was used to make the bit drop. This slotting technique proved to be quite suc-

cessful. In this procedure, the front stabilizer directly behind the bit was removed. The bit was then slowly advanced at 500 to 600 rpm, while making a 10-ft slotting pass 20 to 30 ft from the end of the hole. This was done 3 times for each 10-ft run until the end of the original hole was reached and then for another 10 ft. By the end of the first 20 ft, the bit was cutting a new hole in coal below the original hole. This was apparent by the increase in thrust pressure, and was substantiated later by the multi-shot survey results.

The bit entered the shale below the coal at 530 ft, and the Dyna-Drill with the bent housing was used to turn the hole up into the coal again at 570 ft. From 598 ft to 625 ft the Dyna-Drill with bent housing was oriented up and 60° left. The net result was that between 598 ft and 748 ft the hole went 8 ft left of the original bearing line and dropped 3 ft. At total depth the hole was just above the bottom shale. Before the Dyna-Drill was used to turn the bit left at 598 ft, the hole was only 1 ft left of the original bearing line.

In P-1 the bit was made to climb, drop, or hold vertical angle by changing stabilization or drilling parameters. The bit could be made to drop by removing the stabilizer directly behind the bit and to climb rapidly by removing only the stabilizer directly behind the 20-ft drill collar. Lateral deviation was not a problem.

Hole P-2

The 3 1/2-inch hole P-2 was drilled to a total depth of 1,102 ft in 5 8-hour days. At total depth, the hole was 22 ft left of the original bearing line and near the bottom of the 5-ft coal seam. The first 600 ft were drilled with what is now considered the basic drill string assembly for long-hole drilling: bit, stabilizer, drill collar, stabilizer, mule shoe sub, monel rods, locking sub (for the multishot pump-down survey), and BQ drill string.

At 442 ft the bit went into the shale beneath the coal. The hole was quickly brought up by increasing thrust to 4,000 lb and reducing rate to 100 rpm. At about 600 ft, the bit went into the shale above the coal. The front stabilizer was removed and the slotting technique successfully used to reduce vertical angle and keep the hole in the coal.

The front stabilizer was replaced at 668 ft, and at 675 ft the hole dropped down into the bottom shale. The hole again was brought up into the coal by increasing thrust to 3,000 lb and reducing rate to between 100 and 200 rpm for a short distance.

At 870 ft the bit hit the top shale again. The front stabilizer was removed, and the hole dropped down into the coal. At total depth the hole was in coal near the bottom of the seam.

In P-2, as in P-1, multishot surveys showed that the projected lateral direction of the hole was well within the 30-ft target limit; therefore, no

lateral correction with a deflection tool was required.

HOLE Q-1

The last predemonstration long hole, Q-1, was drilled to 356 ft. At total depth the hole was 3.5 ft right of the initial bearing line and was near the center of the 5-ft coal seam. The vertical angle was good. Q-1 was abandoned at 356 ft to begin drilling the demonstration hole, R-1.

PYRITE BALLS

Pyrite balls ranging from a few inches to about 1 1/2 ft across were encountered while drilling 3 of the long holes; 5 were drilled through in the 278-ft hole (L-1), 9 in the 748-ft hole (P-1), and 14 in the 1,102-ft hole (P-2). Hole deflection as a result of hitting the pyrite balls was not apparent except in hole P-2 at 283 ft. At this point, a slight left deflection occurred. Upon hearing and feeling the rod chatter, which signaled contact with a hard spot, the driller immediately reduced thrust and revolutions per minute until the hard spot was drilled through. His action prevented excess bit deflection.

LONG-HOLE DRILLING TECHNIQUES

Results of Long-Hole Drilling--The result of the long-hole drilling and testing was development of a drilling assembly, range of thrust and revolutions per minute, and special drilling techniques that can be used to consistently drill relatively straight long holes. All of the holes hit well within the 60-ft wide target area. Unusual lateral deviation occurred only as a result of hitting a pyrite ball or using a deflecting tool to change direction. The section of hole before and after the lateral dogleg caused by a hard spot was, in each case, quite straight and did not deviate more than about 2 ft.

Data developed from the predemonstration holes and verified in the long-hole drilling phase was used to prepare the chart in figure 22. This figure shows the relative influence of thrust and revolutions per minute on vertical hole deviation when using the long-hole drilling assembly. It shows the change in angle of inclination as a result of changing parameters and indicates the degree of angular change to be expected.

The following special techniques were developed and tested during the long-hole drilling phase.

Slotting--A slotting technique can be used to rapidly drop a hole that is climbing too steeply. For this method the front stabilizer between the bit and the drill collar is removed and the bit backed off bottom 20 to 30 ft and slowly drilled ahead at 500 to 600 rpm. Two to three 10-ft slotting passes are made for each 10-ft run until back on original bottom. By this time, the bit should be cutting a new hole below the original one. This technique generally resulted in a new hole about 1 ft below the old one at the same total depth of the old hole.

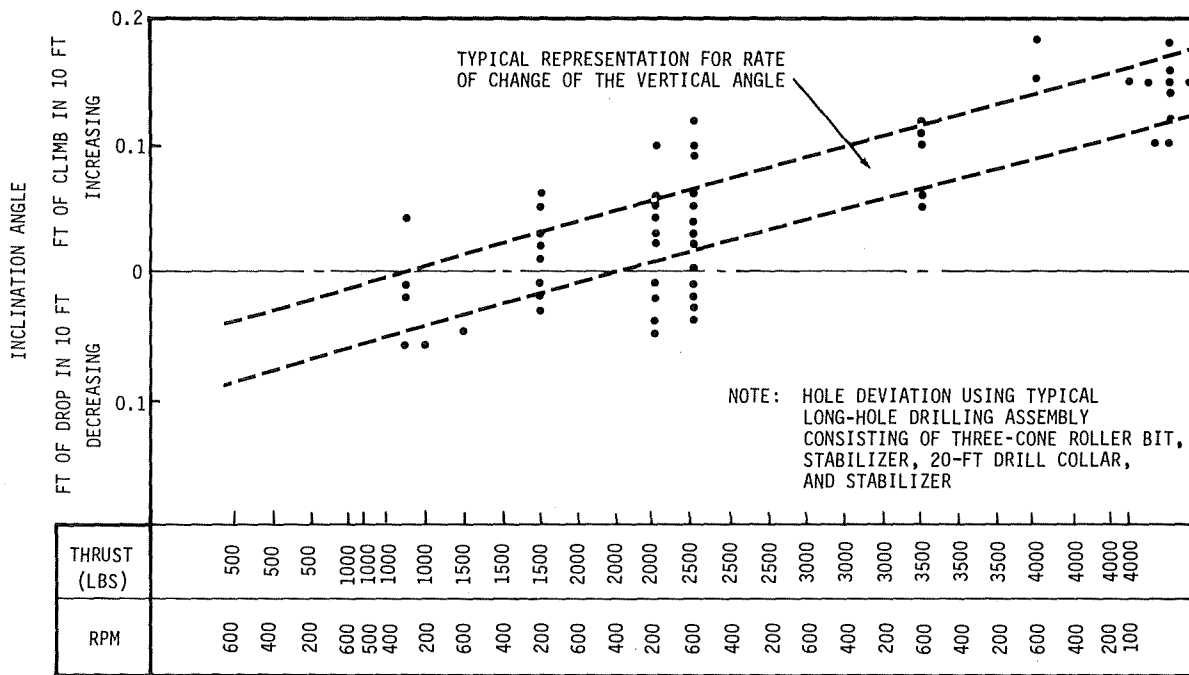


Figure 22. Plot of relative influence of thrust and revolutions per minute on vertical hole deviation.

Reaming--Use of a reaming technique can help induce hole drop-off. No changes are made in the basic long-hole assembly stabilization. After drilling ahead 10 ft with dropping parameters of 1,000/500 or 500/500, one or more reaming passes can be made to wear away the bottom side of the hole. This procedure can be repeated after each 10-ft run for 50 to 100 ft or until survey results show the desired deviation has been achieved. If this technique does not reduce the inclination angle, the slotting technique will have to be used.

The main advantage of reaming is that the assembly does not have to be pulled from the hole to remove the stabilizer (as is done in slotting). This factor takes on more importance as the hole deepens. However, the reaming technique can be slower than the slotting technique because the front stabilizer decreases the amount of weight transferred to the bit and, thus, the bit cuts more gradually into the bottom of the hole. In addition, as the coal increases in hardness, the effectiveness of this method is reduced.

High-Speed Flush--For this method, the bit is pulled 1 to 2 ft off bottom at the end of a 10-ft drill run. The hole is then flushed with water for about a minute while the bit rotates at 400 to 500 rpm. The purpose of this procedure is to adequately flush all large coal cuttings away from the drilling assembly and, at the same time, reduce the size of the cuttings so

they can be more easily washed from the hole. This technique will help to prevent loading the hole with large coal cuttings that could cause a stuck drill string.

The high-speed flush can be incorporated with the hole reaming technique to make the hole drop as well as to reduce cutting size. When used to make the hole drop, the bit should be moved slowly back and forth in about a 3-ft interval to help wear down the bottom side of the hole.

Hard-spot Drilling--To prevent bit deflection, the driller must immediately reduce thrust and revolutions per minute when the bit encounters a hard spot. Then the hard spot should be drilled through slowly. In addition, one or more reaming passes should be made through the hard zone.

Lost Circulation Drilling--Some lost circulation zones were hit during field testing, and these zones caused the drilling fluid returns to drop from between 30 and 40 gpm to between 1 and 5 gpm. When this occurred, thrust was reduced to slow the penetration rate to about 1/2 to 3/4 fpm and revolutions per minute were increased to 500. These conditions produced a large percentage of very fine coal cuttings that plugged off the lost circulation zone. Once the zone was plugged, the return water flow usually increased to between 25 and 35 gpm after drilling ahead 20 to 30 ft.

Hole Collaring--When the hole is collared, the inclination of the drill rig must be properly adjusted to match the apparent dip of the coal seam in the direction of drilling. When the inclination of the drill rig during this test was the same or not more than about $1/2^{\circ}$ less than the dip of the coal, the maximum distance could be drilled before encountering the rock above or below the coal.

FIELD DEMONSTRATION

A final hole, R-1, was drilled to demonstrate the techniques and devices applicable to drilling relatively straight 1,000-ft horizontal holes in coal.

EQUIPMENT USED

The 3 1/2-inch, 3-cone roller bit was chosen for drilling the demonstration hole primarily because of the relatively small cuttings it produces. These cuttings were easier to flush from the hole in the lost circulation zones encountered at the Ohio site. In addition, in previous tests this bit had responded well vertically to changing drilling parameters; lateral stability was good; bit life was good; penetration rate was good; and bit cost nominal.

The basic stabilization used in the long-hole drilling phase was also

used for demonstration hole R-1. A 10-inch long clockwise spiral stabilizer was directly behind the bit, then the 24-ft long telemetry survey collar, and a second 10-inch long stabilizer. In addition, a 23-inch long mule shoe sub, 20 ft of BQ nonmagnetic K-monel rods, a 1-ft locking sub, and another 10-inch stabilizer were placed in the drill string so that the multishot survey instrument could be used to compare the telemetry survey results. The third stabilizer was used to level the nonmagnetic rods for the multishot survey.

DEMONSTRATION RESULTS

R-1 was drilled to 1,034 ft using the devices and techniques previously selected and tested. All but 40 ft of the hole was drilled in coal. The end of the hole was in the coal and within 30 ft of the target center. Total actual drilling time was 3 1/2, 8-hour days. Based on telemetry survey results, the hole at total depth was 12.5 ft to the right of the original bearing line and 1.2 ft above the bottom of the 5-ft coal seam. A check survey, with the multishot, showed the hole was 15.5 ft left of the initial bearing line and 1.3 ft above the bottom of the coal seam. Figure 23 is a horizontal plot of hole R-1 comparing the telemetry and multishot surveys.

The drilling assembly performed well. The thrust and revolutions per minute selected and special techniques developed for the assembly also worked well when used with the telemetry survey system to keep the hole on the correct bearing and in the coal seam.

TELEMETRY SURVEY SYSTEM

The telemetry survey system performed well after some initial electrical malfunctions. The telemetry survey vertical angle was similar to the multishot vertical angle, but the telemetry survey had a slight vertical bias error. The telemetry survey system had a slightly larger bias error to the right. That is, the azimuth, as indicated by the telemetry survey, was greater than that indicated by multishot survey. Later computations by Telcom, Inc., showed an average difference of 2.9° in azimuth for the length of the hole and less than 0.125° in elevation between the telemetry and multishot survey methods.

By providing the correct angle of inclination as the hole was being drilled, the telemetry survey system definitely was an aid to rapid drilling. The inclination angle was available about 1 minute after drilling a 10-ft section of hole. Whenever the hole inclination angle became too high or low, as indicated by survey, the parameters or techniques were changed to keep the hole in the coal seam.

LATERAL CONTROL

Control over lateral hole direction was strictly by drill string assembly

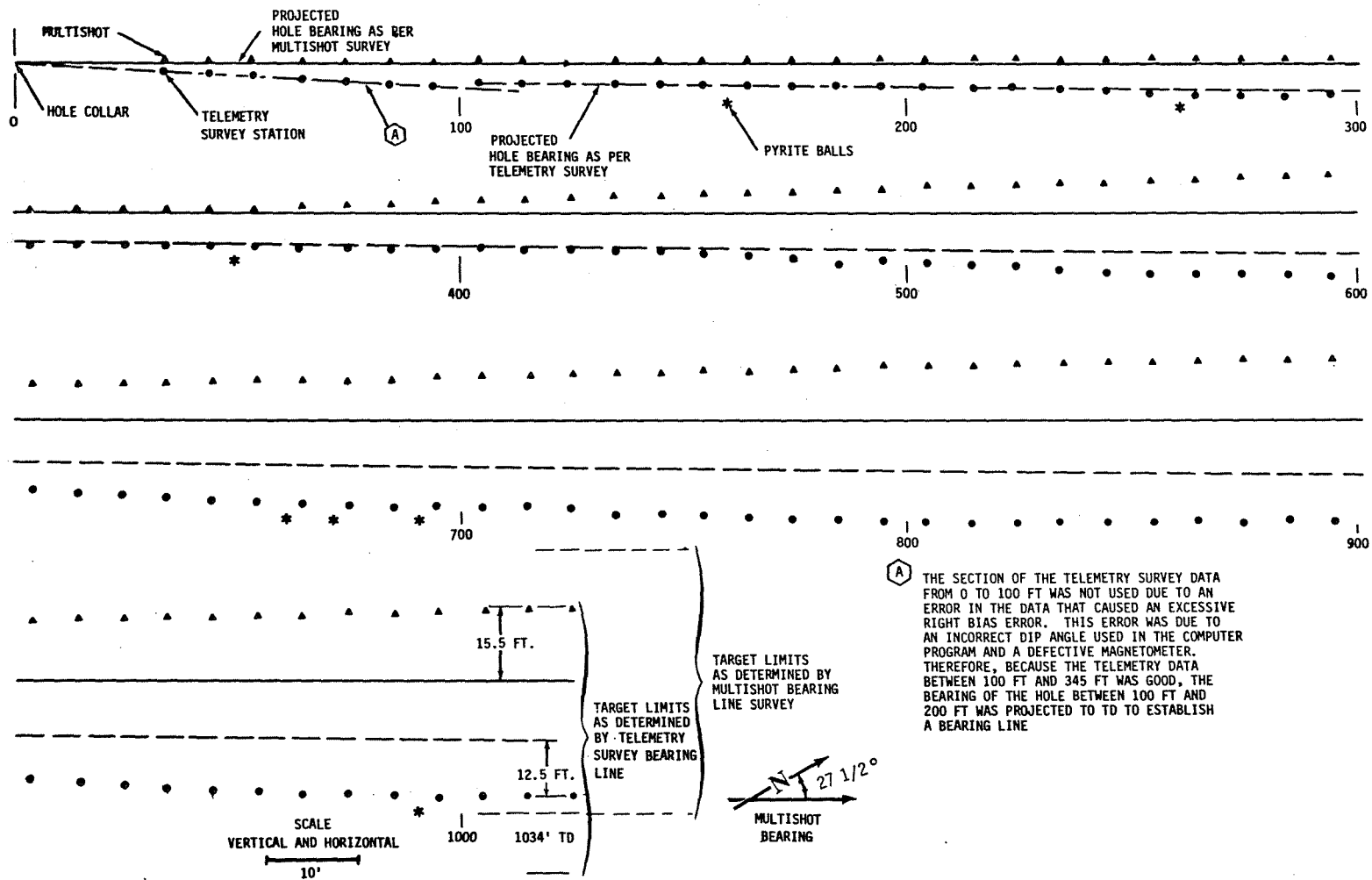


Figure 23. Horizontal plot of hole R-1 as determined by multishot and telemetry survey results.

stabilization. Proper stabilization is the key to drilling a straight hole laterally. As verified by previous test drilling, changing thrust and revolutions per minute does not noticeably affect lateral direction. Drilling at a high thrust of 4,000 lb or more for a considerable distance could possibly produce lateral deviation, but results show that, for distances up to 60 ft, this is not the case.

Pyrite "balls" were penetrated at 159 ft, 260 ft, 350 ft, 660 ft, 671 ft, 686 ft, 690 ft, and 986 ft. The section of the pyrite balls drilled varied in width from about 6 to 18 inches. Only one encounter affected hole direction; the pyrite ball hit at 350 ft deflected the hole slightly left.

VERTICAL CONTROL

During R-1 drilling, a change of drilling parameters caused the bit to climb. For example, in the first 345 ft the bit was allowed to drop to the shale at a shallow angle to locate the coal-shale contact so that it could be projected ahead to 1,000 ft. Then, at 345 ft, climbing parameters of 4,000 lb thrust and 100 to 200 rpm were used to bring the hole up. From 345 to 391 ft, the vertical angle remained relatively constant while the bit was in the softer, lower half of the coal seam. When the shale below the coal was encountered at 391 ft, the vertical angle increased from $89^{\circ} 10'$ to $91^{\circ} 20'$ in the next 30 ft. The hole angle had to be maintained at about 91° to stay in the dipping coal seam. Figure 24 shows a cross sectional plot of hole R-1. The bit was forced to climb slightly between 495 ft and 545 ft to bring it closer to the center of the projected coal seam. Climbing parameters (4,000 lb thrust and 200 rpm) had been used one other time between 135 and 165 ft to increase inclination angle from $89^{\circ} 50'$ to $91^{\circ} 20'$.

The bit was made to drop when required by changing drilling parameters, but, as previously experienced during long-hole drilling, the hole would climb more easily than it would drop. Therefore, the reaming technique had to be used to make the hole drop in addition to using special drilling parameters.

The use of the dropping technique in hole R-1 was first required between 435 and 465 ft. Dropping parameters of 1,000 lb thrust and 500 rpm were used to drill this 30-ft interval. In addition, at the end of each 10-ft drill run, a reaming pass was made by slowly advancing the bit at 500 rpm while flushing the hole with water at 38 gpm. This technique tended to wear away the bottom of the hole and, at the same time, helped flush the coal cuttings away from the drill assembly and reduce cuttings size. The vertical angle was reduced from $92^{\circ} 10'$ to $91^{\circ} 10'$ in this hole interval.

Vertical angle had to be reduced again because telemetry survey collar readout showed a $92^{\circ} 12'$ angle instead of the angle of 91° . Dropping parameters of 1,000 lb thrust and 500 rpm were used from 584 ft to 624 ft. However, the inclination angle was only reduced from $92^{\circ} 12'$ to 92° . Drilling then proceeded slowly between 625 and 655 ft at 600 rpm, and one slow 600 rpm reaming pass was made at the end of each 10-ft drill run. The thrust varied

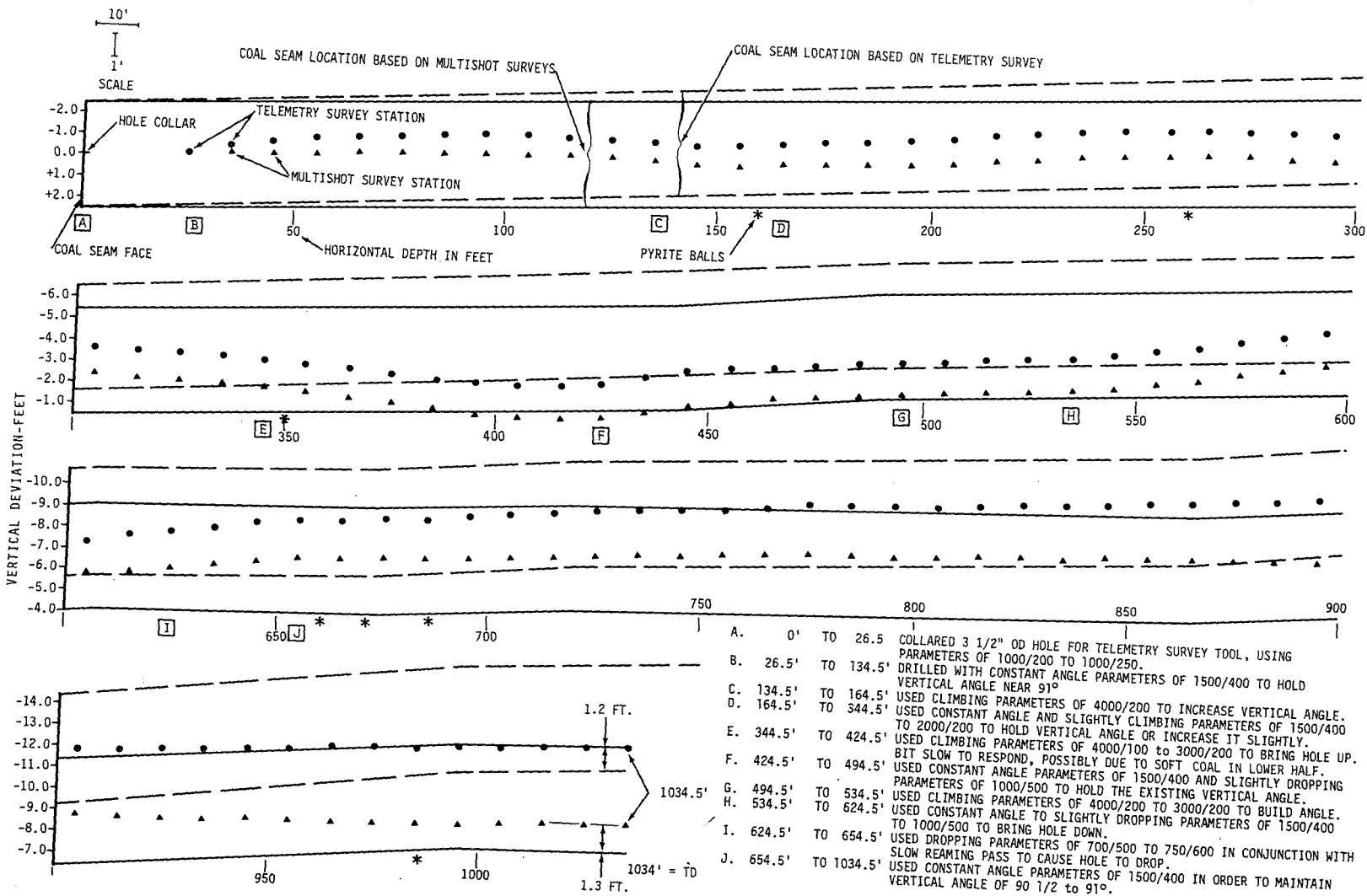
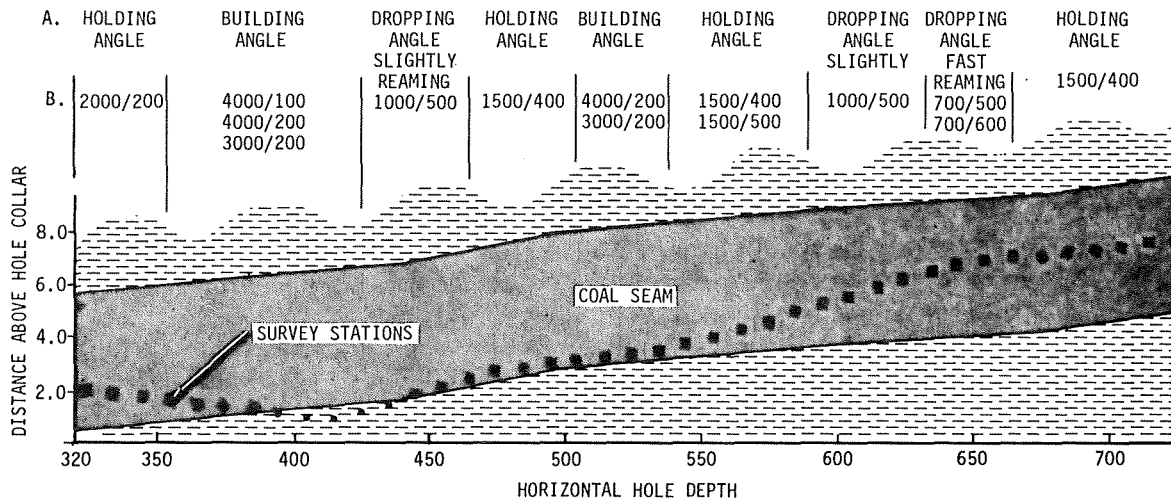


Figure 24. Cross section of hole R-1 as indicated by multishot and telemetry surveys.

between 700 and 750 lb. The vertical angle was successfully reduced from 92° to 91° using this technique.

Figure 25 shows a vertical section through part of hole R-1 between 320 ft and 725 ft and shows in detail the influence of changes in thrust and revolutions per minute on vertical hole direction.



- A. GUIDED DIRECTIONAL DRILLING ACTION
- B. RANGE OF PARAMETERS USED TO PRODUCE DESIRED VERTICAL DEVIATION.
EXAMPLE: 1500/400 INDICATES PARAMETERS OF 1500 LB THRUST AND 400 RPM.

Figure 25. Plot showing influence of changing parameters on vertical deviation in hole R-1.

Table 5 lists the thrust and torque required for the drill rig used in this work to move the drill string at depth in a 3 2/1-inch hole. These measurements were made with the bit at least 2 ft from the end of the hole. As expected, considerably more thrust and torque is required to start the rods moving from rest.

Table 5. Thrust and Torque Required to Move Drill String at Depth.

Hole No. & Depth	Pounds of Thrust Required to Move Rods		Torque Required To Turn Rods (ft-lb)	
	@ Zero rpm	@ 200 rpm	Start Rotation	@ 200 rpm
P-1 700-ft	1700	300	150	100
P-2 760-ft	1000	200	300	100 - 150
R-1 1000-ft	1700	200 to 250	160	140

SECTION 8

MAJOR PROBLEM AREAS AND FUTURE WORK

MAJOR PROBLEMS

Four major problems need to be solved satisfactorily to further advance the state of the art of long-hole drilling in coal.

1. A low cost, rapid, reliable method of changing lateral hole direction is still required. At present, a downhole deflection tool must be used to correct horizontal deviation, and this is both time consuming and costly.
2. A rapid, economical method of downhole survey and orientation is required. Drilling to a target requires frequent surveys to determine bearing, inclination, and possibly axial orientation. Existing methods of survey are either too slow, too expensive, or otherwise limited and are not entirely satisfactory for full hole surveying and downhole orientation.
3. An underground long-hole coal drill that can be easily moved, has adequate thrust and torque, is fully instrumented, and is automated as much as possible is definitely needed.
4. The telemetry survey system costs must be reduced substantially to make the system economically feasible to use.

LATERAL HOLE CHANGE

Possible solutions to the problem of changing lateral hole direction economically, quickly, and reliably are listed as follows:

1. Development of a drilling assembly and/or rock bit that would consistently tend to deviate laterally. In addition, a drill rod could be developed with a locking joint that would enable the rods to be rotated either left or right. Frequent surveys would indicate when the rod rotation needed to be reversed and horizontal hole direction needed to be changed.
2. Development of a directionally stable jet bit that could be used for conventional drilling but, when required, after orientation, could be used to sidetrack a hole. This side-

tracking would create a horizontal dogleg that would direct the hole back toward the target area. The jet bit should be a more effective means of turning the hole than are changes in drill string configuration or drilling parameters. The use of the jet bit will require downhole orientation, which makes the development of simpler and more rapid methods of orientation important.

SURVEY AND ORIENTATION

The survey instrument should be inexpensive, easy to use, accurate, and rugged. Readings should also be quickly available. The pump-down unit is a good example. The angles should be read at the drill rig without having to develop film and use special equipment to read the film.

Although a mechanical device, similar to the Tro-Pari compass and inclinometer, may be adequate, a device also capable of recording axial rotation for orientation purposes would be better. A simple orientation method is required when the hole is sidetracked with a jet bit or other hole deflection device.

HORIZONTAL LONG-HOLE COAL DRILL

This should be the easiest problem to solve. The U.S. Bureau of Mines should be able to develop a rig for drilling horizontal long holes in coal by working closely with drilling equipment manufacturers. Ideally, the underground coal drill should be:

1. Unitized for easy disassembly and movement by two men. Or, it should be provided with its own reliable source of motive power. For instance, a portable unit could have wide rubber tires driven on each side by separate hydraulic motors for ease in turning.
2. Rugged, yet as light weight as possible.
3. Designed with sufficient reserve thrust and torque to drill 3- to 3 1/2-inch 1,000-ft holes in coal.
4. Fully instrumented to record at least thrust, torque, and revolutions per minute.
5. Automated as much as possible, including such features as:
 - a. an automated drill rod handling system

- b. a power driven chuck similar to the one provided on the project test drill by E. J. Longyear Company
6. Capable of handling drill rods as long as possible to cut down on rod handling and drilling cost. Ten feet is a present maximum.
7. Permissible electric motor and hydraulic motors should be mounted as an independent unit that could be located several hundred feet away from the coal drill on the intake air side to meet Federal mine safety laws.

TELEMETRY SURVEY SYSTEM

The telemetry survey system costs could be reduced by eliminating the electronic circuitry required to determine lateral deviation. This is considered possible because this study has shown that lateral deviation is not a major problem when drilling 1,000-ft horizontal holes.

OTHER WORK

Other work projects that would assist in advancing the state of the art are:

1. Development of a drilling assembly that would have more of a tendency than at present to drop or reduce vertical angle when required without impairing the ability of the assembly to build up or hold vertical angle.
2. Testing of the most directionally stable drag bits to increase their lateral stability and improve their ability to reduce the vertical angle when required.
3. Development of a drilling method or assembly that would enable the bit to penetrate hard spots such as pyrite balls without deflection.
4. Development of a quicker way to handle drill pipe when the drilling assembly is run in or out of the hole.

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APPENDIX A

BIT MANUFACTURER'S AND DRILLING CONTRACTOR'S RECOMMENDATIONS

MFG OR CONTRACTOR NO.	RPM			THRUST (LB)			WATER FLOW RATE			REMARKS
	DRAG	ROLLER CONE	DIA-MOND	DRAG	ROLLER CONE	DIA-MOND	DRAG	ROLLER CONE	DIA-MOND	
MFG NO. 1	START HIGH WORK DOWN			START AT 3000 LB.						A 2 3/4" DYNA-DRILL REQUIRES APPROX. 1500 TO 3000 LB. THRUST. BIT WILL LAST LONGER IF START HIGH AND WORK DOWN W/RPM.
MFG NO. 2	150 TO 250	100 TO 200		2000 TO 4000	1000/ 2000 PSI ON VERT. HOLE		120/ 130 FPM ANNU- LAR	25 GPM SHOULD BE ENOUGH		
MFG NO. 3	START AT 100	START AT 100		1000 LB. TO MAX 3000 LB	9000 MAX START 4000 LB					IF THRUST INCREASED, DECREASE RPM.
MFG NO. 4	250 OR LESS	250 OR LESS		1000 TO 2000	1000 TO 2000		10 TO 15 GPM @ 100 PSI	10 TO 15 GPM @ 100 PSI		HOLE EROSION MAY BE BIGGEST PROBLEM IN DIRECTION CONTROL. FLEX IN STRING MUST BE KEPT TO MIN. WHEN CORING COAL, USE MIN. RPM, MIN. WATER MAX. THRUST = 15 FT/MIN PENETRATION.
MFG NO. 5			600 MAX			1000 LB			30 GPM	EST. 1000 FT/LB TORQUE ON BIT. CALC. BASED ON 5 FT/MIN PENETRATION RATE = 10% SOLIDS IN DISCHG. WATER TOOTH BIT - DIAMOND.
MFG NO. 6	60 TO 75 TRY 100	30 RPM DONT EX- CEED 35-40		1000 TO 2000	1000/ 1500 START 3000 LESS FOR 2 CONE		DRILLER WILL DETERMINE DEEPER HOLE REQ. MORE VOL. & PRESS.			IMPORTANT TO KEEP ROD WHIP DOWN FOR DIRECTION CONTROL. USE STRING REAMER BEHIND BIT & EVERY OTHER ROD JOINT FOR AT LEAST 3 JOINTS.
MFG NO. 7	LOW		LOW	HIGH		HIGH	20 TO 25 GPM ADE- QUATE	20 TO 25 GPM ADE- QUATE		INCREASED RPM CAUSES HOLE DEVIATION CONTROL PENETRATION RATE W/THRUST BELIEVES HIGH THRUST & LOW RPM BEST COMBINATION.
CONTRACTOR NO. 1	100			SEE RE- MARKS			15 TO 20 GPM ADE- QUATE			FOR THRUST USE AMOUNT NECESSARY TO KEEP BIT CUTTING. IF IT QUILTS CUTTING IT WEARS OUT.
MFG NO. 8	NOT SURE			NOT SURE			NOT SURE			SUGGESTED WE TALK TO ONE OF CONTRACTORS TO WHOM THEY SUPPLY BITS.
CONTRACTOR NO. 2		LOW			LOW			LOW		HAVE DRILLED 3" Ø HOLES 400' TO 500' IN ALUVIUM UNDER HIGHWAYS. WOULD BE HARD TO HIT 4' Ø TARGET.
MFG NO. 9										BELIEVES A TRICONE BIT WOULD DEFINITELY TEND TO DRILL A STRAIGHTER HOLE THAN A DRAG BIT.
MFG NO. 10			600 TO 800			100 PSI ON GAUGE			15 GPM ±	HOLD PENETRATION RATE 80 FT/SHIFT TO MINIMIZE DEFLECTION. CAN DRILL 250 FT/SHIFT W/O REGARD TO DIRECTION. DONT CROWD WILL TEND TO DEFLECT HOLE DOWN. AT HIGH PENETRATION RT, IF HARD SPOT IS HIT, WILL DEFLECT BIT.

APPENDIX B BITS TESTED

<u>Bit Tested</u> ¹	<u>Description</u>	<u>Footage Drilled (ft)</u>	<u>Bit Wear</u> ²
<u>Drag Bits - 2-blade</u>			
Servco 16 (Servco Co.)	3 in. dia., NW Box, 25° positive face angle 5° positive rake angle, 0° radial rake angle	281	B
Servco 17	3 in. dia., NW Box Zero degree face angle 5° positive rake angle 5° positive radial rake angle	388	B
Servco 18	3 in. dia., NW box 25° positive face angle 3° positive rake angle 5° positive radial rake angle	208	A
EDECO Flycutter (English Drilling Equipment Co., Ltd.)	3 in. dia., ETA pin multi-stage piloted bit	283	A

¹All drag bits tested had tungsten carbide inserts.

²Bit tooth dullness and bearing condition:

<u>Tooth Dullness</u>	<u>Bearing Condition</u>
A - Insignificant	1 - tight
B - Just noticeable rounding of inserts or teeth	2 - medium
C - Obvious rounding	3 - loose

<u>Bit Tested</u>	<u>Description</u>	<u>Footage Drilled (ft)</u>	<u>Bit Wear</u>
<u>Drag Bits - 3-blade</u>			
Hughes DB-400 (Hughes Tool Co.)	Blue Demon 3 in. dia., NW Box	482 (1st bit)	B
	replaceable blade bit, designed	585 (2nd bit)	B
	for light to medium weight drilling equipment. Heavy bit body.	644 (3rd bit)	B
Hughes MP-200	Blue Demon, 3 in. dia, NW Box replaceable blade bit, designed for light-weight drilling equipment. Light bit body.	442	A
Servco 2	3 in. dia., NW Box 25 ^o positive face angle 5 ^o positive rake angle zero radial rake	203	B
Servco 3	3 in. dia., NW Box 25 ^o positive face angle zero degree rake angle zero radial rake angle	197	A
Servco 5	3 in. dia. NW Box 10 ^o negative face angle 5 ^o positive rake angle zero radial rake angle	309	B
Servco 8	3 in. dia., NW Box 0 ^o face angle 5 ^o positive rake angle 0 ^o radial rake angle	176	B
Servco 9	3 in. dia., NW Box 0 ^o face angle 0 rake angle 0 radial rake angle	266	B
Servco 10	3 in. dia., NW Box 25 ^o positive face angle 5 ^o neagtive rake angle 5 ^o positive radial rake angle	155	B
Servco 11	3 in. dia., NW Box 25 ^o positive face angle 5 ^o positive rake angle 5 ^o positive radial rake angle	297	B

<u>Bit Tested</u>	<u>Description</u>	<u>Footage Drilled (ft)</u>	<u>Bit Wear</u>
Servco 14	3 in. dia., NW Box 0° face angle 5° positive rake angle 5° positive radial rake angle	248	B
Servco 19	3 in. dia., NW Box Compound face angle consisting of a negative 15° and positive 30° face angle 0° rake angle and 0° radial rake angle	169	B
Servco 20	3 in. dia., NW Box Compound face angle, negative 15°, positive 30° positive 5° rake angle 0° radial rake angle	232	B
Servco Mill 21	3 in. dia., NW Box Compound face angle, negative 10°, positive 25° positive 5° rake angle positive 5° radial rake angle The bit body is a stabilizer consisting of three clockwise spiral ribs. The leading edge of the ribs are lined with large angular tungsten carbide chips.	1340	C
EDECO Stratabit	3 in. dia., ETA Pin Multi-stage piloted bit	298	A
<u>Drag Bits - 4-blade</u>			
Gault Tool Co.	3 in. dia., 4 thread N Rod Pin Offset 4-way rotary drag	313	A
Varel Products Co.	3 in. dia., 4 thread N Rod Pin CB 4-way rotary drag	698	B
Walker-McDonald Enterprises	3 in. dia., 4 thread Rod Pin 4 wing Walmac heavy-duty rotary	174	A

<u>Bit Tested</u>	<u>Description</u>	<u>Footage Drilled (ft)</u>	<u>Bit Wear</u>
<u>3-Cone Roller Bits</u>			
Williams Rock Bit Co.	3 in. and 3 1/2 in. dia., 4 thread N rod. Hole Maker type K-2 medium formation bit.		
	1st bit, 3 in.	985	C - 3
	2nd bit, 3 in.	404	A - 1
	3rd bit, 3 1/2 in.	839	B - 2
	4th bit, 3 1/2 in.	885	B - 2
	5th bit, 3 1/2 in.	598	A - 2
	6th bit, 3 1/2 in.	1088	C - 3
Gruner & Co.	3 in. dia., 4 thread N Rod "Frio" medium formation bit	243	A - 1
<u>Plug Bits</u>			
Carbonado Diamond American Coldset Corp.	3 in. dia., NW Box Carbonado tooth 3-blade concave bit.	280	A
American Coldset Concave	3 in. dia., NW Box Bit set with 1/8 in. x 3/16 in. carbide chips. Considerable wear on gauge.	332	C
American Coldset Convex	3 in. dia., NW Box Bit set with 1/8 in. x 3/16 in. carbide chips. Considerable wear on gauge.	194	C
American Coldset Convex	1.875 in. dia., AW Box Bit set with carbide chips used with Whipstock.	102	C

APPENDIX C

OKLAHOMA TEST HOLES

<u>Hole No</u>	<u>Depth¹ (ft)</u>	<u>Bit Used²</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
1	72	DB-400 3-blade drag		Complete test in coal. Begin bit evaluation testing from hole 1 through 61.
2	75	DB-400	74	
3	60	DB-400	35	
4	76	DB-400	73	
5	206	DB-400		Complete test in coal
6	80	DB-400	60	
7	30	DB-400	25	
8	240	DB-400	235	
9	120	DB-400	119	
10	5	DB-400		Abandoned
11	30	DB-400	20	
12	100	DB-400 & Gruner 3-cone roller	88	
13	40	Gruner 3-cone		Hit hole 12 at 38 ft
14	31	Gruner 3-cone	30	
15	92	Gruner 3-cone	91	
16	200	Gruner 3-cone & Carbonado Plug	57	

¹All footage rounded off to the nearest foot.

²All Oklahoma holes were drilled with 3-inch diameter bits.

<u>Hole No</u>	<u>Depth (ft)</u>	<u>Bit Used</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
17	60	Carbonado Plug	56	
18	100	Carbonado Plug	97	
19	60	S ³ 9	49	
20	20	S 9	4	
21	206	S 2 & 9	196	
22	18	S 2	18	
23	157	S 2 & 3	137	
24	157	S 3	150	
25	17	S 5		Intersected hole 24
26	406	S 5, 8, & 10	406	
27	75	S 10	70	
28	136	S 11		Intersected hole 16
29	36	S 14		Intersected hole 27 or 28
30	87	S 14	83	
31	67	S 14	67	
32	37	S 14	25	
33	117	S 14 & 16	114	
34	37	S 16		Intersected hole 16
35	67	S 16	62	
36	47	S 16	40	
37	125	S 17	122	
38	139	S 17 & 18	129	
39	89	S 18	79	
40	129	S 18 & 19	124	

³ Servco

<u>Hole No</u>	<u>Depth (ft)</u>	<u>Bit Used</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
41	119	S 19	111	
42	81	S 20	76	
43	47	S 20	45	
44	105	S 20	101	
45	50	S 11	50	
46	145	S 14 & 16	140	
47	136	S 9, 17 & 5	136	
48	20	S 5	20	
49	192	S 5 & Gault 4-blade drag	192	
50	6	Gault 4-blade drag		Intersected hole 49
51	146	Gault 4-blade drag & Varel 4-blade drag	141	
52	174	Varel & Walker- McDonald 4-blade drag	172	
53	190	Walker-Mcdonald 4-blade drag & Williams 3-cone	188	
54	16	Williams 3-cone		Intersected another hole
55	155	Williams 3-cone & Concave plug	153	
56	71	Concave plug	68	
57	76	Concave plug	72	
58	80	Concave plug	79	
59	68	Concave plug Convex plug	67	

<u>Hole No</u>	<u>Depth (ft)</u>	<u>Bit Used</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
60	56	Convex Plug		Intersected another hole
61	60	Convex plug	58	End of primary bit evaluation testing
62	184	Convex plug & MP-400	85	Whipstock test
63	142	DB-400	120	Whipstock test
64	11	DB-400	11	Whipstock test
65	204	Varel 4-blade drag	194	Whipstock test
66	125	Varel 4-blade drag	120	Whipstock test
67	56	Varel 4-blade drag	51	Whipstock test
68	130	S 21 Mill	129	Bit & Whipstock evaluation
69	77	S 21 Mill	75	Bit test
70	34	S 21 Mill		Bit test Intersected hole 69
71	108	S 21 Mill	104	Stabilization test
72	49	S 21 Mill	48	Stabilization test
73	29	S 21 Mill		Stabilization test Intersected old mine working
74	31	S 21 Mill		Stabilization test Intersected old mine working
75	33	S 21 Mill		Stabilization test Intersected old mine working
76	33	S 21 Mill		Stabilization test Intersected old mine working
77	54	S 21 Mill		Stabilization test Intersected old mine working
78	90	S 21 Mill	84	Stabilization test
79	15	S 21 Mill		Stabilization test Intersected hole 78

<u>Hole No</u>	<u>Depth (ft)</u>	<u>Bit Used</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
41	119	S 19	111	
42	81	S 20	76	
43	47	S 20	45	
44	105	S 20	101	
45	50	S 11	50	
46	145	S 14 & 16	140	
47	136	S 9, 17 & 5	136	
48	20	S 5	20	
49	192	S 5 & Gault 4-blade drag	192	
50	6	Gault 4-blade drag		Intersected hole 49
51	146	Gault 4-blade drag & Varel 4-blade drag	141	
52	174	Varel & Walker- McDonald 4-blade drag	172	
53	190	Walker-McDonald 4-blade drag & Williams 3-cone	188	
54	16	Williams 3-cone		Intersected another hole
55	155	Williams 3-cone & Concave plug	153	
56	71	Concave plug	68	
57	76	Concave plug	72	
58	80	Concave plug	79	
59	68	Concave plug Convex plug	67	

<u>Hole No</u>	<u>Depth (ft)</u>	<u>Bit Used</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
60	56	Convex Plug		Intersected another hole
61	60	Convex plug	58	End of primary bit evaluation testing
62	184	Convex plug & MP-400	85	Whipstock test
63	142	DB-400	120	Whipstock test
64	11	DB-400	11	Whipstock test
65	204	Varel 4-blade drag	194	Whipstock test
66	125	Varel 4-blade drag	120	Whipstock test
67	56	Varel 4-blade drag	51	Whipstock test
68	130	S 21 Mill	129	Bit & Whipstock evaluation
69	77	S 21 Mill	75	Bit test
70	34	S 21 Mill		Bit test Intersected hole 69
71	108	S 21 Mill	104	Stabilization test
72	49	S 21 Mill	48	Stabilization test
73	29	S 21 Mill		Stabilization test Intersected old mine working
74	31	S 21 Mill		Stabilization test Intersected old mine working
75	33	S 21 Mill		Stabilization test Intersected old mine working
76	33	S 21 Mill		Stabilization test Intersected old mine working
77	54	S 21 Mill		Stabilization test Intersected old mine working
78	90	S 21 Mill	84	Stabilization test
79	15	S 21 Mill		Stabilization test Intersected hole 78

<u>Hole No</u>	<u>Depth (ft)</u>	<u>Bit Used</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
41	119	S 19	111	
42	81	S 20	76	
43	47	S 20	45	
44	105	S 20	101	
45	50	S 11	50	
46	145	S 14 & 16	140	
47	136	S 9, 17 & 5	136	
48	20	S 5	20	
49	192	S 5 & Gault 4-blade drag	192	
50	6	Gault 4-blade drag		Intersected hole 49
51	146	Gault 4-blade drag & Varel 4-blade drag	141	
52	174	Varel & Walker- McDonald 4-blade drag	172	
53	190	Walker-McDonald 4-blade drag & Williams 3-cone	188	
54	16	Williams 3-cone		Intersected another hole
55	155	Williams 3-cone & Concave plug	153	
56	71	Concave plug	68	
57	76	Concave plug	72	
58	80	Concave plug	79	
59	68	Concave plug Convex plug	67	

<u>Hole No</u>	<u>Depth (ft)</u>	<u>Bit Used</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
60	56	Convex Plug		Intersected another hole
61	60	Convex plug	58	End of primary bit evaluation testing
62	184	Convex plug & MP-400	85	Whipstock test
63	142	DB-400	120	Whipstock test
64	11	DB-400	11	Whipstock test
65	204	Varel 4-blade drag	194	Whipstock test
66	125	Varel 4-blade drag	120	Whipstock test
67	56	Varel 4-blade drag	51	Whipstock test
68	130	S 21 Mill	129	Bit & Whipstock evaluation
69	77	S 21 Mill	75	Bit test
70	34	S 21 Mill		Bit test Intersected hole 69
71	108	S 21 Mill	104	Stabilization test
72	49	S 21 Mill	48	Stabilization test
73	29	S 21 Mill		Stabilization test Intersected old mine working
74	31	S 21 Mill		Stabilization test Intersected old mine working
75	33	S 21 Mill		Stabilization test Intersected old mine working
76	33	S 21 Mill		Stabilization test Intersected old mine working
77	54	S 21 Mill		Stabilization test Intersected old mine working
78	90	S 21 Mill	84	Stabilization test
79	15	S 21 Mill		Stabilization test Intersected hole 78

<u>Hole No</u>	<u>Depth (ft)</u>	<u>Bit Used</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
41	119	S 19	111	
42	81	S 20	76	
43	47	S 20	45	
44	105	S 20	101	
45	50	S 11	50	
46	145	S 14 & 16	140	
47	136	S 9, 17 & 5	136	
48	20	S 5	20	
49	192	S 5 & Gault 4-blade drag	192	
50	6	Gault 4-blade drag		Intersected hole 49
51	146	Gault 4-blade drag & Varel 4-blade drag	141	
52	174	Varel & Walker- McDonald 4-blade drag	172	
53	190	Walker-McDonald 4-blade drag & Williams 3-cone	188	
54	16	Williams 3-cone		Intersected another hole
55	155	Williams 3-cone & Concave plug	153	
56	71	Concave plug	68	
57	76	Concave plug	72	
58	80	Concave plug	79	
59	68	Concave plug Convex plug	67	

<u>Hole No</u>	<u>Depth (ft)</u>	<u>Bit Used</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
60	56	Convex Plug		Intersected another hole
61	60	Convex plug	58	End of primary bit evaluation testing
62	184	Convex plug & MP-400	85	Whipstock test
63	142	DB-400	120	Whipstock test
64	11	DB-400	11	Whipstock test
65	204	Varel 4-blade drag	194	Whipstock test
66	125	Varel 4-blade drag	120	Whipstock test
67	56	Varel 4-blade drag	51	Whipstock test
68	130	S 21 Mill	129	Bit & Whipstock evaluation
69	77	S 21 Mill	75	Bit test
70	34	S 21 Mill		Bit test Intersected hole 69
71	108	S 21 Mill	104	Stabilization test
72	49	S 21 Mill	48	Stabilization test
73	29	S 21 Mill		Stabilization test Intersected old mine working
74	31	S 21 Mill		Stabilization test Intersected old mine working
75	33	S 21 Mill		Stabilization test Intersected old mine working
76	33	S 21 Mill		Stabilization test Intersected old mine working
77	54	S 21 Mill		Stabilization test Intersected old mine working
78	90	S 21 Mill	84	Stabilization test
79	15	S 21 Mill		Stabilization test Intersected hole 78

<u>Hole No</u>	<u>Depth (ft)</u>	<u>Bit Used</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
80	60	S 21 Mill	55	Stabilization test
81	30	S 21 Mill	30	Stabilization test
82	105	S 21 Mill	101	Stabilization test
83	34	S 21 Mill	28	Stabilization test
84	149	S 21 Mill	141	Stabilization test
85	81	S 8 & Gault 4-blade drag	55	Dyna-Drill test
86	61	Gault 4-blade drag	55	Dyna-Drill test
87	61	MP-200	55	Dyna-Drill test
88	82	MP-200	70	Dyna-Drill test
89	44	S 21 Mill	40	Stabilization test
90	110	DB-400	107	Stabilization test

TOTAL FOOTAGE DRILLED - 8,057 ft

APPENDIX D
OHIO TEST HOLES

<u>Hole No</u>	<u>Depth¹ (ft)</u>	<u>Bit Used²</u>	<u>Depth Bit Encountered Shale (ft)</u>		<u>Remarks</u>
A-1	186	Flycutter 2-blade drag	183		Bit test
A-2	97	Flycutter 2-blade drag	92		Bit test
B-1	141	Stratabit 3-blade drag			Bit test--bit stuck in hole & recovered
B-2	158	Stratabit 3-blade drag			Bit test--bit stuck in hole & recovered
C-1	189	DB-400	197		Bit test
D-1	169	Williams 3-cone	162		Bit test
D-2	149	Williams 3-cone	148		Bit test
E-1	148	Varel 4-blade drag	146		Bit test
E-2	108	S ³ 21 Mill	105		Bit test
E-3	111	S 21 Mill	110		Bit test
F-1	137	S 17	135		Bit test
G-1	46	DB-400	35		Stabilization test
G-2	76	DB-400			Stabilization test--ran into hole F-2 or G-1
G-3	86	DB-400			Stabilization test--got stuck in hole due to lost circulation--left bit and 30' BQ rod in hole

¹ All footage rounded off to the nearest foot.

² Holes through L-1 were drilled with a 3-inch bit. From M-1 through R-1 the holes were drilled with a 3-inch bit.

³ Servco

<u>Hole No</u>	<u>Depth (ft)</u>	<u>Bit Used</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
G-4	167	Williams 3-cone	60	Stabilization test
G-5	97	Williams 3-cone	92	Stabilization test
G-6	98	Williams 3-cone	93	Stabilization test
G-7	218	Williams 3-cone	195	Stabilization test
H-1	128	Williams 3-cone	121	Stabilization test
I-1	133	Williams 3-cone	117	Stabilization test
I-2	82	Williams 3-cone	65	Stabilization test
J-1	327	Williams 3-cone	312	Stabilization test
J-2	59	Williams 3-cone	53	Stabilization test
J-3	279	Williams 3-cone		Long-hole drilling test-- stopped drilling due to lack of time
K-1	113	MP-200	85	Dyna-Drill test
L-1	134	MP-200 & Williams 3-cone	115	Dyna-Drill test
M-1 ⁴	56	Williams 3-cone		Dyna-Drill test
O-1	115	Williams 3-cone		Dyna-Drill test
P-1	748	Williams 3-cone		Multishot Survey accuracy test--drilled through other side of hill
P-2	1102	Williams 3-cone		Long-hole drilling test-- drilled to total depth in coal--drilled last 14 ft with telemetry survey collar in string

⁴This and remaining holes drilled with 3 1/2-inch bit.

<u>Hole No</u>	<u>Depth (ft)</u>	<u>Bit Used</u>	<u>Depth Bit Encountered Shale (ft)</u>	<u>Remarks</u>
Q-1	356	Williams 3-cone		Long-hole drilling test--drilled to total depth in coal--drilled last 50 ft with telemetry survey collar in string
R-1	1034	Williams 3-cone		Demonstration hole--drilled to total depth in coal with telemetry survey collar in drill string

TOTAL FOOTAGE DRILLED - 7,040 ft

APPENDIX E
INVENTION DISCLOSURES

This study has yielded three ideas that may be patentable.

1. Downhole Orientation Sub for Horizontal Holes, Fenix & Scisson, Inc., docket number 201-P1
2. Uphole Axial Orientation Instrument, Fenix & Scisson, Inc., docket number 201-P2
3. Rock Bit Gage Cutters, Fenix & Scisson, Inc., docket number 201-P3

The U.S. Department of the Interior Form DI-1216, "Summary Report of Inventions and Subcontracts," is included in this appendix.

UNITED STATES
 DEPARTMENT OF THE INTERIOR

Date February 28, 1973

SUMMARY REPORT OF INVENTIONS AND SUBCONTRACTS

The following report must be submitted in *triplicate* as part of the interim or final report as provided for by the REPORTS and/or PATENT ARTICLE in the grant or contract.

Name of Contractor or Grantee	Address
Fenix & Scisson, Inc.	P. O. Box 15609 Tulsa, Oklahoma 74115
Contract or Grant No.	H0111355

(Check appropriate boxes)

1. Type of Report:

- Interim { From 19.....
 To 19.....
- Final.

2. Interim Report Data:

A. Invention made , not made , during interval of (1).

B. If invention(s) made, provide the following information:

Previously fully disclosed in Invention Disclosures. Give dates submitted, and Contractor's docket numbers.

.....

Invention Disclosures attached herewith. Give Contractor's docket numbers.

.....

3. Final Report Data:

	Date Submitted	Contractor's Docket Number
A. Invention(s) previously reported—		
B. Invention(s) reported herewith—	Feb. 28, 1973	201-P1
	Feb. 28, 1973	201-P2
	Feb. 28, 1973	201-P3

C. Others (explain)—

.....

.....

.....

D. No inventions were made under the grant or contract.

4. Patent application(s) filed and contemplated to be filed by Contractor under the terms of the grant or contract:

Application Serial No.				
Date of filing				
Contractor's Docket No.				

5. Subcontracts containing patent rights article:

None. Listed below are subcontractors.

	Name of Subcontractor	Address	Subcontract Number	Date Executed
(1)	Telcom, Inc.	8027 Leesburg Pike McLean, Virginia 22101	201-1	Dec. 14, 1971
(2)				
(3)				
(4)				

6. Attach a copy of the patent rights article employed in each subcontract set forth in 5.

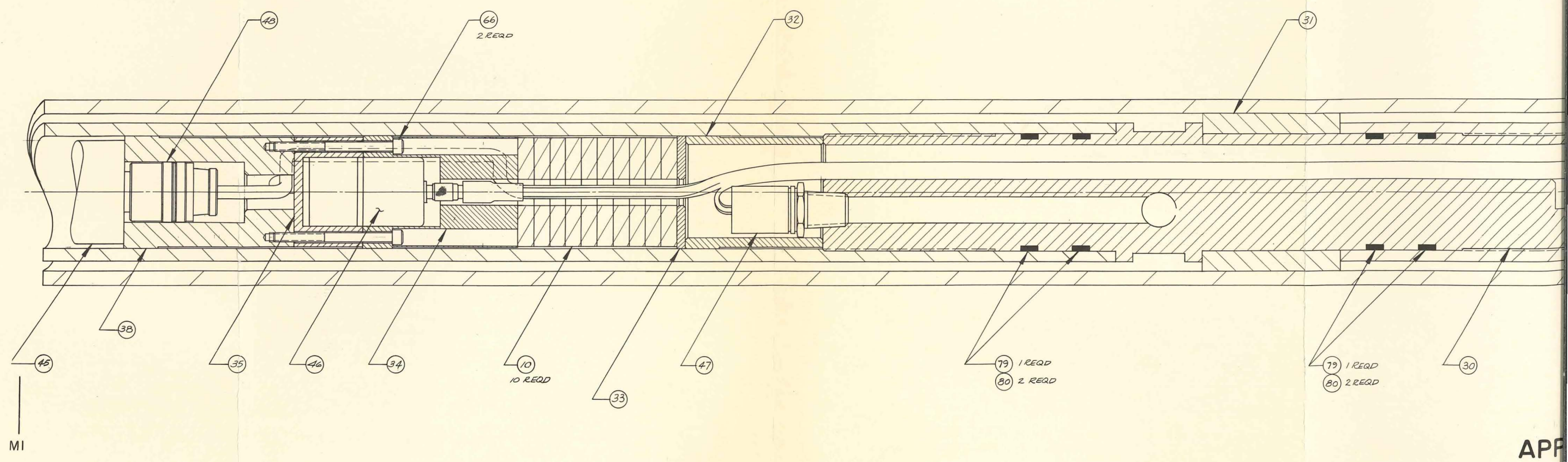
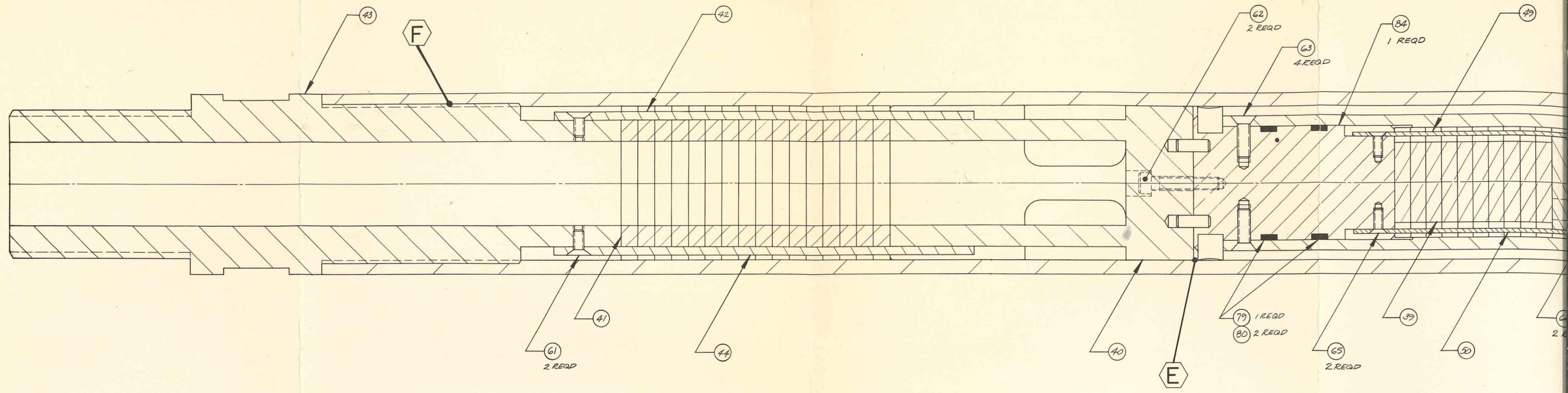
7. Contractor or Grantee certification.

I certify that this Summary Report of Inventions and Subcontracts including any attachments is correct to the best of my knowledge and belief.

Date February 28, 1973

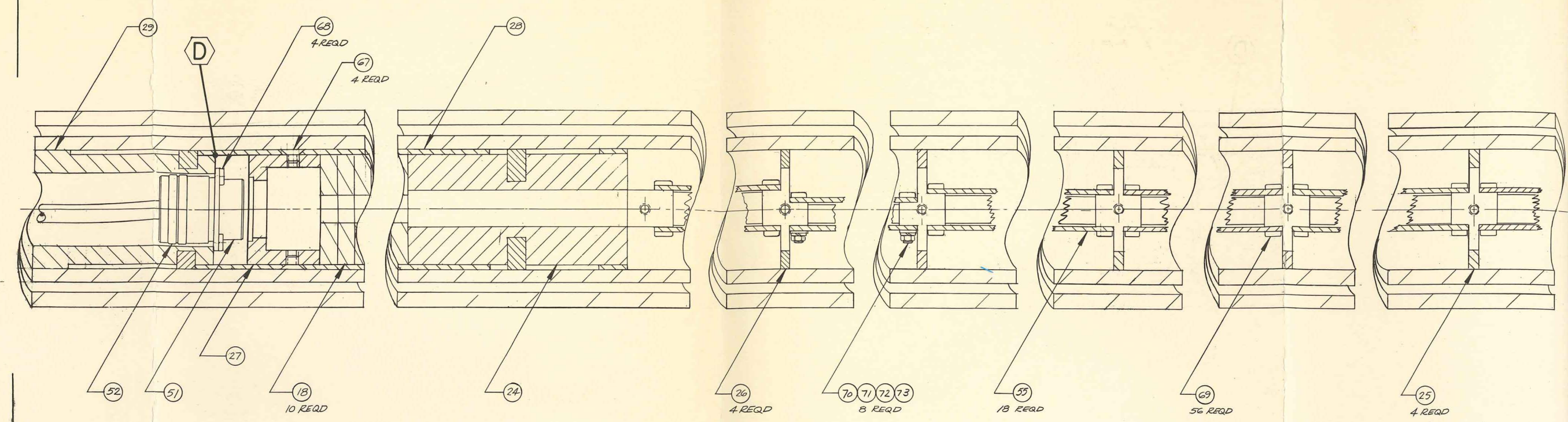
Signature

Title



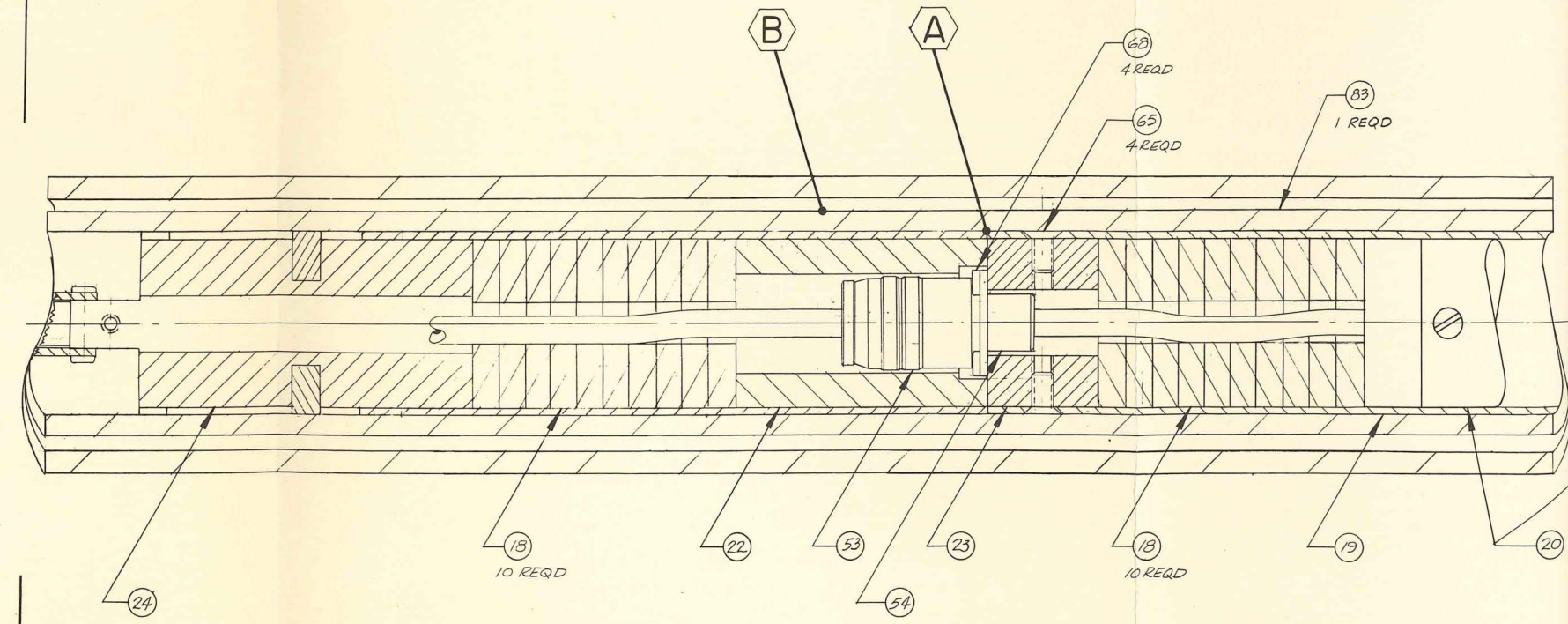
APP
DOWN-HOL

M2



M2

M3

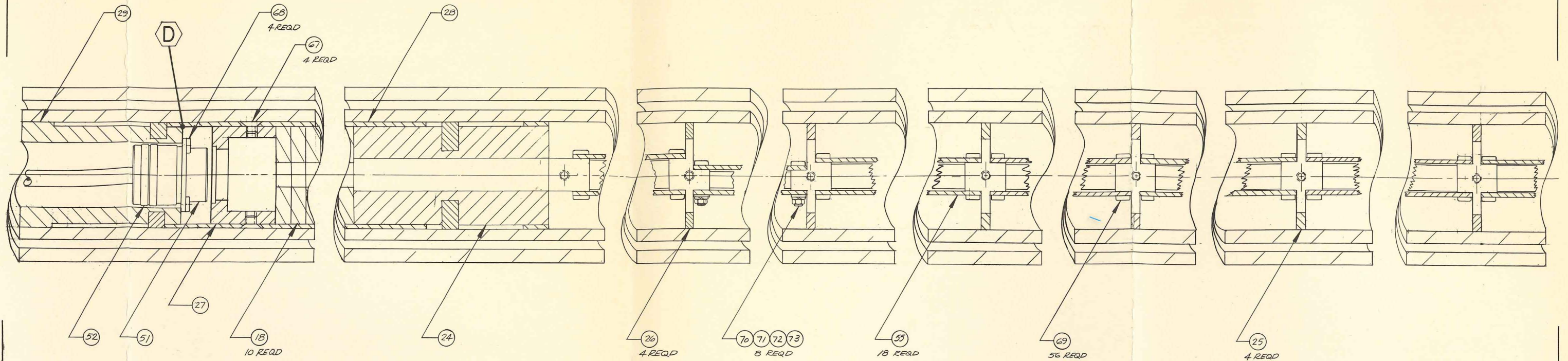


M3

APP
DOWN-HOLE

M2

M3

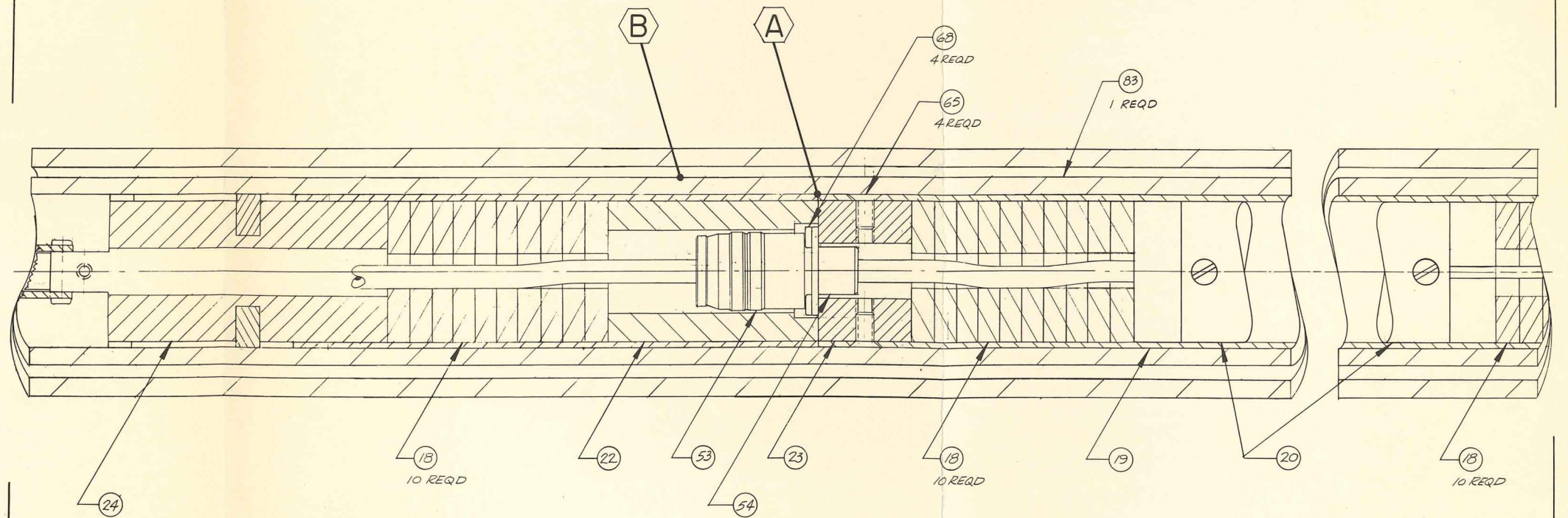


M2

M3

M3

M4

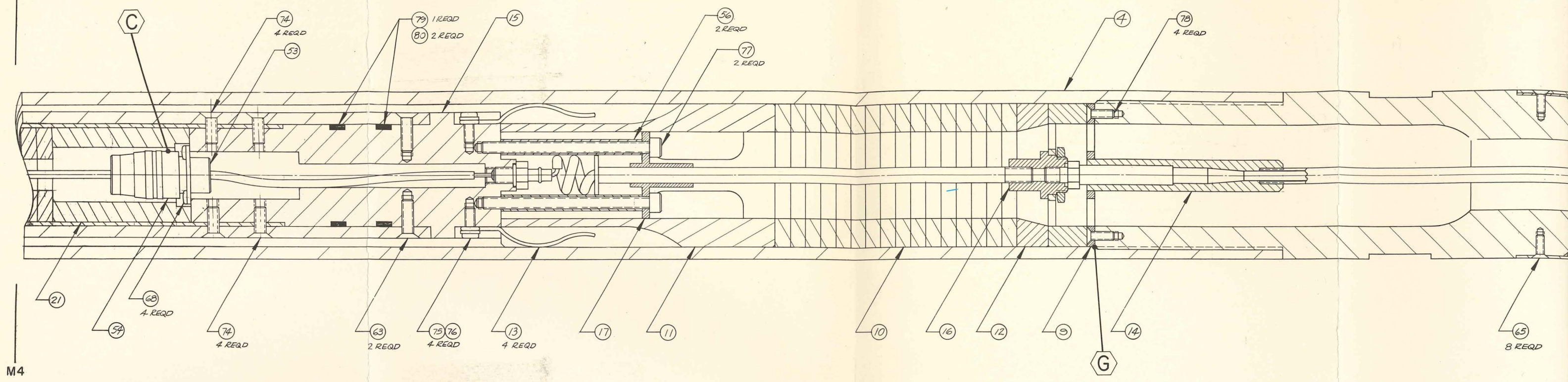


M3

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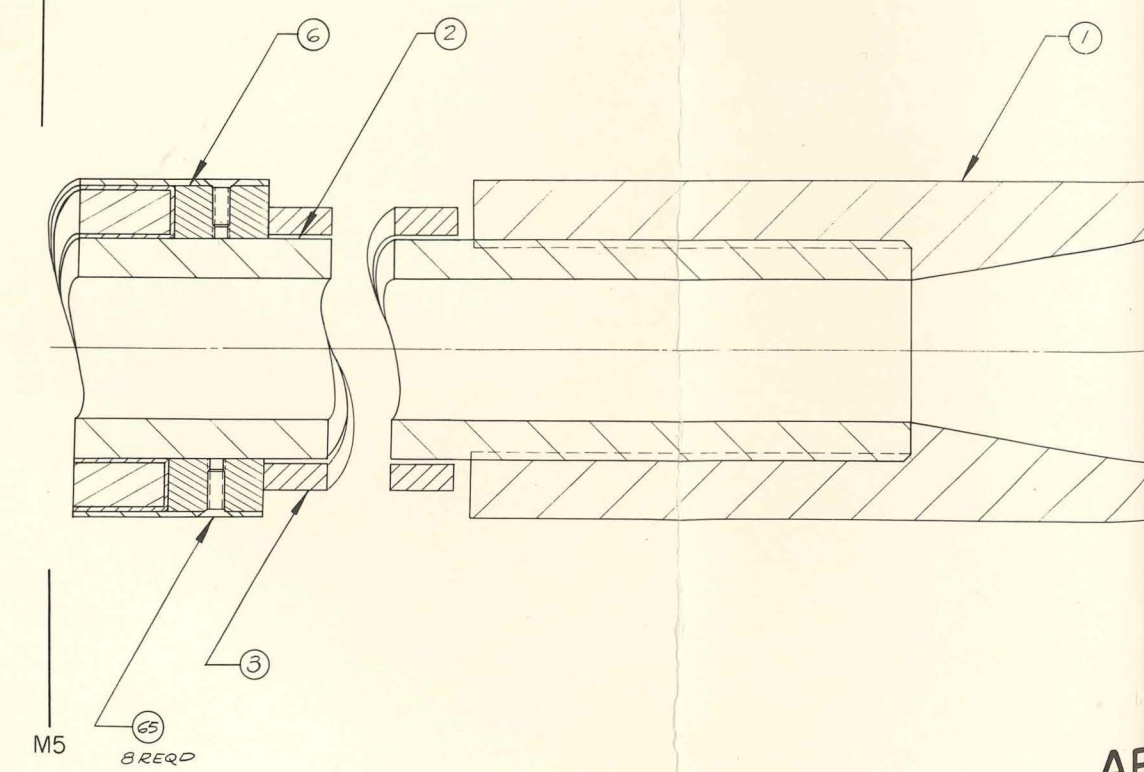
APPENDIX J
DOWN-HOLE SURVEY TOOL

M4

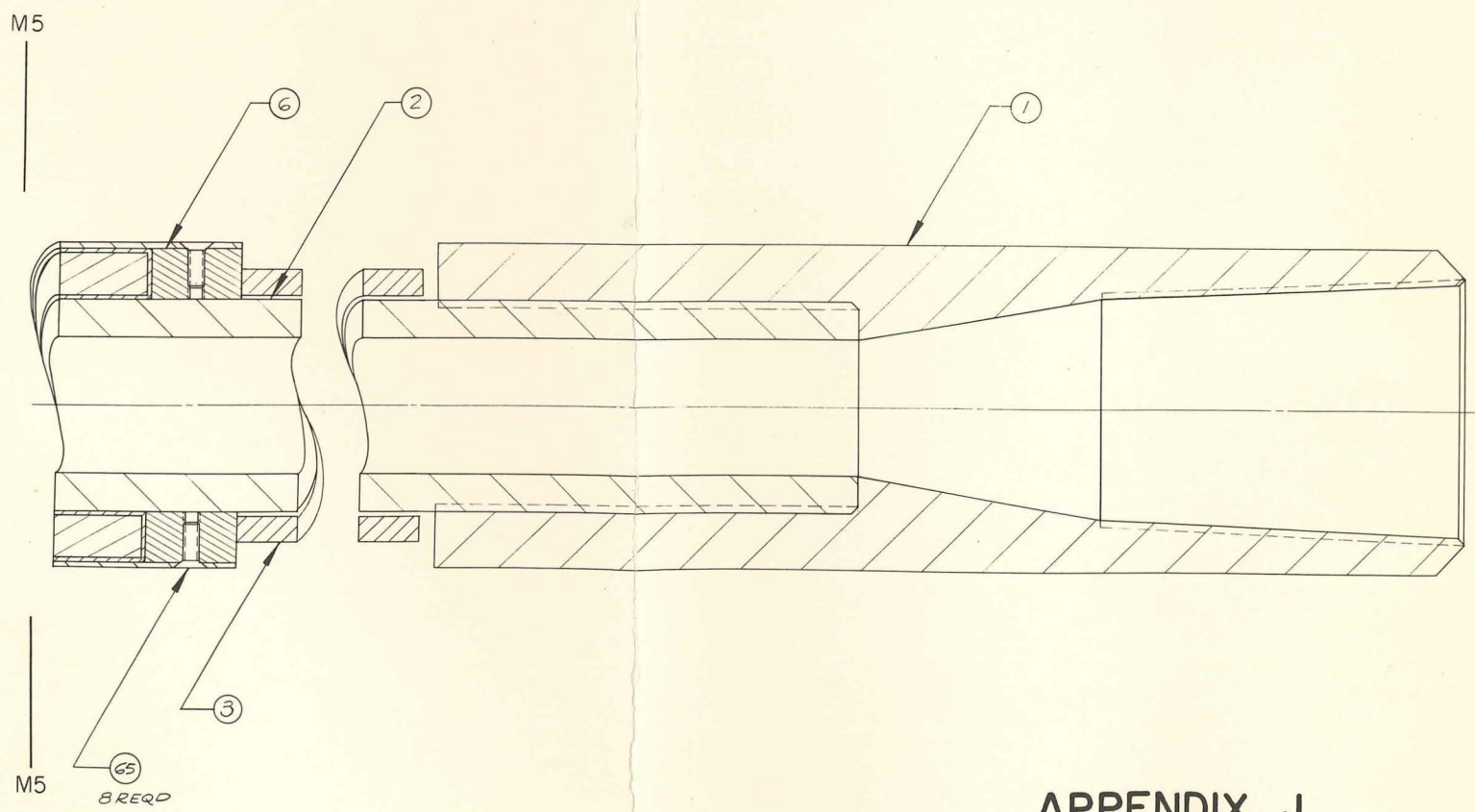
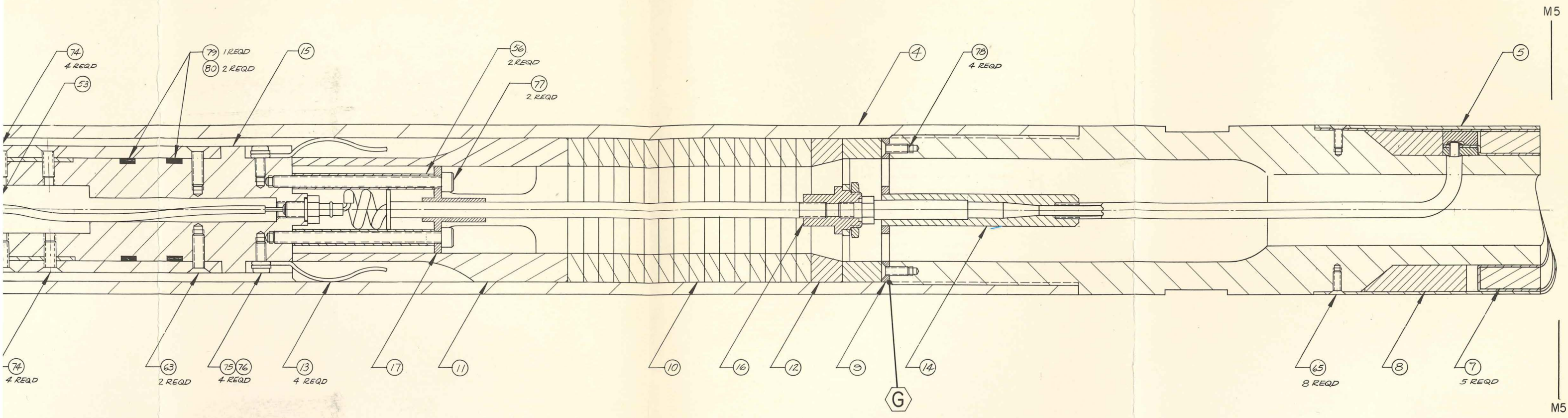


M4

M5



AP
DOWN-HO



APPENDIX J
DOWN-HOLE SURVEY TOOL