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Development of large hole burn cut drift rounds

Joseph J. Yancik Jr.

DEVELOPMENT OF LARGE HOLE BURN CUT DRIFT ROUNDS

BY

JOSEPH J. YANCIK, JR.

A

THESIS

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I. INTRODUCTION

A decided change in the attitudes of mining management toward the need for mine research has taken place during the past decade. More emphasis is being placed not only on the improvement of existing mining methods, but also on the adaptation of new ideas. As the depletion of the high grade ore deposits in this country becomes a reality, the need for reducing the costs of mining is pressing. The successful exploitation of low grade ore bodies will depend upon the continued advancement in the science of mining.

The methods used today in driving a small drift or tunnel in rock have not varied much since the introduction of mechanization in the mining industry. Depending upon the conditions encountered and the types of equipment used, numerous small hole drill round patterns have been developed and successfully used. With the advent of new and better drilling and loading equipment, it has become apparent that present drill round patterns, with their limited depth, cannot fully utilize these advances in mining technology.

The research work presented here is a study of the problems encountered in the designing of a drift round which uses a large diameter hole as part of the cut. The basic function of the large hole is to provide an effective second free face to which the cut holes can break. This large hole effectively increases the stress relief available to the cut holes and permits a much greater advance per round than the conventional small hole drill round patterns.

The use of a large hole to provide a second free face for the cut holes is not necessarily limited to drift rounds, but could also be used, probably to better advantage, in large horizontal stopes.

A review of current literature disclosed that only a few mining companies in the country have experimented with large hole rounds. This work apparently has not led to adoption of this type of round to their regular mining operations. In other countries, the large hole rounds have received more attention. In one particular case, in a German coal mine,[1] this round is used for driving drifts and crosscuts. The average

[1] George, Jules, Personal communication, Westinghouse Air Brake Division, Cleveland Rock Drill Co.; Feb. 11, 1955.

advance per round in a sandstone formation is approximately 15 feet.

The argument exists that for most underground mining conditions a deeper round is of little value because shift work eliminates any great degree of flexibility in the operations. In the average set up, a drift crew mucks, drills, and blasts a round in one shift. It is claimed that any deviation from this cycle produces too much "dead time." With present mining equipment, increasing the round to any great extent would certainly prevent one cycle of operation in a single shift, and thus would result in an increase of non-productive time for the drift crew. But there is another way in which a deep round could be effectively and economically utilized without the advent of better equipment. That is to drill and blast on one shift and to muck out the broken rock on the next. Such a practice would certainly not be any less flexible than the present methods, and should result in a greater advance per shift due to the more economical use of the equipment.

II. DESIGN OF A DRIFT ROUND WITH A LARGE HOLE BURN CUT

Large Hole Burn Cut

There are three general types of cuts which serve to provide a second free face to which the rest of the drift round holes may break-- 1. an angled cut, 2. a burn or shatter cut, and 3. combinations of the preceding two. The large hole burn cut, as is evident by its name, properly belongs to the second group of cuts.

Basically, burn cuts consist of a number of holes drilled in the center of the drift (parallel to each other and as close together as possible) with one or more of the holes unloaded in order to provide open space to which the loaded holes can break.

The fundamental purpose of the burn cut is to break and pulverize the rock and expell it from the cavity created. The use of one large diameter hole therefore takes the place of many small diameter holes to provide the open space to which the loaded holes can break.

The designing of a drift round using a large hole is then primarily the problem of determining the position of the small holes relative to the large hole in order to enlarge the already existing second cylindrical free face represented by the big hole. The significant portion of the round is the cut composed of holes circumscribing the large hole which are designated hereafter as being the burn cut holes. These are considered most critical because the success of the round depends upon the ability of the cut holes to develop a second free face to which the remainder of the round may break.

The factors which affect the successful breaking of a large hole burn cut are listed below. The order of appearance does not imply relative importance.

1. Diameter of the large hole
2. Position of the small holes relative to the large hole
3. Depth of the small holes with respect to the large hole
4. Type of dynamite
5. Type of delays
6. Loading pattern
7. Order of firing
8. Amount of powder
9. Diameter of the small holes
10. Geological structure of the rock
11. Position of the relief holes relative to the cut

The ideal procedure would be to design and analyze the burn cut from purely theoretical considerations. Unfortunately, very little is known of the fundamental laws of blasting and of rock breakage; therefore the design of a burn cut round must be based on experience gained in field trials. However, the relative importance of some variables may be established by intelligent reasoning based on existing facts obtained by the trial and error system.

To limit the number of variables which were studied in the field trials, a study of the existing data on the blasting properties of the mine rock was made. This study allowed a predetermination of the expected effects which some of the factors would have on the results of the burn cut.

The diameter or size of the small holes was kept constant and therefore removed as one of the variables in the field trials. Blasting studies by Noren[2] showed that the size of the drill holes had little

[2]Noren, Charles A., The Influence of Cartridge Diameter on the Effectiveness of Dynamite, thesis presented to the School of Mines & Met. of the University of Missouri, 1948.

effect on the blasting characteristics of this mine rock. With the deep rounds planned up to 20 feet, it was definitely advantageous to keep the holes as small as possible in order to distribute the powder columns and avoid overloading. The dynamite cartridges used were $1\frac{1}{4}$ inches and 1 1/8 inches in diameter. Since drill steel changes of $2\frac{1}{2}$ feet were used to drill the holes, the holes varied from $1\frac{1}{2}$ inches to 1 5/16 inches in diameter. The various increments of a hole which were of one particular diameter depended on the depth of round drilled. In this manner, the holes were bottomed with a 1 5/16 inch bit regardless of the number of steel changes necessary to drill the round.

In a general sense, the geological structure of the rock could be eliminated as a variable because of the nature of the mine rock in which the test rounds were shot. The dolomitic limestone rock is flat-lying, well-bedded, and reasonably uniform in its physical properties and texture. The minor irregularities present would not seriously affect the normal pattern of rock breakage. The consistent pattern of bedding planes practically eliminated them in influencing the results of one burn cut pattern more than another.

It was also decided to eliminate as much as possible the variation of the results caused by the position of the relief holes. Since the relief holes of Round 2 were successful in breaking to the cut, they were selected as the one to be used in future rounds. The relative position of the relief holes did vary somewhat for each round depending on the burn cut location in the drift face, but an attempt was made to standardize their placement.

Note that factors 9, 10, and 11 have been eliminated from field trial consideration. The effects which the remaining variable, Numbers 1 through 8, had upon the results of the burn cut were then investigated by the test rounds.

The position of the cut holes relative to the large hole was considered the most important element which determines the success or failure of the burn cut. The shooting of each successive hole should enlarge the cavity and provide sufficient stress relief for the following holes. The location of the cut holes should be such that the breaking and expanding rock will have ample room to move out of the cavity, otherwise the rock will freeze solidly. For a 5 foot burn cut round (powder factor 0.33) the expansion ratio of the rock is approximately 1.6. In an attempt to determine the maximum spacing of the cut holes from the large hole based on this expansion ratio, it became apparent that to make such computations so many simplifying assumptions were necessary that the results would be useless. Consequently, the holes were placed close enough to the large hole to insure that they would break into the big hole.

The position of the burn cut holes was limited to placing the holes parallel, or nearly so, to the large hole. This limitation was necessary to insure the development of deep rounds which was the primary purpose of the research work.

In order to eliminate one more variable, the original planning of the field trials called for a standard powder factor (tons of rock per pound of powder) for all the burn cuts throughout the testing program. However, because of test conditions, it became necessary to use more or less powder which resulted in different powder factors.

Field trials on a 7 foot burn cut round conducted by Nelson[3] showed

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[3]Nelson, H. P., Effects of Higher Speed Explosives in Drift Rounds, thesis presented to the School of Mines & Metallurgy of the Univ. of Missouri, 1950.

the various results which would be obtained for different types of explosives. The test rounds indicated that Gelex No. 2 (12,600 fps) and 50% Special Gelatin (15,000 fps) were more effective than any faster or slower acting explosive. Although it was decided to try different types of explosives, Mine Gel No. 2 (12,800 fps) was used for the majority of the tests because this type of powder seemed to be much better suited for large hole burn cuts than any other dynamite tested.

Test Site - Experimental Mine

The experimental drift rounds were tested at the Experimental Mine of Missouri School of Mines and Metallurgy, Rolla, Missouri, which is located approximately 1½ miles southwest of Rolla. The mine is entered by an adit and consists of over 1500 feet of underground workings.

The underground workings are in a soft, well-bedded, flat lying, dolomitic limestone of the Jefferson formation. The physical properties and texture of the rock vary little from bed to bed. The physical properties of the rock are as follows:[4]

[4]Buckley, E. R. and Buehler, H. A., The Quarrying Industry, Missouri Bureau of Geology and Mines, Ser. 2, Vol. II, (1901), p. 102.

Specific Gravity	2.801
Porosity	13.000 %
Ratio of Absorption	5.341
Weight per cubic foot	152.200 lbs.
Tensile Strength	220.000 psi
Crushing Strength	8486.700 psi (on bed) 9161.000 psi (on edge)

Other important properties of the mine rock are:[5]

[5] Nelson, H. P., An Experimental Evaluation of Explosives in Blasting Limestone and Granite, thesis presented to the School of Mines and Metallurgy of the University of Missouri, 1951, p. 31.

Modulus of Elasticity.......	3.5×10^6 psi
Modulus of Rigidity	2.5×10^6 psi
Modulus of Rupture	1000 psi

The average petrographic composition of the dolomitic limestone is:[6]

[6] Ibid.

± 65% Dolomite

± 20% Calcite

± 10% Quartz

± 5% Chert, Limonite, Pyrite, and clay minerals

The drillability of the limestone rock is considered very good except in those zones which have a high concentration of chert. The rock, being relatively soft and well-bedded, does not break readily from the solid. The blasting characteristic of the rock can best be described by the term "spongy." Whenever the burden on a hole is too great, the rock tends to break in large blocky slabs.

The test rounds, number 2 through 15, were drilled in two headings, which had an average cover of approximately 50 feet. Both headings were driven near a fault zone, which was visible as a faint crack and which accounted for the presence of some clay and pyrite seams. These irregularities of the rock, when present, had little effect on the blasting properties of the rock. Test Burn Cut 1 was drilled in a bench of a quarry face adjacent to the mine site. The rock in which the cut was drilled was similar in all respects to the mine rock.

Equipment and Materials

The large hole was drilled with an experimental machine, the Cleveland-Failing Large Hole Drill, which was furnished by the Cleveland Rock Drill Company, a division of Westinghouse Air Brake Company. The machine was rubber tire mounted and self propelled. Changeable bits permitted three sizes of holes to be drilled, $5\frac{1}{2}$ inches, 9 inches, and 13 inches in diameter. A diesel engine provided the power for rotation of the drilling column and for the hydraulic pump which controlled the feed pressure. The drill rods, 5 feet in length, were added on to the rear of the drilling column which allowed any depth of hole up to 100 feet to be drilled.

The cut holes of each round were drilled with a column mounted Cleveland HC-10 drill, using 7/8 inch hexagonal steel, $2\frac{1}{2}$ foot steel changes, and Series A Cleveland Throw-away Rock Bits. A column set-up was required because of the need for accurate placement of these holes. The lifter holes of each round were also drilled with the column set-up. The remainder of the round holes were drilled with a Cleveland H-10 AL drill mounted on a 5 foot air leg.

Compressed air for the drills was furnished by an Ingersoll Rand Compressor; the average air pressure at the drills was 95 psi. The water was supplied by a pressure tank which automatically maintained the pressure at 50 psi.

The broken rock was loaded with an Eimco 12-B rocker type loader with an 18 inch wheel base. Twenty pound rails were laid as needed, short sections while mucking a round, and later, permanent sections were installed. The rock was loaded into 1 ton end dumping steel cars and hand trammed to the dump.

Dynamites and Detonators

Various types of dynamites were used in blasting the burn cuts and relief holes of the test rounds. All the rounds were fired electrically from a point outside of the mine.

The following is a list of the grades of powder which were used in the experimental burn cuts and rounds:[7]

[7] Information furnished by the explosive companies.

Mine Gel No. 2 — 1¼″ x 8″ cartridges
Weight Strength: 65%
Bulk Strength: 53%
Rate of Detonation: 12,800 fps.
Cartridge Count: 122 per 50 pounds
Water Resistance: Good

Special Gelatin 40% — 1¼″ x 8″ cartridges
Rate of Detonation: 15,800 fps.
Cartridge Count: 92 per 50 pounds
Water Resistance: Excellent

Special Gelatin 60% — 1¼″ x 8″ cartridges
Rate of Detonation: 17,500 fps.
Cartridge Count: 96 per 50 pounds
Water Resistance: Excellent

Gelatin Extra 40% — 1 1/8″ x 8″ cartridges
Weight Strength: 40%
Rate of Detonation: 8,500 fps.*
Cartridge Count: 110 per 50 pounds

*Rate is based on shooting a 1¼″ by 8″ cartridge in the open with a No. 6 cap.

The blasting caps which were used in the test rounds were:

Regular Delay Electric Blasting Caps No. 6
25 foot and 16 foot leg wires.

The average delay times of the caps are as follows:[8]

[8] Personal correspondence from W. A. Show, Chief Explosives Chemicals Section, Olin Mathieson Chemical Corp., dtd. Sept. 13, 1955

No.	Delay in Seconds	No.	Delay in Seconds
0	Instantaneous	6	4.5
1	0.8	7	5.4
2	1.5	8	6.4
3	2.2	9	7.4
4	3.0	10	8.8
5	3.7		

Millisecond Delay Electric Blasting Caps No. 6
25 foot leg wires

The average delay times of the caps are as follows:[9]

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[9] Ibid.

No.	Delay in Milliseconds	No.	Delay in Milliseconds
0	Instantaneous	6	210
1	30	7	250
2	60	8	300
3	90	9	350
4	130	10	400
5	170		

Millisecond Delay Caps No. 9
12 foot leg wires (See Round 1)

Test Procedure

The experimental test rounds were drilled in the following order: The large hole, the burn cut holes, and finally the remaining holes of the round. All holes were drilled in the same manner as they would have been done in regular mining conditions. No special equipment was used in directing the burn cut holes other than a loading stick and a Brunton compass for turning the angles. As a result, there were several rounds in which the location of the burn cut holes did not conform exactly to the intended pattern. This condition could have been remedied if a template had been used and if more time had been spent in properly collaring and lining up these holes.

The usual procedure of drilling the burn cut holes slightly deeper than the relief holes was not followed in the field tests. All of the drift round holes, except the large hole, were drilled so that they would bottom on the same plane.

The burn cut was loaded with powder and fired, after which the results of the cut blast were noted and the required measurements taken. Any broken rock which remained in the cut was undisturbed so that the relief holes would break to the same cut which would have existed if the entire round had been fired in one continuous sequence. This procedure of firing the burn cut separately and evaluating the results was important in the guiding of future test rounds.

Burn Cut 1 was drilled in a solid rock face of a quarry which was near the mine site. This cut was prepared in the open because underground limitations prevented the use of a high speed camera which was used to record the blasting action of the cut.

Method of Reporting Data

The results of each round are presented by means of a data sheet, a sketch of the round, and a discussion of the results obtained. A photograph of the cut, if obtained, is also included.

The information on the data sheet is mostly self-explanatory, but it would do well to define those terms which might be confusing.

Bearing refers to the position of a cut hole relative to the large hole and is expressed in degrees. Thus, a positive (+) value indicates that the cut hole was inclined toward the large hole, and a negative (-) value indicates that the hole was inclined away from the center line of the big hole .

Loading Pattern shows the placement of the powder column from the bottom to the collar of the hole. For example--Round 2, Hole No. 1, the loading pattern is listed as 12 - x, signifying 12 cartridges and then the primed cartridge, for a total of 13 sticks of powder. The symbol "S" appearing in any loading pattern refers to the use of a $2\frac{1}{2}$ inch asbestos plug which was used as stemming.

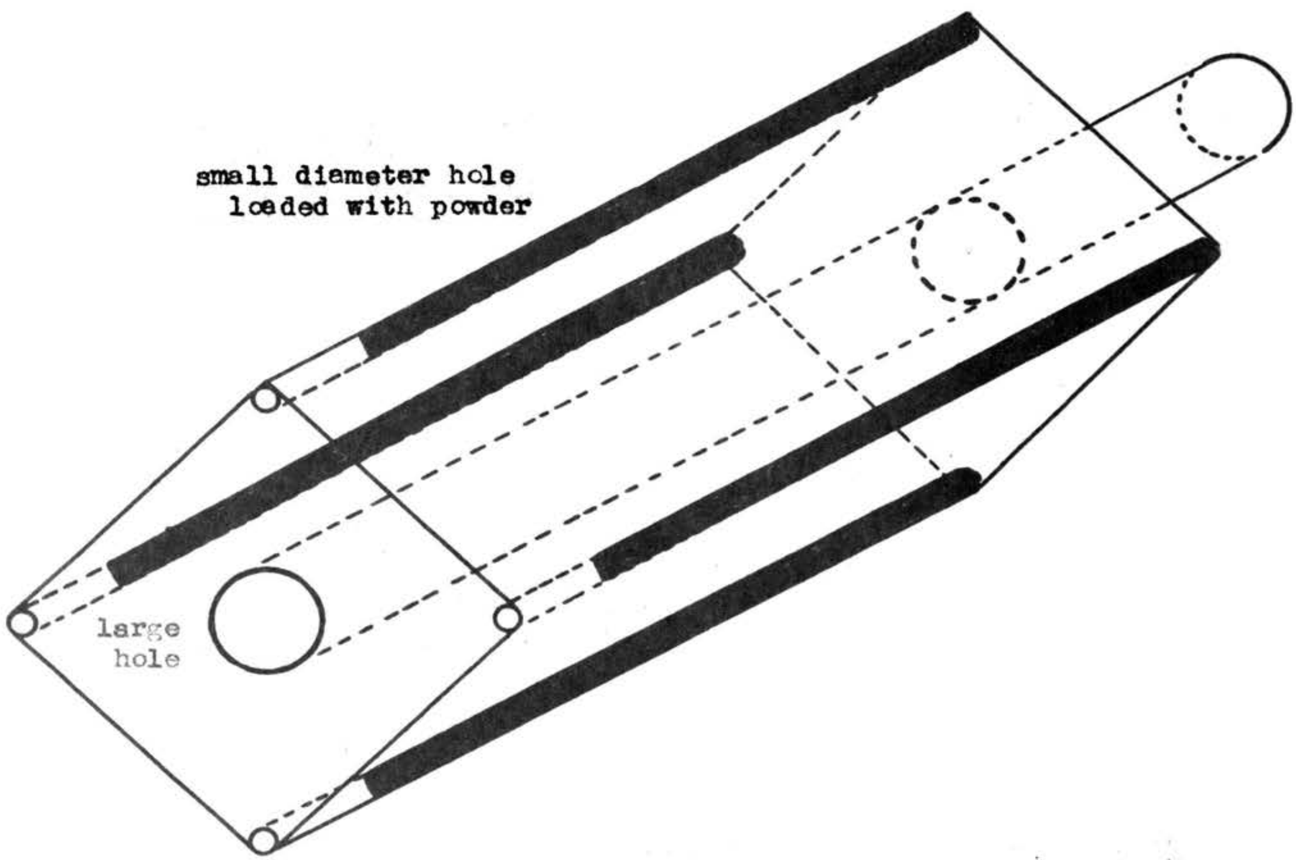
Powder Factor for the cut was computed on the basis of the theoretical amount of rock which should be broken. See Figure A. In other words, the results of the cut did not have any bearing on this figure.

Powder Factor for the entire round was calculated by using the actual calculated tons of rock broken.

The amount of powder used in the burn cuts and rounds is listed in pounds which were computed from the cartridge count reported by the powder manufacturers. Since the manufacturers claim a variation in the powder counts not to exceed a plus or minus 3%, the powder consumption values are also within a $\pm$ 3% of the actual amount used.

The term round holes includes all the holes of the round except those of the burn cut. That is, the round holes include the relief holes, breast or enlarger holes, if any, and the trim holes.

Cavity Burn Cut Results: To provide a general basis on which the various cuts could be compared, an evaluation of the burn cut was made based on two factors - (1) the percentage of the theoretical amount of rock broken by the burn cut, and (2) the percentage of the broken rock thrown out of the cavity. Rather than compute only one average value for each cut, the percentage of the theoretical amount of rock broken and percentage of cut cleared of broken rock was made for various footages of the cut. The break-down of the cut footages was chosen by the appearance of the cut,



The volume enclosed by the 4 small cut holes is the theoretical amount of rock which should be broken by the cut. (Theoretical volume includes that of the large hole).

TYPICAL LARGE HOLE BURN CUT

Figure A

that is, at any significant change in the cut, these two separate values were computed.

Figure A illustrates a typical spiral burn cut. The volume bounded by the four small holes is the theoretical amount of rock which should break. After each cut was fired and examined, the two percentages were computed as accurately as possible without disturbing the cut. For those cuts in which the rock had broken and then recompacted, the recompacted rock was considered as rock not broken because it has the same effect on the relief holes. The symbol (±) after any value indicates an approximate figure which was based on the appearance of the cut rather than upon actual measurements.

III. EXPERIMENTAL DRIFT ROUNDS

ROUND NUMBER 1

Spiral Burn Cut

Hole Number	Bearing	Depth	Sticks of Powder	Loading Pattern and Delays	Bootleg
1	0°	10′0″	14	See Fig. 1-B	None
2	0°	10′0″	15	"	None
3	0°	9′10″	16	"	5′
4	0°	10′0″	15	"	5′
9″ Hole		12′0″	4	"	
			64		

Powder: 40% Gelatin Extra

Blasting Caps: Millisecond Delays, Number 9

Average Depth of Cut: 10′0″

Amount of Explosives Used: 29.2 pounds

Powder Factor: 0.12 tons of rock per pound of powder

Round Holes

None

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0-5′	100%	95%
5′-9′	60%	40%
9′-10′	65%	40%
0′-10′	80%	67%

Summary of Complete Round

Round Incompleted

Discussion and Results of Round 1

In spite of the high percentage of rock broken the cut was not too successful in that only the first 5 feet of the cut was completely broken and cleared of rock. Holes 1 and 2 broke to the bottom, but holes 3 and 4 bootlegged the last 5 feet as is shown in Figure 1-C.

Through the courtesy of the Bureau of Mines, two high speed movies were made, one of the cut blast, the other of the millisecond delay blasting caps which were used to fire the cut holes. The high speed movie of the cap shot will be discussed first because of the unexpected events which undoubtedly affected the results of the cut.

A series circuit of 15 millisecond caps was arranged on the quarry floor which consisted of three caps of each of the delays from 0 to 4. The caps were detonated by a plunger type, 50 cap capacity, blasting machine. The observed time delays among the caps were as follows:[10]

[10]Private correspondence (to Dr. George B.Clark) from Mr. Wilbur I. Duvall, Bureau of Mines, Chief of the Mineral Mining Research Section, dtd. March 30, 1955.

Millisecond Delays Number	Nominal Delay Milliseconds	Measured Delay, Milliseconds A	B	C	Average
0	0	1	0	0	0.33
1	8	10	12	56	26.00
2	25	6	15	27	16.00
3	50	58	57	44	53.00
4	75	100	88	90	92.60

From the data, it is apparent that one of the number 2 delays fired before any of the number 1 caps. Also, one of the number 1 caps was very late in firing. This number 1 cap fired about the same time the number 3 caps were detonating. These caps had been in storage for some length of time which probably accounted for some of the discrepancies noted.

The results of the high speed movie of the cut are summarized below:[11]

[11] Ibid.

Event	Probable Related Hole Detonation	Time Milliseconds
Initial Face Movement		-5
First dust and gas from center hole	Front 1	0
Second dust and gas from center hole	Front 2	11
Upward dust and gas surge	Back 1	14
Dust and gas from shot hole 3	Front 3	27
Big dust and gas surge	Center Hole	36
First appearance of individual rocks		65
Appearance of crack at top of face		70
First measurable fly rock		90
Appearance of crack on surface		140
Large bunch of rocks moving		170

At first glance, the results from the high speed movie appears disappointing. However, a careful study of the data reveals several interesting facts. The first evidence of motion appeared on the face of the heading followed closely by the escape of gas from the center hole. This escape of gas from the large hole before any such events recorded for hole number 1 could possibly mean one of two things—either the burden on hole number 1 was too light, or the charge in the bottom of the big

Velocities	Ft. per Sec.	Time Milliseconds
First dust and gas surge	900	0
Shot hole 3 dust and gas	600	27
Initial fly rock velocity	140	65
Individual rock velocities 1	84	90
Individual rock velocities 2	64	100
Individual rock velocities 3	50	115
Envelope of bunched rocks	70	170

hole detonated first or possibly simultaneously with the front of hole number 1. Remembering the erratic firing sequence of the caps the latter possibility is plausible. Perhaps, the escape of gas from the large hole was caused by both conditions because the burden on hole number 1 (6 inches) was much too light considering the large amount of powder used in the hole.

The movie also showed that the size of the fly rock was very small which is direct evidence that the powder factor (tons of rocks per pound of powder) was much too small. It appeared, therefore, that the amount of powder used in the cut holes could be reduced, at least at the front of the holes. However, it was decided that all future burn cuts would be loaded the same relative amount (equal Powder Factors) even though it was known that the cuts were overloaded. The reason for the above decision was to permit a more detailed study of the other factors which determine the success of a burn cut.

Undoubtedly, a considerable amount of explosive energy was expended in developing the cracks along the bedding planes in the face and at the top of the ledge. These cracks are visible in Photograph 1-A of the cut and also illustrated in Figure 1-C. If there had been sufficient restraint on the surrounding rock, preventing any possible lateral movement, the results of the round could have been conceivably better. The order of events from the movie seems to establish this supposition because the appearance of a crack at the top of the face occurred 20 milliseconds earlier than the first measurable fly rock and 100 milliseconds before the movement of any large amount of rock. This last mentioned rock was probably from the immediate face surrounding the cut and is of less importance.

Several important facts about deck-loaded charges, such as used in this cut, have been discussed by other investigators. Presanis[12] made a

[12] Presanis, A. J., A Study of Sympathetic Detonation, thesis presented to the Colorado School of Mines, Golden, Colorado, 1953, p. 1.

study of sympathetic detonation as applied to charges in a borehole separated by various stemming material. He stated that, "It was found that the length of stemming through which a primer fires depends on the diameter of the hole and on the type of stemming used. Amount of powder and the placement of detonators do not enter as factors in the propagation and sensitivity of the charge."

Presanis,[13] in one particular test used 4 cartridges of dynamite in

[13] Presanis, op. cit., p. 27.

a 1 5/8 inch hole. He separated the two charges, each of two sticks, with 14 inches of dry sand and primed only one of the deck loads. The outcome of this test was sympathetic detonation of the charge which was not primed. He found that charges separated by as much as 15 inches of dry sand would be consistently sympathetically detonated. For his tests, the hole sizes were 2 inches and 1 5/8 inches. The explosive used was Du Pont Gelex No. 2 and the detonators were Du Pont Number 6 caps.

A more extensive investigation of sympathetic detonation in boreholes was reported by Kabbani.[14] He stated that, "The burden which the

[14]Kabbani, F. K., Application of the Crater Theory and Sympathetic Detonation in Mining, thesis presented to Colorado School of Mines, Golden, Colorado, 1954, p. 31.

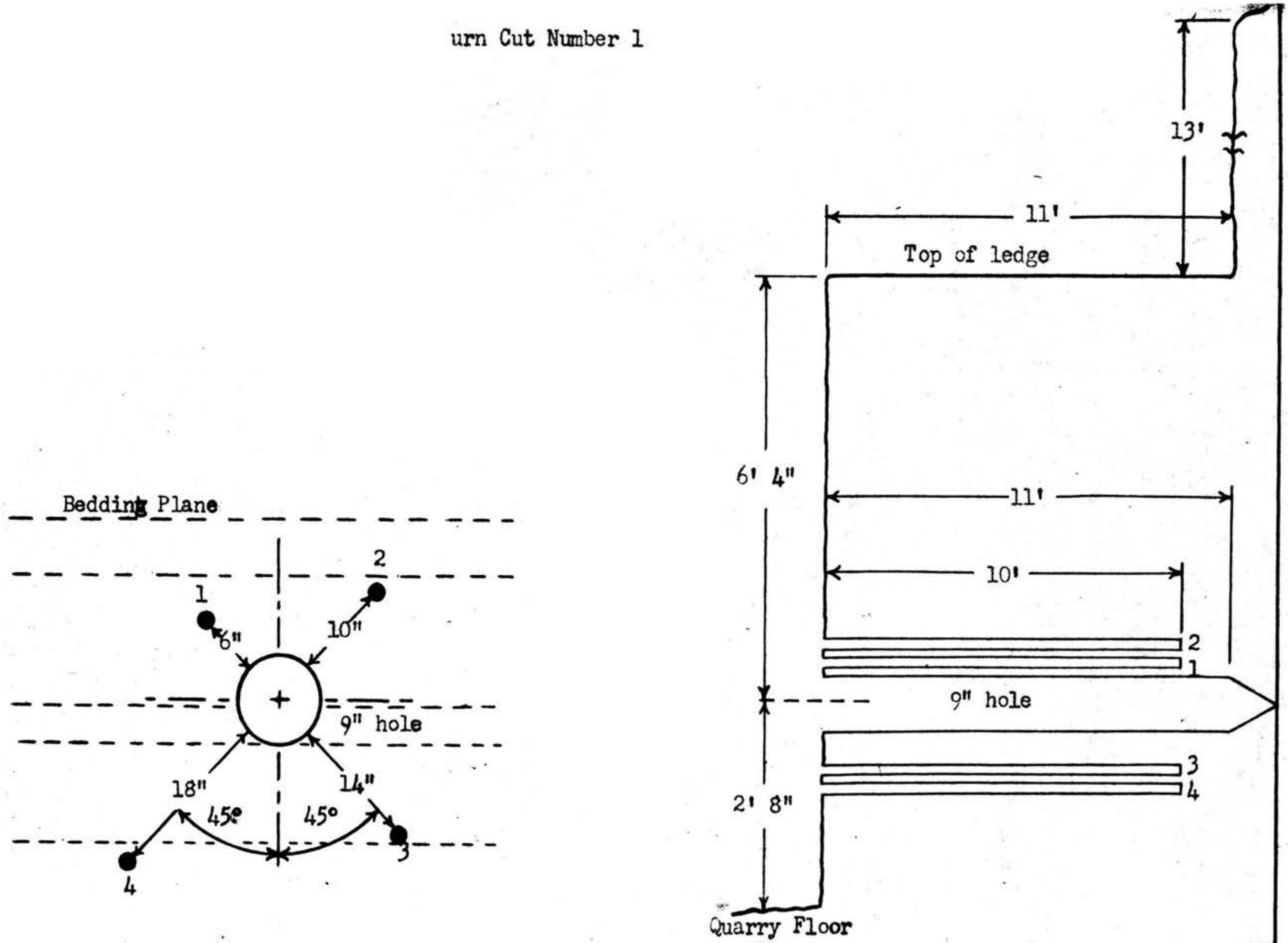
force of the explosive charge has to overcome exercises a major influence in diverting the intensity of the shock wave into the line of least resistance and thus increases the length of the deck stemming. It has been observed that the greater the burden, the greater is the distance of deck-stemming required to prevent sympathetic detonation."

This appears to be a sound conclusion within limits, although the relationship was not proven to be linear.

Considering the experiments conducted by these two men, it would be reasonable to assume that all of the decked powder charges in this test cut were sympathetically detonated because they were separated by only 12 inches of dry sand.

The test site was abandoned without any relief holes being drilled to the cut because of the large cracks in the surrounding rock. The influence on the relief holes by these separations would prevent the determination of the actual depth of round which could be pulled with this cut.

urn Cut Number 1

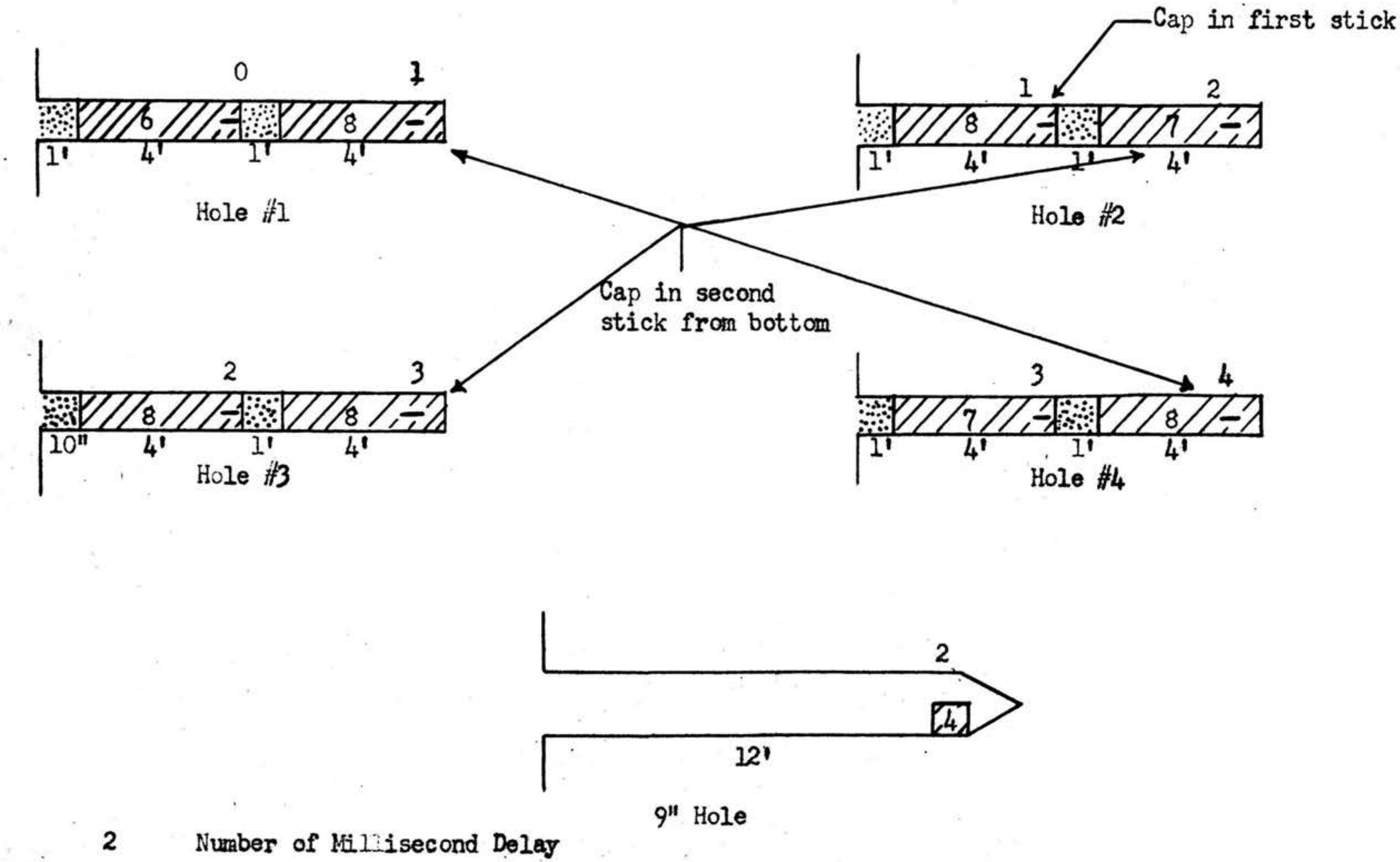


Scale 3/4" = 1'

Side View Thru Center of Large Hole
Not to Scale

Figure 1-A

Loading Pattern of Burn Cut Holes



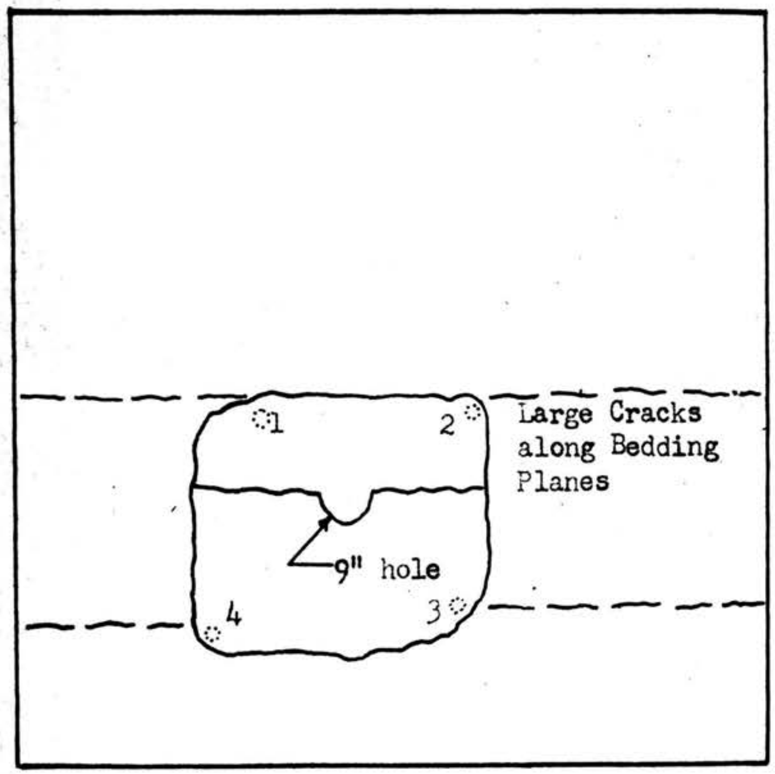
Number of Sticks of Explosive

Sand Stemming

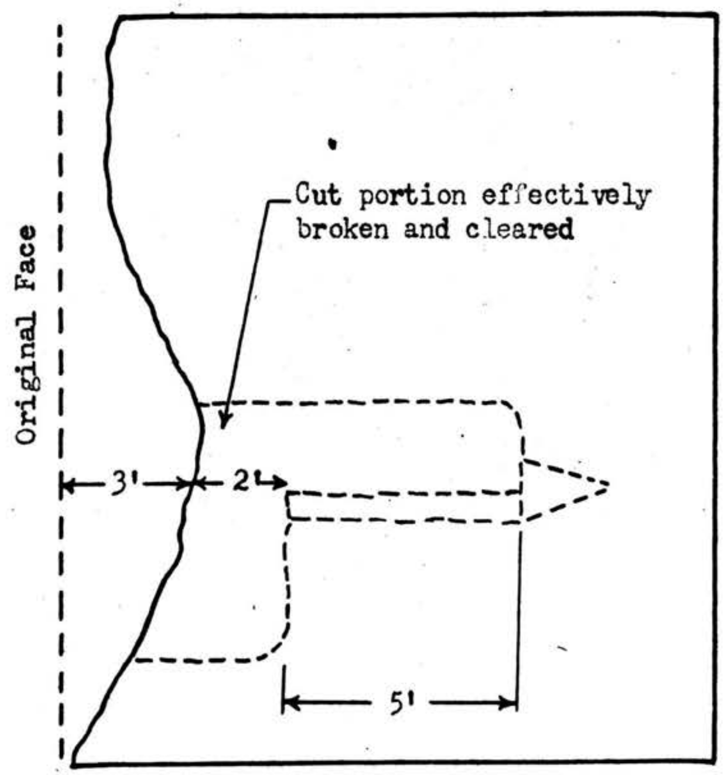
The powder in the holes was tightly tamped.

Figure 1-B

Results of Burn Cut Number 1



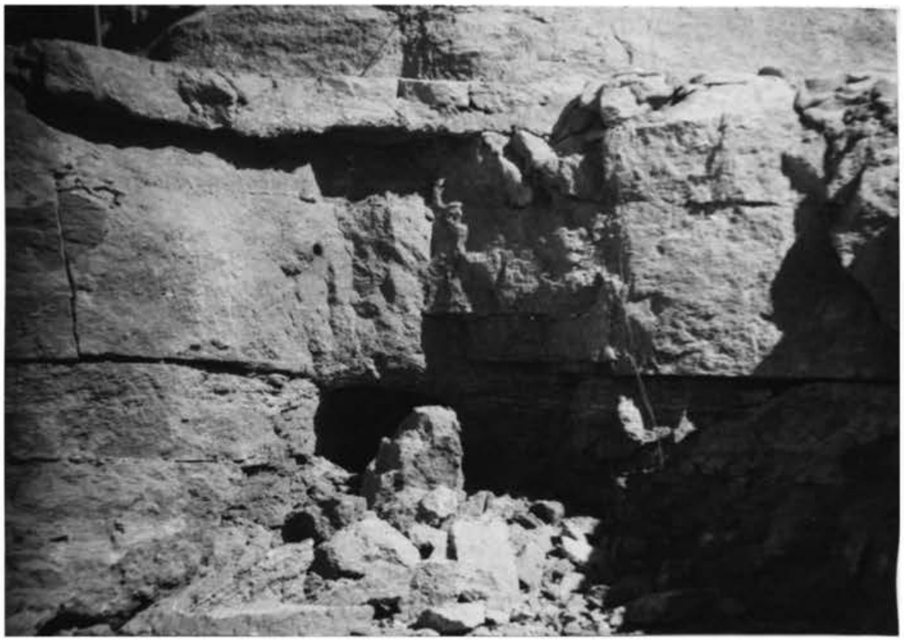
Front View



Side View

25

Figure 1-C



Photograph 1. General View of Burn Cut Number 1 in the Quarry Face.

ROUND NUMBER 2

Modified Spiral Burn Cut

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	0°	9′1″	12	11-X	None
1	0°	9′7″	13	12-X	None
2	0°	10′0″	14	13-X	None
3	0°	9′10″	13	12-X	None
4	0°	9′5″	13	12-X	None
9″ Hole		11′0″			
			65		

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Average Depth of Cut: 9′7″

Amount of Explosives Used: 26.6 lbs.

Powder Factor: 0.13 tons of rock per pound of powder

Round Holes

Average Depth: 10′0″

Powder: Mine Gel No. 2

Blasting Caps: Regular delay

Loading Pattern: Primer, 1 stick from bottom

Amount of Powder used: 96.4 pounds

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0 – 7′	100%	90%
7′ – 9′7″	90%	35%
0 – 9′7″	97%	75%

Summary of Complete Round

Average advance: 10′0″

Average bootleg: None

Total amount of powder used: 123 pounds

Volume of rock broken, cu. ft. in place: 560

Tons of rock broken, calculated: 42.0

Powder factor, tons of rock per pound of powder: 0.34

Loading factor, cu. ft. of rock broken per pound of powder: 4.6

Fragmentation: Very fine

Length of muck pile from new face: 60 ft.

Discussion and Results of Round 2

The burn cut holes were placed in a modified spiral pattern parallel to the large hole in order to take advantage of the clayey zone which appeared at the face and apparently extended the full depth of the ten foot round. Except for the soft decomposed rock and clayey zones, the rock at the face was characteristic of the mine. A very irregular face accounted for the difference in depth of the cut holes, but all the holes of the round bottomed on the same plane.

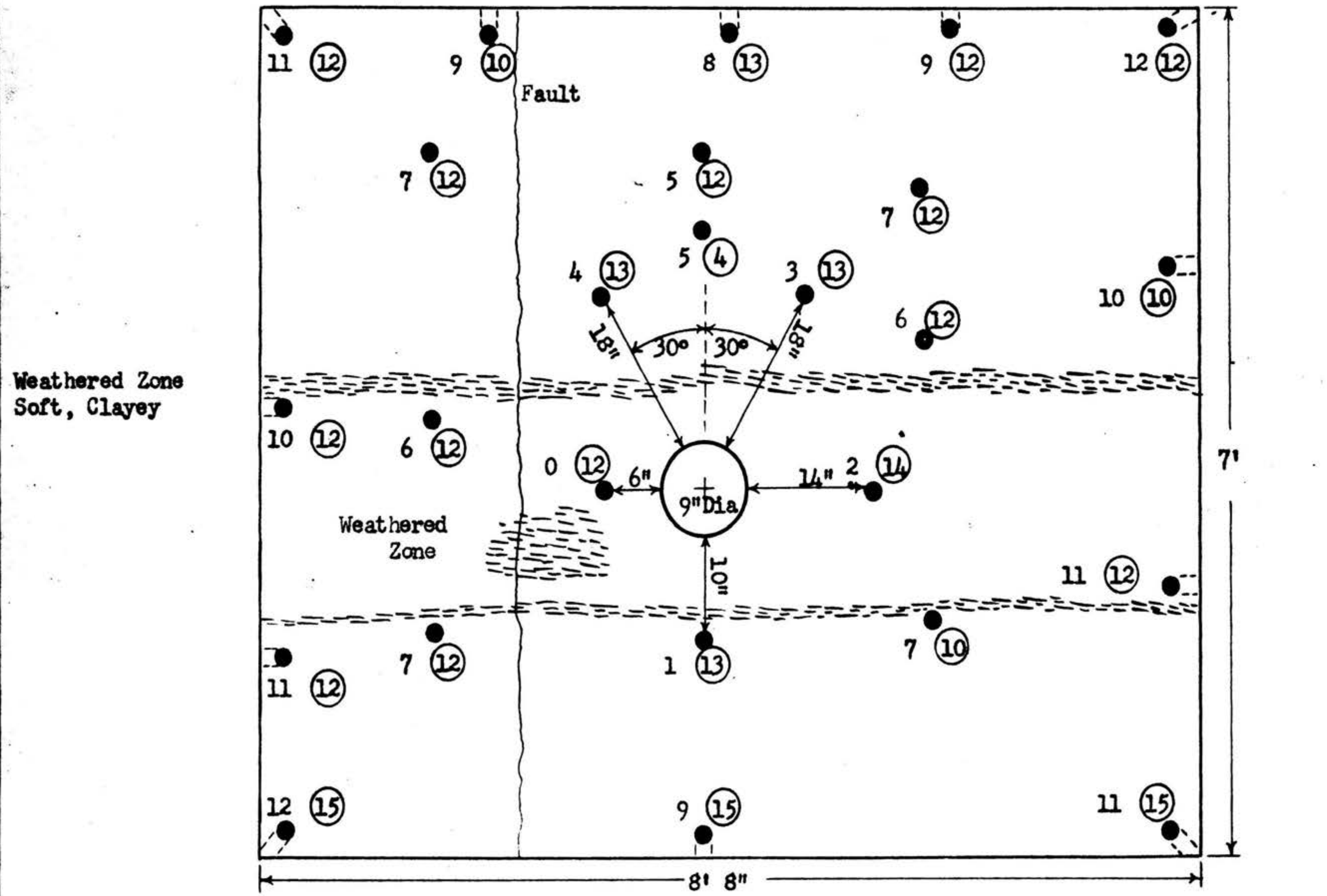
The dynamite cartridges were tamped just enough to insure firm contact between each stick in order to distribute the powder column the full length of the holes.

The cut holes were primed at the collar with the primed cartridge approximately one foot from the face. This reversal of the more normal procedure of placing the pimers at the bottom of the holes was done under the assumption that the rock would break progressively from the face of the cut to the bottom.

When the cut was blasted, hole humber 4 did not detonate. The primed cartridge was nowhere to be seen, nor was there any evidence of it having exploded in the hole. It was assumed that the primer was pulled from the hole by the blast and detonated in the air. Examination of the cut showed holes 0, 1, 2, and 3 had broken their full depth. All of the rock bounded by these holes was broken except for a band of solid rock 6 inches thick and extending 2 feet 7 inches from the bottom of the cut. This unbroken rock was half-way between the plane of holes 3 and 4 and the top of the 9 inch hole. The first seven feet of the cut was effectively cleared of all the broken rock. Hole 4 was reprimed and shot. This improved the burn cut only slightly. Although the band of unbroken rock remained, it was shortened 6 inches.

Nevertheless, the burn cut must be considered a success because the entire round pulled the full ten feet and left a clean face. The shelf of solid rock remaining in the cut must not have been of sufficient size to cut off the advance of the round at this point.

ROUND NUMBER 2



Scale 3/4" = 1'

1 (13) Shows No. 1 delay electric cap; 13 sticks of dynamite
1-1/2 " to 1-5/16 " holes, 10 '
Average Advance: 10' 0"

Burn Cut holes - 0,1,2,3,4
Total Number of Holes - 25
Average Bootleg: None

Photograph 2B. Final Appearance of Burn Cut Number 2

Round Number 3

<u>Spiral Burn Cut</u>

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	-2°	9'8"	14	13 - X	None
1	0°	10'0"	14	13 - X	None
2	0°	9'7"	15	14 - X	None
3	0°	9'6"	15	14 - X	None
9" hole		11' 0 "			
			58		

Powder: 40% Special Gelatin

Blasting Caps: Regular Delay

Average Depth of Cut: 9'8"

Amount of Powder Used: 32.6 pounds

Powder Factor: 0.11 tons of rock per pound of explosive

<u>Round Holes</u>

Average Depth: 10'0"

Powder: 40% Gelatin Extra

Blasting Caps: Regular Delay

Loading Pattern: Primer one stick from bottom

Amount of Powder Used: 84.8 pounds

Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0 - 6½′	100%	74%
6½′ - 7′	100%	60%
7′ - 9′8″	95%	5%
0′ - 9′8″	99%	54%

Summary of Complete Round

Average advance: 10′0″

Average bootleg: 0″

Total amount of powder used: 117.4 pounds

Volume of rock broken, cu. ft. in place: 698

Tons of rock broken, calculated: 52.3

Powder factor, tons of rock per pound of powder: 0.44

Loading factor, cu. ft. broken per pound of powder: 6.0

Fragmentation: Very fine

Length of muck pile from new face: 50 ft.

Expansion ratio of rock: 1.7

Discussion and Results of Round 3

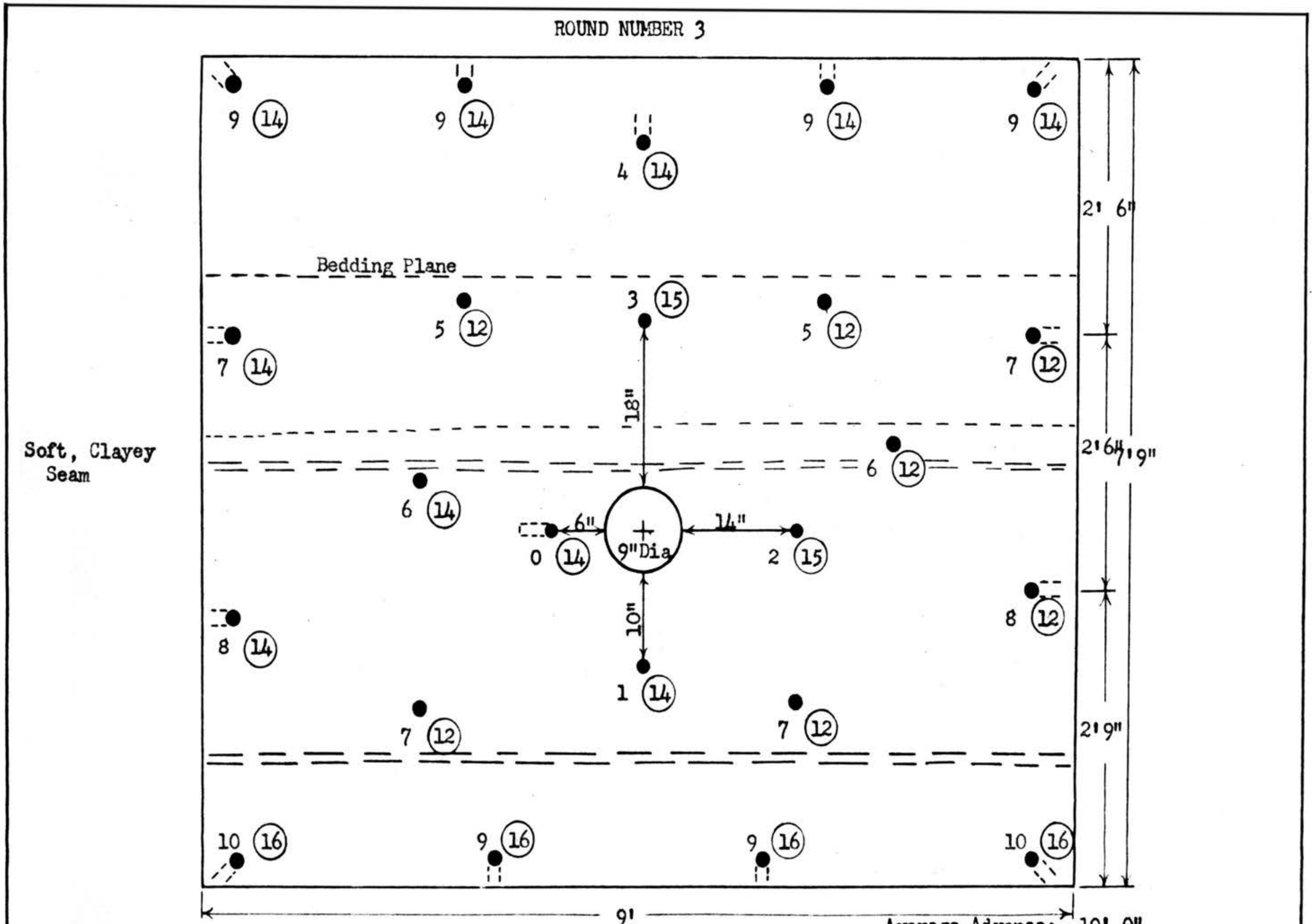
The spiral burn cut was exactly the same as used for test number 1, except for a 45 degree counter clockwise rotation of the pattern. The uneveness of the face presented a problem in placing the holes properly. Consequently, hole 0 angled away from the 9 inch hole instead of being parallel to it. The dynamite cartridges in the holes were not tamped, but they were placed in firm contact with each other. The primed cartridges (1 foot from the collars) in the cut holes were wedged in to prevent them from coming out and causing a misfire.

The results of the burn cut were better than that of round 1. However, they were not as good as round 2. The cut broke the full depth, but hole number 3 only shattered the rock the last three feet. None of this rock was cleared from the cut even though it was not compacted or frozen to any extent.

The 40% special gelatin as compared with mine gel has a much higher detonation rate. Possibly the faster acting explosive with its higher explosion pressure does not allow enough time for the rock to break and be thrown out.

Hole 0, by breaking to the bottom, showed that the first cut hole of the spiral could be at least 10 inches from the circumference of the large hole. Of course this would increase the burden on holes 1 and 3, and possibly require further modifications of the spiral.

Even though the last 2 feet 8 inches of the cut was not cleared of broken rock, sufficient stress relief was available for the relief holes to break the full depth of 10 feet.



Scale 3/4" = 1'

Average Advance: 10' 0"
Average Bootleg: None

1 (14) Shows No. 1 delay electric cap; 14 sticks of dynamite
1-1/2 " to 1-5/16 " holes

Burn Cut Holes: No. delay 0,1,2,3
Total number of holes - 24

Figure 3

Round Number 4

Spiral Burn Cut

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	-2°	8′0″	12	11 - X	None
1	0°	8′0″	11	10 - X	None
2	0°	8′0″	11	10 - X	None
3	0°	8′0″	13	12 - X	None
9″ hole		11′4″	47		

Powder: 60% Special Gelatin

Blasting Caps: Regular delay

Average Depth of Cut: 8′

Amount of Powder Used: 24.5 pounds

Powder Factor: 0.11 tons of rock per pound of powder

Round Holes

Average Depth: 8′0″

Powder: 40% Gelatin Extra

Blasting Caps: Regular Delay

Loading Pattern: Primer one stick from bottom

Amount of Powder Used: 87.0 pounds

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0 - 4′	100%	90%
4′ - 8′	100%	55%
0 - 8′	100%	73%

Summary of Complete Round

Average advance: 8′0″

Average bootleg: None

Total amount of powder used: 111.5 pounds

Volume of rock broken, cu. ft. in place: 558

Tons of rock broken, calculated: 42

Powder factor, tons of rock per pound of powder: 0.38

Loading factor, cu. ft. broken per pound of powder: 5.0

Fragmentation: Very fine

Length of muck pile from new face: 65 feet

Expansion ratio of rock: 1.5

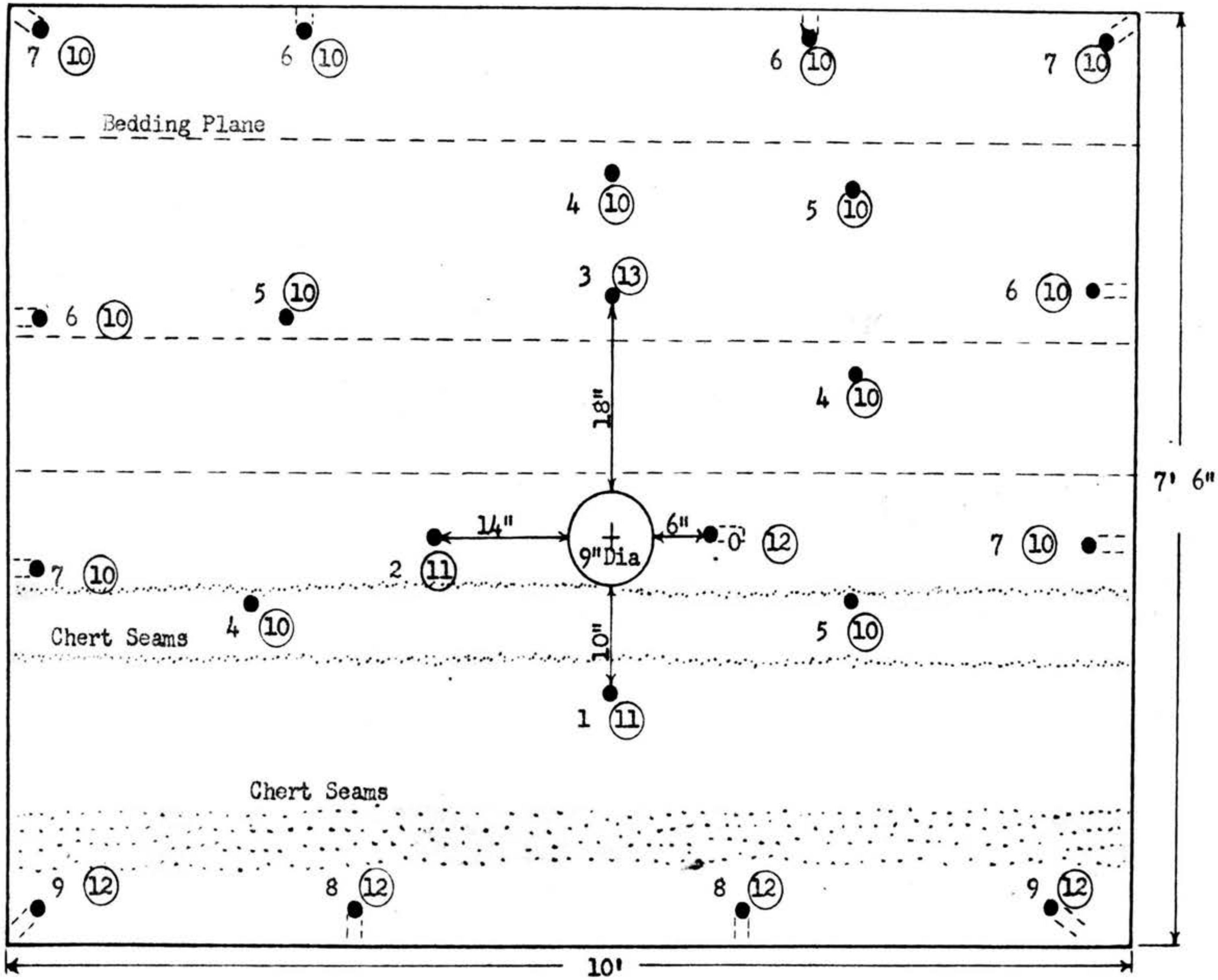
Discussion and Results of Round 4

The burn cut pattern used in this round was similar to round 3 except for the depth of the cut. The cut holes were actually drilled 10 feet deep but they could not be loaded beyond 8 feet because the last 2 feet of the holes were slightly less in diameter than the size of the powder.

The purpose of this round was to compare the effects of using a powder having a higher strength (60% vs. 40% Special Gelatin). When comparing the burn cut results of this test with round 3, it should be remembered that the cuts were not of the same depth. Up to 8 feet, the cut was more successful than any previous round. The significant fact about this cut was the absence of any unbroken or frozen rock.

The cut holes were primed at the collar which placed the primer about 1 foot from the face. The primed cartridges were wedged securely in the holes, as was done for round 3, and again no misfires occurred. This led the writer to the conclusion that if the primers were carefully wedged in the cut holes misfires would not occur.

ROUND NUMBER 4



Scale 3/4" = 1'

1 (11) Shows No. 1 delay electric cap; 11 sticks of dynamite
1-1/2 " to 1-1/4 " holes
Average Advance: 8' 0"

Total number of holes - 22
Burn Cut Holes: No. delay 0,1,2,3
Average Bootleg: None

Figure 4

Photograph 4. Results of Burn Cut Number 4

Round Number 5

Spiral Burn Cut

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	0°	10′6″	15	11 - 3 - X	None
1	0°	10′6″	15	11 - 3 - X	None
2	0°	10′6″	15	11 - 3 - X	None
3	+2°	10′6″	15	11 - 3 - x	1 foot
9″ Hole		11′0″			
			60		

Powder: 60% Special Gelatin, Mine Gel No. 2

Blasting Caps: Regular Delays

Average Depth of Cut: 10′6″

Amount of Powder Used: 23.0 pounds - 60%
6.5 pounds - Mine Gel
29.5 pounds TOTAL

Powder Factor: 0.12 tons of rock per pound of powder.

Round Holes

Average Depth: 10′6″

Powder: 40% Gelatin Extra

Blasting Caps: Regular Delay

Loading Pattern: Primer one stick from bottom

Amount of Powder Used: 103 pounds

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0 - 4′	92%	60%
4′ - 5½″	100%	60%
5½′ - 9½′	100%	30%
9½′ - 10½′	40%	0%
0 - 10½″	91%	43%

Summary of Complete Round

Average advance: 9′6″

Average bootleg: 1′6″

Total amount of powder used: 132.5 pounds

Volume of rock broken, cu. ft. in place: 606

Tons of rock broken, calculated: 45

Powder factor, tons of rock per pound of powder: 0.34

Loading factor, cu. ft. broken per pound of powder: 4.6

Fragmentation: Very fine

Length of muck pile from new face: 40 feet

Expansion ratio of rock: 2.1

Discussion and Results of Round 5

Essentially the same spiral burn cut, as used in rounds 1, 3, and 4 was used in this round. The differences were (1) a greater depth of the small holes, (2) the loading pattern, and (3) the relative depth of the large hole.

The burn cut was loaded with 11 sticks of 60% special gelatin and 4 sticks of mine gel number 2. The last cartridge of the mine gel in each hole was primed with a regular delay. The powder columns were tamped very lightly which placed the primers approximately 1 foot from the collars of the holes.

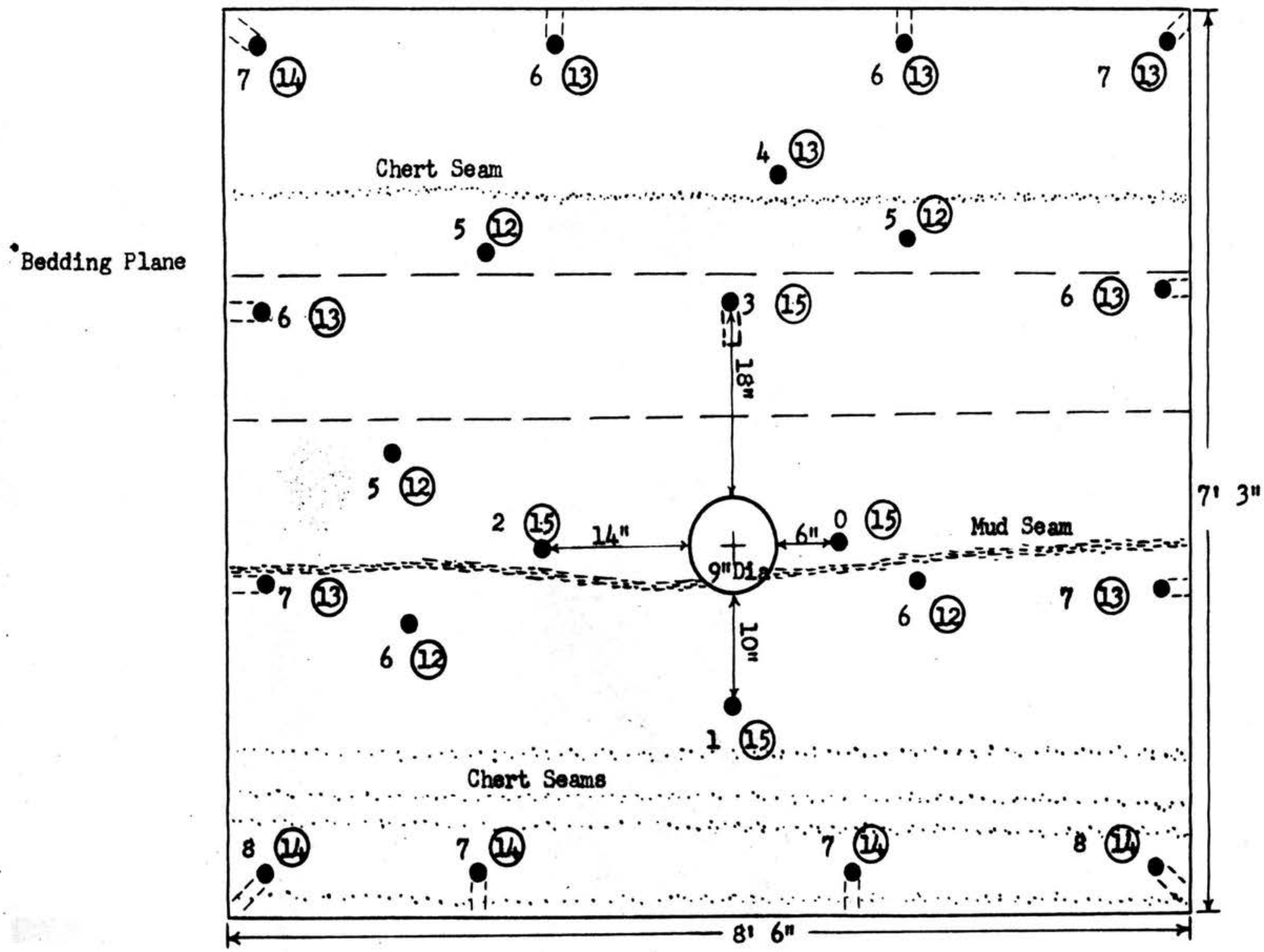
The loading pattern of the holes was designed to utilize the greater explosive pressure of the 60% special gelatin. The mine gel powder was placed at the collar of the hole with the hope that this slower acting explosive would plug the mouth of the cut and increase the effectiveness of the 60% special gelatin in clearing the broken rock from the cut.

The results of the cut were very poor and definitely showed that the 60% special gelatin dynamite is too fast acting for deep cuts. The mud seam directly below the 9 inch hole affected the breaking action of hole 2. This mud seam was horizontal for 4 feet into the face and then dipped downward to the point where it lay directly above hole 1 at the depth of $10\frac{1}{2}$ feet. Hole 2 broke along the mud seam for the first 4 feet instead of breaking along the line between holes 1 and 2. Beyond 4 feet, hole 2 broke along the expected line. Photograph 5 of the cut shows the irregular outline of the cut which was caused by the mud seam.

Holes 0, 1, and 2 broke to the bottom, but hole 3 bootlegged 1 foot and left a triangle of unbroken rock at the bottom of the cut. The remaining volume of the last foot of the cut was compacted solidly with broken rock.

It was decided to discontinue experimenting with different grades of dynamite and use Mine Gel number 2 in all future burn cuts. The data obtained from the first five rounds, although not conclusive, seemed to indicate strongly that Mine Gel number 2 is much better suited for large hole burn cuts than any other dynamite tested.

ROUND NUMBER 5



Scale 3/4" = 1'

1 (15) Shows No. 1 delay electric cap; 15 sticks of dynamite
1-1/2 " to 1-5/16 " holes
Average Advance: 9' 6"

Total number of holes - 22
Burn Cut Holes: No. delay 0,1,2,3
Average Bootleg: 1' 6"

Figure 5

Photograph 5. Results of Burn Cut Number 5
Bottom of Cut is 9½ Feet From Original Face.

Round Number 6

<u>Spiral Burn Cut</u>

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	0°	10′2″	14	13 - X	None
1	0°	9′10″	14	13 - X	None
2	0°	10′6″	14	13 - X	5′
3	0°	10′7″	14	13 - X	7′
9″ hole (4th delay)		10′7″	6		
			62		

Powder: Mine Gel No. 2

Blasting Caps: Millisecond Delay

Average Depth of Cut: 10′3″

Amount of Powder Used: 25.5 pounds

Powder Factor: 0.13 tons of rock per pound of powder

<u>Round Holes</u>

Average Depth: 10′0″

Powder: 40% Gelatin Extra

Blasting Caps: Regular Delay

Loading Pattern: Primer one stick from bottom

Amount of Powder Used: 109.5 pounds

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0 – 3′	100%	100%
3′ – 5′	43%	43%
5′ – 10′3″	28%	25%
0 – 10′3″	52%	50%

Summary of Complete Round:

Average advance: 8′10″

Average Bootleg: 1′2″

Total amount of powder used: 135.0 pounds

Volume of rock broken, cu. ft. in place: 526

Tons of rock broken, calculated: 39.5

Powder factor, tons of rock per pound of powder: 0.29

Loading factor, cu. ft. broken per pound of powder: 3.9

Fragmentation: Very fine

Length of muck pile from new face: 35 feet

Discussion and Results of Round 6

In order to compare the relative performance of regular delay caps with millisecond delays, this test round was similar in all respects to round 2 except for the use of millisecond delay caps, and the use of a booster charge placed in the bottom of the big hole.

The results of the cut were very unsatisfactory because a large part of the rock enclosed by the cut holes did not break. Holes 0 and 1 broke to the bottom, but holes 2 and 3 had blow outs of 5 feet and 7 feet respectively. The necessity of the booster charge could be questioned even though it undoubtedly helped in removing some of the broken rock from the cut.

The appearance of the burn cut is shown by Photograph 6. Note the large band of unbroken rock in the center of the cut which was caused by the failure of holes 2 and 3 to break to the free faces created by the firing of previous holes (0 and 1).

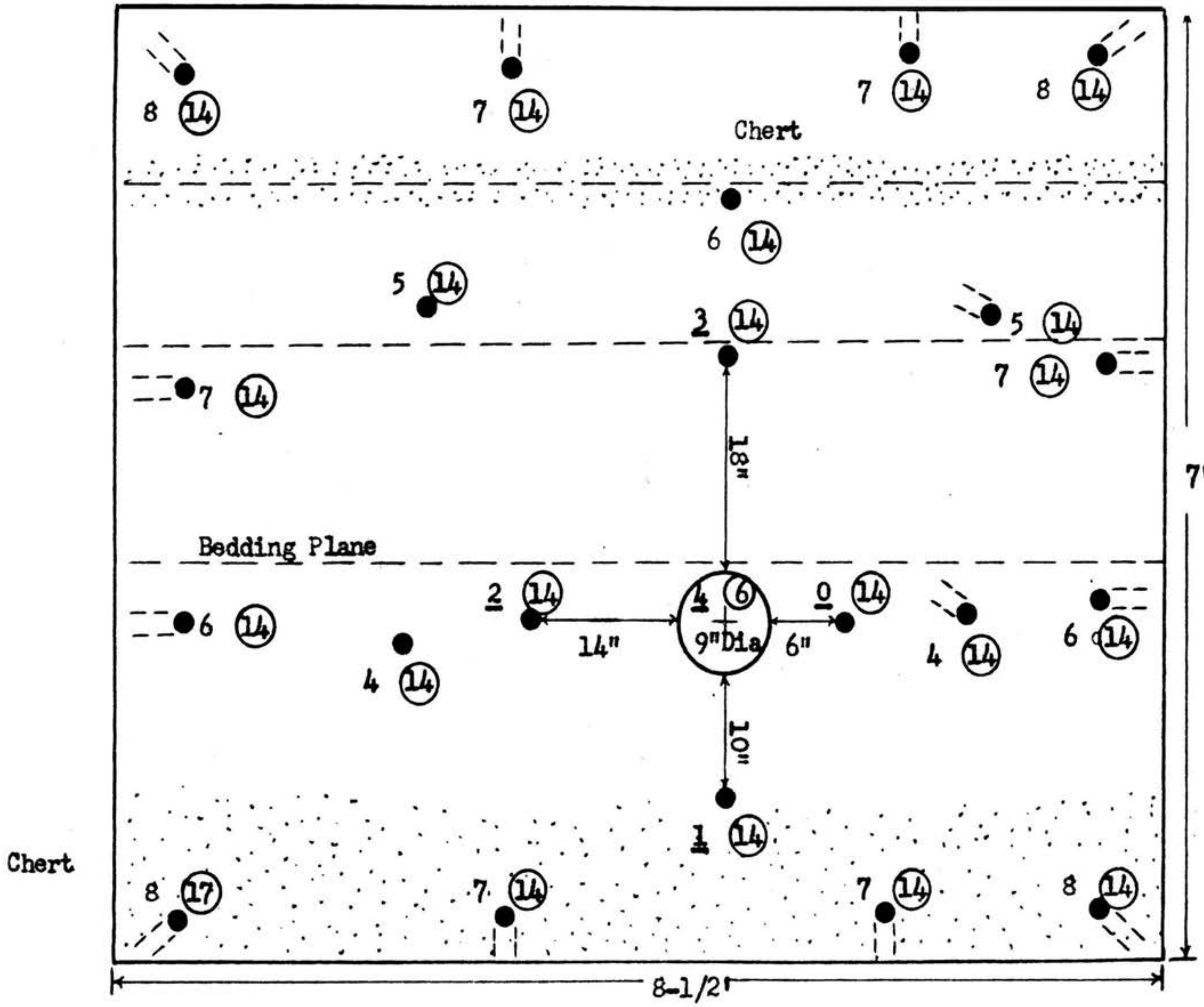
The logical conclusion which can be drawn from this test is that millisecond delay caps do not allow a sufficient time delay between blasting of holes to enable them to break properly. The blasting characteristic of the limestone rock, which can best be described as "springy," requires a certain amount of time after the explosive has detonated before it fractures, breaks away from the solid and is moved sufficiently to allow the remainder of the rock to break without recompaction.

The burn cut was not disturbed and the relief holes were loaded and shot with regular delays. The average advance of 8 feet 10 inches was much greater than expected. However, the round was difficult to muck because the lower four feet of the rock pile was tightly compacted. The fragmentation of the round was very fine except for several large boulders.

A considerable amount of powder was found in the muck which meant one or more holes had been "cut off."

Photograph 6. Results of Burn Cut Number 6

ROUND NUMBER 6



Scale 3/4" = 1'

0 (14) Shows No. 0 Western Minimax Delay; 14 sticks of dynamite

4 (14) Shows No. 4 Western Regular Delay; 14 sticks of dynamite

1-1/2 " to 1-5/16 " holes

Total number of holes - 21
Burn Cut Holes: No. delay 0,1,2,3

Average Advance: 8' 10"
Average Bootleg: 1' 2"

Figure 6

Round Number 7

Spiral Burn Cut

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	0°	12′6″	18	17 - X	None
1	0°	12′6″	18	17 - X	None
2	0°	12′2′	18	17 - X	None
4	-2°	12′6″	18	17 - X	2′9″

9″ hole (3rd delay)		13′6″	6		
			78		

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Average Depth of Cut: 12′5″

Amount of Powder Used: 32.0 pounds

Powder Factor: 0.15 tons of rock per pound of powder

Round Holes

Average Depth: 12′6″

Powder: Mine Gel No. 2 (Lifters - 40% Gelatin Extra)

Blasting Caps: Regular Delay

Loading Pattern: Primer one stick from bottom

Amount of Powder Used: 126.7 pounds

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0 - 5½′	100%	55%
5½′ - 7′	95%	50%
7′ - 9′9″	95%	17%
9′9″ - 12′5″	45%	5%
0 - 12′5″	86%	35%

Summary of Complete Round

Average advance: 11′0″

Average Bootleg: 1′6″

Total amount of powder used: 158.7 pounds

Volume of rock broken, cu. ft. in place: 700

Tons of rock broken, calculated: 52.5

Powder factor, tons of rock per pound of powder: 0.33

Loading factor, cu. ft. broken per pound of powder: 4.4

Fragmentation: Very fine

Length of muck pile from new face: 30 feet

Discussion and Results of Round 7

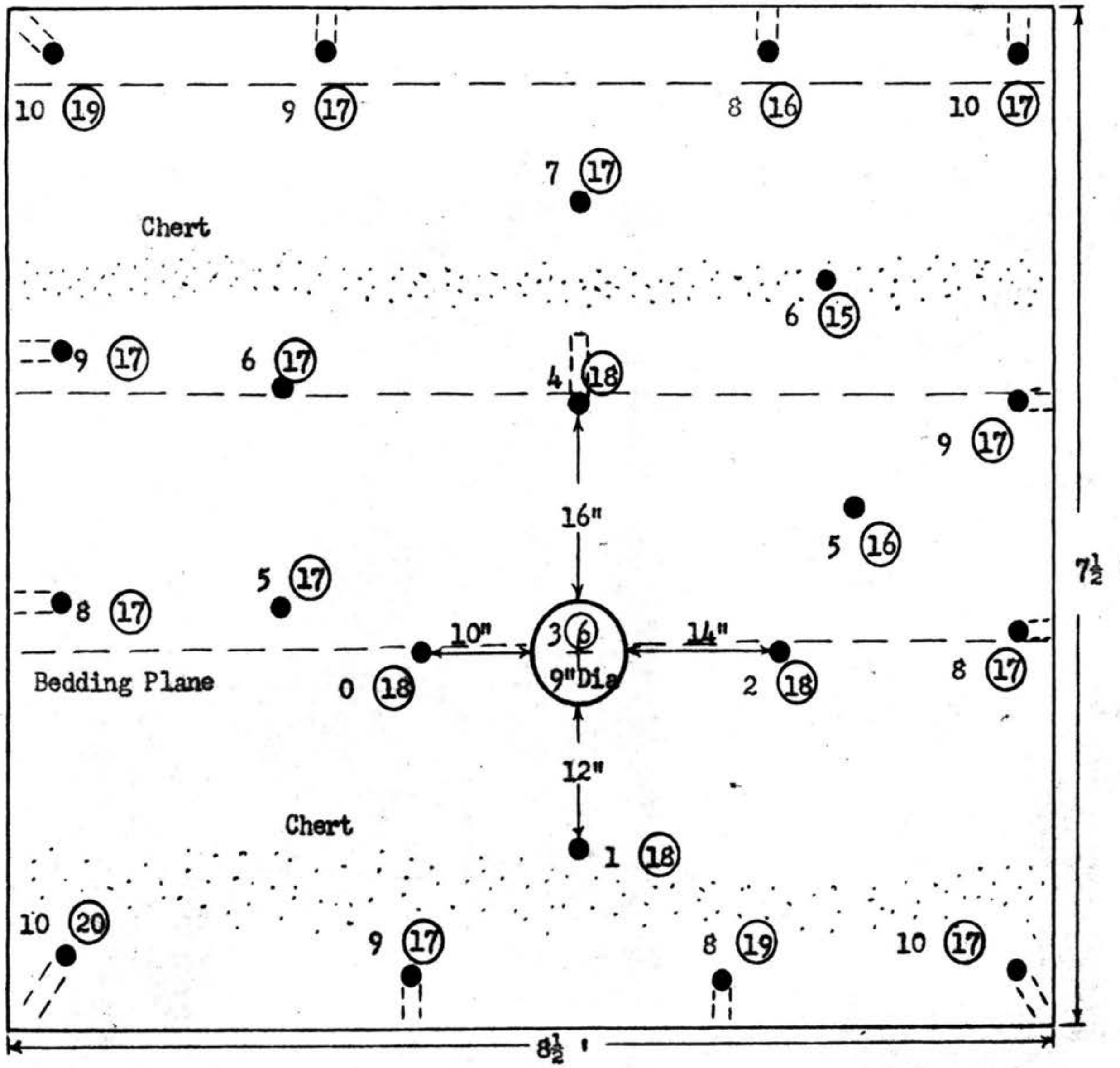
The same general spiral pattern of burn cut holes was used in this test round. The distance of the first cut hole was increased by 4 inches from 6 inches to 10 inches, and each succeeding cut hole was increased by an additional 2 inches. This placed the last cut hole 16 inches away from the large hole.

The burn cut was drilled to a depth of 12 feet 5 inches to determine the depth to which this pattern would be effective. A booster charge was placed in the bottom of the large hole and primed with delay number 3. By detonating the booster charge before the last cut hole, it was hoped that sufficient rock would be removed from the cut to provide enough expansion room for the rock broken by hole 4.

The burn cut did not break satisfactorily. Holes 0, 1, and 2 broke their full depth, but hole 4 bootlegged 2 feet 8 inches. Only 4 blast reports were heard but evidence that the booster charge did help in removing some of the broken rock from the cut can be seen in the photograph of the cut. (Note the large round of broken rock at the mouth of the cut.) A reasonable explanation for the bootleg of hole 4 would be the divergence of this hole with respect to the large hole. The burden of this hole increased from 16 inches at the collar to 22 inches at the bottom. Although this increase in burden was small, it does appear that even a slight angling of the cut holes away from the large hole has a detrimental effect on the cut.

The relief holes were drilled to an average depth of 12 feet 6 inches. Even though the last $2\frac{1}{2}$ feet of the cut was practically "unobtainable," the relief holes pulled 11 feet. The new drift face was very uneven and the rock had a "frozen" appearance.

ROUND NUMBER 7



Scale 3/4" = 1'

1 (18) Shows No. 1 Regular Delay; 18 sticks of dynamite
Average Advance: 11' 0"
Average Bootleg: 1' 6"   1-1/2 " to 1-5/16 " holes

Total Number of Holes - 21
Cut Holes: No. Delay 0,1,2,4

Figure 7

Photograph 7. Results of Burn Cut Number 7
Bottom of Cut is 9'9" From Original Face of Drift

Round Number 8

Pyramid Burn Cut

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	+3°	10′0″	15	14 - X	None
1	+3°	10′1″	9	8 - X	None
2	+3°	10′2″	15	14 - X	None
3	+3°	10′2″	15	14 - X	6″
9″ Hole		11′0″			
			54		

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Average Depth of Cut: 10′1″

Amount of Powder Used: 22.2 pounds

Powder Factor: 0.15 tons of rock per pound of powder

Round Holes

Average Depth: 10′0″

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Loading Pattern: Primer one stick from bottom

Amount of Powder Used: 87.0 pounds

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0 - 5′	100%	22%
5′ - 9½″	100%	12%
9½′ - 10′1″	60%	0%
0 - 10′1″	98%	16%

Summary of Complete Rounc

Average advance: 10′0″

Average bootleg: None

Total amount of powder used: 109.2 pounds

Volume of rock broken, cu. ft. in place: 595

Tons of rock broken, calculated: 45

Powder factor, tons of rock per pound of powder: 0.41

Loading factor, cu. ft. broken per pound of powder: 5.5

Fragmentation: Very fine

Length of muck pile from new face: 50 feet

Discussion and Results of Round 8

A pyramid pattern of burn cut holes was used for this round. All four cut holes (0,1,2,3) were angled in toward the 9 inch hole which placed the bottom of the holes 6, 6, 6.5, and 7 inches respectively from the circumference of the large hole. The cut holes were shot with regular delays. The primers were approximately six inches from the collars of the holes. Hole 1 was loaded with only 9 sticks of powder, because the rock at the face which would be broken by this hole was already fractured.

When the cut was fired, a misfire occurred and hole 0 was the only one to detonate. The powder columns in the remaining holes were intact and no sign could be seen of the primed cartridges or evidence of their having been detonated in the holes. The conclusion was that the first hole (0) created a suction at the face and pulled the primed cartridges from the other three holes.

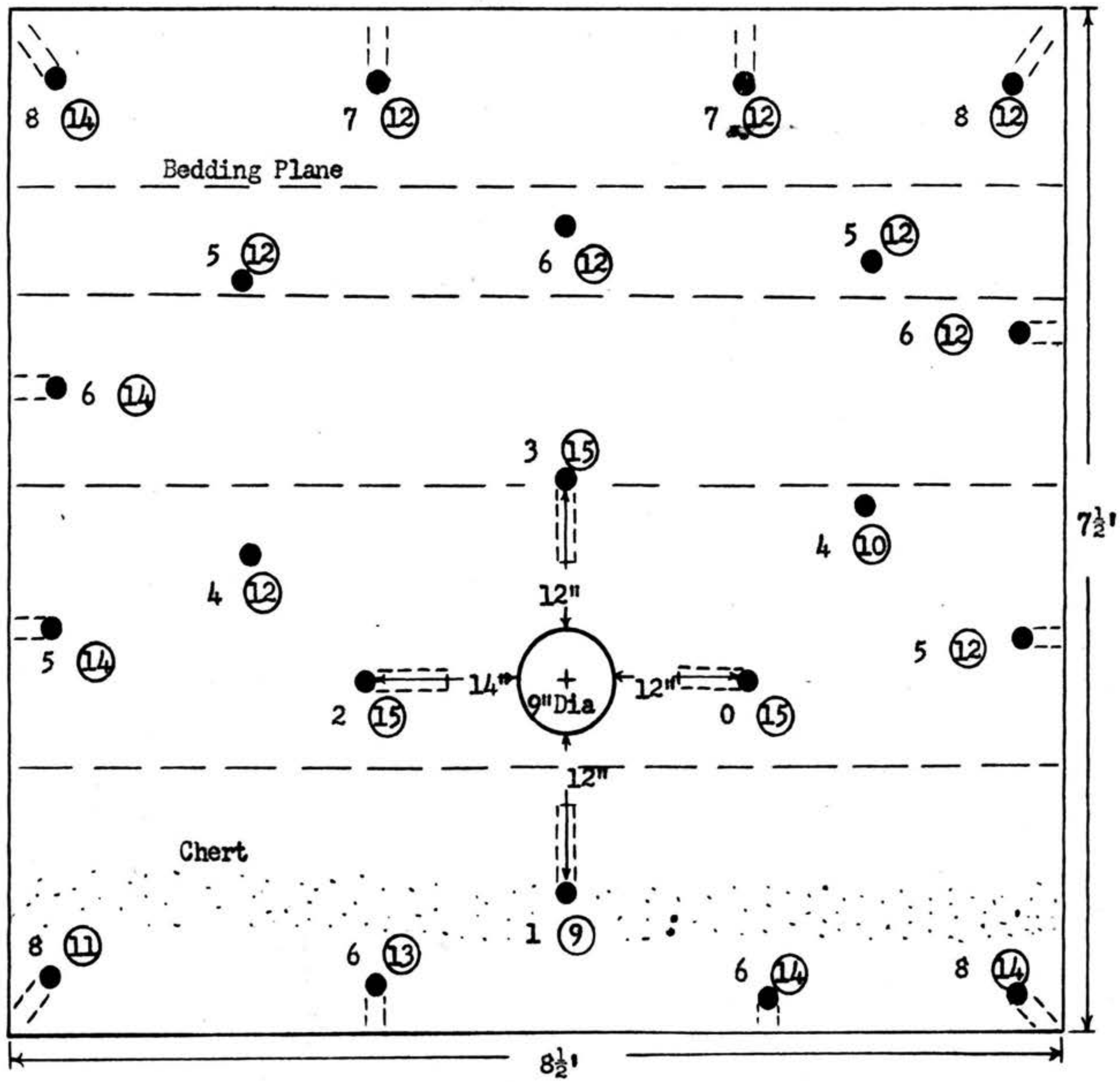
Each cut hole was reprimed and fired separately in order to observe the breaking pattern of the holes. After holes 0, 1, and 2 were fired, approximately 50% of the incompleted cut was filled with broken rock. (Note the final percentage of cut cleared of broken rock.) All of the cut holes broke to the bottom except number 3 which bootlegged 6 inches. None of the broken rock in the cut was frozen. If all the cut holes had been shot in one continuous blast, the results of the burn cut may have been much better.

Although a large percentage of the cut was filled with broken rock, sufficient stress relief was available for the round holes to break their full depth of ten feet.

The results of the burn cut brought out two important facts:

1. that the primers should be at least 1 foot from the collar of the holes and securely wedged in to prevent any misfires; and 2. by angling in the holes, the probability of having any of the holes bootleg is reduced. Even the slightest angle on the cut holes materially helps in throwing the broken rock from the cut.

ROUND NUMBER 8



Scale 3/4" = 1'

1 (9) Shows No. 1 Regular Delay; 9 sticks of dynamite
Average Advance: 10' 0"
Average Bootleg: 0"

Total Number of Holes - 21
Cut Holes: No. Delay 0,1,2,3

1-1/2 " to 1-5/16 " holes

Figure 8

Photograph 8A. Results of Burn Cut Number 8.
Bottom of Cut Visible in Picture is $9\frac{1}{2}$ Feet From Original Face.

Photograph 8B. Muck Pile For Round 8.
Fragmentation of Round Was Typical of All Test Rounds.

Round Number 9

Modified Pyramid Burn Cut

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	+3°	12′9″	20	19 - X	3′*
1	$+2\frac{1}{2}°$	12′9″	20	19 - X	3′*
2	0°	12′9″	20	19 - X	3′*
3	$+2\frac{1}{2}°$	12′9″	18	17 - X	3′*
9″ Hole (fourth delay)		13′6″	8		
			86		

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Average Depth of Cut: 12′9″

Amount of Powder Used: 35.3 pounds

Powder Factor: 0.11 tons of rock per pound of powder

Round Holes

Average Depth: 12′6″

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Loading Pattern: Primer 2 sticks from bottom of hole

Amount of Powder Used: 104.0 pounds

*Rock broken and then compacted.

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0 - 5′	100%	78%
5′ - 9′9″	100%	30%
9′9″ - 12′9″	0%	0%
0 - 12′9″	76%	42%

Summary of Complete Round

Average advance: 11′6″

Average bootleg: 1′0″

Total amount of powder used: 139.3

Volume of rock broken, cu. ft. in place: 690

Tons of rock broken, calculated: 52.5

Powder factor, tons of rock per pound of powder: 0.38

Loading factor, cu. ft. broken per pound of powder: 5.0

Fragmentation: Very fine

Length of muck pile from new face: 50 feet.

Discussion and Results of Round 9

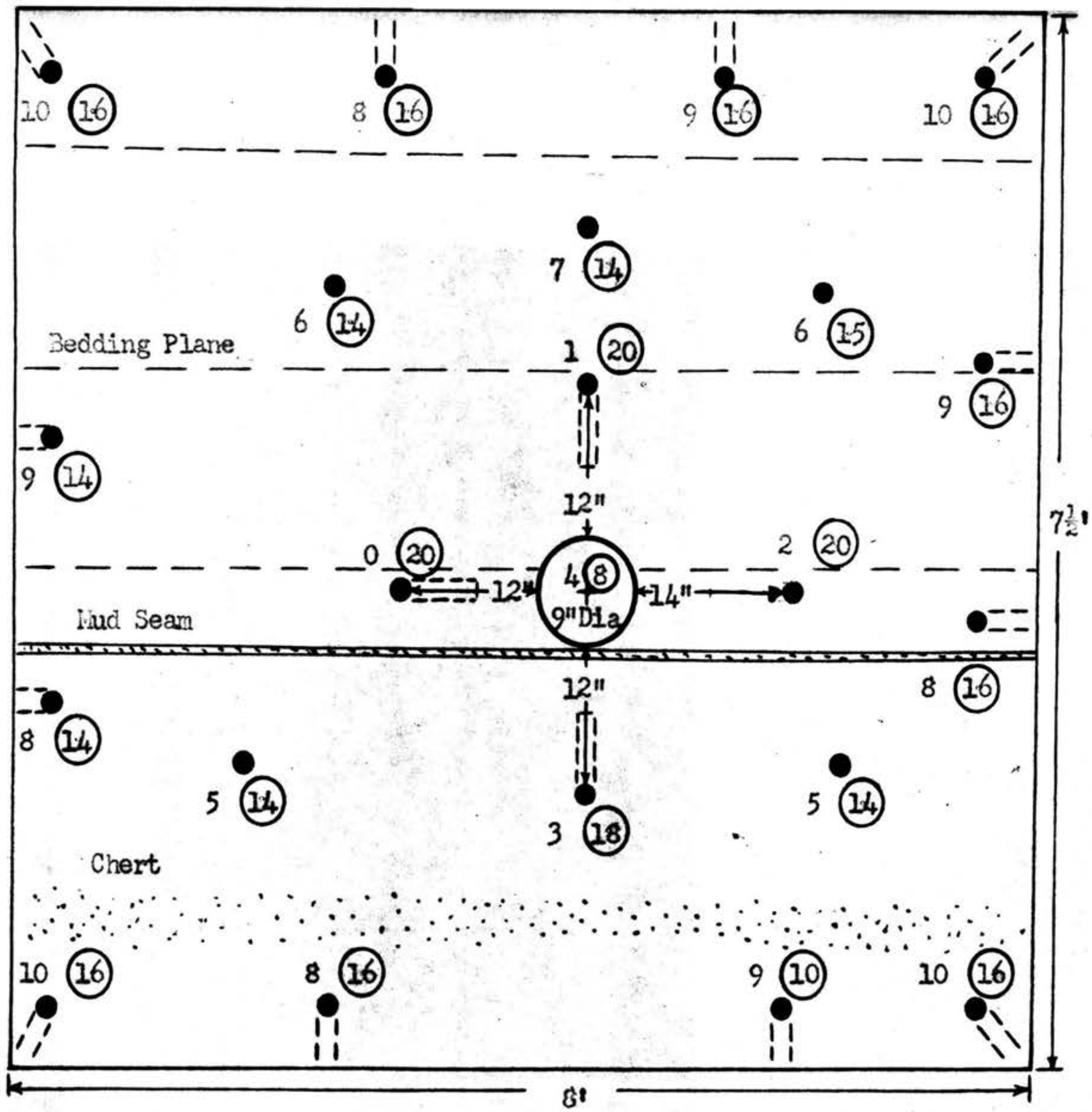
The burn cut of this round was to be similar to the previous round, but difficulties were encountered in drilling hole 2. As a result this hole was parallel to the large hole. The remaining three cut holes bottomed approximately 6 inches from the circumference of the 9 inch hole.

The cut holes were primed at the collars with the primers about 12 feet from the face. The spiral firing sequence of the burn cut was changed so that the bottom hole of the cut was fired last. It was hoped that this hole would place in motion all the broken rock in the cut thereby increasing the effectiveness of the booster shot in preventing freezing of the cut. When the burn was detonated, only four reports were heard which indicated the booster charge had been sympathetically detonated. The burn cut was not successful because the last three feet of the cut had frozen completely. Despite welding of the rock in the cut, however, the average advance of the round was 11 feet 6 inches.

The failure of the burn cut to break its full depth could be attributed to one or more of several factors.

1. The relative position of hole 2 with respect to the large hole.
2. The premature detonation of the booster charge.

ROUND NUMBER 9



Scale 3/4" = 1'

1 (20) Shows No. 1 Regular Delay; 20 sticks of dynamite
Average Advance: 11' 6"
Average Bootleg: 1' 0"

Total Number of Holes - 21
Cut Holes: No. Delay 0,1,2,3

1-1/2 " to 1-5/16 " holes

Figure 9

Photograph 9. Results of Burn Cut Number 9.
The Bottom of the Cut is 9'9" From the Original Face of the Drift.

Round Number 10

Spiral Burn Cut

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	0°	9'6"	12	11 - X - S	?
1	0°	9'6"	12	11 - X - S	?
2	0°	9'6"	12	11 - X - S	?
3	0°	9'6"	12	11 - X - S	?
$5\frac{1}{2}$" hole (4th delay)		11'10"	6		
			54		

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Average Depth of Cut: 9'6"

Amount of Powder Used: 22.2 pounds

Powder Factor: 0.88 tons of rock per pound of powder

Round Holes

Average Depth: 10'0"

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Loading Pattern: Primer 6th stick from bottom

Amount of Powder Used: 85 pounds

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0′ - 1′	0%	0%
1′ - 3′	100%	± 30%
3′ - 9½′		0%
0 - 9½′	± 21%	6%

Summary of Complete Round

Average advance: 8′6″

Average bootleg: 1′6″

Total amount of powder used: 107.2 pounds

Volume of rock broken, cu. ft. in place: 510

Tons of rock broken, calculated: 38

Powder factor, tons of rock per pound of powder: 0.36

Loading factor, cu. ft. broken per pound of powder: 4.8

Fragmentation: Very fine

Length of muck pile from new face: 50 feet

Expansion ratio of rock: 1.7

Discussion and Results of Round 10

To determine what effect the size of the large hole has on the depth of round which can be pulled successfully, a $5\frac{1}{2}$ inch hole was used in the burn cut. The four cut holes were drilled parallel to the large hole and in a spiral pattern. Due to the concavity of the drift face, the cut holes averaged $9\frac{1}{2}$ feet while the relief holes were 10 feet, but all the holes of the round bottomed on the same plane.

The cut holes were loaded with Mine Gel Number 2 and primed at the collar. This placed the primers about $1\frac{1}{2}$ feet from the collars of the holes. A $2\frac{1}{2}$ inch asbestos plug was inserted in each of the cut holes to insure a good contact between the primed cartridge and the powder column, and also to minimize the chances of any misfires either by "cut-offs" or having the primer pulled from the hole by the preceding holes.

The burn cut was fired and examined. At first it appeared as if none of the holes detonated because the face of the rock remained intact and solid. (Photograph 10A) However, close inspection revealed that although the first foot of the cut was intact, the remainder was broken. The drift was strewn with fine particles of rock for a distance of 50 feet which indicated that the booster charge had shot broken rock through the $5\frac{1}{2}$ inch hole, similar to a cannon. Five distinctive reports were heard so the booster charge, which was at the very bottom of the large hole, fired at the proper time. It was impossible to determine to what depth the cut holes had been broken and to what degree the rock was frozen in the cut.

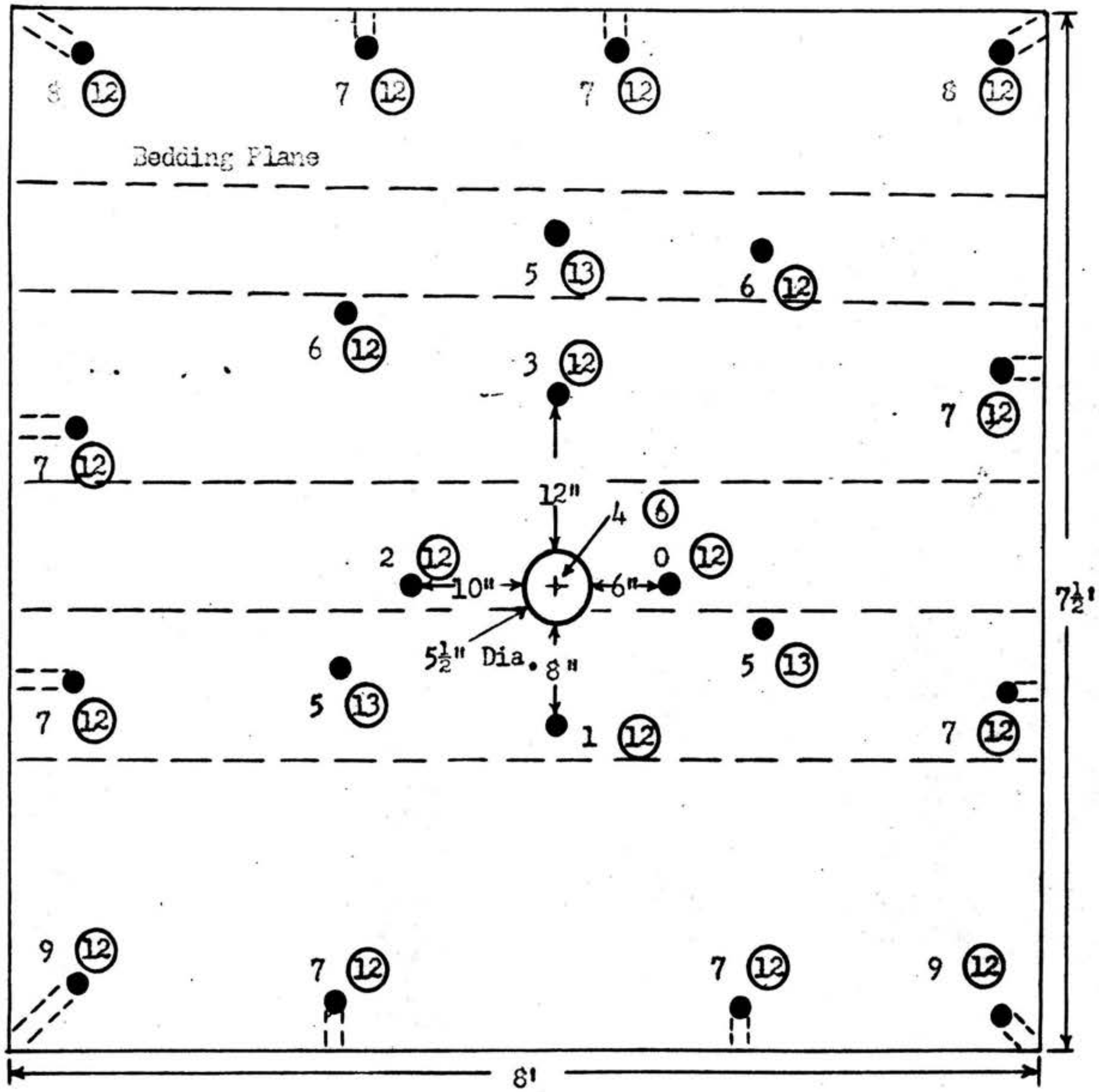
One stick of powder was placed in each of the holes 0, 1, and 2 and fired in the same rotation. The one foot of solid rock at the face was now broken out (Photo 10B). The remainder of the cut was undisturbed. The removal of the solid face from the burn cut probably had little effect on the results of the drift round.

In view of the questionable success of the burn cut, no definite conclusions can be reached on the merits of having the relief holes primed several feet from their bottom. The round pulled an average depth of $8\frac{1}{2}$ feet and left an average bootleg of $1\frac{1}{2}$ feet. An examination of the new face at the burn cut portion of the round showed that the cut holes had bootlegged at least one foot. Also, it was noted that the remainder of the large hole was completely packed with broken rock.

The results of this round emphasized two important points:

1. At least the first firing hole of the cut should be loaded to within 6 inches of the collar. The remaining cut holes should be loaded no closer to the collar than 1 foot. This will reduce the chances of misfires.
2. The booster charge should be at least 2 feet away from the bottom of the cut holes in order to prevent sympathetic detonation or any disturbance of the charge.

ROUND NUMBER 10



Scale 3/4" = 1'

(12) Shows No. 1 Regular Delay; 12 sticks of dynamite
Average Advance: 8' 6"
Average Bootleg: 1' 6"

Total Number of Holes - 21
Cut Holes: No. Delay 0,1,2,3

1-1/2 " to 1-3/8 " holes

Figure 10

Photograph 10A. Results of Burn Cut Number 10 After the First Firing.

Photograph 10B. Results of Burn Cut Number 10 After Repriming and Shooting Holes 0, 1, and 2.

Round Number 11

Pyramid Burn Cut

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	+2°	12′2″	20	16 - X - 3	None
1	+2°	12′5″	19	16 - X - 2	None
2	+2°	12′3″	19	16 - X - 2	None
3	+2°	12′5″	18	16 - X - 1	None
9″ Hole (4th delay)		14′6″	7		
			83		

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Average Depth of Cut: 12′4″

Amount of Powder Used: 34.0 pounds

Powder Factor: 0.09 tons of rock per pound of powder.

Round Holes

Average Depth: 12′6″

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Loading Pattern: Primer 7th stick from bottom

Amount of Explosives Used: 107.0 pounds

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0 - 12′4″	100%	65%

Summary of Complete Round

Average advance: 12′0″

Average bootleg: 6″

Total amount of powder used: 141.0 pounds

Volume of rock broken, cu. ft. in place: 670

Tons of rock broken, calculated: 50

Powder factor, tons of rock per pound of powder: 0.36

Loading factor, cu. ft. of rock broken per pound of powder: 4.8

Fragmentation: Very fine

Length of muck pile from new face: 50 feet.

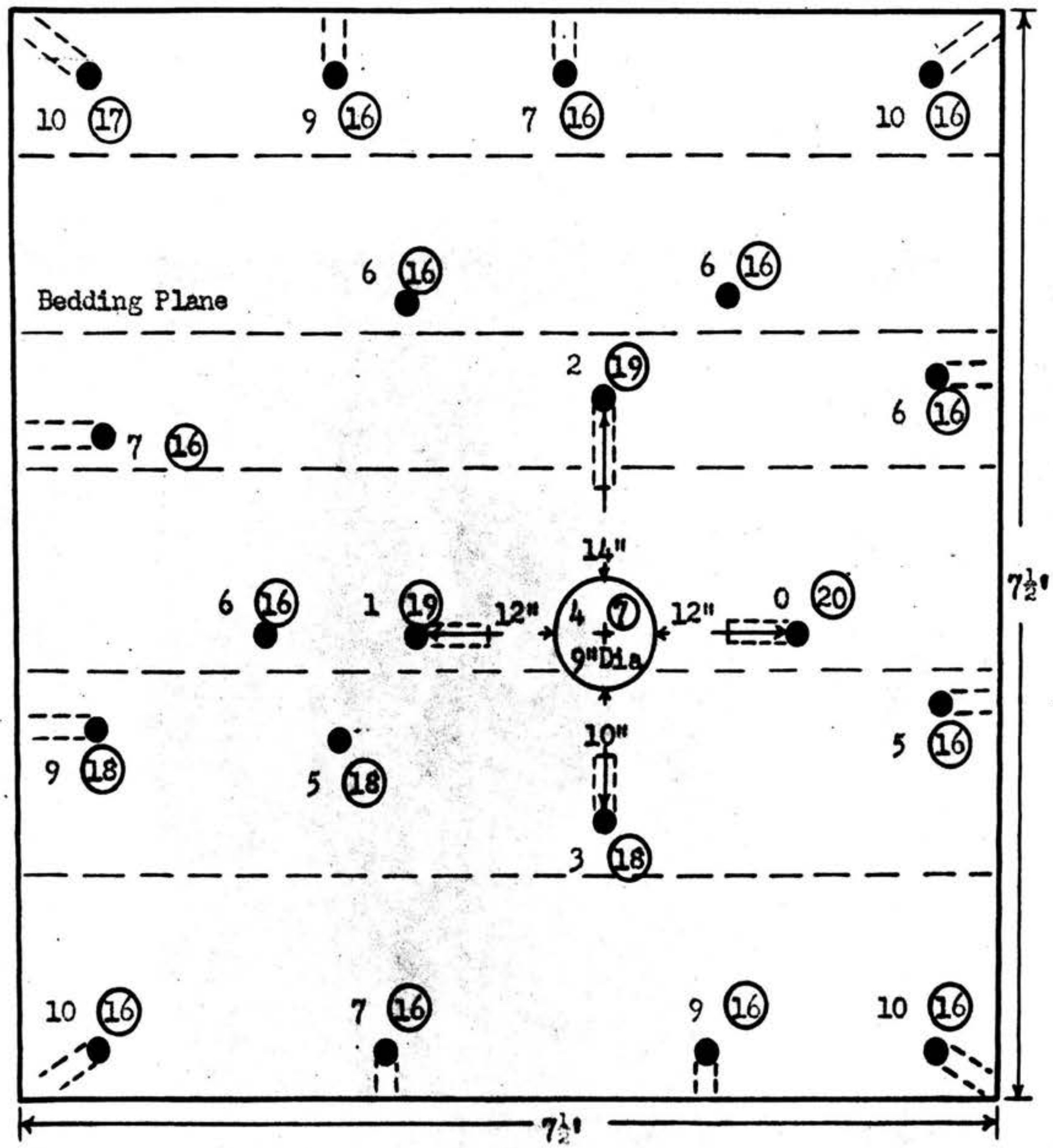
Discussion and Results of Round 11

The burn cut of this test round was similar to that used in round 9. However, the cut of this round was more successful. The holes of the pyramid cut were, at the face, 12, 12, 14, and 10 inches from the circumference of the 9 inch hole; at the bottom of the holes, the distance from the large hole was 6, 6, 7, and 5 inches respectively. The loading pattern of the holes was 16 sticks of powder, the primer, and then the remaining sticks of dynamite to bring the total number to the figure listed on the data sheet. This manner of loading placed the primers about two feet from the collar of the holes which practically eliminated the problem of misfires encountered in previous rounds. Hole 0 was loaded to 8 inches of the collar to assure the face would start breaking. The other holes were loaded to within 1 foot of the collars.

The firing order of the cut was different than that used in any previous cut. Firing the holes in the rotation indicated gave a better cut. None of the rock in the cut was frozen and all of it was of very fine size. Only four blast reports were heard which was good evidence that the booster charge was prematurely detonated even though it was 2 feet beyond the bottom plane of the cut holes. The booster charge in the previous round (No. 10) was also 2 feet beyond the plane of the cut holes, but it was not sympathetically detonated.

Note the manner in which the relief holes were loaded. By increasing the distance of the primer from the bottom of the holes, it was hoped that the relief holes would pull much better. But this did not occur and it was felt that if the primers had been at the bottom, the round would have pulled the entire depth of $12\frac{1}{2}$ feet. The center of the round broke to the full depth of $12\frac{1}{2}$feet, but the side, top, and bottom line holes bootlegged from 8 - 10 inches.

ROUND NUMBER 11



Scale 3/4" = 1'

1 (19) Shows No. 1 Regular Delay; 19 sticks of dynamite
Average Advance: 12' 0"
Average Bootleg: 6"

Total Number of Holes - 20
Cut Holes: No. Delay 0,1,2,3
1-1/2 " to 1-5/16 " holes

Figure 11

Photograph 11. Results of Burn Cut Number 11.
The Bottom of the Cut Visible in the Picture is 12'4" From the Original Face of the Drift.

Round Number 12

Pyramid Burn Cut

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	+1°	14′2″	21	18 - X - 2	None
1	+2°	14′4″	21	18 - X - 2	None
2	+1°	14′3″	21	18 - X - 2	None
3	+1°	14′5″	21	18 - X - 2	None
13″ Hole (4th delay)		15′6″	9		
			93		

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Average Depth of Cut: 14′4″

Amount of Powder Used: 38.1 pounds

Powder Factor: 0.15 tons of rock per pound of powder

Round Holes

Average Depth: 15′0″

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Loading Pattern: Primer 3rd stick from the bottom

Amount of Explosives Used: 130.5 pounds

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0 - 10′	100%	86%
10′ - 14′4″	100%	70%
0 - 14′4″	100%	81%

Summary of Complete Round

Average advance: 14′6″

Average bootleg: 6″

Total amount of powder used: 168.6 pounds

Volume of rock broken, cu. ft. in place: 930

Tons of rock broken, calculated: 71

Powder factor, tons of rock per pound of powder: 0.42

Loading factor, cu. ft. of rock broken per pound of powder: 5.5

Fragmentation: Very fine

Length of muck pile from new face: 45′

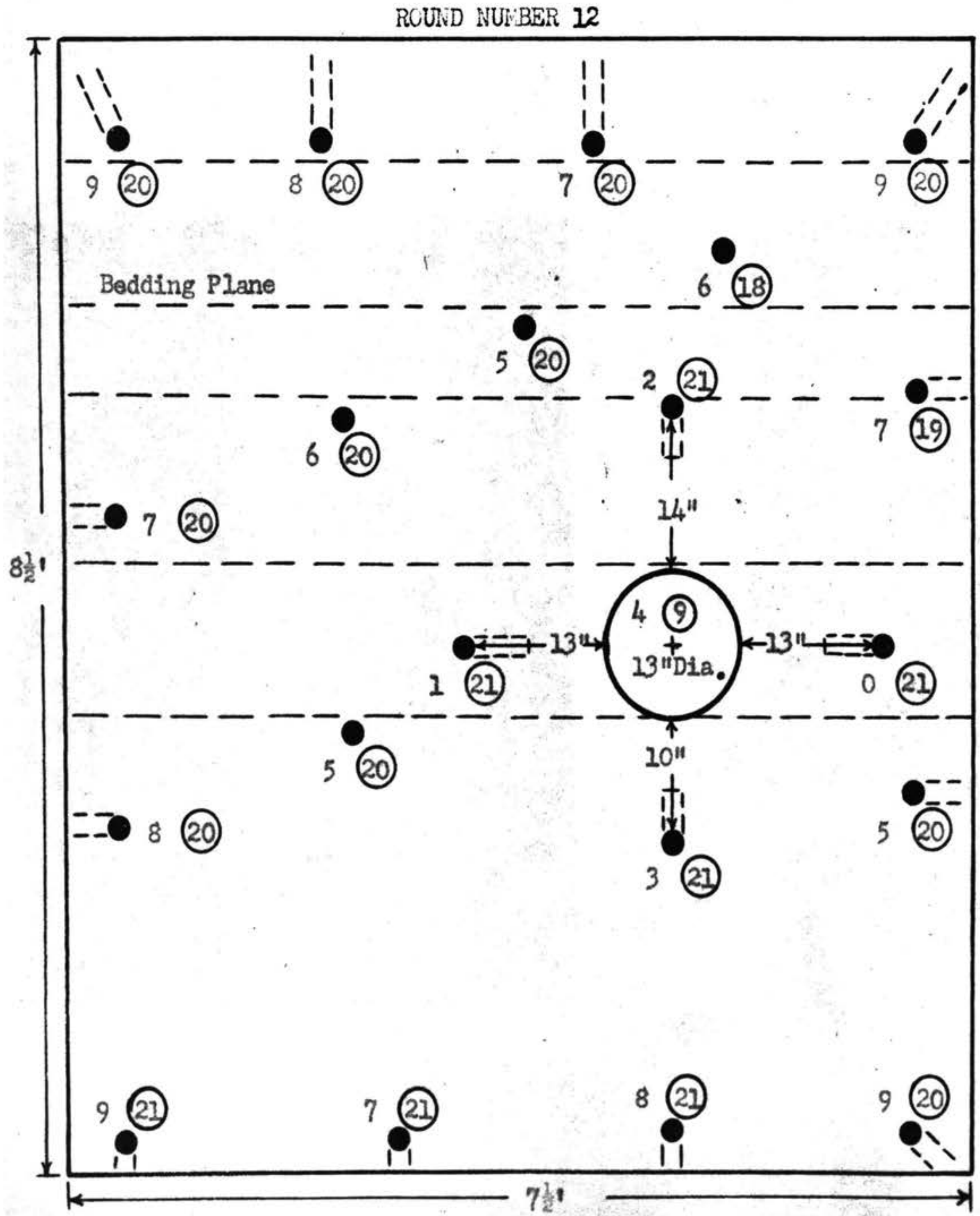
Expansion ratio of rock: 1.4

Discussion and Results of Round 12

The pyramid burn cut consisted of a 13 inch hole with four small cut holes angled toward the large hole. This pattern was similar to round 11 which was very successful. Inasmuch as the big hole was larger than what was used in round 11, it would have been possible to increase the distances of the cut holes from the big hole and still be insured of a clean break. However, the distances were not increased because a comparison of the two cuts was desired. Although this burn cut was highly successful, very little information was gathered on the effects of increasing the large hole size beyond that which is readily apparent.

The burn cut broke to the bottom and none of the broken rock remaining in the cut was frozen. Only four blasting reports were heard but it was evident that the booster charge was effective in clearing some of the broken rock from the cut.

The center relief holes of the round pulled the entire 15 feet, but the trimmer holes bootlegged approximately 1 foot which left a concave face for the next round. The results of the round indicated that a much greater advance could be achieved with a 13 inch hole burn cut.



1 (21) Shows No. 1 Regular Delay; 21 sticks of dynamite

Average Advance: 14' 6"

Average Bootleg: 0' 6"

Total Number of Holes: 20

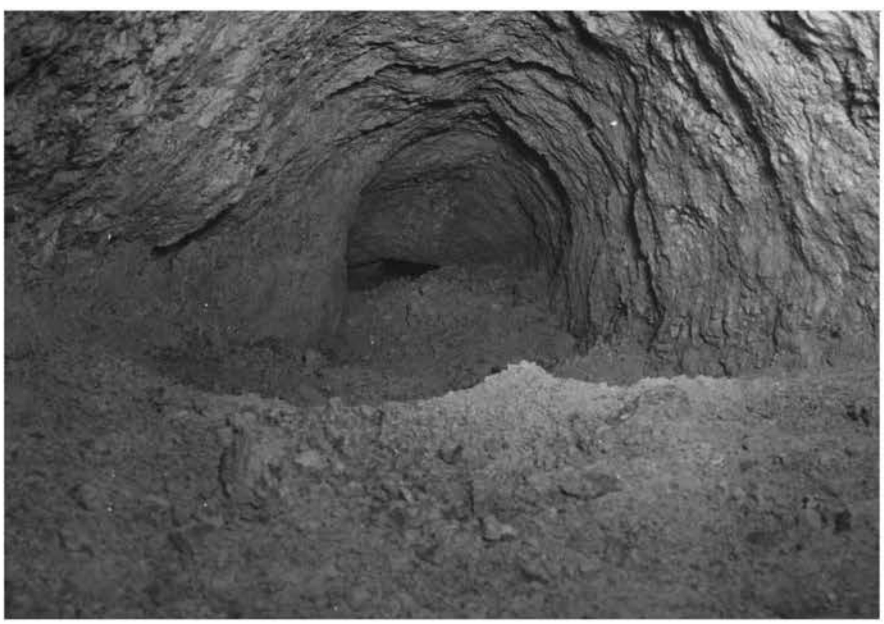
Cut Holes: No. Delays 0,1,2,3.

1-1/2 " to 1-5/16 " holes

Scale 3/4" = 1'

Figure 12

Photograph 12A. Results of Burn Cut Number 12. Bottom of Drilled Cut is Visible in the Picture.



Photograph 12B. Close-Up View of Burn Cut Number 12. A Portion of the Large Hole is Visible in the Bottom of the Cut.

Round Number 13

Pyramid Burn Cut

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	+1°	12′0″	17	15 - X - 1 - S	---
1	+1°	12′0″	17	15 - X - 1 - S	---
2	+1°	12′0″	17	15 - X - 1 - S	---
3	+1°	12′0″	17	15 - X - 1 - S	---
9″ Hole (4th delay)		40′0″	6		
			74		

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Average Depth of Cut: 12′0″

Amount of Powder Used: 30.4 pounds

Powder Factor: 0.10 tons of rock per pound of powder

Round Holes

Average Depth: 12′6″

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Loading Pattern: Primer one stick from the bottom

Amount of Explosives Used: 80.0 pounds

Round Results

Summary of Complete Round

Average advance: 12′6″

Average bootleg: None

Total amount of powder used: 110.4 pounds

Volume of rock broken, cu. ft. in place: 515

Tons of rock broken, calculated: 38

Powder factor, tons of rock per pound of powder: 0.35

Loading factor, cu. ft. of rock broken per pound of powder: 4.7

Fragmentation: Very fine

Length of muck pile from new face: 25 feet

Expansion ratio of rock: 1.5

Discussion and Results of Round 13

The purpose of this test round was two-fold: (1) to determine the effects of firing an entire round as in industrial practice, and (2) to study the effects of having the large hole much deeper than the depth of the round.

The burn cut employed for this round was essentially the same as that used for round 11. One important difference between the rounds was the reduced cross sectional area of this round as compared to round 11. Certainly the boundary stresses are much greater for this round and would tend to decrease the potential of pulling the full depth because the greater the drift face area, the deeper the round which can be pulled.

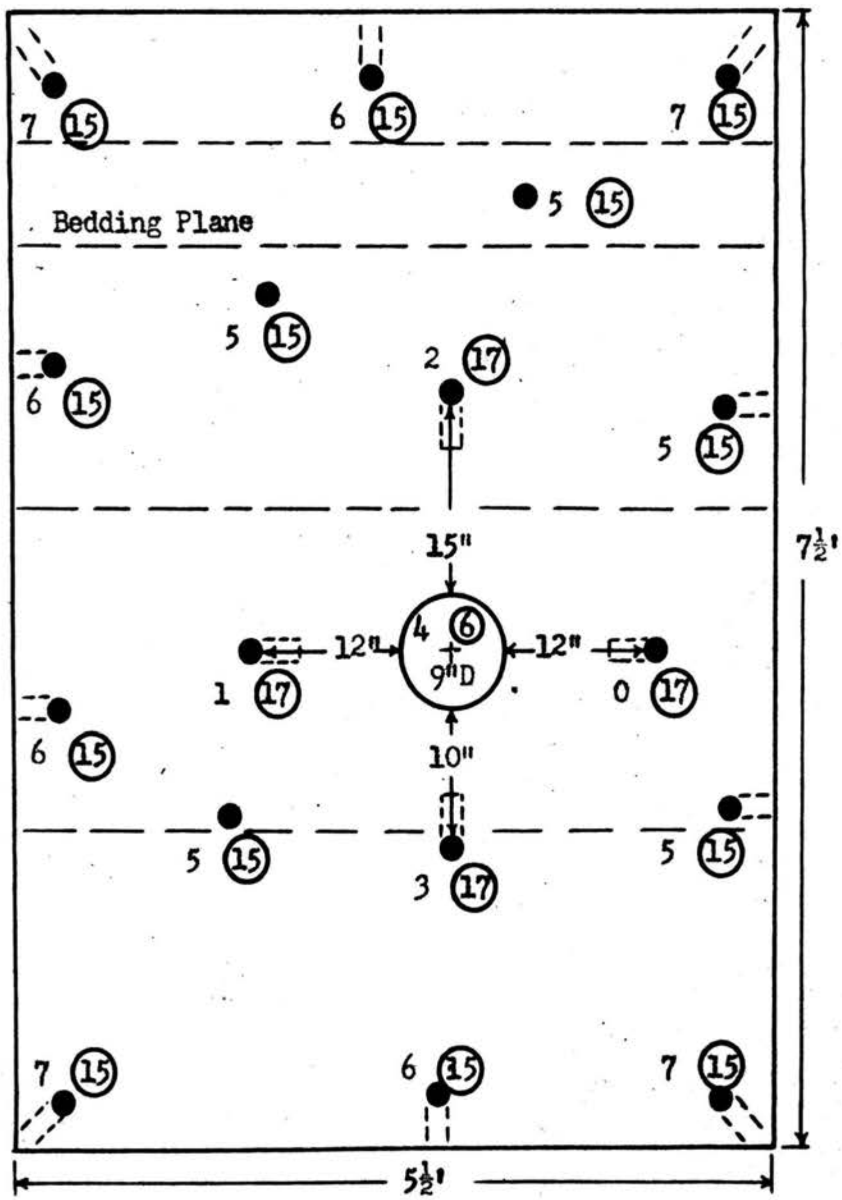
The 9 inch hole was 40 feet deep, or $27\frac{1}{2}$ feet deeper than the round holes. The booster charge in the large hole was primed with delay number 4 and placed about 18 feet from the face to make sure it would not be prematurely detonated.

The entire round was shot at once and in the rotation as shown on figure 13. Evidently the burn cut was very successful because the round pulled the full depth of $12\frac{1}{2}$ feet. After the round had been mucked out, the large hole was found to be completely filled with broken rock for a distance of 1 foot and half filled with rock for the next 10 feet. The broken rock in the large hole was readily cleaned out except for the first foot in which the rock was compacted tightly.

As a possible means of preventing the large hole from filling with rock, a charge could be placed in the hole and fired as the last delay of the round, but this would mean devising a method to prevent both charges in the big hole from detonating together.

This test round gave strong evidence that no adverse results would be obtained when the large hole is much deeper than the round, and the round is fired in one continuous blast. In fact, it appeared as though better results were obtained because of the continuous firing sequence of the round.

ROUND NUMBER 13



Scale 3/4" = 1'

1 (17) Shows No. 1 Regular Delay; 17 sticks of dynamite
Average Advance: 12' 6"
Average Bootleg: 0"

Total Number of Holes - 17
Cut Holes: No. Delay 0,1,2,3
1-1/2 " to 1-5/16 " holes

Figure 13

Round Number 14

<u>Modified Pyramid Burn Cut</u>

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	0°	19′0″	27	25 - X - 1	?
1	0°	19′0″	28	25 - X - 2	?
2	+1°	19′0″	28	25 - X - 2	?
3	+1°	19′0″	27	25 - X - 1	?
9″ Hole (4th delay)		27′6″	9		
			119		

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Average Depth of Cut: 19′0″

Amount of Powder Used: 49 pounds

Powder Factor: 0.14 tons of rock per pound of powder

<u>Round Holes</u>

Average Depth: 19′6″

Powder: 40% Special Gelatin

Blasting Caps: Regular Delay

Loading Pattern: Primer 9th stick from bottom

Amount of Explosives Used: 153.0 pounds

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0 - 8′	100%	95%
8′ - 19′0″	?	0%
0 - 19′0″	42% (?)	40%

Summary of Complete Round

Average advance: 14′0″

Average bootleg: 5′6″

Total amount of powder used: 202.0 pounds

Volume of rock broken, cu. ft. in place: 578

Tons of rock broken, calculated: 44

Powder factor, tons of rock per pound of powder: 0.22

Loading factor, cu. ft. of rock broken per pound of powder: 2.85

Fragmentation: Very fine

Length of muck pile from new face: 45 feet

Expansion ratio of rock: 1.9

Discussion and Results of Round 14

This test round was drilled to the remainder of the 9 inch hole which was left after shooting round 13. The drift face was very irregular, roughly conical in shape, which explains why the cut holes were 19 feet in depth and the relief holes $19\frac{1}{2}$ feet. Actually, all the drill holes of the round bottomed on the same plane.

The original plans for the round called for a pyramid burn cut, but after drilling holes 0 and 1, it was found that they were parallel to the 9 inch hole. This deviation from the desired placement of the holes could not be prevented because it was very difficult to collar the holes on the rough face. Also, the holes undoubtedly veered off course near the bottom because the last five feet had to be drilled with a jack leg drill using a 20 foot steel.

The results of the burn cut were very disappointing. Beyond 8 feet, the rock in the cut appeared to be frozen, but it was impossible to tell whether or not the rock in the cut was unbroken or frozen the remaining distance. Close examination of the cut revealed that holes 0, 1, and 3 might have broken beyond 8 feet, but the exact depth could not be determined. Only four blasting reports were heard in shooting the cut even though the booster charge was three feet beyond the bottom of the cut holes.

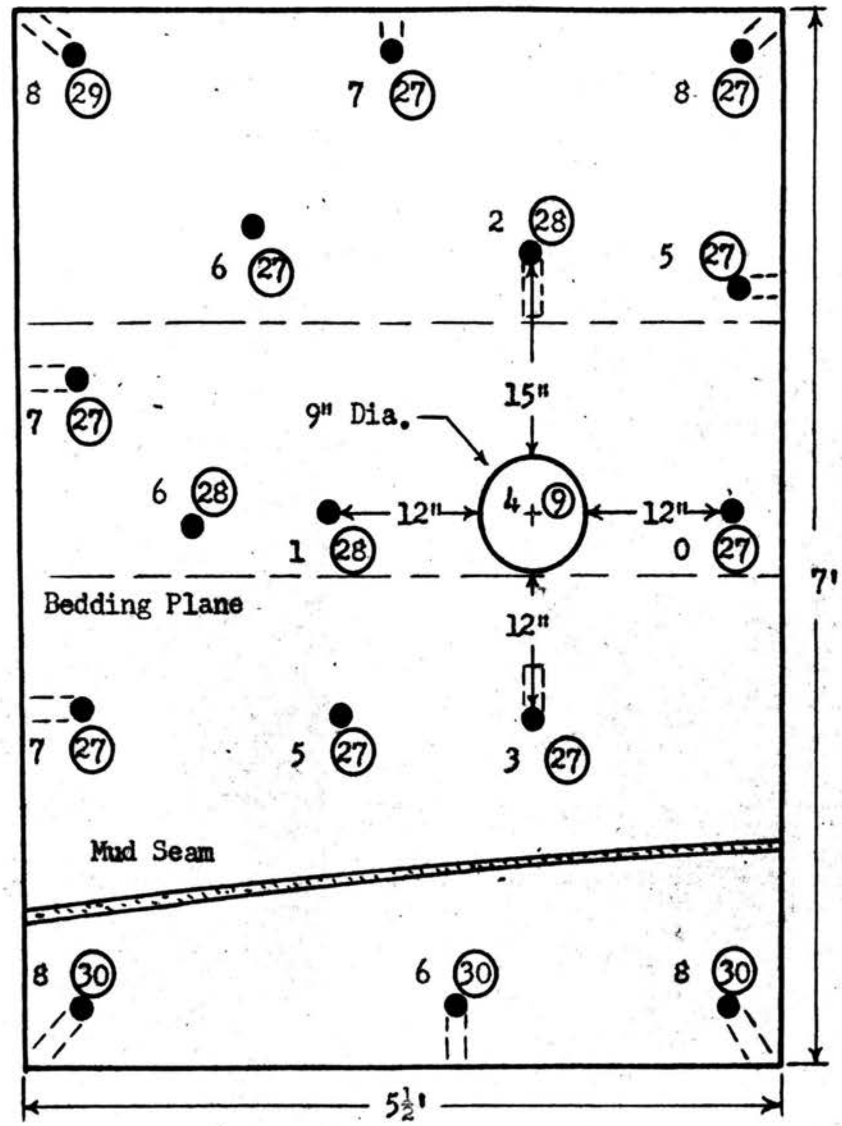
In spite of the realization that the relief holes would not pull much beyond the successful part of the burn cut, they were loaded their full depth of $19\frac{1}{2}$ feet. The primers in the relief holes were placed about $4\frac{1}{2}$ feet from the bottom of the holes. This procedure was followed because it was felt that by doing so, the round would pull a greater depth than the expected maximum of 10 feet.

The average advance of $14\frac{1}{2}$ feet for the round was more than thought possible and brought up the interesting question of whether or not the position of the primers had any effect on how deep the round pulled. This question cannot be answered because none of the previous rounds provided any data for comparison.

The new face was very irregular and the rock had the appearance of having been crushed and then recemented. Nothing definite could be established as to the depth to which the burn cut holes had broken, but judging from the appearance of the rock, the cut had not broken any deeper than $14\frac{1}{2}$ feet. The remainder of the large hole was completely cemented. The rock could be chipped off the face with a pick, but after digging a hole one foot deep at the cut portion this was discontinued. It was almost certain that the large hole was completely cemented over the remaining $4\frac{1}{2}$ feet of the round.

Photograph 14A shows the location of the burn cut with respect to the walls of the drift. Its location probably had some effect on the results of the cut.

ROUND NUMBER 14



Scale 3/4" = 1'

1 (28) Shows No. 1 Regular Delay; 28 sticks of dynamite
Average Advance: 14' 0"
Average Bootleg: 5' 6"

Total Number of Holes - 16
Cut Holes: No. Delay 0,1,2,3

1-1/2 " to 1-5/16 " holes

Figure 14

Photograph 14A. Pattern of Cut Holes For Round Number 14.

Photograph 14B. Results of Burn Cut Number 14
Visible Depth of Cut is 8 feet.

Round Number 15

Modified Pyramid Burn Cut

Hole No. by Delays	Bearing	Depth	Sticks of Powder	Loading Pattern	Bootleg
0	+2°	15′0″	21	19 - X - 1	None
1	+1°	15′0″	23	20 - X - 2	None
2	+3°	14′10″	22	20 - X - 1	None
3	0°	14′10″	23	20 - X - 2	None
9″ hole (4th delay)		17′6″	9		
			98		

Powder: Mine Gel No. 2

Blasting Caps: Regular Delay

Average Depth of Cut: 15′0″

Amount of Powder Used: 40.2 pounds

Powder Factor: 0.09 tons of rock per pound of powder

Round Holes

None

Round Results

Burn Cut Effectiveness

Footage	Percentage of Rock Broken	Percentage of Cut Cleared of Broken Rock
0 - 7″	100%	82%
7″ - 14″	100%	65%
14′ - 15′	100%	0%
0 - 15′	100%	69%

Discussion and Results of Burn Cut

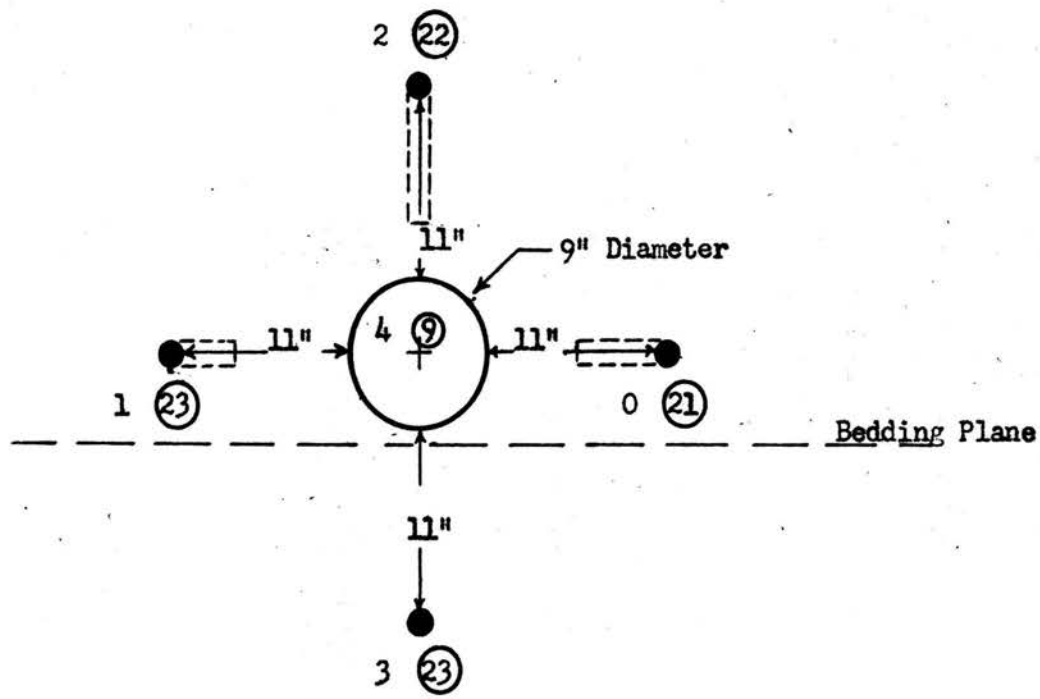
Unfortunately, time did not permit the drilling of the relief holes to this burn cut which was the deepest and most successful cut obtained during the experimental program. All of the cut holes broke to the bottom. The last foot of the cut which was filled with broken rock was not re-cemented. For the second time, five very distinct blast reports were heard when the cut was detonated. Photograph 15 of the cut gives ample evidence that the booster charge was quite effective in cleaning out the burn cut.

If the relief holes were drilled to a depth of 15 feet, the round would pull at least 14½ feet. (Based on previous test rounds.)

Photograph 15. Results of Burn Cut Number 15.
Visible Depth of Cut is 14 Feet.

ROUND NUMBER 15

CUT PORTION



Scale 1" = 1'

1 (23) Shows No. 1 Regular Delay; 23 sticks of Dynamite

Average Depth of Cut Holes: 15'

1-1/2" to 1-5/16" holes

Figure 15

IV. SUMMARY AND ANALYSIS

A total of fifteen large hole burn cuts was drilled and blasted. The degree of success exhibited by the cuts was determined mostly by the average advance of the drift rounds which were drilled to these burn cuts.

The factors studied in the field trials were:

1. Diameter of the large hole
2. Position of the small holes relative to the large hole
3. Depth of the small holes with respect to the large hole
4. Type of dynamite
5. Type of delays
6. Loading pattern of holes
7. Order of firing
8. Amount of powder

Since a large number of variables was taken into consideration and the number of test rounds small, it was difficult to establish all of the individual effects each of the factors had on the large hole burn cuts. However, the data accumulated allowed the relative importance of some of the variables to be established.

As would be expected, the maximum depth that could be obtained with this type burn cut is primarily controlled by the size of the large hole. As the large hole is increased in diameter, the area of the second free face increases as the square of the diameter as does the free volume. If the large hole diameter was increased sufficiently, the rock broken by the "cut" holes would have the necessary free volume even for very deep rounds.

Three different large diameter holes were used in the cuts, $5\frac{1}{2}$ inch, 9 inch, and 13 inch. The $5\frac{1}{2}$ inch and 13 inch holes were each used only once. The balance of the cuts had 9 inch holes. Since the smallest and largest diameter holes were used only once, the comparisons with the 9 inch hole burn cuts are not conclusive. However, in the comparison of round 10 ($5\frac{1}{2}$ inch hole) with any similar 9 inch hole round, the former round broke 85% of the expected rock as compared to the near 100% breakage of the 9 inch hole rounds.

A direct comparison of the 9 and 13 inch hole burn cuts cannot be made because the 9 inch hole (round number 15), which had a burn cut similar to round 12 (13 inch hole), was not completed. Judging from the excellent appearances of the 9 inch hole burn cut, at least 95% of the drilled footage would be broken. Comparing this figure with the actual 97% break obtained with the 13 inch hole round, it may be surmised that this latter round would be successful in blasting a $17\frac{1}{2}$ or even 20 foot advance.

The most successful burn cut pattern for deep rounds in this mine rock was the pyramid type (rounds 11, 13, and 15). Although only the burn cut of round 15 was fired, it was apparent that an advance of $14\frac{1}{2}$ feet could be realized with this 9 inch hole burn cut pattern. The angle of the cut holes could be increased assuring even better results. But pitching the holes inward to any greater degree would place a depth limitation on this type of round.

The maximum depth which the spiral burn cut pattern (9 inch hole) would pull was approximately 10 feet. Cuts of greater depth than 10 feet did give an advance over 10 feet, but as the depth increased the percentage break of the round decreased rapidly.

The most critical factor in the design of a large hole burn cut appeared to be the position of the cut holes. A detailed survey of the test rounds brings out this point in an interesting manner. The study of the test rounds showed that for any type of burn cut the success of the cut was definitely reduced if one hole angled away from the large hole. As the depth of the burn cut increased, the effect of having the holes in their proper positions increased at a much faster rate. Since only reasonable care was taken in drilling these holes, it is apparent that a positive means of lining up the cut holes had to be effected. The extra time spent in drilling the cut properly could mean the difference between obtaining the full advance of the round or breaking only a part of the expected advance.

The advantages gained by using a booster charge in the large hole were not definitely established because this charge sympathetically detonated for most of the burn cuts. This sympathetic detonation, or premature firing of the booster charge, undoubtedly reduced the chances of the charge to perform its intended job; that is, to prevent freezing of the rock, and to remove some of the broken rock from the cut. For some rounds, even with premature firing, the booster charge did improve the appearances of the burn cut, but the important question--whether the booster charge was necessary for the success of the burn cut--was not definitely determined.

With some reservations, the answer to the latter question can be obtained from a theoretical analysis. Before proceeding with the mathematical analysis certain assumptions must be made. 1. That the booster charge would detonate at its proper time and the explosive gases would have sufficient force to prevent welding of the rock and to pick up the broken rock, and 2. that the average velocity of the broken rock coming out of the cut would be approximately 100 feet per second. The average velocity value of the rock was not a pure guess but was based on the data obtained from the high speed movie of burn cut number 1. The measured velocity of the fly rock which was assumed by the writer to consist mostly of broken rock from the center of the cut, was 140 feet per second. The maximum depth of cut which could be cleared of broken rock by the booster charge can be calculated. The average time elapse between regular delays number 4 (cap in booster) and number 5 (cap in first firing relief holes) is 0.7 seconds. Therefore, the maximum depth of cut which would be effectively cleared of rock under these conditions is:

$$S = 100 \times 0.7 = 70 \text{ feet}$$

Although the calculations show the depth of cut which could be cleared, they do not indicate, in any way, the effectiveness of the booster charge in preventing the freezing of the rock. In the test burn cuts, the booster charge was probably sympathetically detonated by the first firing cut hole (No. 0). The tendency of the rock broken by this cut hole to freeze is very small, therefore the only resistance to the booster charge would be only a small amount of loose rock. None of the test rounds conclusively established the ability of the booster charge to prevent welding of the cut.

Rounds 5, 6, and 9, in which the large holes were only slightly deeper than the small cut holes, indicated that for the best cut results, the big hole should be at least 1 foot deeper than the small holes. If a booster charge is to be used, the large hole should be at least $3\frac{1}{2}$ feet deeper to insure that this charge will not be sympathetically detonated. Round No. 13 showed that the results of the burn cuts are not affected by having the large hole considerably deeper than the cut holes.

The most suitable and effective dynamite for the burn cuts appeared to be Mine Gel Number 2. Possibly, a combination of Mine Gel with either a lower or higher speed dynamite would be the answer to very deep rounds.

Test rounds 1 and 6 indicated strongly that millisecond delay caps are not suitable for a burn cut of this type. The inherent blasting characteristics of the mine rock are such that millisecond caps are less effective than regular caps when used in the cut holes. It is doubtful that the short period delays could advantageously be used in any of the burn cut patterns.

Since all the burn cut holes were primed at the collars, no comparisons can be made with the usual procedure of placing the primer at the bottom of the holes.

Even though an attempt was made to keep the powder factor of the cuts constant at 0.12, it varied from 0.08 to 0.15. After the first test burn cut it was evident that the cuts would be overloaded at the 0.12 factor, but it was assumed that better results would be obtained with overloading rather than underloading. The latter reasoning may be seriously questioned because the more powder used, the more the rock will expand and thereby increase the chances of the rock to freeze. A survey of the test burn cuts with this thought in mind does show that some of the freezing exhibited by the cuts could possibly be contributed to an excessive amount of powder in the cut holes.

An accepted "rule of thumb" states that the cross-sectional area of the drift face determines the depth of a round which can be pulled. This maximum depth varies depending on thetype of cut used in blasting the round. Although this rule was established from experience acquired in the field, it can be partially explained from the considerations of stresses induced at the free faces. In essence, the magnitude, character and distribution of the transient stresses at the drift face determine the manner of breakage of the solid rock adjacent to the cut. Hence, it might be expected that these stresses would have basically the same effect on the large hole burn cut round as it has on other types of cuts.

All of the test rounds except 13 and 14 had an average drift face area of 64 square feet. These two exceptions were approximately 40 square feet. A comparison of rounds 11 and 13, which were similar in all respects except for the cross sectional area, showed no significant difference. In fact, round 13, which had the smallest drift face area, was the more successful of the two. A possible explanation for the better results obtained with round 13 could be the continuous firing sequence used in blasting the round.

A more satisfactory explanation would appear to be obtainable from a detailed consideration of both the drift and particularly the large hole as free faces in conjunction with the stresses induced at these faces by the detonating explosive.

Suggestions For Future Study

A considerable amount of work remains to be done before the successful development of deep, large hole burn cut drift rounds is complete. The round should be designed so as to take full advantage of the explosive energy of the dynamite. In this respect, further experimental work is required to determine the minimum amount of powder necessary for the burn cut to break. The author readily agrees that the powder factors of the test rounds could have been increased without any adverse results by reducing the powder consumption of the relief holes, but this would not alter the fact that the burn cuts were overloaded.

Possibly, the development of deep rounds as much as 25 feet, can be accomplished by deck-loading the charges in the cut holes. Deck loaded burn cuts up to 23 feet deep have been obtained in experiments conducted in Sweden.[15] The holes of these cuts were of conventional size, 4 of 80 mm. diameter, and 10 of 34 mm. diameter.

[15] Janelid, Ingvar, Drilling Practice in Swedish Mining, Mining Engineering, June 1954, p. 618.

A critical study should be made of the effects which the booster charge has on the success of the burn cut. If this charge is essential to the breaking of the cut, the problem of sympathetic detonation of this charge must be eliminated.

V. CONCLUSIONS

The tests described herein show convincingly that the large hole burn cut drift round is one of the answers to the problem of development of deep rounds. Certainly, this type of round can fully utilize the advantages offered by the better drilling and loading machines which are being developed at present.

The following conclusions were reached as a result of the experimental test rounds:

1. As the size of the large hole is increased, the maximum depth of cut which can be pulled successfully also increased. The exact relationship between size of hole and depth of round was not established, however.
2. The positions of the small holes of the cut are very critical in that even the slightest divergence of these holes from the large hole can cause a partial failure of the cut.
3. For best results, the large hole of the cut should be at least one foot deeper than the small holes. If a booster charge is placed in the bottom of the large hole, the big hole should be sufficiently deeper than the cut holes to prevent sympathetic detonation of this charge.
4. A booster charge does improve the appearance of the burn cut, but whether or not it is absolutely essential to the success of the burn cut was not determined.
5. The pyramid large hole burn cut pattern is the most effective in this rock when used with Mine Gel No. 2 powder and regular delays.
6. The powder factor of the cut and the round holes (the powder factor of the entire round) could be increased considerably without any adverse results.

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VITA

Joseph J. Yancik, Jr., son of Joseph J. Yancik, Sr., and Ann Yancik, was born December 1, 1930 at Mt. Olive, Illinois. He received his elementary and high school education in this city.

He enrolled at the University of Illinois in 1948 and completed two years of schooling at which time he was called to active duty in the United States Army, Corps of Engineers. His tour of duty, from September 1950 to June 1952 took him to Germany where he was stationed for approximately 16 months. On June 7, 1952 he was discharged from the Service as a Sergeant First Class.

Upon release from active duty he returned to the University of Illinois and received a B. S. degree in Mining Engineering in 1954.

He enrolled at the University of Missouri, School of Mines, in September 1954 for graduate work in the Department of Mining Engineering. At that time he was granted a Graduate Assistantship. On January 1, 1955 he resigned this appointment and received a Research Fellowship.

During the summers of his undergraduate schooling he obtained employment with two Illinois coal mines and one Western metal mine.