

SYMPATHETIC DETONATION
IN
LONG BORE HOLES

Norman R. Zehr

ProQuest Number: 10781508

All rights reserved

INFORMATION TO ALL USERS

The quality of this reproduction is dependent upon the quality of the copy submitted.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if material had to be removed, a note will indicate the deletion.



ProQuest 10781508

Published by ProQuest LLC (2018). Copyright of the Dissertation is held by the Author.

All rights reserved.

This work is protected against unauthorized copying under Title 17, United States Code
Microform Edition © ProQuest LLC.

ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 – 1346

A thesis submitted to the Faculty and Board
of Trustees of the Colorado School of Mines in
partial fulfillment of the requirements for the
degree of Master of Science.

Signed

Norman R. Zehr

Norman R. Zehr

Golden, Colorado

Date June 6, 1955

Approved

L. J. Parkinson

L. J. Parkinson
Head, Mining Department

Golden, Colorado

Date June 20, 1955

J. B. Co. #327

Dep. the Author.

9-7-55

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to those students of the Colorado School of Mines who assisted in the experimental work, and in particular to thank the following persons:

Professor G. T. Bator of the Mining Department
of the Colorado School of Mines.

Professor E. G. Fisher of the English Department
of the Colorado School of Mines.

My wife, Irma, who assisted in the preparation
of the manuscript.

CONTENTS

	<u>Page</u>
Abstract	1
Introduction	3
Location of Experiments	4
Equipment and Materials	6
Equipment	6
Materials	7
Basic Concepts	9
Crater Theory	9
Sympathetic Detonation	9
Procedure of Experiments . . . . .	.14
Drilling Procedure . . . . .	.15
Blasting Procedure . . . . .	.17
Results of Experiments . . . . .	.19
Group I, Holes 1, 2, 3 . . . . .	.21
Group II, Holes 4, 5, 6 . . . . .	.27
Group III, Holes 7, 8, 9 . . . . .	.34
Group IV, Holes 10, 11, 12 . . . . .	.40
Group V, Holes 13, 14, 15 . . . . .	.46
Conclusions . . . . .	.51
Applications . . . . .	.56
Future Investigations . . . . .	.58
Bibliography . . . . .	.60

ILLUSTRATIONS

	<u>Page</u>
Fig. 1 Sketch Map, Edgar Mine	5
Fig. 2 Weight-Depth Relations	10
Fig. 3 Limits of Sympathetic Detonation . . .	12
Plate 1 Group No. I	22
Plate 2 Hole No. 1	23
Plate 3 Hole No. 2	24
Plate 4 Hole No. 3	25
Plate 5 Group No. II	28
Plate 6 Hole No. 4	30
Plate 7 Hole No. 5	31
Plate 8 Hole No. 6	32
Plate 9 Group No. III	35
Plate 10 Hole No. 7	36
Plate 11 Hole No. 8	37
Plate 12 Hole No. 9	38
Plate 13 Group No. IV	41
Plate 14 Hole No. 10	42
Plate 15 Hole No. 11	43
Plate 16 Hole No. 12	44

	<u>Page</u>
Plate 17 Group No. V	47
Plate 18 Hole No. 13	48
Plate 19 Hole No. 14	49
Plate 20 Hole No. 15	50
Photo 1 Group No. I	26
Photo 2 Group No. II	29
Photo 3 Group No. II	33
Photo 4 Group No. III	39
Photo 5 Group No. IV	45

ABSTRACT

A great amount of research has been done to determine more efficient methods of blasting rock in underground mines. Much of this work has been directed toward the design of better drill rounds for driving development openings. The phenomenon of sympathetic detonation of explosives has been observed and studied in holes from 1 to 8 ft long.

The use of long bore holes, up to several hundred feet long, has become common in many stoping methods. If sympathetic detonation would continue down a deck-loaded long hole, a greater efficiency in blasting would be realized.

Experiments were carried out which showed that sympathetic detonation will occur in holes up to 40 ft long containing as many as 9 separate charges, or decks, of explosive. These decks are separated from each other by an inert stemming material. Sufficient energy passes through this stemming, from the primer charge, to detonate the adjacent charge.

In deck-loaded bore holes, the explosive is better distributed in the hole. Less explosive is used than if the hole were loaded entirely with explosive. A slight delay in the detonation of each charge results in better fragmentation of the rock.

The use of sympathetic detonation in long bore holes may be applied to slabbing rounds in development headings as well as to numerous stoping methods.

An understanding of the causes of sympathetic detonation is necessary before it can be applied most efficiently to mining problems.

INTRODUCTION

In the past few years a great amount of research work has been done on specific problems in underground drilling and blasting practice. Graduate students at the Colorado School of Mines have done considerable work on such problems, and their efforts have resulted in the writing of four theses on the design of drill rounds and on sympathetic detonation.

Specific experiments with sympathetic detonation have been carried out in the past in bore holes from 1 to approximately 8 ft long. This work was largely directed toward the design of drill rounds and the control of detonation in these rounds. The question arose whether sympathetic detonation could be expected to continue down a long bore hole which had been deck-loaded (loaded with charges of explosive separated by a stemming material).

The use of deck-loaded bore holes has been largely limited to quarry and open pit blasting, and little used in underground mining. There are definite advantages to deck-loaded bore holes, among them the

saving of explosive and the better distribution of the explosive in the bore hole. The result is higher blasting efficiency.

The use of long bore holes is becoming widely used in many stoping methods (Gardner-Denver, 1954). If these long holes could be deck-loaded and blasted by sympathetic detonation, a higher efficiency of operation could be expected.

Therefore, a series of experiments was undertaken to determine whether sympathetic detonation would occur in deck-loaded charges of explosive in a long bore hole. Because of limitation on available space and drilling equipment the holes were drilled a maximum of 40 ft long.

Location of Experiments

All of the experimental work was carried on at the Colorado School of Mines Experimental Mine, located at Idaho Springs, Colorado, about 35 miles west of Denver on U.S. Highways 6 and 40. This mine is maintained by the School as a laboratory for courses in mine surveying and mining practice, as well as for experimental work by graduate students in the Mining Department.

The older mine workings comprise the Miami adit, the Edgar drift, the Edgar shaft, and the Roy and the Brown raises. In addition to these, there are numerous short drifts, off the Miami adit, in which most of the

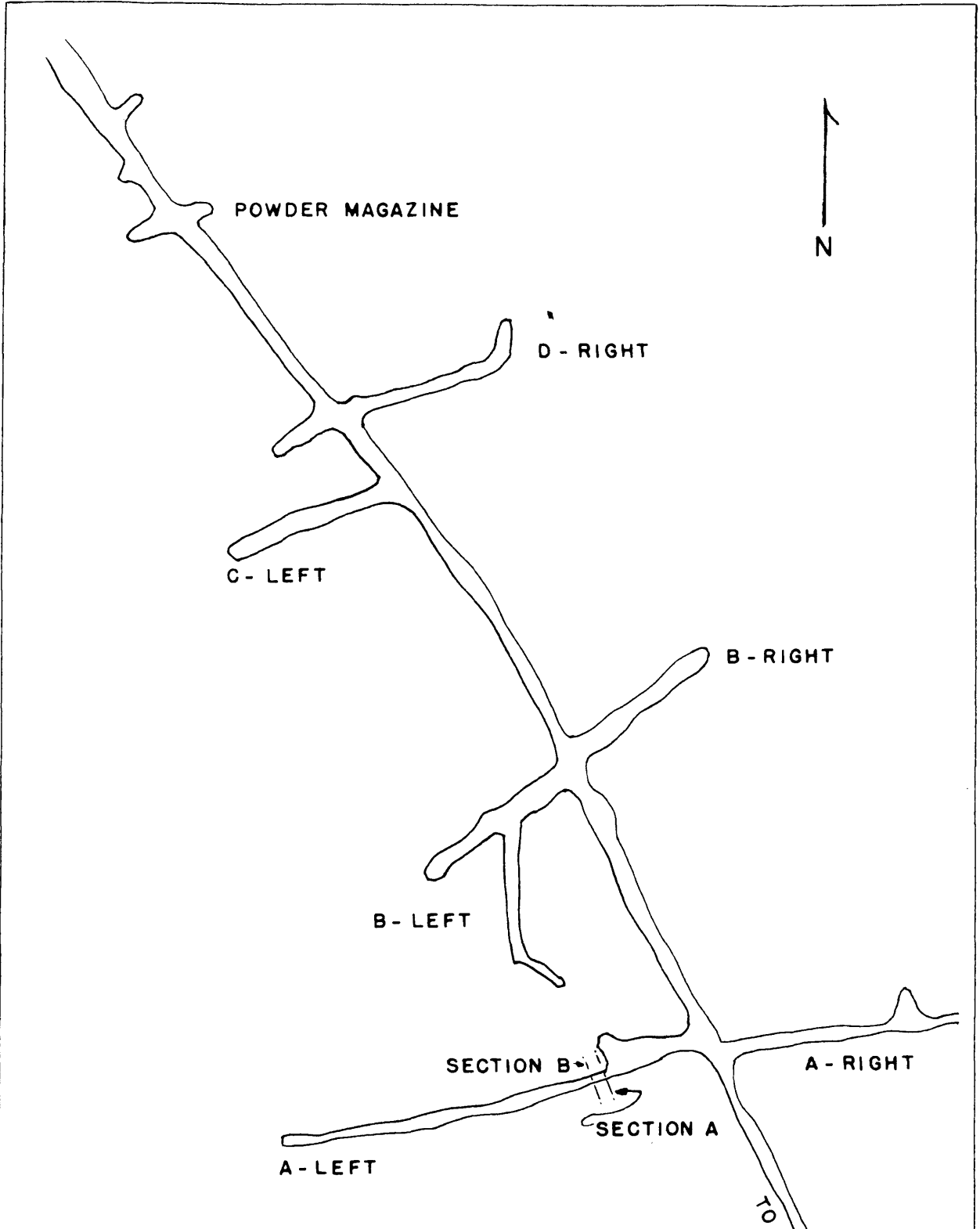


FIG. 1
SKETCH MAP
EDGAR MINE
IDAHO SPRINGS, COLO.
SCALE 1" = 100'

present work is being carried on. In general, these drifts follow narrow mineralized zones. The active workings and the site of the experimental work for this thesis are shown in Fig. 1.

The country rock in the mine is a gneiss, a formation consisting of pre-Cambrian sediments highly metamorphosed and intruded by dikes of monzonite, monzonite porphyry, bostonite, and granite. The gneissic bands strike N. 45°-65° E. and generally dip 60° N.

Equipment and Materials

Equipment

A considerable variety of mining equipment is maintained at the Experimental Mine through donations by equipment manufacturers and purchases by the Mining Department. This equipment is available for use in research projects.

The following is a list of equipment used in this experimental work:

- 1 - Drifter, Gardner-Denver, Model 93.
- 14 - Drill steels, sectional, 4-ft lengths with bit adapter and coupling.
- 4 - Bits, Timken, tungsten-carbide insert, 2-in. diameter.
- 1 - Column, screw-type, with arm.

- 1 - Column, pneumatic, with arm.
- 1 - Jumbo, Joy-Sullivan, two-boom, Hydro.
- 1 - Slusher, Joy, 2-drum.
- 4 - Granby cars, 55-cu ft.
- 1 - Mucking machine, Gardner-Denver, Model GD9.
- 1 - Transit.
- 1 - Steel tape, 100-ft.
- 1 - Steel tape, 8-ft.
- 1 - Brunton compass.
- 1 - Hose, plastic, 50-ft section, with air coupling.
- 1 - Loading stick, wooden, graduated, 8-ft.
- 1 - Pipe wrench.
- 1 - Open-end wrench
- 1 - Cap crimpers.

Facilities are maintained as part of the mine plant to provide water and compressed air at 90 psi at each working place. A diesel locomotive is used to haul broken rock to the dump.

Materials

All blasting was done with either Du Pont Gelex No. 2 (45%) or Du Pont Gelex No. 3 (40%). No. 6 blasting caps, fuse, and Primacord were used in the preparation of the primer charges.

Stemming may be defined as any inert material

placed in a bore hole to separate charges of explosive or to seal the hole to prevent the escape out the end of the hole of products of the explosion. In all the experiments either roasted perlite or vermiculite was used as stemming. Roasted perlite is approximately 96% quartz and 4% orthoclase and other unknown complex minerals (Kabbani, 1954, p.18). Vermiculite is a mica supposed to be a hydrothermal alteration of biotite or phlogopite (Bateman, 1951, p. 731).

BASIC CONCEPTS

Crater Theory

The basic assumptions used in the explosive calculation for the experiments are those of the "Crater Theory" of rock failure. (Livingston, 1950). General discussions of this theory appear in "New Types of Drill Rounds for Development Openings," a master's thesis by Allen D. Gray, Jr., (1952) and in other theses on similar subjects (Carmichael, 1952) (Kabbani, 1954).

The results of experiments based on this Crater theory are tabulated in Fig. 2 (Gray, 1952, p. 46). From this chart, calculations were made of the required amount of explosive for all long-hole experiments.

Sympathetic Detonation

Sympathetic detonation is the instantaneous detonation of one charge of explosive, without a contained detonator, by an adjacent charge which has a detonator. Work has been done by Kabbani (1954) and Presanis (1953)

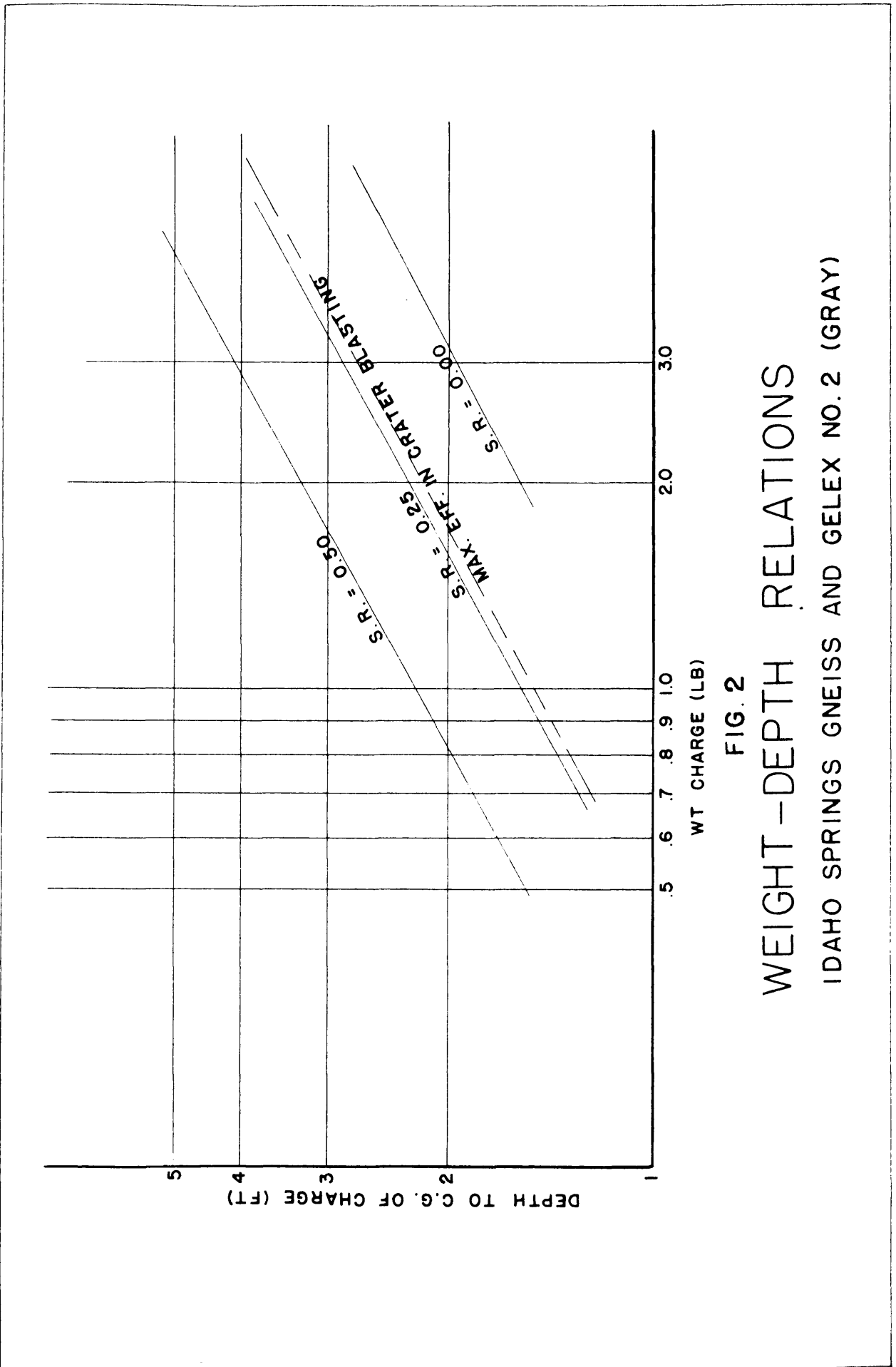


FIG. 2
WEIGHT-DEPTH RELATIONS
IDAHO SPRINGS GNEISS AND GELEX NO. 2 (GRAY)

to determine the limits on the spacing of charges in a bore hole at which sympathetic detonation will, and will not, occur. Kabani (1954) prepared a chart, based on his experiments, which gives the limits on spacing using various types of stemming material in a 2-in.-diameter hole. (Fig 3).

In a bore hole this stemming can be a material such as sand, drill cuttings, vermiculite, and roasted perlite. It is used to give an inert spacing between charges, or "decks," in a bore hole. Fig. 2 shows the chart which was used as a basis for loading the holes in the following experiments.

There are many ideas as to what forces actually produce sympathetic detonation. It is known that detonation of a high explosive causes it to decompose to a gaseous volume equal to the original volume of the cartridge. High temperature and high pressure result from this decomposition. A detonation wave occurs within the cartridge and becomes a shock wave as it passes into the rock surrounding the bore hole. This shock wave is accompanied by the expansion of the gaseous products of the explosion. If the force of these expanding gases and of the shock wave overcomes the cohesive strength of the rock mass, failure will occur (Livingston, 1951). A discussion of the

Material	Length of stemming, inches					
	1.5-in. diameter		2-in. diameter			
	Detonated	Not Detonated	Detonated	Not Detonated	Detonated	Not Detonated
Mill Tailings	15	16	13	14	14	
Drill Cuttings	14	15	13	14	14	
Coarse Sand	17	18	14	15	15	
Coarse Sand -4 +8	16	17	13	14	14	
Coarse Sand - 100 mesh	15	16	13	14	14	
Roasted Perlite	27	28	26	27	27	
Vermiculite	26	27				
Glass Wool	28	29				

FIG. 3

LIMITS OF SYMPATHETIC DETONATION

FOR TWO FREE FACES AND A BURDEN OF TWO FEET (KABBANI)

stability of this detonation is found in Eyring, (1949).

Sympathetic detonation is caused by one, or a combination, of the products of detonation in the first charge. A few observations on the possible causes are made in the chapter "Conclusions."

PROCEDURE OF EXPERIMENTS

The question on which this thesis work was based is: "Will sympathetic detonation continue through all of the charges in a long bore hole as it does in a short (6-to 8-ft) bore hole?"

Experimental work has shown that if proper spacing and stemming materials are used to separate decks of explosives, these decks can be detonated sympathetically in holes from 1 to about 8 ft in length. It was not known whether this detonation would continue in holes from 20 to 40 ft long.

Long bore holes are becoming more widely used in various mining methods, and some methods are being modified to include their use. The common practice is to load these holes completely with explosive and in many cases to lay Primacord, a detonator in itself, down the hole to insure detonation of all the explosive in the hole. These long holes vary from over 8 ft to some 100 or 200 ft in length. The object of the following experiments was to determine whether or not sympathetic

detonation would cause the explosion of numerous decks in a long hole using only one detonator.

A hole length of 40 ft was the maximum used, because space was not available for drilling longer holes with a burden (distance from the explosive in the hole to the free face) of less than 4 ft.

Drilling Procedure

With the exception of two, all of the holes used were drilled with a Gardner-Denver model 93 drifter, using Gardner-Denver sectional steel and 2-in.-diameter Timken carbide-insert rock bits.

The holes were drilled in groups of three. Each group represents a slabbing round on either the rib (side) of the drift or the back (roof) of the drift. The burden was maintained at roughly 2 ft in all holes except those in Group V. In Group V the burden ranged from 3 to 4 ft. Profiles taken with a transit were plotted for each hole in the diagrams (Plates 1 to 20) that follow.

For drilling the holes in Group I the drifter was mounted on a screw-column; for Groups II and III, the drifter was mounted on a pneumatic column; and for Groups IV and V the drifter was mounted on a jumbo. The type of support for the drifter made little difference in the ease of drilling the long holes. The screw

column was the most stable of the three; the pneumatic column was used where lack of headroom prohibited the use of the screw-column; the jumbo provided the easiest positioning of the drifter.

All of the drilling was done by the author and other students. Some difficulty was encountered because the crews were unfamiliar with long hole drilling of this type, and considerable time was lost until a system was developed for adding sections to the drill steel. However, the best crew reached an overall drilling speed (including time for adding sections of steel, but not time for setting-up the drifter or removing the steel from the hole after drilling was completed) of approximately 1 fpm (2-in.-diameter hole).

In general, no appreciable horizontal or vertical deflection was noted in the long holes. However, Hole No. 6 was deflected upward about 8 in. in 40 ft of length because of poor positioning of the drifter. Great care must be exercised in "setting-up" to insure proper hole alignment, especially of long holes.

The drifter itself was adapted for long hole drilling by replacing the normal O-rings, or rubber gaskets, in the water passage with smaller rings which allow the passage of a larger amount of water into the drill steel. An increased flow of water is required to flush the drill

cuttings from a deep hole.

Blasting Procedure

In the holes in Groups I, II, III and IV, Du Pont Gelex No. 2 (45%) dynamite was used exclusively. In the holes in Group V, Du Pont Gelex No. 2 was not available.

In order to facilitate cleaning and loading the holes, a 50-ft section of plastic hose was fitted with an air connection on one end and a removable wooden plug on the other. This hose was used to blow out each hole with compressed air, then fitted with the wooden plug and used to tamp explosive and stemming into the holes. The plastic hose was easily handled in the confined area of the drift.

The amount of explosive in each deck was based on the chart by Gray, (1952), Fig. 2. A stick count of 122 per 50-lb carton of Gelex No. 2 was used (Du Pont, 1949, p. 64). A stick count of 200 was assumed for the Gelex No. 3.

In all holes except No. 3 the detonator (a No. 6 blasting cap) was placed in the deck nearest the collar of the hole. This allowed the sympathetic detonation to proceed through the greatest distance in each hole. Moreover, the loading was safer and less fuse was used than if the primer had been placed

in the bottom of the hole.

The length of each deck of explosive and the intervening stemming was measured by marking the plastic hose with crayon. The cartridges of explosive were not split.

Stemming material, either vermiculite or roasted perlite, was placed in stemming bags before loading it into the hole.

RESULTS OF EXPERIMENTS

The diagrams of each group of holes are preceded by a brief description of each hole in the group. The first plate shows the location of the holes along the rib or the back of the A-Left drift.

Each hole is described, giving its diameter, its length, the profile of the burden, the stemming material, and the explosive used. The number of sticks of explosive in each deck is given to the right of that deck in the diagram. All stemming was 18 in. long, unless otherwise noted. This length was selected after the firing of Group I, for sufficient spacing of charges in the hole was provided and sympathetic detonation reasonably could be expected with this amount of stemming (See Fig. 3).

In the area of the experiments the country rock is fractured along planes with a strike parallel to the bearing of the holes and dipping some 60° to the north. These fracture planes contain numerous veinlets of sulfides such as galena, pyrite, and molybdenite.

The presence of fractures in the country rock was favorable to breaking of the rock and simulated to some extent the condition of ore as it might occur in a stope. However, the fractures caused some trouble during drilling and loading the holes, as noted under the description of the separate holes.

Group I

Group I was drilled in the right rib of the A-Left drift at Section A (See Fig. 1). The holes in this group were detonated one at a time to allow examination of the results of each hole.

Hole No. 1 was broken by the explosion of Hole No. 2, and only the remnants of Hole No. 1 were loaded and blasted.

Hole No. 2 was loaded as shown and detonated by a primer placed near the collar of the hole. Detonation, initiated by the primer, was propagated through all of the charges.

Hole No. 3 was loaded as shown, with the primer at the approximate center of the hole. Charge A was not detonated and it was concluded that there were two possible causes for this failure. First, the length of stemming was close to the critical length (Kabbani, 1954). Second, the burden was slightly less than the length of stemming (Presanis, 1953). All of the other charges were detonated.

A standard length of 18 in. of stemming was decided upon as a convenient and practical length to insure sympathetic detonation. The placement of the primer seemed to make no difference in its ability to detonate all charges in the hole.

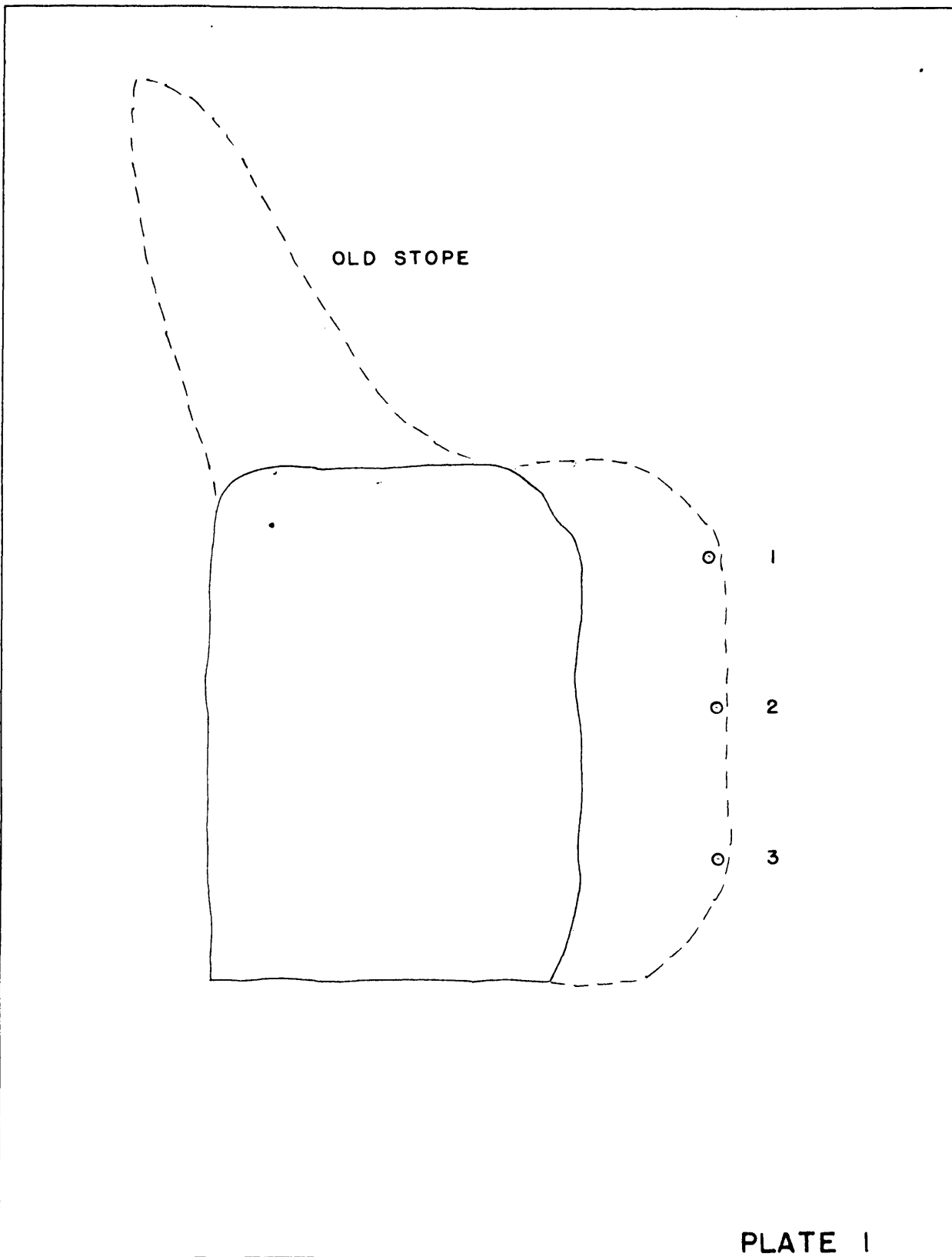


PLATE I

A - LEFT DRIFT
SECTION "A"

GROUP NO. I
VERTICAL SECTION
SCALE: 1" = 2'

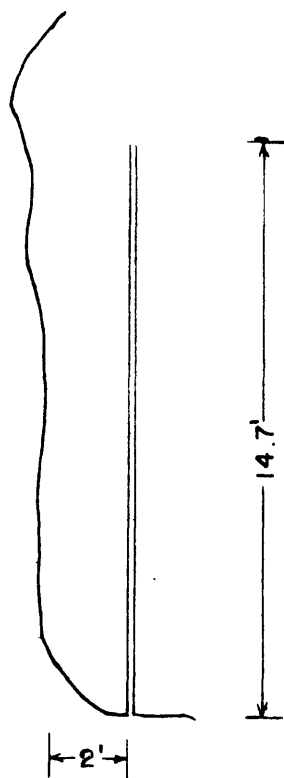


PLATE 2

LENGTH - 14.7'
DIAMETER - 2"
STEMMING - VERMICULITE
EXPLOSIVE - GELEX NO. 2

HOLE NO. 1
HORIZONTAL SECTION
SCALE: 1" = 5'

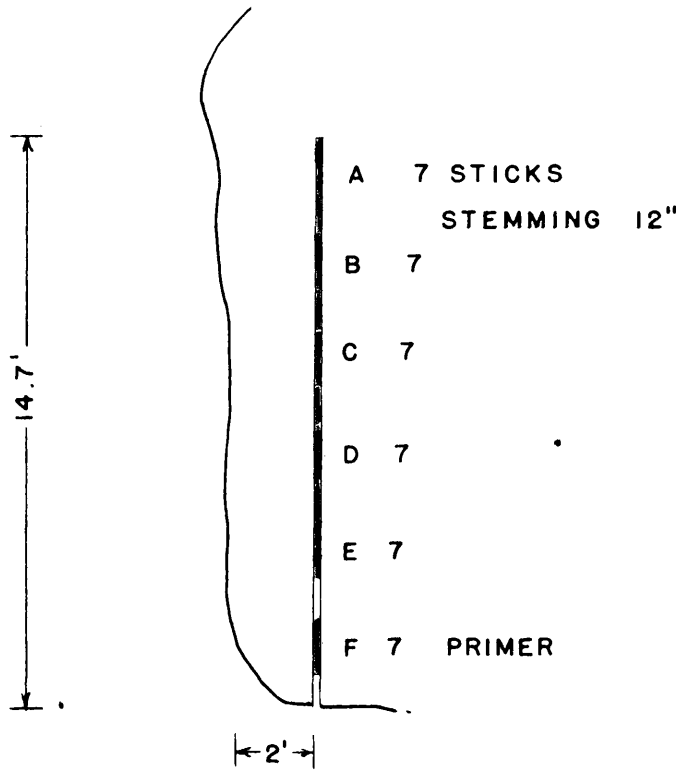


PLATE 3

LENGTH - 14.7"
 DIAMETER - 2"
 STEMMING - VERMICULITE —
 EXPLOSIVE - GELEX NO. 2 —

HOLE NO. 2
 HORIZONTAL SECTION
 SCALE: 1" = 5'

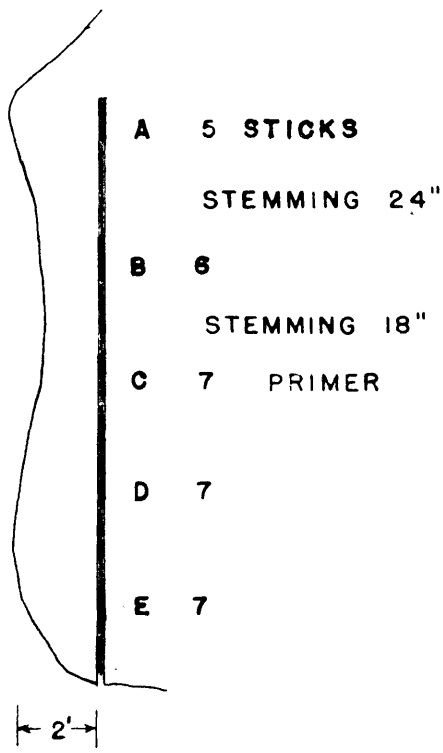


PLATE 4

LENGTH - 15.3'
DIAMETER - 2"
STEMMING - VERMICULITE —
EXPLOSIVE - GELEX NO. 2 —

HOLE NO. 3
HORIZONTAL SECTION
SCALE: 1" = 5'

TOP



PHOTO. I

A - LEFT DRIFT

GROUP NO. I

Group II

Group II was drilled in the right rib of the A-Left drift at Section B. The holes in this group were detonated one at a time to allow examination of the results of each hole.

Hole No. 4 was broken by the explosion of Hole No. 6. The remnants were loaded as shown and blasted. All of the charges in the hole were detonated.

Hole No. 5 was also broken by the explosion of Hole No. 6. The remnants were loaded as shown and blasted. All of the charges in the hole were detonated.

Hole No. 6 was loaded as shown and blasted. Detonation, initiated by the primer, was propagated through all of the 9 charges in the hole. The explosion left approximately half of the bore hole in place, as there was no over-break, or back-break. All rock in the burden was broken.

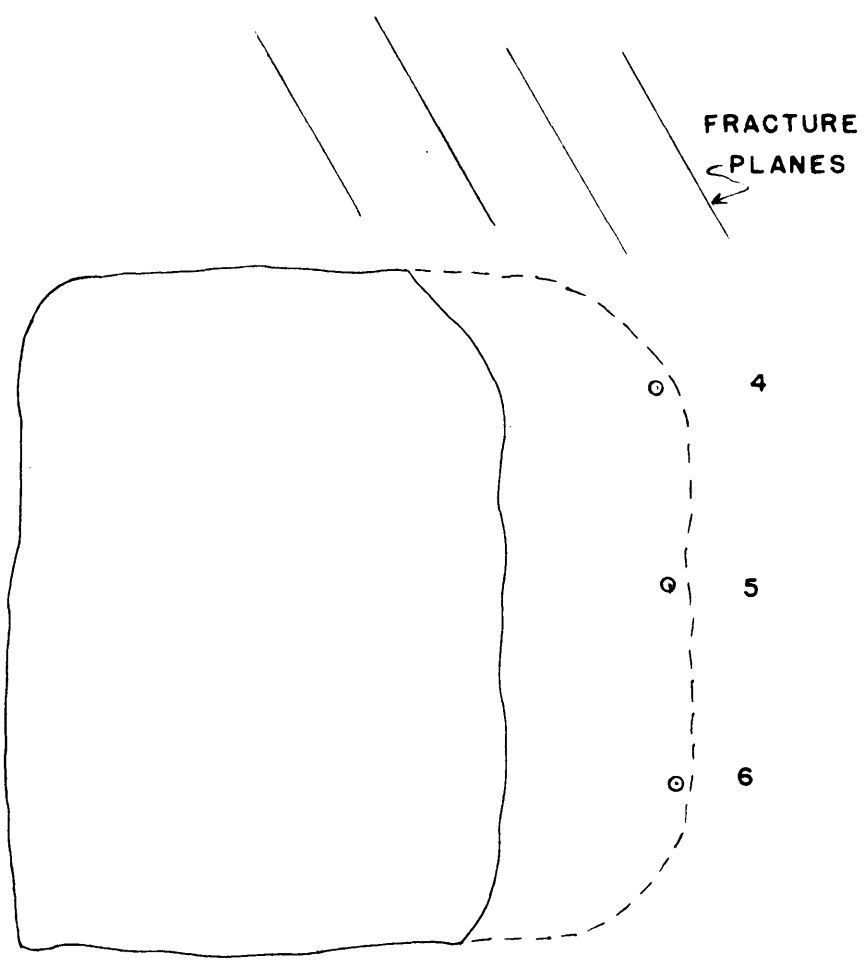


PLATE 5

A - LEFT DRIFT
SECTION "B"

GROUP NO. II
VERTICAL SECTION
SCALE: 1" = 2"

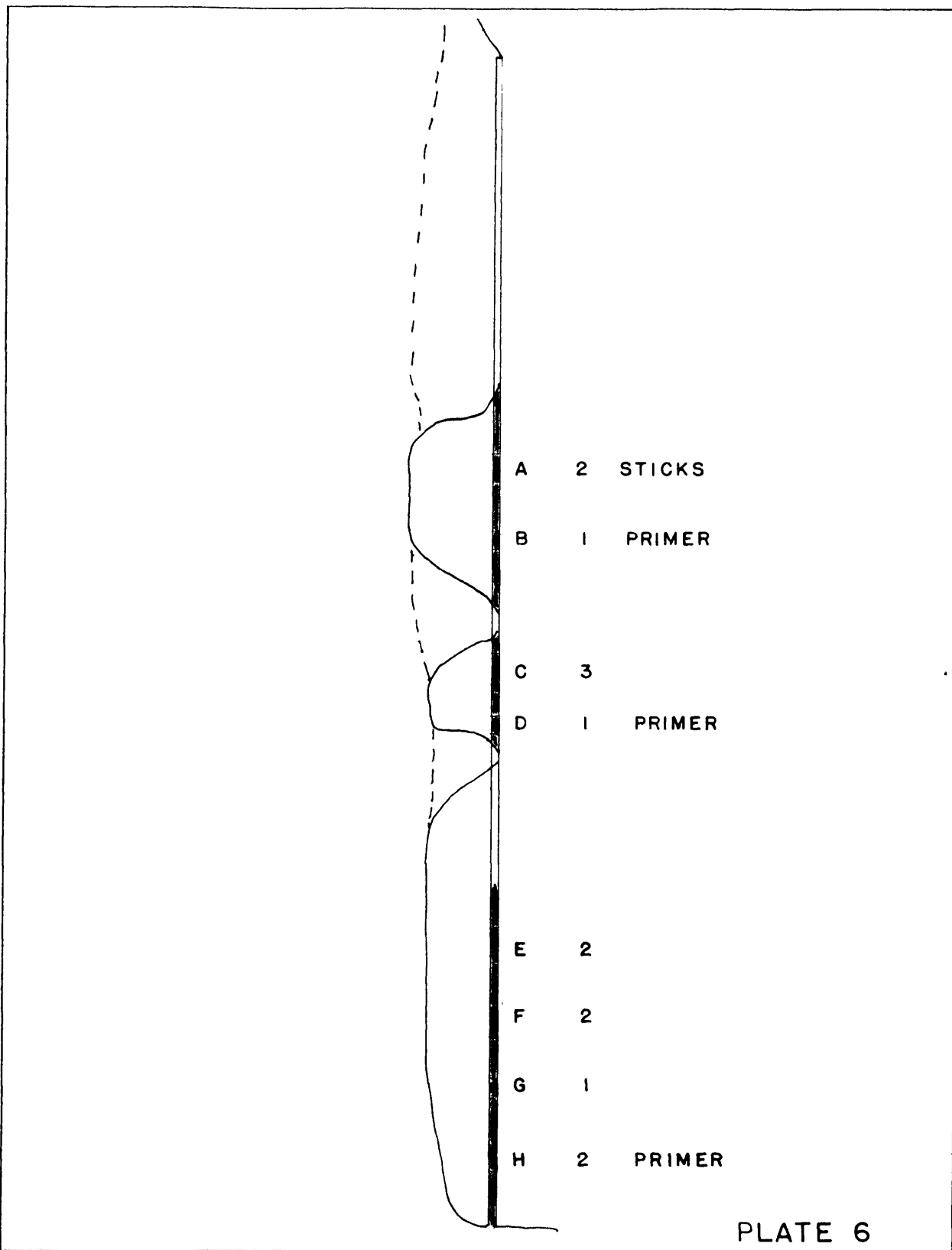


TOP

PHOTO. 2

A - LEFT DRIFT

GROUP NO II



LENGTH - 40.0'
DIAMETER - 2"
STEMMING - PERLITE
EXPLOSIVE - GELEX NO. 2

HOLE NO. 4
HORIZONTAL SECTION
SCALE: 1" = 5'

PLATE 6

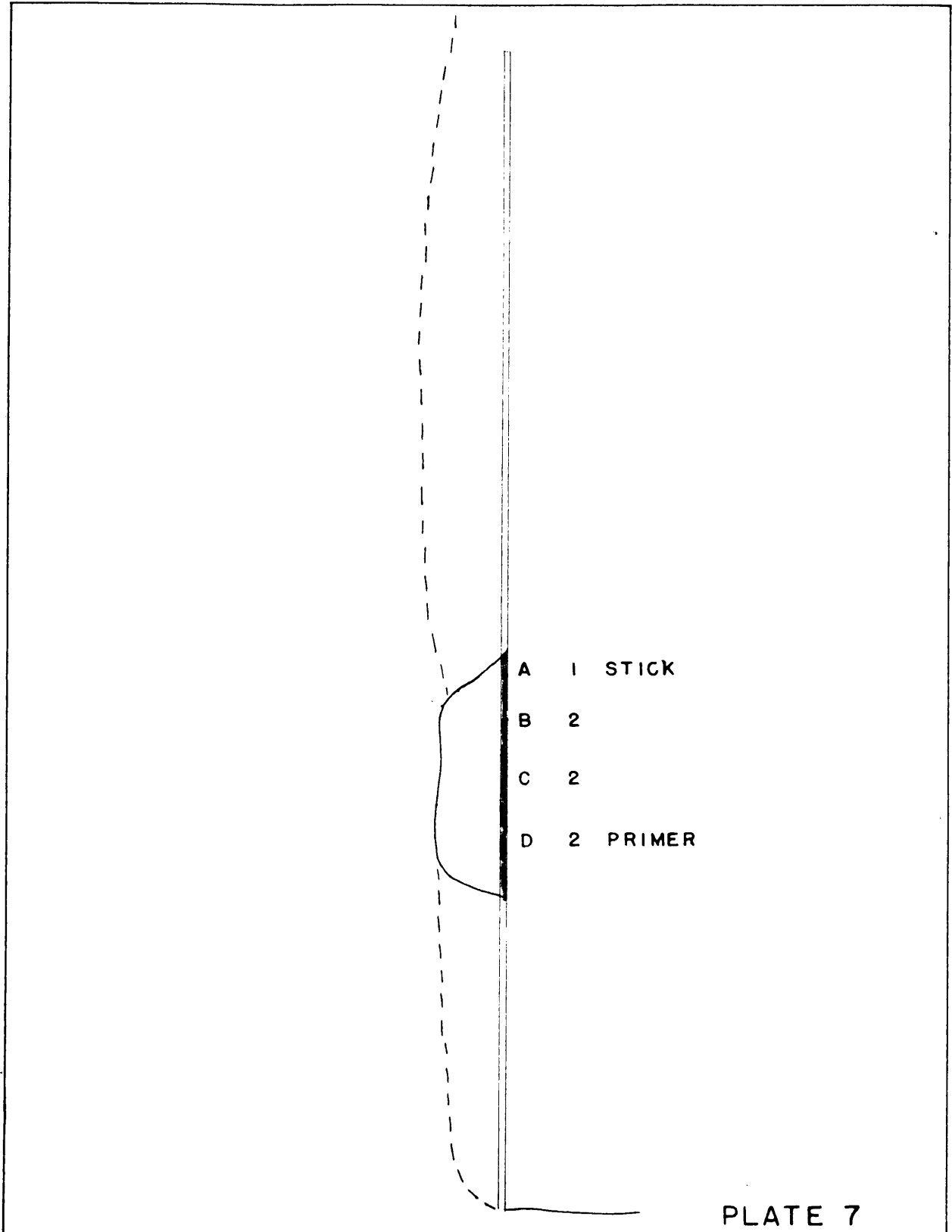


PLATE 7

LENGTH - 40.0'
DIAMETER - 2"
STEMMING - PERLITE
EXPLOSIVE - GELEX NO. 2

HOLE NO. 5
HORIZONTAL SECTION
SCALE: 1" = 5'

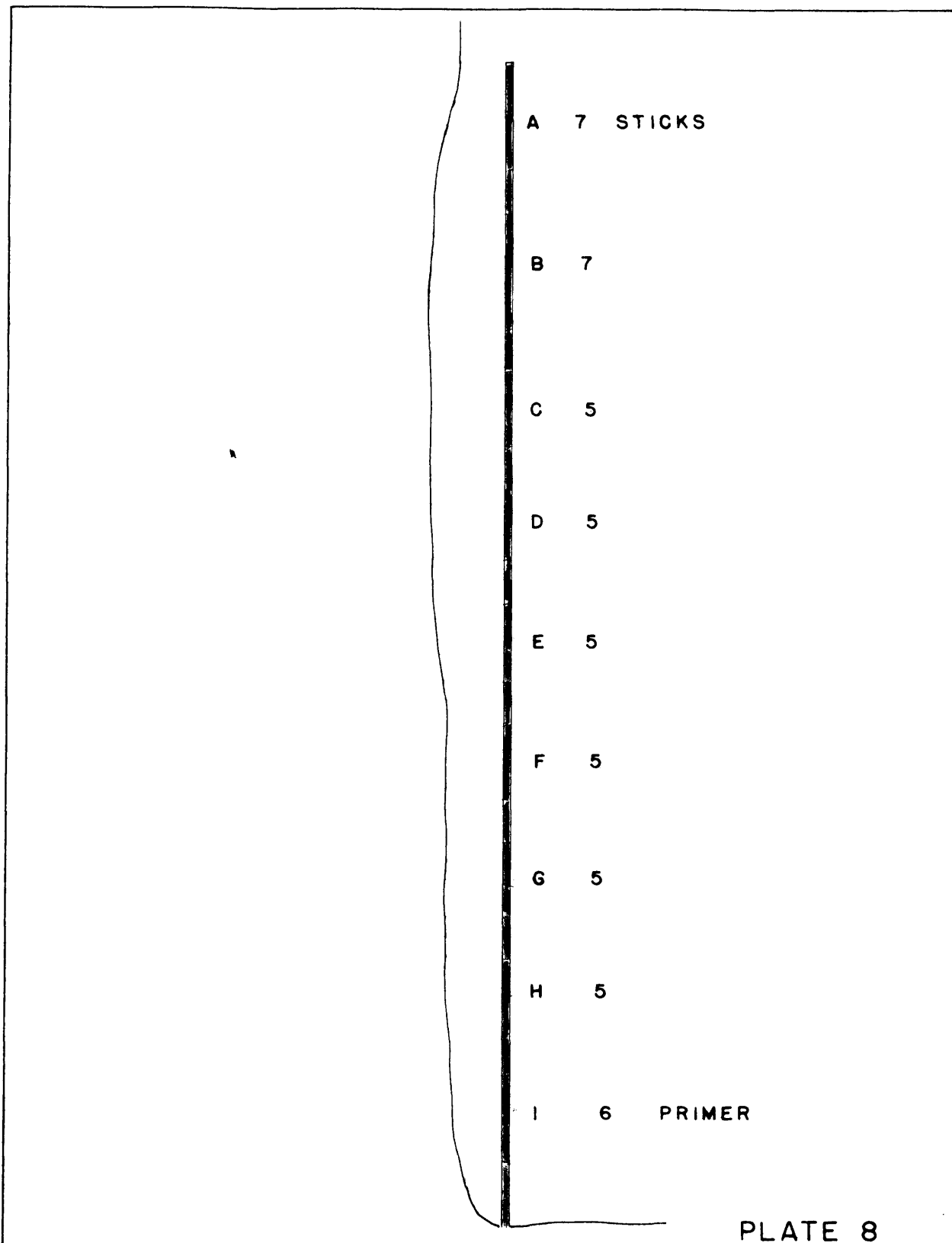


PLATE 8

LENGTH - 40.0'
DIAMETER - 2"
STEMMING - PERLITE
EXPLOSIVE - GELEX NO. 2

HOLE NO. 6
HORIZONTAL SECTION
SCALE: 1" = 5'



TOP

PHOTO 3

A - LEFT DRIFT

GROUP NO. II

Group III

Group III was drilled in the back of the A-Left drift at Section B. The holes in this group were detonated simultaneously, using Primacord to connect only the primers in each hole. All rock in the burden was broken.

Hole No. 7 was loaded as shown and blasted. All charges in the hole were detonated.

Hole No. 8 was drilled with a LeRoi-Cleveland jackleg machine, using a 1 7/8-in.-diameter Liddicoat bit. The hole was loaded as shown and blasted. All charges in the hole were detonated.

Hole No. 9 was also drilled with the jackleg machine. Stemming was reduced to 9 in. between charges because of the smaller hole diameter and reduced amount of explosive in each charge. All charges in the hole were detonated.

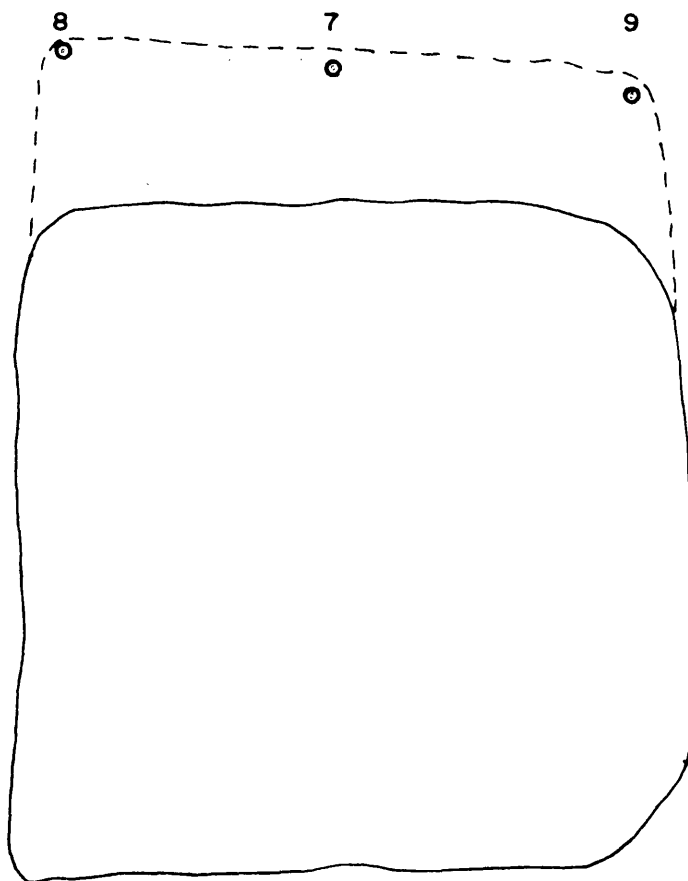


PLATE 9

A - LEFT DRIFT

SECTION "B"

GROUP NO. III

VERTICAL SECTION

SCALE: 1" = 2'

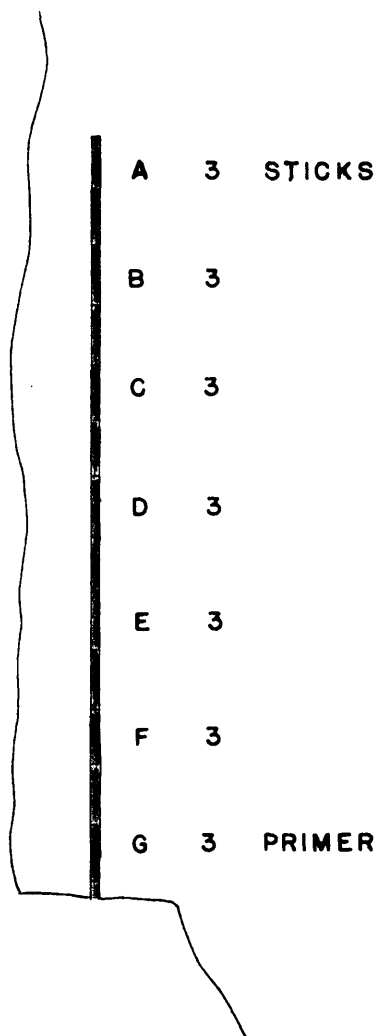


PLATE 10

LENGTH - 20.0'
DIAMETER - 2"
STEMMING - PERLITE
EXPLOSIVE - GELEX NO. 2

HOLE NO. 7
VERTICAL SECTION
SCALE: 1" = 5'

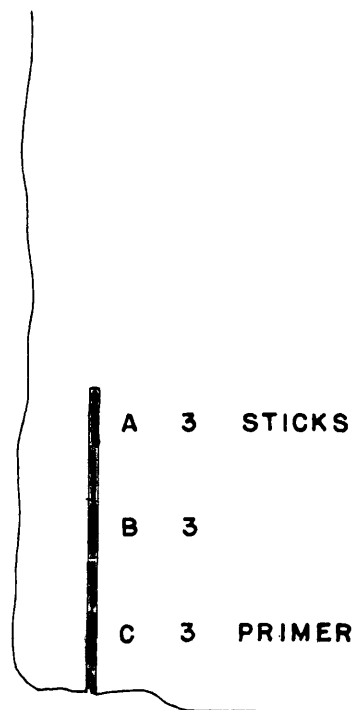
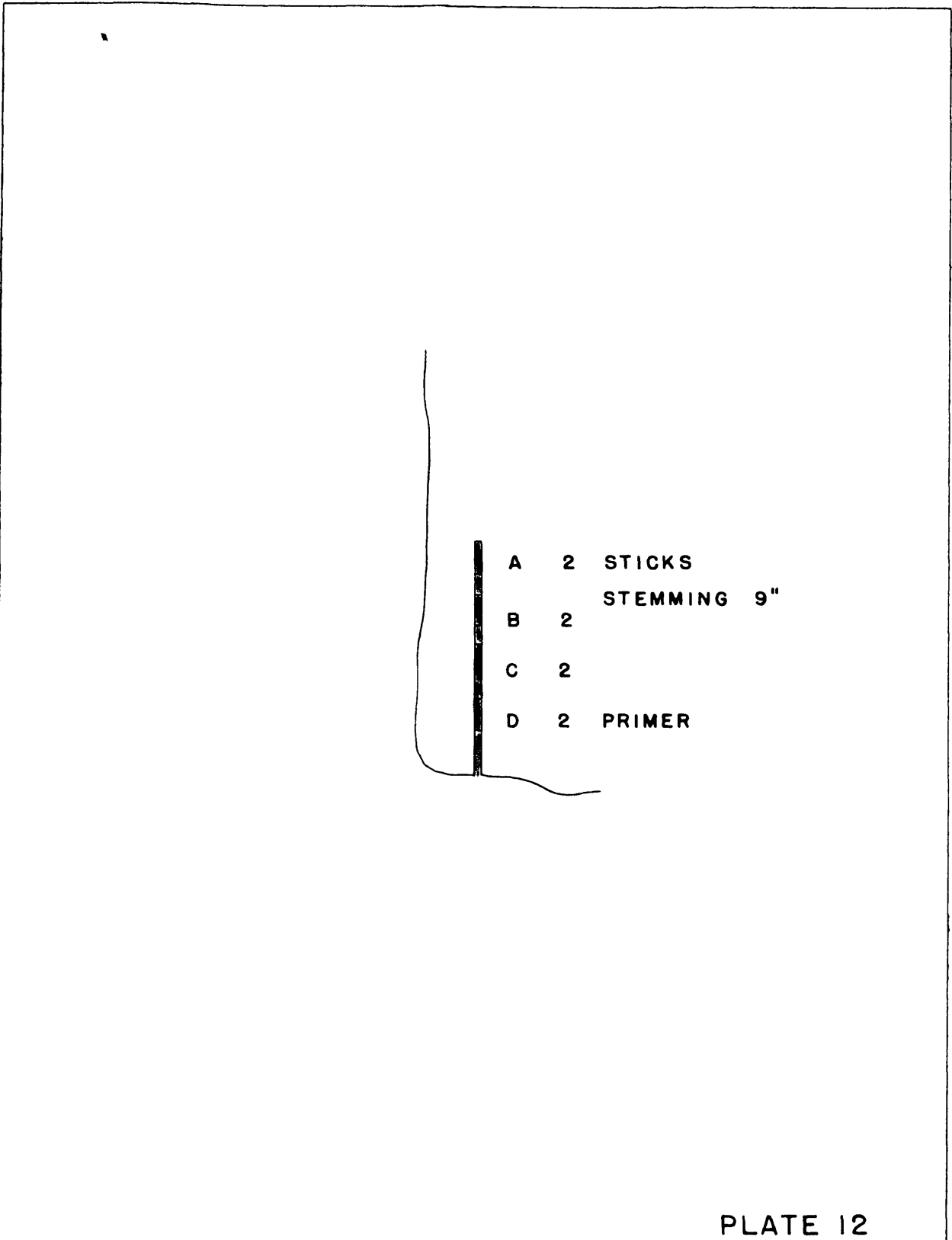


PLATE II

LENGTH - 8.0'
DIAMETER - 1 7/8"
STEMMING - PERLITE
EXPLOSIVE - GELEX NO. 2

HOLE NO. 8
VERTICAL SECTION
SCALE: 1" = 5'



A 2 STICKS
STEMMING 9"
B 2
C 2
D 2 PRIMER

PLATE 12

LENGTH - 8.0'
DIAMETER - 1 7/8"
STEMMING - PERLITE
EXPLOSIVE - GELEX NO. 2

HOLE NO. 9
VERTICAL SECTION
SCALE: 1" = 5'

TOP



PHOTO. 4

A - LEFT DRIFT

GROUP NO III

Group IV

Group IV was drilled in the right rib of the A-Left drift at Section A. The three holes were detonated simultaneously, using Primacord to connect only the primers in each hole. All rock in the burden was broken.

Hole No. 10 was loaded as shown and blasted. All charges in the hole were detonated.

Hole No. 11 was drilled completely through, leaving it open at both ends. Charge F was placed in the rib nearby to blast a space in which to set up the drifter to drill Group V and was connected to Charge A with Primacord. When Charge A was detonated by sympathetic detonation, the explosion was carried to Charge F by the Primacord. Detonation of Charge F indicates that Charge A was detonated and not merely blown out of the hole.

Hole No. 12 was loaded as shown and blasted. All charges in the hole were detonated.

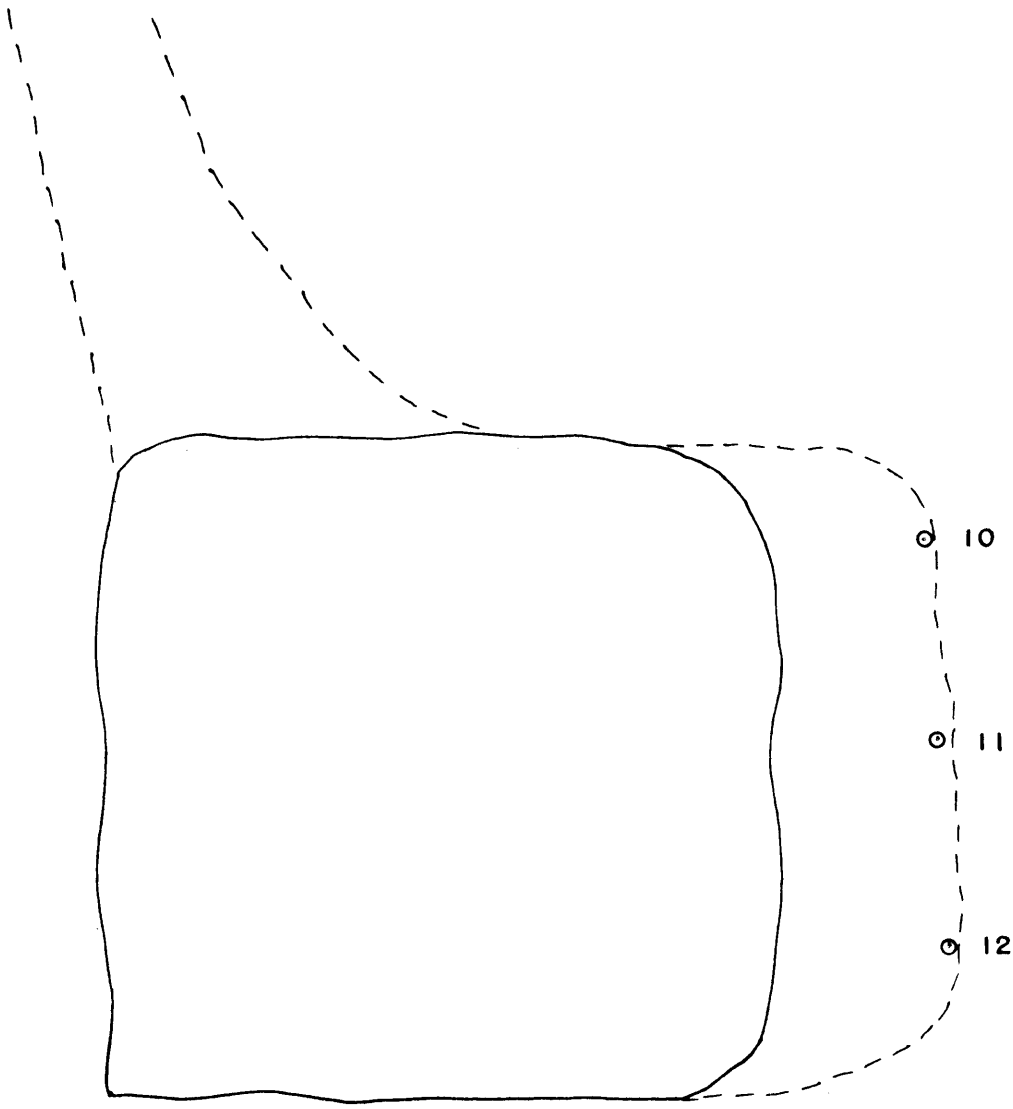


PLATE 13

A- LEFT DRIFT

SECTION "A"

GROUP NO. IV

VERTICAL SECTION
SCALE: 1" = 2'

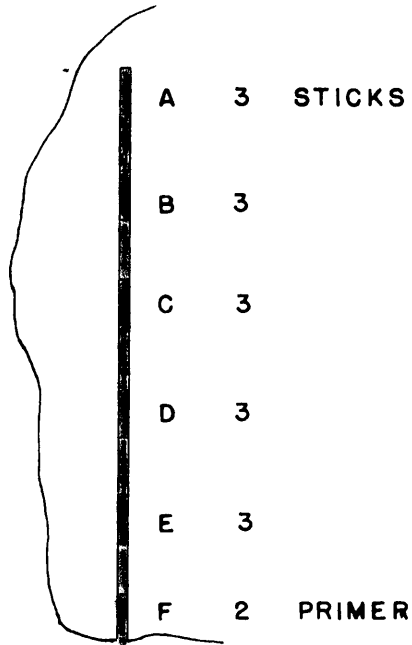


PLATE 14

LENGTH - 15.0'
DIAMETER - 2"
STEMMING - PERLITE
EXPLOSIVE - GELEX NO. 2

HOLE NO. 10
HORIZONTAL SECTION
SCALE: 1" = 5'

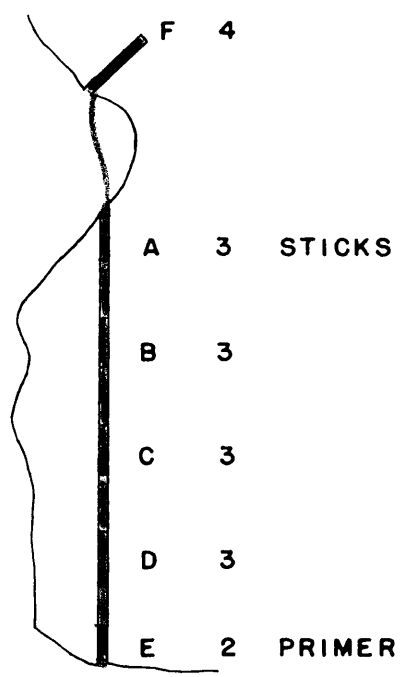


PLATE 15

LENGTH - 12.0'
DIAMETER - 2"
STEMMING - PERLITE
EXPLOSIVE - GELEX NO. 2

HOLE NO. 11
HORIZONTAL SECTION
SCALE: 1" = 5'

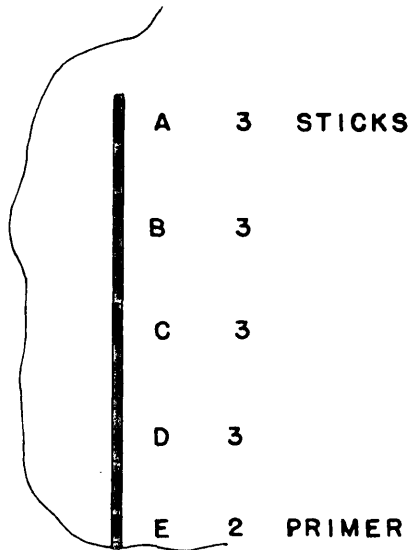


PLATE 16

LENGTH - 12.0'
DIAMETER - 2"
STEMMING - PERLITE
EXPLOSIVE - GELEX NO. 2

HOLE NO. 12
HORIZONTAL SECTION
SCALE: 1" = 5'

TOP



PHOTO. 5

A - LEFT DRIFT

GROUP NO. IV

Group V

Group V was drilled in the right rib of the A-Left drift at Section B. The three holes were detonated simultaneously, using Primacord to connect only the primers in each hole. Some trouble was encountered by the crew loading these 40-ft holes. Parts of the holes were not loaded because the first charge of explosive became lodged in the hole without reaching the bottom. The primers in each hole were connected with Primacord and the holes detonated simultaneously.

Hole No. 13 was loaded as shown and blasted. All the charges in the hole were detonated. The number of cartridges of explosive was increased because a less powerful explosive, Gelex No. 3 (40%), was used.

Hole No. 14 was loaded as shown and blasted. Charge A was not detonated. Failure may be attributed to a stemming distance slightly greater than 18 in. and the use of a less powerful explosive. (Fig. 3 is based on experiments using Gelex No. 2 (45%)). Also, the burden on this hole varied from 2 ft to the excessive amount of 4 ft.

Hole No. 15 was the final hole drilled during the experiments. It was loaded with Gelex No. 3 (40%) as shown and blasted. All charges in the hole were detonated.

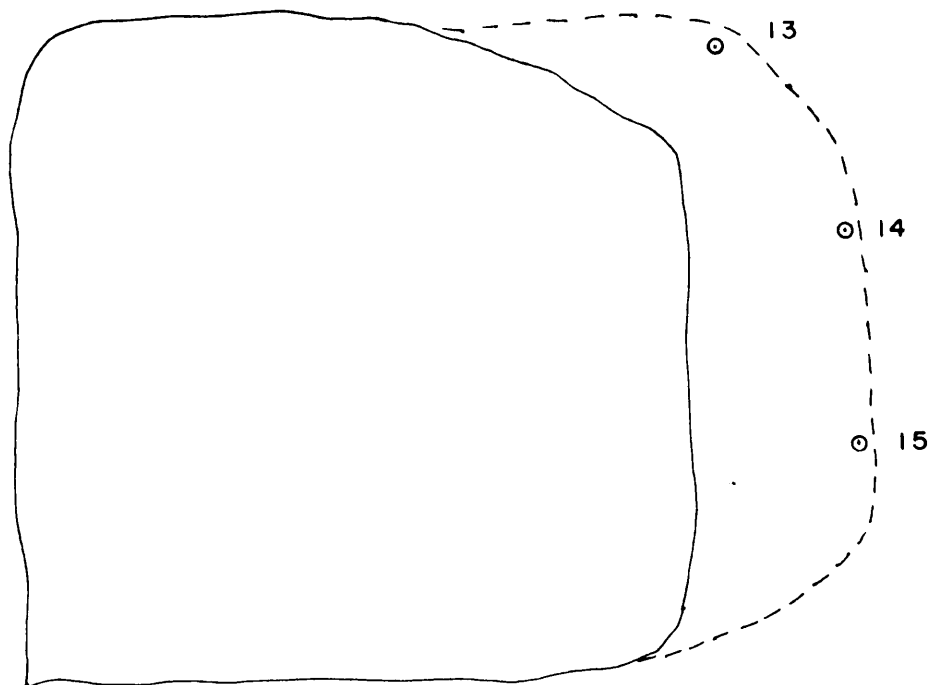


PLATE 17

A - LEFT DRIFT
SECTION "B"

GROUP NO. V
VERTICAL SECTION
SCALE: 1" = 2'

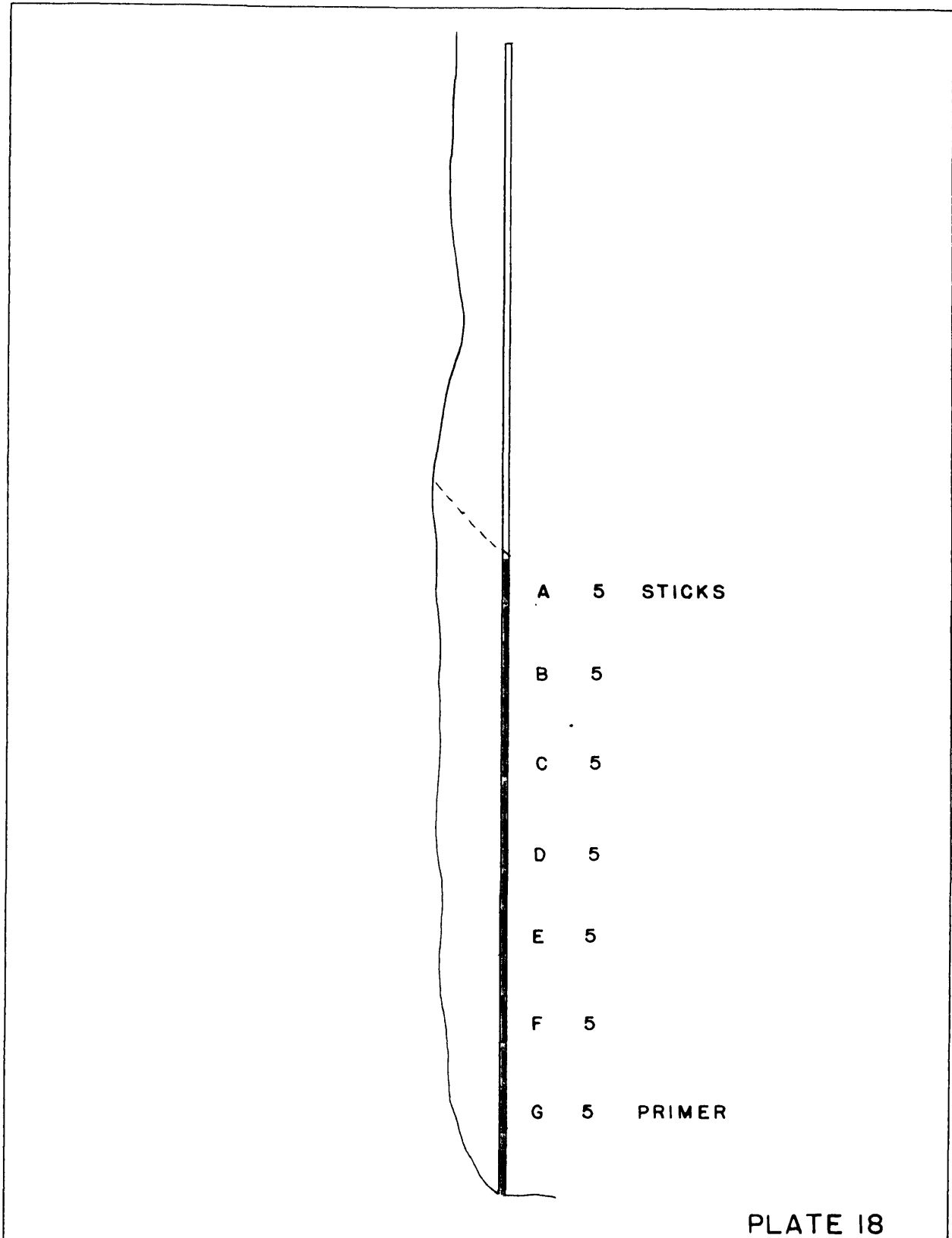
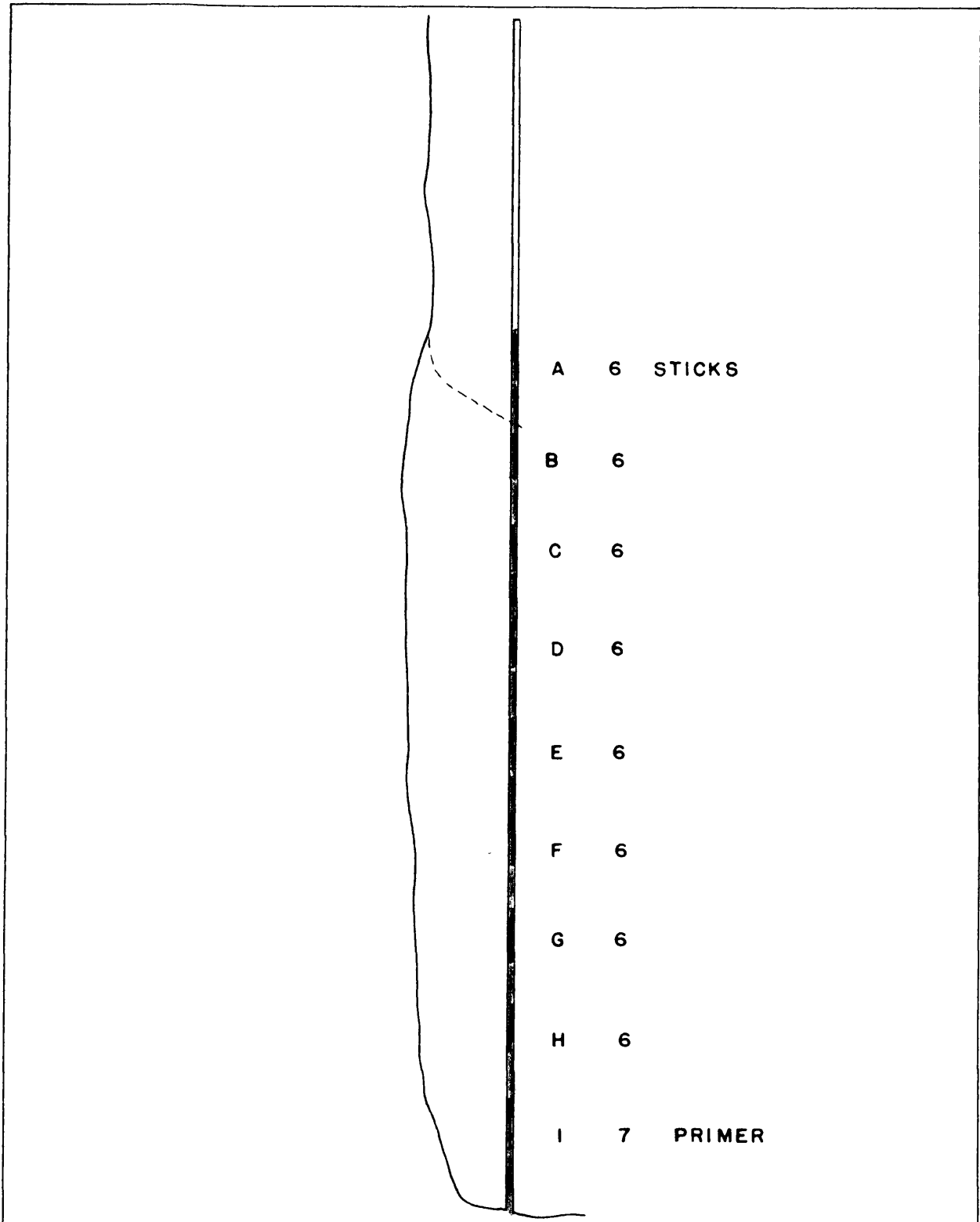


PLATE 18

LENGTH - 40.0'
DIAMETER - 2"
STEMMING - PERLITE
EXPLOSIVE - GELEX-NO. 3

HOLE NO. 13
HORIZONTAL SECTION
SCALE: 1" = 5'

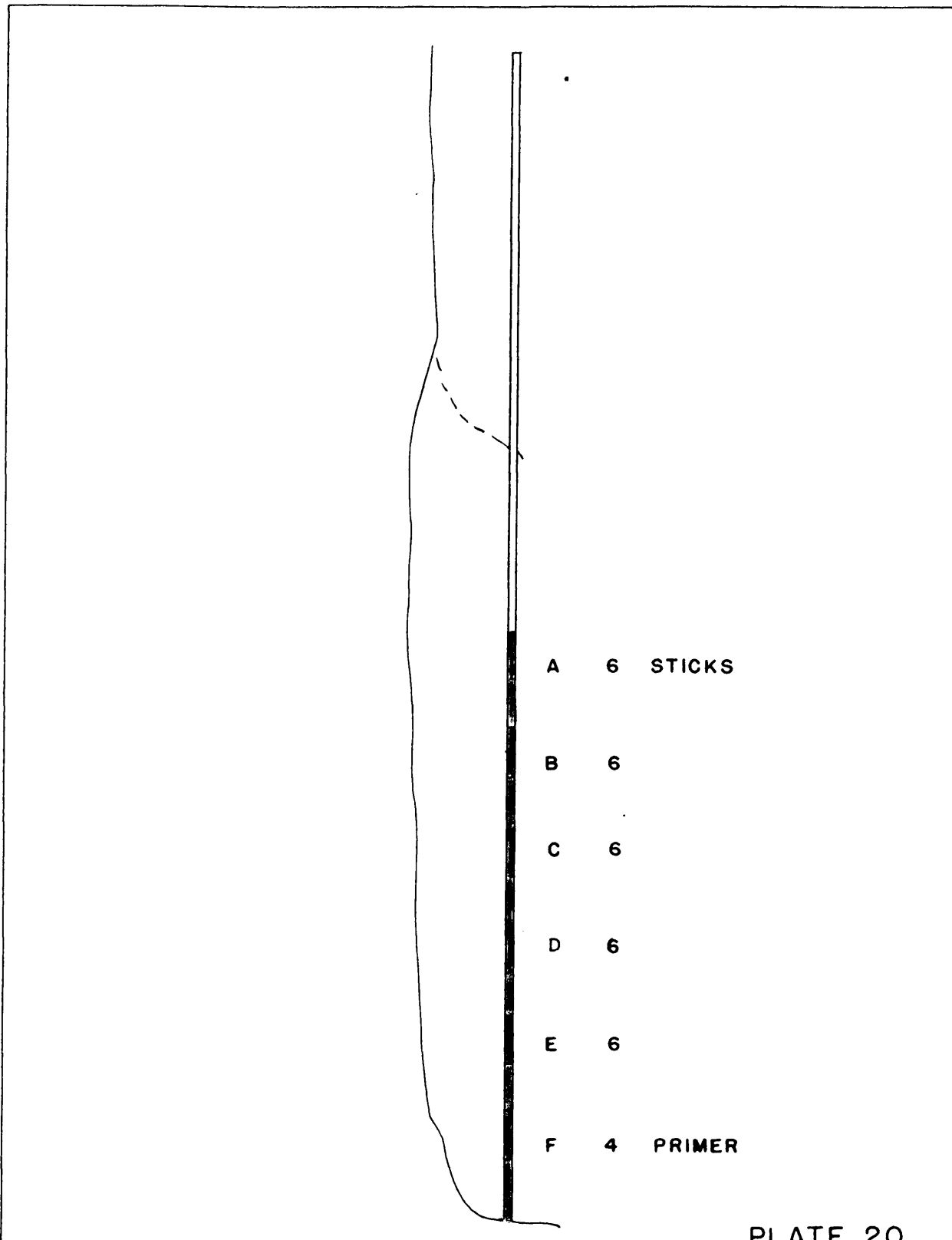


4'

PLATE 19

LENGTH - 40.0'
DIAMETER - 2"
STEMMING - PERLITE
EXPLOSIVE - GELEX NO. 3

HOLE NO. 14
HORIZONTAL SECTION
SCALE: 1" = 5'



A 6 STICKS
B 6
C 6
D 6
E 6
F 4 PRIMER

PLATE 20

LENGTH - 40.0'
DIAMETER - 2"
STEMMING - PERLITE
EXPLOSIVE - GELEX NO. 3

HOLE NO. 15
HORIZONTAL SECTION
SCALE: 1" = 5'

CONCLUSIONS

From the results of the experimental work, the following conclusions have been drawn:

1. Sympathetic detonation will occur in long bore holes where the length and type of stemming, diameter of hole, and type of explosive are carefully controlled. Detonation occurred in up to 9 consecutive charges of explosive in a single 40-ft hole.

The failure of Charge A in hole No. 3 suggests two possible conclusions: either that the length of stemming should exceed the burden (Presanis, 1953), or that the length of stemming approached the critical length (Kabbani, 1954).

The failure of Charge A in hole No. 14 was attributed to the use of slightly more than 18 in. of stemming and the use of a less powerful explosive. The critical length of stemming for Gelex No. 3 (40%) was not available.

Also the amount of explosive must be sufficient to break the rock in the burden. There are

limits on the amount of burden on any one hole, as the amount of explosive that can be loaded into a hole is limited. For example, a 2-in.-diameter hole will hold 1.5 lb of Gelex No. 2 per ft of hole or 1.4 lb of Gelex No. 3 per ft of hole (Du Pont, 1949, p. 423).

2. The use of deck-loaded long holes results in an effect similar to that produced by millisecond-delay caps in drift rounds. The stemming between charges provides a microsecond delay in the detonation of the adjacent charge. Excellent fragmentation of the rock was obtained with a minimum of explosive (See Photo 1), whereas in general mining practice the amount of explosive in the hole is increased in an effort to obtain good fragmentation.

Theoretically, it appears that sympathetic detonation would continue indefinitely down a long bore hole. Each charge would detonate the adjacent charge, essentially just as a primer detonates an adjacent charge. Practically, however, the length of the bore hole is limited because of drilling and loading problems.

Since the actual cause of sympathetic detonation is important in determining the limits of its use, a brief summary of possible causes is presented

below. No attempt is made to present a complete theory on the causes of sympathetic detonation, since the available information is by no means conclusive. Suggestions for further work are made under "Future Investigations."

From Fig. 3 it may be concluded that a medium of low density permits sympathetic detonation more readily than a dense medium. Therefore, it seems that a substance such as vermiculite or roasted perlite gives the best all-round results when used as a stemming material in actual practice.

According to Fig. 3, the heat insulating materials such as perlite, vermiculite, and rock wool allowed sympathetic detonation over distances greater than those possible with sand, mill tailings, and drill cuttings. This fact indicates that a rapid transfer of great amounts of heat does not in itself produce sympathetic detonation. However, it is possible that it is not the insulating effect of these materials, but rather their lower density which is important in reflecting the shock wave (see below).

Fig. 3 also shows that the smaller the diameter of the hole, the greater the distance through which detonation will occur with a given stemming

material. This indicates that the detonation depends on the intervening volume of stemming.

If the shock wave alone is the controlling factor, it would be logical that the velocity and intensity of that wave would be greater in a more dense medium, such as the surrounding country rock, than it would be in the less dense stemming material. Regardless of the degree of tamping of the stemming (and no effort was made in these experiments to tamp the stemming hard), its density would be less than that of the rock surrounding the bore hole. But Presanis (1953, p. 54) has shown that as little as 6 in. of country rock is sufficient to prohibit sympathetic detonation between charges in adjacent holes.

This situation may be explained by the results of tests which show that a detonation wave is reflected by a rigid wall (Eyring, et al., 1949, p.160). Although these tests were confined to the detonation wave within a cartridge of explosive, a similar reflection of the shock wave would occur.

The author feels that sympathetic detonation may result from a combination of shock, heat, and possibly other results of detonation which have not been mentioned. A certain compression of the adjacent charge, which undoubtedly occurs, may cause

the explosive to become more sensitive and susceptible to detonation. Also, a velocity may be imparted to the stemming material itself which then bombards the explosive in place and causes a further sensitivity.

A full and complete explanation of the nature and cause(s) of sympathetic detonation in bore holes must be found if this detonation is to be controlled and its occurrence predicted.

Applications

There are two practical applications of sympathetic detonation in long bore holes.

1. Long holes are used now in many types of stoping such as sublevel stoping and shrinkage stoping. Pillars may be recovered in open stopes and block undercutting completed in block caving by using long holes (Gardner-Denver, 1954). In stoping, a low powder factor (lb of explosive per ton of rock broken) is desirable. The use of stemming, as in these experiments, would reduce explosive consumption to 40 to 50% of that used when long holes are loaded entirely with explosive. In stoping, this saving might be sufficient to warrant dependence on sympathetic detonation, despite the possibility of an occasional misfire.

2. Another application of deck-loaded long holes is the enlarging of development openings, such as the drift in which these experiments were performed. A slabbing round of three or four long holes will widen a drift 2 to 4 ft over any length practical for drilling and loading. Care must be exercised where fractured rock is present so that the holes are not closed by ground movement resulting from near-by blasts. Drilling should be done

Applications

There are two practical applications of sympathetic detonation in long bore holes.

1. Long holes are used now in many types of stoping such as sublevel stoping and shrinkage stoping. Pillars may be recovered in open stopes and block undercutting completed in block caving by using long holes (Gardner-Denver, 1954). In stoping, a low powder factor (lb of explosive per ton of rock broken) is desirable. The use of stemming, as in these experiments, would reduce explosive consumption to 40 to 50% of that used when long holes are loaded entirely with explosive. In stoping, this saving might be sufficient to warrant dependence on sympathetic detonation, despite the possibility of an occasional misfire.

2. Another application of deck-loaded long holes is the enlarging of development openings, such as the drift in which these experiments were performed. A slabbing round of three or four long holes will widen a drift 2 to 4 ft over any length practical for drilling and loading. Care must be exercised where fractured rock is present so that the holes are not closed by ground movement resulting from near-by blasts. Drilling should be done

for only one blast at a time. Loading should be carried out only by experienced crews. A disadvantage of these slabbing rounds is the usual necessity of trimming rock left at the bottom of a round, along the rib. The usual lifter hole in a drift round is drilled at an angle to remove this rock, but long holes should be drilled along the bearing and inclination of the drift to avoid excessive burden at the end of the hole.

Future Investigations

In the field, a long-range program of stoping using deck-loaded long holes would prove on a comparative cost basis the practical value of the method. The cost of filling tamping bags with the stemming material would have to be considered in such a program.

In regard to the theory of detonation, Eyring (1949, p. 179) says: "It is evident . . . that the complete theory of initiation by impact must wait upon a thorough theoretical and experimental program of study" Because this is also true of sympathetic detonation, the following investigations would add to the knowledge of the nature and causes of sympathetic detonation, and to the ability to control it.

A basic study should be begun to determine the heat- and shock-transmitting properties of various stemming materials in bore holes. The products of detonation are fairly well known (Livingston, 1951). A study of a section of a bore hole containing stemming would determine which of these products could influence an explosive through that stemming.

The amount of energy required to detonate an explosive can be determined, as can the velocity of

the detonation wave (Eyring, et al., 1949, p. 93). This amount of energy must be allowed to pass through the stemming in order to detonate an adjacent charge of explosive.

Further tests of various stemming materials, hole diameters, and explosives would provide the basis for development of an empirical formula relating these factors to the length of stemming through which sympathetic detonation will occur. Such a formula would be helpful in the practical application of sympathetic detonation to mining problems.

Recent investigations of sympathetic detonation have been largely of a practical and applied nature. A study of the basic chemical and physical actions involved seems to be the next step. Once its true cause is known, sympathetic detonation can be successfully controlled in bore holes.

BIBLIOGRAPHY

- Bateman, A., 1950, Economic mineral deposits:
New York, John Wiley & Sons.
- Carmichael, R., 1952, The application of the
Livingston theory of rock failure in blasting
to the design of a new type of drift round:
Colorado School of Mines, Doctor's Thesis, 740.
- E. I. Du Pont de Nemours & Co., 1949, Blasters'
handbook: Wilmington, Del.
- Eyring, H., Powell, R., Duffey, G., Parlin, R.,
1949, Stability of detonation: Chem. Revs. 45.
- Gardner-Denver Co., 1954, Deep hole percussion
drilling: Quincy, Ill.
- Gray, A., 1952, New types of drill rounds for
development openings: Colorado School of
Mines, Master's Thesis, 744.
- Kabbani, F., 1954, Application of the crater theory
and sympathetic detonation in mining: Colorado
School of Mines, Doctor's Thesis, 799.
- Livingston, C., 1951, An introduction to the design
of underground openings for defense; Colorado
School of Mines Quarterly, 46, 1.
- Presanis, A., 1953, A study of sympathetic detonation:
Colorado School of Mines, Master's Thesis, 767.