DRILLING AND BLASTING IN THE DEVELOPMENT PHASE OF METAL MINING

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Drilling and Blasting in the Development Phase of Metal Mining

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By

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INTRODUCTION

In the preparation of this thesis, it was my intention to complete sufficient research so that I would have a knowledge of some of the basic fundamentals used in the theory and practice of drilling and blasting in metal mines. My training and experience have not been such that they would qualify me to quote even a small part of this thesis from first-hand knowledge. Therefore, the contents are purely of a library research nature. I believe, however, that this paper has been well worth my time if only for the fact that I have gained a rudimentary background in a field of engineering which may be of use to me in the future. Inasmuch as I could not locate any material on this subject at Michigan State College Library, this thesis may also prove to be of some benefit to any students who may be interested in the subject in the future.

When one considers the enormous amount of labor, power, and powder required to mine and to quarry products annually, one cannot fail to be impressed with the scantiness of literature on the economics and procedure in the use of explosives in metal mining.

The following figures will serve to illustrate the importance and magnitude of this industry. Of the 350 odd million pounds of dynamite manufactured during 1940, construction work used 100,000,000 pounds, metal mining 100,000,000 pounds, quarrying 50,000,000, and coal mining 85,000,000 pounds of dynamite plus 60,000,000 pounds of black powder. The rest was used in non-metallic mining and agricultural work. Upwards of 55,000,000 pounds are used to mine crude ore containing either gold, silver, copper, lead or zinc. Twenty million pounds are used for iron ore. Dynamite is being fired every hour of the day in charges ranging from a few ounces in the coal mines to great 50,000 pound explosions such as those used for blasting valuable molybdenum from Colorado's Bartlett Mountain.

Metal mining operations are usually of four types: prospecting, exploration, development and production. Prospecting involves the location of ores, and exploration the determination of the extent of the ore body. Blasting may or may not be employed in prospecting and exploration. Development is the work involved in providing access to the ore and in providing for systematic removal of the ore body, transportation, and ventilation. Production comprises removal of the ore on a commercial basis.

My original intention was to include all four of these operations in this thesis. However, as I learned more about the subject through research, I found that it would be necessary to limit the scope to one particular phase. Inasmuch as the development phase seemed to offer a more representative example of drilling and blasting procedures, I decided to limit my subject to this phase and present a more complete picture than could be done otherwise in trying to encompass the whole subject.

OPERATIONS IN THE DEVELOPMENT STAGE

As stated previously, the work which is included in the development phase is that which is necessary to provide access to the ore and provide for systematic removal of the ore body, transportation and ventilation. Development operations consist of drifting and cross-cutting, raising, and sinking. These differ from the usual tunnelling and shaft-sinking operations only in that they are frequently smaller in cross section and that less emphasis is laid on the speed of advance. Although drifting, raising and sinking operations are all included in the development stage in this paper, the stress is placed upon the drilling and blasting of drift and cross-cut rounds. This is the most important operation and the procedures used in raising and sinking are nearly identical, with a few exceptions that will be noted.

Drifts and Cross-cuts

Drifts and cross-cuts are horizontal tunnels of varying cross section but usually much smaller than railroad or vehicular tunnels. A drift will follow the direction of the vein or lode and a cross-cut is driven across the trend of the vein or formation. They may be driven for haulage or ventilation purposes. Strictly speaking, an inclusive term that could be applied equally to a round in the face of each would be "horizontal heading round", but such a designation is seldom used. Metal miners in general refer to a round in a horizontal heading as a "drift round", and this designation is used in this sense throughout the paper, irrespective of whether the heading is a drift or cross-cut.

Raises

As the name indicates, raises are small passages driven from a lower level to a higher level. They may vary in inclination from vertical to nearly horizontal and, of course, all drill holes will be pointing upward. They may be driven for drainage, ventilation, chutes and other purposes.

Sinking

Sinking includes shafts and winzes, which are passageways sunk from one level to a lower level. Shafts are normally sunk vertically and in a straight line as they are usually used for raising and lowering material. Winzes are almost always inclined and seldom straight. They are used for exploration, ventilation, or manways.

The term "stoping" may be used at intervals throughout the paper, although it is a part of the production rather than the development phase. It is defined as "mining the mass of ore between the levels".

SELECTION OF EXPLOSIVES

Grades and Composition

Mining explosives may be roughly divided into two classes -- those that have a heaving effect and those that deliver a shattering blow. Black powder, an explosive of the first class, is frequently used in quarry work where the material to be moved does not require shattering. Moreover, in quarry work two or more free faces are usually provided. A high explosive, such as a dynamite, which will shatter the rock is required for breaking most metal mining rounds.

The explosives most commonly used for underground work are gelatin and ammonia dynamites. Gelatin dynamite consists of nitroglycerin which has been gelatinized by the addition of nitrocotton, sodium nitrate, and carbon carriers, such as wood pulp or flour. This is most popular for mining hard ores and all kinds of underground work where the ventilation is poor and work must be carried on at high speed. Gelatin dynamite has the property of plasticity which enables the miner to make the cartridge stick in holes drilled upwards - a great advantage in stoping and raise work in metal mining. It is practically unaffected by water and produces a smaller amount of fumes than other types of dynamite. Where the ore is very hard, gelatin dynamite is used because of its high density, that is, it is possible to concentrate the maximum weight of explosive material in a small space. Ammonia dynamite consists of nitroglycerin, sodium nitrate, ammonium nitrate, and combustible material. It is used in iron ore mining, quarrying and construction work, coal mining and wherever the ventilation is good and little water is encountered. Both the gelatin and ammonia dynamites are made low-freezing by the addition of a small amount of nitrocellulose.

Straight dynamite, which is not ordinarily used underground because of the comparatively large quantities of carbon monoxide in the gases of explosion, consists of nitroglycerin, sodium nitrate, and wood pulp or other combustible material. While it is true that the straight dynamites are the quickest acting and most shattering of all explosives, they are more expensive, more sensitive to shock, and in general produce more fumes than gelatin and ammonia dynamites.

The grade of a straight nitroglycerin dynamite is indicated by the percentage of nitroglycerin in the explosive; for instance, a 40 per cent straight dynamite contains 40 per cent of nitroglycerin. The grades designated for gelatin or ammonia dynamites are more or less arbitrary and are supposed to be equivalent in strength to the corresponding grade of straight dynamite. However, each manufacturer follows his own standard, and two different brands of gelatin dynamite marked "40 per cent strength" may not have the same blasting strength and may also differ in other characteristics. The higher grades of explosive have more propulsive strength; therefore a greater amount of blasting energy can be contained in a given space such as the bore of a drill hole. Moreover, the higher grades generally have a higher rate of detonation, which is an advantage in blasting at many mines.

Gases from Blasting

In general, one of the main considerations in choosing an explosive for use underground is that the products of explosion shall contain a minimum of poisonous gases and smoke. There has been a gradual reduction in the quantity of poisonous gases in the products of explosion, and in this respect the explosives now used are much superior to those in general use several years ago. Even with the present explosives, however, enough toxic gas is present in the atmosphere after blasting to require effective ventilation to remove it before men return to work.

Strength or Pressure Developed

The strength of an explosive is apparently the result of three factors: (1) The heat generated, (2) volume of gases produced, and (3) speed at which the gases are evolved.

The pressures developed in bore holes with various explosives have been calculated by the Bureau of Mines as follows:

	Pounds per square in.
30 per cent straight nitroglycerin dynamite	120,230
40 per cent gelatin dynamite	120,110
40 per cent straight nitroglycerin dynamite	121,030
40 per cent ammonia dynamite	126,900
50 per cent straight nitroglycerin	132,300
60 per cent straight nitroglycerin	140,670

It should be borne in mind that some explosives may indicate strength or other quality when tested under laboratory conditions but behave differently in actual practice. However, these figures do show the comparative strength of the different grades of dynamite.

Size of Cartridges

The explosive used for blasting rounds should be put up in cartridges of as large diameter as can easily be loaded into the drill holes. In hard ground, density of loading is very important; the greatest density can be obtained with the largest diameter cartridges that will go into the holes.

The proportion of the weight of the paper shell to the weight of the explosive increases as the diameter and length are decreased; therefore, with small cartridges a relatively larger amount of paper and less explosive is purchased in each case. Although the paper enters into the reaction of the explosives as a carbon carrier, it is an unmixed ingredient and is responsible for part at least of the poisonous gases in the products of explosion. Also, weight for weight, the paper probably supplies less explosive energy than would a corresponding amount of a carbon carrier intimately mixed with the explosive.

Many miners consider a cartridge a cartridge and will use the same number for blasting a given round, regardless of the size of the stick or kind and grade of explosive. However, where blasting is closely supervised better results should be obtained by using larger cartridges.

Selection of an Explosive

Generally there is some particular kind and grade of explosive that would be the most economical to use for any given piece of work. As the conditions in most mines vary greatly, a large number of different explosives would have to be kept in stock if the best kind for each particular place were used. Generally one, two, or at the most three explosives are chosen, which will give the best average results throughout the mine. Gelatin dynamite has a number of characteristics that make it desirable for underground work in metal mines and tunnels, and it is more commonly used for the purpose than any other explosive. The natural insensitiveness to detonation of these dynamites is largely overcome by the use of strong detonators. Ammonia dynamite as packed in cartridges is often rather hard and consequently more difficult to tamp than gelatin dynamite. Its lack of plasticity makes it less desirable for loading holes steeply inclined upward. This class of explosive takes up moisture unless it is protected. Ammonia dynamite generally has an advantage in a lower cost per pound for a corresponding grade. Its greater bulk as compared with gelatin dynamite may be of advantage in blasting horizontal slabbing holes where it is desirable to have the explosive distributed along as much of the length of the bore holes as possible. Ammonia dynamite may also be better than gelatin for blasting in springy or spongy ground.

Practical experience has shown that straight dynamite is more dangerous to handle than gelatin. Undoubtedly a box of straight dynamite is more likely to detonate on being dropped than is a box of gelatin.

For blasting in easy-breaking rock, 35 or 40 per cent grade explosive is generally chosen. Even lower grades can be used satisfactorily for blasting stope holes in easy-breaking ground. In ground difficult to break, 50 or 60 per cent gelatin is usually better. The use of higher grades, 60 to 80 per cent strength, in the cut holes makes possible the breaking of longer rounds in most classes of rock. These higher grades also give fewer boulders when used in blasting in hard-ore stopes. An 80 per cent grade should not be used unless the ventilation is very good.

Only explosives that have been proved to be relatively safe to be handled and loaded should be used in mines. Other things being equal, the choice of explosives resolves itself into one of cost. Although more energy per dollar can be purchased in the higher grades, it is not economical to use a more expensive explosive where the work can be done as satisfactorily with one costing less per pound.

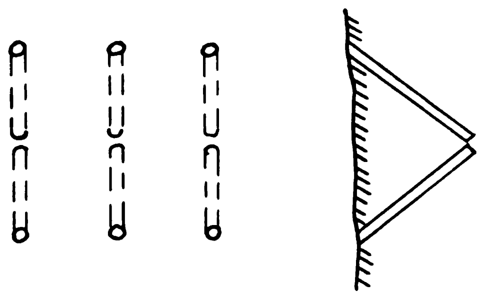
VARIOUS TYPES OF CUTS

Blasting in an underground development heading is always tight. There is only one free face to which the ground can be broken and this is usually of limited size. The first and most difficult step in blasting any heading is to make an opening into the solid ground, usually in the center of the face and as deep as practical to advance the face at one time. This opening is called the "cut" and although cuts may be pulled by a number of methods of drilling and blasting, they all serve the same purpose, namely, to form a second free face to which the remainder of the holes in a round can break. It is therefore obvious that the cut is the most essential part of the round as the rest of the holes cannot possibly pull, unless the cut comes out completely.

The designation of the holes in a round vary with the individual mines. However, the terminology used in this paper for these holes is as follows: The first holes to be blasted in a round are called the "cut holes". The holes immediately above the cut holes are called "breast holes". Those drilled next below the cut holes are designated "skimmers". The holes at the top of the face are called "back holes" and those at the bottom "lifters". Extra holes drilled to assist any hole or set of holes are called "relievers". In large faces the holes at the side of the face for squaring it up are called "side holes".

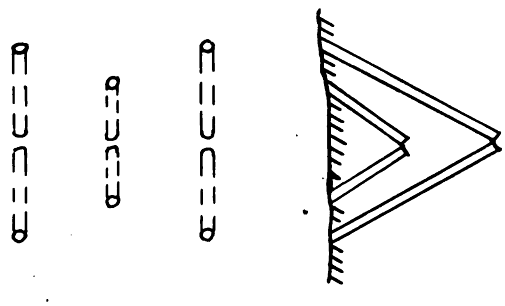
"V" Cut

The V or wedge cut is one of the oldest and still most commonly used. It consists of a pair of holes drilled so as to meet or practically meet at their bottom to form a "V", or two or more pairs of V's in parallel planes to form a wedge (Figure 1). V-cuts in drifts may be horizontal or



Typical V or Wedge Cut

Fig. 1



Double V-cut Showing "Baby" Cut

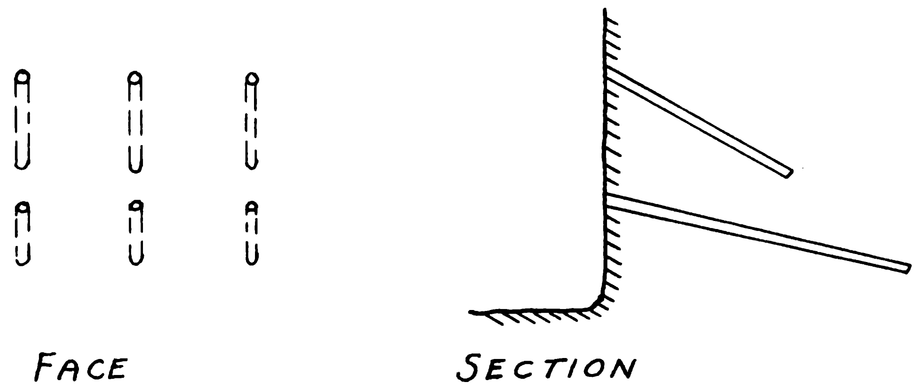
Fig. 2

vertical, the type selected commonly being the one allowing the wider angle to be drilled. Usually bar drill mountings are used for the former type and column mountings for the latter. In deeper drilled rounds or in very hard rock, cuts may consist of double V's (Figure 2), the outer and shallower V-cut being known as the "buster" or "baby" cut.

"Draw" or "Toe" Cut

This type of cut is a modification of the V cut. It is located away from the center of the face and often the holes are purposely drilled so that they do not meet. The

bottom draw cut illustrated (Figure 3) is most common, although it may be located at the top or side of the round.

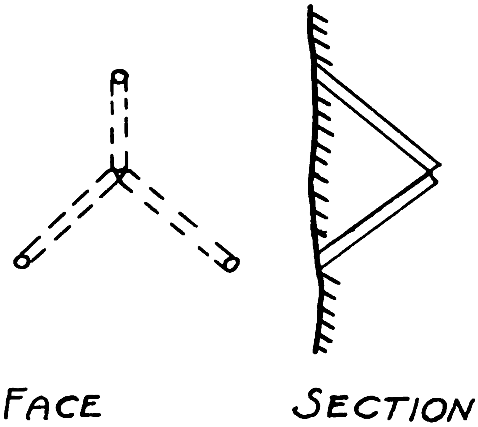


Draw Cut
Fig. 3

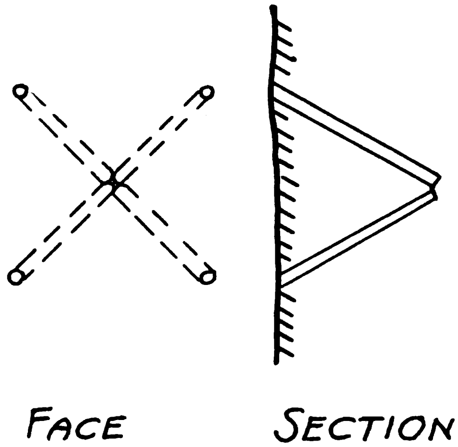
It is particularly useful in small headings, (less than 6 x 6), where drilling must be done with unmounted hammer drills, and where due to lack of room it is difficult to drill a cut in the center of the face.

"Pyramid" Cut

The cut which is probably next in popularity to the V-cut is known as the "pyramid" or "diamond" cut. This consists of three to six holes (Figures 4 & 5) drilled to meet at a single apex near the center of the face. The V-cut or pyramid-cut rounds have an advantage over the toe cuts, inasmuch as two or more charges are detonated together. The added explosive makes it possible to break deeper craters.



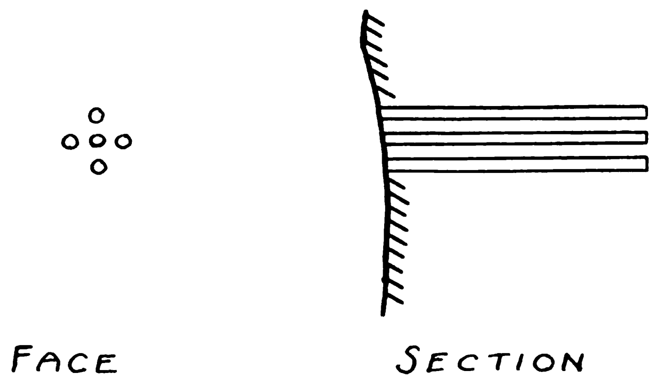
Three Hole Pyramid
Cut
Fig.4



Four Hole Pyramid
Cut
Fig.5

"Michigan" or "Burn" Cut

This type of cut is known also under the names of "burn out", "Cornish" and "shatter" cut. There are many variations of this cut, but all utilize the same principle. Unlike the V or pyramid cuts which are designed to break out a wedge or cone of rock, the burn cut is intended to shatter or pulverize a small section of rock which can be scraped out if not already expelled by the blast, to leave a roughly cylinderical opening approximately perpendicular to the face. This cut consists of three or more holes all drilled in a closely spaced pattern(Figure 6) perpendicular to the face and as nearly parallel to the line of the drift as possible. One or more of the holes is not loaded, but is present in the round to provide space into which others can break. Also, at least one hole must be loaded to the collar, since if this is not done, the collars of the holes may remain intact even though the cut may be broken inside,



Michigan or Burn Cut
Fig. 6

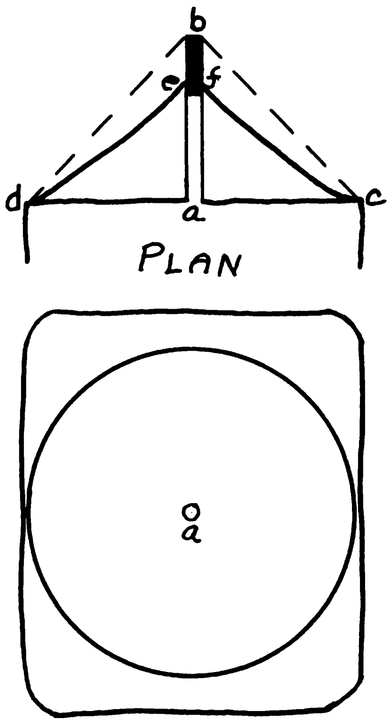
in which case there is seldom anything that can be done except to drill and blast a new cut. One disadvantage of this type of cut is that it is always necessary to return and make certain that the cut is completely out before firing the remaining holes.

THEORY IN THE DESIGN OF ROUNDS AND THEIR DEVELOPMENT

Crater Theory

Before any of the holes of a round are blasted only one free face is exposed in a heading. After the cut holes are broken the succeeding holes have progressively more free faces up to the last lifters and back holes, which have between two and three free faces each to which to break.

According to the crater theory, a normal hole drilled straight in the heading with one free face in homogeneous rock should, on blasting, break out in a funnel-shaped crater, the sides at an angle of 45 degrees to the face. This angle has been considered as being the line of least resistance and is shown by lines "bd" and "bc" in Figure 7. The theory presupposes that the explosive charge is enough to overcome the resistance of the rock and is concentrated at point "b" at the bottom of the hole; in most rounds the explosive is distributed along the bore. Actually, the crater broken by blasting such a hole will be more along line "de" and "cf", depending upon the characteristics of the rock and the speed and strength of the explosive.



Front Elevation
Fig. 7

In blasting out of the solid, the explosive encounters resistance which is practically infinite in all directions except toward the surface. The size and shape of the crater will be influenced by the amount of force reflected back from the sides, which in turn, depends upon the elasticity and compressibility of the rock. In rock that takes a relatively smaller amount of energy to overcome the tensile strength in proportion to that required to shear it, the angle of the crater will be wider. If the rock has a high tensile strength, the break will be more by shearing, in which case the crater will be narrower.

If the explosive is too slow or of insufficient strength, no rock, or only a small amount at the collar of the hole, will be broken. If more explosive of a high rate of detonation is used than is needed to break the line of least resistance, the rock may be broken beyond this line.

Should the holes of a round be drilled no deeper than would allow the explosive to break the rock only to the theoretical line of least resistance, the advance per round could be only one-half the shortest dimension of the face of the drift, which would not be satisfactory in most work.

Except in very easy breaking rock, it is not practicable to break a round with holes drilled straight in the face; therefore, the cut holes are drilled on an angle to the face. By doing this, the line of least resistance is not along the direction of the bore holes but through the solid rock; also more of the explosive is behind the rock to be broken. Other things being equal and within practical limits, as the resistance of the rock increases, more pitch must be given the cut holes in order that they may be broken to the bottom.

Disregarding, for the time being, the occurrence of planes of weakness in the rock, when a charge in a round is detonated, it must detach the rock from the solid mass and overcome the inertia of the rock to be moved. The rock is detached by crushing, shearing, and overcoming its tensile strength. Less energy is required to overcome the tensile strength of rock than to shear it. Crushing requires more force than shearing.

Planes of Weakness

Were it not for planes of weakness in the rock, the amount of explosive of known propulsive energy required to break a given round could probably be calculated by determining the resistance of the rock to be overcome. It can readily be conceived that the existence of planes of weakness in the rock is an important factor governing the quantity of explosive required. For example, suppose that the ground in which a drift round was drilled was cut up by planes of weakness, making the rock similar to carefully piled bricks. In this case, the only force required of the explosion would be to overcome the inertia of the rock and the friction of the blocks on each other. The hardness, toughness, or mechanical strength of the rock would exert no influence on the amount of energy required. Going to the other extreme, to a face in which no planes of weakness occur, the physical characteristics of the rock would completely govern the quantity and quality of explosive required to break a standard round. As the planes of weakness in the rock decrease such characteristics of the rock as hardness, toughness, porosity, cohesion, and probably other qualities have an increasing influence upon the amount of explosive required to break a round. The rock in metal mines almost invariably contains some planes of weakness due to external forces. Also, the rock generally contains jointing planes.

Where standard drift rounds are used in mines, consideration should be given to the planes of weakness or slips in the rock in working out the standards. In a bedded formation standing at an angle, it is quite likely that the best form of round for a heading running with the formation would not be the best type in a cross-cut. Also, a round in a drift on a vein with a well-defined free wall should not be the same as in a heading in country rock. In the first case, the round should be designed to break to the wall, which would correspond to a major plane of weakness.

Where standards are not used, some miners drill their rounds to take advantage of planes of weakness, but the majority do not. At many mines the planes of weakness have a definite relation to the lode, and each plane represents a series of slips extending throughout the formation instead of just being one slip.

Classification of Planes of Weakness

To be able to ascertain the effect of the planes of weakness in rock under any given set of conditions, a method or plan of classifying the planes is necessary. There is no universally applicable plan. To be of value, a classification must be worked out for each mine or district. A table is given here to illustrate the method used at a western metal mine.

Symbol	Planes		
	Major	Minor	Jointing
1	None	None	No assistance.
2	None	None	Indistinct assistance only.
3	None	48" apart, 1 way.	6" apart, 2 ways.
4	None	36" apart, 2 ways.	6" apart, 2 ways.
5	None	24" apart, 1 way.	6" apart, 2 ways.
6	None	24" apart, 1 way; 1 at right angle.	6" apart, 2 ways.
7	None	24" apart, 2 ways.	4" apart, 2 ways.
8	None	24" apart, 1 way; 12" apart, 1 way.	4" apart, 2 ways.
9	None	12" apart, 2 ways.	4" apart, 2 ways.
10	1 with drift.	12" apart, 2 ways.	4" apart, 2 ways.
11	2 with drift assisting.	12" apart, 2 ways.	4" apart, 2 ways.
12	2 with drift assisting.	8" apart, 2 ways.	4" apart, 2 ways.

Classification of Planes of Weakness in Rock, Bisbee (Ariz.) District
Table 1.

In the table the term "major" is used to designate fault planes or well-defined fractures along which there is no adhesion of the rock on either side. These major planes are generally identified by talc or slickensides.

The term "minor" is applied to well-defined bedding planes or fractures along which the rock has a tendency to break on blasting. To be classed as "minor" the planes of weakness must be extensive enough to influence the break.

The term "jointing" refers to the jointing planes in the rock. These planes assist the explosive in crushing the rock, as in blasting the first cut holes. Incipient fractures also are grouped in this class.

This classification considers planes of weakness only in one or two dimensions. Where slips occur in all three dimensions the rock is ordinarily called "blocky" and is correspondingly easier to break. At mines where the rock is blocky a different table of classification would be necessary.

The rock is classified by inspecting the face, tops, and sides of the drift at the face. Slips parallel to the drift are shown in the face; cross slips are estimated by those appearing in the drift for the same distance back of the face as the depth of the round. Of course, the number and kind of cross slips can not always be accurately determined in this manner, but in a large majority of cases a close approximation can be made.

The planes of weakness in a face will very seldom conform exactly with any one class, but judgment must be used in putting the face in the right column. If alteration has occurred along the minor slips, the rock will be easier breaking, and the face must be put in a class requiring less explosive. If recementation has taken place, the influence of the planes of weakness will be reduced and a higher classification must be used. Also, in some cases planes of weakness in the rock will not affect the break favorably or may influence it adversely. This generally can be deduced from an inspection of the face. Cross slips in the rock may reduce the break of the round. A well-defined slip of a foot from the face in a four foot round would probably limit the break to three feet. The same slip at the end of the holes would probably increase the break. Soft places in the rock and other fractures may offset the advantage of planes of weakness in some cases.

Theory in Design of Rounds

Rounds should be so designed that each hole can break as nearly as possible to the lines of least resistance. Cut holes should be drilled to break a cavity in the center of the face. Each succeeding hole should be placed to take full advantage of the cavity made by preceding ones. The side holes, when blasted next after the center cuts, break out to the first crater by shearing and overcoming the tensile strength and shear or crush the rock out to the line of the heading. Equivalent holes above or below have an advantage in that less crushing is required, as there is a larger area in the face to which they can break.

Theoretically, it appears that in breaking rounds a wedge-shaped slot with a length at the face equal to the shortest dimension of the heading should be broken in the middle of the drift in the line of the largest dimension. Next a cross slot should be blasted out the full width across the middle in the other direction. The succeeding holes, which are mainly slabbing ones, should be placed to break into the opening already made. These succeeding holes should also be so arranged that the lines of least resistance from the explosive are as nearly the same as practicable in all directions in which the break is required. To secure this in some of the holes, a special distribution of the explosive in a hole will occasionally be necessary.

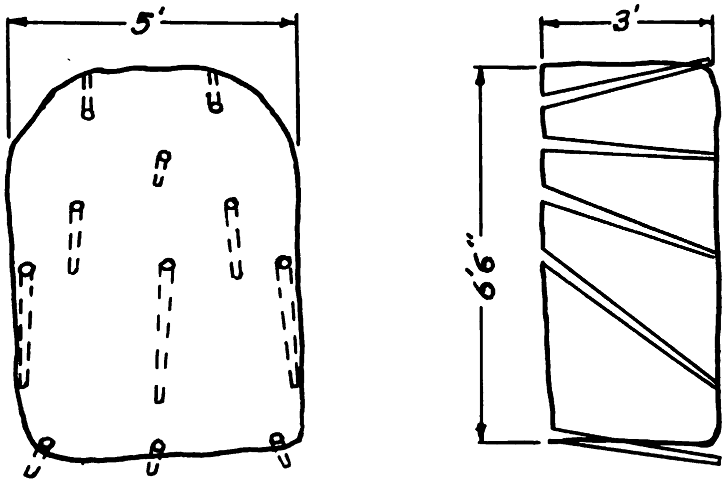
The force of the detonation of previous holes frequently collapses some of the holes in a round, particularly the lifters, as was found in blasting tests where rounds were shot one hole at a time. This is more frequent in overloaded rounds or in plastic rock. Also, the rock may move along a plane of weakness and partly collapse a hole. Fuze may be cut off or pinched by this ground movement and cause misfires. Therefore, rounds should be designed with this in mind and the holes placed to reduce this hazard to a minimum.

Development of Drift Rounds

In the early days of mining, when holes were drilled by hand, each hole was placed to take advantage of the planes of weakness in the rock, the contour of the face, or other features that would assist in blasting the ground. Explosives were used more effectively, both because each hole was drilled to the best advantage and because shorter rounds were shot. The men soon learned by experience the best method of blasting each face, and they could generally ascertain the rock broken by each hole.

With the advent of air drills, longer rounds were drilled. The first machine rounds drilled were patterned after the hand-steel rounds, except that holes with a downward angle were substituted for holes pointing upward. Flat or upward-inclined holes were difficult to drill with the old piston machines, which were the first type to be used in metal mines. The modern Leyner-type machine, which forces air and water to the cutting edge of the bit through hollow steel, cuts faster where the removal of drilling cuttings is assisted by gravity. However, the drilling speed of many machines now on the market is so fast that drilling upward-pointing holes gives but little material advantage.

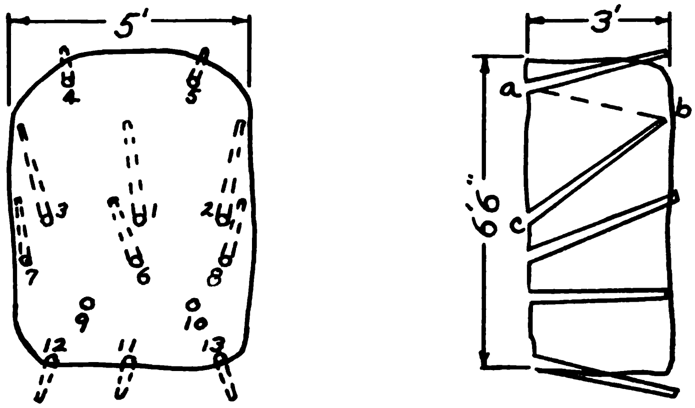
The first type of round drilled with the piston machine is shown in Figure 8. Practically the same round is now being drilled, using a crossbar, at some mines, ex-



Toe Cut Round Drilled with
Piston Machines
Fig.8

cept that the two back holes are generally drilled at an upward rather than a downward angle. As most drifts are wider at the bottom than at the top, the cut holes have a better chance to break when drilled downward.

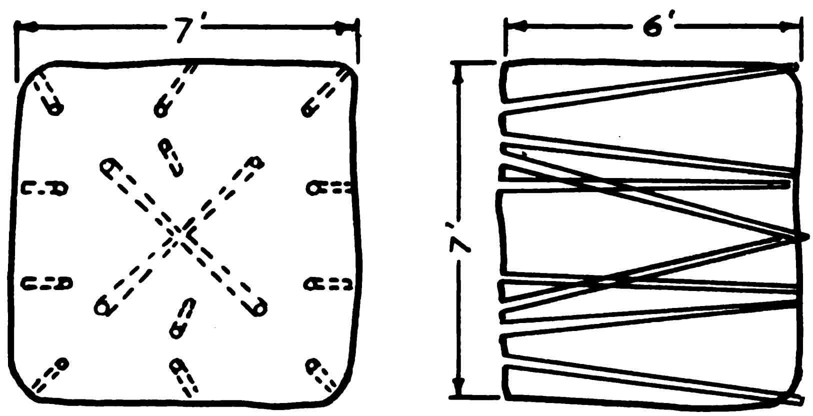
To take advantage of the faster drilling speed of upward-inclined holes with the Leyner machines, a round as shown in Figure 9, is drilled at some mines where the broken rock is removed previous to drilling in the face. Under favorable conditions, after blasting the cut holes 1, 2 and 3,



13-Hole Round with Upward Toe Cut
Drilled with Leyner Type Drill
Fig. 9

a wedge-shaped section of the face will be removed, as shown in the side elevation by the lines a, b, c. The other holes have the openings made by the first ones to which to break. When the cut holes break well, the subsequent holes normally break to the bottom without difficulty.

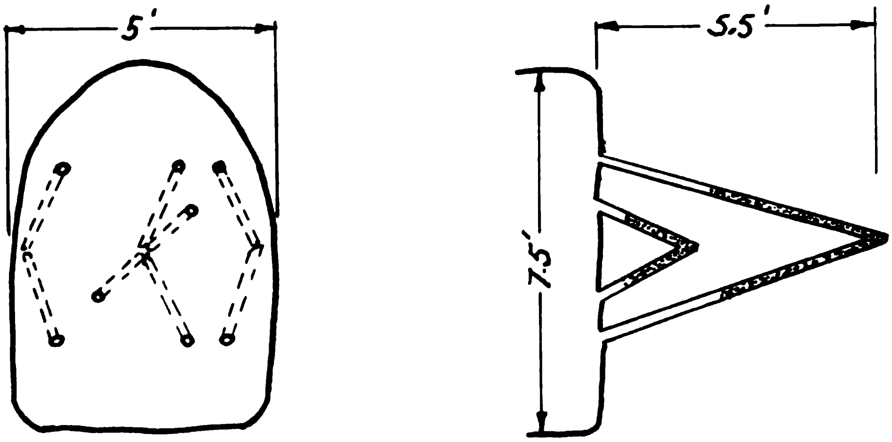
The introduction of faster drilling models made possible the drilling of deeper rounds in a shift, but it was found that the full depth of the longer toe-cut rounds was rarely broken except under very favorable conditions. As the depth of round that can be broken depends largely upon the execution done by the cut holes, many experiments were made to develop forms of cut holes that would break more ground than the toe cut. As a result of these investigations, the V-cut and pyramid-cut rounds with a number of variations were developed. In a pyramid-cut round three or four or even more holes are drilled to bottom together or close enough together that they will detonate simultaneously. A four-hole pyramid-cut round is shown in Figure 10.



16-Hole Round with 4-Hole Pyramid Cut
Fig. 10

In ground particularly difficult to break or in deep rounds, advantage is sometimes gained by drilling either a short single hole or a pair of holes to relieve the main cut holes of a round, as shown in Figure 11.

It is very important to know how the holes of a round break in choosing the best form of round for any particular class of ground. Quite frequently improvement in placing the holes and in the distribution of the explosive is suggested by observing the results of blasting rounds a hole at a time.



Short Cut Holes to Relieve Burden of Main Cuts
Fig. 11

Depth of Rounds: The drilling and the blasting of rounds are closely related and must be considered together in developing methods for breaking rock. Several factors govern the number of holes and the amount of explosive required for any particular round. At most places, a low cost per foot is desired for all headings. Sometimes speed is more desirable than low cost, in which case the most economical manner of performing all operations can not be carried out.

Experience has shown that in many instances, the most economical round to drill in a drift is one that can be finished and blasted in one shift; it is also desirable to break only as much material as can be removed in the next shift to keep a cycle of operations. Sometimes in large headings or in ground that is easily broken, it is possible in one shift to drill a round that will break more rock than can be shoveled out in the next unless a mechanical loader is used. In hard or medium ground, however, the shovelers can ordinarily remove as much rock in one shift as can be broken in one blast on the preceding shift. At most places blasting in drifts is done only at the end of a shift, thus avoiding the interruption of other operations and the pollution of the mine atmosphere.

Where blasting can be done at any time or where operations are continuous, as deep a round as can be broken may be drilled. At some places such deep rounds are drilled that the cut holes must be re-blasted several times to get a full break.

The depth to which a round can be broken depends upon the following factors, which are more or less related to each other:

1. Planes of weakness of the rock.
2. Physical characteristics of the rock.
3. Kind, grade, and quantity of explosive.
4. Distribution of explosive in holes of round.
5. Number of holes in a round.
6. Cross section of heading.
7. Form of round.
8. Diameter of drill holes.

In blasting, the rock must be taken as it comes. The planes of weakness constitute the most important factor concerning the rock that limits the depth to which a round can be blasted. The physical characteristics of the rock are important but are subordinate to the planes of weakness.

The depth to which a round can be broken depends obviously upon the explosive used and its distribution in the holes. These matters will be discussed later.

The number of holes in a round determines the distribution of explosive in the face and the quantity that can be loaded. Frequently the number of holes drilled depends upon the time available. If the ground looks difficult to break and he has time, the miner may drill an extra hole; otherwise he will load heavier those already drilled.

The size of the heading determines the angle that the cut holes can be drilled, which in turn, affects the depth to which a round can be broken. The depth and angle of a cut hole is limited by the distance from the collar of the hole to the limits of the drift on the line of the hole, a distance that must equal or very nearly equal the length of the longest steel used. In long holes, the bit of the last drill will be one-fourth to one-half inch smaller than the diameter of the hole at the collar, which allows the steel to be pushed into the hole even if slightly out of line at the start. The most economical height of drift in development work may depend upon the cost of disposing of the blasted material. Where the waste is desired for filling in stopes or where a short tram to a dump is available, a drift eight feet high may cost less to run than one only seven feet high. If disposal of waste is costly, a higher blasting cost due to a lower back may give a lower cost per foot advance.

The form of round is important, and under some conditions a longer advance can be made with one form of round than with another. In hard ground, the distance possible to break may depend on the inclination of the cut holes. With the size of the heading remaining the same, the deeper the round the less angle can be given the cut holes.

There has been a tendency to reduce the diameter of bore holes to lower drilling costs. Within reasonable limits it costs less to drill holes of small diameter. However, in the smaller diameter holes, less explosive can be used. This disadvantage in some cases can be compensated for by using a higher grade explosive that will contain the same breaking energy in a smaller compass. The diameter of the holes should not be reduced to less than one inch, as below this diameter the explosive may not detonate at its high rate. The drill-steel stock used at most mines prevents holes of smaller diameter being drilled.

As the time taken to set up and take down the drills is the same, the cost per foot of drilling holes in deep rounds is less than in short ones, other conditions remaining the same.

The cost of drilling is the major item in advancing a drift. The cost of explosive is about one-third of the cost of drifting; therefore, it would appear economical to blast as long rounds as could be practically drilled and broken.

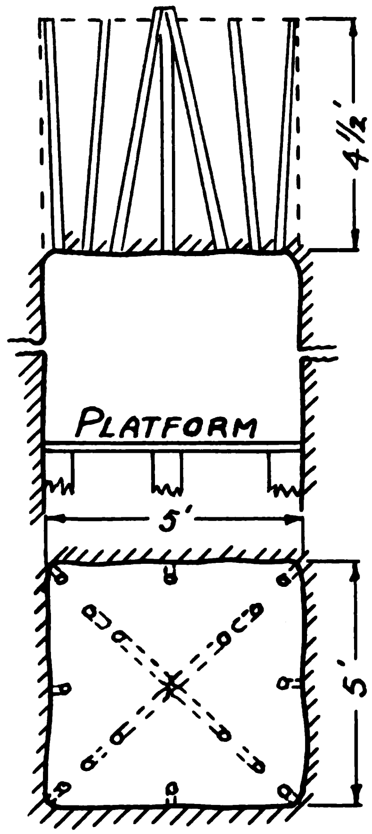
Standard Rounds: Certain kinds of rounds seem to be favored over others in some districts, irrespective of the kind or nature of the rock or improvements in explosives. Miners are conservative by nature, and once they have learned to drill any particular form of round it is difficult to change their ways. At some mines a form of round favored by the superintendent or foreman is used, whereas another form might be better suited for the conditions existing there.

Where the individual miners are skilled in placing the holes of a round and have no inherent prejudice, the best results can be obtained by leaving them free to drill and blast the holes to take advantage of all favorable conditions in each round. Many such skilled miners are still working in the mines, but the proportion of workmen who do not have an adequate knowledge of the effect of the explosive is so large that where the form of round drilled is left entirely with the miners, the best results throughout the mine are not always obtained. Under such conditions a standard round worked out for average conditions for each type of ground would seem desirable.

Instances have occurred where green men taught to drill rounds by a standard have made better progress than miners whose experience has been gained elsewhere, and who, influenced by their preferences, insist on drilling a modification of the standard round.

Raising Rounds

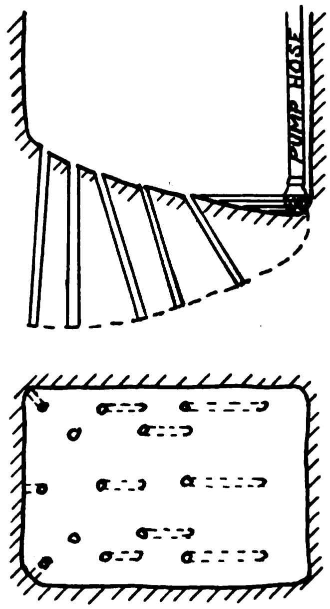
Raises are small passages driven from a lower level to a higher level. They may vary in inclination from vertical to nearly horizontal and all holes will be pointing upward. It is necessary to build a platform for the men to drill from and ordinarily, this platform is left in place during the shooting to catch the ore and control its descent to the mucking level. Figure 12 shows a typical raise round in moderately hard rock. The method for blasting this type of round will be discussed later.



Vertical Raise Round
Fig. 12

Sinking Rounds

Shafts and winzes are passageways sunk from one level to a lower level. Figure 13 shows a satisfactory type of shaft round for small shafts. It does not utilize the usual wedge or cone-type cut but makes use of a principle known as a "sumping" cut, in which each round forms a sump to collect the water so that it can be pumped out easily and leave a relatively dry bench on which the men can do their drilling. This type of round is almost a necessity in very wet work.

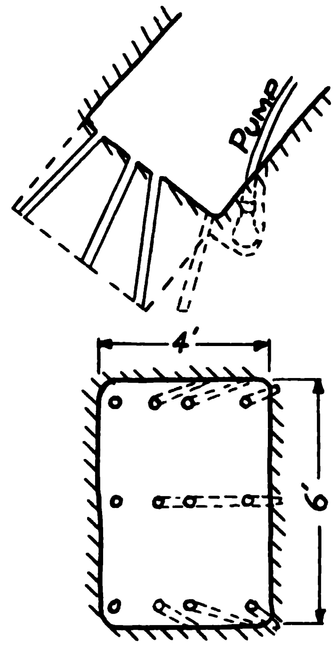


Small Shaft Round with Sumping Cut
Fig. 13

One of the greatest items of expense in shaft sinking is the drilling which normally cannot be carried on until all of the rock from the previous blast has been mucked out. Hammer drills are usually employed as they are much more flexible and rapid than arrangements for mounting the drills on cross bars. The number of drills that can be used depends, of course, upon the size of the shaft. The holes should never bottom less than 1 1/4" in diameter and preferably larger in order to allow the placing of more explosive in the toe of the hole where it is needed. The most economical size of dynamite cartridge for hard rock is usually 1 1/4 x 8" and this will require a hole bottoming from

1 3/8 to 1 1/2" in diameter. As in the case of tunnels, both the diameter of the shaft and the type of rock govern the number of holes necessary to pull the round.

Figure 14 shows a winze round using a draw cut. This type of cut is very practical if the winze happens to run along a vein or slip. If there is a free parting at



Winze Round Using Draw Cut
Fig. 14

this point it is usually unnecessary to drill the holes along the bottom, although it is advisable to put in one of the lower corner holes and shoot it last in order to furnish a sump.

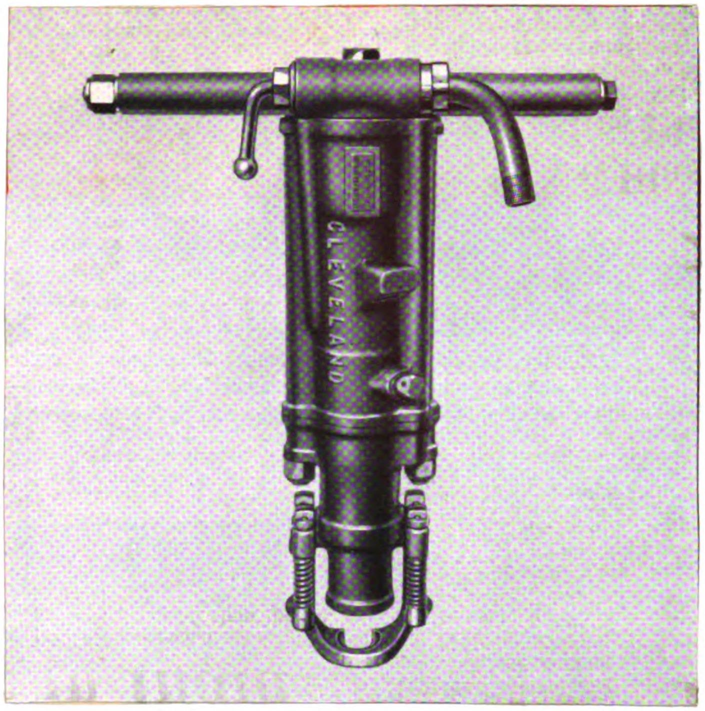
DRILLING MACHINERY

Three methods of drilling rounds are used in American metal mines: (1) by drills from mountings set up at the face, (2) by means of unmounted drills held in the hands of the operator, (3) by hand power. The last method of drilling is seldom used in present-day mining and will not be discussed in this paper.

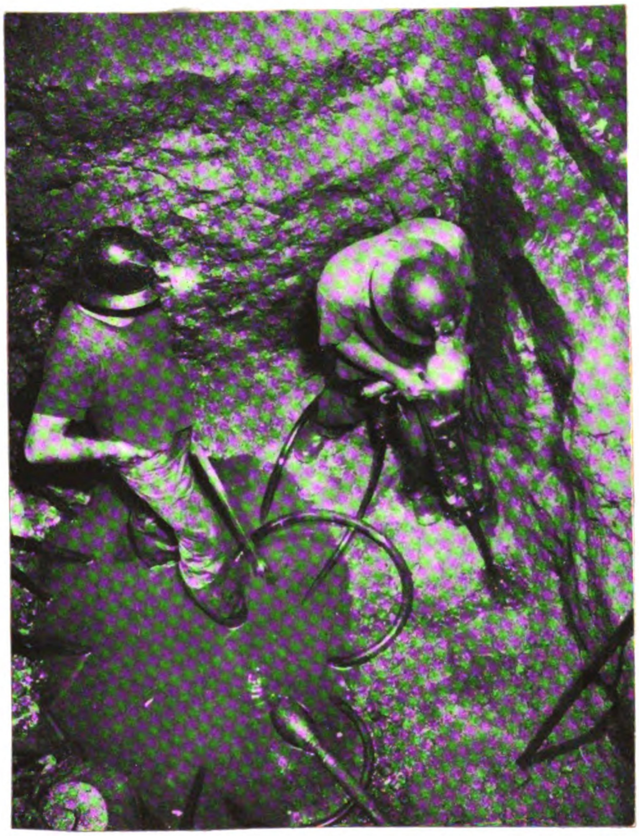
Hammer drills operated by steam or compressed air have largely replaced the older piston-type drills in metal mining. These drills can be operated either wet or dry. The Leyner drill is an American drill especially adapted for use in rock where a water jet enables a bit to cut faster. The Leyner drill has a hollow drill rod through which the compressed air forces the water which escapes through holes near the bit. The compressed air is the principal agent in cleaning the hole, the water laying the dust and assisting in the cleaning. The drill steel is not fastened to the drill piston, and is not churned up and down in the hole, but is struck by the piston, which also rotates the drill bit automatically.

Sinker Drill

This drill, which is usually operated by compressed air, is most serviceable for drilling holes up to 10 feet in depth, and is adaptable for use in drilling bore holes for shafts. The drill is comparatively light and easily carried. The required air is furnished by a portable compressor when a stationary compressor outfit is not convenient.



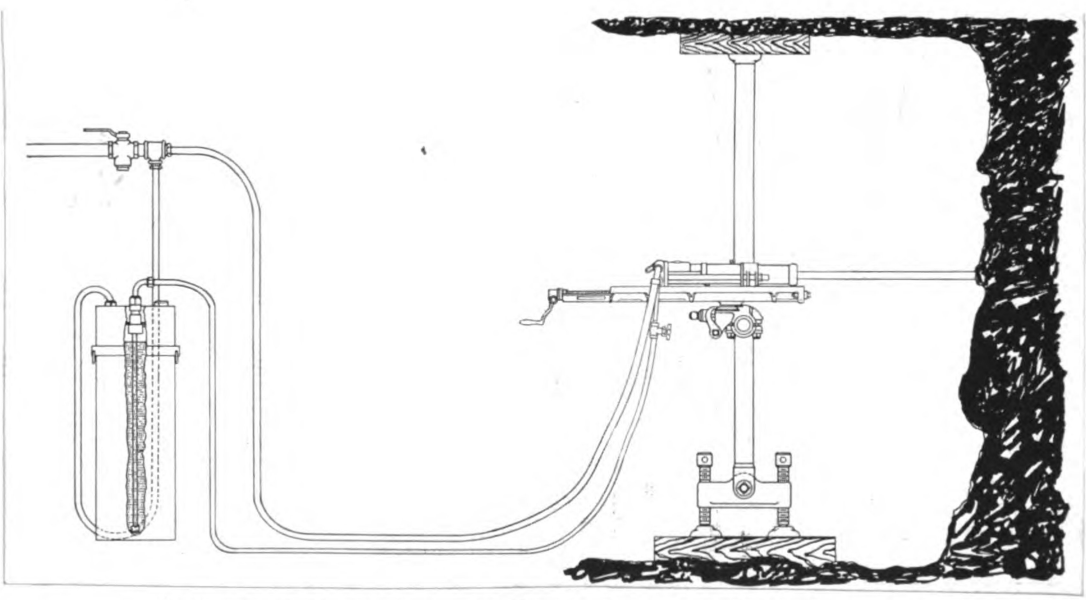
Sinker Drill
Illus.1a



Sinker Drill Operating in Shaft
Illus.1b

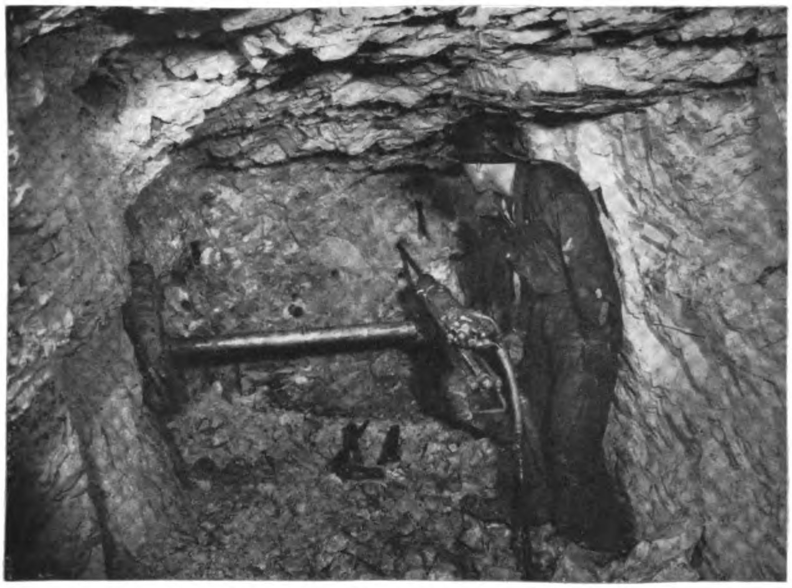
Drifter Drills

A slight modification of the mounting permits the hammer or sinker drill to be mounted on a vertical column or horizontal bar in a drift or cross-cut. This permits rapid drilling, and is much used in tunneling and mining operations. When the vertical column is used the drilling machine is mounted on a cross arm on the column. This arrangement allows latitude in starting holes in a face, as the drill can be used in any position desired. Holes are generally drilled in sequence, beginning at the top of the face. The broken rock from the previous round must be removed or thrown back from the face to allow the column to be set up. When rounds are blasted on each shift, extra work is required to shovel back the broken material to set up the column. Illustration 2a shows a wet drifter mounted on a vertical column, with the arrangement of water tank and hoses.



Wet Drifter Mounted on Vertical Column
with Arrangement of Water Tank & Hoses
Illus. 2a

At most places where drilling must be started before the broken rock is removed, crossbars are used. Most of the holes can be drilled from a set-up at the upper part of the drift above the broken material. By the time these holes are drilled the rock is generally removed, then the bar is torn down and set up again at the bottom to drill the lifters and at some places, other holes of the round. Illustration 2b shows the drifter mounted on a horizontal crossbar.



Drifter Mounted on Horizontal Crossbar
Illus. 2b

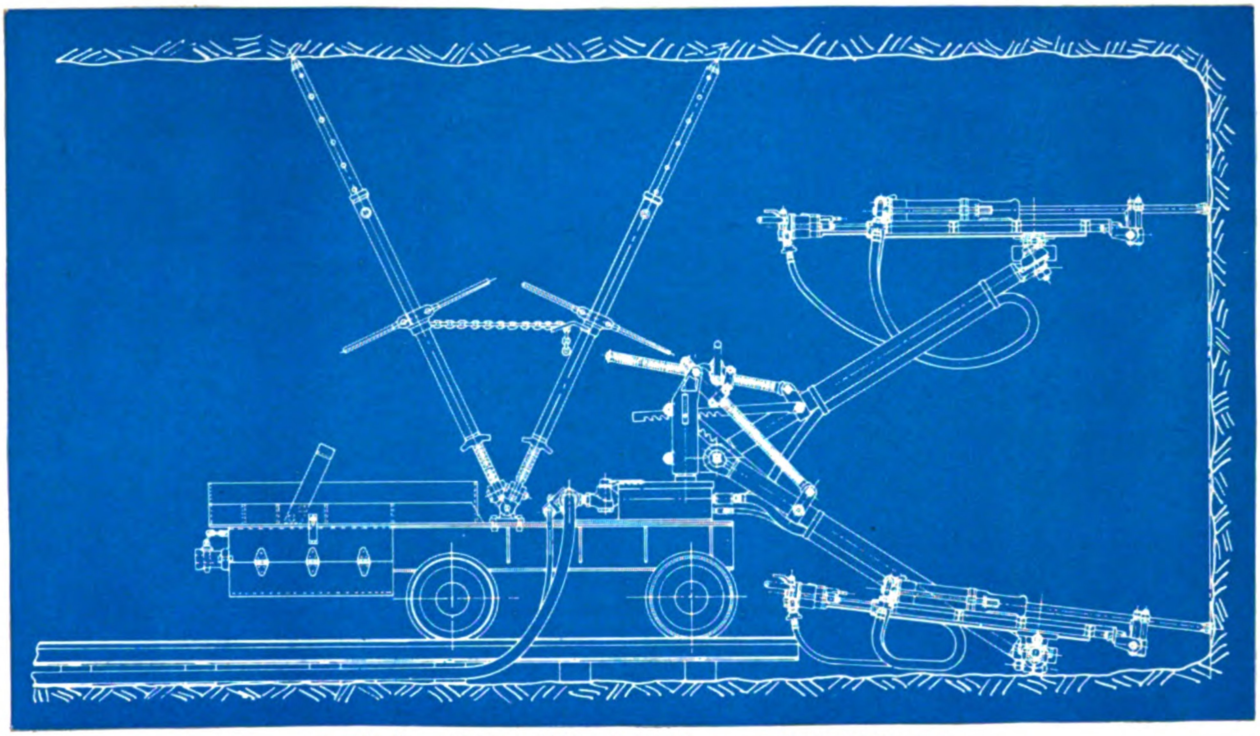
Stoper Drills

These are special hammer drills used for overhead drilling, as in raising and in overhand stoping. Stopers require no separate mounting since they stand on a telescoping air leg. The air leg not only serves as support but is also the feed mechanism. Illustration 3 shows a stoper in operation on a vertical raising round.

Stoper in Operation on Vertical Raising Round
Illus. 3

Drill Carriages

In recent years, tunneling operations have made good use of the drill carriage of "Jumbo" mounting. The drill mounting consists of a heavy framework for carrying the columns, arms, and bars for mounting two or more drills. Up to thirty-five drills have been mounted on the largest carriage. The carriage also comprises platforms for the drillers to stand on, usually designed to drop to the side when not in use; facilities for carrying drill steel, bits, and tools; manifolds attached to the main air and water lines and providing outlets for each drill; and finally, headlight or flood lights to illuminate the working face. Drill carriages may be built on trucks to run on rails or on self-tramming caterpillar crawlers, or may be mounted on the bed or chassis of a motor truck. Illustration 4 shows a print of a drill carriage outfitted with two drifter drills.



Print of Drill Carriage Outfitted
with Two Drifter Drills
Illus. 4

BLASTING DRIFT ROUNDS

After a round has been drilled, the sludge made by the cuttings and any drilling water are blown out of the holes by means of compressed air through a blowpipe. The blasting supplies are then brought up to the face, primers made, and the round loaded and blasted.

Primers

A primer is a cartridge of explosive with some means of firing it attached. It is placed in the bore hole along with the remainder of the charge and when fired, explodes the latter. Both the method of making up primers and the location of the primer cartridge in the loaded bore holes vary with the kind of explosive used, the type of igniter or detonator used, and with certain conditions of blasting. In blasting drift rounds the primer cartridge is generally of the same explosive used for the main charge, but occasionally a different kind or grade will be used. In metal mines, fuze and detonators (caps) are mainly used as the detonating device for blasting drift rounds. Wet drifts are frequently blasted with electric delay detonators, and at a few places, all drift rounds are blasted in this manner. The number of metal miners familiar with electric blasting is relatively small, and apparently the lack of trained men is one of the main reasons why this method of shooting rounds is not more generally used.

Primers should be carefully made so that they satisfy the following conditions:

(1) That the igniter or detonator cannot be pulled out of the primer cartridge.

(2) That the igniter or detonator be in the safest and most effective position in the primer cartridge.

(3) That the fuze or the wires of electric firing devices are not subject to harmful strains.

(4) That the primer is waterproof if necessary.

(5) That the whole primer assembly can be loaded safely, easily, and in the preferred position in the charge.

Capping Fuze: Preliminary operations include cutting the fuze and crimping on the caps. This work should be done in a dry place and care taken that all fuze for specific purposes is cut accurately to length. The length of the fuze cut should be sufficient to reach from the primer in the bore hole to the collar plus some additional length outside the hole. In all blasting, the minimum length should be sufficient to allow the blaster enough time to reach a place of safety after lighting the fuze plus what additional length is required for trimming. Under no circumstances should less than two feet of fuze be used. The fuze should be cut squarely across with a sharp instrument. The capping of the fuze with a detonator should be done in such a manner that the explosive composition of the detonator fits snugly against the end of the fuze. (See Figure 15) Also, the detonator should be securely crimped on the fuze in order that the fuze will not be pulled away from the detonator during loading or by the concussion of the preceding shots.

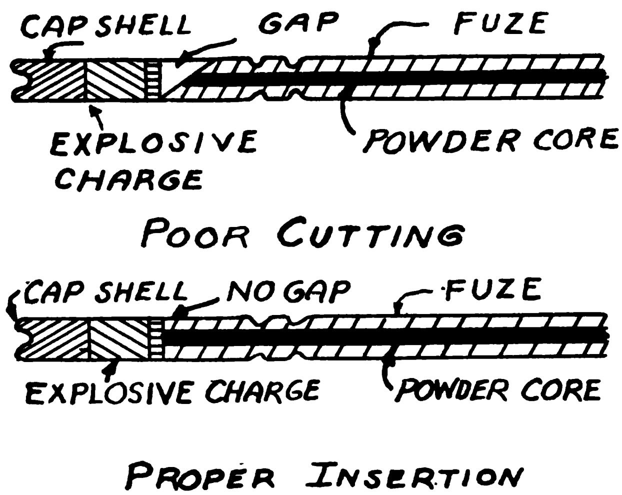


Fig. 15

Strength of Detonators: The Bureau of Mines recommends the use of No. 8 detonators, No. 8 electric detonators, or No. 8 electric delay detonators for all blasting in metal mines. A strong detonator imparts a greater initial impulse to the explosive, which theoretically brings the explosive wave in the charge to full speed more quickly and thereby increases the effectiveness of the blast. Gelatin dynamites are relatively insensitive to detonation and become more insensitive with age. Fewer misfires should occur when strong detonators are used.

Handling Detonators: Capped fuze should be sent underground in closed rigid containers and taken to detonator lockers, which should be at least fifty feet from the powder magazines. Capped fuze should be issued to miners separately from the explosive and carried to the working faces in separate bags. Electric and electric delay detonators should be handled in the same manner.

Primers with Fuze and Detonators: Considerable variation exists in the method of placing the detonator in the cartridge; and many experienced men, including both miners and bosses, have different and decided ideas of how the work should be done. In making a primer, the first consideration is that it can be loaded safely, the second that when the primer is loaded the detonator will be firmly anchored in the primer cartridge, and the third that there shall be no sharp turns or kinks in the fuze that would be likely to pinch the powder core of the fuze.

There are at least four methods in general use for making primers with fuze and detonators as illustrated in Figure 16. From the standpoint of effectiveness and safety, Primer "A" is probably the best as it is difficult to pull out and it takes advantage of the fact that the greatest force of a blasting cap issues from the base in the direction of the longitudinal axis of the cap. Primer "B" is practically as good both from the standpoint of effectiveness and safety. The methods shown in "C-3" and "D" are very poor as the sharp bends caused by lacing may crack the waterproofing so badly that moisture present in a bore hole or in the stemming will cause a misfire. The poorest primer is one in which the base of the cap is near the outside of the cartridge, "C-1" and "C-2", where it is likely to break through if tamped hard and cause a premature explosion.

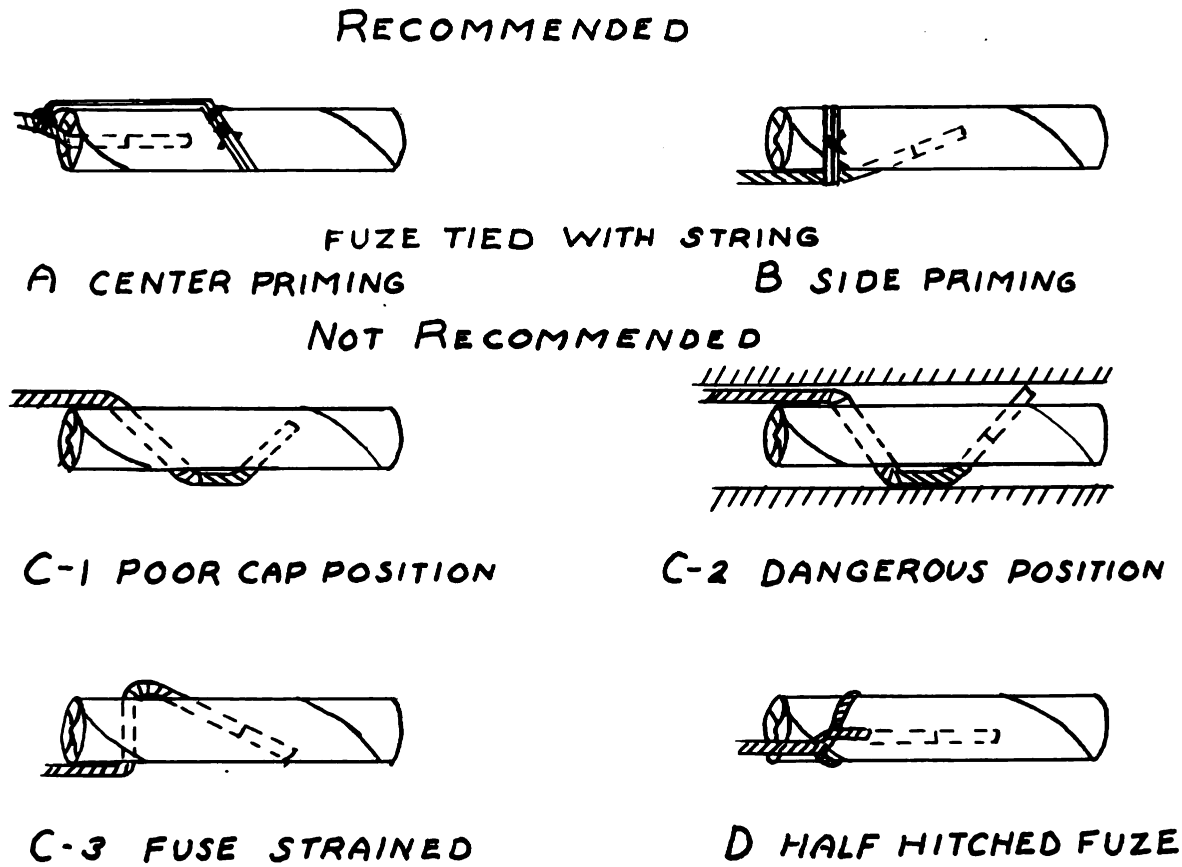
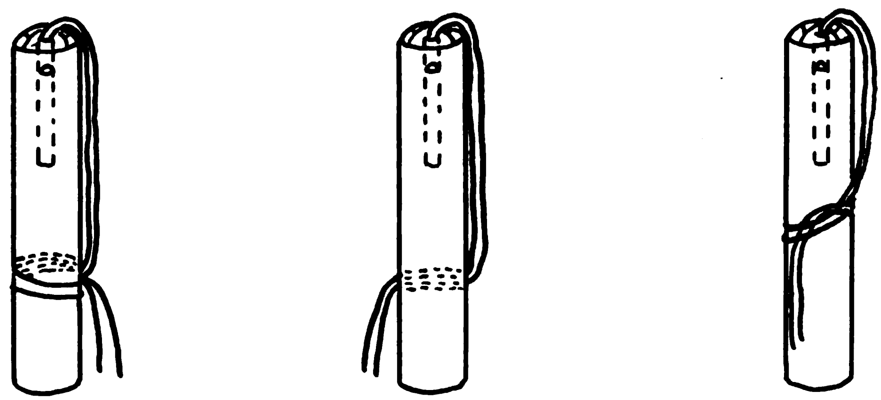


Fig. 16

<u>Primers with Electric Delay Detonators</u>: There are numerous methods of priming dynamite cartridges with electric blasting caps but the preferred methods (Figure 17) involve several fundamental principles: (1) The detonator should be in the center of the section of the cartridge and parallel to the long axis of the cartridge. (2) The wires should be attached so that they will not slip off or permit the cap to be pulled out of the cartridge; so that the primer can be loaded with either end foremost and drawn out of the hole, if necessary; and so that there are no sharp kinks, knots, or overlaps in the wires that might cause the wires to break or to cut into each other through the insulation

and short circuit. In Figure 17, Cartridges A and B illustrate the recommended methods of making up a primer with small diameter cartridge and electric blasting cap. Cartridge C illustrates the method which is most frequently practiced although not recommended.



METHOD A METHOD B METHOD C

Fig. 17

Position of Primer

Theoretically, the ideal method of priming is with the primer near the outer end of the hole and the detonator pointing toward the back. However, in multiple shots or rotation firing, it has been observed that almost invariably the fuze of all holes except the lifters are sheared off even with the collars of the holes by the blast of the first cut hole. Therefore, it is necessary that the primer should be in such a position that the fuze will not be cut off at any point before the train of fire has passed it. Obviously each primer should be far enough below the collar of the hole that the train of fire in the fuze is within the solid rock before the first cut hole explodes. Figure 13-A shows the recommended method for priming dynamite charges in dry holes, 13-B for firing in wet holes.

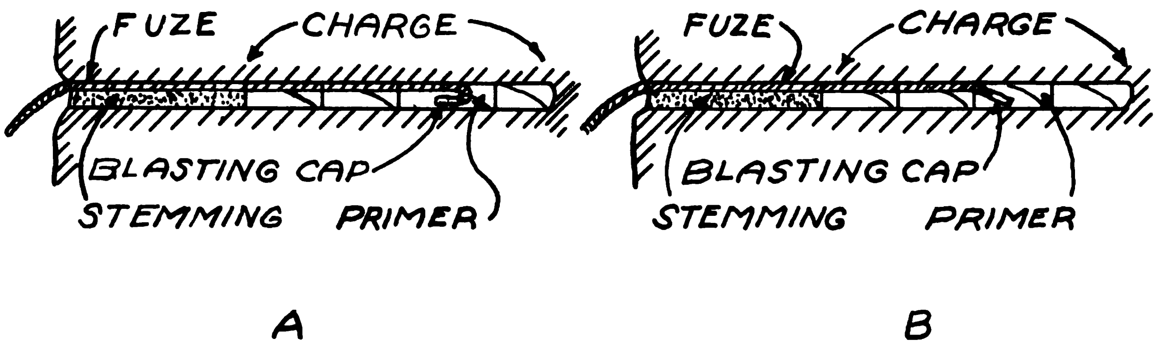


Fig. 13

To protect the detonator, one cartridge is generally placed in the drill hole and is tamped well before the primer is loaded. This should always be done when the fuze is turned back along the primer cartridge.

When electric blasting caps are used the ideal method of priming charges, with the primer near the outer end of the charge and the cap pointing toward the back, can nearly always be used. This applies equally to single shots and multiple and rotation firing. There is no danger from cut-offs in the latter instances because the electric blasting caps fire together and always are the first to fire in rotation rounds.

Tamping

Tests have been made which indicated that in hard rock there is an advantage in having as great a loading density of the explosive as it is possible to obtain by ordinary methods. Granting the advantage of a high density, the charges should be tamped to fill completely the section of the drill hole. The general practice is to slit the paper covers of all cartridges except the primers before placing the explosive in the bore hole, which allows the cartridge to "mushroom" when pressure is exerted against it.

In tamping a hard explosive, fuze or the legs of electric delay detonators may be kinked enough to cause a misfire; therefore, care should be taken in loading the cartridge next to the primer not to damage the primer or cause a kink in the fuze or the wires of an electric detonator at the outer end of the primer cartridge.

Enough time should always be allowed for charging a round. Hurried or careless work causes many misfires and some premature explosions. The explosive can not act to the best advantage if the men doing the work do not take time to prepare and tamp the charges properly.

Stemming

Stemming may be defined as an inert material placed in the outer portion of a bore hole to confine the charge of explosive. In some localities, it is called "tamping" by the miners. Numerous tests have shown conclusively that stemming increases the efficiency of explosives in blasting rounds in underground metal mines in all places except in very soft rock.

Mine superintendents generally concede that the use of stemming saves explosive in blasting, and at a few mines a constant effort is made to see that it is used throughout the workings. However, at most places it is considered that the effort necessary to enforce the use of stemming costs more than the saving effected by its use.

Moist clay appears to be the best stemming material, but damp sand is nearly as good. Coarse or angular stemming should not be used, as there is danger of damaging the fuze or wires of electric detonators. Most mining companies use dry tailings sand from concentrators, as the cartridges are more easily made by hand with this material. Empty powder cases are packed with the paper shells with the open end upward. The sand is then poured into the shells, after which it is moistened, and then the opened ends of the shells are closed by hand. Clay cartridges are cheaply made with a molding machine.

The main valid objection to the use of stemming is that it is harder to take care of a misfire with stemming in the hole. However, most missed holes can be reblasted by placing a new primer in the hole on top of the stemming. Of the explosive in the hole is too insensitive for this, most of the stemming can be removed without undue danger.

Firing Holes with Fuze & Detonator

The final act in blasting is the actual firing of the loaded charges. With each method of firing some preparation is required, such as trimming fuze, connecting up and testing electric circuits, and the like.

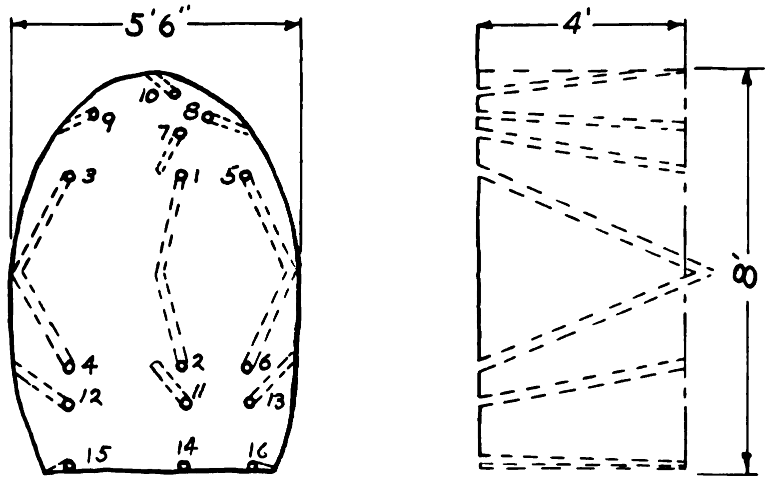
Seven-foot fuze are generally used for blasting ordinary drift rounds. To get the proper sequence of firing, a piece 12 to 18 inches long is ordinarily cut from the fuze in the first hole to be shot and a section one-half to one inch less than that for the preceding hole is cut from each succeeding fuze, except that in the last lifter which is not cut. Safety fuze is made in two distinct speed ranges, namely, that which burns at approximately 40 seconds per foot and approximately 30 seconds per foot. The manufacturers hold the variations to 10 per cent either way at the time of manufacture.

Holes are lit in the same rotation as the firing sequence, and where no difficulty is experienced the time required to light an 18-hole drift round with an open-flame lamp is three-fourths to one and one-fourth minutes.

In most rounds, no advantage is obtained by having a certain group of holes fire before others. Thus, after the cut holes fire, it is immaterial whether the breast holes or skimmers fire next. Also, in most rounds either one of a pair of side holes could detonate before the other without influencing the break of the round. Such holes are grouped and shot with the same delays in firing electrically. However, this practice is not generally followed when used fuze and detonator as is shown in Figure 19, which illustrates the rotation firing of the holes.

In a 16-hole round drilled as in Figure 19, the holes could be grouped in this manner: (1) 2 center cuts; (2) 4 side V cuts; (3) center breast and center skimmer; (4) 2 side breasts and 2 side skimmers; (5) back hole and center

lifter; and (6) 2 side lifters.



16-Hole Round, Figures Indicate
the Rotation of Firing Holes
Fig. 19

Attention should be called here to a very important precaution in the firing of blasts -- the safeguarding of all persons including those working directly on the blast, and those engaged in other work in the vicinity. Two - and only two - men should be present while a drift round is being lit. If one man loses his light, the second is there to give him another.

Wet Holes: When wet holes are to be shot with fuze, they should be lit as soon as possible after loading. Even with the best protection, misfires are likely to occur if wet holes are left standing over fifteen minutes. In wet work most misfires are caused by the failure to make a waterproof connection between the detonator and fuze.

Waterproofing Fuze: Most fuze used in metal mines will withstand water for a considerable time. However, detonators are made insensitive by small amounts of moisture and will fail to fire if wet. Therefore, in blasting in wet places the capped end of the fuze is treated with some waterproofing material. Various preparations are used. Grease and candle tallow are the old stand-bys used by miners when other material is not available. P.& B. paint No. 1 is successfully used at many places. The fuze companies recommend that only cap-sealing compounds made for the specific purpose be used for waterproofing the crimp joint between the detonator and the fuze. Waterproofing compounds should not contain anything, such as gasoline, that will tend to soften or penetrate the waterproofing coats of the fuze. Some materials used for sealing the connection may have excellent waterproofing qualities, but if they attack the fuze they will defeat the purpose for which they are intended.

Firing Holes with Electric Delay Detonators

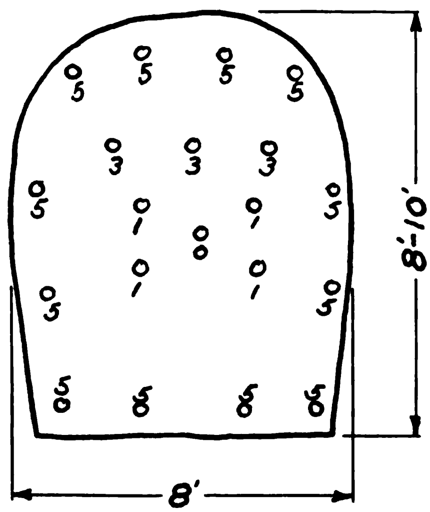
There has been a large amount of material written as to the relative values of blasting with electric delay detonators over the use of safety fuze. A predominance of the blasting in metal mines is still being done with safety fuze even though it seems apparent that electricity is as efficient and safer, although the cost will run slightly higher. In sinking and raising, electric detonators have come into almost exclusive use as it is necessary to give the miners plenty of time to retreat to safety before the blast is fired.

In the larger mines electric current from lighting or other circuits is generally available for firing electric detonators, but occasionally a blasting machine will be required. When there is ample current, the detonators of a round should be connected in multiple, but where it is necessary to use a portable blasting machine, it is best to connect the holes in series. There is less likelihood of misfires from leakage of current or short-circuiting when a high voltage is used. When wiring in multiple, the legs of the individual detonators should be long enough to reach to the bus wires without splicing. The leg wires for a 6-foot round in a 6 x 7 foot face should be 10 feet long. Each detonator should be tested with a galvanometer before and after loading to insure that no circuits are broken. The ends of the two leg wires of each detonator should be twisted together before the detonators are taken underground to prevent possible premature explosion by stray electric currents. After the round is loaded the bus wires, which should consist of uninsulated copper wire of about No. 16 B.& S. gage, are strung across the face and fastened to two wooden plugs or stakes. Care should be taken that the bus wires do not touch each other. One wire of each detonator is attached to one bus wire and the other wire to the opposite bus wire. Each wire should be attached individually and care taken that connections are well made and that no short circuits occur.

The temporary firing line, which should consist of No. 14 lead wire, No. 18 annunciator wire, or No. 20 connecting wire, should then be connected to the bus wires and the work proceed away from the face. The ends of the permanent blasting line should be touched together to make sure they carry no current before the connections to the temporary firing line are made. Two single wires rather than a duplex lead wire are to be preferred. The use of single lead wires prevents line losses of current and also makes the location and repairs of breaks simpler. The round should be fired through a safety switch, which must be kept locked in an open position; the miner in charge of the blasting should have the only key.

Delay electric blasting caps are similar to regular electric blasting caps, except that a delay element is inserted between the electrical firing element and the detonating charges. They are manufactured in standard periods of delay. For instance, Dupont Delay Electric Blasting Caps are manufactured in ten standard periods of delay, ranging in numbers from a 1-delay to 10-delay. The time interval of delay for the first period is approximately one second and the time intervals increase gradually up to approximately 2½ seconds between the ninth and tenth periods. Figure 20 illustrates the use of electric delay detonators in a typical drift round at the Cliffs Shaft Mine, Ishpeming, Michigan.

The central hole in the cut section is fired with a regular electric detonator or a #0 delay. The remaining cut holes are fired with #1 delays; the breast holes with #3 delays; the side breasts, side skimmers, back holes, and lifters are all fired with a #5 delay.



20-Hole Round Cliffs Shaft Mine, Michigan.
Numbers Indicate Electric Delay Detonators
Fig. 20

Electric blasting has a two-fold advantage over fuze and detonators in wet drifts; there is less likelihood of misfires occurring caused by moisture, and the danger is eliminated of men staying too long at a face while lighting wet fuze. Hangfires are less frequent with electric blasting, and men can take plenty of time to reach a place of safety before firing a round. The possibility of misfires from fuze being cut by previous shots is eliminated, and the rotation of firing is surer with electric blasting.

Amount of Explosive Per Hole

The distribution of the explosive in the holes of a round is important and will depend upon the explosive used, the characteristics of the rock, the number of holes, and the kind and depth of the round drilled.

As an example, the following distribution was found to be best in a 16-hole round 5½ feet deep, containing three pairs of V-cut holes drilled in a 5 x 8 foot drift in limestone at the Copper Queen mine at Bisbee, Arizona:

		Cartridges
2 center V cuts	-	7 each
4 side V cuts	-	6 each
Center breast	-	5 each
2 side breasts	-	4 each
Center skimmer	-	5 each
2 side skimmers	-	4 each
Back	-	3 each
3 lifters	-	4 each

For ordinary work, it was not considered practicable to use parts of cartridges. When the cut holes broke as expected, one less cartridge per hole would have been required for the other holes of the round. However, occasionally the cut holes failed to break well; and in each case, the extra cartridge partly made up for this deficiency, and a fair break for the round was still obtained. Lifters are almost always overloaded. A missed hole at the bottom of the round is more dangerous than one elsewhere, as it is likely to be covered with the broken material from the other holes. Should it not be noticed, it might be picked into by the shoveler. One reason for overloading the lifters is to make a misfire more evident. An excess of explosive is also used in the lifters to throw back the broken rock on the shoveling sheet to make the work of the shoveler easier. Where it is necessary to shovel back rock to set up a column excessive explosive is also used to throw as much of the rock back from the face as possible.

Misfires

Safety of operation is the first requirement in loading holes, as it is with all branches of mining. The charging must be done in such a manner that no premature explosions occur. Misfires or cut-off holes are also a source of danger that can largely be prevented by care in loading and by the use of proper explosives and blasting supplies. Misfires materially reduce the "break" of the blast, besides interfering with the work of the following shift while missed holes are being reshot.

Despite precautions, the fact remains that occasionally for one reason or another, a misfire is encountered and it is important to know how to handle it safely. All faces should be carefully inspected for misfires before any work is done at the place. In case of a misfire in a drift round, no one should be allowed to return to the face for one hour if fuze was used or one-half hour if the round was blasted electrically. Missed charges should never be withdrawn from a hole but always reblasted by inserting a fresh primer in the top of the explosive. No picking or drilling should be done in a face in which a misfire occurs until the missed charge is blasted. Where no stemming is used, it is a simple matter to push a new primer down a hole and shoot it in the ordinary manner. When stemming is used, the charge may not fire through the inert material, in which case the stemming must be removed. Where the stemming is in paper shells, it is generally removed with the iron scraper used for cleaning holes. There is an element of danger in this, and washing the stemming out with water from the blowpipe would appear safer.

Shafts, Winzes and Raising Rounds

The procedure used in blasting sinking and raising rounds is essentially the same as that in blasting drift rounds, with the exception that electric detonators are used instead of fuze and detonators.

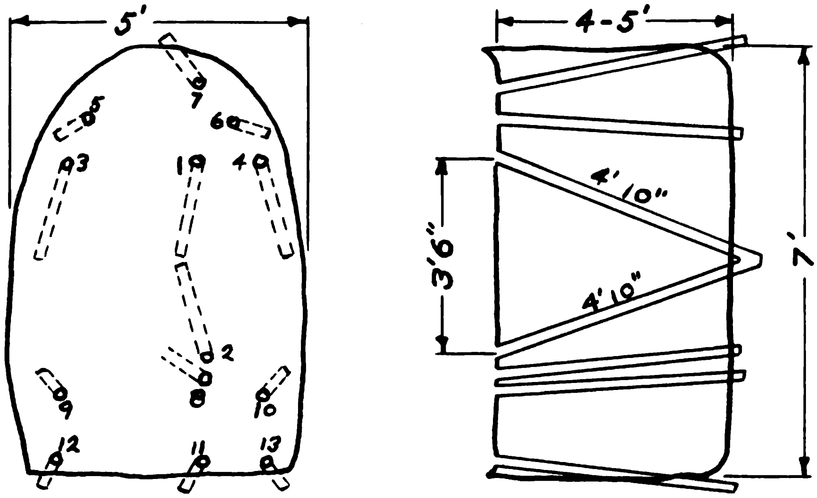
All shaft rounds should be fired electrically so that the entire crew can be out of the shaft before the switch is thrown. Great care must be exercised to see that the delays are properly loaded so that all holes will fire in the desired order.

While small shafts requiring thirty holes or less per round can usually be fired with a blasting machine using a straight series connection, it is generally more satisfactory to use a power circuit and connect the caps in either straight parallel or parallel series. Connections in shaft work are likely to get wet and if series connections are used, some holes may be shorted out, causing a poorly pulled round, loss of time, and possibly a serious accident. This trouble can be largely eliminated by using the straight parallel connection and firing with the power circuit. When the work is not too wet, the parallel series hook-up may be used, connecting all instantaneous caps in one series, all first delays in another, all second delays in a third, and so on, finally connecting all these series in parallel.

TEST DATA FROM BUREAU OF MINES BULLETIN #311

Relationship of Planes of Weakness to the Quantity of Explosive Required for Breaking Drift Rounds

To obtain data on the relationship of the planes of weakness to the quantity of explosive required for breaking drift rounds, the blasting of a series of eight rounds was observed at the Pilares mine of the Moctezuma Copper Company in April, 1927. These rounds were all blasted in a hard-drilling, difficult-breaking porphyry. Figure 21 shows a standard 13-hole round used at the Pilares Mine. Rounds were blasted with 60 per cent gelatin dynamite. Stemming was generally used in the rounds.



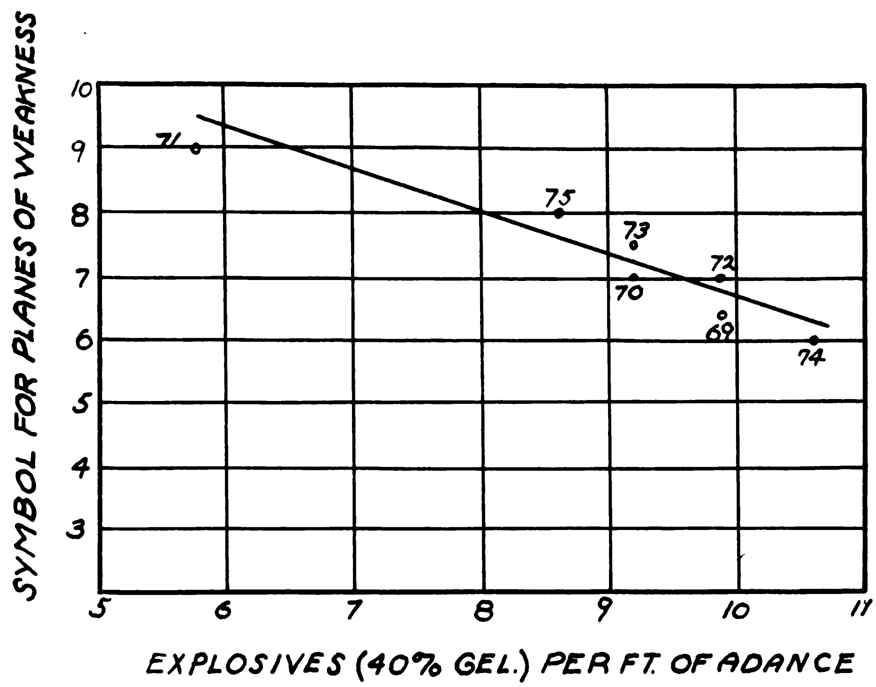
Standard 13-Hole Round, Pilares Mine
Fig. 21

A description of the rounds and the results of blasting are shown in Table 2, and Figure 22 is a curve showing the relation between the quantity of explosive required per foot of advance and the classification according to the planes of weakness of the rock. The points used are for the estimated quantity of 40 per cent gelatin to give an equivalent of the propulsive energy of the 60 per cent strength used. The same classification scale and symbols for the planes of weakness were used as those shown in Table 1.

Round No.	Size of Heading	No. of Holes	Depth of Round	Drilling Speed in./min.	* Symbol	Explosive per ft. Advance	Est. Equiv. 40% Gelatin
69	5 x 7.5	16	3.5'	9	6.5	8.6#	9.9#
70	5 x 7.5	13	4	9	7	8.0	9.2
71	5 x 7	10	5	6	9	5.0	5.8
72	5 x 7	16	3.5	10	7	8.6	9.9
73	5 x 7	13	4	---	7.5	8.0	9.2
74	5 x 7	16	4	6.5	6	9.2	10.6
75	5 x 7	16	4	7	8	7.5	8.6

Table 2

*Refers to the classification of the planes of weakness in the rock as described in Table 1.



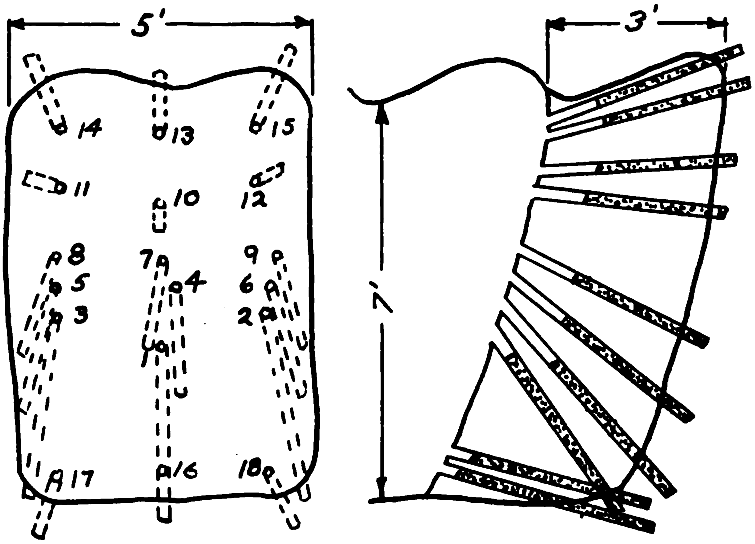
Curve Showing Relation of Amount of Explosive and Planes of Weakness
Fig. 22

Typical Drilling and Blasting Procedure as Used in the Portland Mine, Victor, Colorado

It is impossible to give a complete picture of the specific methods of drilling and blasting used in present-day metal mining as the procedure will vary considerably with the individual mines, types of rock encountered in the various localities and with the ability and knowledge of the men carrying out the work. The procedure used at the Portland Mine may be considered as representative of a metal mine and is herein given to illustrate the use of some of the general principles of drilling and blasting that have been stated previously in this paper.

The standard size for drifts and cross-cuts in the Portland Mine at Victor, Colorado, is 5 x 7 feet. Three lengths of steel are used for drilling most of the drift rounds. The starters average about 2½ feet long; the second steels are about 4 feet long; and the third is from 5½ to 6½ feet in length. The gage of the starters is 2 3/16 inches, and there is a difference of about one-fourth inch in gage in each successive bit. The average drilling speed is about 9 inches per minute.

Rounds are drilled and blasted on each shift. Cross-bars are used for holding the drilling machines. One set-up is made near the top of the drift, and all of the round except the lifters is drilled from this position. By the time these holes are drilled the shovelers have removed the broken rock, the bar is set up near the bottom of the face, and the lifters are drilled. The first position of the bar is usually a pick handle length (31 inches) from the top and the same distance from the face of the drift. Some miners place the bar a little closer to the face to give the cut holes greater pitch. Figure 23 shows an average 18-hole round in hard rock at this mine.



Typical 18-Hole Round, Portland Mine
Fig. 23

Thirty-five per cent strength special gelatin dynamite in 1 1/8 x 8 inch cartridges is used for all blasting in the mine. The holes are loaded to near the collars, and no stemming is used. No. 6 primers and fuze are used for blasting drift rounds. Primers are made according to the miner's preference. Most miners in the district insert the capped end of the fuze centrally in the end of the cartridge. In loading primers the fuze is not turned back along the cartridge except where two primers are used in the same hole, in which case one is turned end for end in order that both lengths of fuze will extend the same distance from the hole. The capped ends of the fuze are protected from moisture by dipping them into an air-drying insulator liquid, which appears to be efficient for the purpose. A large proportion of the drift rounds, at the Portland, are wet but apparently an excessive number of misfires do not occur from this cause. Double primers are used in nearly all lifters.

Data for twenty-nine and twenty-one rounds, respectively, in two headings at the Portland Mine, furnished by Fred Jones, General Superintendent of the mine, are as follows:

	No. 1	No. 2
Place -	2,300 crosscut.	2,400 N. 3 drift S.
Ground -	Medium soft.	Fairly hard, "ravelly".
No. of holes -	15	13
Powder used -	93 cartridges 1 1/8 x 8" 35% gelatin dynamite.	80 cartridges 1 1/8 x 8" 35% gelatin dynamite.
Types of round -	3 back, 3 breast, 3 cuts, 3 lifters; center cut & center lifter connected at bottom & detonated together.	2 back, 6 breast, 3 cuts, 2 lifters.
Distribution of powder -	7 cartridges in lifters; 6 in all other holes.	7 cartridges in cuts & lifters; 6 in outside breast; 5 in center breast and back holes.
Advance, ft. per round -	3.2	3.7.
Powder per ft. of advance -	14.9#, average for 29 rounds.	10.25#, average for 21 rounds.
Fuze per round -	129.5	153.6
Cost of powder per linear ft. advance-	$2.023	$1.375
Cost of cap per linear ft. advance-	$0.223	$0.234
Cost of labor per linear ft. advance-	$4.190	$4.823
Total cost -	$6.436	$6.432

SUMMARY

Development operations consist of drifting, crosscutting, sinking and raising. In each of these, drilling and blasting is an important part of the work and the general procedure used is similar in all four phases.

Gelatin dynamites, ranging from 33 to 80 per cent strength, are the most commonly used explosives in metal mines. This class of dynamite is adaptable to most of the conditions met in development work, although special gelatin dynamites are used occasionally in some mines. Ammonia dynamite may be used in some work where a bulky charge of lesser density is an advantage or the saving in money justifies its use.

A cartridge size of 1 1/8 x 8 inches is the standard used at most mines. In any case, the size should be as large as can be easily loaded into the bore hole so that a high density may be obtained and minimum amount of "free space" left in the bore hole.

The cut holes of a round are the most important and care should be exercised so that these holes are drilled and loaded as to give the maximum break. The depth to which the other holes will break is largely dependent upon the effectiveness of the cut holes, and when the cut holes break well, a full advance for the whole round is generally assured. The "V" cut, or "Pyramid" cut, is the type which is most commonly used and will produce a larger crater than the "Burn" cut or "Toe" cut. The depth and volume of this crater can be increased by using higher strength dynamite than would be necessary in the surrounding holes. Also, tests have shown that 40 per cent of the explosive for a round should be concentrated in the cut holes.

The planes of weakness in the rock bear a direct relationship to the amount of explosive necessary to break a given round. Therefore, it is important that these planes be taken into account in placing the drill holes so that a saving in explosives may be had.

It has been shown that the standard round for a given class of rock under given conditions will reduce the cost per foot of advance. The placing of holes in a standard round can be best accomplished by observing the break which occurs by firing a round one hole at a time. Rounds should be designed to take advantage of regular planes of weakness which occur in the rock.

Primers should be made so that they satisfy the following conditions:

1. That the igniter or detonator cannot be pulled out of the primer cartridge.
2. That the detonator be in the safest and most effective position in the primer cartridge.
3. That the fuze or wires of electrical firing devices are not subject to harmful strains.
4. That the primer is waterproof if necessary.
5. That the whole primer assembly can be loaded safely, easily and in the preferred position in the charge.

The charge should be tamped in the bore hole as a higher density will give more energy per cartridge.

Stemming increases the effectiveness of the charge and should be used unless there is a valid objection to its use.

Care should be taken in all operations so that a minimum of misfires will occur. Hurried or careless work has no place in any operation that involves the use of dynamite.

DRILLING AND BLASTING IN THE DEVELOPMENT PHASE OF METAL MINING

I. INTRODUCTION

II. PHASES AND DEFINITIONS OF OPERATIONS WHICH ARE INCLUDED IN DEVELOPMENT STAGE.

A. Drifting
B. Cross-cutting
C. Raising
D. Sinking

III. SELECTION OF EXPLOSIVES FOR METAL MINES.

A. Various grades and composition.
B. Gases developed.
C. Strength or pressures developed.
D. Size of cartridges.
E. Facts concluded for proper selection.

IV. VARIOUS TYPES OF CUTS

A. "V" cut with sketches.
B. "Draw" cut or "Toe" cut with sketches.
C. "Pyramid" cut with sketches.
D. "Michigan" or "Burn" cut with sketches.

V. THEORY IN THE DESIGN OF ROUNDS AND THEIR DEVELOPMENT.

A. Crater theory and effect of physical characteristics of rock.
B. Effect of planes of weakness.
C. Classification of planes of weakness.
D. Theory of designing rounds.
E. Development of drift rounds.
   1. Depth of rounds.
   2. Standard rounds.
F. Raising rounds.
G. Sinking rounds.

VI. DRILLING MACHINERY

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B. Drifter drills
C. Stoper drills
D. Drill carriages

VII. BLASTING DRIFT ROUNDS

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  - 2. Strength of detonators.
  - 3. Handling detonators.
  - 4. Methods of making primers with fuze and detonator.
  - 5. Making primers with electric delay detonators.
- B. Position of primers in bore holes.
- C. Tamping.
- D. Stemming.
- E. Firing holes with fuze and detonator.
  - 1. Wet holes.
  - 2. Waterproofing fuze.
- F. Firing holes with electric delay detonators.
- G. Amount of explosive per hole.
- H. Handling misfires.
- I. Blasting shafts, winze and raising rounds.

VIII. TEST DATA FROM BUREAU OF MINES BULLETIN #311

- A. Relationship of planes of weakness to the quantity of explosives required for breaking drift rounds.
- B. Typical drilling and blasting procedure used in the Portland Mine, Victor, Colorado.

IX. SUMMARY

ACKNOWLEDGMENTS

I am indebted to the following persons and firms for furnishing me with help and material, which were of value to me in compiling this thesis:

Professor Amundsen, Agricultural Extension Department, Michigan State College, East Lansing, Michigan.

W. L. Dover, Sales Representative, E.I. du Pont de Nemours & Company, Bay City, Michigan.

John Jeffries, Assistant to Director of Sales, Atlas Powder Company, Wilmington, Delaware.

Francis Thomas, Civil Engineer, Ishpeming, Michigan.

E.J. Longyear Company, Minneapolis, Minnesota.

The Explosives Engineer, Wilmington, Delaware.

Hercules Powder Company, Wilmington, Delaware.

McGraw-Hill Catalog Service, New York, New York.

The Cleveland Rock Drill Company, Cleveland, Ohio.

Ingersoll-Rand Company, Phillipsburg, New Jersey.

Le Roi Company, Milwaukee, Wisconsin.

Chicago Pneumatic Tool Company, New York, New York.

Gardner-Denver Company, Quincy, Illinois.

E.I. du Pont de Nemours & Company, Wilmington, Delaware.

American Institute of Mining & Metallurgical Engineers, New York, New York.

Michigan State Department of Conservation, Lansing, Michigan.

Geology Department, Michigan State College, East Lansing, Michigan.

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3. Blaster's Handbook, E.I. du Pont de Nemours & Company.

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5. Tunneling, Charles Prelini.

6. Blasting with High Explosives, W.G. Boulton.

7. Drilling & Blasting in Metal Mine Drifts & Crosscuts, S.D. Gardner, (Bureau of Mines Bulletin 311).

8. Drilling & Blasting in Some American Metal Mines, Theodore Marvin.

[redacted]

Mar 12 '49 [redacted]

CORRESPONDENCE

123
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THS
Suppl. 2

May 21, 1947

Department of Mining Engineering
University of Utah
Salt Lake City, Utah

Gentlemen:

I would appreciate it very much if you could send me a copy of "Application of shaped explosive charges to mining operations", by R.S. Lewis, published in 1946, or advise me where I may obtain such a copy.

If you are able to send me a copy of the requested publication, kindly advise me what the charge is for it.

Thanking you in advance, I am

Sincerely,

P.J. Rockenbach

Send to:

Mr. P.J. Rockenbach
707 W. Ionia
Lansing, Michigan

May 21, 1947

U.S. Department of Interior
Bureau of Mines
Washington, D.C.

Gentlemen:

I would appreciate it if you would send me Bulletin #311, published in 1929 entitled "Drilling & Blasting in Metal Mines - Drifts and Crosscuts"by E.D.Gardener.

Also, Information Circular 7387 published in September 1946, regarding some safety practices for metal mines, non-metal mines (other than coal), mills, Metallurgical plants and quarries.

Any other bulletins or information which you have on blasting procedure in mining would be very much appreciated. Kindly advise me of the charges for these bulletins, if any.

Thanking you in advance, I am

Sincerely,

P.J. Rockenbach

COPY

Send to:

Mr. P.J. Rockenbach
707 W. Ionia
Lansing, Michigan

Rec'd information

123
546
9145
Suppl. 4

May 23,
1 9 4 7

American Institute of Mining &
Metallurgical Engineers
29-35 West 39th Street
New York 18, N.Y.

Gentlemen:

I am contemplating using the subject "Drilling and Blasting in American Metal Mines" as a thesis for my B.S. degree in Civil Engineering and would appreciate it greatly if you would send me any bulletins or information you may have concerning this subject. I will be glad to reimburse you if there is any charge for such information.

Thanking you in advance for any help you may give to me, I am

Sincerely,

P.J. Rockenbach

COPY

Address:

P.J. Rockenbach
707 West Ionia St.
Lansing, Michigan

Rec'd info.

123
546
446
Suppl. 10

June 1,
1 9 4 7

E.J. Longyear Company
Mining Engineers
General Office
Fochay Tower
Minneapolis 2, Minn.

Gentlemen:

I am planning to use the subject "Drilling and Blasting in American Metal Mines" as a thesis for my B.S. degree in Civil Engineering and would greatly appreciate it if you would send me any bulletins of information you may have concerning the machinery and drilling operations in metal mines. I am interested in the types and costs of the drill machinery used and your recommendations as to their use under various conditions.

Inasmuch as the thesis must be in triplicate, I would appreciate it if you would send any illustrations of your equipment in triplicate. If there is any charge for this information, I will be glad to reimburse you.

Thanking you in advance for any help you may give to me, I am

Sincerely,

P.J. Rockenbach

Address:

P.J. Rockenbach
707 W. Ionia
Lansing, Mich.

COPY

E. J. LONGYEAR COMPANY

MINING ENGINEERS

GENERAL OFFICE
FOSHAY TOWER
MINNEAPOLIS 2, MINNESOTA

DIAMOND DRILLING
SHAFT SINKING
GEOLOGICAL AND MINING REPORTS
MANUFACTURE OF DIAMOND DRILLS AND SUPPLIES

June 4, 1947

Mr. P. J. Rockenbach
707 W. Ionia
Lansing, Michigan

Dear Mr. Rockenbach:

Thank you very much for your letter of June 1st in which we cannot help but be interested.

We are glad to send you our complete catalog and recently published Bibliography of Diamond Drilling under separate cover, both of which may be of interest. We believe that after looking over the catalog you will find certain equipment which is of major interest to you, and if you will advise us of those models in which you are particularly interested we will be glad to send you additional copies of the bulletins and can possibly locate some reasonably good photographs which you might wish to use..

If it is at all possible for you to do so, we suggest that you might like to take a trip up here and discuss those points which would be of interest to your thesis. If this seems desirable to you, it would be well to let us know a week or ten days in advance so that we could plan to have some time to discuss your work and be sure that the men with whom you wish to talk will be in the office.

Yours very truly,

E. J. LONGYEAR COMPANY

R L Loofbourow

R. L. Loofbourow
Sales Manager

RLL/lb

123
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THS
Supplement

July 5,
1 9 4 7

Gardner-Denver Company
Quincy, Illinois

Att: Mr. E. Church

Gentlemen:

I have received the bulletins and information which you so kindly sent to me. These publications are proving extremely helpful in the compilation of my thesis on "Drilling and Blasting in American Metal Mines", and I wish to thank you for your fine cooperation.

In appreciation, I am

Sincerely,

P.J. Rockenbach

123
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Suppl. 17

July 5,
1 9 4 7

COPY

Mr. R.L. Loofbourow
Sales Manager
E.J. Longyear Company
Minneapolis 2, Minnesota

Dear Mr. Loofbourow:

I have received the catalog of equipment and the "Bibliography of Diamond Drilling", which you so kindly sent to me, and am finding both extremely helpful in the compilation of my thesis.

I am particularly interested in the development phase of metal mining and any photographs which you could send to me illustrating the use of your equipment in shaft sinking, drifting, raising and cross-cutting would be very helpful as illustrations in my thesis. As stated previously, the thesis must be in triplicate and I would appreciate it if you would send three copies of each of the photographs.

I regret that it is impractical for me to make the trip to Minnesota as suggested in your letter since I am attending summer school. However, I appreciate your invitation as I know it would be very interesting as well as informative.

Thanking you for your fine cooperation, I am

Sincerely,

PJR:y

P.J. Rockenbach