Diamond Drilling Equipment

William R. Cox

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Mining Methods

Report
Submitted to
Professor K. S. Stout

Diamond Drilling Equipment

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Montana School of Mines
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HISTORY OF DIAMOND DRILLING

In approaching the subject of diamond drilling, a brief history of the origin and development of the diamond drill may be of interest.

The invention of the diamond drill is generally ascribed to Rudolf Leschot, a French engineer, who made use of diamonds in 1864 in drilling blast holes in the Mont Cenis tunnel in Switzerland. But W.M. Flinders Petrie, in his book "Pyramids and Temples of Gizeh," (1865), describes the use of core drills for drilling short holes in blocks of masonry in the construction of the pyramids (3000 to 2500 B.C.) and other purposes. His conclusions are that copper or bronze tubes were used and that the face of the tubes were set with gems in the same fashion as the diamond bit of today. The tubes were probably rotated by hand.

W.M. Flinders Petrie's principal argument that the gem stones were set in the bit, rather than the use of abrasive powder, is that the granite cores show regular spiral grooves. But grooving or rifling is common in both diamond and shot drilling. In diamond drilling it is probably caused by vibration, the grooves being deepened by a rhythmic accent of a particular cutting stone. A. Lucas, in "Ancient Egyptian Materials and Industries" (1931), discusses this problem fully, and is inclined to believe that sand was the abrasive used.

In either case, however, the early Egyptian engineers employed core drilling. Therefore, we must date the origin of core drilling back to 3000 B.C.

3. Ibid.
in the United States in the late eighteen sixties. The first deep
diamond drill hole was drilled for coal in 1870 near Pottsville,
Penn., by M.C. Bullock. This hole was seven hundred and fifty
feet deep. It can be inferred that the diamond drill was introduced
into Canada in 1871 when a bore-hole, known as Harper's bore-hole
was drilled for coal at Springhill, Cumberland County, Nova Scotia.

The early diamond drill was a crude machine but was said to
have been successful in drilling a hole about 130 feet deep in the
Michigan iron-mining area in 1869. The advance per drill-shift with
the early diamond drill was low and its usefulness very limited.
Within a few years, the diamond drill was being used to drill holes
400 to 1100 or more feet and speeds of about 1 to 2 feet per drill-
hour were reported. The introduction of a swivel head that could
be swung out of the way when the rods were hoisted or lowered, the
inclusion of a hoist integrated with the machine, the adoption of
the double-tube core barrel, and the application of the hydraulic
feed raised drilling rates further.

During the last two decades of the Nineteenth Century the dia-
mond drill was used extensively for core drilling and also for the
drilling of blast holes under special conditions, for instance, in
the iron ore in Northern Minnesota. Black carbons were used al-
most exclusively in the drill bits and they were in this period
relatively cheap.

With the advent of the hammer drill in the next decade and the
development of better steel for bits, considerable progress was made
in rock drilling technique. On the other hand, the black carbons,
which had cost around $2.00 per carat in 1870, went up in price

5. Lindqvist, O.V., Blast Hole Diamond Drilling (New York: J.K.
6. Ibid.
CURVE SHOWING PRICE OF BLACK DIAMOND

FIG. 1-A
which had cost around $2.00 per carat went up in price to reach a peak of about $150.00 per carat in 1929. The result is the diamond drill was discontinued for all types of blast hole drilling and used exclusively for core drilling, where no substitute existed.

The result of the excessive price of carbons was the development of bits set with borts, either Brazilian, South African or Congo, which were set by hand in the beginning and later mechanically. Due to this and better drilling machines the cost of diamond drilling decreased rapidly, and it was discovered again that diamond drilling could be used to advantage for the drilling of blast holes. During the late 1930's diamond blast hole drilling was used in a number of mines in Canada and the United States.

The development of drilling machinery and technical skill used in the diamond drilling industry was greatly hindered by conventionalism and secrecy. For years, diamond drilling had been an art mastered only by a few specialists, as was the setting of the diamond drill bits by hand.

GENERAL INFORMATION OF DIAMOND DRILLING

The following section will cover a brief description of the diamond drill, overburden troubles, drilling in bed rock, and underground drilling. This will give the reader a general picture of the purpose and use of the diamond drill.

General Description of a Diamond Drill

Diamond drilling is based on the extreme hardness of the diamond enabling it to cut or abrade rocks, minerals or other materials found in the earth's crust, or that may be manufactured by man.

In diamond drilling, a ring-like bit, armed with small diamonds, rotates and cuts out a cylindrical core of rock through which it passes.

Mechanically, the diamond drill consists of a power unit rotating a tubular steel bit in the face of which are set diamonds that may be of several types and sizes, depending on the job. This bit and attached core barrel are rotated under controlled pressure, by means of hollow steel, flush-jointed rods through which water is pumped to cool the bit and remove the rock cuttings.

With the advance of the bit, a cylindrical core of rock passes up into the core barrel where it is held by a core lifter or other means. The circulating water raises the sludge or cutting to the surface outside the rods. This sludge may be collected in a settling box for sampling.

The rods are withdrawn at intervals, usually every five or ten feet, and the core removed form the core barrel for examination and storage. The core and cutting present a tangible and accurate record of the various formations through which the bit has passed.

The drawing of a typical diamond drill, see Fig. 1, shows the main features of a surface drill putting down and ordinary hole in
FIG 1. TYPICAL DIAMOND DRILL SET-UP
overburden, and bed rock.

Because the diamond drill is a most versatile machine, it may be employed for many different purposes:

(1) Exploration and development of mineral deposit, including coal.

(2) Drilling of blast holes in mine and quarry operations.

(3) Soil and foundation testing and grouting.

(4) Water-well drilling.

(5) Special projects, such as drainage holes and cableways.

(6) Oil structure investigation and oil well drilling.

In mining the diamond drill may be used for exploration and development, control of mining, to obtain geological data, to block out ore reserves, drainage, conduits, shaft sinking, blast hole drilling, grout hole drilling, foundation tests and diamond drill holes in which the Geiger-Mueller counter can be used.

Drill core sizes vary with the type of machines used and the purpose of the test. In the same way machinery will vary according to type of work being performed, money available, location of the working area, labor and desired results. The machinery and bits will be treated in detail under the appropriate heading.

Overburden Troubles

Before operation, with diamond bit drilling in rock can begin, it is usually necessary to drive a standpipe down through the overburden at whatever angle is desired, until it reaches the ledge rock. The usual methods to drive the standpipe are:

(1) driving a section of pipe with a hammer weighing approximately 350 pounds, while the pipe is turned slowly with a pair of

chain tonge,

(2) wash boring (where the pipe is sunk, the core is broken up by a jet of water, and the disintegrated water is brought to the surface by the current of water), (9)

(3) use of kerosene chilled to -30 degrees fahrenheit by the use of dry ice, as wash solution. The United States Bureau of Mines has done considerable experimenting with the use of chilled kerosene. After the hole has been drilled to the ledge it remains open long enough to place the casing.

When a boulder is encountered a charge of dynamite is lowered into the hole. Connected to the charge of dynamite is an insulated copper wire, an electric cap and at the surface a blasting machine, which will set off the charge on top of the boulder at the proper time. In order to avoid blasting the standpipe, it is necessary to jar or pull the pipe back in the hole a few feet before the dynamite is set off. If the boulder is too large to be broken by the explosion on top of it, it is then necessary to drill a hole into the boulder by using the diamond bit.

When the standpipe reaches bed rock the standpipe is chopped or bored in a few inches, to make a tight joint, to prevent influx of surface material, and to insure return of drilling water to the surface. When this has been done and the casing cut off at the surface to the proper length, the regular operation of diamond drilling commences.

**Drilling in Bed Rock**

After the standpipe is in place the hole is ready to start the drilling operation. For this operation a ten-foot single or double tube core barrel is used. A bit set with many small commercial dia-

---

monds called bortz, is screwed into a reaming shell. Fig. 2

Fig. 2(10) Broken Section of Double Tube Core Barrel, Rigid Type, and Bevel Wall Coring Bit.

This reaming shell has a number of diamonds set in the side and is used, as its name implies, to keep the drill hole reamed out and to hold a constant gauge at all times so as to allow the free lowering

of the new bit.

The bit and reaming shell are screwed onto the bottom of the core barrel, and the whole column is lowered through the casing by adding ten-foot sections until the bottom is reached.

The top drill rod is passed through the hollow feed screw and chuck and screwed to the rods already in the hole. A water swivel, which is connected to the water pump by a wire-bound pressure hose, is then screwed to the last rod now in the chuck, the chuck is then tightened, the water turned on, and the drilling begins.

The water from the pump passes through the hose and water swivel, and then down through the drill rods until it reaches the top of the core barrel. The water passes between the inner and outer tube of the barrel, then around the face of the bit and back up on the outside of the rods. If the rock drilled through is solid and not badly fractured, the water will return through the casing to the drill platform.

When the rock is fractured and it is difficult to get the bit to the bottom of the drill hole, or if it is desired to catch the rock cuttings or sludge and water does not return to the surface, it becomes necessary to cement the hole, and for this purpose, a quick-setting cement is used that will set hard enough to make a core and seal the broken-up formation.

Under ideal drilling conditions, once the bit is lowered to the bottom of the hole and the drilling begins, the drill cuts a round section or core, see Fig. 2, out of the rock. The bit rotates at a high rate of speed and is fed downward by the action of the feed gear. When the feed screw has run its full length, the chuck is loosened and runs back again. This operation continues until ten feet or the capacity of the core barrel has been reached. Then the
drill rods are hoisted to the surface, unscrewed, and stacked.

When the core barrel reaches the surface it is disconnected, the bit and reaming shell taken off and the inner or core tube removed. Then the core is taken out of the tube and placed in the core boxes.

If the formation is badly fractured, and a solid drill core cannot be cut, the cuttings or sludge may be saved by use of a sludge box. The water returning from the drill hole, which contains the cuttings from the bit, is collected in the sludge box. Both the sludge and core samples are marked and sampled. These sludge samples are a valuable check on the core assays.

The above generalized description covers the drilling of an average surface diamond drill hole.

**Underground Drilling**

Drilling in mine workings is somewhat simpler. The drill, usually a light air-driven machine, see Fig. 3, is mounted on a single or double drill column, power is available from the mine compressor and water is available from the rock drill water line. Due to the confined workings, rods are usually pulled in 5 to 10 foot lengths instead of 20 feet.

Horizontal and upward holes are common and for blast hole drilling, non-coring bits are commonly used.
MACHINERY USED IN DIAMOND DRILLING

The equipment of the diamond drilling machinery covered in this report will include the diamond drill machines, drill rods and couplings, casings, casing couplings, core barrels, wire-line core barrel, and diamond bits.

Diamond Drill Machines

Diamond drills are made in so many types and sizes that a full description is impossible. The design of diamond core drilling equipment has improved tremendously with the increase in core drilling activity since World War II. Main emphasis has been on greater power, smoother and more efficient transmissions, improved mobility and flexibility, stronger and more durable parts, and more reliable, maintenance-free, low-cost operation. The component parts of a drill and the general factors that control the various alternative designs will be described below.

Essentially, a diamond drill has four requirements\(^{(10)}\):

1. Means for rotating the drill rods;
2. Means for controlling the pressure on the bit and the downward motion of the drill rods and bits;
3. Means for hoisting and lowering the drill rods; and
4. A pump for circulating water to the face of the bit.

1. Power Units and transmission:

A large majority of the drills include the motive power as a built-in part of the unit. This motive power may be steam, air, electricity, gasoline or fuel oil.

Drill motors range from 5 to 70 hp. and to 140 hp truck engines using power takeoff. In all but the lightest drills the trend is

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10. Gummimg, op. cit., p. 30
is from gasoline to diesel engines. Most of the diamond drilling equipment companies list the following advantages for the diesel engine.

1. The cost of operation is about 40 per cent less. (11)
2. The cost of maintenance is greatly reduced.
3. The diesel engine retains its rated power throughout its life. It has better torque at lower speeds and has superior "lugging" characteristics.
4. It has better power characteristics at high altitudes.
5. Due to more complete fuel combustion the exhaust from a diesel engine contains less carbon monoxide than the gasoline engine. Therefore, the diesel engine is used in confined spaces and underground (with suitable precautions) where the gasoline engine cannot operate.
6. The fire hazard is greatly reduced by using diesel fuel. The diesel engine has the following disadvantages.

1. Diesel engines, for comparative hp rating, cost about two and one-half times as much as gasoline engines.
2. The diesel engines are approximately 25 per cent heavier.
3. Repairs are costly and the job of repairing the engine in the field is difficult.
4. The necessity for personnel with diesel experience.

Diesel-powered diamond drills have been used underground by Sherritt-Gordon Mines (12) at Lynn Lake, Manitoba. Exhaust gases are passed through suitable scrubbers and ample ventilation is provided in the heading.

Compressed air and electric drill motors are used for under-

12. Ibid.
ground exploration.

The use of air, gasoline, diesel and electric motors for the power units on the diamond drills makes possible a great variety of hook-ups, and a survey of the many models which have been produced leads one to believe that almost every possibility has been tried. Varied drilling conditions do require different applications in the hook-up, but on those drills most ordinarily used in mineral prospecting, modern design features a straight line drive, without the use of belts or chains in bringing the power to the boring head. Power is transmitted to the main shaft through a clutch and a set of transmission gears. This design makes possible an efficient two, three, four or five speed transmission, giving a wide selection of hoisting, bit advance and bit rotating speed.

Considerable study is being made into the use of fluid drive and torque converters, which reduce the shock load on the drill motor and the boring column. So far their use is limited to the bigger drillrigs but the development could well prove to be extremely helpful.

2. Feed Mechanisms:

All diamond drills are equipped with boring heads that control the advance of the bit as well as its speed of rotation. Except in large special drills, the swivel head is in a vertical plane and attached to the swivel frame by a hinge and bolt, see Fig. 3 & 4. This allows the head swivel to be swung out of the way when hoisting and lowering the rods.

Most drills can be obtained with swivel heads equipped with either screw or hydraulic feed.

Hydraulic feed is used almost universally on the larger drills. The hydraulic swivel or boring head is essentially a cylinder, or
two cylinders in the twin cylinder type, with a hollow piston, piston rod and chuck to hold the drill rods, see Fig. 3. An oil pump supplies oil to either end of the cylinder controlling the piston. This piston then controls the feed pressure as required.

Pressure gauges, see Fig. 3, attached to the head enable the operator to follow the pressure on the bit at all times. The spindle travel is between 16 to 24 inches.

Fig. 3  Diesel Engine UG Straitline Diamond Core Drill (Longyear)  
Equipped with a 30 hp diesel engine. The twin hydraulic swivel head is shown with duplex type pressure gage.

In Fig. 4, the water pressure is used to control the motion of a piston rod, which feeds forward the drill rods through a chuck.

Hydraulic feed is best in broken or vuggy ground since the feed pressure is constant and there is consequently no danger to the bit on passing from soft to hard ground. In spite of this, many drillers
prefer screw feed, claiming that the constant advance of the screw feed tells them of slight differences in the hardness of rock, and of the presence of thin seams or crevices. However, in varying ground, it is necessary to run through soft strata at reduced speeds so that the bit may not be damaged on meeting hard rocks. A further advantage of hydraulic feed is that in deep holes the weight of the drill rods is counterbalanced to maintain optimum pressure on the bit and to avoid damaging the bit on drilling through cavities.

Fig. 4: Electric Driven UG Straitline Diamond Core Drill (Longyear)

Equipped with "A" size twin cylinder hydraulic swivel head. The motor develops 20 hp at 1800 rpm. The cable is in position to move drill under its own power.

Maintenance cost of the hydraulic swivel head is considerably less than for the screw-feed type. Another advantage of the hydraulic system is that it permits the use of a hydraulic chuck. This is a fast-acting, self-centering device, which is a great time-saver.
Fig. 5 UG Straitline: Diamond Core Drill (Longyear)

Equipped with 30 hp gasoline motor and A size screw feed swivel head. Cable is shown over roller and between sheaves for moving drill under its own power.

Fig. 6 Prospector Air Driven Drill

Develops 3 1/2 hp and is equipped with a screw feed head, E-size, and has a total weight, motor with adaptor and column clamp 130 lbs and screw feed swivel head 150 lbs, of 280 lbs.
when drilling in soft formations where penetration speeds are high.

Most of the smaller machines, X-ray and prospector drill, are equipped with screw feed head, see Fig. 5 & 6. These diamond drilling machines are used underground for blast hole drilling, grouting and exploration. The small diamond drill may be used for surface prospecting to the depth of 600 ft.

Due to these uses of the screw feed and the general lack of understanding the screw feed, this report will cover this operating principle in great detail.

First, this report will state the object of the screw feed, and then a short description of it's operating principle. This will be given to give the reader a better understanding of the detailed description.

The hydraulic and screw feed perform the same function of controlling the advance of the bit but by different methods.

With the screw feed head, the downward feed is obtained by transmitting the rotary motion of the spindle back through a set of differential gears to the feed nut, in a ratio that will revolve the feed nut a definite number of revolutions faster or slower than the feed screw or spindle. This feeds or forces the spindle down in a definite ratio to bit revolutions. Splines on the spindle permits its downward movement while it is rotating.

The detailed description of the operation of the feed-screw assembly which follows will not be difficult to understand if the following simple scheme of power transmission is borne in mind.

"The drive sleeve bevel gear rotates the drive-sleeve and consequently the drive-sleeve drive-gears and, as these mesh with the countershaft drive-gears, rotation is imparted to the countershaft.

As this countershaft carries the countershaft feed-gears, which engage
Fig. 7 Swivel Head or Feed-Screw Assembly (partly in section) (13).

with the feed-gears on the feed-mut, the latter is also made to revolve, thus causing the feed-screw either to advance or retract, depending on whether the machine is in forward or reverse gear" (Fig. 7)

On the inner side of the drive-sleeve are cut two key-ways, corresponding to key-ways cut on the whole length of the feed-screw and the latter is keyed to the former by the insertion of keys or splines. When the drive-sleeve rotates, therefore, it carries the feed-screw with it and it is important to note at this stage that the only function of the drive-sleeve is to provide the rotation of the feed-screw, whereas the forward or reverse motion of the feed-screw is provided by the feed-mut.

At the outer end of the drive-sleeve there is another key-way cut to take a key which keeps in place a pair of gear-wheels, known as the drive-sleeve drive-gears, which engage another pair of gears fitted to the countershaft and known as the countershaft drive-gears. Mounted at the other end of the countershaft is a further pair of gear-wheels, known as the countershaft feed-gears; these mesh with two gears keyed to the brass feed-mut and called the feed-mut feed-

gears.

The inner diameter of the feed-nut is square threaded, with three threads to the inch and through it passes the feed-screw, similarly threaded; these two sets of square threads are the only left-hand threads on the machine.

It will now readily be seen that the chain of power transmission is therefore:

(a) Drive-sleeve bevel-gears to drive-sleeve.
(b) Drive-sleeve to drive-sleeve drive-gears.
(c) Drive-sleeve drive-gears to countershaft drive-gears.
(d) Countershaft drive-gears to countershaft feed-gears.
(e) Countershaft feed-gears to feed-nut feed-gears.
(f) Feed-nut feed-gears to feed-nut.
(g) Feed-nut to feed-screw.

At the front end of the feed-screw the chuck assembly is fixed. This consists of the chuck-head, the chuck-jaws, and the chuck-bolts. Through the chuck-assembly passes the string of drilling rods, these being held in position by the chuck-jaws, which are clamped tight by screwing down the chuck-bolts. Being thus firmly held the drilling string is forced to rotate with the feed-screw.

The countershaft is hollow and is slotted near each end to receive the feed shifter-keys and the feed shifter-pins; at both ends of the countershaft the feed shifter-rods, see Fig. 7, are inserted. The inner ends of these rods are bored to receive the feed shifter-pins that pass through the countershaft and the feed-shifter steel collar, which is free to slide laterally in the slots of the countershaft. Fitting over the feed-shifter steel collar is the feed-shifter brass collar, into which is screwed the feed-shifter handles; these feed-shifter handles travel in helical slots in the swivel-head casting,
thus producing a lateral motion of the feed-shifter collars in the countershaft.

The outer end of each feed shifter-rod is slotted to receive the feed shifter-key; this key, when the feed shifter-handle is in its central position in the helical slot, is free to rotate within the countershaft gear wheels, as these are recessed on their inner sides for that purpose. Movement of the feed shifter-handle, therefore, up or down the helical slot, causes the feed shifter-key to engage in one of the two pairs of slots cut in the inner side of the countershaft gear wheels, which thus become positively engaged.

To obtain various rates of speed for drilling the gear-wheels have different numbers of teeth, as it is obvious that the amount of forward advance produced in the feed-screw depends entirely on the gearing through from the drive-sleeve drive-gear to the feed-nut feed-gear; to obtain a positive feed the feed-nut must gain considerably on the feed-screw, while a perceptible lag on the feed-nut will produce a reverse direction of the feed-screw.

On the new UG Stralline Diamond Core Drill (Longyear), see Fig. 5, the feed gears are driven from the gear on the sleeve, through another gear with a friction disc on both sides, this being held in contact by a compression spring capable of being adjusted to any desired degree of tension. This friction escapement prevents undue pressure on the bit when encountering hard seams or in case feed is too fast.

The oil-operated, hydraulic-feed, swivel head is preferred in the United States, while the screw-feed type, which automatically sets the rate of feed depending on the feed gears selected, is preferred in Canada.
3. hoist:

A hoist is used on a diamond drill for handling rods, casing and standpipe into and out of the drill hole. It is also employed for hoisting the drive blocks, which are used for driving the casing or standpipe. In the small to medium size skid-mounted drills, the hoist and cable is used for moving the drill from hole to hole, see Fig. 5.

The hoisting drum is usually a two or more speed drum driven by gearing from the crankshaft. A compound gear reduction is provided for deeper holes where the weight of drill rods may be several tons. On light drills, the hoisting drum is sometimes omitted, the rods being raised by a rope coiled around a cathead.

4. pumps:

![Gasoline Motor UG Straitline Diamond Core Drill (Longyear)](image)

Equipped with 30 hp gasoline motor and "A" size twin cylinder hydraulic drilling head. Built-in water pump at the rear. Oil pump for operating hydraulic is shown at side of engine.
A dependable water supply is necessary in diamond drilling to prevent "burning", polishing or glazing of the diamonds in the bit to remove the rock cuttings from the bore hole, and to keep the core from sticking in the core barrel.

The water passes down through the drill rods, through the core barrel, and out and around the diamonds set in the core bit. If a double tube core barrel is used, the water passes down between the inner tube and the core barrel. The diamond-set bit is working at speeds up to 2000 revolutions per minute or higher, and under considerable pressure so any water stoppage is disastrous to the bit. Proper waterway design is essential particularly on non-coring and pilot bits.

The water washes the rock cuttings up the outside of the rods to the surface where they may be allowed to run to waste or collected for checking the assays of the core. In very bad ground where core recovery is nil or poor, these sludge samples may be the only record of ore conditions in an expensive hole.

When drilling in mine workings, water is sometimes available from another drill hole nearby that makes enough water for the diamond drill. The mine pump, the standpipe or the water discharge column is also used as a source of supply but sometimes a pressure reducing valve is necessary, at lower mine levels.

Pumps, suitable for drilling purposes, should be as light as possible and designed to minimize line surge. Water pumps are generally powered by gasoline engines; however, diesel engines in the low hp range are becoming manifest, and as drill rigs become diesel-powered, the tendency will be to provide the same type of power for water pumping.

The drill may have a built-in water pump, see Fig. 8, or the
water may be supplied from a separate pumping plant, see Fig. 9.

Fig. 9 Pump, Model BB5-12 with Enfield Diesel Engine.

A built-in pump increases the weight of the unit and gives no flexibility in the location of the pump. The pump may be operated independently of the drill or hoist, assuring a continuance of circulating water when the drill is shut down. Frequently the power for the drill will be lacking when the pump is called on for heavy service and may result in sticking the bit if the motor stalls. But the built-in pump saves an extra piece of machinery and reduces the first cost of the outfit. In Canada and the United States separate water circulating pumps are preferred and in other countries the built-in pump is preferred.

It should be remembered that in addition to the pump at the drill, another pump is required to supply water from the primary source of water. Underground the supply of water is usually under pressure thus, the second pump is unnecessary.
This section of the report will cover specific examples of diamond drilling machines and list a few of their features.

For convenience, drills with capacities of 300 to 2,000 ft EX core are classified as medium, those with capacities greater than 2,000 ft as heavy exploration drills and those with capacities of 300 ft or less as small exploration drills.

1. Small exploration drills:

A small machine recovering a 3/4 inch diameter core, with a working depth capacity of 150 ft, is described by J. D. Cumming, as an "X-Ray drill. This drill was developed for shallow work.

Fig. 10 Gasoline Driven Prospector (Longyear)

These light core drills can be powered by air gasoline or electricity.

These small cores are designed to give a rapid test and might be considered small channel samples. Sometimes they merely go 10 or 20 feet below the surface and still shallower holes have been used for the blasting of rock trenches across zones for sampling purposes.

Fig. 11 The Longyear Prospector Hi-Speed Air Drill (15)

This air drill develops 9 hp (at 80 psi) and has an air consumption of 2.5 cfm. It is equipped with a 2-speed transmission and screw feed swivel head in either size E (I.D. of feed screw is 1 5/8 in) or size A (I.D. of feed screw is 1 3/16 in). The rated capacities for EX and AX are 500 or 1,000 ft respectively. The air motor is a rotary Longyear Duplex, vane type.

This X-Ray drill is similar to the Longyear Prospector (16), see Fig. 10.

The Prospector air model combines features which meet the basic requirements in a core drill designed for underground exploration work, see Fig. 6 & 12. The light weight assures easy moving, and the small size permits setting up in limited working area, see Fig. 12. Expensive station cutting for the assembly is unnecessary.

The Prospector air model has three practical uses in underground operations. (17) First, as a preliminary to mining, ore occurrence may be located and tested for grade. Second, blast holes may be diamond drilled. Third, certain problems in mining operations may be solved.

The small size of the Prospector permits its use in the limited area. For example, the drill can be set up in a six-foot drift from which vertical, angle or horizontal cross-cut holes may be drilled. Short hole penetration into the walls of the drifts or stopes is often desirable to test for ore values which may be hidden by intervening rock. As an aid in development work, the Prospector may be used to determine the location, size and shape of vein or orebody; also, to define the limits of workable areas. An analysis of recovered core samples reveals the grade of ore and the minerals present. Such data are essential as a guide to intelligently planned drifting, raising and stoping.

The Prospector air drill is well adapted for drilling blast holes. There is a minimum of noise in the operation, and dust from drilling is practically eliminated.

In certain mine operation problems Prospectors may be used to

17. Longyear, op. cit., p. 3.
drill holes through which power cables may be run, or for drainage purposes. Often one or two drill holes will provide ventilation of closed areas such as the top of raises. Another use is in drilling holes for grouting, when this method is adopted for sealing off seepage into shafts or drifts.

Prospector drills, equipped with air motors, are designed for easy handling underground. Reduced weight has been made possible because a transmission is unnecessary, as bit rotating speeds are regulated by throttling the air motor. When moving from one set-up to another, the drill may be separated into two units by removal of the hinge bolt, see Fig. 6 & 11.

The 3 1/2 hp, see Fig. 6, 4 cylinder, piston type air motor is economical in operation and dependable. At maximum drilling speed the air consumption is 70 to 80 cubic feet per minute.

The head is supplied in E-size, and the feed screw has a travel of 18 inches before rechucking of the rod is necessary. The head swivels 360 degrees, permitting holes to be drilled at any angle. Proper clearance for lowering or hoisting rods is obtained by swinging the head open on its hinge pin.

A hand wheel, see Fig. 6 & 11, operates as a brake on the feed nut, allowing the drill spindle to be run back after each 18 inches of drilling. It has a further practical use in "finding" the bottom of the hole. When the rods are lowered to the approximate depth of a hole, a turn or two of the wheel brings the bit easily to rest on the bottom. Sharp, sudden contacts which might endanger the bit, are avoided.

The rate of advance of the bit in drilling is controlled by the ratio of the particular set of feed gears in use. There are four sets of feed gears in this swivel head. The operator can regulate
the rate of bit advance by shifting from one set of gears to another. This shift may be made while the motor is running. The operator may select various sets of gears to use on different types of rocks.

The Prospector air drill can be mounted on a single mine column, cross-bar or side arm.

A rod puller for hoisting rods may be equipped on the Prospector air drill. The operation of the rod puller is simple. When ready to pull, the swivel head is swung out of line with the hole and the rod puller guide is dropped into place. Then the grip arm with the cam is dropped into position on the rods, air is turned on, and the pulling starts.

The Prospector gasoline (18), see Fig. 13, with an air-cooled, 5 3/4 hp gasoline motor, is designed for core drilling from the surface. This model is adapted for general scout drilling of holes up to 300 feet. The Prospector gasoline drill is suited for sinking shallow standpipe, and core drilling after bed rock is reached.

Industrially, the gasoline model may be used in testing foundations sites for bridges, dam and power installations. Also, it is often desirable to secure core samples of concrete dams, bridge piers, tunnel linings, road beds, floors, and walls.

Power from the motor is transmitted through a clutch, see Fig. 13, and a 3-speed transmission directly to the drilling head, or to the spool hoist. When drilling, the hoist may be disengaged. The swivel head and feed gears are the same as those for the Prospector air-driven model.

The electric model may be used on surface for the same purpose as those described for the gasoline driven drill. Mounted on a

---

double column for underground work, see Fig. 1h, the electric drill is adapted for the many uses outlined for the air model.

Fig. 1h Electric Driven Prospector Drill (Longyear)

The clutch, transmission, spool hoist, swivel head and feed gears are similar to those of the gasoline model.

Electrically driven drills, while smooth running and economical, are bulky and heavy. Necessary electrical connections underground also present difficulties. For use underground, such motors and controls should be totally enclosed, or at least splashproof with specially impregnated winding.

Longyear produces one electrical drill weighing about 600 lbs.\(^{(19)}\) It must be pointed out here that electrical drills are much more economical in producing power than the air motor, but the difference in weight is a big factor. Two men can lift 200 lbs but moving 600 lbs

\(^{(19)}\) Ibid., p. 4.
1. Drill Rod
2. Waterswivel Assembly
3. Waterswivel Hose Assembly
4. Suction Hose Assembly
5. Relief Valve
6. Pump Tree Assembly
7. Suction Hose Strainer
8. XRT Diamond Set Cashing Bit
9. XRT Casing
10. Rod to casing Bushing
11. Starting Barrel or Corebarrel
12. XRT Diamond Set Reamer Shell
13. XRT Diamond Set Coring or Plug Bit

Fig. 15 X-Ray Diamond Drill
is very awkward for two men. When a light flexible electrical machine is developed, it will create a larger field for blast hole diamond drilling.

Another portable diamond drill is the X-Ray model produced by Stanco, see Fig. 15. The power unit on this machine can be an air or gasoline motor, interchangeable for either surface or underground drilling. This complete drilling machine can be obtained at a cost of $2,800. The drilling capacity is guaranteed to 200 ft.

2. Medium exploration drills:

Most of the medium size drills, see Fig. 3, 4, 5, & 16, are used on the surface, but they can also be used underground where the drilling space is large. The power unit may be gasoline, air, electric or diesel. Usually the transmission is either three or four speed. The weight of these machines vary from 500 to 3,250 lbs.

The modern trend in the medium size drill is the use of diesel power units and hydraulic feed.

The following is a short list of medium sized drills.

<table>
<thead>
<tr>
<th>Drill</th>
<th>Capacity</th>
<th>Feed</th>
<th>Weight</th>
<th>Cost</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teredo LD</td>
<td>100 ft</td>
<td>EX</td>
<td>500 lbs</td>
<td>$2,200</td>
<td>Acker Drill Co.</td>
</tr>
<tr>
<td>S &amp; H 30</td>
<td>600 ft</td>
<td>S or H</td>
<td>1,350</td>
<td></td>
<td>Sprague &amp; Hemwood</td>
</tr>
<tr>
<td>Mayhew 1,000</td>
<td>1,000</td>
<td>Rotary</td>
<td>1,145</td>
<td>1,873</td>
<td>Mayhew Supply Co.</td>
</tr>
<tr>
<td>S &amp; H 1h2</td>
<td>2,000</td>
<td>EX</td>
<td>3,300</td>
<td></td>
<td>Sprague &amp; Hemwood</td>
</tr>
<tr>
<td>UG Straitline</td>
<td>2,000</td>
<td>S or H</td>
<td>2,200</td>
<td></td>
<td>E.J. Longyear Co.</td>
</tr>
<tr>
<td>NXO Hydraulic</td>
<td>1,000</td>
<td>H</td>
<td>3,100</td>
<td>5,500</td>
<td>D.D. Contracting Co.</td>
</tr>
<tr>
<td>Teredo TH</td>
<td>800 AX</td>
<td>S or H</td>
<td>2,300</td>
<td>3,000</td>
<td>Acker Drill Co.</td>
</tr>
<tr>
<td>BBS-1</td>
<td>1,200</td>
<td>E</td>
<td>1,145</td>
<td>1,873</td>
<td>Boyles Bros.</td>
</tr>
<tr>
<td>BHD-C</td>
<td>1,500</td>
<td>Rotary</td>
<td></td>
<td></td>
<td>Winter Weiss Co.</td>
</tr>
</tbody>
</table>

Table 1-AA
Fig. 16 Air Motor UG Straitline Diamond Core Drill (Longyear).

Equipped with 4-cylinder air motor developing 18 hp at 1000 rpm. The swivel head is a twin hydraulic type in "A" size.

3. Large exploration drills:

This class of diamond drill falls into the group that has a capacity of 2,000 ft to 8,000 ft.

The example in this group that we shall cover is the Master Straitline diamond drill by Longyear. (19)

Master Straitline, see Fig. 17, has the following rated capacities: AX size holes are drilled to 4,250 ft recovering core 1 1/8 inches in diameter, BX size holes to 3,250 ft recovery core 1 5/8 in, and NX size holes to 3,000 ft recovering core 2 1/8 in diameter.

The power unit can be a choice of gasoline, diesel, electric, or air. It has a four-speed transmission, driven by the power unit through a sturdy clutch, permitting instant stopping of the drill without shutting down the engine. The hoist and hydraulic swivel head are similar to those explained above.

Fig. 17 Master Straitline Diamond Drill (Longyear)

This Master Straitline is gasoline driven, showing built-in water pump and operating controls. This drill has a total weight of 7,200 lbs and this same model equipped with a diesel motor weighs 7,700 lbs. This drill is rated at 50 hp at 1500 rpm and length of feed is 18 inches.

For pulling, or lowering rods the drill unit mounted on the sub-base is pulled back 16 inches by means of a hydraulic cylinder. Pressure gages are attached to the head to enable the operator to determine the pressure which the bit carries.

These larger machines are used for exploratory work that requires
deep penetration. It has also found use in drilling holes for ventilation, drainage and for various test purposes.

Another deep-hole machine with a capacity of more than 5,000 ft is the Longyear DH-5 drill. Drilling is done through a kelly and rotary table, \(^{(20)}\) with twin hydraulic pull down assembly used for the first few hundred feet. The hydraulic tension control cylinder is used for feed control at depth. A 75-ft derrick is used for 60-ft pulls.

The Boules Bros. Model AAS-1 drill is rated at 5,000 ft with B equipment, has a five-speed transmission. It is equipped with a gasoline or diesel engine, with rating of approximately 88 hp. The unit is equipped with either a hydraulic or a gear-friction feed swivel head.

This unit was used to put down a 70-degree hole to a depth of 5,800 ft in the Michipicoten district of Ontario. \(^{(21)}\) The hole contained twelve wedges and the job was completed in seven months.

There is still room for improvement in design of underground drill rigs. For moderate depth capacity machines, about 600 ft, there is a tendency to power the machines by rotary, vane type air motors. These motors require air pressure not less than 80 lbs in order to maintain the relatively high rpm required to develop the hp rating. They are lighter in weight than piston-type air motors and are desirable for underground use. Where capacity ratings of more than 600 ft are required, or where air pressure cannot be maintained, the piston-type air motor would be preferred. There is a preference for the air-operated rod pullers in lieu of drum hoists.

21. Ibid.
because such a set-up is more flexible. For depths beyond 1,000 ft it is usually advantageous to rig up for use of the hoist.

The continuing demand for higher bit rotating speeds has necessitated careful studies of the effects of such speeds upon the wearing quality of gears, shafts and bearings; also of tendencies to set up vibrations in the drilling head. Therefore, the equipment companies must use steels of proper alloys and correctly heat treated parts, thereby increasing durability to meet the stress of high-speed drilling.

Drill Rods and Couplings

A drill rod, see Fig. 18, is a hollow flush-jointed or coupled rod that is rotated in a diamond drill hole and on the lower end is attached a core barrel, a reaming shell and a diamond core bit. There are many variants from this assembly. In oil well drilling, the term drill pipe is used instead of drill rod.

In operation the rod or rods, with the drilling assembly on one end and a water swivel and water hose at the other or top end, are held by a jawed chuck at the lower end of the feed screw. The rotation of the feed screw and the feed nut, rotates the rod assembly and forces it into the rock so that the cutting action will take place.

The bulk of rods in use are made of seamless carbon steel tubing with parallel walls that do not need upsetting to take the end threading. Modern rods are usually made of thinner seamless alloy steel tubing, with or without upset ends and with female, modified square threads. Male end, see Fig 18, (pin to pin) couplings are used to connect the rods. Various types of couplings and substitutes (couplings with dissimilar threads at each end) are used to connect rods to special fittings, such as casing, casing barrel assemblies, pipe barrel assemblies, core barrel heads, and to introduce larger or smaller rods in the line.
DRILL RODS AND COUPLING

PARALLEL WALL DRILL ROD WITH COUPLING

UPSET WALL DRILL ROD WITH COUPLING

PK UPSET WALL DRILL ROD WITH COUPLING

FIG. 18
Rods for rock drilling usually come in 10 ft lengths, although shorter lengths are used for starting holes on the surface and underground. For drilling in drifts and restricted quarters underground, five foot lengths are common.
Casings and Casing Couplings

Diamond drill casing is used in drill holes to:

1. Keep walls of the drill hole from caving.

2. Prevent the loss of circulating water in broken or fissured formations, and to assure its return.

Diamond drill casing is made in a nesting series as shown in figure 19. Each size of casing has an inside diameter large enough
to take a core bit of the same designated size, and the next smaller size casing, casing bits or shoes. For example, BX casing will permit passage of BX core bit, AX casing and AX casing bits or shoes. The outside diameter of casing is such that it will fit a hole drilled with the next larger size core bit. For example, BX casing can be inserted in a hole drilled by NX core bit.

All diamond drill casing is flush on the outside. This aids its advance into, or its withdrawal from the hole. Casing can be driven, or rotated to the desired depth.

Casing is manufactured in two styles:

1. Flush joint casing, see Fig. 20, has a box thread in one end

![Diagram](image)

**Fig. 20** Flush Joint Casing and Flush Coupled Casing

and a pin thread on the other. When making up a string of casing, one piece is screwed directly into the next. No couplings are used.
2. Flush coupled casing, see Fig. 20, has box threads in each end. A casing coupling with pin threads on each end is used to connect the pieces of casing.

Most of the casing and casing couplings are made from cold drawn seamless steel tubing which has been subjected to closely controlled manufacturing processes.

Core Barrel

At the lower end of the line of drill rods, is the core barrel which holds the core while drilling and in which it is brought to the surface.

The reaming shell attached to the core barrel, furnishes a connection for the core barrel bit and gives space for the core-lifter or core spring. The reaming shell is a threaded short cylinder with diamonds set in its outside face, and keeps the drill hole reamed to exact size.

There are many core barrel designs to suit different drilling conditions, and they may be grouped into the following types. (22)

1) Single-tube barrels.
2) Double-tube barrels.
3) Stationary-inner-tube barrels.
4) Mud barrels.
5) Starting barrels.
6) Casing barrels.
7) Blast-hole barrels.
8) Duffield barrels.
9) Soil sampling barrels.

1. Single Tube Barrels:

These single tube barrels are generally used for drilling hard

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and compact formations. This barrel, see Fig. 21, is of simple and rugged construction. Maximum bit pressures can be applied thereby obtaining high drilling progress. Cores can be removed easily and quickly.

Fig. 21. Single Tube Core Barrel

1. Core Barrel Head
2. Tube 10, 5, 2 ft
3. Reamer Shell Blank
4. Core Lifter
5. Core Bit Blank Bevel Wall
6. Core Bit Blank Straight Wall

In operation, the tube revolves around the core as long as the
core remains unbroken. The circulating water flows alongside the core and through the bit.

2. Double-tube Barrels:

In the double-tube barrel the back-end or water separator is designed to pass the water down between the inner and the outer tube, see Fig. 22, thus preventing this heavy flow of water, usually at high pressure, from coming into contact with the core. The water separator also provides a passage for some water to pass upward on

1. Core Barrel Head
2. Outer Tube 10 or 5 ft
3. Inner Tube 10 or 5 ft
4. Reamer Shell Blank
5. Core Lifter
6. Core Bit, Bevel Wall
7. Core Bit, Straight Wall

Fig. 22 Double-tube Barrel.
the inside of the inner tube and this has a tendency to float the core up the inner tube. This tends to wash grit from the core and reduce the wedging or blocking of core in the inner tube.

The inner tube, being much closer in inside diameter to the size of the core cut, has a tendency to hold split or fractured cores together, thereby reducing the possibility of blocking. It is not unusual to recover a length of core split from end to end yet held perfectly in place by the inner tube. This core would have fallen apart in a single tube, or would even have been washed apart by the circulating water.

3. Stationary-inner-tube Barrels:

The stationary-inner-tube barrel, see Fig. 23, has the advantages of the double-tube barrel and has much less tendency to block. The design endeavors to eliminate rotation of the inner tube, but in operation it will rotate to a certain extent, because of friction, as it receives the core.

4. Mud Barrels:

Mud drilling is a technique developed over the last 45 years by rotary drillers, but not until around 1946 was it applied to diamond drilling for mineral prospecting.

Principal design requirement of a mud barrel, compared with standard diamond-drilling barrels, is that it have greater clearance for mud circulation.

The first mud barrel manufactured by Mineral Drillers Ltd. was the NM double tube, in which the inner tube was rigid. It was supplied to contractors for the West Australian Government, but little information could be obtained on its performance. It is understood that the present contractors, McCallum Bros., & Grigg, are using this barrel, and Mr. E. E. Brisbane stated that, they were maintaining an average
Fig. 23-A Stationary-inner-tube Barrel

1. Sub (N Rod Box)  
2. Guide Ring  
3. Outer Tube Cap  
4. Outer tube  
5. Reaming Shell Blank  
6. Spindle  
7. Thimble  
8. Ball Bearing  
9. Lock Nut  
10. Lock Washer  
11. Ball Bearing Retainer  
12. Garlock Klosure  
13. Inner Tube Cap  
14. Protective Cover  
15. Inner Tube  
16. Inner Tube Shoe
of 80 per cent core recovery."

The Mineral Drillers Ltd. re-designed this barrel to incorporate an inner-tube extension, which brought the inner tube within half an inch of the cutting face, and right up to the inside clearance stones in the bit. With the bottom discharge bit and corresponding reamer shell, washing of the core was eliminated. Contractors had core recoveries up to 99 per cent (23) with this improved barrel and bit.

Recently it was pointed out that the inner tube in this barrel has a tendency to unscrew, and, if this happened, it locked up against the shoulder of the core bit, virtually making it a rotating inner tube. Consequently, the barrel has been redesigned to give a left hand assembly on the inner tube, both at the top end, where it screws on to the water end, as well as the bottom, where the inner tube extension screws on. In all other respects, this barrel, and bits and shells are interchangeable.

This special barrel is especially valuable in broken formations or when coring soft materials.

6. Casing Barrel:

After a hole has been drilled and it becomes necessary to ream to the next size of casing, a casing barrel is used behind the reamer and pilot, assisting in maintaining a straight hole and reducing vibration.

7. Blast-hole Barrel:

The term blast-hole barrel is a misnomer. Actually it is an adapter from the reaming shell to the rod line. If used, it is most important that the outer diameter be up to the size of the rod line, to assist in eliminating vibration. In many cases, Mineral Drillers Ltd. has discontinued using this barrel by cutting a male coupling

23. Ibid. p. 136.
thread on the back end of the reamer shell.

8. Duffield Barrel:

So that the core may have an uninterrupted passage into the inner tube, the core lifter in the Duffield barrel is located on the outside of the inner tube. It is expanded and slipped over the lower end of the inner tube, and does not come into operation until required.

The barrel functions as follows: Immediately when the inner tube is filled or the core becomes jammed by wedging, or by any obstruction, the inner tube stops revolving. It is held stationary by the core, and the outer barrel containing the valve mechanism continues to travel downward, thus closing the valve and cutting off the water supply. The inner tube, thus being pushed up, is drawn out of the core lifter, where it is retained in the reaming shell, allowing the spring to snap on to the core and take a grip. The spring-loaded inner tube then rests on the top of the core lifter and forces it onto the taper of the bit, insuring a firm hold on the core.

A sudden increase of water pressure, shown by the gauge, indicates to the runner that the core lifter has been pulled off the end of the inner tube. This is the signal that drilling must be discontinued and the barrel withdrawn from the hole.

In order to wash the hole clear of sediments before pulling the rods, the barrel is raised slightly, so releasing the valve and allowing the water to circulate again.

This barrel should eliminate the possibility of grinding core, as it possibly gives a more positive indication of a block than do standard barrels.
Diamond Bits

The section Diamond bits will be broken down into four main parts, the diamond, the bits, oriented diamond bits, and the care of the drill bits and shells.

1. Diamonds:

The diamond is the key to dependable and economical drilling so this element of a diamond bit will be considered first.

Diamonds are of 3 classes: white or slightly tinted crystalline brilliant; less pure crystalline form, known in trade as "bort" or "bortz"; and the opaque, known as "black diamond". The white diamond, and similar but imperfect bort, have cleavages along which they can be split, and when cut they refract light brilliantly. The black diamond is an irregular shaped stone, of granular to compact crystalline structure, with no cleavage.

Only two of the major types of diamonds have been used in the diamond drill bits, originally the black diamond from Brazil, and later the bort diamond from Africa. The black diamond as used in a drilling bit is considerably larger than the bort diamond. Because of its large size, only a small number of black diamonds are used in a bit. The bort diamonds are smaller in size and used in large numbers as shown in figures 25 and 26.

Hardness, see Fig. 23, in its application to diamonds refers to its resistance to abrasion when a pointed fragment of rock or other material is drawn across it. Toughness refers to resistance to vibration or sudden shocks. Black diamonds vary in hardness to a much greater degree than bortz. While all types of diamonds are brittle under shock, black diamonds are tougher in that their resistance to shock is greater than that of gemstones, bortz and congos.
# Peters and Knoop Scale of Hardness

<table>
<thead>
<tr>
<th>Material</th>
<th>Mohs Hardness</th>
<th>Knoop Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum</td>
<td>2</td>
<td>32</td>
</tr>
<tr>
<td>Calcite</td>
<td>3</td>
<td>135</td>
</tr>
<tr>
<td>Quartz</td>
<td>7</td>
<td>710 - 790</td>
</tr>
<tr>
<td>Topaz</td>
<td>8</td>
<td>1250</td>
</tr>
<tr>
<td>Carboloy</td>
<td>9</td>
<td>1050 - 1500</td>
</tr>
<tr>
<td>Silicon Carbides</td>
<td>10</td>
<td>2050 - 2150</td>
</tr>
<tr>
<td>Boron Carbide</td>
<td>10</td>
<td>2250</td>
</tr>
</tbody>
</table>

**Scale**: 1000 - 8000

**Comparison of Hardness**

Based on National Bureau of Standards tests with Knoop Indenter

**Diamonds**

8200 - 8500

**Fig. 23**
The majority of black diamonds are unsuited for drill use in their natural form because of irregular shapes and varying sizes. As the black diamond possesses no planes of cleavage as does its sister stone, the white diamond, it cannot be shaped by the same methods. Being a homogeneous mass of tangled minute crystals, it must be broken into desirable shapes in special machines designed for this purpose.

The ideal shape for drilling is a blocky stone without sharp corners, points or edges. The stones are artificially blunted on special machines, by grinding carbon against carbon, by some suppliers. This treatment also give a fairly accurate index of the hardness and wearing qualities of each stone.

The above mention of the black diamond was made because it was the first type of diamond to be used in diamond drilling on a large scale. Today, however, only a very small percentage of diamond drill footage is drilled with black diamonds, bortz having taken their place. The main reason for discontinuing the use of the black diamond was it great increase in cost, see Fig. 1-A.

In recent years, bortz has almost entirely superseded carbon for diamond drilling. It was found that its extreme hardness, relative cheapness, the multiple cutting edges of the many small stones in a bit, and the use of lighter faster drills gave increased drilling speed and lower drilling costs as compared to the hand-set black diamond bits.

2. Bits:

Three types of bits are considered here: coring, non-coring, and casing. Coring bits are those which produce samples of the material through which they pass. Non-coring bits merely produce holes for various purposes, such as blasting or drainage. Casing bits are used
to introduce casing into a hole or enlarge a hole.

All three types of bits mentioned above comprise mainly three parts: blank, matrix, and cutting medium. The blank is usually made of steel. The matrix is of copper alloy, including beryllium-copper or tungsten and nickel, or of powdered metal alloys which also produce tough settings. The cutting medium is of diamond or diamond substitute. Diamond substitutes have only a limited application, so they will not be considered.

The diamond is the key to dependable and economical drilling. Until recently most of the diamonds were set in the bits by mechanical methods. The setting of diamonds in the bit by orientation will be explained under the heading of oriented diamond bits.

The stones are set in the bits by means of a pouring or a sintering process, when a mechanical setting method is used. Poured bits are manufactured using a molten metal, or matrix, which is poured in such a manner that it joins diamonds to a steel bit blank, the diamonds being located in a predetermined manner on the surface of the bit. Sintered bits are usually formed by combining heat and pressure to a powdered metal in such a manner that diamonds are located in a random fashion throughout the powder, and are termed impregnated bits. The diamonds may also be located on the surface in a predetermined position as in the pouring process.

In the manually set bits, annealed, cold-rolled steel is used for the blank bit and matrix. In the mechanically set bit, various compositions have been tried. Originally a copper-beryllium alloy was employed because the melting temperature is sufficiently low to permit pouring at a relatively low temperature. This method is still used extensively. More recently, harder alloys with slightly higher
melting points have been used with notable success. These later types have produced a matrix or diamond-retaining metal considerably harder than the earlier metals. This harder matrix can withstand abrasion in a drill hole much better than the original softer matrix. In the previously mentioned powdered metal process, combinations including tungsten and nickel as the main ingredients have been used to develop matrices of varying degrees of hardness.

From the brief discussion above, it is evident that there are numerous combinations of materials which may be used in the manufacture of a diamond bit. No one combination of materials or method of manufacture will produce the most dependable and economical results under all drilling conditions.

Early in 1930 the Diamond Core Drill Manufacturers Association of the United States adopted new dimensional standards covering four sizes of bits and casing and more definite specifications for drill rod threads. The purpose of these commercial standards is to produce greater efficiency and to make fittings of different manufacturers interchangeable. All threads on standard bits, casing and rods are tested with gauges.

Table 1-A Standard Bit Sizes, Inches (2h) (After Longyear)

<table>
<thead>
<tr>
<th>Designation</th>
<th>O. D.</th>
<th>Core Diameter</th>
<th>Bit Blank O. D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>EX</td>
<td>1 1/2</td>
<td>7/8</td>
<td>1 7/16</td>
</tr>
<tr>
<td>AX</td>
<td>1 7/8</td>
<td>1 1/8</td>
<td>1 27/32</td>
</tr>
<tr>
<td>BX</td>
<td>2 3/8</td>
<td>1 5/8</td>
<td>2 5/16</td>
</tr>
<tr>
<td>NX</td>
<td>3</td>
<td>2 1/8</td>
<td>2 15/16</td>
</tr>
</tbody>
</table>

A few of the most common diamond bits are illustrated on the following seven pages. (25)

Coring bits:

Face Discharge Coring Bit
4 ports, no waterways, extra hard matrix. Recommended for maximum core recovery in broken and severely abrasive rocks.

Bevel Wall Core Bit
Hard matrix, 25 per carat diamonds, no waterways, approximately 12.5 carats. Used for moderately abrasive rocks, where rock is free cutting, and where maximum diamond concentration is desired.

25. Christensen, Company, "Christensen Diamond Products", Bulletin No. SD-506
Bevel Wall Core Bit
2 waterways, 100 per carat diamonds, regular matrix, maximum diamond exposure. This bit, set with small diamonds, is recommended for non-abrasive formation, when sludge removal is imperative.

Straight Wall Coring Bit
2 waterways, 100 per carat diamonds, about 1.50 carats, regular matrix. This bit is recommended for drilling extremely hard solid igneous and metamorphic rocks in which diamond polishing causes premature retirement of the bit.

Bevel Wall Core Bit
8 waterways, 15 per carat diamonds, hard matrix. This bit gives fast penetration in soft sediments and is especially recommended for sticky shale.

Fig. 25
Core Bit

\[ \text{per carat diamonds, medium price large stones, maximum diamond exposure, hard matrix. This bit is suitable for drilling soft sedimentary rocks where rapid penetration makes removal of sludge an important factor.} \]

This core bit is made expressly for use with low pressure air circulation. The design of the bit permits free flow of air to cool the bit and to remove cuttings.

This bit has been used very successfully, using compressed air or mud, in drilling sandstone and shale. It has 16 waterways, about 60 carats of \( \frac{1}{4} \) per carat size diamonds set in a hard matrix.

This bit is designed for use with air or mud. It has 6 waterways, hard matrix, with approximately \( \frac{1}{3} \) per carat size diamonds.

Fig. 26
Non-coring bits:

Concave Bit

Concave diamond bits are used for purposes of drilling where no core is desired. They can be used profitable for drilling blast holes, drain holes for grouting, and for drilling cement. Illustrated is a EX Concave bit, 10.5 carats, 25 per carat size, one waterhole, one reinforced waterway, regular matrix. This type is usually the fastest cutting non-coring bit. Used in drilling limestone, rhyolite or porphyry.

The Concave bit can be used for exploration drilling through the rock formation until the mineralized zone is reached; from this point on the core bit can be used. Illustrated is a EX Concave bit, 25 per carat size stones, 2 waterholes, no waterways, about 11.0 carats, hard matrix. Bits of this design drill well in dolomite, rhyolite, porphyry, granite and tactite.

Pilot Bits

Pilot bits are especially valuable for drilling straight holes in steeply dipping strata, and in drilling perimeter holes in tunnel enlargements. Illustrated is EX Pilot bit, one waterhole, one waterway, hard matrix, 25 per carat size diamonds, approximately 11.5 carats.
Core Bit

Bits of this type are made to order for recovering concrete cores and for drilling holes in other material when cores are not required. Crowns may be constructed in one piece or may be made with inserts as illustrated. This bit contains 32 one carat each inserts.

Tapered Reamer

This reamer is set with approximately 130 carats of 10 per carat size diamonds. The leading end is threaded to use an AX size concave bit. Tapered reamer are used for reaming long sections of hole.
Casing bits:

Casing Shoes
Casing shoes are used for reaming over stuck tools, for reaming hole and for drilling in casing before reducing size of hole. Casing shoes are set without inside gauge stones in order that bit and reaming shell may pass, thus elimination necessity of removing the casing from the hole. Illustrated is a NX casing shoe, with box thread, no waterways, regular matrix, 25 per carat size diamonds, about 16.0 carats. Both casing bits and casing shoes may be set with regular, hard or extra hard matrices.

Casing Bits
Casing bits are commonly used for collaring holes and for reaming a hole for casing. Since diamonds are set on both the inside and outside gauge, passage of a corresponding size bit or shell is not possible. It is recommended that both casing bits and casing shoes be used without waterways. Illustrated is a NX casing bit, with box thread, regular matrix, 25 per carat diamonds, approximately 20.0 carats.
Reaming shells:

Balanced Type
On the leading edge are bands of abrasion resistant metal to resist the cutting action of sludge. Several rows of diamonds set in the powdered metal matrix at evenly spaced intervals provide the reaming action necessary. Special sizes and tapers are available. Illustrated is a double tube reaming shell, balanced type, for double tube rigid core barrel, with 6.5 carats.

Insert Type
Insert strips contain about 1,50 carats of diamonds each, 15 per carat size, set in extra hard matrix. Illustrated is a reaming shell for double tube rigid core barrel, set with four inserts.

Hard Faced Type
The addition of tungsten carbide grit hard facing or tungsten carbide inserts to the reaming shell blank is available if conditions warrant. This prevents premature retirement of the shell due to excessive erosion on the reamer shell blank. Illustrated is a BX reaming shell, balanced type, with hard facing for the double tube core barrel, with 6.5 carats of diamonds.
3. Oriented diamond bits:

Since the fall of 1949, attention has been given to the practicality of orienting drilling bort in hard-vector directions in drill-bit crowns on a production basis. Some question that savings, as demonstrated through controlled drilling tests, could be realized under actual drilling conditions in the field. Some also contend that orienting diamonds in bit crowns is a process too technical in nature to adapt to quantity setting without exorbitant cost.

The experience of Sprague and Henwood Inc., (27) indicates that orienting diamonds in drill crowns is practical and that diamond drilling costs may be reduced through the use of such bits. These conclusions are based on the experience gained by this company in setting over 1,000 cast and powdered-metal oriented diamond bits which were used by its contract drilling crews. Results covering a portion of these 1,000 bits have been compiled and evaluated. The procedures used in orienting diamonds in the bits were based on a Bureau of Mines publication.

In order to produce the number of bits required for large-scale testing, personnel trained to orient diamonds was needed. Through trial-and-error methods, and after some lapse of time, enough workers were trained who could produce oriented diamond bits in a volume sufficient to extend the scope of the field tests to include a wide cross section of rock types and drilling conditions.

A series of test bits, paired in the same manner as those in the first field test, was manufactured. These bits were sent to the field in 17 separate groups, consisting of 6 to 12 pairs of bits per shipment. Also, 11 extra oriented bits were included in the tests. Dif-

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ferent types and grades of diamonds were used, but the majority were medium-grade drilling bort, ranging in size from 10 to 15 stones per carat.

Both solid and broken formations, ranging in hardness from shales to granitic gneiss, were drilled. Group shipments were made to drill crews in eight localities, one of which was outside of the United States and seven of which were scattered at various places within its boundaries. Some of the bits were subjected to various forms of abusive use, such as drilling over broken core and tramp iron, but the majority were used in a normal manner.

By January 30, 1953, all the 272 bits included in the 17 test groups had been salvaged. A tabulation of the results is shown in Table 1-B.

The oriented bits outperformed the random-set bits in the majority of these tests, but there were some inconsistencies in the performance of individual bits. There were three of the 17 groups in which results failed to conform to the averages shown in Table 1-B.

Table 1-B(28)

<table>
<thead>
<tr>
<th></th>
<th>RANDOM-SET BITS</th>
<th>ORIENTED BITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of bits tested</td>
<td>129</td>
<td>113</td>
</tr>
<tr>
<td>Total feet drilled</td>
<td>2,773</td>
<td>1,381</td>
</tr>
<tr>
<td>Feet drilled per bit</td>
<td>21.5</td>
<td>30.6</td>
</tr>
<tr>
<td>Total diamond loss, carats</td>
<td>354.53</td>
<td>338.08</td>
</tr>
<tr>
<td>Diamond loss per foot drilled, carat</td>
<td>0.012</td>
<td>0.008</td>
</tr>
<tr>
<td>Bit cost per foot drilled</td>
<td>$1.05</td>
<td>$0.66(29)</td>
</tr>
</tbody>
</table>


29. Does not include charge for extra time required to orient diamonds in setting.
The following difficulties are encountered in the manufacturing of the oriented diamond bits.(30)

1. Bit Setters:

Only individuals having certain aptitudes, which must be determined through special tests, can be successfully trained to orient diamonds.

2. Rate of Setting:

When orienting diamonds, even the most highly skilled setter cannot approach the speed of a setter placing diamonds at random orientation in a bit mold.

3. Diamond Size:

Generally speaking, Sprague & Hemwood, Inc., and the Bureau of Mines have confined their efforts to orient diamonds to those sizes larger than 20 per carat. Some diamonds smaller than 20 per carat have been oriented, but only to a limited extent. The size limitation is very important because many drilling programs are conducted in regions where diamonds smaller than 20 per carat are preferred, see Fig. 26-C, 26-D, and 25-B.

4. Resetting Used Diamonds:

Within the size limitation as stated above, trained setters generally can orient a large percentage of the new diamonds, but when the diamond shapes have been greatly altered through wear or the surface features have been obscured by a dark coating, the percentage of stones that the setter can orient successfully is greatly decreased.

5. Diamond Selection and Cost:

It has been found that even with new diamonds not all shapes are oriented readily and that after diamonds have been used this situation is greatly magnified. Therefore, in time, those shapes that are readily orientable will doubtless command a premium price.

30. Ibid. p. 163.
These are a few of the problems connected with orientation that must be solved by the bit manufacturer before the average diamond-bit user can hope to purchase oriented diamond bits at a reasonable price.

1. Use and Care of the Drill Bits and Shells:

In diamond drilling, labor is the principal cost. After labor, in other than very soft rock, yet depending upon the type of rock for its equation, the cost per foot for diamonds exceeds the combined cost per foot for all other materials, including depreciation on the capital items. Consequently, the economical success of the average drilling project will depend very largely upon the use and care of the diamond-set bits and reaming shells.

The selection of the best bit for a given job is a prime consideration in its successful use and care. The character of the ground and rock, through which the bit will pass determines this selection. Soft, loose formations may normally be drilled most economically with larger and less expensive diamonds than those required for hard compact formations. Stones must be located in the bit so that they cover effectively the surface being drilled. The contour of the bit surface must be such that minimum wear, minimum loss of stones, and minimum reduction will be realized. The matrix must be of such a hardness that in the case of the surface-set bit, the wear will be negligible, and in the case of the impregnated bit, the wear will be only sufficient to permit proper exposure of the diamonds.

The use of a diamond bit in a drill hole requires knowledge and skill. Careless drilling practices may result in crooked, inaccurate holes and loss of core. It is essential that a modern drill rig,

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designed to provide adequate speeds of rotation and proper rates of penetration, be applied with correct load. Too rapid penetration at the start of a hole results frequently in drifting as well as excessive wear on the bit. After a hole is started, these same costly results may be obtained, but to a slightly lesser degree. Throughout the drilling operation the proper use of a coolant is important. Usually the coolant is water. If the supply is inadequate, diamonds overheat, and the cuttings remain in the hole and wear the diamonds and matrix unnecessarily. Blocking of the core in the bit results. The core recovery is then less reliable and the drilling much more expensive.

From a cost viewpoint, careful selection of bit and drill rig together with adoption of the best drill practices are all ineffective if bits are not withdrawn for resetting at the proper time. The most rapid penetration of the drill bit is not always the most economical. Nor is the longest possible run with a drill bit always wise. Drilling work is usually performed on a cost-per-foot basis. This practice encourages rapid drilling and maximum use of a drill bit, particularly if long core barrels are used. A driller is reluctant to withdraw a bit in the middle of a run just because the bit appears to be running smooth. On a deep hole, time for this withdrawal and entry of a string of rods frequently exceeds drilling time. However, in order to secure the most dependable results at the lowest cost, all of these factors must be balanced carefully. Labor, time, gasoline consumption, and equipment wear must then be balanced carefully against diamond loss, and resetting charges.

Diamond bits should never be used for drilling through gravel and other loose and unconsolidated material except when using special impregnated bits, or bits set with diamond chips especially for this
purpose.

When preparing to lower the drilling tools into the hole, the operator should be certain that the core barrel is clean and all threads lubricated. The core barrel should be lubricated on the outside over its entire length with a good water-repellent, viscous grease. This will help to reduce vibration destructive to diamonds.

As the tools are lowered near the bottom, the operator should start circulation to wash out the settled cuttings which usually extend up some distance from the bottom.

When drilling through highly abrasive rock, there is a tendency for the metal to wear away from the stones. In these cases when the stones become exposed approximately one third of their size, the bits should be removed and reset. After one third of the bulk of each of the stones extends from the metal, there is danger of further wearing away of the metal to the point where the stones will drop out.

When removing the diamond bit from the core barrel or core shell, great care should be taken to avoid allowing the wrench jaws to contact the diamonds. This is probably the most common abuse to which diamond bits are subjected.

When the diamond-set bits and shells are not in use they should be well oiled over their entire surfaces and packed in a separate box used only for that purpose. Each tool should be protected by waste, rags or other soft packing to prevent damage to the stones.

It should be remembered that the use and care of all diamond drilling bits is dependent upon a careful selection of the properly designed and manufactured bit, skillful and efficient use of a modern drill rig and equipment, and the accurate determination of the bit changing time.
Wire-line Core Barrel

The application of the wire-line principle and core barrel is not new; the petroleum industry developed the basic equipment and the method for its use many years ago, and successfully applied the technique to large-diameter drill holes. When the application of this principle to small-diameter diamond drill holes was first considered, there were two possibilities which were judged important. First, it appeared that the wire-line method, if properly applied, would increase net drilling time, and, second, because of improved hole stabilization, core recovery should be materially improved.

But scaling the practices of core recovery in oil well drilling down to the small BX hole presented a number of problems. The technique, difficult even for large holes, was complicated by the exacting limitations of the small diameter in which durable and foolproof mechanisms would be required to operate. Since the maximum benefits could be realized from this system in holes 1000 feet and deeper or in holes in badly fractured ground, the drill string would have to be able to withstand heavy stresses. Most vital to the success of the idea was the development of a positive latching mechanism to assure proper positioning of the inner tube of the core barrel when the tube is dropped into place. Lastly, little was to be gained from the wire-line method without diamond bits that would give optimum penetration rates and a long service life in the drill hole.

At the end of 1953 these difficulties had been solved, or eliminated, together with others such as dry drilling, angle holes, and incorporation of proved principles for maximum core recovery. The BX-size wire-line core barrel and accessory equipment was made available to all users in January, 1954. (32)

The following information is a brief description of the operation of the wire-line core barrel. When the core has filled the inner tube of the barrel, or when a core "block" develops, drilling is stopped and the drill string raised slightly so that the top joint is in a convenient position for "breaking". The hole is flushed, and the top drill rod removed. The overshot assembly is then lowered on the wire line through the drill rods. The lifting dogs of overshot assembly hook on to the spear head of the inner tube assembly. By pulling up the wire line, the latches that lock the inner tube assembly in position retract, and the core-retaining inner tube may be pulled out of the hole through the drill string which remains in the hole.

As soon as the inner tube assembly is out of the hole, a second standby assembly can be dropped through the drill rods if the hole is full of fluid. Coring can be resumed immediately while the loaded inner tube is cleared of core and serviced.

If the drill hole is dry the fast descent would act destructively on the equipment. In dry holes, therefore, the inner tube assembly is lowered with the overshot on the wire line at a rate of about 300 fpm. The rate of descent of the inner tube in water-filled vertical hole is about 200 fpm.

In tight vertical holes over 700 ft deep, the inner tube is pumped into drilling position. Sufficient time is available to re-establish circulation from the moment the inner tube is released until it reaches the core barrel. The drill operator can determine when the tube is in position either by a sharp increase in the pump pressure, if the circulating pump is in closed circuit with the face of the bit or by the shock produced in the drill string when the inner tube makes contact with landing shoulder of the outer tube.

In angle holes up to 30 degrees from the horizontal, the inner
tube is easily pump or lowered into coring position. The rate of
descent is increased by rotation of the rods and the fluid pumped
into the string.

An optional feature of the Longyear wire line core barrel is a
simple water shut-off valve that immediately alerts the driller to a
core block. It consists of rubber washer that is squeezed by the
core block, thereby filling the annular space between outer and inner
tubes. This causes the pump pressure to jump and the driller knows
he has a core block. Simple but effective, the shut-off valve helps
increase core recovery, lower diamond losses and reduced wear on the
inner tube assembly. With the water shut-off device, a closed pump-
ing circuit must be used.

The time saved in wire line operations was clearly revealed in
figures presented by V. N. Burnhart, assistant general manager for
Longyear,(33) at the February 1955 meeting of the AIME. Although
coring 10 ft in a 1500-ft deep drill hole took 60 minutes with wire-
line equipment, as compared to 90 minutes with conventional tools,
total elapsed time from pulling core to resumption of drilling was
21 1/2 minutes for the wire line, against 105 minutes with conven-
tional tools. In other words, wire line drilling and "round trip"
cycle was 81 1/2 minutes compared to 115 minutes for conventional
equipment.

Advantages of the wire line core barrel start with the speed of
resuming drilling. On top of this the wire line obviously means
easier work on the rig floor. For instance, only one round trip for
the drill rods may be required for 100 ft of coring at 10 ft inter-
vals with wire line, as opposed to 10 round trips with conventional

33. Ibid., p. 550
Because the drill rods aren't traveling in and out of the hole every time a core is pulled there's less chance of battering pieces of rock from weak beds causing cave. Furthermore, since the bit remains near the bottom of the hole, the problem of drilling through caved material is virtually eliminated.

Perhaps the greatest advantage of wire line equipment is a result of all these things. Because removing core is so quick and easy, and because he doesn't have to worry about caves that may occur if the drill rod is removed, the driller finds himself in a position to concentrate on good drilling technique without compromising with the expedient. For instance, he will pull the core in a bad spot, rather than grind it as might be the temptation with orthodox core drilling.

In the U. S. the BX wire-line equipment has been successfully applied to formations widely varying in physical characteristics. These include conditions encountered with coring in the Southwest copper districts, Midwest sediments containing gypsum and fluor-spar deposits, and Lake Superior Pre-Cambrian rocks with iron and nickel ores. Both sedimentary and crystalline rocks of the Appalachian and the western altered volcanic rocks containing precious metals have been drilled with wire-line methods. Angle and vertical holes have been completed to depths of 300 to 4000 ft.

As of December 1951, some 75,000 ft of hole had been cored with the BX wire-line core barrel, producing and average measured core recovery of 94.01 pct.

Now to discuss the conditions where the use of the wire-line is not economical.

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34. Ibid.
Bit life and hole depth are the keys to application. Since the drill rod must come out of the hole when the bit is changed, there would be no advantage if bit life is just about that of the core barrel.

In ideal coring ground Longyear engineers state that operating cost for the wire-line and conventional equipment are about comparable to 500 ft. From there down, advantage grow for wire-line with probable 15 to 20% lower costs in a 3,000-ft hole.

In difficult coring ground costs may be identical but recovery is much better with wire-line.

Evidence compiled during the short time this new drilling tool has been available, see Table 1, show that this basic advantage is pyramided into faster and better drilling, better core recovery and lower cost. Its performance certainly classifies the wire line core barrel as one of the greatest advances in exploratory drilling in 50 years.
Experience of Four Mining Companies with Wire Line Equipment (35)

<table>
<thead>
<tr>
<th>Questionaire</th>
<th>Company &quot;A&quot;</th>
<th>Company &quot;B&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Depth of hole.</td>
<td>4,652 ft of which lower 2,486 ft, from 2,166 ft, was drilled with wire line.</td>
<td>No. 1-818 ft; No. 2-919 ft.</td>
</tr>
<tr>
<td>3. Drilling speed.</td>
<td>30 ft per shift including core pulling and bit changing.</td>
<td>No. 1-12 ft per shift; No. 2-20 ft per shift;</td>
</tr>
<tr>
<td>4. Percent core recovery.</td>
<td>In excess of 87%.</td>
<td>No. 1-74%; No. 2-94%;</td>
</tr>
<tr>
<td>5. How does this recovery compare with that of conventional barrels?</td>
<td>Favorably. Core recovery is maintained consistent with conventional core barrels.</td>
<td>Considerably higher.</td>
</tr>
<tr>
<td>6. Size of bits used.</td>
<td>OD BX yielding AX size core approximately.</td>
<td>BX wire line (2 3/8 in hole; 1 1/16 in. core)</td>
</tr>
<tr>
<td>7. What advantages have you experienced with wire line equipment?</td>
<td>Advantages inherent when faster core pulling is involved. A previous hole of similar nature took twice as long to drill using conventional methods, and so it seems conservative to estimate that at least 50 shifts were saved.</td>
<td>Much faster beyond depth of 300 ft and better core recovery.</td>
</tr>
<tr>
<td>8. How do wire line drilling costs compare with conventional diamond drill equipment?</td>
<td>Due to unusually hard rock in upper part of the hole and consequent renegotiation of contract, no rebates on the original figures were possible, but in the future it is expected that important cost reductions will be gained.</td>
<td>50% cheaper below 500 ft (estimated).</td>
</tr>
</tbody>
</table>

Table 1

TABLE 1 Con't

<table>
<thead>
<tr>
<th>Questionaire</th>
<th>Company &quot;C&quot;</th>
<th>Company &quot;D&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Type of rock drilling.</td>
<td>Mainly soft bentonitic sandstones and mudstones.</td>
<td>Latites and andesites.</td>
</tr>
<tr>
<td>2. Depth of hole.</td>
<td>Vary from 200 ft to 500 ft.</td>
<td>2,490 ft. wire line used from 1,367 ft to bottom.</td>
</tr>
<tr>
<td>3. Drilling speed.</td>
<td>Over-all contract</td>
<td>1,123 of hole 65 days (1/1 shift).</td>
</tr>
<tr>
<td></td>
<td>average 89 ft per shift with individual drillers averaging 80 ft.</td>
<td></td>
</tr>
<tr>
<td>4. Percent core recovery.</td>
<td>81% over a three month period.</td>
<td>About 97%.</td>
</tr>
<tr>
<td>5. How does this recovery compare with that of conventional barrel?</td>
<td>An increase of approximately 7%.</td>
<td>Drilling down to 1,367 ft gave about 75% recovery with conventional rig.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Might have been 65% below 1,367 with conventional rig.</td>
</tr>
<tr>
<td>6. Size of bit used.</td>
<td>NX</td>
<td>BX (EX hole with AX core resulting).</td>
</tr>
<tr>
<td>7. What advantages have you experienced with wire line equipment?</td>
<td>Greater drilling speeds have reduced our overhead per foot and saved recovery.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>casing costs as the hole oftentimes is completed before serious wall caving is encountered.</td>
<td></td>
</tr>
<tr>
<td>8. How do wire line drilling costs compare with conventional diamond drill equipment?</td>
<td>Wire line equipment has approximately doubled our diamond drill footage resulting in a substantial reduction in our overhead costs per foot.</td>
<td>About the same for one hole we drilled. No saving. Inexperience of the drillers with wire line equipment caused serious delays that boosted costs. More experience would eliminate these problems.</td>
</tr>
</tbody>
</table>
1. Acker Drill Co.
   725 West Lackawanna Ave.
   Scranton 3, Pa.

2. American Coldset Corp.
   87-89 Court St.
   Paterson, N. J.

3. Chicago Pneumatic Tool Co.
   6 East 44th St.
   New York 17, N. Y.

4. Christensen Diamond Products Co
   1937 South 2nd West St.
   Salt Lake City 10, Utah

5. Consolidated Diamond Drill Corp.
   Ltd.
   33 Melinda St.
   Toronto, Ontario, Canada

   244 Madison Ave.
   New York 16, N. Y.

7. Diamond Drill Contracting Co.
   South 18 Stone St.
   Spokane 15, Wash.

8. Diamond Products, Inc.
   336 Prospect Ave.
   Elyria, Ohio

   2006 S. Industrial
   Dallas, Texas

10. Failing Co., George E.
    Enid, Okla.

11. Halvick, J.J.
    112 S. Cedar St.
    Spokane, Wash.

    Co.
    P.O. Box 426
    Punxsutawney, Pa.

13. Houston Tool Co., Inc.
    P.O. Box 251
    Santa Susana, Calif.

    Henry W. Oliver Bldg.
    Pittsburg 22, Pa.

15. Kennametal Inc.
    Latrobe, Pa.

    9456 Grinnel
    Detroit 13, Mich.

17. Longyear Co., J.E.
    1700 Foshay Tower
    Minneapolis 2, Minn.

    P.O. Box 7726
    Dallas, Texas

19. Mc Clintock Co., R.S.
    W. 418 Second Ave.
    Spokane, Wash.

20. Metal Carbides Corp.
    107 E. Indiana Ave.
    Youngstown '7, Ohio

21. Mott Core Drilling Co.
    830 Eighth Ave.
    Huntington 17, W. Va.

22. Pennsylvania Drilling Co.
    1201 Chartiers Ave.
    Pittsburg 20, Pa.

23. Reed Roller Bit Co.
    Box 2119
    Houston 1 Texas

24. Salem Tool Co.
    Salem, Ohio.

25. Smit & co., Anton  
   111 Eighth Ave.  
   New York 11, N. Y.

27. Sprague & Henwood, Inc.  
   221 West Olive St.  
   Scranton, Pa.

29. Star drill-Keystone Co.  
   920 17th St.  
   Beaver Falls, Pa.

   Box 13146  
   Dallas, Texas

33. Westinghouse Air Brake Co.  
   Cleveland Rock Drill Plant,  
   Le Roi Div.  
   12500 Berea Rd.  
   Cleveland 11, Ohio

   Murray Hill, N. J.

28. Star Expansion  
   142 Liberty St.  
   New York 6, N. Y.

30. Snyder Mine & Chemical Lab.  
   Box 212  
   Richmond, Ore.

32. Westinghouse Air Brake Co.  
   3 Gateway Centre  
   Pittsburg 22, Pa.

34. Wheel Trueing Tool Co.  
   3200 W. Davidson Ave.  
   Detroit 38, Mich.
DIAMOND CORE VS CHURN DRILLING IN EXPLORATION

Now we shall examine a few cases where both churn drilling and diamond core drilling were used and list the advantages and disadvantages of each type of drilling. (37)

In the cement region of the Lehigh Valley, a difference of 2 to 3 pct in CaO_3 can make or break a new quarry development, and experience of the Dragon Cement Co. has shown that values of calcium carbonate, as reported from churn drill samples, have been increased as much as 6 pct on the average when the same area was diamond drilled. This calcium carbonate increase consequently lowered the values for silica, iron, and alumina and made these sections much more attractive.

From 1926 to 1950 an extensive churn drilling program was carried out by the Lawrence Portland Cement Co., now the Cement Co., Inc. In 1950, an accurate compilation of all churn drill data available since 1926 was begun in an attempt to evaluate the company's overall holdings. Much difficulty was encountered when subsurface sections were drawn, for it was impossible to correlate one churn drill hole with another drilled 50 ft away. This type of problem also existed with the other local cement plants. But it must be remembered that churn drilling was done, not to provide geologic correlation, but to provide indication of the chemical content of the stone that would some day be quarried. Some diamond drilling was done, but the cost and general operation at the time were not considered satisfactory.

Prior to the 1930's geologist were practically unheard of in cement plant operations, and the work of interpreting churn drill sample was left to men who were better trained in other fields and had no

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working knowledge of geology. Now the picture has changed within the last few years. Reserves have become low in many localities and intensified exploration, under the guidance of trained geologist and geological engineers, has been undertaken.

The type of drilling rig used is similar to the one in figure 1. The overburden, ranging to 50 feet in thickness is penetrated with an MX size diamond bit attached to a 2-ft core barrel. This same bit cores approximately 1 ft into the rock, and the tools are withdrawn. Casing pipe is inserted into the hole and a 15-ft BX core barrel and bit inserted within the casing and drilling started. Water pressure supplied to the bit is controlled at 125 psi and 50 gpm, for BX bits, but varies with other sizes used. Fifteen lengths of core are drilled and then brought to the surface and placed in core boxes in correct orientation. When drill cutting are taken, a special screen is attached to the top of the casing pipe and the collected cutting stored with the appropriate core intervals. If trouble is encountered in BX size drilling the size may be reduced to AX size.

In churn drilling a 6-in OD bit was used by the Dragon Cement Co. Overburden was drilled to the rock surface and a section of casing pipe inserted. The hole was then drilled through this casing. Samples were taken by a sample bail at footage intervals.

After reviewing the 1973 churn drill logs and being unable to accurately evaluate the area, the company-owned property at Myers-town, Pa., immediately east of Lebanon was diamond drilled in the spring of 1950. This drilling was done in the Annville limestone in sections that were previously explored with churn drills. These diamond core holes were drilled within a 2-ft radius of the churn drill hole. Fourteen churn drill holes were thus checked, and a
Partial tabulation of the check results obtained is shown in the following table.

<table>
<thead>
<tr>
<th>Sample Interval</th>
<th>Churn Drill Holes</th>
<th>Diamond Drill Holes</th>
</tr>
</thead>
<tbody>
<tr>
<td>59 to 69ft</td>
<td>93.78% CaO₂</td>
<td>95.63% CaO₂</td>
</tr>
<tr>
<td>69 to 79ft</td>
<td>93.10% CaO₂</td>
<td>95.55% CaO₂</td>
</tr>
<tr>
<td>79 to 89ft</td>
<td>A-11</td>
<td>95.6% CaO₂</td>
</tr>
<tr>
<td>5 to 75ft</td>
<td>94.17% CaO₂</td>
<td>95.74% CaO₂</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>50-33</td>
</tr>
<tr>
<td>0 to 50ft</td>
<td>95.62% CaO₂</td>
<td>96.10% CaO₂</td>
</tr>
<tr>
<td>5 to 65ft</td>
<td>82.82% CaO₂</td>
<td>96.11% CaO₂</td>
</tr>
</tbody>
</table>

Table 2

Diamond drilling raised the grade of the limestone considerably, but, with the exception of the last comparison, the indication are that limestone is present. So why dispute a few percentage points difference? Many of the Lehigh Valley cement plants import limestone to raise the CaO₂ content of their raw mixes, and many of these plants specify a stone that must have in excess of 95% CaO₂. This illustrates that it is possible to drill and sample an area with churn drills, and after interpreting the results, to misclassify the area as unusable because the grade is less than 95% CaO₂. The comparison of the log for the hole number B-18 shows an important point. At 60 feet in the diamond drill hole a clay seam, 3 inches thick, was encountered. Hole size was reduced to 10x, casing off the part of the hole already drilled, and drilling a smaller diameter core. The hole was carried to completion after this change. The analyses of the churn drill samples, which were thoroughly washed prior to analysis, show a definite contamination from clay washing into the hole or catching in the sampling bail during raising and lowering.

Other chemical compounds than CaO₂ enter into this comparison

38. Ibid., p. 1179.
of the two drilling methods. For cement manufacturing purpose, silica (SiO₂), iron oxide (Fe₂O₃), and alumina (Al₂O₃) are also important. In the churn drill and diamond drill sample analyses, these compounds were reported, and additional comparative data made available. The table below illustrates some of these comparisons.

<table>
<thead>
<tr>
<th>Sample Interval</th>
<th>Churn Drill Holes</th>
<th>Diamond Drill Holes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fe₂O₃</td>
<td>Al₂O₃</td>
</tr>
<tr>
<td>9 to 99 ft</td>
<td>0.61</td>
<td>0.82</td>
</tr>
<tr>
<td>5 to 75 ft</td>
<td>0.61</td>
<td>0.92</td>
</tr>
<tr>
<td>0 to 50 ft</td>
<td>1.00</td>
<td>0.70</td>
</tr>
<tr>
<td>5 to 65 ft</td>
<td>2.00</td>
<td>3.21</td>
</tr>
</tbody>
</table>

Table 3

Note that all analyses for silica, iron oxide, and alumina in the diamond drill holes are lower than those for churn drill holes. It is believed that this is a result of the ability to seal off a diamond drill hole with casing, where clay seams encountered in churn drilling cannot be sealed off. In churn drilling, after the overburden has been drilled, a section of casing pipe is inserted into the hole and driven down as far as possible, but usually not into the rock. In diamond drilling, the overburden is drilled and the rock penetrated and cored for approximately a foot. After drilling the tools are withdrawn from the hole and casing is driven tightly into the rock, providing an almost perfect seal against clay infiltration. The inability to seal this contact point in churn drill holes allows occasional clay to enter, thus contaminating the sample and giving the higher silica, iron and alumina values and the consequent lower calcium carbonates values. Even excessive washing to the churn drill

39. Ibid., p. 1179.
bail samples fail to remove all contamination.

A subsurface clay seam will contaminate a sample and provide false results. With proper casing in diamond drilling, contamination is virtually eliminated.

The diamond drill is a far better tool than churn drill for exploration in that it is easily maneuvered (one hour elapsed in time after finishing a 300-ft hole, withdrawing tools, moving drill, platform and equipment, laying water line, and starting a new hole), 2. a hole can be drilled at any angle into the ground, and 3. with the proper machine, holes can be drilled to much greater depths than with churn drills.

One disadvantage of diamond drilling is that large amounts of water must be used as coolant for the bits. The most outstanding feature of diamond drilling, of course, is that an actual section of the rock is observed at the surface. The first churn drill hole checked at Northampton showed 21 ft of clay, then solid rock. Actually, there was only 11 ft of clay present, plus a weathered zone of cement rock that was not noted or sampled with the churn drill. The weathered zone was cored with the diamond drill by using special double tube, swivel-type core barrels where the inner tube remains relatively stationary.

In churn drilling, it is very difficult to make a clean break between sample intervals, since even under the strictest supervision the sampling bail does not collect the entire sample. As a result, the next sample taken has a carryover of material from the previous drilled interval.

Churn drilling can be done for less than diamond drilling, but

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Section through completed drill holes compares churn and diamond drilling. In the later, NX size is first drilled 1 ft into rock, then 2 7/8-in. casing is inserted and driven, BX size is drilled to clay seam, and finally seam is cased with 2 1/4-in. pipe and hole completed AX size. Contamination of diamond drill samples form overburden or clay seams is impossible, and drill core accurately reveals exact thickness of clay or other unwanted material. With churn drilling, analyses and plotting of data on limestone was undependable.
the cost differential is offset by the type of information gained. Northampton drilling costs averaged less than $1.75 (h1) per ft of core drilled, including all sizes.

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**Diamond Drilling Costs (h2)**

Average drilling costs at Northampton for one month, two units operating:

1. Labor, 4 men $1,311.83
2. Supplies and rig moving with bulldozer $91.18
3. Amortization of drill rigs 641.11

**TOTAL COST** $2,064.12

4. Total feet drilled - 22 days 1,474.00 ft
5. Total cost divided by Item 4 $1.658 average cost per ft.

*An amortized cost per ft for both rigs over 20,000 ft of drilling.
**Includes 178 ft of NX drilling through overburden and into rock.

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**Table 4**

It is shown in this particular instance that only diamond drilling could provide satisfactory answers. In the case of the Dragon Cement Co., the conditions were ideal for diamond drilling. If the company had been seeking indications, churn drilling would have been satisfactory, but in seeking accuracy of analyses in addition to indication, only diamond drilling would suffice.

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h1. Ibid., p. 1180
h4. Ibid.
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Bibliography


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33. Longyear, E.J., Company, "Core Barrels," Bulletin No. 200, Section II.
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39. Sprague and Hemwood, "Oriented Diamond Bits," **Bulletin No. 320-1.**

40. Stanco, "Diamond Drill," **Bulletin.**


