Drilling and Drilling Trends in the United States for Mining

Sidney D. Cooper

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Drilling and Drilling Trends in the United States for Mining

by
Sidney D. Cooper

May 13, 1955
Montana School of Mines
Mining 68
Second Semester 1955
Mine Practice

Report
Submitted to
Professor K. S. Stout

Drilling and Drilling Trends in the United States for Mining

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Sidney D. Cooper

May 13, 1955
Montana School of Mines
ACKNOWLEDGMENTS

I wish to express my appreciation for the help, encouragement, and generous assistance of many individuals and companies in the preparation of this thesis.

The author is especially grateful to Prof. K. S. Stout for his painstaking efforts and guidance; also to Robert L. Olund of Ingersoll-Rand, R. S. Gibson of Gardner-Denver Co., and R. L. Benjamin of Joy Manufacturing Co. from the local offices of the respective companies for photographs included in this report and many hard-to-get costs, which should be a part of a report of this nature. Robert L. Sandvig has given many helpful suggestions from his experience with the research department of the Anaconda Copper Mining Company.
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Carboloy
Central Mine Equipment Co.
Chicago Pneumatic Tool Co.
Christensen Diamond Products
Cleveland Rock Drill Division
Copco Pacific, Ltd.
Diamond Core Drill Mfg. Ass.
Four Wheel Drive Auto Co.
Gardner-Denver Company
C. K. Hillman Company
Hossfeld Manufacturing Co.
Ingersoll-Rand
Jeffrey Manufacturing Co.
Johnson Co.
Joy Manufacturing Co.
Leestonia Tool Co.
Liddicoat
Linde Air Products

Longyear, E. J., Co.
Loomis Machine Co.
Mobile Drilling Co.
Pennsylvania Drill Co.
Raytheon Mfg. Co.
Salem Tool Co.
Sanderson-Cyclone Drill Co.
Sanford-Day Iron Works
Seismograph Service Corp.
Sprague and Henwood Inc.
Stanco Mfg & Sales, Inc.
Stardrill-Keystone Co.
Sullivan Machinery Co.
Syntron Company
Tammerfors Mekaniski Verkstad
Thor Mfg. Co.
Timken Roller Bearing Co.
Varel Mfg. Co.
Vascoloy-Ramet Corp.
Warsop Power Tools Ltd.
The Winter-Weiss Co.
INTRODUCTION

This thesis, which is a requirement for a degree in Mining Engineering, emphasizes many current drills and drilling trends; however, without a complete discussion of the numerous factors that effect drills and drilling the reader would still be at a loss in selecting a drill to fit his particular need.

With this purpose in mind, I have first attempted to discuss the many variables which must be considered and this is followed by the various types of drilling and drills.

A supplementary book, containing all data received by the author in connection with this report from the numerous companies involved, will be placed in the Mining Department of the Montana School of Mines for those interested in further details on particular items and equipment. Costs are included in the report, however, many costs were unobtainable.

I would like to note here that there are many instances throughout this report where certain types of drills and other subject matter fall into a wrong category. In many cases this material was found in the literature and comparisons were made of one type of drill with another so that the unity of such a feature was not broken.

In the form letters that I sent out to the various companies for information, I emphasized clearly that, besides the statistics on their equipment, I was particularly
interested in cost and comparative drilling speeds. These two items are very hard to secure for obvious reasons.

As far as the costs are concerned many companies do not wish to give them because they change from time to time and from one locality to another. However, the local distributors were excellent on this score. Anyone interested in costs of drilling equipment should contact the companies nearest his specific location.

The same difficulty was encountered in obtaining comparative drilling speeds. The obvious reason for this is quickly realized when one stops to think that no two rocks of the same composition will have the same hardness. There have been many attempts to classify rock and mineral hardness, but a complete classification of all the rocks in the world or even in the mining districts of the United States would take more years than would be practical. Much testing has been done by drill manufacturing companies, but to sell bits, steel, and drills on the results of their tests would generally prove unsatisfactory.

Many mining companies make tests of this nature to determine future needs of one product over another, and much of this information can be found in the current literature.
THE VARIABLES THAT EFFECT DRILLING

In the field of drilling today there are numerous types of drills. Fortunately these different types of drill have specific application. It is to the efficient use of these drills and supplementary equipment that a great deal of research has been done in recent years.

J. D. Jorrester has this to say in connection with the selection of percussion drilling machines. "When speaking of drills it is insufficient to speak of the drills alone. To them must be added the complete drilling unit. The drilling unit used in mine and quarries is made up of three basic components, the machine, the rod, and the bit. Each of these components is made for a specific function, but when put together must operate as a unit with one purpose, to drill holes quickly and economically."

The variables that effect drilling are listed below.

Compressed Air

Compressed air is almost an indispensable feature of any mining operation. Besides the many uses in mining, we are mainly interested in this report in the use of compressed air as the force necessary to operate pneumatic drills and accessory equipment.

The over-all efficiency of compressor-to-drill is not as high as say an electric drill, but the inherent advan-
tages of the rock drills far out weigh any comparison on this basis.

One cause of decreased efficiency with compressed air is the loss due to friction and leaks in long pipe lines. The cost of compressed air comes high, but it's utility is a compensating factor.

Recent trends to reduce this large loss have been to mount air compressors on or near the point of application which gives increased air pressure at a lower cost, but in many mines this is not always possible and one centrally located compressor plant is by far the cheaper than many smaller dispersed units. In the field of surface exploration and prospecting this trend has greatly surpassed that in development and mining. Many self contained mobil drilling units has materially cut costs with increased efficiency of compressed air.

On the following page is a table\(^1\) which relates the number of machines run by different size compressors at various pressures.

"The use of portable compressors supplying hot compressed air directly to rock drills increases the number of feet drilled per shift by 15 to 25%, as compared with the use of cooled air from remote stationary unit."\(^2\) This practice has been used at the Kiruna iron mines in Sweden because of severe climate conditions that prevail. The hot

\(^1\) Refer to bibliography at the end of this report.
The number of tools that can be operated from the various sizes of compressors are listed below in the table.

<table>
<thead>
<tr>
<th>Compressor capacity, cu ft/min</th>
<th>Air pressure, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>60   80  105  160  210  315  365  420  500</td>
<td>70  90  90  90  90  90  90  90  90</td>
</tr>
</tbody>
</table>

**Rock Drills:**

- **Very light, wet or dry**
  - Lightweight: 1 1 2 1 2 2 4 3 5 3 7 5 8 6 10 7 13 9
  - Very light, blower style: 1 1 1 1 1 3 2 4 3 6 5 7 6 8 6 11 8
  - Light, wet or dry: 1 1 1 2 1 3 2 4 3 6 4 7 5 8 6 11 8
  - Light blower style: 1 1 2 1 3 2 5 3 6 4 7 5 8 6 9 6
  - Medium, wet or dry: 1 1 1 2 1 3 2 5 3 6 4 7 5 9 6
  - Medium, blower style: 1 1 1 2 1 4 3 6 4 7 5 8 6 11 8
  - Heavy blower: 2 1 3 2 4 3 4 3 5 4

**Wagon Drills:**

- **Lightweight**
  - Lightweight: 1 1 2 1 3 2 3 2 4 3 5 4
  - Medium drifter: 1 1 1 2 2 2 2 2 2
  - Heavy drill: 1 1 1 1 2 2 2 2
  - Grinder for detachable rock-drill bits: 1 1 1 2 1 2 2 4 3 *

* Compressor capacity more than needed for usual number of tools.
Air enters the machines around 165°F and is believed to improve the lubrication. "The volume of the air required for drilling is smaller, and this means that the capacity of the compressor can be reduced accordingly."²

If in any mine where this portable feature could be maintained to the fullest extent, hot compressed air portably mounted is well worth investigation.

With the current trend of lighter and smaller machines, in many instances, the effect on compressed air is that less air is used and a greater saving is realized.

**Bits**

As J. D. Forrester has previously indicated, bits are one of the basic components of the drilling unit.

Prior to A. L. Hawkesworth's invention of the detachable bit in the 20's, drill bits forged integral with the rod have been the standard for many years.³ With the advent of tungsten carbide and alloy steel, Swedish drilling practice, and more recently in the rest of the world, this use has come back more that the intermittent years from the 20's to the present. Tungsten carbide has also proved very successful in the detachable bits with alloy rods, thus eliminating the handling of tremendous amounts of steel for sharpening.

Generally, the shape and design of the bits used for percussion drilling has four points (cross bit), and more
recently the chisel type bit; however, there are many variations to these on the market. The water holes in the bit are either through the center or side or both.

The prices of various sizes of steel and carbide bits are listed on the following pages. The KC bit has been used frequently in the Colorado Plateau and the Columbia River projects.

A popular steel bit used in Butte, Montana, is the Liddicoat bit; often called a knock-off bit, and it is manufactured by the Western Rock Bit Company. The bit slips on the steel with no threads and a knock-off block is required for removal of the bit.

It will be noted the prices of similar bits from different companies are very nearly the same. The price of Liddicoat steel bit is much cheaper because no thread machining is required.

The Stanco Mfgs. and Sales Company has listed bit prices for their gasoline percussion drill, which can be found in the supplementary volume on file at the Montana School of Mines.

The churn drill bit design is generally of the chisel shape with many variations from this. Large grooves perpendicular to the chisel allow for water and mud ways. Water is admitted usually to the bottom of the holes by the bailer.
## Ingersoll-Rand Carset Jackbits

<table>
<thead>
<tr>
<th>Thread Symbol</th>
<th>Bit Size</th>
<th>Price-up to 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Series 113</td>
<td>1 1/4&quot;</td>
<td>$12.25</td>
</tr>
<tr>
<td>Series 113</td>
<td>1 3/8&quot;</td>
<td>12.85</td>
</tr>
<tr>
<td>Series 113</td>
<td>1 1/2&quot;</td>
<td>14.70</td>
</tr>
<tr>
<td>Chisel</td>
<td>1 3/8&quot;</td>
<td>12.00</td>
</tr>
<tr>
<td>Series 115</td>
<td>1 1/2&quot;</td>
<td>14.70</td>
</tr>
<tr>
<td>Series 115</td>
<td>1 5/8&quot;</td>
<td>15.90</td>
</tr>
<tr>
<td>or Series 116H</td>
<td>1 3/4&quot;</td>
<td>16.55</td>
</tr>
<tr>
<td></td>
<td>1 7/8&quot;</td>
<td>17.10</td>
</tr>
<tr>
<td></td>
<td>2&quot;</td>
<td>18.70</td>
</tr>
<tr>
<td>Series 119D</td>
<td>1 7/8&quot;</td>
<td>17.10</td>
</tr>
<tr>
<td></td>
<td>2&quot;</td>
<td>18.70</td>
</tr>
<tr>
<td></td>
<td>2 1/8&quot;</td>
<td>22.45</td>
</tr>
<tr>
<td></td>
<td>2 1/4&quot;</td>
<td>24.95</td>
</tr>
<tr>
<td></td>
<td>2 3/8&quot;</td>
<td>27.95</td>
</tr>
<tr>
<td></td>
<td>2 1/2&quot;</td>
<td>30.45</td>
</tr>
<tr>
<td>Series 121</td>
<td>2 1/4&quot;</td>
<td>24.95</td>
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<tr>
<td></td>
<td>2 3/8&quot;</td>
<td>27.95</td>
</tr>
<tr>
<td></td>
<td>2 1/2&quot;</td>
<td>30.45</td>
</tr>
<tr>
<td></td>
<td>3&quot;</td>
<td>37.20</td>
</tr>
<tr>
<td></td>
<td>3 1/2&quot;</td>
<td>60.50</td>
</tr>
<tr>
<td>Series 127K</td>
<td>4&quot;</td>
<td>71.50</td>
</tr>
</tbody>
</table>

### Steel Bits

| Series 115    | 1 1/2"    | 0.632           |
|               | 1 5/8"    | 0.617           |
|               | 1 3/4"    | 0.662           |
|               | 1 7/8"    | 0.676           |
|               | 2"        | 0.685           |

### Timken Carbide Bits

#### H Thread

| 1 1/2"    | 14.70 |
| 1 5/8"    | 15.90 |
| 1 3/4"    | 16.55 |
| 1 7/8"    | 17.10 |
| 2"        | 18.75 |
Timken Steel Bits

<table>
<thead>
<tr>
<th>Size Range</th>
<th>Approx. Av. Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1/2&quot;</td>
<td>$0.615</td>
</tr>
<tr>
<td>1 5/8&quot;</td>
<td>0.630</td>
</tr>
<tr>
<td>1 3/4&quot;</td>
<td>0.645</td>
</tr>
<tr>
<td>1 7/8&quot;</td>
<td>0.659</td>
</tr>
<tr>
<td>2&quot;</td>
<td>0.668</td>
</tr>
</tbody>
</table>

Timken KC Tungsten Carbide Bit

<table>
<thead>
<tr>
<th>Size Range</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 3/4&quot;</td>
<td>36.50</td>
</tr>
<tr>
<td>3&quot;</td>
<td>41.00</td>
</tr>
<tr>
<td>3 1/2&quot;</td>
<td>60.50</td>
</tr>
<tr>
<td>4&quot;</td>
<td>71.50</td>
</tr>
</tbody>
</table>

Liddicoat Steel Bits

<table>
<thead>
<tr>
<th>Type</th>
<th>Size Range</th>
<th>Approx. Av. Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-L</td>
<td>1 7/8&quot; to 1 1/4&quot;</td>
<td>0.195</td>
</tr>
<tr>
<td>1-H</td>
<td>1 11/16&quot; to 1 7/16&quot;</td>
<td>0.20</td>
</tr>
<tr>
<td>2-L</td>
<td>2 1/4&quot; to 1 7/16&quot;</td>
<td>0.21</td>
</tr>
<tr>
<td>2-H</td>
<td>1 15/16&quot; to 1 1/2&quot;</td>
<td>0.21</td>
</tr>
<tr>
<td>5-S</td>
<td>3&quot; to 2 3/8&quot;</td>
<td>0.40</td>
</tr>
<tr>
<td>5-L</td>
<td>2 1/4&quot; to 1 3/4&quot;</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Used With Different Steels

<table>
<thead>
<tr>
<th>Type</th>
<th>Used With Different Steels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-L</td>
<td>7/8&quot; Q.O., 7/8&quot; Hex., and 1&quot; Hex. Steel</td>
</tr>
<tr>
<td>1-H</td>
<td>7/8&quot; Q.O.</td>
</tr>
<tr>
<td>2-L</td>
<td>1&quot; Q.O., 1 1/8&quot; Round, and 1 1/4&quot; Hex. Steel</td>
</tr>
<tr>
<td>2-H</td>
<td>1&quot; Q.O., 1 1/8&quot; Round, and 1&quot; Hex. Steel</td>
</tr>
<tr>
<td>5-S</td>
<td>1 1/4&quot; Round</td>
</tr>
<tr>
<td>5-L</td>
<td>1 1/4&quot; Round</td>
</tr>
</tbody>
</table>

* Quarter Octagon
** Hexagonal
The size of bit used in churn drilling ranges generally from 4 to 20 in. and is 3.5 to 6 ft in length. The bits weigh from 170 to 3750 lb and connect on the string of tools consisting of first the auger stem, jars, sinker bar, and finally the rope socket, which is fastened to the rope.

To my knowledge, carbide tipped bits are not used in churn drilling. The reason being that the great force and impact of the bit and string of tools causes severe breakage and increased cost, however alloy steels are used.

The various designs of bits for auger drilling are many and varied. The costs and description of these bits will not be listed in this report. Anyone interested in this information is referred to the supplementary book. It can be found under Central Mine Equipment Company, The Leetonia Tool Company, Salem Tool Company, Carboloy a department of General Electric Company, and The Jeffrey Manufacturing Company.

The Carboloy booklet, "How to Economically and Efficiently Maintain Carboloy Cemented Carbide Mining Tools", gives an excellent treatment of maintaining cutter bits, finger bits, roof bolt drills, and auger drills. Also included in this booklet are many helpful suggestions indicating the necessary equipment for doing a good job of sharpening.
Cone, roller, drag, blade, and fishtail are types of rotary bits. The bit heads are heat-treated alloy steels, and the blades are drop forged from chrome-nickel steel and hard surfaced with Stellite or tungsten carbide. The reader is referred to the supplementary book, where Varel Manufacturing Company gives good cost and description data for cone and blade bits. The Vascoloy-Ramet Corporation has announced the development of a new rotary spade head bit for use in rotary methods. It is tipped with special carbide developed for mining uses. Some tests indicated that the bit used with a rotary drill produced a $2\frac{3}{4}$ time faster penetration rate than a percussion drill.

Diamond bits come in standard sizes from 1 7/16 to 2 15/16 in. outside diameter and weigh from 1 to 4 lb. The diamonds are set into the shell by a powder metal process in an abrasive resistant matrix. Most present day diamonds are the small stones called bortz. "Another type of bit recently developed is made by heating a mixture of powdered tungsten carbide, powdered metallic cobalt and bortz in a mold under pressure." This produces a hard matrix impregnated throughout with diamonds. Drilling is carried out under heavy pressure. Diamond bits are coring, those which retain the core, and non-coring.

The cost of diamond bits and general information can be found in the supplementary volume under the E. J. Long-
year Company, Christensen Diamond Products, and Sprague and Henwood, Inc.

The high cost of diamonds has restricted the use of diamond drills, but a recent chemical discovery in the production of synthetic diamonds may extend the use of diamond drilling where it has been prohibitive.

A most recent trend in diamond bits is the orientation of the diamonds as opposed to the previous method of placing them at random. "Orientation is used to denote a diamond set in such a manner that a hard vector direction of the crystal is in opposition to the rock surface to be cut or drilled."

Large savings are realized by the use of oriented bits even though the cost of the bits have been increased as it takes more time and skill to orient the diamonds.

An important feature with the alloys composing the bit is the fact that much smaller diameter bits can be started than in previous steel bits and yet the finished hole will be of the diameter required. It is well to remember that the smaller the diameter of the starting bit, the greater will be the drilling rate; drilling varies inversely as the square of the diameter of the holes.

The recent trends in bit manufacturing have been new methods and alloys with proper design.
Steel

Steel is another basic component of the drilling unit, and much progress has been done in recent years to keep the advances of steel abreast with new machines and bits.

One important factor with steel for drilling purposes has been that its length should be no longer than maximum distances drilled by standard bits in the different kind of rock in a mine, thus enabling standard drill-steel sets to be made for holes of various depths. "The fewer the steel changes, the greater the time saved in drilling a hole of given depth. It is evident that for the shorter the increment the number of drill steels per hole is doubled thus requiring a greater time in changing steel, more time in getting steel to and from the working, and a greater amount of blacksmithing." 3

Drill steels are made in round, square, flat, octagon, quarter octagon, and hexagon shapes. The shank ends are straight, lugged, and collered.

Stronger steels made with alloys are keeping pace with the advances in lighter drills and tungsten carbide bits. Some of the principal alloys are carbon, chromium, vanadium, manganese, and molybdenum. Carbon steels were popular, but alloy steels have recently been out-performing them.

Sectional drill rods are being used more and more in long-hole drilling. These rods come in various lengths and are connected together by couplings and to the machine by
shank piece or adapter. The bit is connected to the steel by bit adapters. On the following page steel prices are listed.

One feature, which has previously slowed down long-hole drilling, was that water could not be supplied at large enough pressures necessary to remove the cuttings from long holes. Water swivels are now available which do this job with great satisfaction. The water swivel usually connects to the steel without passing through most of the machine as it is normally done. Seals are provided to confine the water in the hollow steel. The holes in the steel are larger for passing a greater quantity of water.

"An interesting variation of long-hole drilling has come out of Sweden, where operators use flat steel 12 mm (approx. ½ in.) by 26 mm (approx. 1 in.) with an integral tungsten carbide bit on one end to drill holes up to 50 ft deep and sometimes over. The steel is not coupled, but it is flexible enough to be bent in the level so that it can be placed in the hole."8

Recent trends in steel are longer steels and sections to keep pace with tungsten carbide bits and the longer feed changes available in drills. There are many who feel the added expense of the alloying is not economical.
Gardner-Denver Steel

Used with wagon drills for long-hole drilling

Sectional Drill Rods *

<table>
<thead>
<tr>
<th>Length</th>
<th>Steel Type</th>
<th>Code</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1'</td>
<td>Hex. Steel</td>
<td>CL5-404</td>
<td>$13.25</td>
</tr>
<tr>
<td>6'</td>
<td>CL5-408</td>
<td></td>
<td>16.90</td>
</tr>
<tr>
<td>8'</td>
<td>CL5-418</td>
<td></td>
<td>20.50</td>
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</tbody>
</table>

Ring Sealed Shank Adapter

<table>
<thead>
<tr>
<th>Shank Type</th>
<th>Code</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1½&quot; Round</td>
<td>CL5-403</td>
<td>10.85</td>
</tr>
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</table>

Couplings

<table>
<thead>
<tr>
<th>Thread Type</th>
<th>Code</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1½&quot; Buttress Thread</td>
<td>CL5-400 Rod</td>
<td>4.65</td>
</tr>
</tbody>
</table>

Bit Adapter for Timken H Threads

<table>
<thead>
<tr>
<th>Code</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL5-409</td>
<td>7.85</td>
</tr>
</tbody>
</table>

* These rods are fully heat treated and carborized.

For Jackhammer with Air Leg

<table>
<thead>
<tr>
<th>Shank Length</th>
<th>Shank Type</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>4'</td>
<td>7/8&quot; Hex.</td>
<td>5.62</td>
</tr>
<tr>
<td>6'</td>
<td>&quot;</td>
<td>8.56</td>
</tr>
<tr>
<td>12'</td>
<td>&quot;</td>
<td>11.76</td>
</tr>
</tbody>
</table>

Stoner Steel

<table>
<thead>
<tr>
<th>Shank Type</th>
<th>Shank Length</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square Steel</td>
<td>1&quot; Q. O.</td>
<td>4.20</td>
</tr>
<tr>
<td>with plain</td>
<td>1.5' change</td>
<td>5.41</td>
</tr>
<tr>
<td>Shank</td>
<td>3.0'</td>
<td>6.62</td>
</tr>
<tr>
<td></td>
<td>4.5'</td>
<td></td>
</tr>
</tbody>
</table>

Ingersoll-Rand Sectional Steel

<table>
<thead>
<tr>
<th>Component</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hose Connection complete</td>
<td>8.20</td>
</tr>
<tr>
<td>1½&quot; Rod Lug Shankpiece</td>
<td>13.20</td>
</tr>
<tr>
<td>Water swivel bare</td>
<td>16.50</td>
</tr>
</tbody>
</table>

Semi-Bridge Couplings

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Overall Length</th>
<th>TD*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 5/8&quot;</td>
<td>3 3/4&quot;</td>
<td>1 9/16&quot;</td>
</tr>
<tr>
<td>1 13/16&quot;</td>
<td>4 1/4&quot;</td>
<td>1 13/16&quot;</td>
</tr>
</tbody>
</table>

* Thread Depth
Conditions and Physical Characteristics

Listed above are some important variables which may restrict the selection of equipment and application of certain drilling trends. A very brief discussion of these will follow.

Most types of drills have specific application, but there are some which may overlap and it is to the advantage of an operator to know the limitations of each type in choosing his drilling equipment for future needs.

"The selection of a drill should consider two important elements. 1. Conditions under which the equipment is to be used, such as mining method practiced, type of labor available, character of rock material. 2. Physical characteristics or features of the given drilling machine. Regardless of the controls of class 1, above, the elements of this category are fixed by several factors. All of them are interrelated and, though some often are more important in one case than in another, an unfavorable variation of any -- others being essentially equal -- is sufficient to discredit the optimum applicability of the particular drill machine."9

The discussion of the individual drills will endeavor to show the application of each.
Mining Method

The selection of a drilling unit depends greatly on its use and the mining method in which it will be applied. The following types of drills are listed where they are used most.

**Prosp ecting**
- Hand drills
- Auger "
- Wagon "

**Exploration**
- Rotary drills
- Diamond "
- Auger "
- Churn "
- Jack-legs "

**Open Pit Mining**
- Churn Drills
- Jet-Piercing
- Wagon drills
- Rotary "
- Auger "

**Underground Mining**
- Stopers
- Drifters
- Sinkers
- Jack-Leg
- Rotary drills
- Auger "

**Shafts**
- Calyx drills
- Jack-leg drills
- Drifters
- Sinkers

Some recent costs published in the September 1954 issue of the Engineering and Mining Journal are typical of the Colorado Plateau.

**Exploration Drilling**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost (in dollars per ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond Drill</td>
<td>$4.00</td>
</tr>
<tr>
<td>Rotary drill (to 300 ft)</td>
<td>1.00</td>
</tr>
<tr>
<td>Rotary drill (to 1000 ft)</td>
<td>4.00</td>
</tr>
<tr>
<td>Diamond bit cost per ft</td>
<td>0.25 to 0.30</td>
</tr>
<tr>
<td>Percussion drill with air to 350 ft</td>
<td>0.75 to 1.00</td>
</tr>
</tbody>
</table>

**Mining**

Calyx drill hole for 36 in. shaft -------- 35.0 to 40.00
Human Element

It has been proven in industry that the better and easier the work is for the worker, the more efficient and productive he will be.

The mining industry and drill manufacturers have done this in various ways. "Drill construction is being reviewed with the lightweight aluminum and aluminum alloys being used for the push-legs and shells for drifters. It is not inconceivable that, in the future, many parts of the drill be made of lightweight metals; such practice will further reduce the weight and consequently diminish operator fatigue. To be noted also is the trend to concentrate all controls on the machine in one handy and convenient location, and some attempts at streamlining have been made, the result of which reduces the machine projections. These projections are a potential source of injury to drill operators when working in tight places."

Many advances have taken place in the removal of dust in surface and underground drilling. Many types of drills with dust prevention equipment will be discussed later.

Increased study and effort in improving the conditions of the miners will pay large dividends to the mining industry.
Mountings

Drill mountings have been manufactured to meet most drilling problems, but much research is constantly being done to improve present mounts and invent new ones. The sole purpose of different mountings is to do a particular job of drilling efficiently and economically.

Mobility of equipment has been with us during the 20th Century in different forms, but in the last decade there has been a tremendous concentration in the mobility of equipment.

It is the endeavor of this section to mention various mountings and many of these will be illustrated with photographs. Emphasis is placed on the mobil mounts in this part, but many illustrations of drill mounts will be shown under the drilling section.

Rather than give descriptions of each type of mount, I have listed the different kinds of mounts and equipment under the company that manufactured them. However, generally drifters and light mounted drills are supported upon arms attached to columns.\(^3\) Recent practice has made more use of the pneumatic columns, but on long-hole drilling set-ups the screw type column is still preferred.

Light hand-held drill mountings have switched completely to the air leg where applicable. Steel tripods with leg weights still are still being used in open-pit
work, but the trend in these mines has converted to the mobil type drill -- both rubber and crawler type equipment. Jumbos of many different designs are used in small and large-section crosscut and tunnel work. Jumbos of many different designs are used in small and large-section crosscut and tunnel work. Jumbos of many different designs are used in small and large-section crosscut and tunnel work. Wagon drill mountings are employed mostly in open-pit and quarry. Wagon drill mountings are employed mostly in open-pit and quarry. The wagon drill has recently found favor in long-hole drilling, because of its versatility and flexibility. It can drill holes from a vertical to a horizontal position.

Following are listed equipment from different companies. These companies listed below are by no means the only ones who manufacture mountings etc., but they are important concerns which will give the reader an idea what equipment is presently available.

Ingersoll-Rand

Hydra-Boom Jumbos

<table>
<thead>
<tr>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight boom</td>
<td>$1500</td>
</tr>
<tr>
<td>with hydraulic pump</td>
<td>$2050</td>
</tr>
<tr>
<td>&amp; 5' Hyd. Ext.</td>
<td>$2360</td>
</tr>
<tr>
<td>The Separate booms are available for mounting on trucks or tractors.</td>
<td></td>
</tr>
<tr>
<td>HBJD Hydra-Boom two boom Jumbo with car mount</td>
<td>$4870</td>
</tr>
<tr>
<td>Three</td>
<td>$6320</td>
</tr>
<tr>
<td>Single - screw column 3&quot; with arms and Clamps</td>
<td>166</td>
</tr>
<tr>
<td>Double -</td>
<td>109</td>
</tr>
<tr>
<td>Pneumatic-feed</td>
<td>265</td>
</tr>
<tr>
<td>Tripod drill mounting - A-86 with weights -479 lb</td>
<td>215</td>
</tr>
<tr>
<td>Quarry Bar -5.5&quot; - length 12' &quot;</td>
<td>255</td>
</tr>
</tbody>
</table>

* For pictures and data not included in this report, refer to the supplementary volume.
The illustration on page 22 shows a large track mounted jumbo with 5 Ingersoll-Rand (IR) booms with drifters mounted. On page 23 shows 2 drifters mounted on a bar which is clamped to a single-screw column.

**IR Wagon drill mountings**

<table>
<thead>
<tr>
<th>Mounting</th>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>JHM alone</td>
<td>-</td>
<td>$1540</td>
</tr>
<tr>
<td>&quot; &quot; with J 50 Hammer</td>
<td>-</td>
<td>$1940</td>
</tr>
<tr>
<td>&quot; &quot; DB 30 Drifter</td>
<td>-</td>
<td>$2250</td>
</tr>
<tr>
<td>GM alone</td>
<td>-</td>
<td>$2600</td>
</tr>
<tr>
<td>&quot; &quot; with X-71 WD type Drifter</td>
<td>-</td>
<td>$3500</td>
</tr>
</tbody>
</table>

**Jack drill with telescopic leg mount**

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>JR-38 with 6 ft leg</td>
<td>-</td>
<td>$750</td>
</tr>
<tr>
<td>&quot; &quot; standard leg</td>
<td>-</td>
<td>$665</td>
</tr>
<tr>
<td>&quot; &quot; 2' leg</td>
<td>-</td>
<td>$665</td>
</tr>
<tr>
<td>&quot; &quot; 3' leg</td>
<td>-</td>
<td>$665</td>
</tr>
<tr>
<td>&quot; &quot; 4' leg</td>
<td>-</td>
<td>$665</td>
</tr>
</tbody>
</table>

Page 24 shows the construction of the Ingersoll-Rand (IR) wagon drill, and on page 25 the IR JR-38 with the telescopic leg.

**Stoppers with regular pneumatic leg**

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-38</td>
<td>-</td>
<td>$665</td>
</tr>
<tr>
<td>R-48</td>
<td>-</td>
<td>$735</td>
</tr>
<tr>
<td>R-58</td>
<td>-</td>
<td>$810</td>
</tr>
</tbody>
</table>

The stopers are shown on page 26. This illustration of 2 IR R-48 stopers operated by miners are plugging out the back of a drift.

Cleveland Rock Drill Division

**Air leg alone for attachment to sinker drills**

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL-93</td>
<td>4' leg</td>
<td>$270</td>
</tr>
<tr>
<td>&quot; &quot;</td>
<td>6' leg</td>
<td>$285</td>
</tr>
</tbody>
</table>
Copco Pacific

Air leg and machine --------------------------------- $ 543

Gardner-Denver

GD Wagon drill mountings

URM 99 complete with D99D drill --------------------- $ 3320

Stoper

R-94 ----------------------------------------------- $ 735

Air Leg

Air Leg attachment to use with regular sinker 4' $ 215
FL-48 drill with 3 or 4' leg (standard)------------ $ 645
" " " telescopic leg ------------------------------- $ 750

Drifter without mount

CF 79 3" complete with aluminum shell & hole spotter 1260

Jumbos

J1H hydraulic drill jumbo complete, single boom,
hand pump and roof jack ----------------------------- $ 2535

Tractor mounted compressor and drills

Compressor GD Model WH-600 -------------------- $ 5800
2 booms $1210 each ----------------------------- $ 2420
Hydraulic JOM pumps $285 each -------------- $ 570
" tank ------------------------ 75
Mounting bracket for double boom ---------------- 300
Misc. fittings for double boom drills ---------- 100
RM 6' feed $1090 each ------------------------ 2180
2 D99dT drills $940 ---------------------------- 1880
Total less Cat ---------------------------------- $13325

The Gardner-Denver Company recommend the use of a D-8 Cat. The compressor is direct connected to the power take-off, and it requires 1200 rpm's for the maximum compressor capacity of 600 cfm.
A very important invention in drill carriages is manufactured by J. W. Burress in Roanoke, Virginia. It is called the Air Trac. The Air Trac is self-propelled, self-equalized, and self-stabalized. It is propelled by 2 Gardner-Denver air motors and has ample power to tow a 5 Ton compressor on a 10 % grade. Drifter type drills are mounted on the Air Trac and is made up for steel changes of 6, 8, or 10 ft. The total weight is 3000 lb with standard guage and draw bar. Information and pictures are available in the supplementary volume.

On page 29 is shown the D-8 Cat with compressor and drills. Page 30 illustrates the Gardner-Denver mobiljumbo. The drills are CM 73 drifters and are the next smaller size than the one priced on page 27. The price of the complete unit was not available. Page 31 illustrates a small rotary drill mounted on a jeep.

Joy Manufacturing Company

Wagon Drill and mount

| Light weight LW-6A mount with LM drill | $ 1940 |
| Medium " " T350 " " | 3160 |
| Heavy " " T400 " " | 3520 |

Drillmobiles

| Chasis only with Piston Air 95 & chain feed " " 01 " " | 5305 |
| You can mount either the T-350 or T-400 on either | 6305 |
Hydro Drill Jibs

DBT with hydraulic hand pump ----------------- $ 2360
T-350 automatic drill, 6' change, 3 1/2" bore --- 1145
T-400 " " " 4" " " " " " --- 1300

Middle Weight Champion Rotary Drill Mount

Mounted on 3 wheel rig without compressor app. 14700
The regular Joy Champion Blasthole drill is crawler mounted.

Sanford-Day Iron Works, Inc.

The Gismo, which is more noted for its ability as a transporter of ore in mines, can be mounted with from 2 to 5 jib mounted drills. On page 33 is a picture of this Gismo with 4 drills mounted. This drilling equipment will drill parallel holes 22' high and to a width of 32' from one setting of the drill jumbo. The Sanford-Day Iron Works, Inc. recommends that a customer purchase two Gismos and one tractor. One of the Gismos is to be used for mucking and one for drilling. 10

"The current price of the mucking Gismo is $9800.00 and the price of the tractor with all modifications for underground work is $16,700.00. We will equip and rig the other Gismo as a drilling jumbo for the same price. That is, we prepare the Gismo for mounting of the drilling equipment. All prices are f.o.b. Knoxville." 10

The use of the proper mounting for specific drilling job is essential for efficiency and economy. The revolutionary air leg has made it possible for many small mines
to incorporate one drill for many different jobs.


"Except for the item of first cost, all of the foregoing factors bearing on the selection of drilling machines can be evaluated specifically for any given case only by testing them in the drilling cycle which is, in turn, governed by the nature of the rock, the type of labor, and the mining method."9
DRILLS AND DRILLING TRENDS

In this section of the report a discussion of the drills will be included and supplemented with costs and data on the very recent equipment when available. Mention will be made of the conventional machines that have and are being used which include some recent trends, but the emphasis is placed on the current universal jack-legs, rotary drills, jet-piercing drills, and sonic drills. Remarkable advances have been made recently with these machines and are well worth the lengthier discussion. Also included, though not presently being applied to the mining industry, is a discussion of the ultrasonic drill.

A drill that is making miraculous advances in the oil industry is the Bodine sonic drill, though not truly ultrasonics in a sense of the word, but it does deal with sonics set up by a large head of mud. Great possibilities for future drilling lie in sonics -- the research of which should not be way-laid.

The classification of these drills, though not complete, is as follows:

1. Percussion drills
   a. Stopers, Drifters, Jumbos, Wagon drills, and Sinkers
   b. Churn drills
   c. Jack-leg drills
   d. Misc. drills

2. Rotary drills
   a. Hydraulic drills
   b. Diamond drills
   c. Auger drills
   d. Chilled shot drills
3. Jet-piercing drills

4. Sonics
   a. Ultrasonic drills
   b. Sonic oil-well drills

Excerpts of current literature are presented to illustrate some important features of the different drills, drilling speeds, and costs.

Percussion Drills

There are two principle types of percussion drills.
1. The piston drill
2. The hammer drill. "In the piston drill the steel itself moves, being lifted from and driven against the bottom of the hole. In the hammer drill the drill steel is in constant touch with the bottom of the hole and separated from the hammer."[15]

Piston drills are not used very much these days, but the Ingersoll-Rand company has used the piston and hammer types of drills in submarine drilling. They find their greatest application in river and harbor improvements, deepening canals, removing submerged reefs, and ledges, and are usually mounted on drill barges. The advantages of the hammer drill over the piston type are:
   1. Increased drilling speed
   2. Shorter steel and less breakage.

"Most all of the percussion drills being used today for blast hole drilling are of the hammer-type drill. They are classified as hand-held hammers (jackhammers, sinkers, air
legs, sinkers with air legs, etc.), drifters (light or heavy), and stopers and are of many sizes; varying in weight and rotative and blowing power. Most makes of drill machines fundamentally are the same in principle of operation as they are designed to strike a blow on the end of a drill rod in the manner of early-day hand drilling.\(^9\)

The specifications of rock drills include essentially the weight of the machine, the over-all length, the bore (piston), the length of feed travel, and generally the size of air and water hose. The information that I have available is incomplete so I will neglect the specifications in most instances.

**Stopers, Drifters, Jumbos, Sinkers, and Wagon Drills**

These machines have not changed in any great degree to warrant much discussion. The changes that have been made are: longer feed which allow longer steel changes (as much as 36 in. in stopers and from 6 to 10 ft in drifters), lighter machines and carriages made from different alloys, better location of controls, automatic rotation, in many cases the reduction of the bore on these machines to accommodate the smaller sizes of steel and bits, and standardization and inter-changeability of parts and leg types.

On page 38 is shown a Joy S-91T which displays a telescopic leg on their stoper. Also on page 26 is shown 2 Ingersoll-
stoppers. On page 40 shows a Gardner-Denver light weight, sturdy wagon drill, and on page 41 show an Ingersoll-Rand jackhammer which is being used for drilling plugs for secondary pit blasting.

Of particular importance in this section is the use of long steel change drifters and other machines for long-hole blasting purposes. Long hole drilling methods have cut costs in mining and prospecting and if this trend continues more savings will be realized with the adaptation of better machines to particular conditions.

Following are listed the cost of sinkers not previously mentioned.

<table>
<thead>
<tr>
<th>Source</th>
<th>Model</th>
<th>Weight</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleveland Model</td>
<td>H-111</td>
<td>55 lb</td>
<td>$400</td>
</tr>
<tr>
<td>Gardner-Denver</td>
<td>S-48</td>
<td></td>
<td>380</td>
</tr>
<tr>
<td>Joy Manufacturing</td>
<td>L-37</td>
<td></td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>L-47</td>
<td></td>
<td>380</td>
</tr>
<tr>
<td></td>
<td>L-57</td>
<td></td>
<td>400</td>
</tr>
<tr>
<td>Ingersoll-Rand</td>
<td>J-30</td>
<td></td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>J-40</td>
<td></td>
<td>380</td>
</tr>
<tr>
<td></td>
<td>J-50</td>
<td></td>
<td>400</td>
</tr>
</tbody>
</table>

**Churn Drilling**

In mining the churn drill is used for prospecting and for blast hole drilling in open pits and quarries. The churn drill is most applicable to alluvial and sedimentary deposits; it drills slow in hard and crystalline rocks. The cost of churn drilling for shallow holes (about 300 ft) should range from $1.00 to $2.50 per foot. Holes up to 1000 ft should cost between $2.50 to $4.50.
"The weight of the string of tools, the length of stroke, the number of strokes per minute, and the nature of the rock determine drilling speed."\(^3\)

"Drilling is performed by rhythmic raising and dropping of the bit on the bottom of the hole. The striking end of the bit is relatively blunt, and the rock is crushed rather than chipped by the impact of the bit. At the start of its downward cycle the bit is allowed to fall freely until it is close to the bottom of the hole. At this point the return motion of the cable is inaugurated with the result that as the bit hits the rock the cable is stretched and the bit rebounds quickly. The "snap" is a prime requisite for proper drilling. The driller adjusts the speed of the cycle and the rate at which the cable is fed into the hole by judging the "snap" as he holds his hands on the cable."\(^6\)

Some data concerning churn drills are listed below:

**Loomis Machine Co.**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super Clipper 32 -- one man operation</td>
<td></td>
</tr>
<tr>
<td>Portable - ready for truck mounting</td>
<td>8000 lb</td>
</tr>
<tr>
<td>Cost alone</td>
<td>$4480</td>
</tr>
<tr>
<td>Casing reel or catheads</td>
<td>$560</td>
</tr>
<tr>
<td>Mounted on caterpillar treads</td>
<td>13000 lb</td>
</tr>
<tr>
<td>Weight of tools</td>
<td>$8835</td>
</tr>
<tr>
<td>49 hp engine, 1250' of 5/8&quot; line, and 40' mast</td>
<td>2000 lb</td>
</tr>
</tbody>
</table>

**Sanderson Cyclone Drill Co.**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 35-A Sr. Drill suitable for truck mounting(1-ton truck)</td>
<td></td>
</tr>
<tr>
<td>Net weight</td>
<td>3700 lb</td>
</tr>
<tr>
<td>Cost</td>
<td>$2670</td>
</tr>
</tbody>
</table>
| Hole size                                        | 2 to 4 in.
No. 44 O F Full oil field drill for truck mounting

Weight ---------------------------------- 12500 lb
Cost with gas engine ---------------------- $6975
" " diesel " ---------------------- $8175
Hole size ------------------------ 6 to 18 in.

**Bucyrus-Erie Company-crawler mounted Churn Drills**

- **22-T** -- 1500 lb of tools, Holes 5 5/8" to 6 5/8", and 34' 6" all steel derrick
- **27-T** -- 2000 lb of tools, Holes 6" to 6 5/8", and 40' all steel derrick
- **29-T** -- 3000 lb of tools, Holes 6 5/8" to 9", and 38' all steel derrick
- **50-T** -- 6000 lb of tools, Holes 9" to 12", and 46' steel derrick

On page 44 is a photograph of a churn drill. The drillers are ready to add another length of steel pipe.

In the November 1954 issue of E & M J, page 101, Wm. H. Gaines has designed a small churn drill for depths to 75 ft. It is powered by a 1/2 hp gasoline engine and uses Timken bits. The drill is operated at 60 drops per min, and through a height of 10 to 16 in. It is portable and a good tool for small prospects.

**Jack-legs**

In the discussion of jack-leg drills three companies will be illustrated which typify the general type of research being done by most of the larger companies. As has been previously pointed out not only the jack-legs will be discussed, but also the many variables which make up a complete drilling package.

The use of the terms air-legs, jack-legs, and push feed
drills are synonymous. Some relative costs and drilling speeds are brought out, and Bob Sandvig's description of drill efficiency comparisons is excellent.

At the Holden Mine, in Washington, the advances in drilling equipment and techniques have resulted in some startling savings. "Since the mine's first inception in 1938, drilling in development and explorations headings passed through a series of improvements from hand crank machines and conventional steel; next came the one-use or throw away bit, and finally the present combination of tungsten carbide bits and automatic machines mounted on jumbos with long chain feeds became standard." The savings which resulted are as follows:

1. Tonnages of drill steel in circuit has been reduced, which gives lower nipping costs.
2. Steel shop crews have been cut from 10 man shifts per day to about 2 shifts per day.
3. Drilling speeds have increased from an average of 6 in. per min in 1937 to 1938 to 19 and 20 in per min in 1950 to 1951.
4. This increase per man shift has resulted in less physical effort on the part of miners.

In 1940 diamond drill blastholes had replaced powder blasting for ore breaking by 1944; and with the advent of increased diamond bit costs, tungsten carbide bits for blast-hole drilling replaced the diamond bits with reduced cost.

One of the chief secrets in longhole drilling is to maintain water at high pressure and volume at the bit end
to keep the cuttings washed clean from the hole.

By 1950 powder blasting was completely eliminated; drilling rock had passed through the cycle from conventional steel to tungsten carbide insert bits; and the diamond drills have been completely replaced by percussion drills for ore breaking by longholes.

Since the advent of push feed drills in this country a few years ago, several types of drills and steels were tried, but no combination could measure up to the equipment then in use until 1952 when test work began to show definite possibilities. Continued work with lightweight machines and alloy steels indicates that a successful combination of push feed drills, alloy steel, and tungsten carbide bits may be found, which will replace some or a substantial part of the equipment now considered standard for regular drifting and raising. Also, lightweight drills equipped with stoper legs are meeting with considerable favor by some raise miners. 18

A photograph of a Gardner-Denver FL-48 air leg and sinker is shown on page 47.

"The Homestake Mine in Lead, South Dakota, has switched from 3\(\frac{1}{2}\)-in. drifters and 3 1/8-in. stopers using 1-in. quarter-octagon integral forged drill rods to light drill machines with 2 5/8-in. bore, small 1 3/8-in. carbide detachable bits, and smaller 7/8-in. hexagonal carbon steel.

Below are listed the advantages by this change after
years of test work and correlation of the data obtained.

1. Substantially higher efficiency in tons per man shift in stope and feet per man shift in development headings.
2. Greater drilling speed.
3. Greater mobility.
4. Lighter weight equipment in stope with less strain on men.
5. Lower air consumption by 50 percent.
6. Explosives savings are slightly lower.
7. Lower capital investment per stope. Fifty-eight percent decrease.
8. Lower nipping costs.
9. Lower cost for racking and distributing bits.
10. Lower tonnage of dull steel in circulation.

In shrinkage stopes the total footage drilled in a shift has increased over 50 percent.

Several years of testing has shown that tungsten carbide bit life and drilling efficiency depends on the correct rock drill". 19

As C. N. Kravig indicates, with mounted machines it is necessary to maintain drill rods in lengths and sizes that are multiples of the change length of the machine, but with the pneumatic leg setup, this is not necessary. This feature permits more flexible use of the drill steel, with less waste and lower tonnage in circulation. With the pneumatic drill, a starter and a second can drill the same length hole that it takes a stoper with four drill rods.

Also of interest in his article was the fact that the net result of the smaller equipment and lower air consumption is somewhat slower drilling speed. But savings in man
hours, steel and bits, and auxiliary equipment reduces total cost per man shift sufficiently so that the cost per foot of advance is lower.

A figure of 10 to 12-in. per min was given as the drilling speed using the smaller bit and the one-use steel bit, which was to compare appreciably the same using the larger drills and integral drill rods. No comparable drilling rates were given for the pneumatic sinkers and air legs.

The photograph on page 50 shows three miners using Ingersoll-Rand JR-48 jack-legs drilling out a drift round.

Bob Sandvig, research engineer for Anaconda Copper Mining Company, states that "drilling of parallel holes is the most important feature to be exploited from the push feed. This permits breaking of longer rounds with out disturbing the walls". 20 This factor subsequently reverts to the use of rock bolts which can be used at 1/10 the cost of timber. 20

"One prominent advantage of the air-leg drills is that they reduce miners fatigue, enabling him to drill long rounds with less physical energy and increasing his take home pay. The main objection in Butte as in other places is the miners acceptance of the drill, but once he knows he can increase his earning power the change in many cases has not been so difficult." 21

"Using stopers in Butte square set stopes, a survey show that 3.8 cu ft per foot of hole is a good yield. With push feed drills, 6.3 cu ft are broken per foot of hole, and
averages of 13.0 cu ft per hole are on record.

Mr. Sandvig also states that powder consumption is reduced even with the increased burden on the holes. In Butte they have by using the air-leg drill reduced the number and size of hole and also were able to reduce the powder from 45 percent to 30 percent.

"Shaft sinking in hard rock can be simplified by hanging the crowfoot of the push feed drill from a rock bolt, stull, or end plate, and using the air feed to increase the drilling speed of the sinker. The hand held sinker depends upon a man to force it, and a time study in Butte shows that the air feed increases the drilling speed by roughly 20 percent, in addition to reducing the fatigue of the driller."21

"In early August 1953, 7954 ft of push feed drilling time study data were on file from tests conducted since June 1952. At the same time, comparative time study data were collected on 1579 ft of drilling with conventional drills. On the average, the push feed drill will complete a given footage of holes in 16 percent less time than a stoper. The competition with drifters depends upon the size of heading and depth of round to be drilled."21

"Two significant factors are determined from the recaptitulation of a drilling time study. The minor factor is the traditional, inches per minute, and it is significant only in judging the performance of the drill. The major
factor significant in comparing drilling methods is man-minute per foot drilled. That is representative of the labor spent to attain a necessary footage of drill hole, and it is derived by dividing the total time spent in completing a round by the total footage in the round. 21

"Note that the stoper drills 20 percent faster than the push feed, but because the driller must change steel every 18-in., his drill is running only 54 percent of the over-all drilling time. With the slower push feed, a driller need not change steel at all to get the same depth of hole as the stoper, but since he has cut his drilling time 40 percent by eliminating six holes and 16 percent more by using the long change steel, thus keeping his drill running 84 percent of the time, he can break twice as much rock as the stoper man in approximately the same time spent in drilling. 21

"In much of the Butte round, steel bits remain sharp up to 25 ft, so tungsten carbide is used only in abrasive quartz or unaltered quartz monzonite -- then only because it is necessary to preserve that important principle in push feed drilling, namely, the long steel change. 21

"Using steel bits in an unaltered quartz monzonite crosscut, collaring and finished with an 8-ft 5-in. rod for a net depth of 8 ft, a push drill (23/4-in. bore) averaged 8.9-in. per min for 36 holes at 80 psi. Overall drilling efficiency was 1.76 man-min per ft. Thirty-six bit changes were required.
Using tungsten carbide in similar ground, same drill, same steel, and same pressure, drilling speed was increased to 11.2 in per minute and over-all efficiency was 1.15 man-min per foot. In similar ground and at the same air pressure, a 3\(\frac{1}{2}\)-in. bore drifter mounted on a pneumatic column bar using a 2\(\frac{3}{4}\)-in. steel change averaged 18.5-in per minute and over-all drilling efficiency was 1.54, not counting the 18 min required to set up the column bar and mount the drill. Steel bits used with the drifter were 1/8-in. larger in diameter that those used with push feed.\(^{21}\)

"Using steel bits in softer, less abrasive rock, a push feed averaged 16.9-in. per min for 23 holes eight ft deep. Efficiency was 0.92 man-min per foot. In the same ground and at the same pressure, a 3\(\frac{1}{2}\)-in. bore drifter mounted on a single boom drill carriage averaged 27.3-in. per min with efficiency at 0.89 man-minutes per foot. Not included in the over-all efficiency figure was the time required to move a mechanical loader out of the heading and move the drill carriage in. Preparing the drill carriage for drilling after being spotted by the motor required 7 min, while the moving usually requires 18 min, for a total of 25 min. However, the push feed is not considered competitive with the drill carriage for long rounds in large headings at this time because of height limitations and the need for larger diameter holes to take a heavier powder charge. For drift rounds 5 ft
4 in. deep, the push feed drills without carbide bits can do a better job of drilling in less time than either the bar mounted or drill carriage mounted heavy drifters, due to quick set-up time for the push feed."

"Ten push feed drills can be purchased for the price of one boom type drill carriage and the drill or drills it must mount. Likewise, either two or three push feed drills can be had for one bar mounted drill and its bar, clamps, chuck wrenches, etc."21

"To drill an 8-ft hole with a stoper requires five pieces of steel for a total of 31 linear ft of drill rods. One piece of steel 8 ft 5 in. will suffice for an 8-ft horizontal hole, while for vertical holes, using a 31-in. change, 17 ft 6 in. of drill rods are enough for the 8-ft hole. Further, the life of a drill rod used on the light machine is from three to ten times the life of a drill rod used on the heavier stopers and drifters."21

"Since straight shank drill rods have been standard in the Butte mines for many years, a study was conducted to determine the practicality of using tappet construction in the light drills. Recapitulation of time study data from a large footage shows that conventional construction gives 36.4 percent higher drilling speed than with the tappet and straight shank. A recent development in collaring 7/8-in. hexagonal steel, namely, the "pear-shaped collar" has elimi-
ated the desirability of using straight shanked steel, so this finding has only academic value. Likewise, time studies show that the 7/8-in. hexagonal steel will give from 10 to 30 percent higher drilling speeds than the 7/8-in. quarter octagon rods, using conventional construction. That is because greater rotation effort is required to overcome the greater drag of the quarter octagon section."21

"So long as a steel bit remains sharp enough to cut, it is faster than the carbide bits. Since most of the Butte ground is soft and contains much clay, use of steel bits will not only be cheaper but will be faster. Carbide care places an extra load on a supervisor, so in practice, supervisors do not ask for carbide bits unless the ground requires them; that is, when the ground is so hard or abrasive that the long changes cannot be made without carbide bits. They are certainly justified from an economic standpoint under those conditions because they make the difference of whether a 5' 4" or 10' 8" round will be made. Bit sizes between 1 5/8-in. diameter and 1 3/8-in. diameter all perform equally well. A 1 3/4-in. bit slows the push feed drill quite appreciably, while lower drilling speed results with the small bits of 1 5/16-in. and 1 1/4-in. diameter. The apparent reason for this is that cuttings do not escape fast enough with the small bits."21
"Plugging steel in the clay rich Butte rock has always been a problem to Butte miners. Since regulation of feed leg pressure is vital in efficient push feed drilling, upstroke rotation combined with good feed leg pressure did not work out. However, by dampening the foot pound blow of the drill and increasing the power and speed of rotation, by using downstroke rotation, drilling speed is substantially increased, correct feed pressure maintained, and the hazard of plugging steel virtually eliminated. In the hard rock where carbide bits are necessary, upstroke rotation would give slightly higher drilling speed, but bit life is cut in half. Therefore, the use of downstroke rotation has been a big factor in the success of push feed drills at Butte. Likewise, the use of carbide bits will be much more economical because of downstroke rotation."21

A comparison of the results of three progressive companies doing extensive research indicates in many instances that the results are similar in some cases and opposite in others -- depending upon conditions.

The obvious situation that research for any particular mine is essential to evaluate the facts and come up with the right answers that will save money. It is important that those individuals doing the research are truly interested in the cheapest method and are unbiased in their opinions.

The jack-leg is truly a boon to the mining industry,
with its potential ability of cutting mining costs, it extends the world ore reserves and opens the door for new lower grade deposits which previously were uneconomical.

Miscellaneous Drills

Worthy of mention are many small gasoline, air, and electric drills. Some of these drills should be included under the rotary section, but will be included here.

The small electric and air drills are used underground as well as surface work. The gasoline drills, being limited only to surface work, are very useful for prospecting and small drilling jobs. Generally the companies manufacturing these machines make various attachments for different types of work.

The gasoline drills are priced from as little as $50 to about $1000. The names of a few companies that make the gasoline and/or electric drills are as follows: Barco Manufacturing Co., Black and Decker Manufacturing Co., Stanco Mfgs. & Sales Inc., and Syntron Company.

Included on pages 58 to 61 is a chart of rock drill rock drill troubles and remedies.

Rotary Drills

The trend for many large companies, which previously used churn drills for blast hole purposes, has changed to the
<table>
<thead>
<tr>
<th>Trouble</th>
<th>Cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid wear of Rifle Nut and/or Rifle Bar</td>
<td>Usually due to faulty lubrication. May also be due to grit in machine or contaminated oil</td>
<td>Keep the machine clean and use plenty of the proper rock drill oil</td>
</tr>
<tr>
<td>Breaking pistons and/or Rifle bars</td>
<td>Usually due to heat cracking caused by faulty lubrication. May also be caused by bad steel shanks or excessive chuck wear</td>
<td>Proper lubrication and replacement of worn parts</td>
</tr>
<tr>
<td>Spalling of piston face</td>
<td>May be due to steel shanks being too hard or having improperly shaped striking faces. May also be caused by badly worn chuck allowing steel to be struck at an angle</td>
<td>Check shank hardness. Check shank faces. Replace worn chucks</td>
</tr>
<tr>
<td>Breaking side rods</td>
<td>May be caused by uneven tension on rods or by loose rods. Usually caused by piston and/or spacer bushing worn beyond limits allowing piston to strike front end</td>
<td>Check tension on side rods. Check clearance between spacer and piston and replace one or both if necessary</td>
</tr>
<tr>
<td>Broken pawls</td>
<td>Invariably caused by the operator turning the drill steel in the wrong direction with a pipe wrench in an effort to free stuck steel</td>
<td>Replace and instruct operator</td>
</tr>
<tr>
<td>Broken or battered water tubes</td>
<td>Shanks improperly punched. Badly worn chucks</td>
<td>Check shanks. Replace worn chucks</td>
</tr>
<tr>
<td>Trouble</td>
<td>Cause</td>
<td>Remedy</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>Insufficient feed pressures (Cleveland HC air feeds)</td>
<td>Worn cup leathers and/or dirt. Low air pressure</td>
<td>Clean and replace cup leathers. Check air pressure</td>
</tr>
<tr>
<td>Insufficient holding pressure in pneumatic column. Column falls when air pressure released</td>
<td>Same as above. Too small column for size drill used. Falling caused by dirty check valve</td>
<td>Same as above. Use proper size column. Take check valve out and clean</td>
</tr>
<tr>
<td>Machine freezing at exhaust ports</td>
<td>Excess moisture in compressed air, usually coupled with low ambient temperatures</td>
<td>Install moisture traps in air lines. Some relief may be had by feeding in small amounts of alcohol or other anti-freeze into the air line</td>
</tr>
<tr>
<td>Side Rod and front end breakage in stoper drills</td>
<td>Generally due to low air pressure allowing the machine to fall away from the work and allowing the piston to expend its energy on machine parts rather than on drill steel</td>
<td>Use correct air pressure. Check cup leathers and clean drill and feed leg</td>
</tr>
<tr>
<td>Trouble</td>
<td>Cause</td>
<td>Remedy</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Drill does not have standard hitting power</td>
<td>May be due to short shanks, short piston (thru wear or regrinding), loss of front end cushion, low air pressure (at source, long runs of small diameter hose or pipe, or plugged air passages in drill). If an air line filter is used may be due to plugged filter</td>
<td>Check shanks and piston. Check front end cushion. Check air passages in drill and be certain air filter is clean. Check compressor for proper loading and unloading pressures. Check air lines to be certain they will carry required volume of air.</td>
</tr>
<tr>
<td>Drill Heats</td>
<td>New drills may heat, particularly at spacer due to close fits and heavy work load or lack of oil. Heating in other than new drills is always caused through faulty lubrication although hot air from an overloaded compressor is a contributing factor</td>
<td>Take it easy with a new drill and give it lots of oil. With older drills use enough of the proper oil and use a compressor large enough to avoid overloading</td>
</tr>
<tr>
<td>Stoper has insufficient feed pressure</td>
<td>Usually due to worn cup leathers. May be due to plugged air passages. Low air pressure</td>
<td>Clean and replace cup leathers. Check air pressure</td>
</tr>
<tr>
<td>Trouble</td>
<td>Cause</td>
<td>Remedy</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td>--------</td>
</tr>
<tr>
<td>Broken steel shanks</td>
<td>Usually caused by poor fabrication. May also be caused by worn chucks or striking faces not square and flat. Breaks through collar itself are always the result of poor fabrication.</td>
<td>Check shank source for fabrication troubles. Replace worn chucks.</td>
</tr>
<tr>
<td>Spalling of shank striking face</td>
<td>Too hard. Usually caused by accumulation of water in bottom of quenching tank.</td>
<td>Drain quenching tank and check tempering temperatures.</td>
</tr>
<tr>
<td>Drill refuses to start</td>
<td>May be plugged exhaust ports, frozen piston due to faulty lubrication, <strong>valve</strong> stuck by gummy lubricant or plugged air passages due to dirt or rubber from worn hose lining.</td>
<td>Check exhaust ports. Dismantle drill, clean and recil. Clean air passages. If due to frozen piston remove piston and repair surfaces where possible by stoning or fine emery cloth. Replace rotten hose.</td>
</tr>
<tr>
<td>Drill refuses to rotate or weak rotation</td>
<td>May be caused by bad drilling ground (ravelly, fitchery, any or all worn parts clay seams, vug holes etc.). May be loss of bit gauge allowing bit to bind in hole. Also may be due to worn chuck, chuck nut, piston, rifle nut, rifle bar or any combination of the above.</td>
<td>Replace bit if worn. Replace any or all worn parts.</td>
</tr>
</tbody>
</table>
the faster more economical method of rotary method. The rotary method of drilling accounts for the deepest holes. Holes greater than 16,000 ft have been on record.

"In rotary methods, the weight of the drill rods and cutting tools, the speed of rotation, the kind of cutting tool, and the nature of the rock determine the rate of drilling."¹

At the Mohogany Ledge near Rifle, Colorado, the Bureau of Mines in tackling the oil-shale problem for the production of oil have done much research in the mechanization of drills, in the development of hard-surfaced bits, and alloying of drill rods. Even though vast strides have been made in the mechanization of percussion drills powered with compressed air it was felt that rotary drills with auger type bits would prove even more successful, and a research program has been made to meet this end.²³

The advantages of the rotary drill are as follows:

1. A higher drilling rate.
2. Less drill rod breakage.
3. Cheaper electric power than compressed air.
4. Elimination of noisy air-drills.

Many types of auger bits, used with rotary drills, have attained drilling rates of from 36 to 42 in. per minute actual drilling time.²³

A Swedish engineer Craelius designed an excellent machine which is used for shallow depths generally up to 500 ft. It can be powered by hand or most any type motor. This machine
is lightweight and small, it drills in any direction and is adapted to flush holes with water.15

In Washington the Northwest Magnesite Company has gone through many different stages of drills in their open pit operations. From jackhammers, wagon drills using steel bits to tungsten carbide bits, and finally to the rotary drill which provides the most satisfactory method of producing blastholes.

"A comparison for drilling speeds in this type of ground is as follows:

1. Diamond drills, taking an EX core -- 40-ft to 50-ft per gross shift.
2. Churn drill, 6-in. bit -- 21.5-ft per gross shift.
3. Rotary drill, 6-½-in. bit -- 104 ft per gross shift.

   Net drilling rate was 18.88 fph for the past two years.

One noticeable advantage of this machine is its ability to drill through as much as 50-ft of dirt and mud overburden without the use of steel casing. The rotary action of the bit produces less vibration than percussion type drills, and seems to pack and stabilize the walls of the hole.

This drill has proved to be the most satisfactory method of primary drilling at this property. Yield per man shift has increased 37.9 percent in primary breaking and 11.2 percent in secondary breaking. Total increased efficiency over previous methods is 26.9 percent. In addition the loading of a drilled pattern has been speeded up five times over previous methods.
Only three limitations have been found with the rotary drill. It is not possible to drill horizontal holes with the type of rotary drill which we employ and roadways must be provided over extremely rough terrain.

A wagon drill is better suited to both conditions than the rotary drill.

The third disadvantage is that bit life is greatly reduced when chert is encountered.

The rotary drill has been successfully used for a sufficient period of time to state unhesitatingly that it provides the most satisfactory method of producing primary drill hole in Washington magnesite.\(^2\)

One of the most recent revolutionary drills embodies three separate methods of drilling. The Drillmaster manufactured by Ingersoll-Rand is a rotary drill, a percussion drill, and a combination rotary and percussion drill. This latter feature is known as a "down the hole" drill where the bit connects directly to the drill and follows it down the hole. The chief advantage of the "down the hole" drill or Depth Master is that the drill, being next to the bit, has no transmission energy losses. In most conventional types of drills the transmission energy losses decrease greatly the efficiency of the drill caused by the long heavy steel. The "down the hole" receives its air through the center of the hollow drill rods.
The Drillmaster can be secured with three different drills, the Roto-Master, the Power-Master, and the Depth-Master ("down the hole") drill previously described. The Roto-Master can be used independently or in combination with the Power-Master or the Depth-Master.

This drill is made generally with the crawler mounts, but can be obtained for truck or tractor mounting. A complete dust collection unit is available for dry drilling and the drill is operated by a 600 cfm Gyro-Flo portable rotary compressor. The picture on the following page shows the Drillmaster with the Roto-Master at the top of the mast and the "down the hole" drill or Depth-Master at the bottom of the drill rod next to the bit.

The Drillmaster is an efficient drill and embodies in one unit many current trends, eg. long steel change (20 or 25-ft), rotary drill for speed and economy, "down the hole" drill for maximum efficiency, and a powerful suction dust collection unit.25

The price and estimated performance of the Drillmaster is listed on page 67.

"The Belgians' have reported a novel long-hole drill; the machine follows down the hole behind the bit"8 Although this has been used only in quarries, Prof. Stout states, it may have some use in long-hole drilling underground if a suitable means of handling the dust is available.
Drillmaster
Price and Performance

DM-DH3 Drillmaster with Down Hole Drill
Self propelled crawler mounting including Rotary 600 cfm Portable Compressor
complete and ready to run ........................................ $48,500.00

DM-DH3 Drillmaster with Down Hole Drill
Including tower for 20' steel change,
complete & ready to mount on a truck
or tractor................................................................. $20,000.00

DM-OHD5 Drillmaster with Out Of Hole Drill
Self propelled crawler mounting including
Rotary 600 cfm Compressor
Complete with all accessories......................... $47,000.00

DM-OHD5 Drillmaster with Out Of Hole Drill
Including 20' drill tower & ready to
mount on truck or tractor................................. $18,500.00

Estimated Performance

OUT OF HOLE DRILL
Dia. of hole -- 4 1/4"
Depth -- 60 ft
Drilling speed in hard limestone -- 80'1/hr
Drilling speed in hard granite --- 24'1/hr

DOWN HOLE DRILL
Dia. of hole -- 6"
Depth -- 150 ft
Drilling speed in hard limestone -- 40'1/hr
Drilling speed in hard granite --- 12'1/hr

ROTARY DRILL
Dia. hole -- 6 1/4"
Depth -- 150 ft
Drilling speed in hard limestone -- 30'1/hr

The Quarrymaster, a rotary and percussion drill, sells
for approximately $70,000 and is shown on page 67 a.
It is the understanding of the author that the manufacturers of underground percussion drills are working on a small rotary type drill which can be used in the mines for blast-hole purposes. With the many advantages of rotary drills it is very possible that the small rotary drills if perfected for this type of work will decrease the effectiveness of the percussion drill. The CP-555 Rotauger discussed under auger drills may be considered a drill in this class.

**Hydraulic rotary drills**

The hydraulic rotary method is the predominant one used in the oil well drilling.

The general design of hydraulic rotary rigs consist of a bit attached to a string of drill pipe, which is actuated by a motor through a rotary table. All kinds of motors are used to drive them. Water and drilling mud are introduced through a water swivel and flows down inside the pipe, and the return sludge follows up between the outside of the pipe and the wall of the hole.

A picture of a small portable rotary rig is shown on page 31. A water well is being drilled in which plastic type of casing is used. This well 80 ft deep was pumping water 2 hours and 11 minutes after the drill was moved into position.
A list of some of the manufacturers of rotary drills are as follows: Stardrill-Keystone Company, Seismograph Service Corporation, The Winter-Weiss Company, Bucyrus Erie, Ingersoll-Rand, and Joy Manufacturing Company.

**Diamond drills**

Diamond drills are used for prospecting and blast hole drilling. These drills are powered by air, gasoline, diesel and electric motors. The diamond drill can drill holes in any direction. These drills can drill deeper than churn drills.

"In diamond drilling a core as well as a sludge is produced, the later being washed out by a stream of water introduced through the drill rods."³

The cost of diamond drilling generally runs from $2.00 to $5.00 per foot. At the Hollinger Mine costs are reported to be as little as $0.58 per foot, but for long difficult holes the cost increased above $5.00 per foot.⁶

Some illustrations of the use of diamond drills with different companies follows:

"Diamond drill blast hole stoping is used at the Tennessee Copper Company. It was primarily a safety measure to protect the miner in the sub-level under-hand stopes, where the mining bench had a tendency to slough off or fall away. Secondly, the economic factors involved were the estimated
greater productivity per driller and the minimizing of coarse muck from sloughing."

"Drilling is with Joy HS-15 machines, with 24-in. feeds, rotating up to 5000 rpm. This permits cutting rates up to 2.5 fpm. The two-ft "H" rods with adapters permit rod changing ahead of the machine. Standard EX concave plug bits are used and set with about 8.8 carats of highest quality bortz. The center of the bit is set with stones at 15 per carat; the kickers and outside stones are 25 per carat and the face is set with 40 per carat stones. The footage per bit averages 183, with 75 percent diamond salvage. An average of 135 ft of hole is drilled per man shift.

Due to the large fragmentation from the long diamond drill holes, which required nearly as much secondary blasting as did the primary blasting, experimental deep hole testing started in 1953 using 2 1/8-in. carbide insert bits for the purpose of larger holes and subsequently more powder for better fragmentation.

The deep hole drilling equipment consisted of 4-in. percussion drifter; one-in. hex., 3-ft change, alloy steel rods; 1 1/4-in. round lugged, 12-in. over-all, ring sealed shanks; 1 3/4-in. diameter rod couplings, and rod to bit adapters. Sixty-ft holes proved most efficient with this equipment, as the bits needed changing after this depth.

The blowing and washing apparatus of the 4-in drifters was found unsuitable to remove the heavy sludges from the
down holes. Air pressures greater than 75 psi and water pressure at least 120 psi were found to operate the drill efficiently and remove the sludge.

The diamond drill is better adapted to drill faster on holes 50 to 100 ft deep and is more advantageous to one-man operation. On the other hand, the deep hole machine, while drilling more slowly and requiring two-man operation, does drill a larger hole. This larger hole means that more explosives can be loaded, insuring better fragmentation and allowing a larger burden between slice rounds, therefore a lower cost per ton of ore broken is obtained.27

The results of a time study of blast hole drilling are as follows:

**Time Study of Test Drilling**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feet drilled</td>
<td>2.217</td>
</tr>
<tr>
<td>Feet per min, average (while drilling)</td>
<td>0.71</td>
</tr>
<tr>
<td>To change rods</td>
<td>45 sec</td>
</tr>
<tr>
<td>To collar hole with steel bit</td>
<td>1 min</td>
</tr>
<tr>
<td>To drill hole and set casing (on down holes)</td>
<td>3 min</td>
</tr>
<tr>
<td>To set dip on machine</td>
<td>1 min</td>
</tr>
<tr>
<td>Rod pulling, change bit and go back in hole</td>
<td>1.62 ft per min</td>
</tr>
<tr>
<td>Rod pulling (long holes)</td>
<td>2.13 ft per min</td>
</tr>
<tr>
<td>Average blowing and washing time (Holes 55-90 ft)</td>
<td>12 min</td>
</tr>
</tbody>
</table>

"Diamond drilling costs, in the Grants District, New Mexico, have averaged about $2.00 per ft, compared with approximately $0.75 per ft for wagon drilling. Below 60 ft, wagon drilling costs rapidly approach those of diamond drilling. Although the greater depth limits and representativeness of the sample favor the use of diamond drills for deep
exploration, the wagon drill is ideally suited for cheap exploration in favorable areas of shallow drilling."

Diamond drilling has lost out cost wise with tungsten carbide drilling for shorter holes, but for deep exploration the diamond drill still holds its own. The core remains an important means of sampling and of determining geological conditions. With many new types of core barrels for core recovery this method has not by any means been replaced with the dust collecting methods for sampling. "An interesting innovation in exploration drilling tools is the development of the Brown-Madson core barrel and driver, which was designed to produce from soft ore, structure samples which would not be contaminated or disturbed in recovery. Thus in addition to providing the usual chemical analysis, such samples also provide moisture, structure, and density data."29

Diamond drills have been used in many cases with other types of drills, viz., the churn drill. The churn drill is well adapted for drilling through the over-burden and when bedrock or non-friable material is drilled into the diamond drill comes into play.

The advent of the new chemical process for diamond production if economical may well give the diamond drill its former position before tungsten carbide came into being and it could possibly overshadow the percussion types of drills with its high drilling rates.
Auger drills

Auger drilling is a form of continuous extraction in that it completely replaces with a one-cycle operation the older conventional material. 6

Tremendous production in the coal industry is met by means of auger bits and drills. Adaptation of the alloying to this type bit may find its way into some metal mines with favorable conditions.

Large auger drills are now being mounted on truck chassis to increase flexibility.

The main use for auger drills are in prospecting, well drilling, and other soft type of rocks and minerals. The depth of the auger drill is limited to the depth of overburden, but most augers drill holes less than 100 ft, however, many have been used to as much as 300 ft.

Below are listed some auger drills from different companies.

The McCarthy Drilling Company makes auger drills ranging to 48-in. hole diameters. Their units are portable if desired.

The Chicago Pneumatic Tool Company has recently produced a machine called the CP-555 Rotauger. It is fashioned much on the order of a stoper. It was primarily designed for underground drilling of long blastholes in softer sedimentary formations, such as talc, gypsum, medium limestone
and the softer iron ores.

Actually the rotary method of drilling is used with sectional auger steel and drilling speeds range from 2 to \( \frac{1}{4} \) ft per minute. It can drill to 100 ft depth with 2\( \frac{1}{2} \)-in augers. It is powered by a 12.5 hp rotary type motor.

The Jeffrey Manufacturing Company makes a complete line of small electric and air auger drills. Many are hand operated and others are mounted on coal cutting machines as auxiliary equipment to speed the extraction of coal.

The Mobile Drilling Company manufactures a complete line of rotary drills. On page 31 is shown a picture of one of their small rotary rigs using auger type steel for drilling a well for water. The brochure of this company gives a complete price list of their drills and equipment which is in the supplementary volume.

A photograph on page 75 shows a portable auger drill used for shallow holes.

Anaconda experimented with the use of a Cardox-Hards-cog coal auger to determine if a cheaper method for uranium tunnel prospecking could be obtained. Using a 30-in. diameter cutting head, 4 holes were drilled; two holes on top of the two previous holes which formed the tunnel were drilled 65 ft long in 12 hours actual drilling time. They discontinued the work, but reported that with the proper adaptation of equipment such entries could be drilled economically. 16
The use of augers are very important and useful, but account only for a minor portion of the drilling done in the United States. The method is very fast and the cost per foot is low.

**Chilled-shot or calyx drills**

In chilled-shot drilling a core as well as a sludge is produced, the sludge being washed out by a stream of water introduced through the drill rods.

"In principle, shot drilling is similar to diamond drilling, but the cutting medium, instead of set diamonds, consists of loose chilled-steel shot fed into the rods with the wash-water and rolling under the bit. Shot drill holes are usually larger than diamond drill holes, in fact enormous bores five feet in diameter, for use as mine shafts, have been sunk successfully at Grass Valley, Cal., and Zenith, Minn., by placing the rotating mechanism down in the hole. In Northern Rhodesia, where the shot drill has found its greatest use in exploration, cores were four inches in diameter. The rods are considerably smaller than the bit, which means that the ascending return water slackens in velocity above the bit, and the heavy particles in the sludge fail to rise to the collar. Accordingly, the sludge is collected in a sediment tube or calyx (hence the alternative name Calyx drill), an open-topped hollow cylinder which forms an upward extension of the core-barrel."
In chilled-shot drilling slant holes at moderate angles from the vertical can be drilled. The Ingersoll-Rand Company manufactures calyx drills which produce cores as small as 1\(\frac{1}{2}\)-in. to as large as 72-in. in diameter. Depths as much as 2800 ft have been drilled.

The calyx drill is still used for drilling shafts and ventilation holes, but in recent years the costs have been excessive and this method is not used too frequently. As shown on page 17 the cost of a 36-in. calyx shaft was between $35 and $40.00 per foot.

The different rotary methods of drilling have progressed tremendously in the last few years; they offer low cost drilling with maximum drilling speed.
Jet-Piercing Drills

"The jet-piercing machine is probably the most revolutionary device for making blastholes; but even this is not a new method. It is the same principal as described in "De Re Metallica" wherein rock is broken by heating it with a wood fire and then cooled suddenly with cold water. The rapid changes in temperature causes the rock to spall. This is also the principle of jet-piercing."¹³

"The term "fusion piercing" was applied in early years to a method of producing blast holes because it was thought necessary to use a flux along with the fuel in order to actually smelt the hole into the rock. This term has now been replaced by "jet-piercing"."¹² It was later found out through tests that fluxes were eliminated by using a blowpipe, a radical new design using oxygen and fuel oil, and utilizing thermal energy to spall the material under tremendous heat. Unlike churn drills, pneumatic drills, and jackhammers which pulverize rock, jet piercing eats its way through ore and rock.

The new jet piercing process by Linde Air Products Co., produces blast holes in rocks such as granite, syenite, quartzite, sandstone, magnetic taconite, and even the hardest of spallable rock formations. Using supersonic jets of flame, it pierces rock at speeds which are sometimes as much as 10 times faster than conventional drilling methods. "The
flame which jets out of a rocket-type burner and disintegrates or spalls the rock in its path, is produced by a mixture of oxygen and petroleum-base fuel. Jet-piercing operations are continuous -- the force of burning gases, plus steam formed from cooling water which flows to the burner, carry the spalled particles out of the hole."

"Machines like The Linde Air Products Jet-Piercing machine will penetrate taconite rock at 90 to 150 ft per shift, and make possible the mining of 30 to 40 million tons of iron ore a year from the eastern end of the Mesabi Iron Ore Range.""14

"The first experiments in jet-piercing were conducted 16 years ago in the underground operations at the Sudan Mine of the Oliver Iron Mining Co., in Minnesota."12

The type of equipment listed below combines to make up a jet-piercing machine. "A standard Bucyrus-Erie N27T churn drill was converted for jet-piercing tests. A platform was provided on which the process controls for oxygen, fuel and water were located in such a position as to enable the operator to maintain complete control of lighting the burner, shutting down, and drilling. The fuel pump, water pump, and oxygen-regulating apparatus were mounted on the drill rig. The spudding action of the churn drill was changed to provide a 4-in. oscillatory stroke to the blowpipe instead of the 12-, 18-, 24-, or 36-in. stroke
normally used when churn drilling. A 3/4-in., 6 by 19 plow steel, left-lay cable is used, as it was believed that the power on the main hoist was large enough to snap a smaller cable should the blowpipe become jammed in the hole.

An auxiliary sheave or narrow reel was located on the mast about 15 ft below the top sheave. This facilitated handling the oxygen, fuel and water hoses in and out of the hole and prevented their looping. The hoses are attached at five intervals to the drill cable by means of toggle wrenches.

An adequate supply of water is important, as it keeps the combustion chamber of the copper burner from being consumed by its own heat. It also forms steam along with the combustion gases to eject continuously the spalled material from the hole. A water pump and small tank are provided at the drill rig to furnish water from the main water line at a pressure of 60 p.s.i. An electric light on the control board warns the operator of any water failure, so that the oxygen and fuel can be cut off.

An exhaust fan is installed at the front of the drill rig to remove the steam and exhaust gases from the vicinity of the operator. The suction side of this fan is provided with a screen to prevent the entrance of large rocks. The fan housing has a drain at the bottom to remove condensed water as well as fine rock particles.
The liquid-oxygen supply is delivered to the Linde Cascade storage unit by means of a truck. The present storage unit has a capacity of 40,000 cu. ft., or approximately four hours burning time. Oxygen is under a pressure of 2300 to 2400 p.s.i. at the storage unit and is reduced to the gaseous state for use in drilling at 150 p.s.i.

Water and oxygen are delivered to the drill through 2-in. standard pipelines and 1½-in. hose. The fuel or kerosene supply presents no problem, as the fuel is delivered by truck to a small, skid-mounted tank near the drill rig. The fuel pump on the drill rig takes its supply from this tank, which is moved or skidded to each drill site.

The blowpipe consists of a long, seamless, steel tube, at the bottom of which are attached the burner and hole sizer or reamer. Oxygen, kerosene, and water hoses are attached to the upper end of the steel tube. Oxygen and kerosene are carried to the burner through separate tubes inside the larger tube, and water is carried to the burner in the remaining space.

The burner is a single-orifice, high-velocity type, consisting of an atomizer section, a combustion section, and a face cap. The kerosene and oxygen are atomized, admixed and burned under pressure in the combustion chamber.
The hot burning gases are ejected at supersonic speed (velocity of gases has been determined to be 6,000 f.p.s.) from an orifice in the face cap. Water is emitted on the periphery of the blowpipe in a series of jets at a point just above the atomizer section.

The burner operates at a flow of 10,000 cu. ft. of oxygen, 40 gal. of kerosene, and 800 gal. of water per hour, respectively. The life of the burner itself depends on the arrangement of the cooling system along with a sufficient flow of water at 60 p.s.i. The burner is constructed from special oxygen-free bar copper with the face cap, combustion, and atomizer sections silver-soldered together. The present type of burner used in the tests is commercially feasible, but future operations may dictate an alternate burner design and possibly use of a rotating, multiple-jet type burner.

Various hole sizers or reamers have been tested, and no definite conclusions could be drawn as to the best type. Hole sizers 5\(\frac{1}{2}\) in. in diameter used in the burning or initial pass were of the 3-, 4-, and 6-in. prong and saucer-like types. The hole sizer, 6\(\frac{1}{2}\) in. in diameter, used in the reaming or second pass had four tapering ribs which were securely welded outside the shell.

Maintenance problems are not difficult or excessive. The face cap of the burner which is exposed to the sandblasting action of the cuttings is easily replaceable, as
it is silver-soldered to the burner. Current indications are that the face cap must be replaced after 20 to 25 hours of piercing. The life of the balance of the burner is estimated as approximately 300 burning hours. The hole sizes are built up locally to size by welding a hard facing material on the prongs or ribs. As certain abrasive solids pass through the exhaust fan some wear will occur, but as this installation is comparatively new, nothing is known of the life of the fan and ducts."

The operating results of experiments were as follows:
"Holes varied from a depth of 15 ft. for hole No. 1 to 116 ft. for hole No. 2. Most holes varied between 84 and 108 ft. in depth.

The time in minutes is recorded for the intervals from lighting the burner to shutting it off for both the first pass and the reaming operation. Table 1 shows the piercing time and rate of piercing in feet per hour. As more operating experience was gained, the average piercing rate, in feet per hour, improved.

<table>
<thead>
<tr>
<th>Hole No.</th>
<th>Total Depth</th>
<th>1st Pass Piercing Time in Min.</th>
<th>Piercing Rate in ft/hr.</th>
<th>Ream Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>237</td>
<td>---</td>
<td>598</td>
<td>---</td>
</tr>
<tr>
<td>4-5</td>
<td>1189</td>
<td>2366</td>
<td>268</td>
<td>2634</td>
</tr>
<tr>
<td>27-40</td>
<td>1100.5</td>
<td>2709</td>
<td>256</td>
<td>2965</td>
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<tr>
<td>40-50</td>
<td>938</td>
<td>1817</td>
<td>181</td>
<td>1998</td>
</tr>
<tr>
<td>50-82</td>
<td>3133</td>
<td>7225</td>
<td>667</td>
<td>7892</td>
</tr>
<tr>
<td>Totals</td>
<td>6705.5</td>
<td>---</td>
<td>1087</td>
<td>---</td>
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<td>4-5</td>
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<td>6705.5</td>
<td>---</td>
<td>1087</td>
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</tr>
</tbody>
</table>
Table 2 shows the average oxygen, in cu. ft., and kerosene, in pounds, consumed per foot of hole. Detailed records were kept for the first 15 holes as a check. The burner uses approximately 10,000 cu. ft. of oxygen and 270 lb. of kerosene per hour of burning time.

Some sections of holes were pierced at rates of 42 f.p.h. but the average rate is expected to be 30 f.p.h. The operating crew was recruited from a churn-drill crew and is constantly improving as experience is gained."

Table 2 - Average oxygen and fuel consumption/ft of hole

<table>
<thead>
<tr>
<th>Hole No.</th>
<th>Oxygen consumption cu. ft./Fuel consumption lb &amp; gal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ream 1st pass pass Average Total 1st Ream Pass Pass Average Total</td>
</tr>
<tr>
<td>1-3</td>
<td>---</td>
</tr>
<tr>
<td>4-15</td>
<td>331.9</td>
</tr>
<tr>
<td>Av.</td>
<td>---</td>
</tr>
</tbody>
</table>

The costs of jet-piercing are shown in Table 3.

Table 3 - Preliminary estimates of cost of jet-piercing

<table>
<thead>
<tr>
<th>Item</th>
<th>$ per foot of hole</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>$1.77</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>.20</td>
</tr>
<tr>
<td>License fee</td>
<td>.19</td>
</tr>
<tr>
<td>Water pumping</td>
<td>.01</td>
</tr>
<tr>
<td>Drill repairs</td>
<td>.10</td>
</tr>
<tr>
<td>Labor</td>
<td>.25</td>
</tr>
<tr>
<td>Total Direct Cost</td>
<td>$2.52</td>
</tr>
</tbody>
</table>

"Formerly drilling was done with churn and wagon drills, the latter accounting for one-third the total drilling. The Consolidated Quarries Corp. does not segregate churn and wagon drilling costs. The average footage drilled during the
past year, including delays, for churn drills was 1.6 f.p.h. It is expected that, in the future, 10 f.p.h. can be maintained by jet-piercing.

During 1951 primary drilling cost was 6.8 cents per ton for churn and wagon drilling. Using the above estimated costs per foot of hole, the costs per ton are expected to be lowered to approximately 5 cents."

A photograph of a jet-piercing machine is on the following page.

"The drilling of blastholes has been one of the problems confronting the commercial development of magnetic taconites. There are strong indications that jet-piercing has met and overcome this problem by giving a high unit production per machine at a reasonable cost per ton of ore in front of the shovel. To these advantages are added the flexibility possible in hole diameters and the current development of automatic control in jet-piercing.""

The future of jet-piercing looks extremely favorable. The method at present is used mostly on very hard rock types in quarries and open-pit mining. I predict that in the near future the use of jet-piercing will find its way into underground mines, where hard rock makes other methods of drilling too costly.
Ultrasonic Drills

The most recent drill to be manufactured, and as yet has not been applied to mining, is the Ultrasonic Machine Tool. It is made by the Raytheon Manufacturing Company.

"The Raytheon Ultrasonic Machine Tool converts electrical energy into mechanical motion by means of a Magnetoestrictive Transducer. This motion is transferred to a cutting tool which vibrates in a plane perpendicular to the surface of the work. As a frequency of 25 Kc, acceleration is on the order of 150,000 gravities for an amplitude of 0.004"."ll

"An abrasive such as boron carbide, silicon carbide or aluminum oxide in liquid suspension is made to flow between the vibrating tool and the work surface. The abrasive particles which are bombarded against the work surface at these tremendous accelerations are responsible for the cutting mechanism. A continuous supply of abrasive is maintained at the work surface and is recirculated by a specially-designed pump."ll

"Cutting tools are shaped in the male or female counterpart of the desired cavity or boss in easy to work cold-rolled or unhardened steel, and are attached to removable cone tips. The machine is built throughout to the highest machine tool standards. Transverse and longitudinal work table adjustments are made with ball bearing feed
screws with large micrometer dials. Table elevation is by crank, with the knee sliding on precision-ground dovetail ways. All electrical parts meet Raytheon's standard of Excellence in Electronics."

Specifications

Work Area
- Size of table 6" x 18"
- Longitudinal feed 15"
- Transverse table travel 5"
- Vertical travel of knee 12"

Transducer
- Input - variable wattage
- Coolant - water
- Spring calibrated
- Ball bearing support
- Rotary adjustment of tool
- Construction - stainless steel

Slurry Tray (casting)
- 12" x 8" x 3"
- Net Weight -------- 450 lb
- Electronic unit ---- 225 lb
- Abrasive pump unit --- 35 lb

Electron Driver
- Input 1.0 KVA @ 115 VAC 60 cy.
- Width 24" (including handles)
- Depth 18"
- Height 43" (including casters)

Abrasive Pump
- Type - centrifugal
- Power - 1/8 hp @ 115 V 60 cy.
- Height 18"
- Diameter 10"

The Raytheon Ultrasonic Machine Tool will cut, shape, slice, drill or grind the following hard materials:

- Alnico
- Aluminum
- Glass
- Ceramics
- Ferrite
- Germanium
- Granite
- Graphite
- Hardened Steel
- Quartz
- Ruby
- Stellite
- Silicon
- Sapphire
- Glass Bonded Mica
- Rixalloy
- Tungsten
- Tungsten Carbide

Many purchasers of the Ultrasonic Tool are using the tool for the following purposes:

1. Drawing Dies -- Working from either solid or cored carbide inserts, the approach and land can be machined for the most complex shapes. Finishes within 10 to 15 micro inches can be produced with average abrasives.

2. Blanking Dies -- Dies for complex shapes can be produced from single hardened steel or tungsten carbide blanks without sectioning. Dimensional accuracy can be held to 0.0003" and corners square well within 0.0005".
3. Extrusion Dies -- New materials such as Rexalloy which make possible extrusion of more complicated shapes with greater accuracy and longer die life can be machined as readily as standard die materials.

4. Ceramics -- Complex holes of any shape can produced with accuracy and without the problems of shrinkage or chipping associated with other processes. Ideal for producing multiple holes or holes of small diameter.

5. Quartz -- Rings or wafer-thin slices can be cut with smoothness that eliminates much of the lapping and finishing normally required to remove tool marks.

6. Semi- Conductors -- Dicing, slicing or multiple sawing of germanium, silicon and other materials used transistor applications are readily accomplished.

7. Glass -- Designs, ornaments or complex shapes can be cut in cameo or intaglio. Holes of any size including holes or slots of very small diameter (1 mil at 2 mil spacing) can be drilled; also holes of multiple diameter.

"Prior to the advent of ultrasonic machining, designers of machines, tools and complete products were restricted in their designs by the limitations of conventional methods of casting, forging and machining. Now a whole new manufacturing process gives them a latitude undreamed of five years ago. In this short time such things as cutting 0.004" slots 5/8" long in stainless steel in 10 minutes have become standard procedure. Sizing shaped wire drawing dies in carbide in 15 minutes, cutting a carbide stamp 0.025" deep in 2 minutes, sinking a complete blanking die of intricate shape in hardened tool steel to a tolerance of 0.0002" in 45 minutes, simultaneously cutting a dozen or more holes accurately spaced in ceramic spacers in a matter of seconds, dicing several hundred jewel bearings simultaneously in a matter of minutes,
all these and many more using soft steel or even copper or lead as the cutting tool."

The list price of the new Model T 2525 Raytheon Machine Tool is $5,850.00. The Model T 2525 is a stand model for shop use, but if a machine drill of this type could be adapted for use in mining some revolutionary speeds could be obtained at greatly reduced cost.

The most recent revolutionary tool that is being applied to the oil industry is the Bodine sonic oil-well drill. This drill will find great application in mining. It is so recent that very little information can be obtained, but the grape-vine speaks well for it. A photograph of its integral workings is shown on the following page.

The available information is as follows: "Borg-Warner's most exciting new product is the Bodine sonic oil-well drill. The drill uses the terrific hydraulic power in the well's column of mud to drive a turbine that turns a series of unbalanced gear weights at high speed. Vibrations set up in the drill are imparted to the bit with such force that the hardest rock formations crumble before it. The drill is used with an ordinary rotary rig, but tests indicate that the drill needs little rotation. It is reported to be from four to eight times faster in hard formations than present drills, twice as fast in soft ones."
Drill mud

Vibration-isolators

Mud-driven turbine

Seal

Mounting web

Unbalanced gear weights
Conclusion

The author hopes that the many trends that have been compiled in this report are of a beneficial nature to those interested in choosing a drill, in drills, and in drilling.

Research in drilling is the greatest contributor to new trends. The research in the mining industry has lagged other industries by a number of years. The cooperative method of research used by the oil industry should be adopted by other industries to keep pace with the ever changing demands.
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