PRESPLITTING ROCK IN THE PRESENCE OF A STATIC STRESS FIELD

By Harry R. Nicholls and Wilbur I. Duvall

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US Department of Interior
Office of Surface Mining
Reclamation and Enforcement

Kenneth K. Eltschlager
Mining/Explosives Engineer
3 Parkway Center
Pittsburgh, PA 15220
Office: 412.937.2169
Cell: 724.263.8143
Keltschlager@osmre.gov

UNITED STATES DEPARTMENT OF THE INTERIOR
Stewart L. Udall, Secretary

BUREAU OF MINES
Walter R. Hibbard, Jr., Director

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by

Harry R. Nicholls[1] and Wilbur I. Duvall[2]

ABSTRACT

Preliminary tests on presplitting rock in the presence of an in situ static stress field were undertaken to study the influence of a horizontal static stress field on the creation of a vertical presplit fracture plane. These tests indicated that it is easier to fracture the rock parallel to the in situ maximum compressive stress than in other directions. Instrumented shots indicate that the interaction of stress waves generated by the detonating charges is probably responsible for starting tensile fractures between shotholes and that expanding gases may propagate these initial cracks by a wedging action. The hole spacing for good presplitting appears to be equal to the half wavelength of the stress wave. However, wider hole spacing appears feasible if the initial fracture is started by closer hole spacing.

INTRODUCTION

Presplitting is the creation in solid rock of a fracture plane with predetermined direction and extent by the proper use of explosives and drill holes. The method of presplitting, as developed by D. K. Holmes and refined by others (5),[3] consists of drilling a series of 2- to 3-inch-diameter holes in a plane, loading the holes 10 to 20 percent full with short charges of explosive taped to detonating fuse, and stemming the holes with stone chips or gravel. An electric blasting cap is used to initiate a detonating fuse trunk line which ties the branch of each hole together.

Presplitting is useful where clean, smooth rock walls are a requisite. The method has been used extensively and successfully for road cuts,

[1] Former Bureau of Mines research geophysicist, College Park, Md.; now with Environmental Science Service Administration, Rockville, Md.

[2] Supervisory physicist, Denver Mining Research Center, Bureau of Mines, Denver Colo.

[3] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

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hydroelectric power projects (spillways, channels, etc), shaft sinking, foundation excavations, and similar applications.

The method has been less successful when applied to underground workings. In driving tunnels, drifts, or openings in underground working areas, vertical cuts have been made as successfully as on the surface. Horizontal cuts and arches have generally been disappointing because vertical cracks are generated through the drill holes rather than on the plane of the holes. As a result a poorer roof condition may be produced by presplitting than that produced by normal blasting procedures.

It was believed that the inability to presplit in a horizontal direction underground was a direct consequence of the static stress conditions. If the in situ stress is due primarily to the weight of the overburden, the vertical component of the stress should be approximately three times the horizontal and both would be compressive. Thus, to create a vertical tensile fracture, a tensile stress greater than one-third of the vertical stress would be needed, whereas to create a horizontal fracture a tensile stress greater than the total vertical stress would be needed, if the method requires that the in situ static compressive stress be overcome by the explosive process.

Similar difficulties would be expected in surface outcrops which contained moderate or large residual or tectonic stresses. Previous Bureau studies have shown that outcrops of the Lithonia granite gneiss near Lithonia, Ga., were under compressive stresses ranging from 1,200 to 2,000 psi (2). This area was selected for the preliminary test program.

The tests were designed to determine if it would be easier to create a vertical presplit fracture plane in a direction parallel to the maximum horizontal compressive stress rather than normal to this stress. The tests were also designed to obtain some preliminary data on hole spacing and to determine if the half wavelengths of the stress pulses generated by the detonation of the explosive charges were related to the maximum hole spacing that would presplit the rock with a given charge size.

Four uninstrumented presplit tests were conducted to study the influence of the in situ stress field and the hole spacing on the ease with which a presplit fracture plane could be created. Four instrumented shots were detonated to study the generation of strain waves between two shotholes, fired singly and then fired together with detonating fuse trunklines. For simultaneous firing, the shotholes were spaced so as to preclude the development of a presplit fracture, thus facilitating the analysis of the interacting strain waves.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the Consolidated Quarries Division of the Georgia Marble Co., Lithonia, Ga., and in particular to Nelson Severinghaus, vice president, and W. B. Hawkins, quarry superintendent, for providing the test site and for their cooperation during the test program.

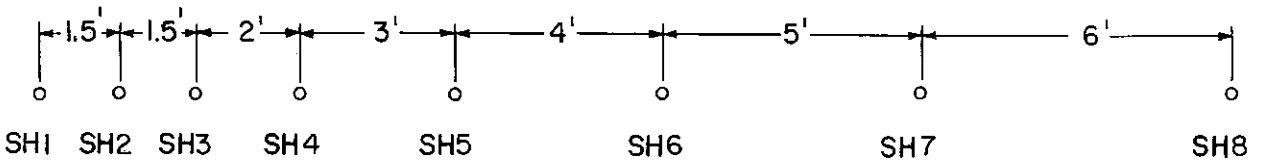

FIGURE 1. - Typical Plan, Showing Shotholes in Arrays 1 and 2.

EXPERIMENTAL PROCEDURE

Two arrays of vertical, in line, 2.5-inch-diameter holes were drilled to study the effect of the in situ stress. Each array consisted of eight holes, 15 feet deep. The hole-to-hole spacing in each array was 1.5, 1.5, 2, 3, 4, 5, and 6 feet (fig. 1). Array 1 was oriented N 56° E which had been reported to be the average direction of the maximum secondary principal stress in this general area (2). Array 2 was perpendicular to array 1, with an orientation of N 34° W.

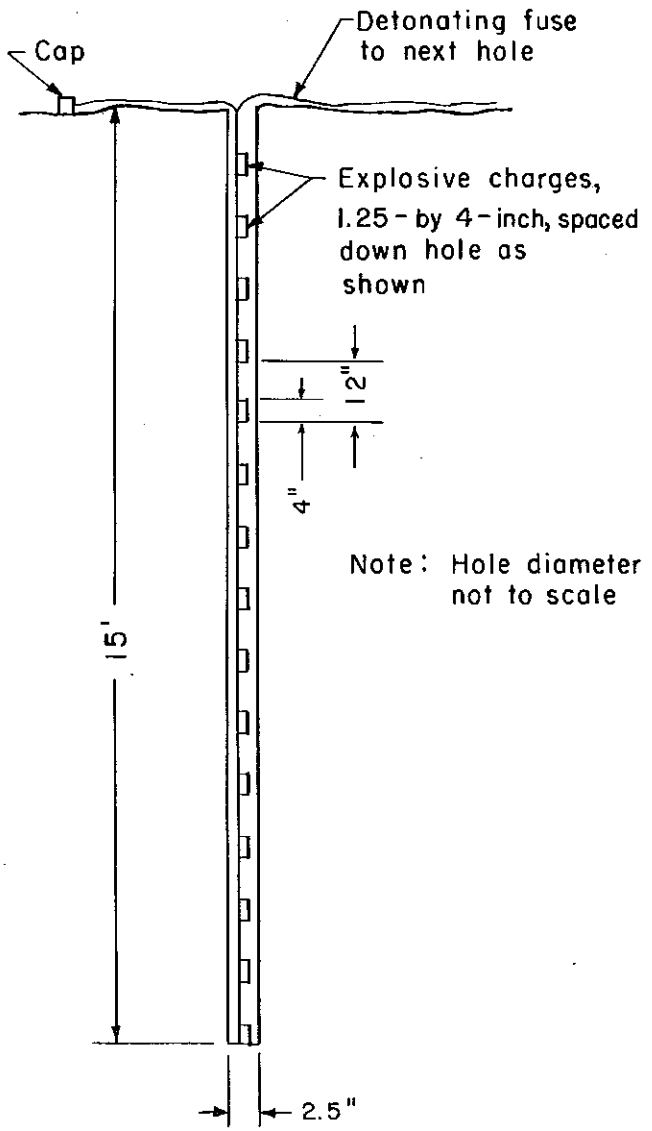

FIGURE 2. - Vertical Section Showing Charge Configuration for Arrays 1, 2, and 3.

Short cartridges, 1.25-inch diameter by 4 inches long, of 40-percent gelatin extra dynamite were taped at 12-inch intervals on lengths of detonating fuse equal to the full depth of each hole (fig. 2). The explosive-detonating fuse charge was suspended in the center of the hole, and coarse sand was used as stemming to fill the space surrounding the charge. At the collar of each hole, the detonating fuse was tied to a trunkline to connect the charges in all the drill holes together. An electric blasting cap was used to initiate the detonation at hole SH1, where the hole spacing was the smallest.

Arrays 1 and 2 were loaded and shot. Presplitting was obtained in array 1 but not in array 2. Details of the test results are given in the section entitled "Data, Analysis, and Discussion." On the basis of the results obtained in array 1, three 2.5-inch-diameter by 15-foot-deep holes were drilled. This was

array 3. The holes were in line, oriented N 40° E, and 3 feet apart. These holes were loaded and shot in the same manner as in array 1.

In array 2, there was no visible damage to the rock surface or drill holes. A second charge was made up and detonated in a further attempt to split the rock. The charge and loading procedure were identical with the original charge and loading procedure except that 1.25-inch-diameter by 8-inch-long charges were taped on 12-inch centers on the detonating fuse branch lines in the drill holes. This effectively doubled the charge size of the previous shot in these holes. This charge was detonated in array 2, and visible effects to the rock were noted.

The array for the instrumented shots was laid out in the form of a T, as shown in figure 3. All holes were vertical. The gageholes (GH) were 3 inches in diameter and 3 feet deep, and the shotholes (SH) were 2.5 inches in diameter and 2.5 feet deep. The shotholes were placed 6 feet apart to preclude

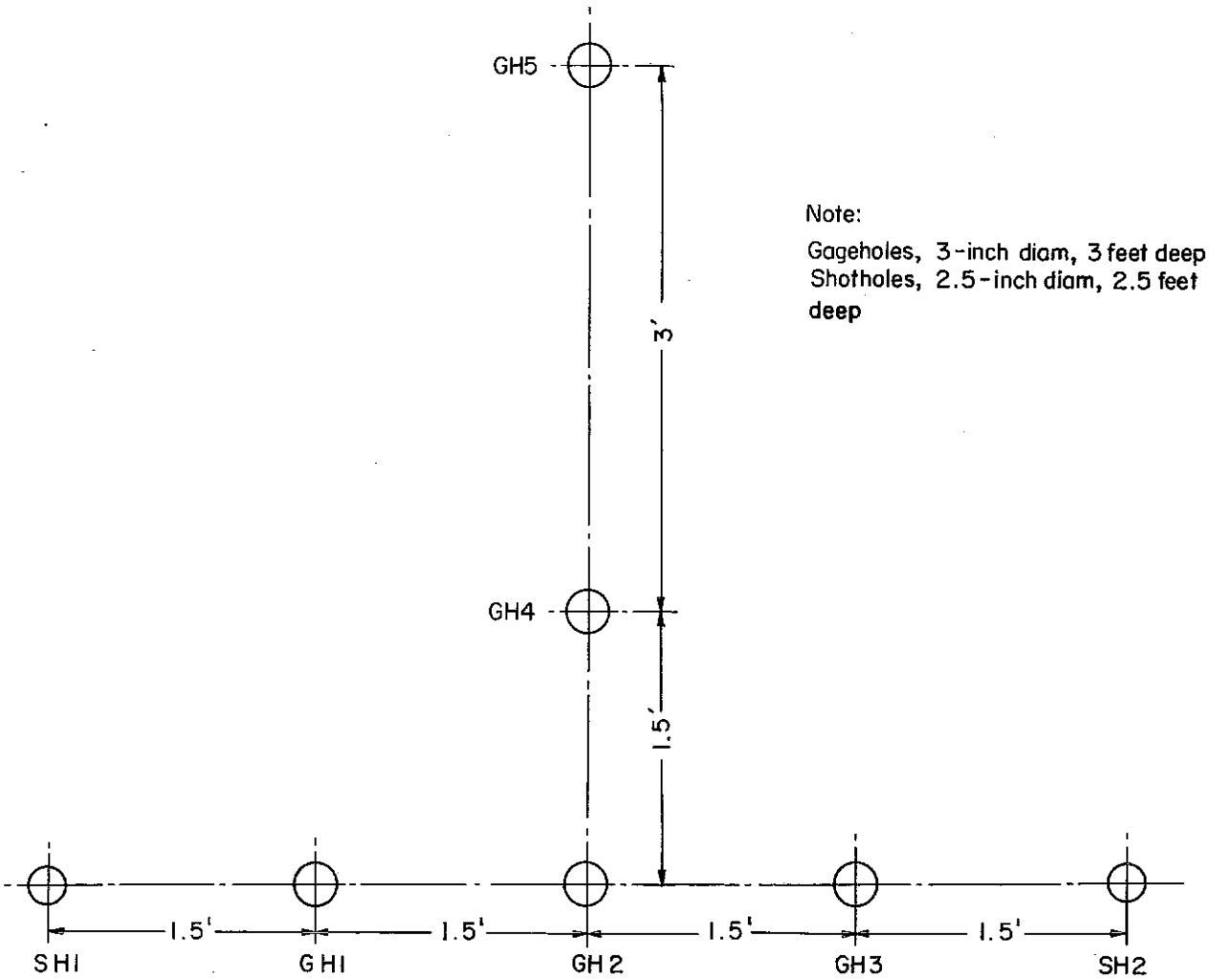

FIGURE 3. - Plan, Array 4.

the generation of a presplit fracture line. Four shots were detonated in this array. Table 1 gives the charge data configuration of the individual shots in array 4.

TABLE 1. - Shot data, array 4

Shot	Shotholes used	Cartridges per hole	Spacing between cartridges, feet
S1.....	SH2	2	1
S2.....	SH1, SH2	2	1
S3.....	SH1	1	-
S4.....	SH1, SH2	1	-

The charges for array 4 were one or two cartridges of 40-percent gelatin extra dynamite taped to a detonating fuse. The detonating fuse was centered in the shothole. Sand stemming was used to fill the hole. An electric blasting cap was used to initiate the detonation. For the two-hole shots, equal lengths of detonating fuse linked the cap and the two holes, providing simultaneous detonation of the charges. Shots S1 and S3 provided a basis for comparison of the effects from single- and double-charge detonation. There was no visible effect or damage from any of these shots.

Two-component strain gages were used in each of the gageholes shown in figure 3. These were SR-4 strain gages[4] mounted on granite-gneiss core and cemented in place with a Hydrocal cement, a technique developed by the Bureau of Mines (4). The component oriented along or parallel to the line between the shotholes is termed radial. The gage component perpendicular to the radial component is termed tangential. The strain pulses were recorded on a 14-channel FM magnetic tape recorder and played back on a direct-writing oscillograph for analysis.

DATA, ANALYSIS, AND DISCUSSION

The presplit charge detonated in array 1 generated a fracture system through the shotholes. Figures 4 to 7 show the surface expression of the fracture system. Shotholes in these figures run from bottom to top; thus SH1 is at the bottom of figure 4, etc. The most striking aspect evident in the photographs is that the fractured surface is not a simple plane running directly through the line of holes, but is a series of parallel fractures emanating from each hole. Between holes there are usually two parallel fractures which tend to curve toward and intersect the next hole. This fracture is readily apparent in all four figures. Figure 8 is a view of the array, indicating the parallelism of the individual fractures in the foreground. Figure 9 shows the fracture system graphically. The trend of the parallel fracture system was N 48° E. The orientation of the line holes was N 56° E, assumed to be an average direction for the maximum secondary principal stress. It is believed that the direction of maximum stress in the specific area was N 48° E.

[4]Reference to specific brands is made for identification only and does not imply endorsement by the Bureau of Mines.

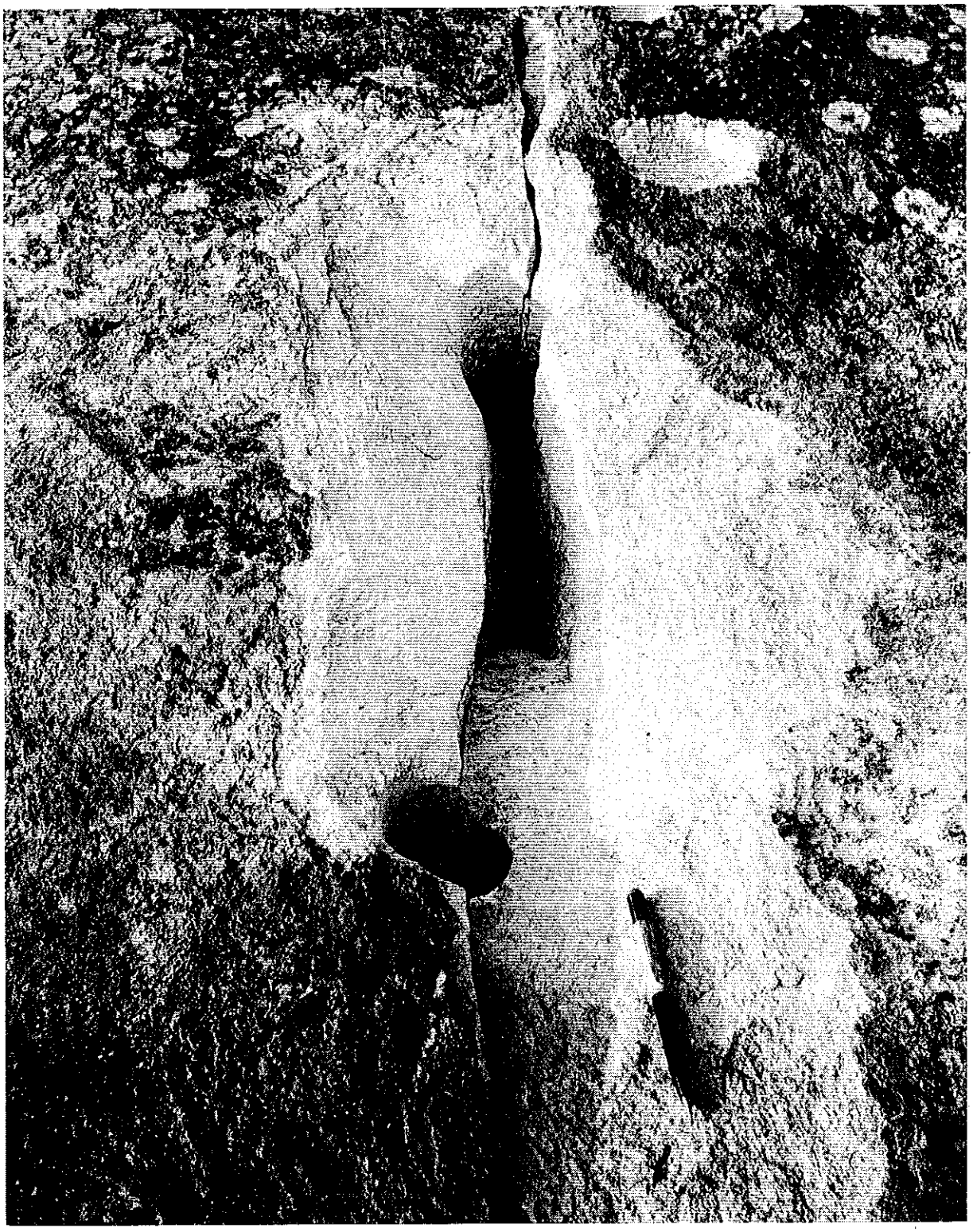

FIGURE 4. - Shotholes SH1 to SH2, Array 1.

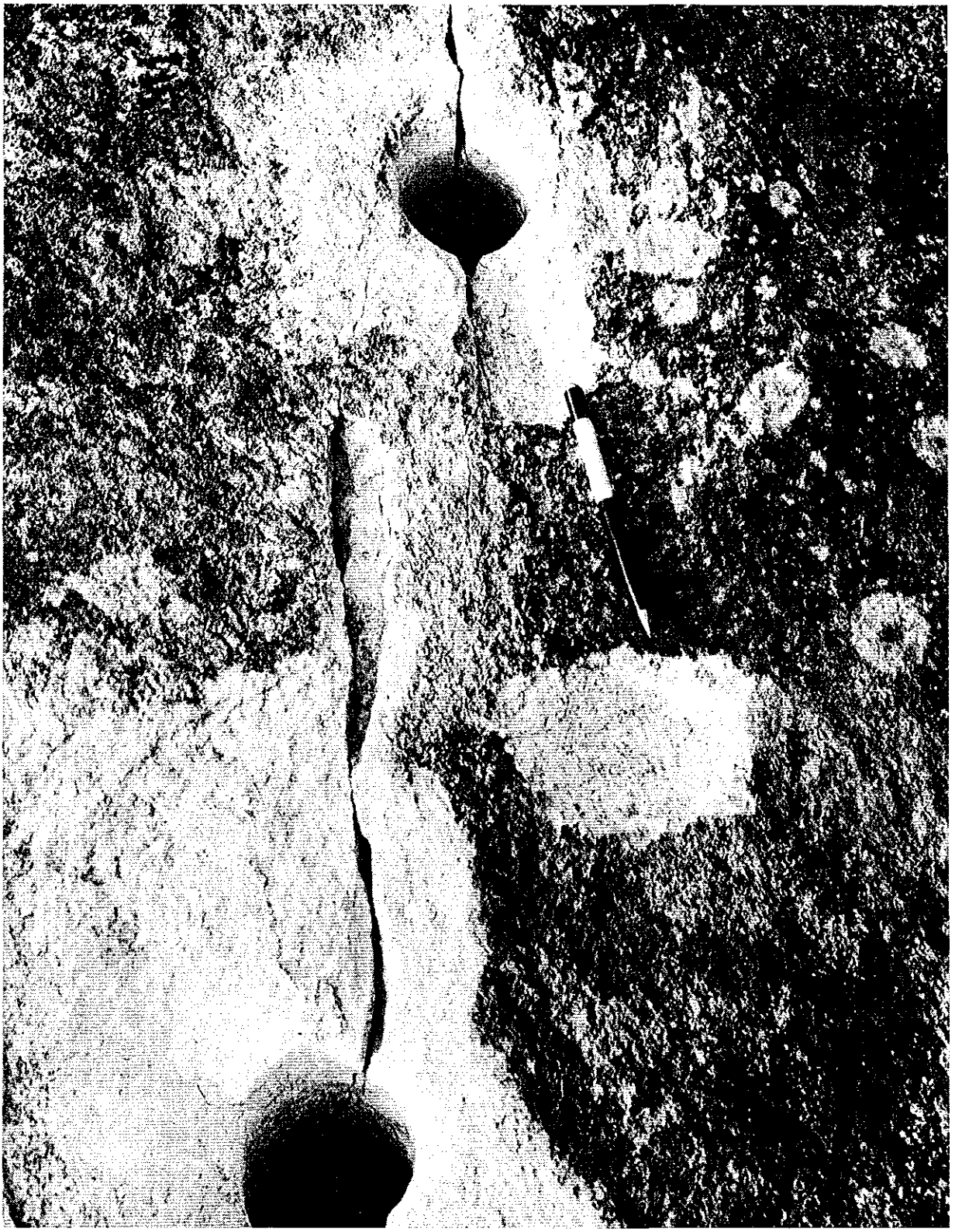

FIGURE 5. - Shotholes SH2 to SH3, Array 1.

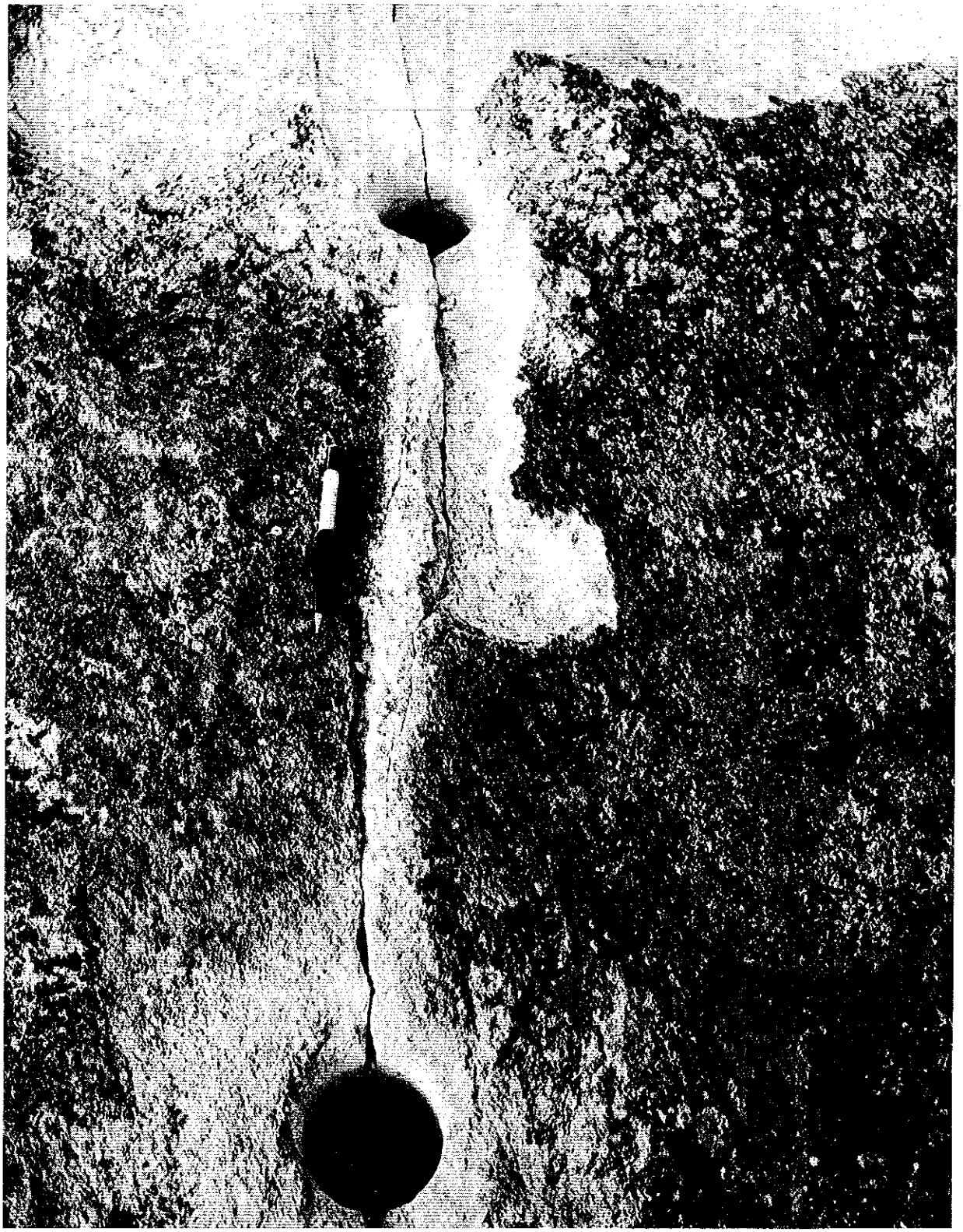

FIGURE 6. - Shotholes SH3 to SH4, Array 1.

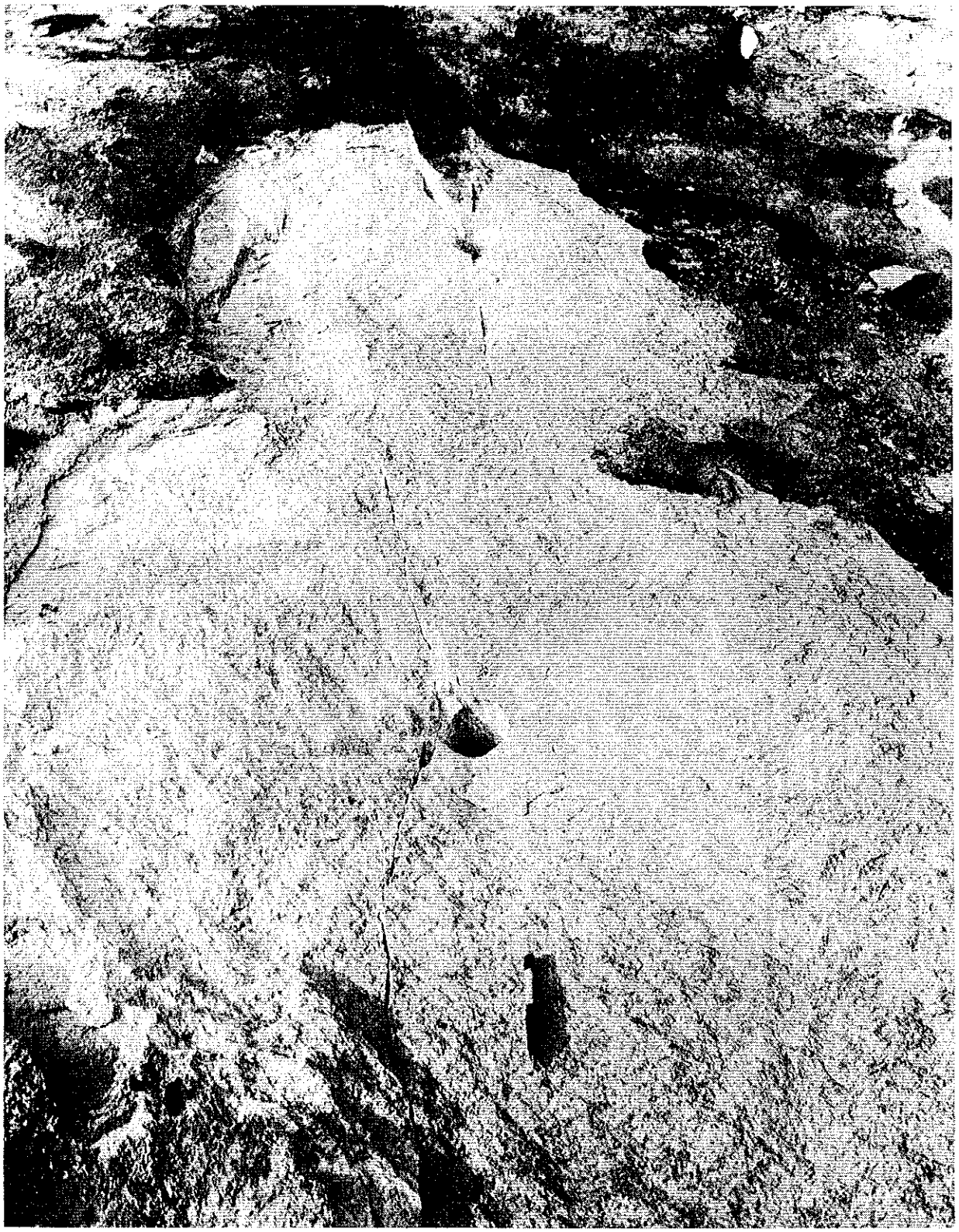

FIGURE 7. - Shotholes SH5 to SH6, Array 1.

FIGURE 8. - Surface Expression of Presplit Fracture, Array 1. Shothole SH1 in foreground.

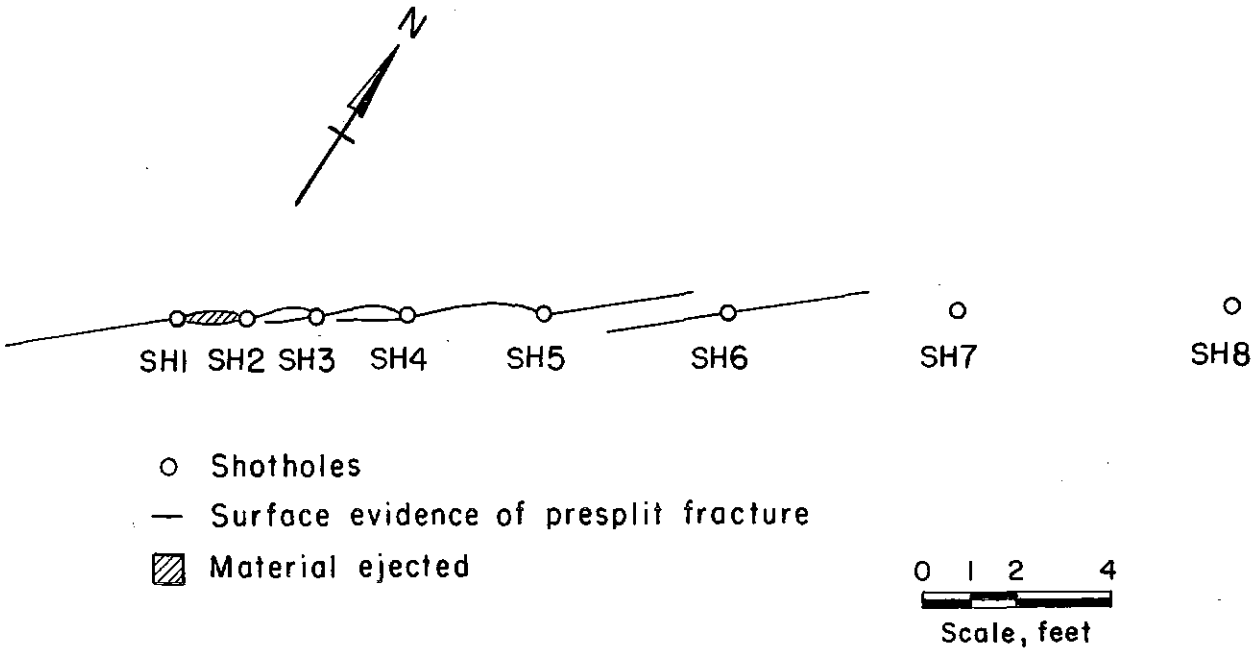

FIGURE 9. - Graphic Representation of Presplit Fracture, Array 1.

Continuous fracturing was limited to hole spacings of 3 feet or less. The largest cracks were, of course, associated with the smallest hole spacing, 1.5 feet. These cracks were greatest between holes SH1 and SH2, the first two holes with a spacing of 1.5 feet, implying that failure by presplitting is influenced by the next successive hole. That is, hole SH3 (1.5 feet from SH2) had a greater effect on splitting between hole SH1 and hole SH2 than hole SH4 (2 feet from SH3) had on splitting between hole SH2 and hole SH3.

One purpose of spreading the hole spacing was to determine if a presplit fracture, once generated between closely spaced holes, would continue to propagate between more widely spaced holes. As shown in figure 9, a continuous fracture was generated over a 3-foot spacing, and 2.5- to 3-foot discontinuous cracks were generated over 4- and 5-foot spacings. As stated previously, array 3 was laid out on the basis of the results from array 1. Three holes were drilled 3 feet apart, which was the widest spacing in array 1 where continuous fracturing had occurred. If the more closely spaced holes had acted to enhance crack propagation in array 1, no crack would be expected in array 3 from the detonation of a similar charge. No observable crack was generated in or around the holes in array 3.

Array 2, identical with array 1 but oriented in the direction of the minimum secondary stress, developed no observable cracks. A second charge, with double the charge size, was detonated and produced extensive fractures. Figure 10 is a photograph looking from hole SH1 along the array. Figure 11 is a graphic representation of the presplit fracture generated. Damage is considerably greater than in array 1, probably due to the increased charge size. Holes SH3 and SH4 are believed to be the widest spaced holes that are connected by fracturing. Holes SH4 and SH5 were 3 feet apart and are believed to be connected by a fracture system only at the surface. This is because a small piece of rock, connecting the almost parallel fractures emanating from holes SH4 and SH5, was ejected. An interesting feature is the fracturing around holes SH4, SH5, and SH6 which occurs at abrupt angles to the arrays and to the static stress field.

Tracings of the strain pulses obtained from shots S1 to S4 in array 4 are shown in figures 12 to 15. For all traces, motion above the baseline represents compressive strain, motion below the baseline represents tensile strain, and time increases from left to right. R following a gage number indicates a radial gage, and T indicates a tangential gage. Table 2 gives the peak amplitudes for the gages between the shotholes. Gages G4 and G5 were installed to determine the rate of decay of the tensile strain perpendicular to the line of center of the shotholes with distance from the line of centers. However, the complexity of the geometry and the records precluded completion of this phase of the analysis.

Figures 16 and 17 show the compression and tension amplitudes plotted as a function of distance for each of the four shots. Straight lines have been fitted to the data from shots S1 and S3 by the method of least squares. In general, the amplitudes from shot S1 are greater than those from shot S3 for similar distances. This was expected because shot S1 had two charges in the hole, and shot S3 had only one charge. Of greater significance is the

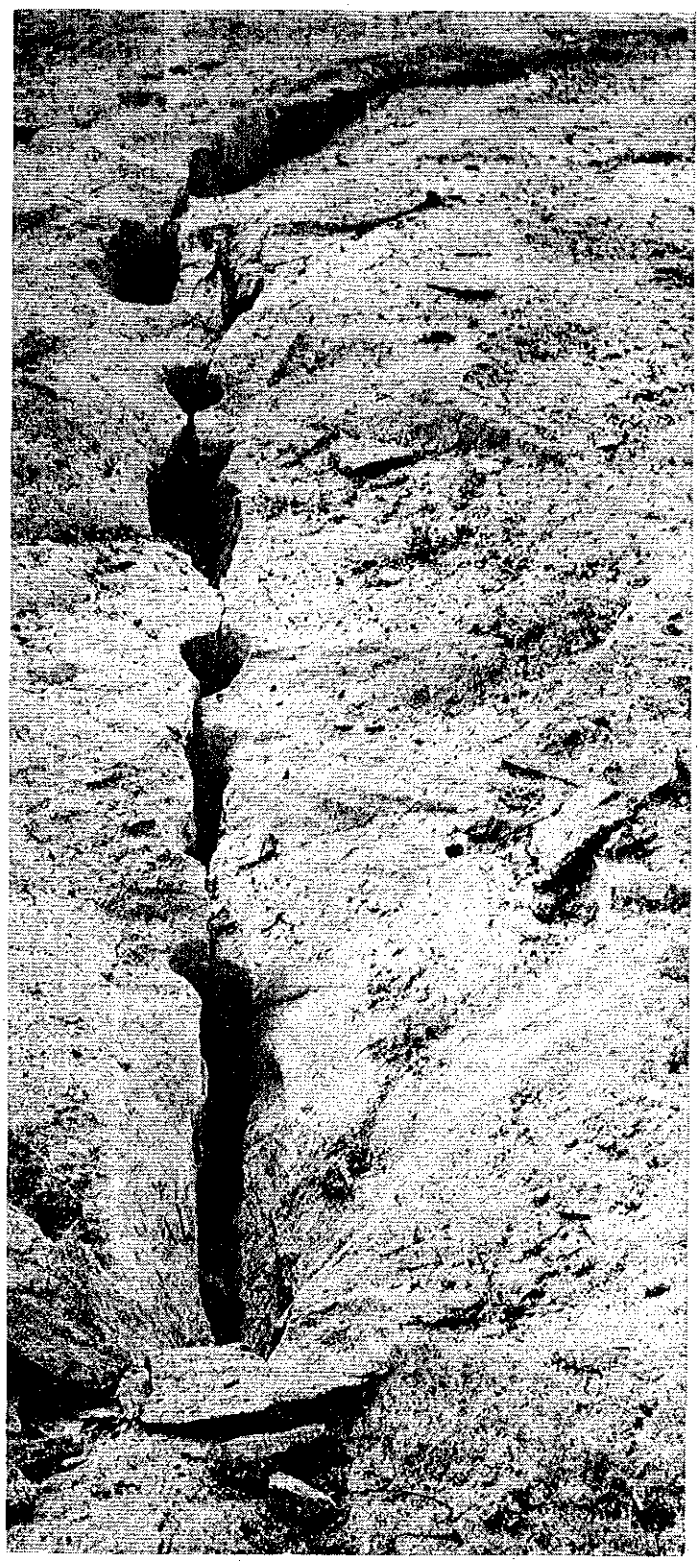

FIGURE 10. - Surface Expression of Presplit Fracture, Array 2. Shothole SH1 in foreground.

difference in slopes between shots S1 and S3. The slopes of the compression data are -1.40 and -1.90 for shots S1 and S3, respectively. For tensile data the slopes are -1.80 and -2.16 for shots S1 and S3, respectively. The lower values of slope from shot S1 are probably a direct result of spreading the charge out in the hole (two charges in reality). This is analagous to the lower slope obtained from a cylindrical charge as compared with a charge with a length-to-diameter ratio approaching unity. The important consequence of the lower slope or lower attenuation rate of strain amplitudes from multiple charges is that more strain is available at a distance from the charge. If addition of waves between holes is a major factor in presplitting, the additional strain available due to the multiple charges in the hole or a long cylindrical charge certainly enhances this addition of waves. Therefore preliminary tests conducted to determine hole spacing for presplit lines must be done with multiple or long cylindrical charges in each hole. Shallow holes with short single charges will give erroneous results.

A comparison of the data from shots S2 and S4 indicates that addition of waves at the center gage between the two shotholes is quite pronounced. Little or no addition has taken place at gages that were 4.5 feet from either shothole. As gages 4.5 feet from one shothole were only 1.5 feet from the other shothole, the strain data from these gages for shots S2 and S4 are plotted in figures 16 and 17 at 1.5 feet.

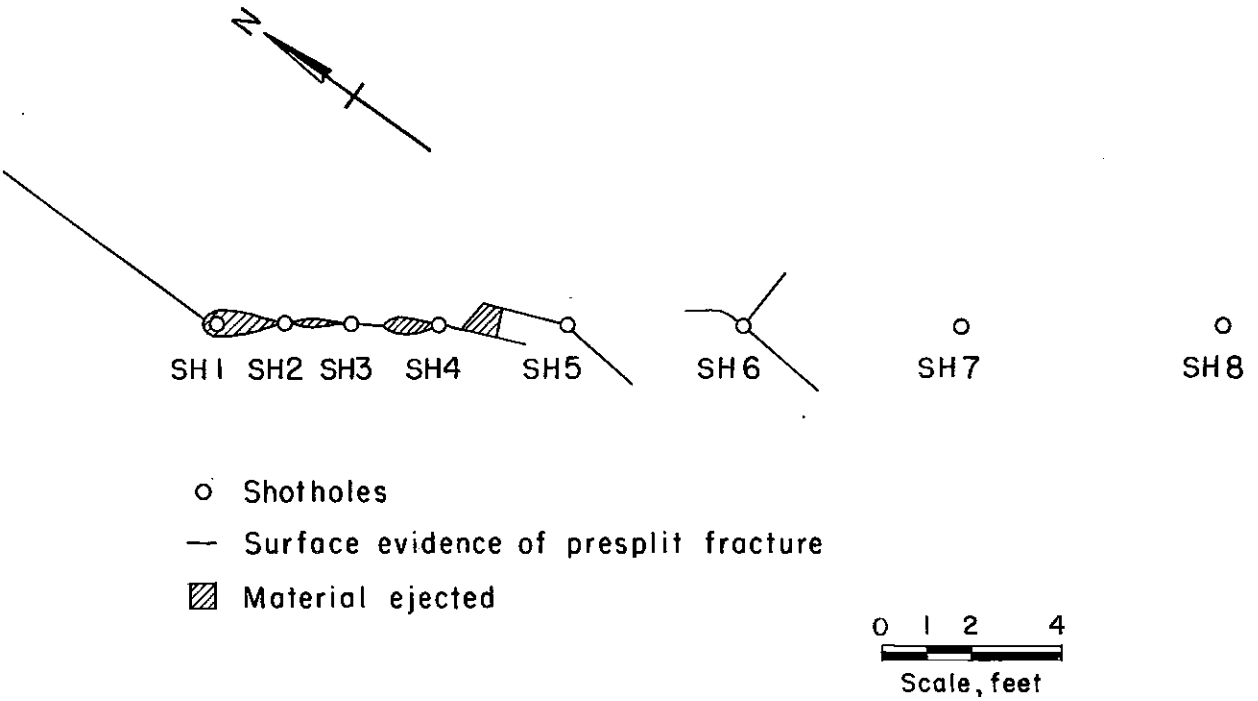

FIGURE 11. - Graphic Representation of Presplit Fracture, Array 2.

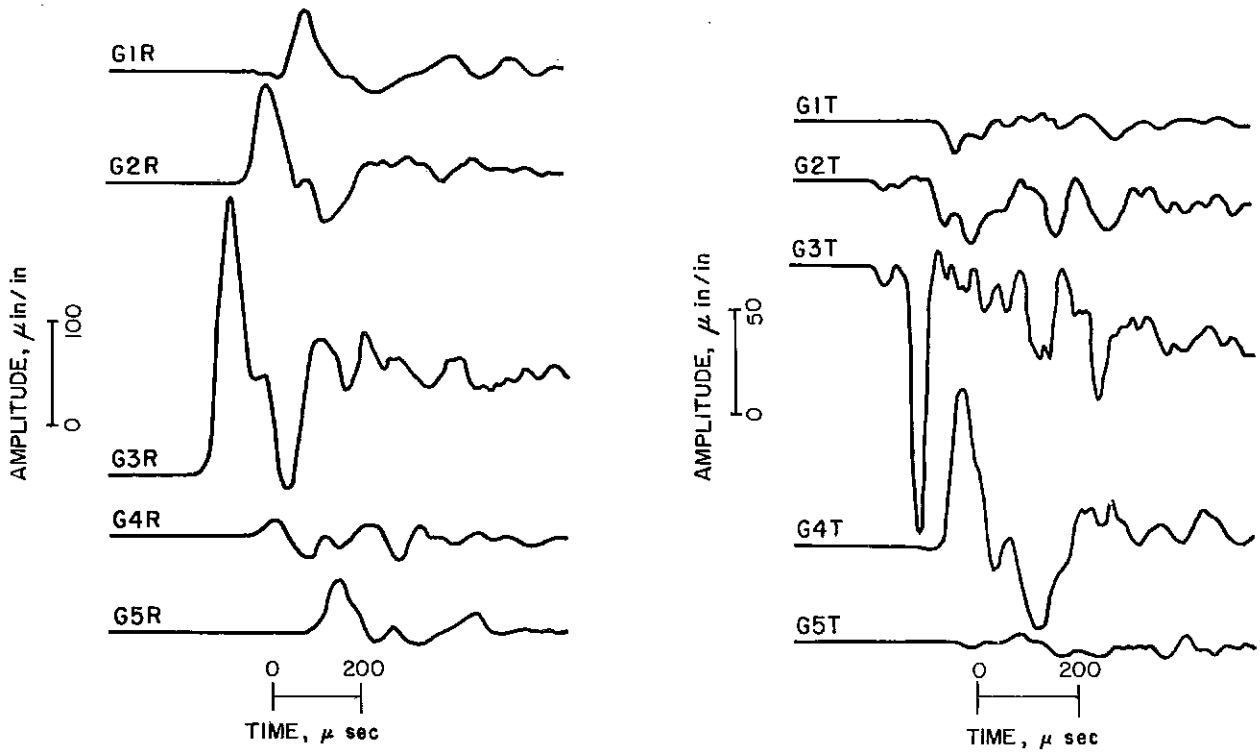

FIGURE 12. - Tracings of Strain Pulses, Shots 1, Array 4.

TABLE 2. - Strain amplitudes, μin/in

Gage	Shot			
	S1	S2	S3	S4
Compression				
G1R.....	59.4	402	264	276
G2R.....	101	175	69.5	226
G3R.....	272	340	33.6	269
Tension				
G1T.....	18.0	114	62.0	111
G2T.....	32.9	41.4	13.1	28.3
G3T.....	125	133	6.0	78.9

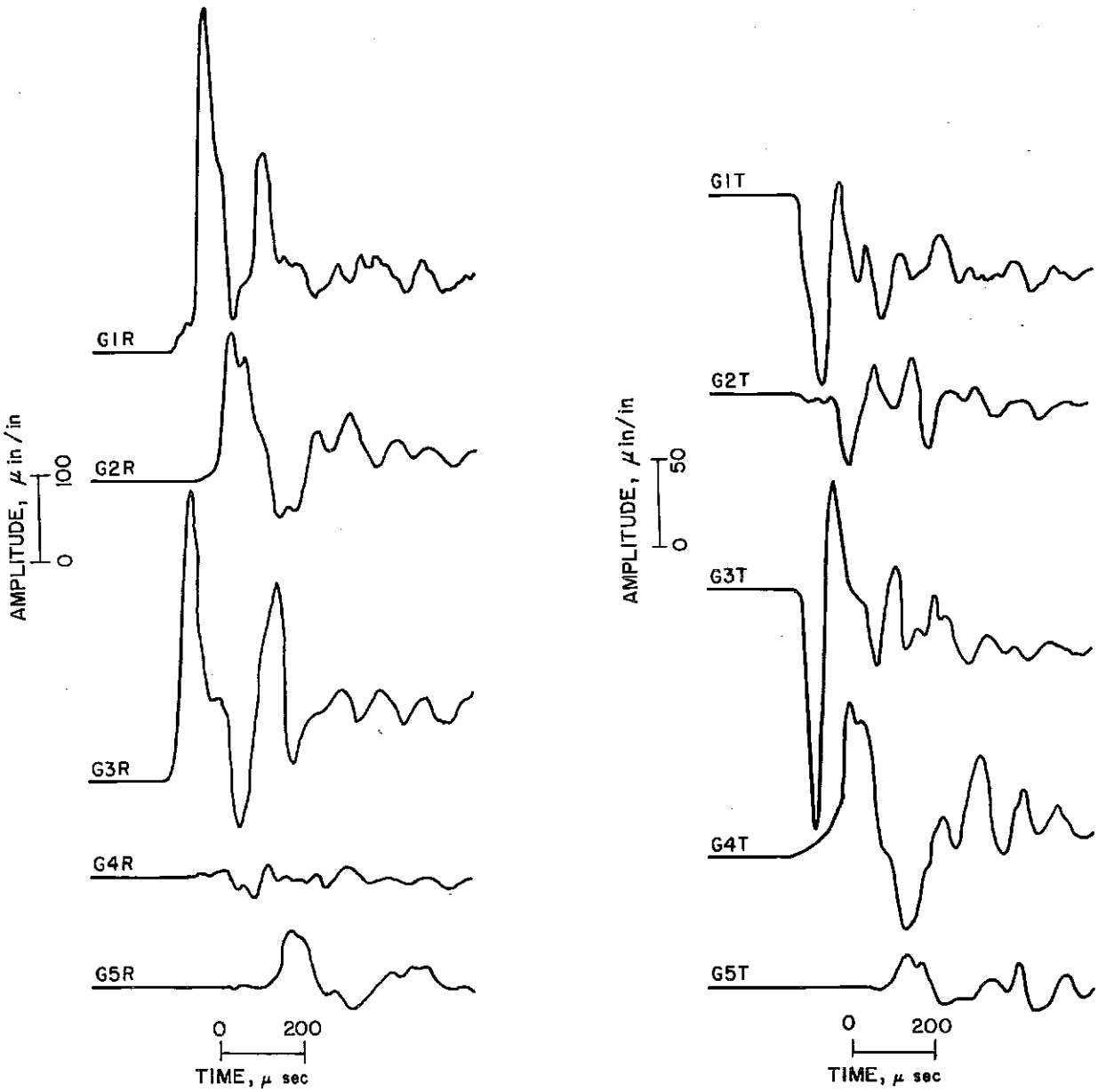

FIGURE 13. - Tracings of Strain Pulses, Shot S2, Array 4.

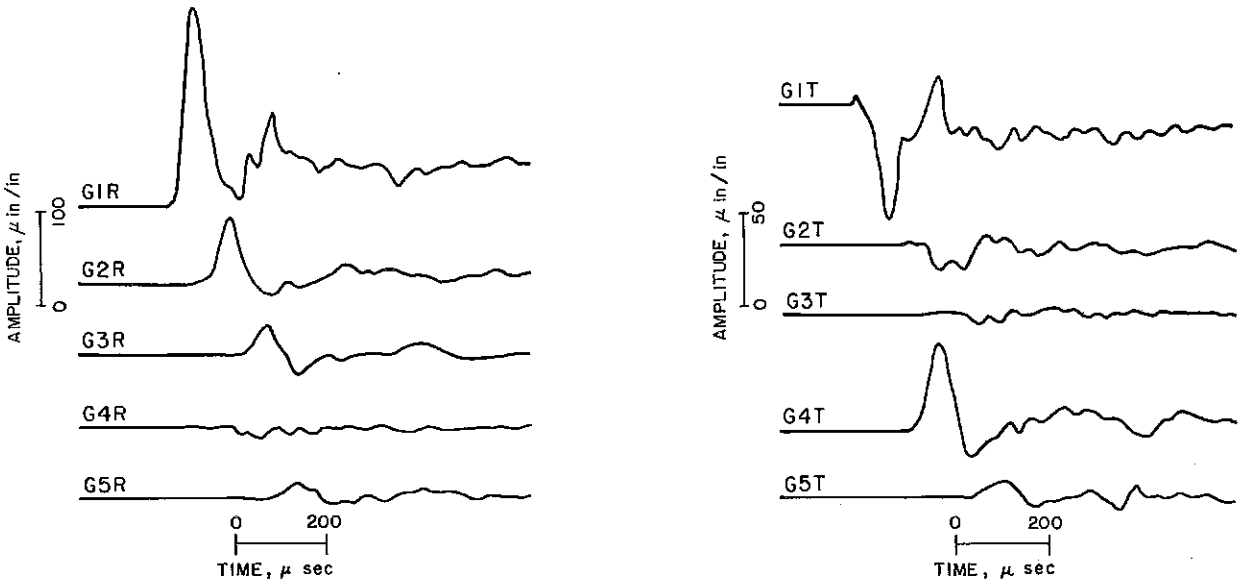

FIGURE 14. - Tracings of Strain Pulses, Shot S3, Array 4.

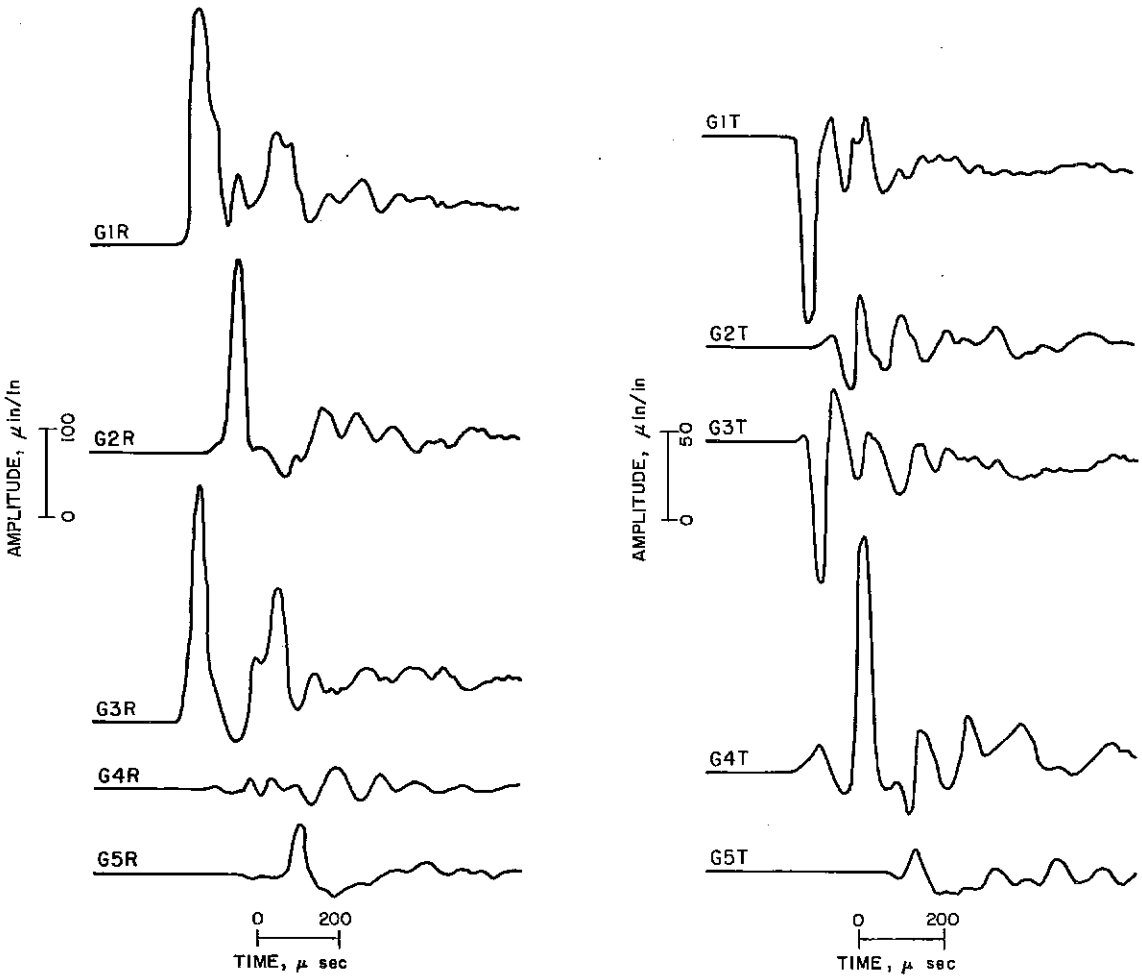

FIGURE 15. - Tracings of Strain Pulses, Shot S4, Array 4.

Young's modulus for the rock has been determined to be 9.5×10^6 psi (3). The product of this value and the peak strain approximates the stress developed. For presplitting to occur, the stress at the center between holes has to exceed the static stress field plus the dynamic tensile strength of the rock. For 2-foot shothole spacing, the compressive stress generated at the center between the holes was 4,600 and 5,400 psi from shots S1 and S3, respectively. This is considerably below the sum of the minimum static stress present and the static compressive strength of the rock. It is obvious, therefore, that compression plays only a small part in presplitting. The in situ stress normal to the line of holes is 1,200 psi, and the dynamic tensile strength of the rock has been estimated as 3,700 psi (1). Thus to create a tensile fracture, the tensile stress should exceed 4,900 psi. For shots S1 and S3 (single-hole shots) the calculated tensile stresses at a distance of 1 foot are 2,400 and 1,400 psi, respectively--insufficient to fracture the rock. However, the additional strain available due to a lower slope or attenuation rate from a series of charges spaced 1 foot apart in each of two holes spaced only 2 feet apart could easily result in a tensile stress exceeding 4,900 psi.

Table 3 shows half pulse times and half wavelengths for gages between the shotholes. The average half wavelengths range from 1.0 to 2.3 feet with a grand average of 2 feet. The smaller average half wavelengths are associated with the tensile strain pulses for simultaneously detonated holes. Continuous addition of waves between two simultaneously detonated holes would not be expected to take place if the spacing exceeded the half wavelength. As previously pointed out, little or no addition occurred at a distance of 4.5 feet from either of two simultaneously detonated holes on shots S2 and S4. This distance exceeds the half wavelength and substantiates the importance of the half wavelength.

TABLE 3. - Half pulse times and half wavelengths

Gage	Shot			
	S1	S2	S3	S4
Half Pulse Time (m sec)				
G1R	0.090	0.110	0.150	0.110
G2R	.105	.170	.120	.110
G3R	.155	.150	.095	.110
G1T	.075	.100	.145	.075
G2T	.180	.080	.120	.040
G3T	.110	.065	.110	.050
Half Wavelength (ft)				
G1R	1.6	2.0	2.7	2.0
G2R	1.9	3.1	2.2	2.0
G3R	2.8	2.7	1.7	2.0
Average	2.1	2.3	2.2	2.0
G1T	1.4	1.8	2.6	1.4
G2T	3.2	1.4	2.2	.7
G3T	2.0	1.2	2.0	.9
Average	2.2	1.5	2.3	1.0

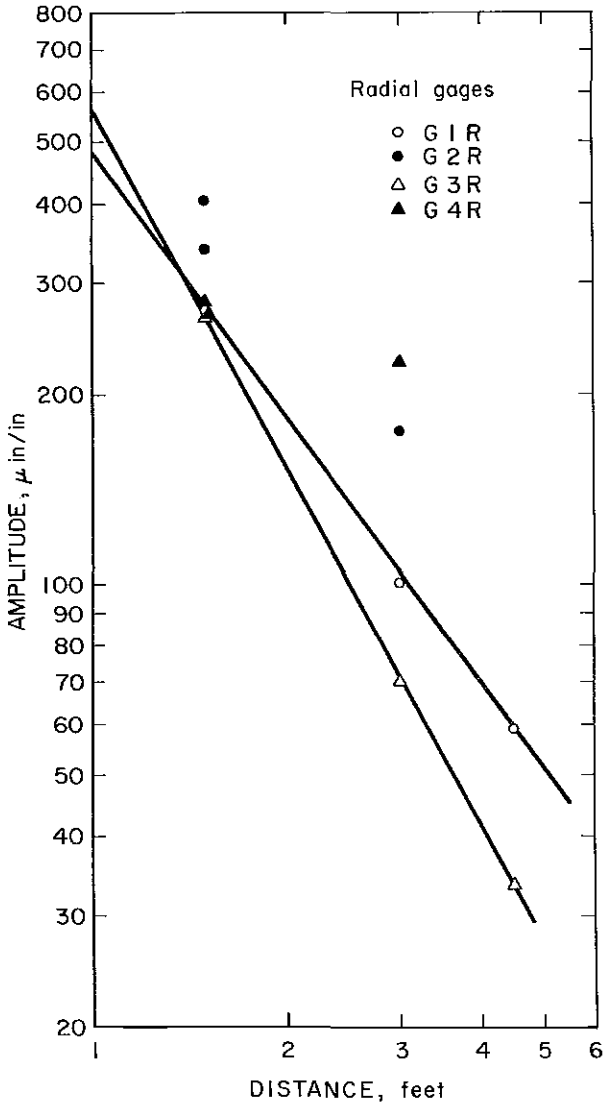

FIGURE 16. - Compression Amplitude Versus Distance, Array 4.

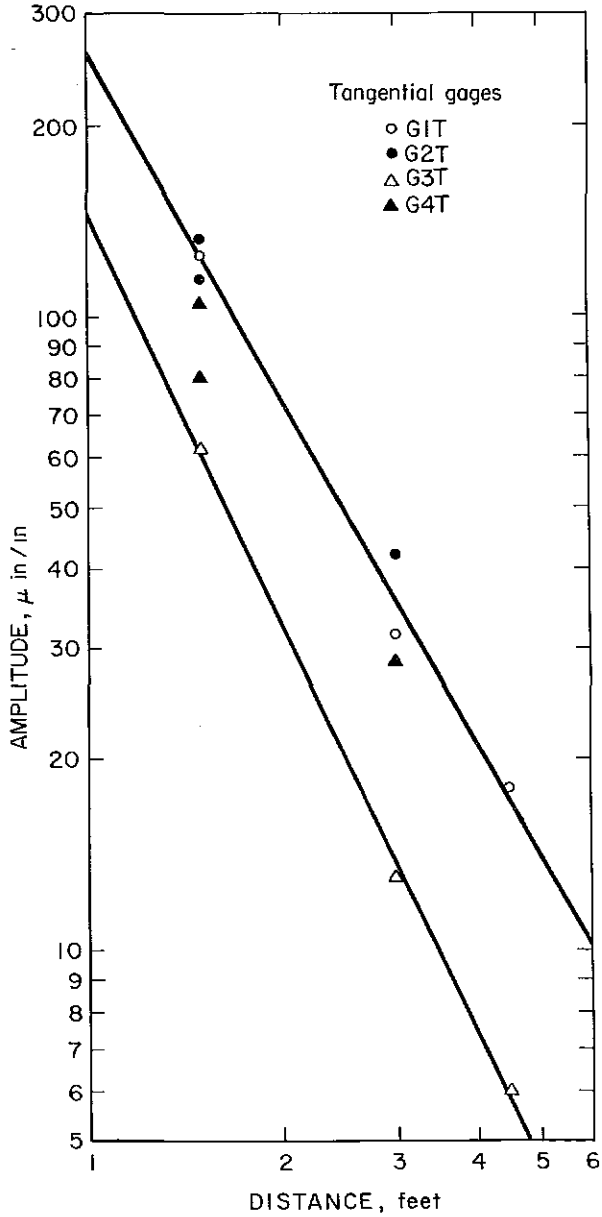

FIGURE 17. - Tension Amplitude Versus Distance, Array 4.

From tensile strains and half wavelength considerations, hole spacing in this granite gneiss appears to be limited to 2 feet or less for adequate presplitting to occur when using 2.5-inch-diameter holes loaded with 1.25-inch-diameter charges spaced at 1-foot intervals. This is in general agreement with results from arrays 1 and 2. It is entirely feasible that spacing may be increased in the direction of the maximum secondary principal stress as compared to the direction of the minimum stress. In the case of array 1, the closely spaced holes (SH1, SH2, SH3, SH4) may have generated a crack that was

propagated in a wedgelike manner by the gas pressure. The role that expanding gases play in propagating presplit cracks is not known. However, from the limited data included in this report it appears that both expanding gases and interaction of stress waves in the rock are responsible for the creation of presplit fracture planes.

CONCLUSIONS

The results from arrays 1 and 2 empirically verify previous results in attempts to presplit in underground openings. It is much easier to presplit in the direction of the maximum in situ compressive stress than at any angle to this direction.

On the basis of the instrumented tests in array 4, it appears that the tensile stress generated must exceed, at every point between holes to be presplit, the sum of the in situ compressive stress at right angles to the presplit line and the dynamic tensile strength of the rock. The hole spacings predicted from stress considerations and from half wavelengths are about the same.

Results also indicate that a presplit line may be generated over wider spacing if the initial holes in the line are closely spaced. This may be a result of gas pressure invading the cracks in a wedging-type action.

The exact phenomena involved in presplitting are not precisely defined herein. The limited amount of field testing has provided some clues and some verification of the nature of presplitting in the presence of a static stress field.

The work presented should be used as a basis for future field investigations. Instrumented tests should be conducted where a presplit fracture is expected. Break circuits should be applied to the surface of the rock where fracture is expected so that the time of crack growth may be correlated with strain data. This may provide better definition of the role that expanding gas pressure plays in presplitting.

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