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A study of the effect of jointing on the blasting of granite, Graniteville, Missouri

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A STUDY OF THE EFFECT OF JOINTING ON THE BLASTING OF GRANITE
GRANITEVILLE, MISSOURI

BY

AVERY ALA DRAKE, JR.

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE, MINING ENGINEERING,

MINING GEOLOGY OPTION

Rolla, Missouri

1952

Approved by - J. D. Forrester
Professor of Mining Engineering

ACKNOWLEDGMENTS

I am grateful to the many individuals whose generous aid and cooperation made this study possible. Dr. J. D. Forrester, Chairman, Department of Mining Engineering, suggested the problem, supervised it, and critically read the manuscript. The management of the A. J. Sheahan Granite Quarry granted free access to their property. Mr. Dan N. Miller, now Geologist, Stanolind Oil and Gas Company, and Mr. I. L. Propst, now Engineer, Monsanto Chemical Company, served as rodmen during various phases of the work. Mr. Fred Brackeen, Project Driller, and his assistants cooperated in every way possible. I am particularly grateful to Mr. Harve P. Nelson, formerly Research Fellow in Mining Engineering, for his wholehearted assistance during the course of this study.

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INTRODUCTION

Purpose of investigation:

The purpose of this investigation is to attempt to determine the influence that joints exert upon the blasting of granite and if joints are induced by blasting. The problem grew out of an explosive evaluation project that was conducted by the Mining Department, Missouri School of Mines. In late May 1950, the project was moved into the granite area near Graniteville, Missouri. It became apparent upon study of this area that the jointing would have certain effects upon the results obtained. Dr. J. D. Forrester, Chairman, Department of Mining Engineering, Missouri School of Mines, Rolla, Missouri, suggested that the writer undertake this study. The management of the Sheahan Granite Quarry, upon whose property the test area is located, had expressed a concern as to what effect the blasting would have upon their dimension stone operation. A close check was made upon all joints to determine if the shock waves of the blasting were reopening them, and to check the area for any new joints that might have been induced.

Conditions under which work was done:

Field work was completed during the summer and early fall of 1950. Necessary thin section work was conducted in the petrography labratory, Geology Department, Missouri School of Mines.

SUMMARY OF PREVIOUS WORK

Although much has been written of the blasting of granite and other rock, and quarrying in general, the writer could find no previous works of the scope of this report. Harris(1) suggests that a good quarrymaster should study the area to be blasted and endeavour to find all cracks and joints before placing his holes. Daw and Daw(2) reccommend that the shot holes be placed so as to make the greatest use of the joints as free faces. Howe(3) states that for the greatest convenience in quarrying, joints should neither be so near together as to break up the rock into blocks too small to use nor so far apart as to render the abstraction of large blocks a

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(1) Harris, George F., Granite and Our Granite Industries, cited by Daw, A. W. and Daw, Z. W., The Blasting of Rock, London E. & F. N. Spon, Ltd., 2nd Edition, 1909, pp 1-2.

(2) Daw, A. W. and Daw, Z. W., The Blasting of Rock, London E. & F. N. Spon., Ltd., 2nd Edition, 1909, pp 97-98.

(3) Howe, J. A., The Geology of Building Stones, London, Edward Arnold, 1910, p 53.

difficulty. Gillette(4) states that: "Igneous rocks, while not possessing bedding planes, also have vertical joints, cutting at about right angles in most cases; but these joints are seldom so regular in spacing as in sedimentary rocks. In certain trap rocks the joints cause the rock to break out in vertical columns, often of great regularity; and in some cases the joints are so close together that upon firing the blast the rock comes down in chunks not much larger than a man's head, even where very little explosive is used; but, on the other hand, certain traps break up in very large chunks on blasting". Gillette(5) further states: "If the joints are close together it will, of course, be impossible to quarry building blocks; though, on the otherhand, the quarrying of stone to be crushed for concrete or macadam is greatly facilitated by numerous joints. Bowles(6)

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(4) Gillette, H. P., Handbook of Rock Excavation, New York, McGraw-Hill, 1916, p 5.

(5) <u>Ibid</u>., p 541.

made the following observations on joints and their relation to marble qurrying: "The most important feature of joints in relation to channeling is their occurrence in more or less definite systems. The importance of recognizing such systems and quarrying in accordance with them can scarcely be overestimated. In quarries in which joints are prominent the quarrymen should endeavor to make their channel cuts parallel with the chief joint systems. Blocks that are intersected by oblique joints are almost useless. If, on the other hand, the joints parallel one pair of faces, the waste is greatly reduced". In a later publication, Bowles (7) recommends that joint seams be utilized to the highest extent in order to lower expenses. Also, he states that if the joint seams are not present, it is necessary to blast artifical breaks to facilitate quarrying. Young (8) gives

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(6) Bowles, Oliver, The Technology of Marble Quarrying, U. S. Bureau of Mines, Bull. 106, 1916, p 61.

(7) Bowles, Oliver, The Granite Industry Dimension Stone, U. S. Bureau of Mines, Information Circular 6268, 1930, pp 5-6.

the following as the physical characteristics of rock that effect its breakability: hardness, toughness, brittleness, softness, plasticity, the presence of bedding planes, sheeting planes, joints, cleat, or rift in the rock mass. Peele(9) mentions the importance of joints and cleavage planes in quarrying dimension stone and rubble. The most exhaustive treatment of granite and granite quarrying is presented by Dale.(10) He presents both a scientific and an economic study of the New England granites including their petrography, structure, physical and chemical properties, and use. He discusses also, the active and inactive quarries of the region, their quarrying methods, and their finishing and transportation facilities.

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(8) Young, George J., Elements of Mining, New York, McGraw-Hill, 1946, p 121.

(9) Peele, Robert, Mining Engineers Handbook, New York, Wiley, 1948, pp 5-23 - 5-25.

(10) Dale, T. N., The Commercial Granites of New England, U. S. Geological Survey, Bulletin 738, 1923, 488 p.

DESCRIPTION OF THE TEST AREA

Location:

The test area was located about 300 yards northwest of the Sheahan Dimension Stone Quarry in the NW¼ of the NW¼ of Section 14, T34N, R3E, near Graniteville, Iron County, Missouri. The granite outcrop consists of an elongated hill or ridge one and three-fourths miles long and one-fourth to three-eights of a mile wide. The Bonneterre dolomite of Cambrian age flanks the granite on all sides except the northeast. The granite rhyolite porphyry contact occurs to the northeast.

Previous work in the area:

In 1895 Haworth (11) reported on the crystalline rocks of Missouri. He discussed the general geology of the pre-Cambrian area, classified the eruptive rocks, and described each exposure in limited detail. In 1896, the report areal geology of the Iron Mountain Sheet was published. (12) In this report the Graniteville area is

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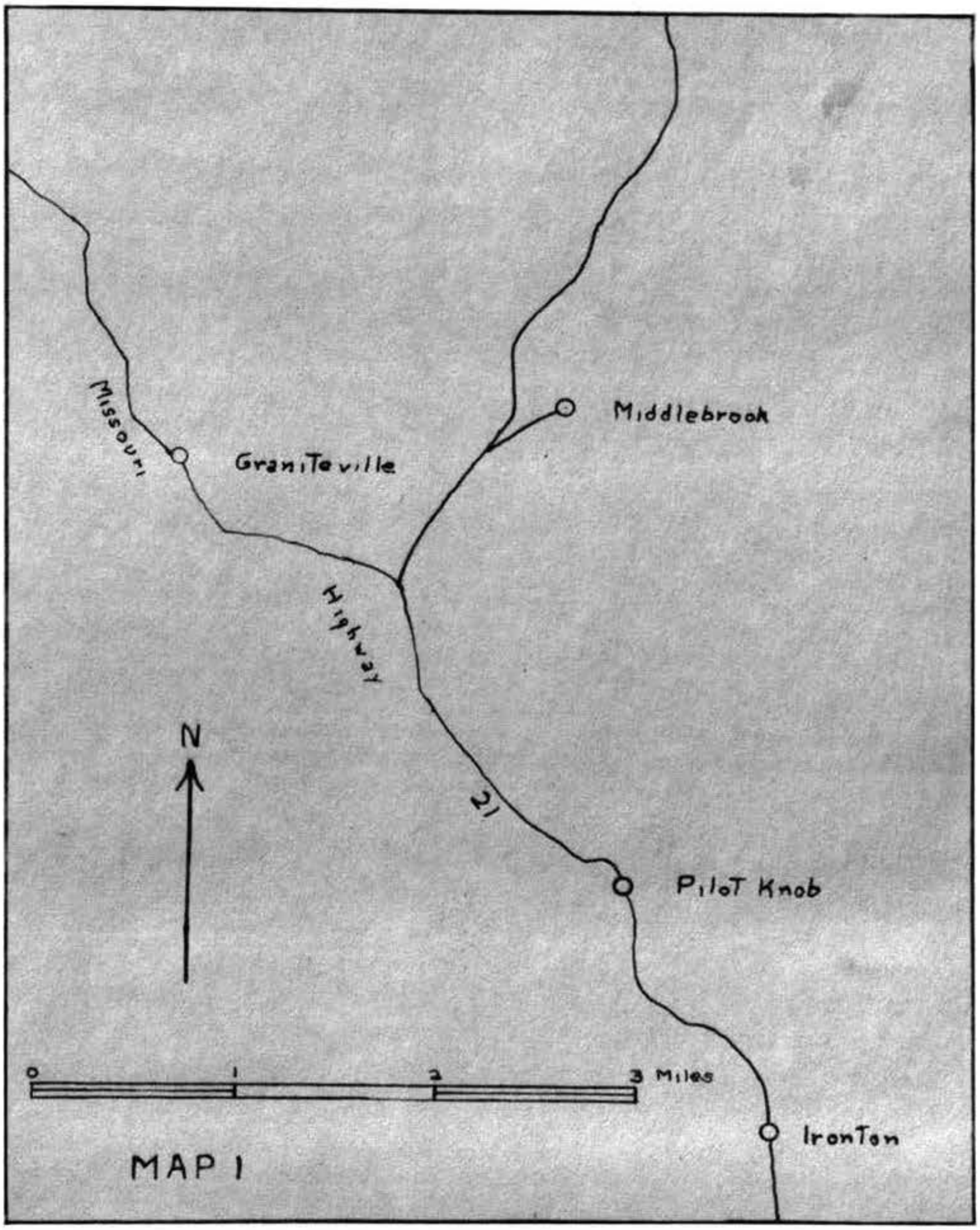
(11) Haworth, Erasmus, Crystalline Rocks of Missouri, Missouri Geological Survey, Annual Report for 1894, Vol. 8, 1895, pp 84-220.



GRANITEVILLE, MISSOURI AND VICINITY

described briefly, as well as the quarries in the vicinity. The Graniteville area was discussed and the quarries described in detail by Buckley and Buehler in their report on the Quarrying Industry of Missouri.(13) Tolman(14) and Goldich reported on the petrography and and petrology of the present Sheahan quarry in their paper of 1935. Branson(15) mentions the Graniteville area in his brief analysis of the Missouri pre-Cambrian. He

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(12) Winslow, A., Haworth, E., and Nason, F. L., A Report on the Iron Mountain Sheet, Missouri Geological Survey, Reports on Areal Geology (Sheets 1-4), Vol. 9, 1896, 75 p.

(13) Buckley, E. R. and Buehler, H. A., The Quarrying Industry of Missouri, Missouri Bureau of Geology and Mines, Vol. 2, 2nd Series, 1904, pp 66-74.

(14) Tolman, C. and Goldich, S. S., The Granite, Pegmatite, and Replacement Veins in the Sheahan Quarry, Graniteville, Missouri, The American Mineralogist, Vol. 20, No. 4, pp 229-239, (1935).

(15) Branson, E. B., Geology of Missouri, Columbia, University of Missouri, 1944, pp 13-14.

also mentions the granite industry in his treatment of the economic geology of the state.(16)

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(16) Ibid., p 387.

The granite:

The granite is the so-called "Missouri Red Granite". It has some economic importance as dimension and monument stone. The rock is of pre-Cambrian age and is a tight, uniformly textured, crystalline rock. It is composed of about 96 per cent feldspar and quartz. The feldspar includes two generations of albite, microcline, and orthoclase. Both microcline and orthoclase are intergrown with albite forming several types of perthite. Accessory minerals, some of which are secondary products, include apatite, biotite--largely altered to chlorite, fluorite, magnetite, hematite, muscovite, and zircon. The rock is properly a Johannsen Kalialaskite (1,1,5).(17)

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(17) Johannsen, Albert, A Descriptive Petrography of the Igneous Rocks, Vol. I, Chicago, University of Chicago, pp 140-158 (1931).

The biotite occurs in narrow bands parallel to the major system of jointing. This is an important feature in the

FIGURE 1

Photomicrograph of Granite

Showing textural relations. x 8 x nichols interpretation of the jointing of the area and will be treated later. The chemical composition and physical properties of the granite are listed respectively in TABLES I and II. Pegmatitic phases of the granite occur in a number of places in the Sheahan Quarry. One of particular note is exposed on the upper bench of the north face of the quarry, near its western edge. The writer did not study the pegmatite in detail, but noted the presence of topaz and beryl. Tolman (18) and Goldich in their study state that both the magmatic and hydrothermal stages of mineralization were present. The magmatic stage was represented by perthite and quartz; hydrothermal minerals present include topaz, muscovite, albite, beryl, biotite, rutile, cassiterite, sericite, fluorite, pyrite, chalcopyrite, and galena. Tolman (19) and Goldich also describe replacement veins and joint veinlets containing quartz, magnetite, muscovite,

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(18) Tolman and Goldich, *Op. cit.*, p 239.

(19) *Ibid.*, p 237.

TABLE I

CHEMICAL ANALYSIS AND CLASSIFICATION OF MISSOURI RED GRANITE FROM SHEAHAN QUARRY,(20) GRANITEVILLE, MISSOURI. S. S. GOLDICH, ANALYST.

	Per Cent	Mol. No.
SiO_2	76.81	1.280
Al_2O_3	12.23	.120
Fe_2O_3	0.52	.003
FeO	0.41	.006
MgO	0.12	.003
CaO	0.98	.018
Na_2O	3.85	.062
K_2O	4.59	.049
H_2O+	0.26	
H_2O-	0.01	
CO_2	0.07	.0016
TiO_2	0.08	.001
ZrO_2	0.02	.0003
P_2O_5	Trace	
S	0.01	
Cr_2O_3	0.00	
MnO	0.00	
BaO	0.01	
F	0.17	.0045
	100.14	
Less O	.07	
	100.07	

Norm	
Quartz	35.14
Zircon	0.05
Orthoclase	27.24
Albite	32.49
Anorthite	2.50
Diopside	1.14
Magnetite	0.70
Ilmenite	0.15
Fluorite	0.35
Calcite	0.16
	99.92

Specific Gravity $26^{\circ}/4^{\circ}$ - 2.607
Class I, Subclass I, Order 4, Rang 1, Subrang, 3
Rock name: LIPAROSE

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(20) Tolman and Goldich, Op. cit., p 232.

TABLE II

PHYSICAL PROPERTIES OF GRANITEVILLE GRANITE (21)

Specific Gravity	2.60
Porosity	1.40%
Compressive Strength	17,000 psi.
Modulus of Rupture	2,270 psi.
Impact Toughness	8 cm.
Modulus of Elasticity (E)	7.72×10^6
Modulus of Rigidity (G)	1.62×10^6

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(21) Nelson, Harve P., An Experimental Evaluation of Explosives in Blasting Limestone and Granite, Ph.D. Dissertation, University of Missouri, Columbia, Missouri.

fluorite, specularite, pyrite, and chlorite. The writer noted one replacement veinlet in his mapping of the test area.

<u>The jointing</u>:

"The joint in the rock, thin as a hair, and straight as a measuring rod, that piece of petrified geometry, promises much, yet discloses little." (22) Many authors in the past have considered joints as simple structures. They are, however, very complex structures even when completely understood. Forrester (23) defines joints as fractures in the earth's crust along which movement has been normal to the fracture surface. For convenience, Nevin (24) has classified joints into two general groups: those caused by tension and those

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(22) Nevin, C. M., Principles of Structural Geology, 4th Edition, New York, Wiley, 1949, p 146.

(23) Forrester, J. D., Field and Mining Geology, New York, Wiley, 1946, p 23.

(24) Nevin, *Op. cit.*, p 147.

MAP 2
EXPLOSIVE TEST AREA

Scale 1"=20'

Contour Interval = 2'

Joints

resulting from shear. These groups do not indicate the type of applied force. Forrester(25) presents a more workable classification, in which he classifies joints by the type of stress that developed them. Cloos(26) classifies joints by their relation to the flow structure in rock (see TABLE III). The test area at Graniteville is characterized by one major system of joints. The joints of this system vary in strike from N 60° E to N 70° E, averaging N 65° E. Their dips are nearly vertical, ranging from 80° SE to 80° NW. These joints are known locally as "rift seams", as the granite breaks best along planes parallel with them. As the strike of these joints and the slope of the hill correspond, they have served as water courses. Weathering has greatly accentuated them. The above mentioned linear parallelism of the biotite is the crucial factor in classifying the

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(25) Forrester, *Op*. *cit*., p 23.

(26) Cloos, Hans, Uber Ausbau und Anivendung der Granittekonischen Methode, cited by Balk, R., Structural Behavior of Igneous Rocks, New York, Geological Society of America, 1937, pp 27-42.

TABLE III

NOMENCLATURE OF PRIMARY JOINTS AND ARTIFICAL PARTING PLANES (27)

Natural Joint Systems

Q - Cross joints (German-Querklufte), those joints striking essentially at right angles to the trend of the flow lines.

S - Longitudinal joints (German-Spaltseite), steeply dipping joints, coinciding in strike with the trend of the flow lines.

L - Primary flat joints (German-Lager), flat-lying joints, embracing the flow lines.

Artificial Parting Planes

k - Hardway planes (German-Kopfseite), steep planes, generally at right angles to the flow lines, along which the rock is harder to split than in any other direction.

s - Rift planes (German-Spaltseite), steeply dipping planes, coinciding usually with the strike of the flow lines; along them, the rock splits most readily.

l - Bedding, or sheeting planes (German-Lager), flat-lying primary planes of parting, which may or may not, embrace the flow lines. Ease of splitting is as good, or better than, the rift. In the latter case, the steep planes of good splitting are called "grain".

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(27) Ibid., p 34.

of the area. The joints parallel the linear streaks of biotite, and therefore, are the longitudinal joints of Cloos (see TABLE III). The mode of formation of longitudinal joints is not well understood. "As flow lines introduce an element of mechanical weakness into the rock fabric, it stands to reason that fractures that embrace the lines will form relatively easily."(28) The writer believes, in this case, that they are due to the contraction of the cooling granite. The above mentioned pegmatite has filled a joint of this longitudinal system. This proves that the joint was present early enough to serve as a channelway for the pegmatite forming solutions. A second poorly developed joint system was found striking at almost right angles to this major system. These joints dip steeply; varying from 80° E to 80° W. They have rougher faces than the major system and are limited in linear extent. As they are essentially normal to the linear parallelism, the writer chooses to classify them as the cross joints of Cloos (see TABLE III). Flow lines represent the direction of maximum lengthening, thus, the

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(28) Balk, Robert, Structural Behavior of Igneous Rocks, New York, Geol. Soc. Amer., p 35, (1937).

direction of maximum compression lies within the plane of cross joints, normal to the elongation. Cross joints, therefore, are the equivalent of tear fractures or tension joints that are obtained in compression tests.(29)

Flat-lying bedding plane or sheeting joints occur sporadically. They lie practically horizontal, and they have served as water courses. They are an inch or more in width in numerous places and are often filled with clay. The bordering rock is badly weathered. The origin of such joints is a controversial issue. Dale(30) cites the theories of a number of authors. The two most logical hypothesis are as follows: (1). Dale(31) and others have found that many granites have remained under compressive stress. Sheet joints have been determined by

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(29) Balk, *Op. cit.*, p 31.

(30) Dale, *Op. cit.*, pp 33-35.

(31) *Ibid.*, p 34.

them to be the result of this stress. (2). There is an undoubted sheeting effect of expansion under solar heat within a short distance of the surface. It is possible that the thin surface sheets have originated in this way.(32) At the surface both causes may have cooperated.

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(32) Ibid., p 35.

Artifical planes of parting:

The artificial planes of parting have been denoted as rift, grain, and hardway. They are quarrymen's terms for the planes, approximately at right angles to one another, along which the stone fails under tension most readily, with a medium ease, and with the most difficulty, respectively.(33) These planes may often be determined by

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(33) Osborne, F. F., Rift, Grain, and Hardway in some Pre-Cambrian Granites, Quebec, Econ. Geol., Vol. 30, p 541, (1935).

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the megascopic inspection of a hand specimen or somewhat weathered outcrop. At times, however, it is necessary to test the directions. Osborne(34) suggests that this is best done by blasting a single unreamed hole with black powder in a block equally free on all sides. Often it is only necessary to break the rock with a sledge. The writer was unable to see these planes; so he checked the directions by breaking oriented blocks of granite with a sledge. It was found that the rift paralleled the major joint system of the area, N 65° E, the hardway paralleled the cross joints, N 25° W, and the grain was essentially parallel to the sheeting. This parallelism is not found in all eruptive rocks. Many investigators have attempted to determine the cause of the rift direction. Various authors have attributed this phenomenon to: crystalline action at the time of consolidation, local differences in cohesion, a parallelism of the cleavage planes of the feldspars, original arrangement of the particles by flowage, pressure from only one side that did not find adequate relief in jointing. A primary effect of compressive strain, microscopic faults that follow the feldspar cleavage, fluid inclusions, cracks in the feldspars, cracks in the

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(34) Ibid., p 541.

quartz, and to the parallel arrangement of the micas. The writer believes that any of the above are correct for the rock in which they were studied, but that none apply for granite in general. It appears that the rift direction in the granite of the test area is due to slight linear parallelism, as the direction of the longitudinal joints and the rift coincides. The writer feels that a petro-fabric study by a qualified observer must be made before any definite conclusions are made. The grain is produced by any of the above methods that are less perfectly developed than those forming the rift. The hardway is determined by the attitude of the other two planes.

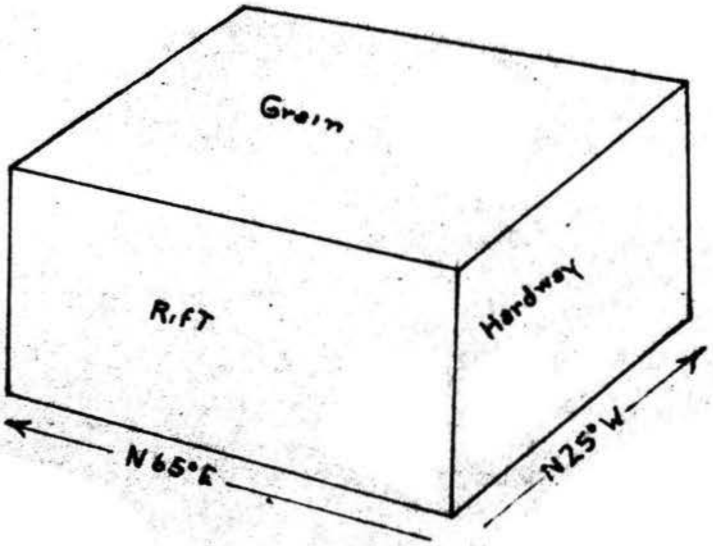


FIGURE 2

Diagram showing the relation of the artifical parting planes in the granite of the test area.

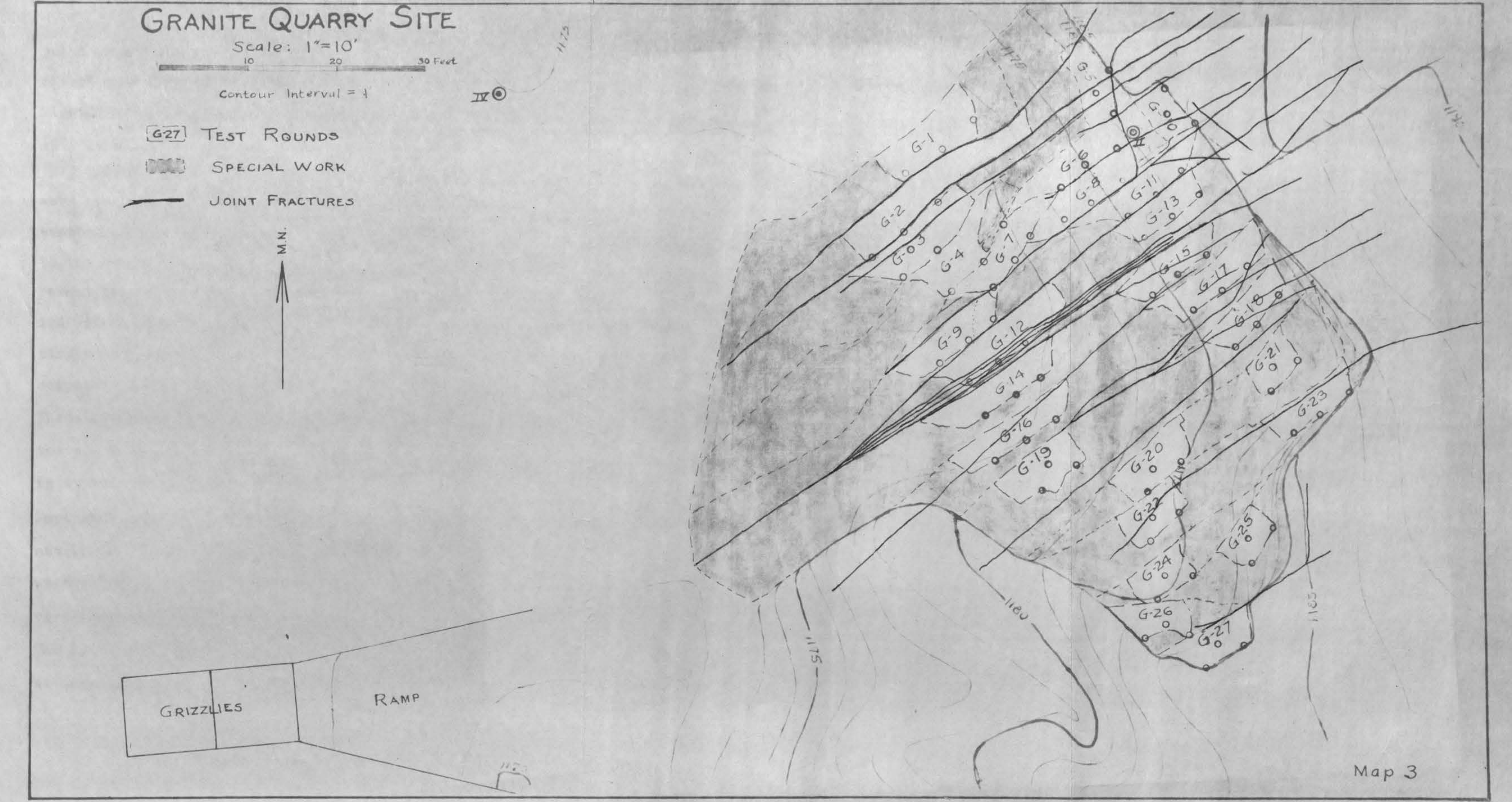
METHOD OF STUDY

Mapping:

The topography of the area was mapped with plane table and alidade to a scale of one inch to twenty feet. The contour interval used was two feet. Horizontal control was established by a series of triangulation stations. The elevation of the principal station was established by aneroid barometer. The base reference for the barometer was U.S.G.S. Bench Mark 1926, Middlebrook, Missouri.

The joints of the area were mapped by brunton and tape traverses on field notebook sheets. The starting and end points of the traverses were located previously by plane table and alidade. When the traverses were completed, the information was traced onto the topographic map (see Map 2).

When the test quarry was opened, a new map was made on a scale of one inch to ten feet with a contour interval of one foot. A plane table and alidade was used until September 1, 1950. The remaining surveying was done with transit and stadia rod. After each round was fired, the face was surveyed to determine the area of breakage. Also the shot holes for the next round were located. Sections were then made of the quarry face showing every


GRANITE QUARRY SITE
Scale: 1"=10'
10
20
30 Feet
Contour Interval = 1
IV
G-27 Test Rounds
Special Work
Joint Fractures
M.N.
G-1
G-2
G-03
G-4
G-5
G-6
G-7
G-8
G-9
G-10
G-11
G-12
G-13
G-14
G-15
G-16
G-17
G-18
G-19
G-20
G-21
G-22
G-23
G-24
G-25
G-26
G-27
II
1170
1175
1180
1185
Grizzlies
Ramp

Map 3

joint or induced fracture present. The original joints of the area were then inspected for any reopening that might have resulted from the round.

Interpretation:

After the results of each round were compiled, they were studied to determine the effect that the jointing exerted on the round. As the face sections were all made to the same scale, they were studied in juxtaposition to reveal the extent of the induced fractures. After each individual round was studied, the rounds fired under similar conditions, except for joint patterns, were compared to better interpret the effects of the jointing. Three different drill hole patterns were used in the tests. They are shown in FIGURES 3, 4, and 5. Ideally, in a study of this sort, all conditions should have been kept standard, so that the variances could better be attributed to the joints. This was impossible, as the writer's study was only part of a major undertaking. The variables, such as hole pattern, type of explosive, and the location of the primer, were changed by Mr. Nelson as necessitated by his plan of evaluation.

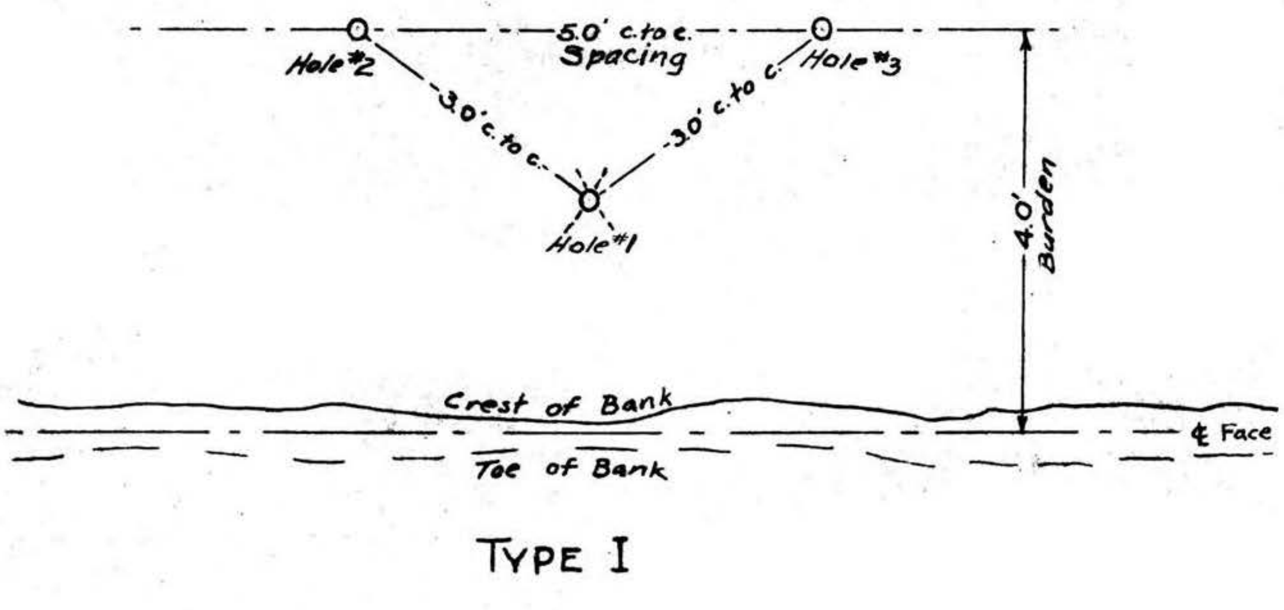


FIGURE 3

Type I Pattern

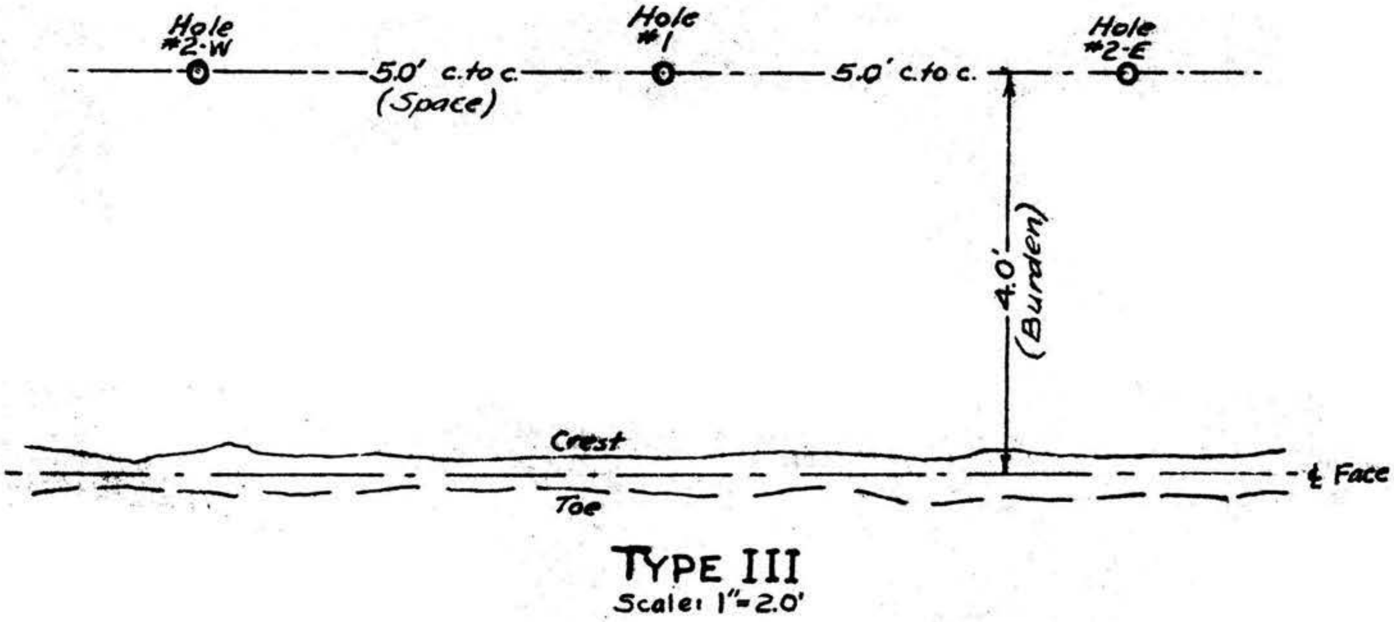
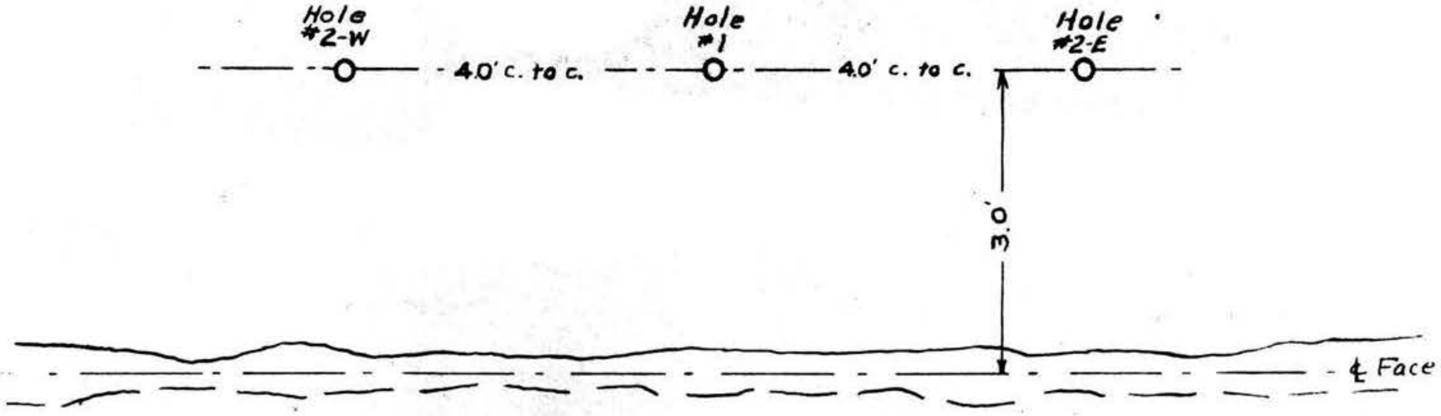


FIGURE 4

Type III Pattern



TYPE VIII
Scale: 1" = 2.0'

FIGURE 5

Type VIII Pattern

FIGURE 6

A typical round as fired at Graniteville. Note the blocky character of the material in the round.

DESCRIPTION OF TEST ROUNDS

Round G-1:

Round G-1 was drilled in Pattern III. It was loaded with the explosive having the highest rate of detonation tested, with the primer in the next to top stick of powder. The round was drilled parallel to and in front of a major longitudinal joint. (See Map 3). The joint dipped 80° northwest so as to intersect the drill holes. It cut the west hole near its bottom, the center hole about half way down, and passed beneath the toe of the east hole. Upon firing, the upper 4.5 feet of the burden broke clean to a sheeting joint. (See FIGURE 7). Below this, the round bootlegged. The longitudinal joint in the bootlegged portion of the ground was reopened considerably, and the rock, in general, was lifted throughout the full depth of the round. It appears that the firing sequence was such that the explosion of the center hole caused displacement along the sheeting joint and displaced the powder column in the other two holes. The upper portion of the round broke back to the longitudinal joint. This joint apparently acted as a free face to allow this overbreak. The results of the round were poor. Yield was low due to the incomplete breakage. Numerous oversize boulders were

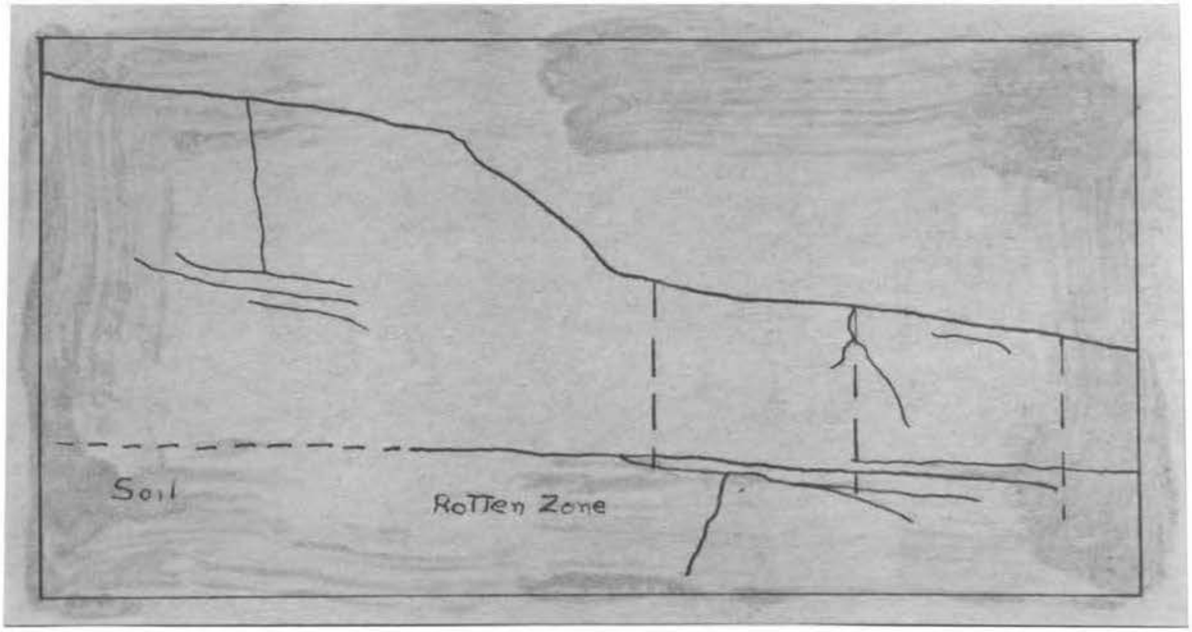


FIGURE 7

Quarry face after Round G-1. Plane of section N 62° E, looking east. The dotted lines are drill holes. Scale 1" = 5' found. A great many of these boulders were rectangular in shape and showed joint planes on two sides. The blocky nature of the oversize was probably due to the intersection of the sheeting and longitudinal joints. Few fractures were induced by this round. Minor fractures were developed around the center drill hole, and in the vicinity of a cross joint 9.5 feet northeast of hole number 2 E.

Round G-2:

The holes of Round G-2 were collared in the surface contact of a longitudinal joint. The joint dipped in such a manner, 84° NW, that the holes progressed away from it in depth. The drill pattern, explosive, and primer location were the same used in Round G-1. The drill hole was increased to 2 inches in diameter to concentrate a greater amount of explosive near the toe of the burden. There was no back-breakage in this round, as it broke cleanly to the longitudinal joint. Considerable overbreak occurred on the wings. The east wing broke for a distance of 8.5 feet beyond the east hole, and the west wing broke 5.4 feet beyond the west hole. The material from the wings was coarse and blocky. The shock on the wing material was much less than that at the center of the explosion, therefore, it appears that the granite failed

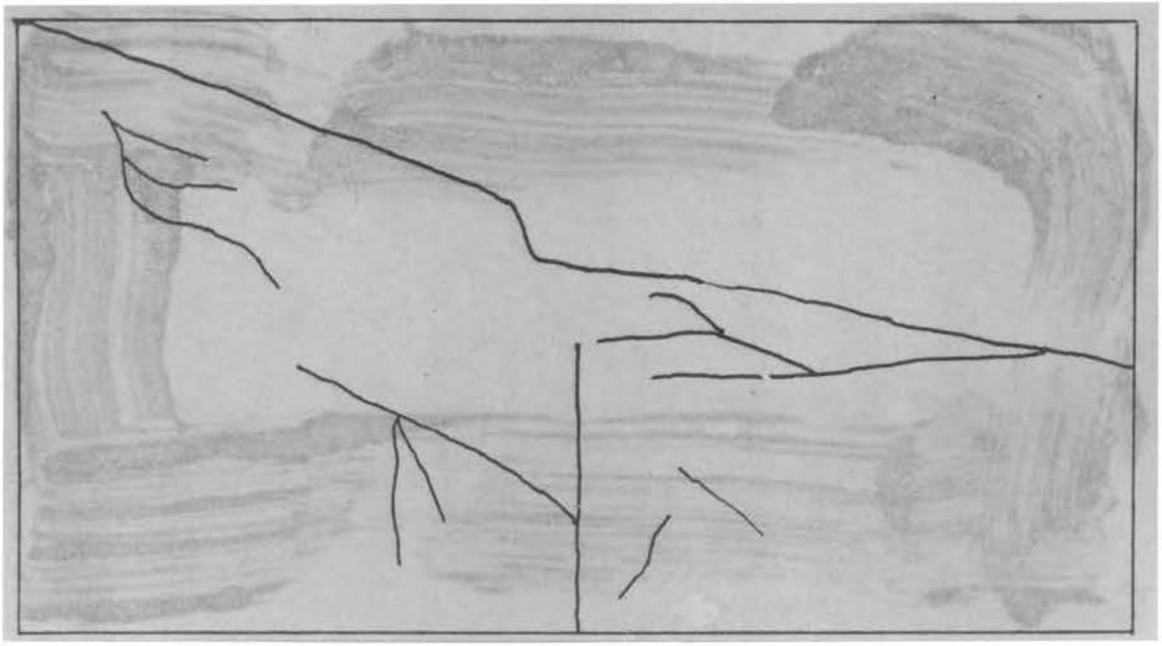


FIGURE 8

Quarry face after Round G-2.
Plane of section N 60° E,
looking East. Scale 1" = 5'

along the artifical parting planes, thus forming the coarse, blocky fragments. Several large blocks were produced also from the upper part of the round between the holes. A sheeting joint was found near the surface, approximately parallel with a line through the tops of the drill holes. The intersection of this sheeting joint and the longitudinal joint produced a block. The writer believes that this block was broken into the smaller fragments, which were in turn pushed off the sheeting plane. Several fractures were induced by this round, the major of which, was a vertical joint that was developed directly behind the center drill hole. The other fractures formed were largely parallel to the surface of of the quarry. These were probably induced along weakness planes in the granite that were produced by concentric weathering. The fragmentation of the round was poor, 49 per cent of the material produced was oversize.

Round G-3:

Round G-3 was drilled in Pattern I. (See FIGURE 3). The drill holes were 1½ inches in diameter. These smaller holes were loaded with about one-half as much explosive (same as in G-1 and G-2) as the preceding rounds. A steeply dipping longitudinal joint was located about one foot northwest of hole 1. It essentially paralleled the pattern. (See Map 3). The west wing of the round broke well at angle of approximately 45 degrees. The east wing broke clean for a distance of seven feet beyond the east hole. At this point, it intersected the above mentioned longitudinal joint. The joint was opened 0.6 feet at the point of intersection. Several fractures were induced by this round. It appears that the joint induced in the previous round did not carry through. A cross joint occupies the approximate position that the induced joint would have had, but the joint was too well weathered to have been of recent origin. The induced fractures carried to the point where the round intersected the longitudinal joint. In the upper right of FIGURE 9, a block has been developed by the intersection of an induced hardway fracture and a sheeting joint. The induced fractures in the left part of FIGURE 9 were developed in squaring up the face. Future boulders were developed by this fracturing. The results of Round G-3 were fairly good.

Round G-4:

The variables in Round G-4 were the same as those in Round G-1. No visible joints cut the area of the round. (See Map 3). On firing, the rock in front of the

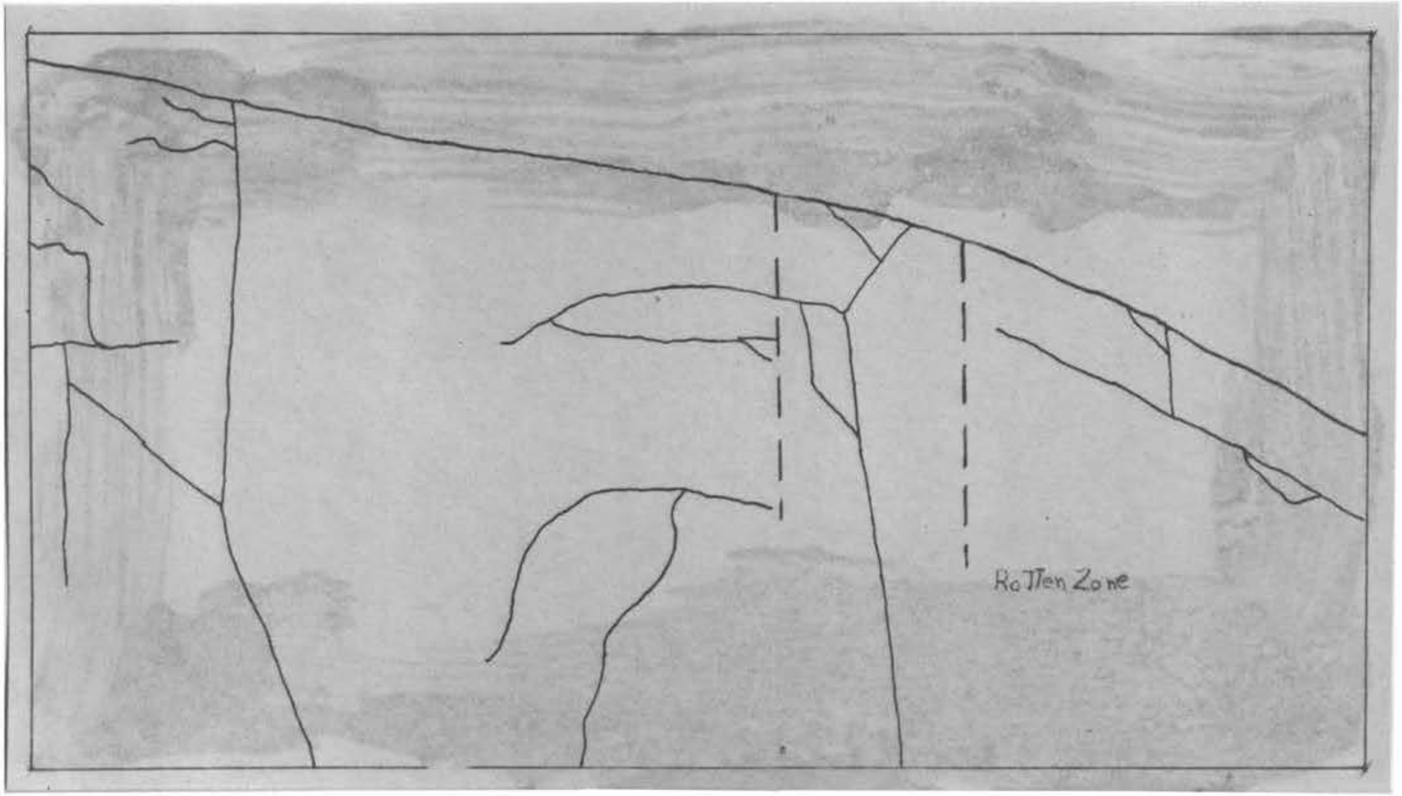


FIGURE 9

Quarry face after Round G-3. Plane of Section N 55° E, looking East. The dashed lines are drill holes. Scale 1" = 5' west and center holes broke out from the face. The rock in front of the east hole was split into large block which remained in place. When these boulders were removed, it was found that the hole had not completely detonated as powder was found in the broken rock near the bottom of the hole. Additional powder was found scattered throughout the broken rock. Stains of unexploded powder were found on the face from the bottom of the hole to the point where an induced fracture from the center hole cut it. (See FIGURE 10). It appears that the explosive column in the east hole was cut off by an induced fracture developed in the firing of the center hole. The firing of the west hole of the round developed two persistant induced fractures. One of these, a sheeting break, extended almost 10 feet into the west wing. The other, a nearly vertical hardway fracture, was developed in the bottom 1 foot of the hole, and extended into the quarry floor. The other induced fractures, as seen in FIGURE 10, were developed by the square up rounds. The vertical fractures were the sites of the drill holes. Fragmentation was very poor; 49 per cent of the material was oversize.

<u>Round G-5</u>:

Round G-5 was drilled in Pattern I on the east face

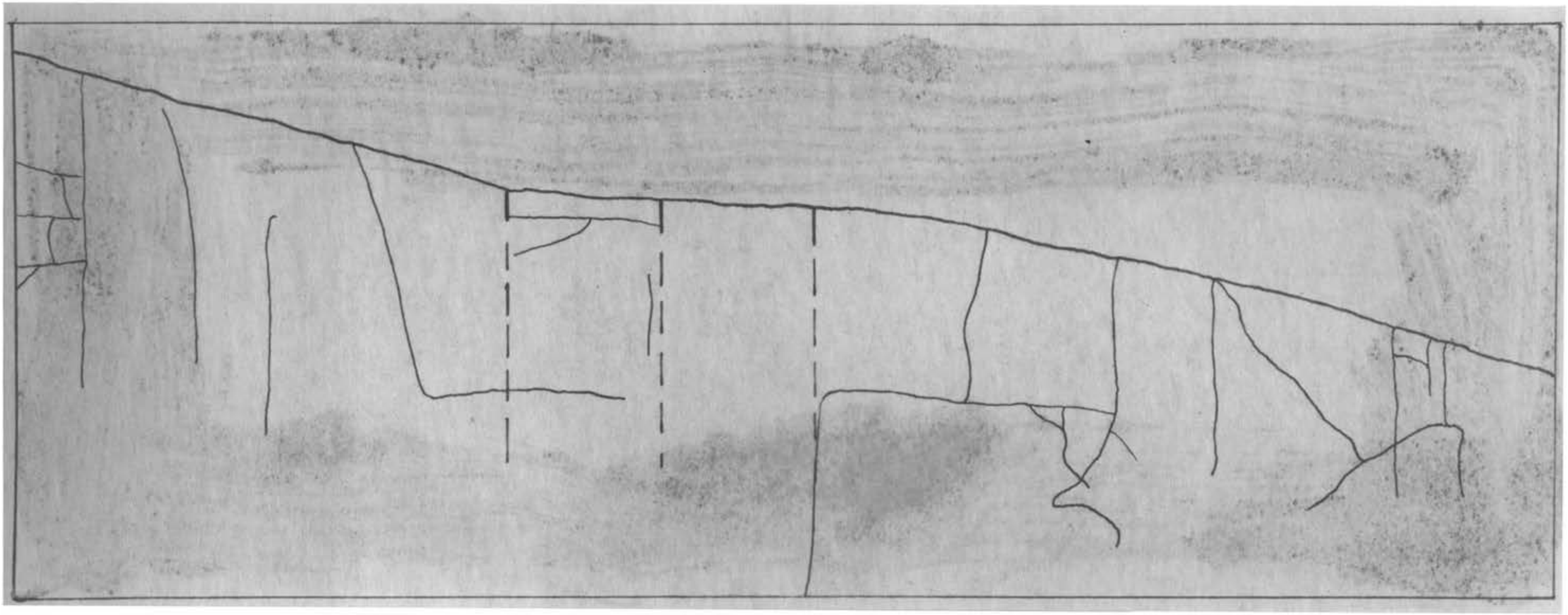


FIGURE 10

Quarry face after Round G-4. Plane of Section N 42° E, looking East. The dashed lines are drill holes.
Scale 1" = 5'

of the quarry with the line of back holes approximately perpendicular to the strike of the longitudinal joints. Two of these joints separated the back drill holes. The holes were loaded with an explosive having a slower rate of detonation than that used in the preceding rounds. When fired, the round broke to longitudinal joints on both the north and south sides. Excellent fragmentation was obtained from this round. This is attributed, by the writer, to the numerous, closely spaced joints. (See FIGURES 11 and 12). An induced joint of major proportions was developed by this round. North of drill hole 2N, it trended essentially parallel with the longitudinal jointing for a distance of 12 feet. At hole 2N it pivated almost 90 degrees so as to parallel the line of back holes of the round. It was traced in this direction for a distance of 15 feet. Other minor fractures were also induced by this round. A replacement veinlet was found in a joint 5 feet from the south wing of the face. The granite was badly weathered in the vicinity of the closely spaced longitudinal joints.

Round G-6:

G-6 was drilled in Pattern VIII, 1 foot in front of a longitudinal joint. The holes were loaded with the same explosive used in Rounds G-1, G-2, G-3, and G-4.

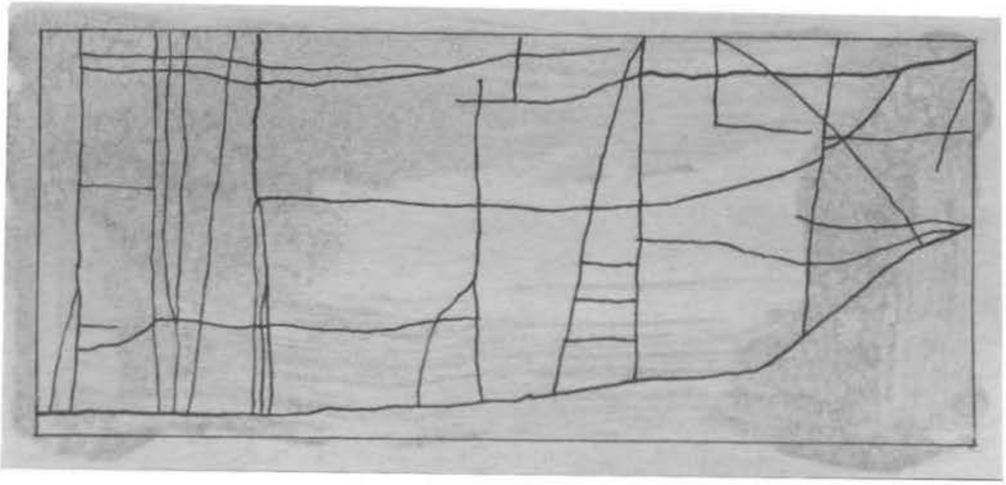


FIGURE 11

Quarry face after Round G-5. Plane of Section N 10° W, looking North. Hole number 2N lies in the joint in the center of the figure.
Scale 1" = 5'

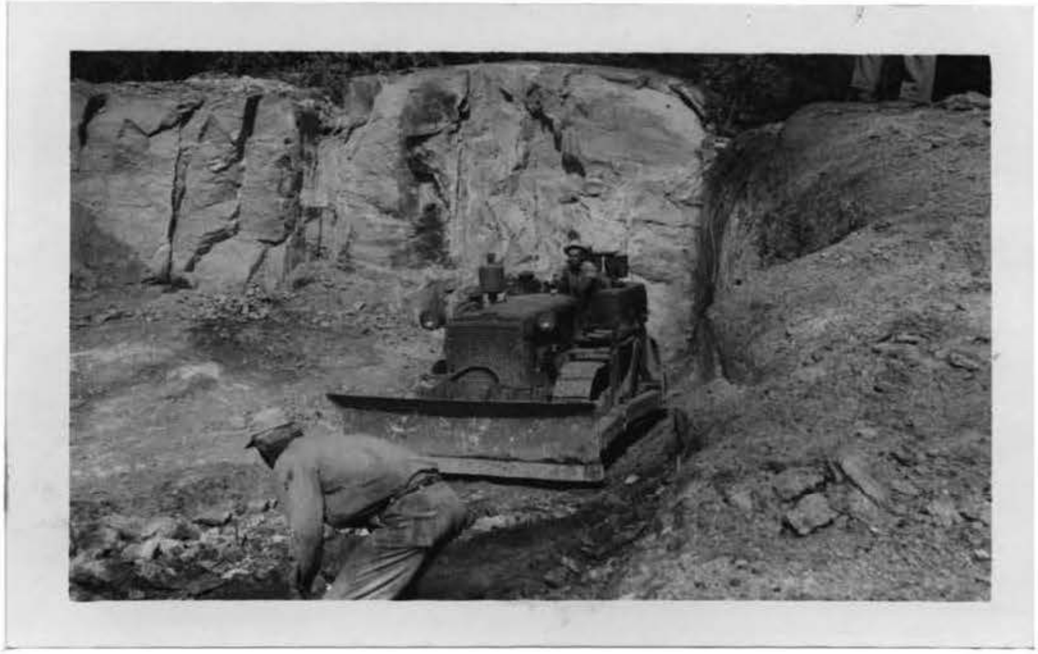


FIGURE 12

East face after Round G-5. Note the numerous joints and other fractures.

The burden broke back to the joint, and downward to a sheeting joint. On the east, the round broke to the joint induced by G-5. One fracture of importance was produced by this blast. It was induced by hole 2W, parallel to the sheeting and 3.3 feet beneath the surface. Several hardway fractures were developed to the east of hole 2E. The fragmentation produced was fair. No large boulders were produced.

Round G-7:

Round G-7 was fired in the Type VIII Pattern. After the blast, the charge in hole 2E was found to be intact in the hole from the bottom to a point 3.3 feet below the surface. The unexploded charge was cut off from the rest of the explosive column. It appears that the earlier firing of the center hole pushed the block, which was formed by the previous round, to the east; thereby displacing the powder train. The face broke to an outline which would have been expected if all the holes detonated properly. The fragmentation was poor. Most of the blocky oversize material was determined to have come from the vicinity of the east hole. The material lying in front of the center and west holes was well-broken. Five peculiarly shaped fractures were induced in the west portion of the face. (See FIGURE 13).

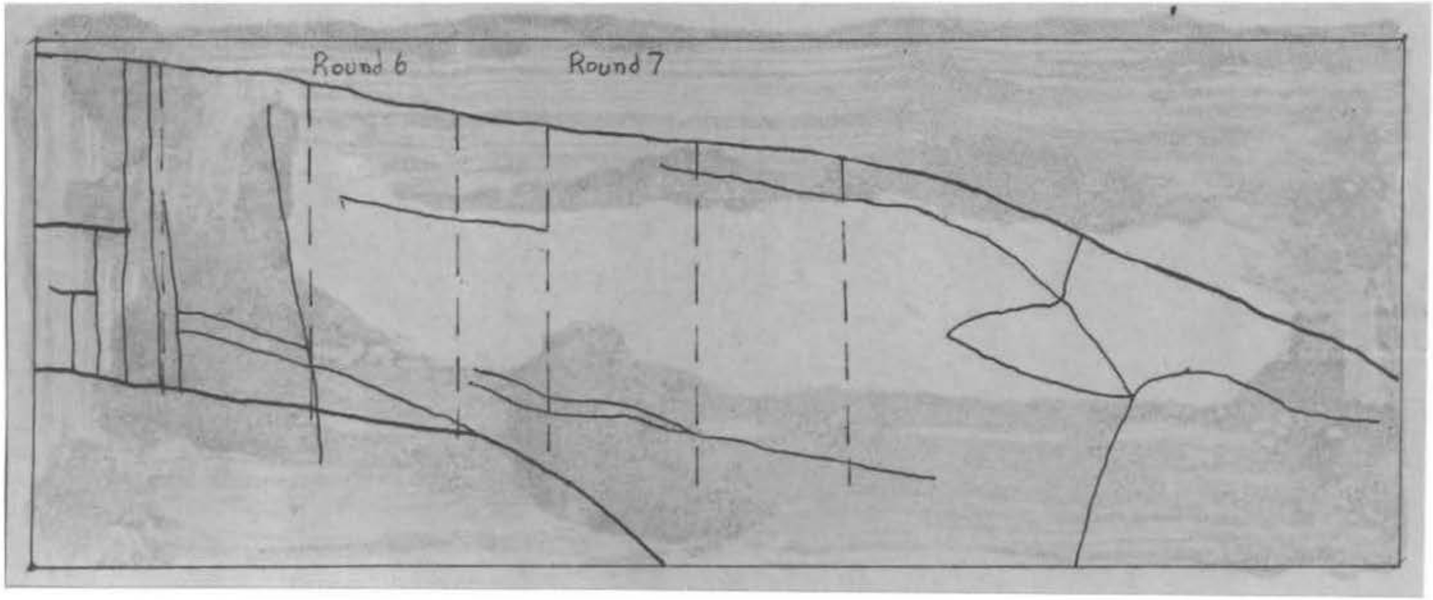


FIGURE 13

Quarry face after Rounds G-6 and G-7.
Plane of Section N 60° E, looking
East. Dashed lines are drill holes.
Scale 1" = 5'

The granite was extremely weathered in this area.

Round G-8:

This round was drilled in the face produced by Round G-6, as in Pattern VIII. The primers were placed in the centers of the charges. This was done so that the lower part of the charge would fire even if the column were cut-off. A longitudinal joint paralleled the line of holes, 1 foot behind them. When fired, the round broke back to the joint. The break to the east extended to the joint induced by Round G-5. The round broke to a depth of 10.6 feet. This breakage was controlled by the presence of a sheeting joint at this depth. Fragmentation was excellent; only three oversize boulders were produced.

Round G-9:

The round was drilled from 1 to 1.5 feet in front of a longitudinal joint. Drill Pattern VIII was used. The face was located in the peculiarly fractured ground from Round G-7. When the round was fired, the east hole failed to detonate. The misfire was caused by the electrical failure of the blasting cap. The center and west holes broke the face rather well but left 2.5 to 3 feet of burden around the east hole. This hole was fired separately. The round did not break back to the

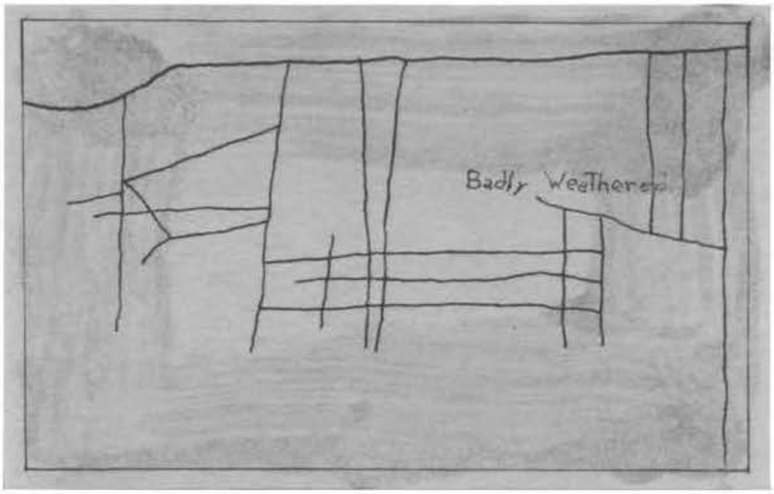


FIGURE 14

Quarry face after Round G-8. Plane of Section N 56° E, looking East.
Scale 1" = 5'

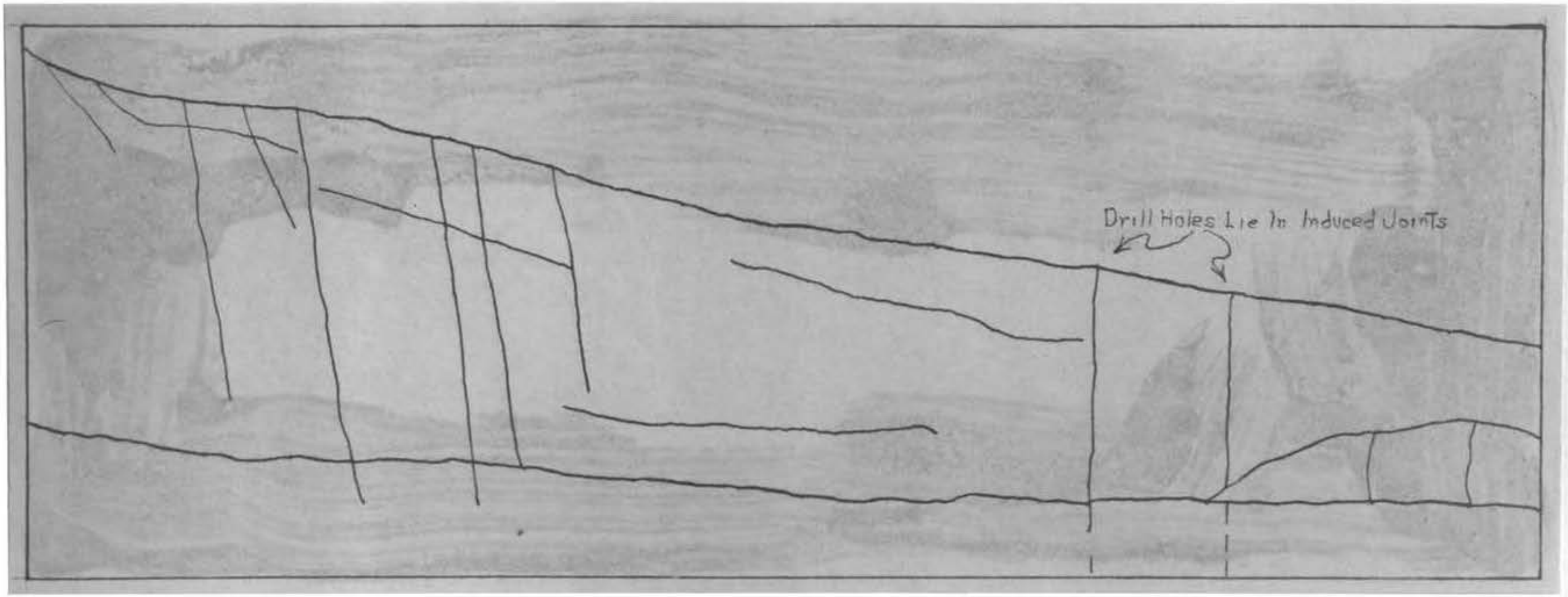


FIGURE 15

Quarry face after Round G-9. Plane of Section N 56° E, looking East. Scale 1" = 5' longitudinal joint. This was due probably to the lack of shock due to the misfire. The joint, however, was opened from 0.3 to 0.5 feet. The round broke to a depth of 7.6 feet, the location of a sheeting joint. The face was extremely fractured to the east of the east hole. The sheeting and hardway fractures in the east wing were opened. It is thought that the delayed blast is directly responsible for this fracturing and reopening. Strong hardway joints were developed directly behind the center and west holes. These joints, however, extended only to the longitudinal joint which paralleled the face. The fragmentation was fairly good considering the misfire and delayed blasting. It was determined, by observing the boulders, that part of the oversize was due to the peculiar fractures induced by Round G-7.

Round G-10:

Round G-10 was prepared in Pattern I. The shape of the face presented ideal conditions for this pattern. The line of the two rear holes was perpendicular to the strike of the longitudinal joints, and the round was bounded on both the north and south by prominent joints. (See Map 3). This round was perfectly oriented with respect to the jointing. Another longitudinal joint cut the round between hole 1 and hole 2S. The preceding

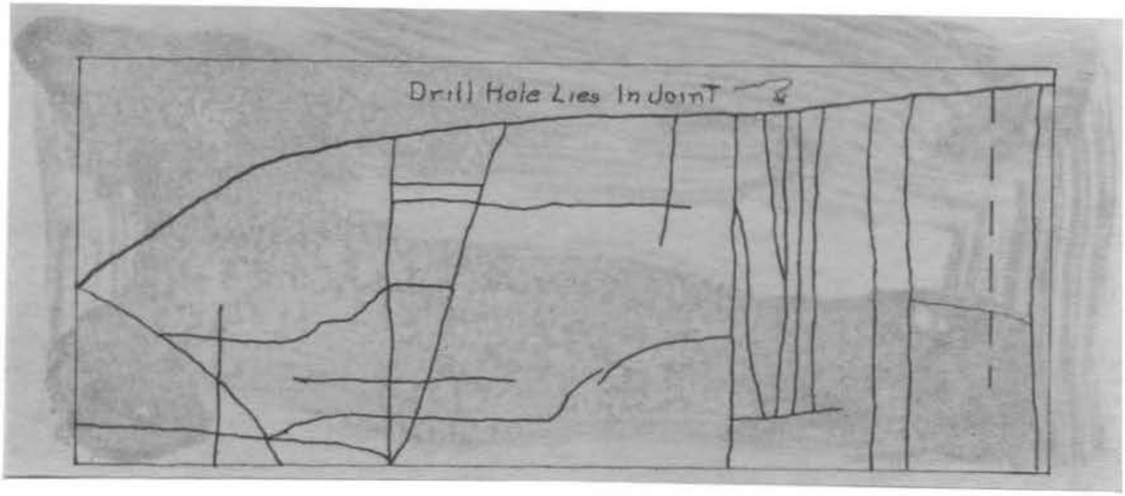


FIGURE 16

Quarry face after Round G-10. Plane of Section N 40° W, looking North. The dashed line is a drill hole. Scale 1" = 5' square-up round had fractured the face and opened the joints. On firing, the round broke out to the bounding joints and 10 feet downward to a sheeting plane. The confining joints reduced the total tonnage obtained from the blast. The fragmentation produced was good. This can be attributed to the closely spaced fracturing which desallowed the pushing out of many large blocks. The longitudinal joints were opened from 1 to 3 inches for distances of 5 to 10 feet perpendicular to the face. A joint was induced in the north wing. It extended 3 feet to the northeast, where it intersected a major longitudinal joint. Several other fractures were formed in both the rift and sheeting planes. The most notable of these were formed in drill holes number 2 and 3. They could be traced only 1.5 feet to the northeast.

Round G-11:

The round was drilled in Pattern VIII. The drill holes were collared parallel to a prominent longitudinal joint which dipped 82 degrees to the southeast; therefore, the holes did not intersect the joint in depth. After firing, part of a cartridge was found in a large fragment. This boulder was determined to have come from the top of the west hole. Evidently, it had been cut off by the earlier firing of the center hole. An induced sheeting fracture was found in the correct position to have allowed the movement necessary to cut off the hole. As the total fragmentation was good it is thought that the rest of the charge in the west hole exploded with a high order of detonation. The round broke to the longitudinal joint and downward to a major sheeting joint (10.9 feet). The east wing formed an angle of 48 degrees with the longitudinal joint that had bounded Round G-10. Hardway fractures were developed in and around the drill holes by the blast. The vertical and curved fractures in the right portion of FIGURE 17 were induced by square-up blasting.

<u>Round G-12</u>:

Round G-12 was drilled in Pattern VIII in the center of a heading zone (an area of closely spaced fractures) which was composed of a number of longitudinal joints which dipped steeply to the north. The jointed area had a maximum width of 1.5 feet and was extremely weathered. On firing, the round broke to the east margin of the zone directly behind the line of holes. The east wing traversed the heading at angle of approximately 20 degrees. As there was no sheeting joint present in depth,

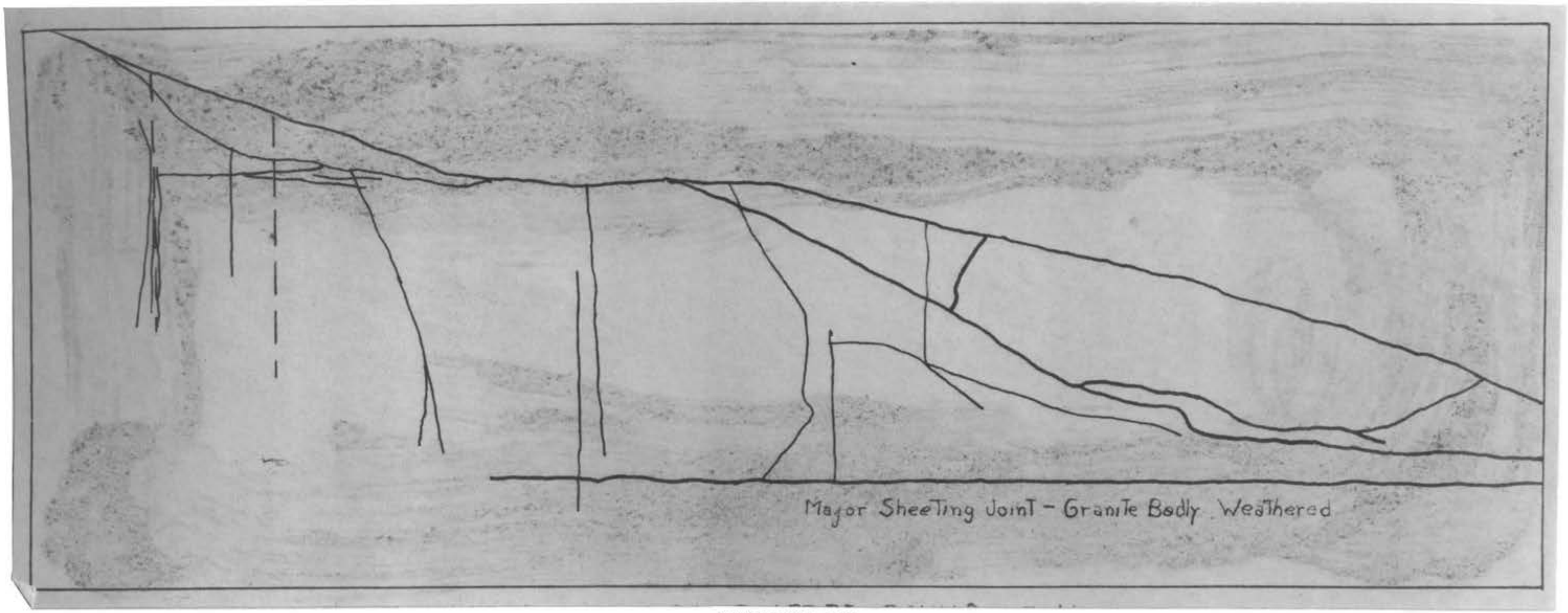


FIGURE 17

Quarry face after Round G-11. Plane of Section N 55° E, looking East. The dashed lines are drill holes.
Scale 1" = 5'

FIGURE 18

East face after Round G-11. Note that the top of the right hole is cut off. The guilty fracture can be traced from the center hole across the outline of the remaining hole.

the round broke only 0.2 feet deeper than the drill holes. The blast was fired without opening the joints beyond the point of breakage as several other rounds with similarly placed drill holes had done. A high degree of fragmentation was achieved; only one large boulder was produced.

Round G-13:

The round was drilled midway between the face produced by Round G-11 (a joint plane) and the prominent northeasterly striking heading zone. Pattern VIII was used. On firing, the ground between the face and the holes broke in a favorable manner. The round broke to the eastern margin of the area of close jointing. The upper portion of this material was crumbled and shattered and slumped over the lower portion which was split in large boulders. The numerous longitudinal joints of the heading combined with three sheeting joints provided the potential blocks for such a breakage. A large slab (10.5 feet x 5.2 feet x 3.6 feet) was heaved 5 feet from the quarry face. The block was pushed from the west wing, where a sheeting joint was found 3.6 feet below the surface. This distance corresponed with the short dimension of the boulder. The joint set was opened to the west as far as the wing left by round G-12. The

FIGURE 19

Quarry face after Round G-13.

FIGURE 20

Preparing the slab, produced by Round G-13, for secondary blasting.

heading zone also was opened to the east. Numerous new fractures were induced by the blasting. The normal burden of the round was thrown clear of the material produced by the back-breakage. The fragmentation of this material was in the medium and fine catagories.

Round G-14:

Round G-14 was drilled parallel to the face produced by the firing of G-13. The remaining weathered material had been removed by the square-up. No fractures traversed the burden of this round. The holes were drilled in Pattern VIII. When fired, the blast produced a large number of oversize boulders. On study of the face, eight cross joints were found. These breaks were cut by three sheeting joints. The intersection of these fractures on the face developed nineteen possible oversize blocks. If similar conditions had been present in the face of G-14 before blasting, it could well have produced the oversize fragments. The writer, unfortunately, had found it necessary to be absent from the test site the day the round was fired; therefore, he did not examine the quarry face before G-14 was shot. No fractures of importance were noted.

Round G-15:

This round was drilled approximately behind Round

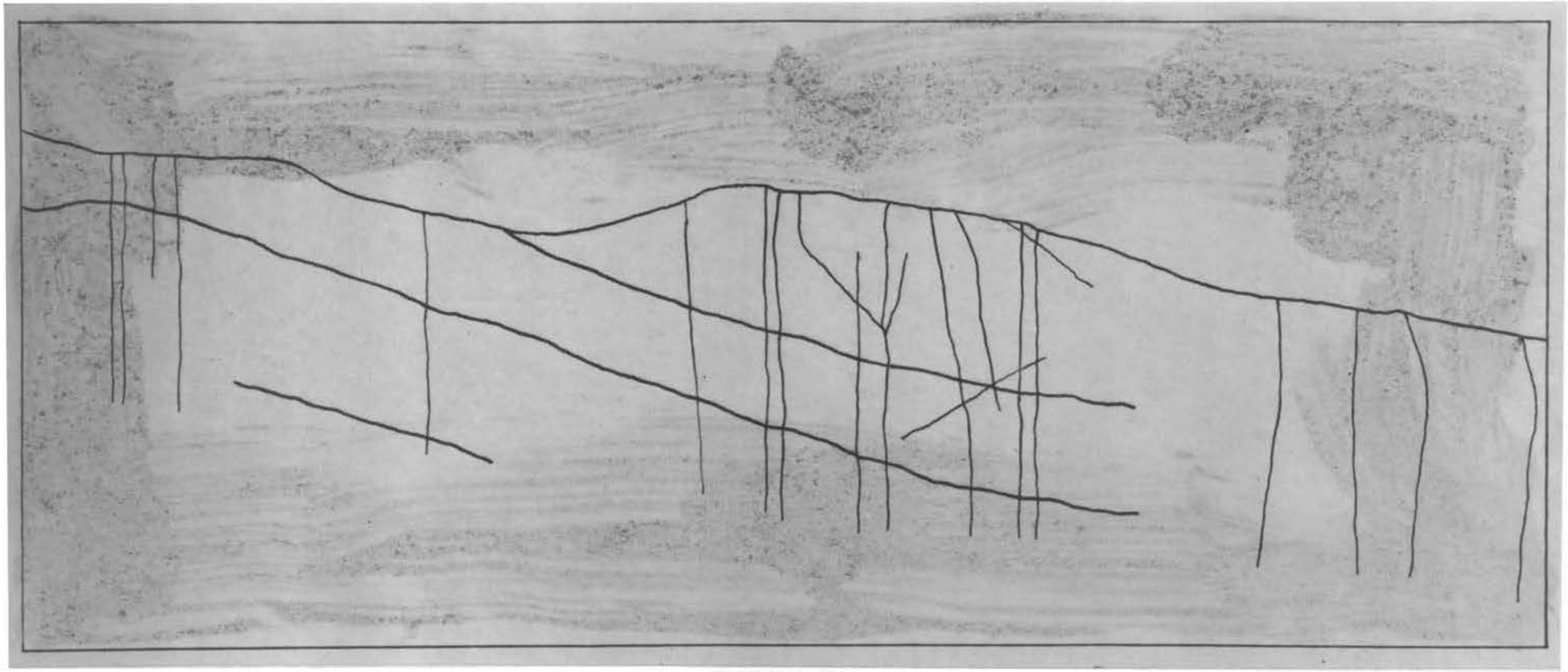


FIGURE 21

Quarry face after Rounds G-14 and G-15.
Plane of Section N 58° E, looking East.
Scale 1" = 5'

G-13. The material of the heading zone that had not been broken by G-13 was removed, and the face in general was squared-up. The face was a joint plane. A longitudinal joint cut diagonally across the burden. Another longitudinal joint paralleled the line of holes, 1 foot to their rear, but appeared to die out behind the center hole. A high percentage of well fragmented material was produced. There was no concentration of cross joints as in Round G-14. The burden broke exactly to the depth of the drill holes, 8 feet. No important fractures were induced.

Round G-16:

The round was drilled in Pattern VIII. The burden was diagonally cut by a longitudinal joint. Another longitudinal joint was located 1.75 feet to the north of the east hole. The face to the east of the center hole was cut by cross joints. Two sheeting joints were located respectively 5.1 and 8.3 feet below the surface. When fired, satisfactory fragmentation was produced. The blast induced a major joint, which appeared to develop 1.5 feet north of the east hole. It extended over a straight line distance of 33 feet. The fissure broke roughly with an irregular trend. (See Map III). Numerous cracks were developed parallel to this break, between it and the quarry face. The longitudinal joint was opened for a length of 22 feet along its strike. It appears that the weakened rock, due to the numerous cross joints, was the major factor in the production of these induced breaks. These numerous fractures necessitated a large amount of waste work before the next round in this section of the quarry could be drilled. The sheeting plane that lay 8.3 feet below the surface controlled the depth of break.

Round G-17:

The round was drilled in Pattern G-VIII. A longitudinal joint of small magnitude lay in the burden half way between the face and the line of drill holes. The fissure that was induced by Round G-16 passed through the area just to the north of the east hole. Another longitudinal joint, of a strike of N 66° E, lay just to the west of the west hole, cut the center hole, and passed 1 foot to the south of the east hole. The east hole was drilled in one of the five cross joints that were observed in the face before the shot. Also, two sheeting joints were present. When fired, the round broke a favorable percentage of small sized fragments. No induced fractures of any consequence were found after

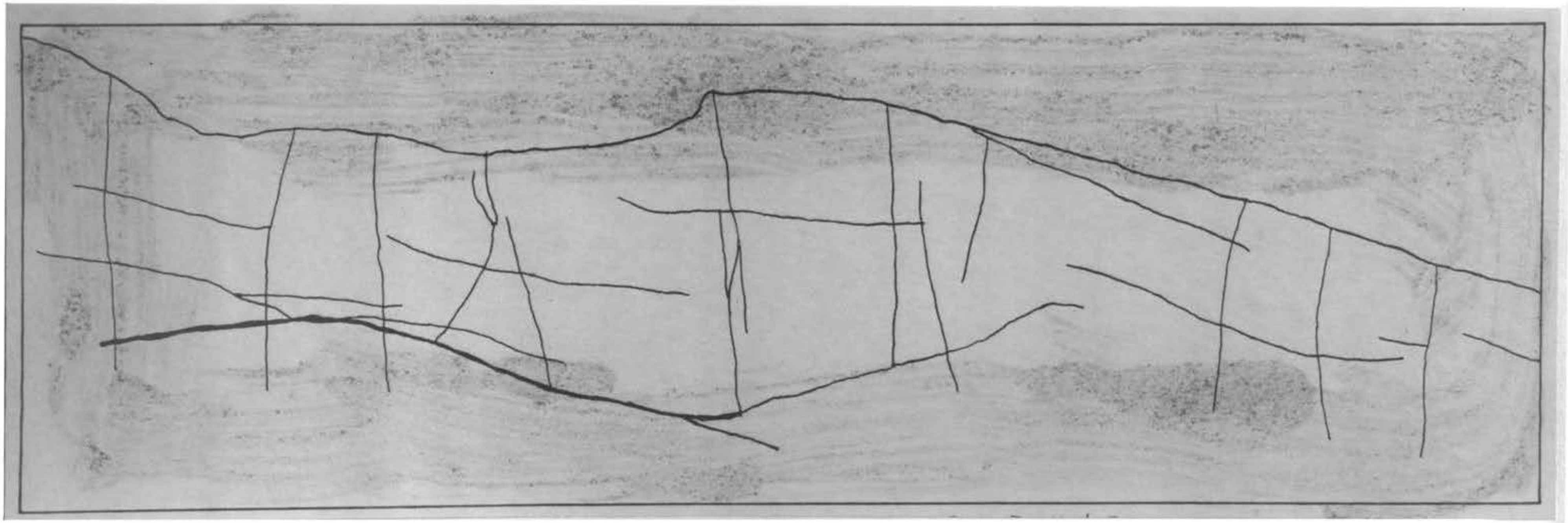


FIGURE 22

Quarry face after Rounds G-16 and G-17.
Plane of Section N 56° E, looking East.
Scale 1" = 5'

the blast.

Round G-18:

Round G-18 was drilled in Pattern VIII at an angle of 22 degrees with the longitudinal joints. One of these joints cut through the burden just in front of the east hole, while another passed between the east hole and the center hole. The face was cut by numerous hardway fractures. A major sheeting joint lay 6 feet below the surface. This joint was filled with from 0.5 to 2 inches of clay. Two minor sheeting fractures lay between this major joint and the surface. Good fragmentation was produced when the round was fired. The numerous hardway fractures undoubtedly acted as an aid to fragmentation and produced a backbreak of from 1.5 to 3 feet. Numerous fractures were opened parallel to the longitudinal jointing in the north wing of the quarry. These fractures could be traced for several feet before they were lost under the soil covering. (See FIGURE 23). Numerous hardway fractures were observed in the resulting face. The sheeting joint exerted no control on the depth of breakage as the round broke to a depth of 9.3 feet.

Round G-19:

The round was drilled in Pattern I. The line of back holes was parallel to and 2.4 feet in front of a

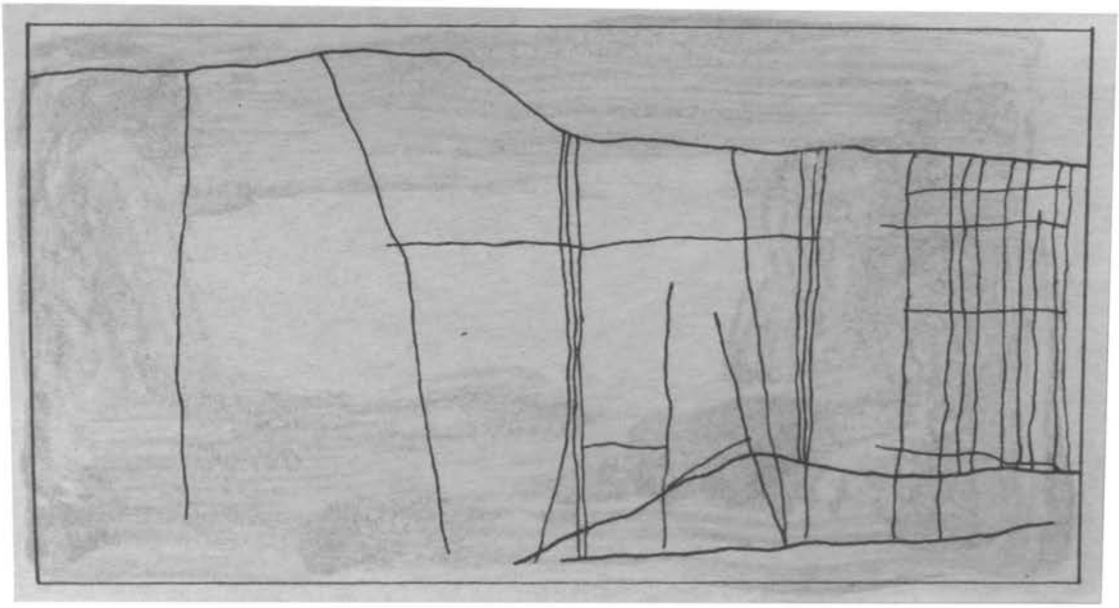


FIGURE 23

North quarry face after Round G-18. Plane of Section N 37° W, looking North. Scale 1" = 5'

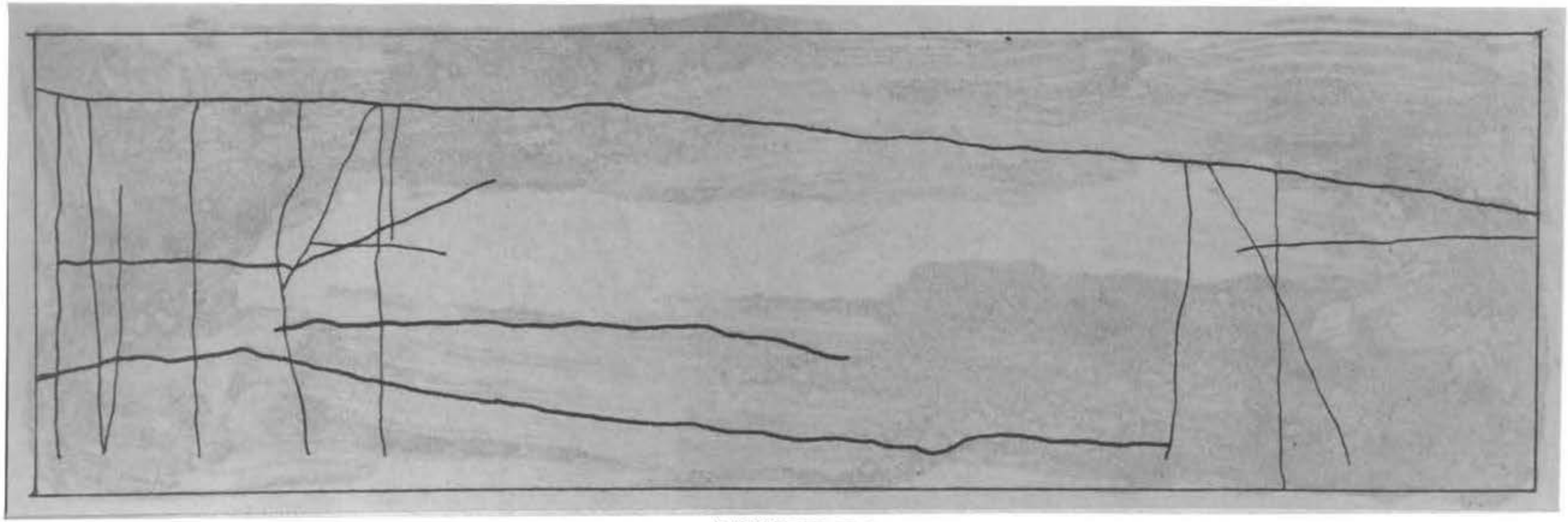


FIGURE 24

East quarry face after Rounds G-18 and G-19. Plane of Section N 60° E, looking East. Scale 1" = 5' longitudinal joint. Three cross joints were observed in the face of the round. Also, two sheeting joints cut the face. When fired, the round broke to a major sheeting joint 7.9 feet below the surface. The round broke back 1.6 feet in the center of the pattern, but it did not reach the longitudinal joint. Numerous fractures, however, were produced parallel to this joint, between it and the quarry face. These cracks were all of small magnitude and could not properly be considered joints. The formation of these fissures necessitated considerable waste work to prepare the quarry for Round G-20. Fragmentation was good, although eleven boulders were found with a dimension greater than 16 inches. These blocks were determined to have come from the upper part of the round where the intersection of a sheeting joint and the cross joints produced favorable conditions.

Round G-20:

The burden of Round G-20 was not cut by any longitudinal joints. The nearest fissure was 2 feet to the south of the holes which were drilled in Pattern I. The quarry face was remarkably free of fractures. Only two sheeting joints were present. The fragmentation attained by this round was better than that of any of the preceding rounds. Six fractures were developed in the hardway direction by the blast. The strongest of these lay behind the east drill hole. These fractures were noted in the face, but it was impossible to trace them on the surface.

Round G-21:

Round G-21 was drilled in Pattern I. The nearest longitudinal joint was 3 feet behind the line of back holes. Both the back holes were drilled in hardway fractures developed by the firing of Round G-18. Five other hardway fractures, three sheeting joints, and numerous diagonal fractures were present in the face. No back-breakage occurred. The fractures that were present in the face before firing appeared to carry through to the new face. In addition, six new hardway fractures were developed. They appeared to die out within 0.5 to 1 foot behind the face.

Round G-22:

Round G-22 was drilled in Pattern I. A longitudinal joint passed through the burden just to the front of the center hole. The face was moderately fractured. Eight cross joints and five sheeting joints lay within the normal area of influence of the round. The intersections of these joints provided several potential boulders.

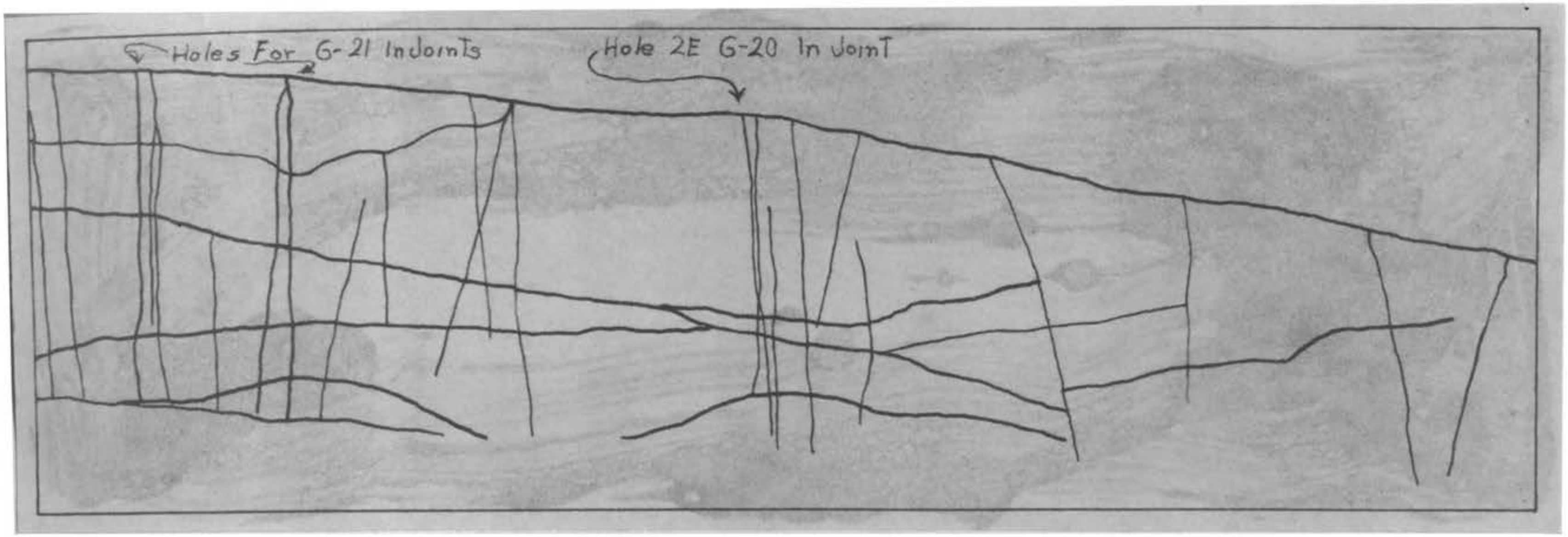


FIGURE 25

Quarry face after Rounds G-20 and G-21. Plane of Section N 52° E, looking East. Scale 1" = 5'

When fired, the blast produced a moderate percentage of small sized fragments. No large (one dimension greater than 26 inches) boulders were produced, but six small (no dimension greater than 26 inches) oversize fragments were found. This oversize constituted 11.1 per cent of the broken material. No fractures of importance were noted after the shot.

Round G-23:

Round G-23 was prepared in Pattern III with the line of holes parallel to a longitudinal joint. The joint passed through the burden 1 foot behind the face. A large number of fractures were present in the face. (See the eastern one-third of Section 25). The granite was extremely weathered in the vicinity of the round. When fired, the round produced excellent fragmentation. No fragments were found with a dimension greater than 16 inches. The closely spaced fractures and the weakened condition of the weathered rock apparently combined to produce this excellent breakage. Because of the numerous fractures and the weakened condition of the rock, it was decided to abandon this portion of the quarry. This was necessary in order to obtain conditions comparable to the other test rounds, so that the effectiveness of the

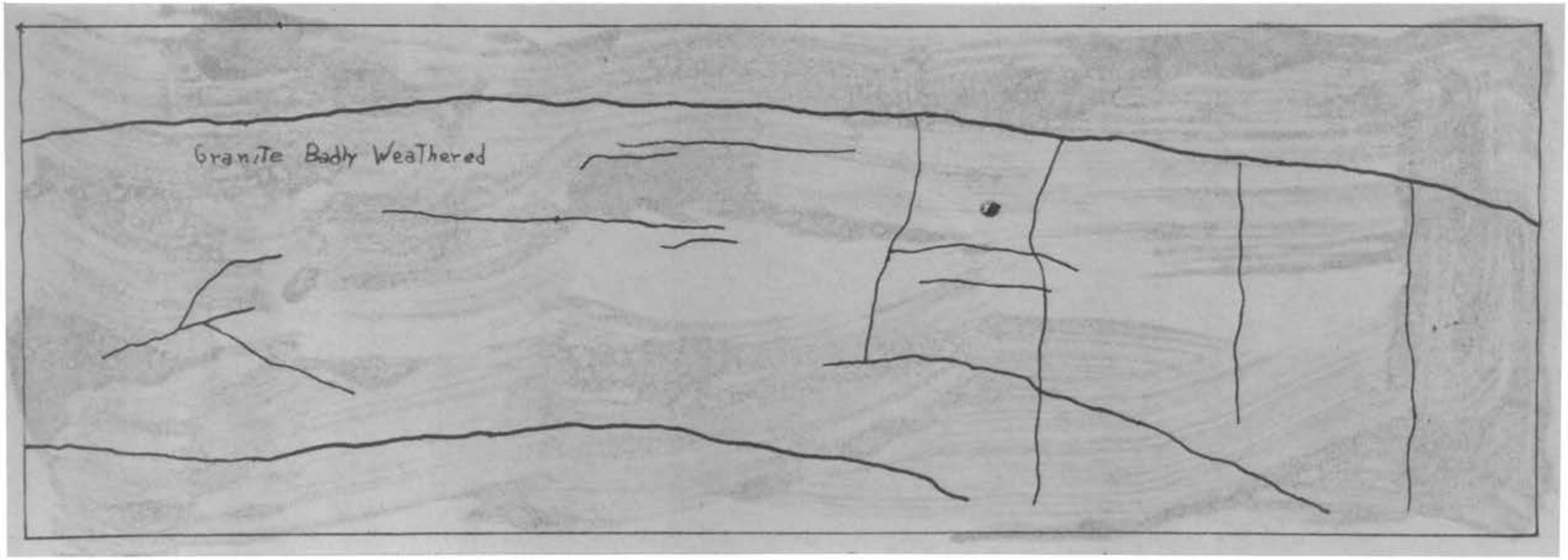


FIGURE 26

Quarry face after Rounds G-22 and G-23. Plane of Section N 60° E, looking East. Scale 1" = 5'

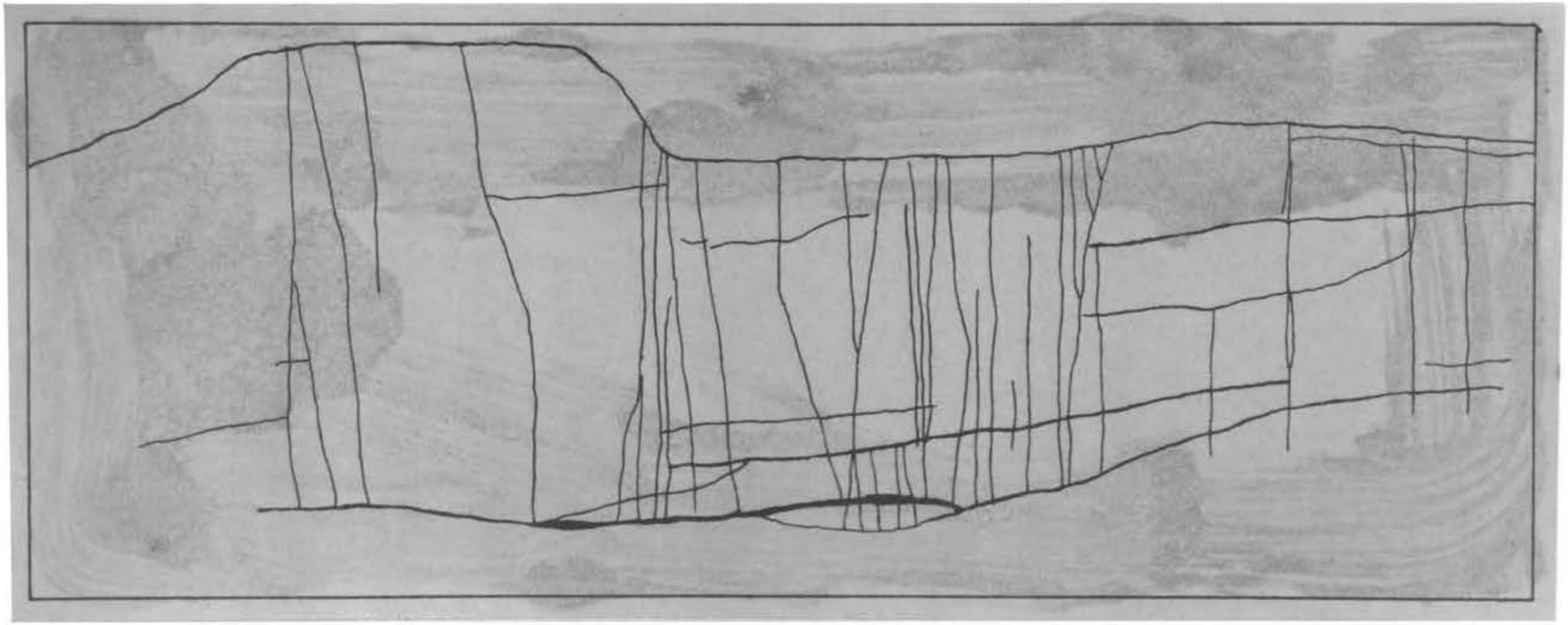


FIGURE 27

North face of quarry from Round G-10 to Round G-23. Plane of Section N 37° W, looking North. Scale 1" = 5' explosives (the principle project) could be better evaluated.

Round G-24:

The round was drilled in Pattern I. No longitudinal joints were present in the area. Four cross joints were observed, two of which bounded the drill pattern. When fired, the wings of the round broke to these cross joints giving a short face. The fragmentation produced was fair, although 10 per cent of the material broken had one dimension greater than 16 inches. The cross jointing undoubtedly affected the breakage, as the coarser material was observed to have a joint plane on one side.

Round G-25:

Round G-25 was drilled in Pattern I at an angle of 29 degrees with the rift. No longitudinal joints were present in the area. Two sheeting joints and three hardway fractures were observed in the face previous to the firing. On firing, the round produced a considerable amount of large fragments. Again, the oversize material showed joint planes on one and two sides. The character of the fractures in the face undoubtedly affected the size of the material broken. Two hardway fractures were induced behind the back holes. These apparently died out

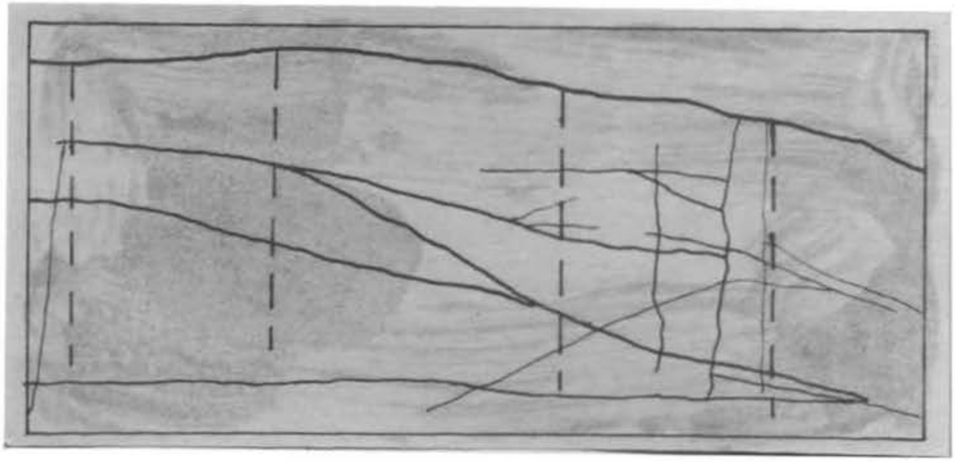


FIGURE 28

Quarry face after Rounds G-24 and G-25. Plane of Section N 80° E, looking East. The dashed lines are drill holes. Scale 1" = 5' within 6 inches of the face.

Round G-26:

The line of holes of the round was drilled at an angle of 25 degrees to the rift in Pattern I. No longitudinal joints were observed to be in the area. Two sheeting joints cut the face. When fired, the round produced the best fragmentation of any of the test rounds. No material was found with a dimension of 16 inches or greater. According to the driller, the rock was the most solid tested. An induced joint was produced parallel to the line of back holes. It extended 3 feet to the northeast, where it intersected a major longitudinal joint. This joint was opened slightly for a distance of 12 feet along its strike.

Round G-27:

Round G-27, the last test round, was drilled parallel to a longitudinal joint in Pattern I. Four closely spaced cross joints lay to the east of hole 2E. A major sheeting joint was present 8.1 feet below the hole collars. On firing, the round produced good fragmentation. The round broke to a depth of 8.1 feet. It is difficult in this case to determine whether the jointing controlled the depth of breakage, as the depth of the holes was 8 feet. Hardway fractures were developed in the rear of the back drill holes, but they could not be traced on the surface.

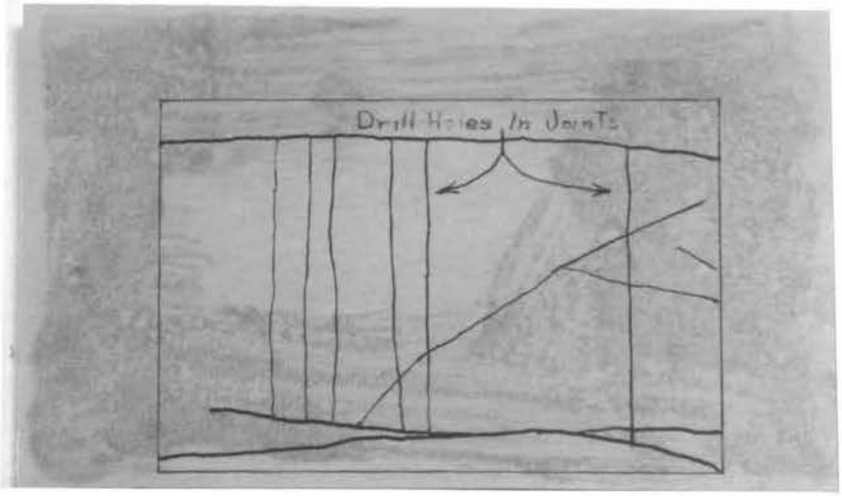


FIGURE 29

Quarry face after Round G-27.
Plane of Section N 60° E, looking
East. Scale 1" = 5'

THE EFFECTS OF JOINTING ON SIMILAR ROUNDS

In this study, rounds that were fired with the same explosive, loaded with approximately the same amount of explosive, and prepared in the same drill pattern are considered similar. The degree of fragmentation produced, the tonnage of material broken, and the number of joints present, are listed for each test in TABLE IV.

The first group of comparable rounds is comprised of G-1, G-2, and G-4. A comparison of these rounds is impossible because of the unfavorable results produced by the cut-off holes in G-1 and G-4. The character of the jointing was thought to have caused this bootlegging. The jointing definitely effected the results obtained from these tests. The influence of the jointing has been discussed previously in the descriptions of the rounds.

No tests were made that can be compared to Round G-3.

Rounds G-5 and G-26 were prepared in a similar manner. However, G-5 was placed at right angles to the direction of longitudinal jointing whereas G-26 was drilled at an angle of 25 degrees to this jointing. Numerous fractures bounded the burden of G-5, but only two sheeting joints were found within the area of influence of G-26. After G-5 was fired, 74 per cent of the broken material was found to have a maximum dimension of less than 12 inches. Of the material broken by G-26, only 5 per cent of the fragments had a dimension greater than 12 inches. A comparison of these rounds shows that a high degree of fragmentation can be obtained from a strongly fractured area, but that better results are produced from unjointed regions.

Rounds G-6, G-7, and G-8 were prepared in the same manner. Both G-6 and G-8 were drilled parallel to longitudinal joints and were bounded on the east by an induced joint. The faces of the three rounds were cut by a number of joints, but G-7 was characterized by numerous intersections of cross and sheeting fractures which formed many potential blocks. The cross joints in the face of G-8 were more closely spaced than in the other two rounds. The highest degree of fragmentation was obtained from G-8 which broke 82.5 per cent of the material produced to a size smaller than 12 inches. Rounds G-6 and G-7 developed similar fragmentation, although several more large blocks were broken by G-7. The east hole of G-7 was cut-off, and it was determined that the oversize came from the vicinity of this hole.

A comparison of these rounds shows again that a high degree of fragmentation is obtained from closely fractured areas.

The next group of similar rounds includes G-9, G-14, and G-15. Rounds G-14 and G-15 were prepared to the east of and parallel to a zone of closely spaced fractures. The faces of the rounds were about equally fractured. The east hole of round G-9 misfired, therefore, 50 per cent of the material broken by the blast had a dimension greater than 12 inches. The best fragmentation was obtained from G-15 which broke 87 per cent of its material to a size smaller than 12 inches. G-14 yielded fair breakage as 30 per cent of the rock was found to have a dimension greater than 12 inches. Round G-15 was thought to have broken a higher amount of small fragments because of a bounding longitudinal joint which acted as a free face. The writer believes that G-9 would have broken a comparable percentage of small fragments if the east hole had not misfired. The fragmentation produced by G-14 and G-15 probably would not have been so high in unweathered rock.

Rounds G-10 and G-27 were prepared in a like manner. G-10 was drilled at right angles to the prominent jointing, whereas G-27 was placed parallel to this jointing. The burden of G-10 was cut by 38 fractures, whereas only 2 cross joints were observed in the face of G-27. Of the material broken by G-27, 83.8 per cent was smaller than 12 inches. Round G-10 broke 80.1 per cent of its burden to a size smaller than 12 inches. The above results show that comparable results may be obtained from either strongly fractured or unfractured rock.

The next group of similar rounds includes Rounds G-11, G-13, and G-16. G-11 was bounded on the east by a longitudinal joint, and its face was cut by several intersecting cross and sheeting breaks. The faces of G-13 and G-16 were characterized by closely spaced cross joints. The percentage of -12 inch fragments produced by G-16, G-13 and G-11 respectively was 88.3, 83.8, and 79.3. The rock from the backbreak of G-13 was not considered in the percentage calculation. A comparison of these rounds shows that similar results were obtained from areas that have similar joint patterns.

Rounds G-12, G-17, and G-18 were prepared in the same manner. G-12 was drilled parallel to and in a zone of longitudinal joints. Two cross joints and two sheeting fractures were observed in its face. G-17 was drilled at a slight angle to the rift, and several joints cut the burden. Two longitudinal joints traversed the area of Round G-18 with numerous small cracks paralleling them. Numerous fractures parallel to the hardway and grain were present in the face. The percentage of -12 inch fragments produced by G-12 was 77.1; by G-17, 82.3; and by G-18, 90.8. G-12, however, broke 4 per cent of its material with a dimension of greater than 26 inches. These large fragments were a result of the overbreakage along the zone of longitudinal joints.

Rounds G-18, G-19, G-20, G-21, G-22, G-23, G-24, and G-25 are uncomparable as they differed either in explosive or drill pattern used.

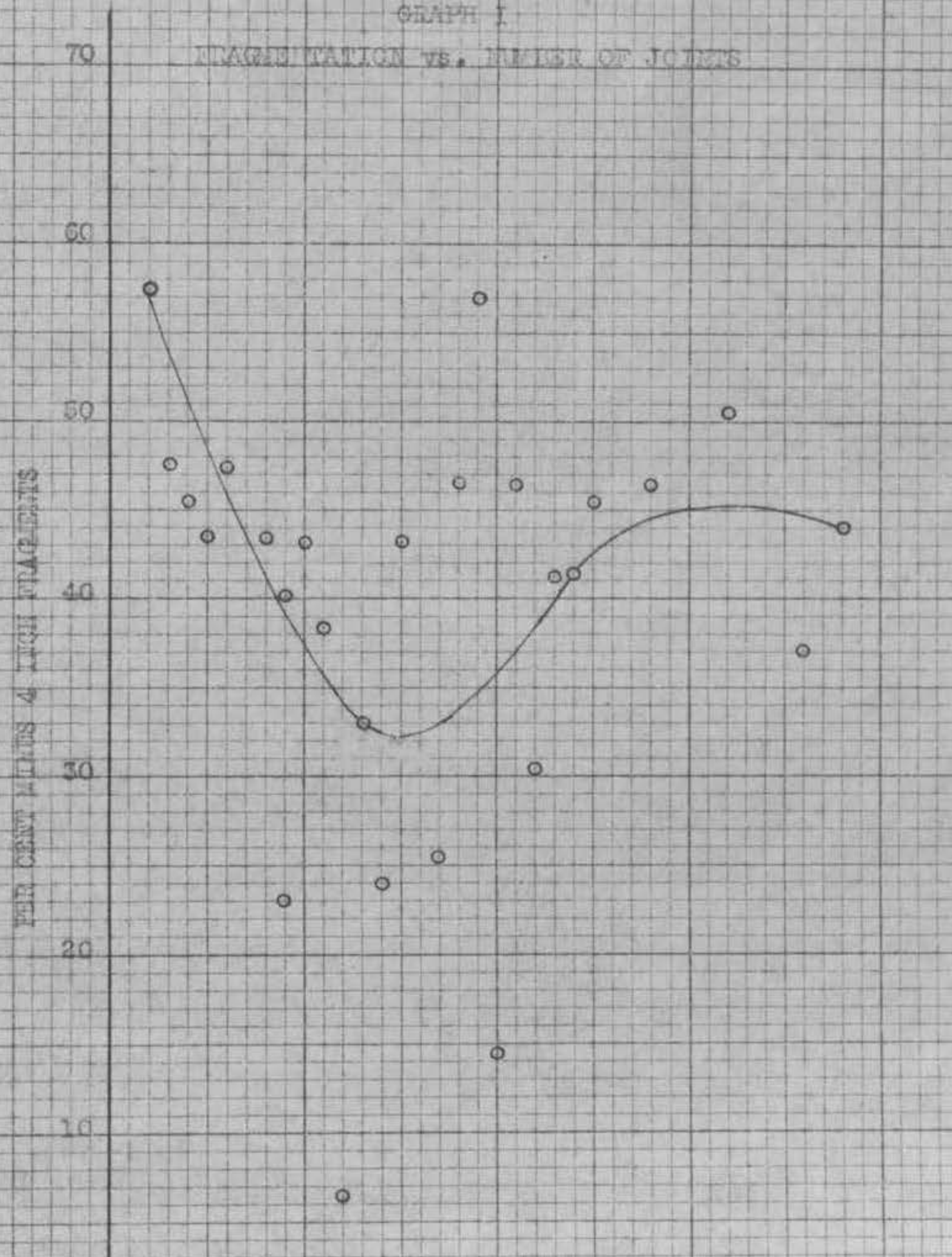
TABLE IV

FRAGMENTATION PRODUCED BY THE TEST ROUNDS

Test			Fragmentation (%)			Tons	No. of
No.	-4"	+4"-12"	+12"-16"	+16"-26"	+26"	Broken	Joints
G-1	6.5	9.8	8.9	62.6	12.2	21.4	12
G-2	38.5	5.0	7.9	38.1	10.5	45.7	11
G-3	24.0	39.3	9.9	26.8	None	28.4	14
G-4	14.4	22.3	16.2	32.7	14.4	34.0	20
G-5	36.9	36.9	20.8	5.4	None	24.1	36
G-6	25.4	32.6	17.7	24.3	None	26.0	17
G-7	30.4	34.1	14.8	30.7	None	27.0	22
G-8	46.7	35.8	12.3	5.2	None	34.9	18
G-9	23.0	27.6	12.6	36.8	None	26.1	9
G-10	43.9	36.2	8.7	11.2	None	19.6	38
G-11	43.2	36.1	6.8	13.9	None	39.5	15
G-12	46.4	30.7	6.1	12.8	4.0	32.8	28
G-13	57.0	26.8	10.1	6.1	None	22.8	19
G-14	32.7	37.6	15.7	14.0	None	30.0	13
G-15	43.5	43.5	7.3	5.7	None	24.6	8
G-16	46.7	41.6	7.2	4.5	None	22.1	21
G-17	43.2	39.1	9.2	8.5	None	27.1	10
G-18	45.4	45.4	4.4	4.8	None	25.1	25
G-19	41.2	38.4	7.4	13.2	None	31.2	23
G-20	47.5	45.0	4.9	2.6	None	26.5	6
G-21	41.5	27.7	10.3	20.5	None	19.5	24
G-22	40.1	37.8	11.0	11.1	None	21.7	9
G-23	50.5	41.9	7.6	None	None	29.1	32
G-24	45.6	31.6	12.8	4.0	None	18.0	4
G-25	47.8	28.1	2.2	7.0	None	17.8	3
G-26	57.4	37.7	4.9	None	None	20.4	2
G-27	43.7	40.1	11.2	5.0	None	22.2	5

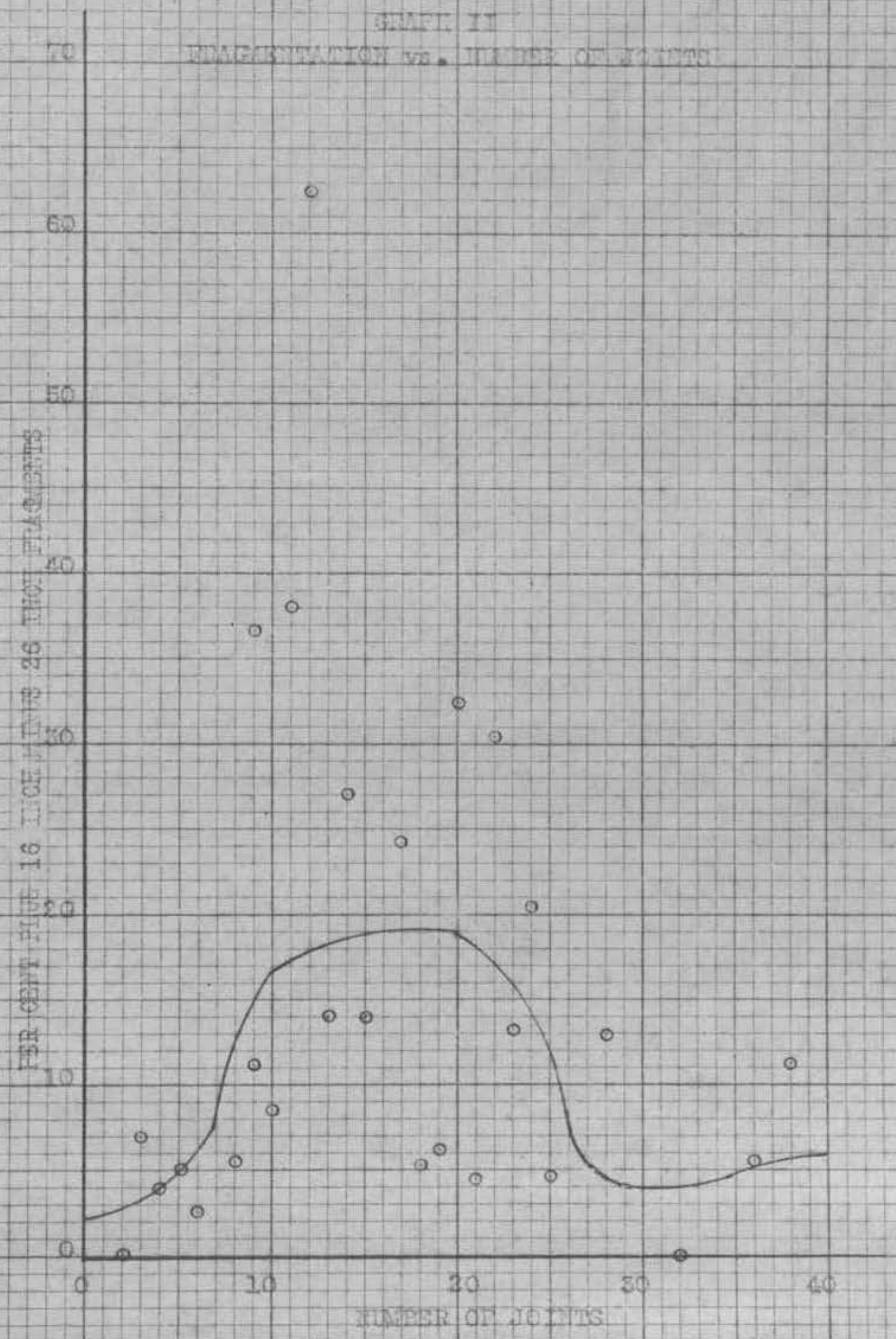
FRAGMENTATION

In this study, it was desired to obtain well broken rock. An attempt was made to break material with a maximum dimension of less than 4 inches. All material with a dimension of greater than 12 inches was considered oversize, as that was the maximum sized material the rock crusher, for which this project was designed, would take. It was found that the best percentage of small material was produced from rock masses that were not jointed and from granite that was characterized by a large number of closely spaced joints. The areas in which a few widely spaced joints were present produced a considerable amount of blocky oversize material. TABLE IV gives the per cent of each type fragment broken, the tons broken, and the number of joints present, for each test round. GRAPHS I and II were plotted with the number of joints against the percentage of small size and large size fragments produced respectively. They show, in a general way, that the largest amount of small material was produced from unjointed and strongly jointed areas, and that the largest amounts of large material came from areas of few widespaced joints.



GRAPH I

FRAGMENTATION vs. NUMBER OF JOINTS



GRAPH II
FRAGMENTATION vs. NUMBER OF JOINTS

DEVELOPMENT OF JOINTS BY BLASTING

It was thought, at the beginning of this study, that the development of joints by blasting might endanger the Sheahan dimension stone operation. Although fractures were induced by the test rounds, none were of the magnitude or so placed to disturb the rock of the main quarry. Only four joints of importance were produced by the test firing. Of these fractures, two were formed by rounds placed parallel to the longitudinal jointing and two by rounds at right angles to this jointing; three were induced by rounds blasted with the same explosive; and three (not the same three as above) were prepared in the same drill pattern, Pattern III. The faces of G-5 and G-10 were characterized by a large number of fissures; G-16 was moderately jointed, and G-26 was essentially devoid of fractures. None of the rounds, which induced breaks, were bounded on the rear by joints. Of the above conditions, the lack of joints parallel to the line of drill holes was the principal and probably the only factor that controlled the development of induced joints.

To explain the controlling influence of the joints, it is necessary to consider the action of an explosion. An explosion is the chemical action that takes place between the elements of an explosive.(35) It suddenly liberates a great volume of gas at high temperature, which moves in all directions with equal velocity and in equal quantity. As the gas leaves the explosive, it expands in all directions, but when it encounters an object, it bounds from the object, tears its way through the object, or hurls the object aside.(36) Like other fluids, the gases produced by an explosion will take the direction of least resistance; therefore, when the gases reach a joint, they will pass along it with a rush. The rapid movement and expansion of the gases will tend to increase the opening. Joints will react to this force by reopening. That this happens, was well evidenced at Graniteville, where numerous joints were opened. If the force produced by these rushing gases is great enough, it will push the confining material (in this case the material toward the face) away. The above explains the backbreakage produced by many of the rounds which were bounded by longitudinal joints. The energy that the gases have retained upon

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(35) Gillette, *Op. cit.*, p 402.

(36) Gillette, *Op. cit.*, p 403.

reaching the joint will determine the degree of breakage obtained from the heaving action. It appears evident that the gases utilize the majority of their energy in rushing along joint planes and in opening the fractures, rather than in breaking across the openings to induce new joints.

Seismic vibrations also are produced by blasting. In this study, they were thought to be unimportant. Thoenen and Windes (37) found that ground and structural displacements ranged from 0.0001 to 0.06 inch for quarry shots varrying in weight of explosive charge from 4 pounds at 185 feet to 15,400 pounds at 600 feet. They concluded that the seismic vibrations necessary for damage is much greater than that produced in ordinary quarry blasting. (38)

The writer had no way of measuring the vibrations produced in the test area, but as the test shots were of smaller magnitude than regular quarry rounds, he feels that the seismic effects were negligible.

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(37) Thoenen, J. R., and Windes, S. L., Seismic Effects of Quarry Blasting, U. S. Bureau of Mines, Bull. 442, 1942, p 80.

(38) Thoenen, and Windes, _Op_. _cit_., p 81.

In the discussion of the test rounds, the writer stated that numerous minor fractures were produced by the blasting. These fractures extended over short distances and were usually measurable in inches. The writer feels that the majority of these fissures represent the opening of previously invisible joints. Gillette(39) and Bowles(40) mention the presence of such joints in granite and marble. It is possible that some of these cracks were breaks along the artifical parting planes, as they were so oriented. The joints in the face of Rounds G-5 and G-10 could have easily been produced along such planes, as they strike with the direction of greatest weakness, the rift. It was impossible to determine definitely which of the above conditions favored the induction of the fractures, as the directions of artificial parting and jointing were the same.

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(39) Gillette, *Op*. *cit*., p 541.

(40) Bowles, Oliver, The Technology of Marble Quarrying, U. S. Bureau of Mines, Bull. 106, 1916, p 148.

CONCLUSIONS

1. The occurrence of joints influenced the degree of fragmentation achieved during the blasting of granite. Large amounts of small sized material were produced from both closely jointed and unjointed rock masses, but the best fragmentation was obtained from rounds drilled in essentially unfractured granite. Oversized fragments were produced where the intersections of widely spaced joints had developed potential blocks. The amount of medium sized fragments broken was approximately constant for all rounds except those that misfired.

2. Jointing influenced the tonnage of rock broken by controlling the area of breakage. In many cases, rounds broke to joints bounding the burden on the sides, rear, and bottom.

3. Overbreakage affected the fragmentation achieved as the material so produced was largely of boulder size.

4. The presence of sheeting joints allowed blocks to be moved by the first delay shots, thereby cutting the explosive columns of the later holes. The cut-off holes resulted in lower tonnages and poorer fragmentation.

5. High degrees of fragmentation were obtained from both extremely weathered and solid granite.

6. Fractures were induced by blasting.

7. The four major induced joints were formed by rounds that were not bounded on the rear by prominent joints. Two were formed by rounds drilled parallel to the rift, and two by rounds placed parallel to the hardway. All of the four induced joints intersected pre-existing fractures but did not cross them.

8. No fractures were formed that endangered the Sheahan Dimension Stone Quarry. All but two of the tests were drilled parallel to the direction of the longitudinal jointing, N 65° E. The majority of the energy, of the gases produced by the explosion, was expended in passing along the joints and in reopening them.

9. More major joints probably would have been produced if more rounds had been placed in the north part of the quarry at right angles to the major jointing. A joint was induced by each round fired in the above manner. No cross joints were noted in the area that could have served as channels for the gases.

10. Numerous minor fractures also were induced. These fractures were probably both invisible joints that had been opened and original fractures along artifical parting planes. The strongest of these fractures were formed at the rear of the drill holes.

11. The effect of seismic vibrations was assumed to be negligible.

SUMMARY

Twenty-seven test rounds were studied at Graniteville, Missouri. The objects of these tests were: (1) to determine if joints are induced by blasting, and (2) to study the effects of jointing on the blasting of granite. The test area was characterized by a prominent system of longitudinal joints which were found to strike N 65° E and to dip almost vertically. A poorly defined system of steeply dipping cross joints intersected the major system at approximately right angles. Flatly dipping sheeting joints were sporadically present also. The number of joints present within the area of influence of a test round was found to control the fragmentation produced by the round. A high degree of fragmentation was obtained from granite that was extremely fractured and rock that was unjointed. The largest percentage of small sized material, however, was produced from unjointed areas. Also, joints were found to effect the amount of rock broken by a particular blast, by controlling the area and depth of breakage. Rounds, when bounded by fractures, tended to break both laterally and downward to such fractures. Large blocks often were produced from the extremities of overbroken rounds. The explosive forces in such locations were reduced so as to

possess only a heaving action. Sheeting joints were found to have a detrimental effect where holes were drilled through them. As the delay system of blasting was used, the firing of the early hole caused movement along sheeting planes cutting-off the explosive column. Therefore, the part of the charge separated from the primer would not fire, and the fragmentation produced would be poor. It was found that joints are induced by blasting. Four major fractures were developed by the test rounds. The location of the majority of the drill holes parallel to and in front of major joints was thought to have prevented the inducement of more joints. In the above case, the gases of the explosion dissipated most of their energy by rushing along and opening the fractures. The position of the major jointing prevented the formation of fissures that would have endangered the Sheahan's dimension stone operation. Numerous other fractures were developed parallel to the artificial parting planes. Many of these fractures were thought to be the result of the opening of previously invisible joints. Others were probably breaks along the rift, grain, and hardway planes. The induced breaks extended over only short distances and never passed through primary joints. Generally, they appeared to have had little effect on subsequent rounds, but G-23 fractured the area around it so extremely, it was abandoned.

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