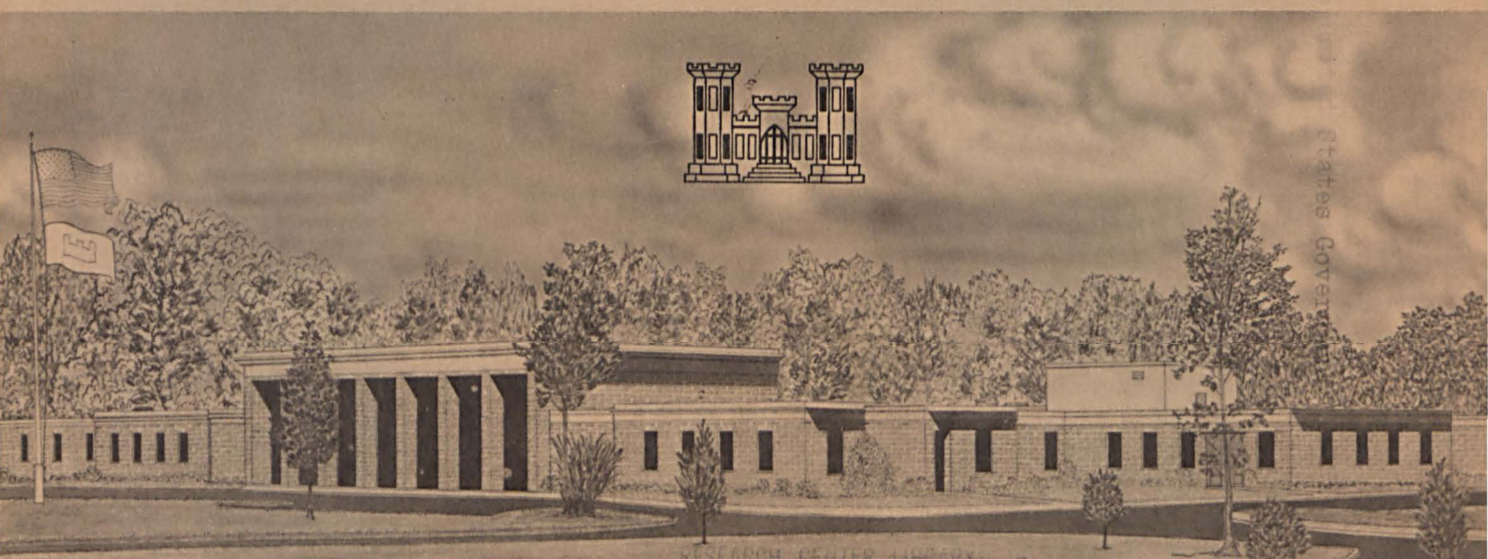
MISCELLANEOUS PAPER N-70-4

OPERATION MINE SHAFT SURFACE EFFECTS AND CAVITY RESULTING FROM THE DETONATION OF A 16-TON CHARGE DEEP IN GRANITE

by

J. N. Strange, W. H. McAnally, Jr.



July 1970

Sponsored by Defense Atomic Support Agency

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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ARMY-MRC VICKSBURG, MISS.

ABSTRACT

This report describes the time history of the above-surface phenomena associated with the MINERAL LODE Event of the MINE SHAFT Series, 1969. The report also documents the subsurface cavity as inferred from postshot slant holes that had as an aiming point the original center of detonation.

MINERAL LODE involved detonation of a 16-ton ammonium nitrate slurry at a depth of burial of 100 feet in granite at the MINE SHAFT test area near Cedar City, Utah.

A summary of the MINERAL LODE results, particularly of the quantitative measurements obtained, is as follows:

(a) Jointing patterns in the rock significantly affected the mound shape. The total volume of the mound was calculated to be 2700 ± 50 cubic yards.

(b) The initial rise velocity of the ground surface immediately above the charge (GZ) was approximately 30 feet per second. After 250 milliseconds, the rise velocity was about 85 feet per second.

(c) Ejecta heights and ranges were probably less than 150 feet for both. Ejecta sampling showed that 75 percent of the visible (surface lying) fragments were smaller than 3.5 feet, 50 percent were smaller than 2 feet, and 25 percent were smaller than 1 foot.

(d) The mean radius of the below-surface explosion cavity was established as 20 to 25 feet.

PREFACE

The MINE SHAFT Series, sponsored by the Defense Atomic Support Agency (DASA), is a multipurpose test program involving participation of a number of different agencies. The main purpose of the experiments was to obtain quantitative information on blast and shock effects, and on cratering and ejecta phenomena associated with essentially surface detonations over rock.

The MINE SHAFT Series-1969, consisted of two events: MINERAL LODE and MINERAL ROCK. Mr. L. F. Ingram of the Nuclear Weapons Effects Division (NWED), U. S. Army Engineer Waterways Experiment Station (WES), served as Technical Director of the Series. Field support activities for the 1969 tests were under the direction of DASA Test Command.

This report was prepared by Messrs. J. N. Strange and W. H. McAnally, both of the NWED staff, WES. During the period of these tests, Mr. G. L. Arbuthnot, Jr., was Chief of the NWED. COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE, were Directors of the WES, and Messrs. J. B. Tiffany and F. R. Brown were Technical Directors.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows.

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles (U. S. statute)	1.609344	kilometers
feet per second	0.3048	meters per second
cubic yards	0.7645549	cubic meters
pounds	0.4535924	kilograms
tons (2,000 lb)	907.1847	kilograms

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In order to provide design-level protection of underground facilities (facilities that are inextricably linked with a variety of weapons systems), the Defense Atomic Support Agency (DASA) has sponsored a number of explosion effects research projects aimed at defining free-media and free-field phenomena and effects. The various research efforts have sought to ascertain also the changes in the amplitude, character, and frequency spectra of shock motions that result from explosion energy sources that are initiated in a variety of materials typical of those occurring in the earth's crust.

To date, such experiments have been carried out in desert alluvium, playa, granite, tuff, limestone, and basalt at the Nevada Test Site (NTS), and in glacial till at Canada's Defence Research Establishment, Suffield (DRES). During the fall of 1968, a high-yield, high explosive (HE) test series, known as the MINE SHAFT Series, was initiated in a massive granite outcropping near Cedar City, Utah.

Two shots were fired during the fall of 1968; these shots were code named MINE ORE and MINE UNDER (Reference 1). Both were nominal 100-ton[1] detonations of stacked TNT arrayed as a sphere. The MINE UNDER charge

[1] A table of factors for converting British units of measurement to metric units is presented on page 7.

was positioned so that its center of gravity was two charge radii above the granite surface (~16 feet). The MINE ORE charge was positioned such that its center of gravity was 0.9 of a charge radius above the granite surface.

In 1969, the MINE SHAFT Series was continued (Reference 2) with a 16-ton slurry detonation on 5 September 1969; this shot was code named MINERAL LODE. A second shot, MINERAL ROCK, was fired on 8 October 1969; its yield was 100 tons (TNT).

1.2 OBJECTIVE

The MINE SHAFT series is being conducted primarily to learn how explosion-induced ground shock, both direct and airblast induced, propagates through rock so that concurrent theoretical efforts may be quantified, improved, and made more reliable as a tool in predicting weapon effects.

The detailed objectives of the MINERAL LODE Event are presented elsewhere (Reference 3). Briefly though, the objectives were to measure ground shock from an explosion in granite where all interfaces (other than the existing rock joints) were sufficiently removed from the zero point so as not to influence the various measurements in the regions of interest.

Since the charge center of gravity was placed 100 feet below the surface and scaling relations for this depth of burial (assuming TNT) are such that the probability of significant venting and mounding of the surface was estimated to be about 0.5, no project was set up to study or evaluate such effects. However, interest in various effects increased shortly before the shot because of uncertainties regarding venting and possible throwout phenomena. Moreover, the unusual shape and size of the surface mound produced by the explosion made it desirable to document the surface effects in as much detail as postshot surveys would permit.

The objective, therefore, of this report is to document to the degree possible important quantities pertinent to cavity expansion, mounding, venting, ejecta, etc., that were associated with the MINERAL LODE Event.

1.3 PRESHOT ESTIMATES OF SURFACE AND SUBSURFACE EFFECTS

Estimates of the extent and height of surface ejecta were made in the interest of establishing minimum safe distances for siting instrument bunkers, camera stations, etc. The extent and amount of uplift in the vicinity of ground zero (GZ) were also estimated along with a prediction of the precollapse cavity size.

1.3.1 Precollapse Cavity Size. Based on cratering and camouflet experiments in various types of rock, the MINERAL LODE precollapse cavity radius was predicted empirically by Rooke and Strange to be 24 ± 5 feet.

For prediction purposes, the explosion yield was assumed to be the equivalent of 20 tons of TNT, which, at the time the predictions were made, was the planned yield of MINERAL LODE.

The cavity predictions were made empirically by developing scaled mean cavity radii for camouflet and venting-type cratering shots (but deeply buried) in a variety of rock materials (References 4 - 9) and selecting the mean scaled value most nearly suited to the rock mass characteristics of the Cedar City granite (tonalite). For this case the mean scaled cavity radius amounted to

$$r_c/W^{1/3} = 0.7$$

which for a yield of 20 tons produced

$$r_c = 0.7\ W^{1/3} = 0.7\ (34.2)$$

$$r_c = 24 \text{ feet}$$

The spread in the data was characterized by about $\pm$ 20 percent.

1.3.2 Zone of Uplift. Mound extent and maximum height were also estimated by Rooke and Strange to be approximately 110 feet in diameter and 3 to 5 feet in height, respectively. The extent of the mound was based on an approximation of the shear cone boundaries emanating from the zero point (ZP). Normally the shear cone angle closely approximates 40 to 45 degrees for such shots; but because of the existence of rock joints, this angle was reduced to an angle of 30 degrees allowing for earlier venting than would occur without joints (Figure 1.1). This gives a calculated mound diameter of 114 feet. The mound height was estimated, on the basis of a volume bulking factor of 1.1, to be between 3 and 5 feet.

1.3.3 Ejecta. Estimates of surface ejecta (fly rock) were made from observations of ground rise velocities measured in other experiments in which the scaled depth of burial was similar for roughly similar media (References 8 and 9). A rise velocity of 80 feet per second is characteristic for such shot geometries at the yield level involved. From this fact, both peak ejecta height and range were estimated by Rooke and Meyer to be 100 feet.

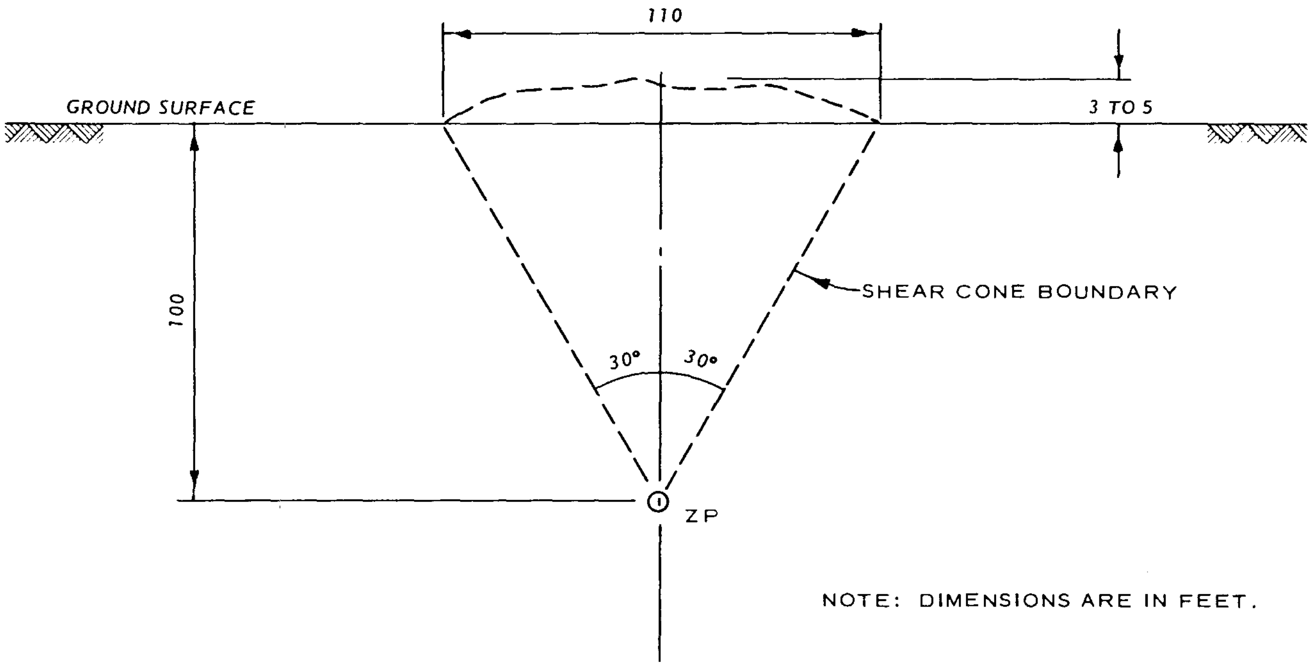


Figure 1.1 Predicted dimensions of mound, MINERAL LODE Event.

CHAPTER 2

DESCRIPTION OF THE EXPERIMENT

2.1 SITE DETAILS

2.1.1 Location. The MINERAL LODE Event was executed in Site 6 at the MINE SHAFT test area near Cedar City, Utah. The test area is in the vicinity of The Three Peaks, about 10 air miles WNW of Cedar City; the GZ coordinates are: Latitude, 37°48'20.803" N; Longitude, 113°10'27.588" W.

2.1.2 Geology. The details of the site geology are to be published in a separate WES report entitled: "Geologic Investigation of MINE SHAFT Test Sites, Cedar City, Utah" (scheduled for publication in calendar year 1970). A qualitative description of the site geology is summarized here for information purposes.

The rock formation containing the MINERAL LODE zero point (ZP) is a massive igneous intrusion of granitic rock. That part of the intrusion that is exposed to the atmosphere is surficially weathered, somewhat jointed, and potted. Explicitly, the rock is described as tonalite; its quality improves with depth down to about 20 feet. At greater depths, its properties, on an average, remain reasonably constant. Depth of the granitic mass is undetermined; it does extend however to a depth of more than 200 feet.

Although surface jointing was somewhat random in the GZ area, the dominant joint system ran roughly in a north-south direction; generally these joints were spaced in the range of 3 to 5 feet. Intersecting joints (trending east-west) were spaced in the range of 5 to 10 feet apart. All joints were reasonably well healed. Unfortunately, a detailed joint map was not prepared before the MINERAL LODE Event.

2.1.3 Topography. A contour map of the GZ area is presented in Figure 2.1. Because of the selected contour interval, surface irregularities are not altogether detailed, or in some instances, even apparent. A photograph of the site (preshot) is presented in Figure 2.2 to illustrate the randomness of the igneous outcrops and the characteristics of the surface roughness.

2.2 DETAILS OF THE EXPLOSIVE CHARGE

2.2.1 Type of Explosive. The charge consisted of a slurry-type explosive made and emplaced by Intermountain Research and Engineering Company, Inc. (IRECO) of West Jordan, Utah. The slurry, designated DBA-XDM, is a proprietary mixture, the complete formulation of which is known only by IRECO; however, the basic ingredients are ammonium nitrate sensitized with aluminum powder. Some of the properties of this explosive as given in Reference 10 are summarized as follows:

Density = 1.20 $\pm$ 0.04 g/cm^3

Detonation velocity = 4,500 $\pm$ 200 m/sec

Detonation pressure = 60 $\pm$ 5 kilobars

The main reason for using this explosive was to provide a relatively low-pressure loading of the rock compared to high-explosive loadings such as are provided by TNT.

2.2.2 Weight of Explosive and Estimated TNT Equivalent Yield. A total of 31,760 pounds of the slurry explosive were poured (at a controlled rate) into the charge placement cavity. On the basis of energy release (calories per gram), the slurry has about 0.7 the energy release of TNT, or about 750 to 800 calories per gram (Reference 10). Thus the 31,760 pounds of slurry when detonated released about the same total energy as 22,250 pounds of TNT. The cube root of the TNT equivalent yield is

$$W^{1/3} = 22,250^{1/3} = 28.1$$

and the 1/3.4th root is

$$W^{1/3.4} = 22,250^{1/3.4} = 19$$

Similarly, the cube root of the slurry yield is

$$W^{1/3} = 31,760^{1/3} = 31.6$$

and the 1/3.4th root is

$$W^{1/3.4} = 31,760^{1/3.4} = 20.8$$

The charge was initiated by two high-energy detonators (RP-1 modified) placed in a 5-pound tetryl booster located in the center of the sphere.

2.2.3 Explosive Cavity and Stem. An added advantage of using the slurry was ease of placement; as mentioned previously, it was simply poured into the mined spherical cavity, which was nominally 9 feet in diameter (working tolerance of the cavity diameter was ± 2 inches) and 100 feet below the surface. The cavity was waterproofed with shotcrete containing a Sitka waterproofing compound to preclude any possibility of slurry leakage. Access to the cavity was gained by a 56-inch-diameter cored shaft. The shaft was stemmed with high-strength concrete.

2.3 SHOT GEOMETRY

The charge center of gravity was situated 100 feet below the surface. This corresponds to scaled depthsof 3.56 and 5.27 when cube root and $1/3.4^{th}$ root scalings are used, respectively (in each case, the TNT equivalent yield is assumed as 22,250 pounds). The shot geometry and stem detail are shown in Figure 2.3.

2.4 PHOTOGRAPHY

Photographic coverage of the above-ground explosion phenomena was provided by three cameras. Two high-speed cameras were mounted atop a 20-foot tower 800 feet southwest of GZ. A slower speed camera covered the phenomena from the visitors' observation point (VOP) about 8,000 feet south of GZ (Figure 2.4).

The high-speed cameras consisted of a Nova operating at 3,200 frames per second (at detonation) and a Milliken operating at 400 frames per second. Both used Ectachrome EF film, type 7241, and timing marks were provided to calibrate film speeds. The third camera was a Bell and Howell operating at a speed of 64 frames per second.

Zero time was indicated in the cameras' field of view by a short length of primacord and a detonator, wired in parallel with the main charge. The zero-time signal appeared as a flash and puff of smoke on the film. For length calibration, two 2- by 12-inch boards painted with alternating 2-foot red and white stripes were placed 20 feet to either side of GZ in a plane perpendicular to the cameras' line of sight.

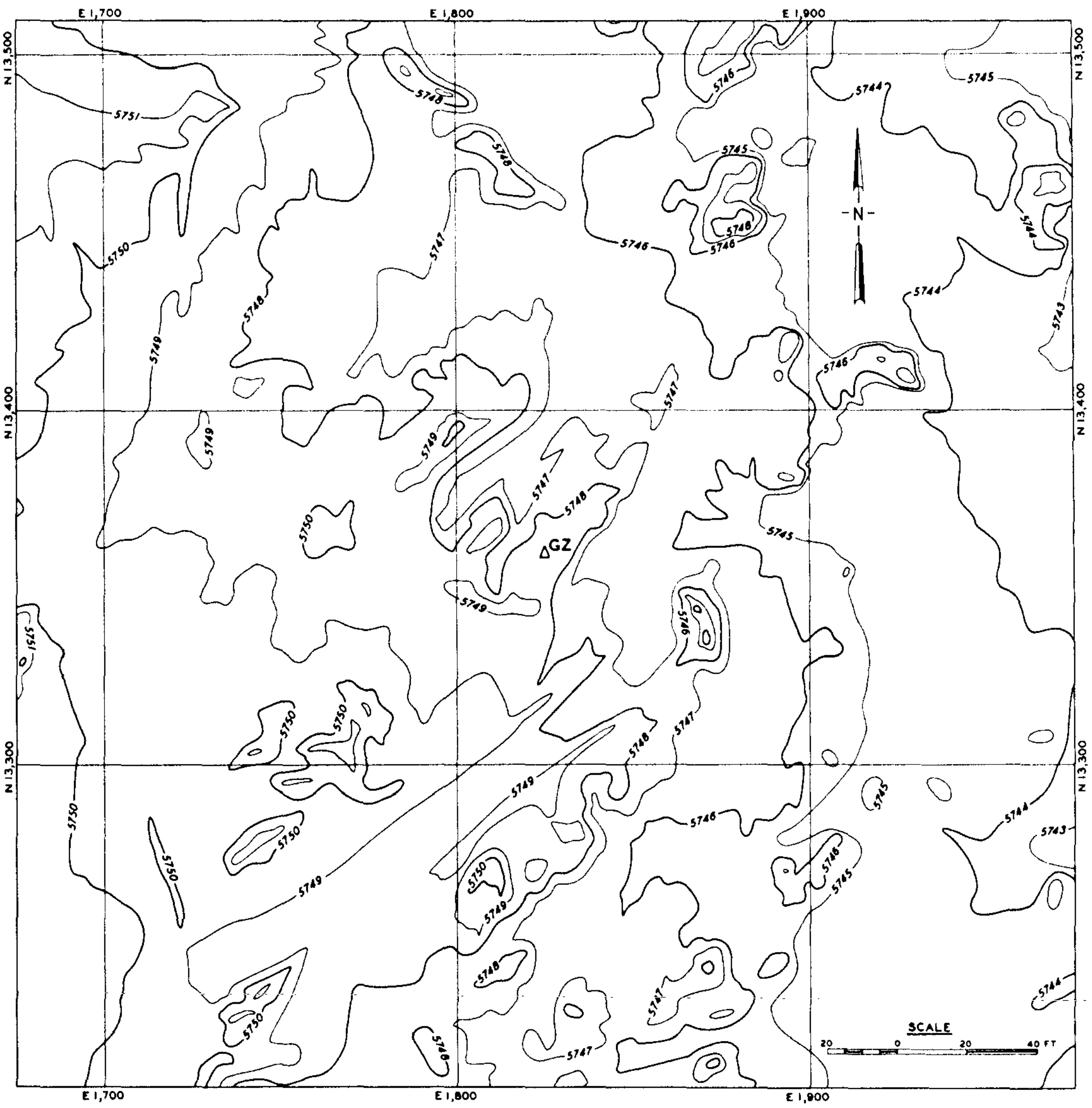


Figure 2.1 Preshot contour map of GZ area, MINERAL LODE Event.

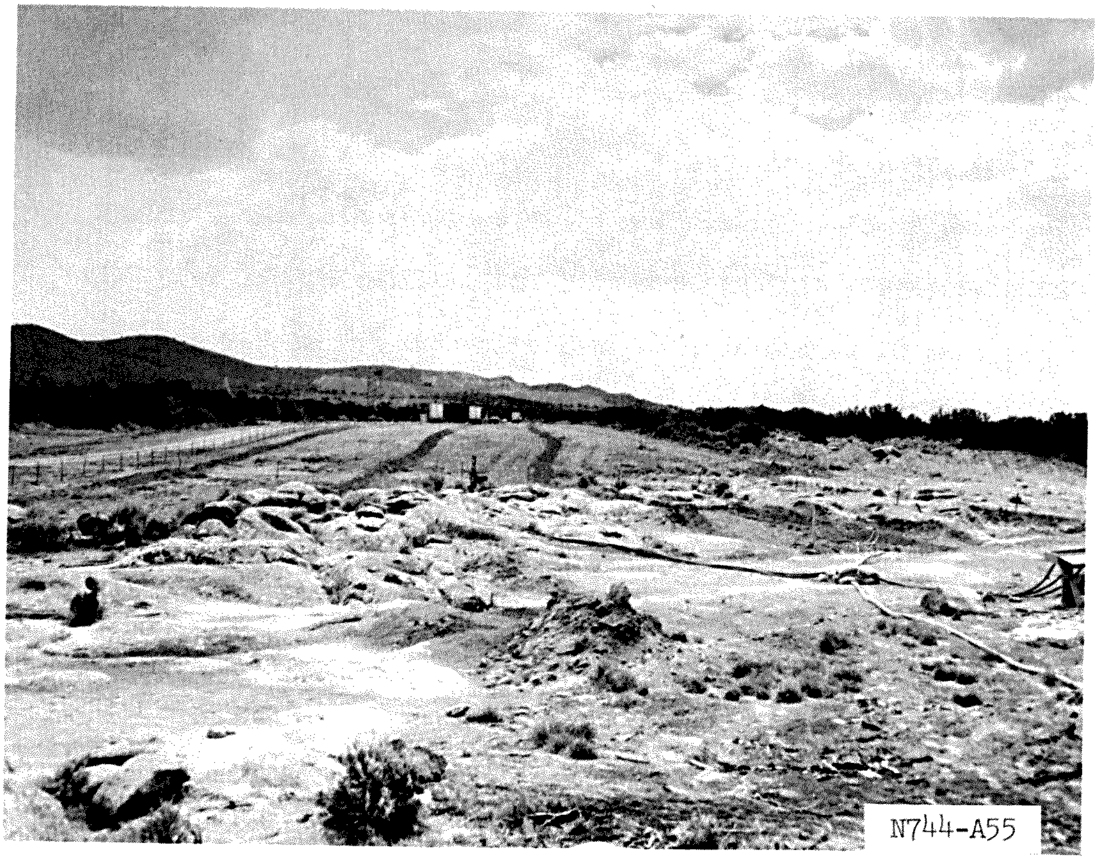


Figure 2.2 General topography and rock outcrop patterns at GZ, MINERAL LODE Event.

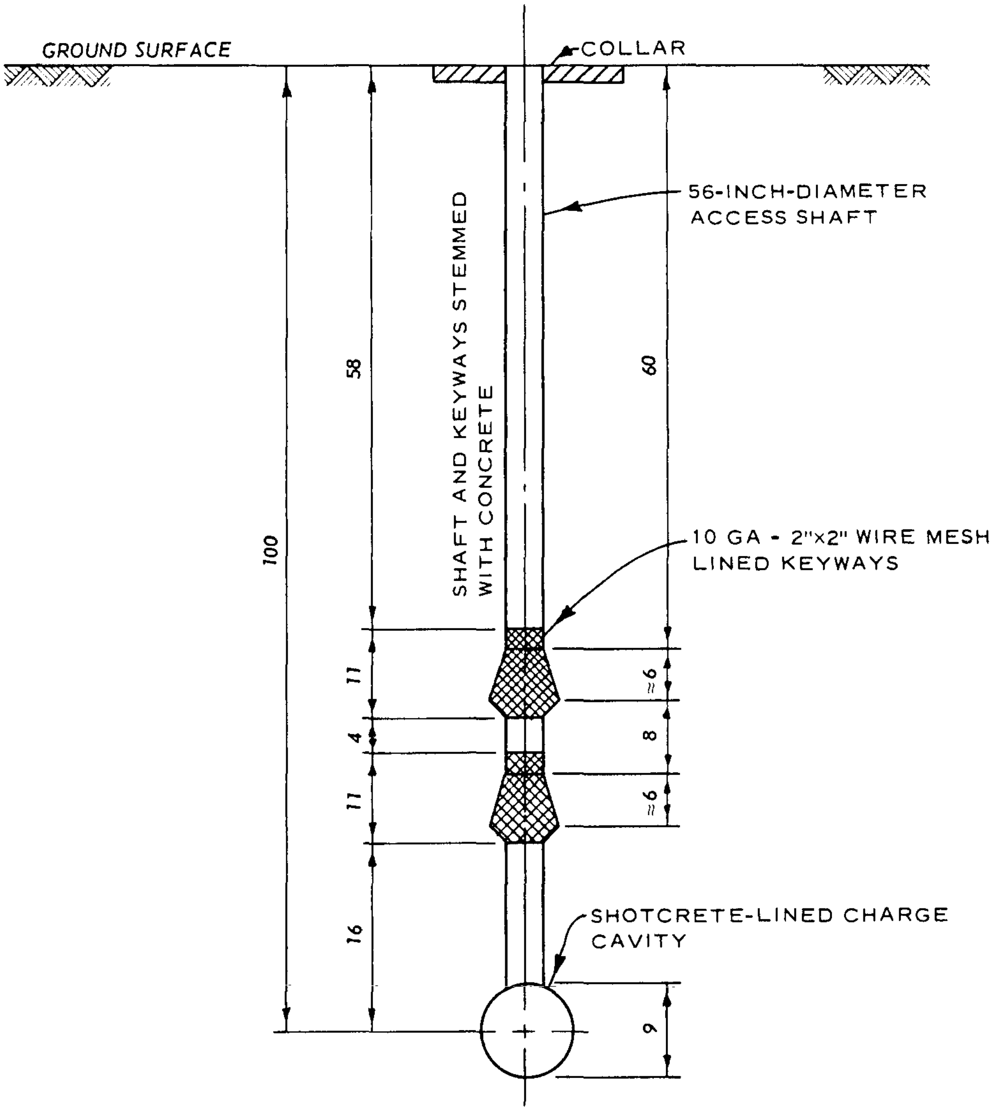


Figure 2.3 Shot Geometry and stemming detail for MINERAL LODE Event.

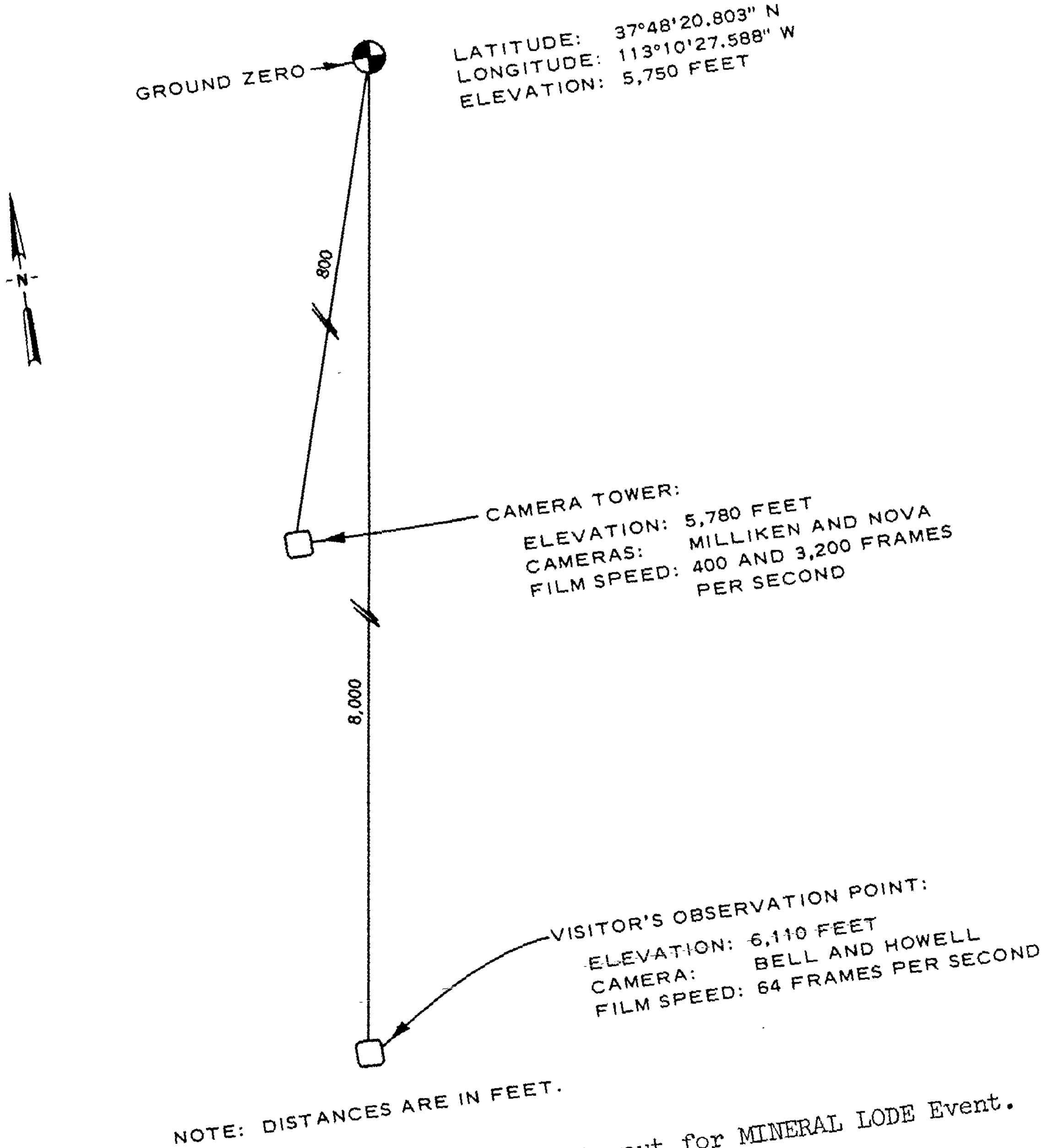


Figure 2.4 Camera station layout for MINERAL LODE Event.

CHAPTER 3

PRESENTATION OF RESULTS

3.1 GENERAL DESCRIPTION OF EXPLOSION

The first perceptible ground motion occurred about 13 milliseconds after detonation. The earth mass near ground zero appeared to rise monolithically, and then as breakup occurred, the center portion rose more rapidly. Dust and ejecta continued spreading upward and outward, obscuring some details of the actual surface uplift. Shortly thereafter, three nearly vertical smoke and dust plumes (venting) penetrated the dust cloud and reached a maximum height of 90 to 95 feet.

3.2 SURFACE EFFECTS

3.2.1 Ground Rise and Venting Phenomena. The ground rise history was evaluated from motion-picture photography; the results are graphically represented in Figure 3.1. From these data, displacement as a function of time for the GZ location was obtained and is shown in Figure 3.2. An analysis of the displacement-time curve indicates an initial rise velocity of about 30 feet per second, and a rise velocity of about 85 feet per second at 250 milliseconds after detonation.

Venting of the explosion gases was first detected about 1200 milliseconds after zero-time. Secondary venting (venting from other locations along the surface of the ground rise mass) was noted at about 1400 and 1800 milliseconds after detonation. The venting jets had initial velocities in the range of 110 feet per second.

3.2.2 Ejecta and Dust Cloud. By studying the motion-picture photography, observations were made of maximum ejecta trajectories. Ejecta thrown upward had reached a maximum height of some 35 feet about 1500 milliseconds after detonation. Several rocks of up to 1 foot in diameter attained this height. Boulders 3 to 4 feet in diameter were thrown as high as 15 to 20 feet vertically and several yards horizontally. Dust and small rocks ejected by the venting gas are estimated to have reached a maximum height of about 95 feet. Using a rise velocity of 85 feet per second as the launch velocity of ejected particles (particles not further accelerated by explosion-produced forces) gives a rise height of about 110 feet. Thus one could conclude with some confidence that ejecta heights were probably less than 150 feet.

3.3 DESCRIPTION OF MOUND

The postshot contour map of the MINERAL LODE GZ area is shown in Figure 3.3. Also on the map are the alignments (stations) along which elevations were obtained to permit development of the map and to permit the plotting of detailed cross sections across the mound in order to calculate the volume of material in the mound. The preshot profiles along these alignments were obtained from direct elevation readings and from interpolations of the preshot contours shown in Figure 2.1. The cross sections so developed are shown in Figures 3.4-3.13. Various photographs of the mound are shown in Figures 3.14-3.18. In Figures 3.16 and 3.17 note the upthrusted vertical face marking generally the eastern boundary of the mound. The western boundary is shown in Figure 3.18.

3.3.1 Size and Shape. The maximum residual mound height was 10.8 feet; this point was located about 20 feet southwest of GZ. The total volume of the mound was 2700 ± 50 cubic yards; this includes all voids that may be contained within the mound. The bulk of the mound volume lies within a circle with a radius of 40 feet; such a circle encompasses approximately 70 percent of the mound volume.

The mound shape may be described as a distorted quadrilateral. Its geometry and plan dimensions are shown in Figure 3.19. Its odd shape was apparently controlled by abrupt failure boundaries which are believed to have been defined by fault/joint systems that existed preshot.

3.3.2 Fragmentation of Near-Surface Rock. A visual sampling technique was employed to obtain an estimate of fragmentation. The sampling technique consisted of standing in a fixed location on the mound and then sizing the individual rocks within a radius of 15 feet. The center of gravity of an individual rock had to lie within the circle for the rock to be included in the sample. Four such samplings were obtained over the surface of the mound; no sampling circles overlapped. It was assumed that no stratification as to fragment size was involved in the mound material; i.e., the surface materials were representative of those beneath the surface. Each rock-size group was then converted to a percent of the total count in the sample. Results obtained from these samplings are reflected in Table 3.1 where the various sampling statistics have been summarized.

The degree of fragmentation was also evaluated using the aerial photograph shown in Figure 3.15. The results of the photographic evaluation are given as the values in parentheses (Table 3.1). A less-than ogive for the fragmentation count statistics is provided in Figure 3.20. A more meaningful ogive would have been a study of total fragment volume in relation to volume of individual fragments but time and fiscal resources would not permit the rather large effort involved in volumetric sampling.

3.4 SUBSURFACE CAVITY

The size of the subsurface cavity was inferred from two postshot slant hole borings; one was at an angle of 45 degrees with the horizontal and the second was at an angle of 54 degrees. The points of entry of these holes are located on the map shown in Figure 3.3.

Interpretations of the boring logs for the two slant holes were developed and the results are detailed in Figure 3.21. The radius of that portion of the cavity which lies below the shot point elevation ranged from a maximum of like 30 feet to a minimum of 15 feet. The average radius probably lies between 20 and 25 feet. The scaled radius (cube root scaling) would thus average between 0.7 and 0.9. If one uses $1/3.4^{th}$ root scaling, the scaled radius ranges between 0.6 (for a radius of 20 feet) and 0.8 (for a radius of 25 feet).

TABLE 3.1 RESULTS OF FRAGMENTATION SAMPLING

Largest Dimension of Fragment or Dissociated Rock	Total Count in Sampled Areas	Percent of Total Count in Sampled Areas
feet		
> 20[a]	1 (1)	0.4 (0.3)
15 to 20	2 (2)	0.8 (0.6)
10 to 15	4 (4)	1.6 (1.2)
5 to 10	14 (16)	5.5 (4.7)
3 to 5	47 (58)	18.3 (16.7)
1 to 3	117 (164)	45.5 (47.3)
0.5 to 1	72 (102)	28.0 (29.1)
< 0.5	(Omitted from sample count)	
	257[b] (347)[c]	

[a] Largest fragment observed was 23 feet across as its largest dimension.

[b] Total fragment count for visual sampling technique.

[c] Total fragment count for photographic sampling.

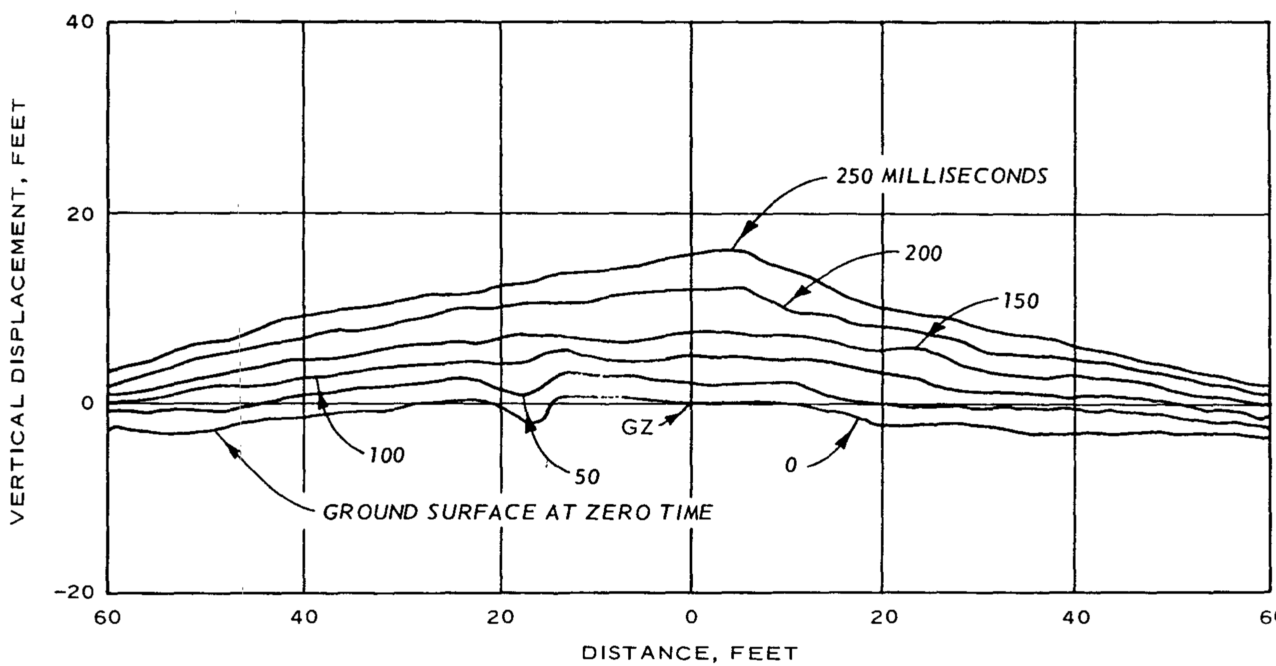


Figure 3.1 Vertical displacement history of the ground (rock) surface along an ESE-WNW plane through ground zero.

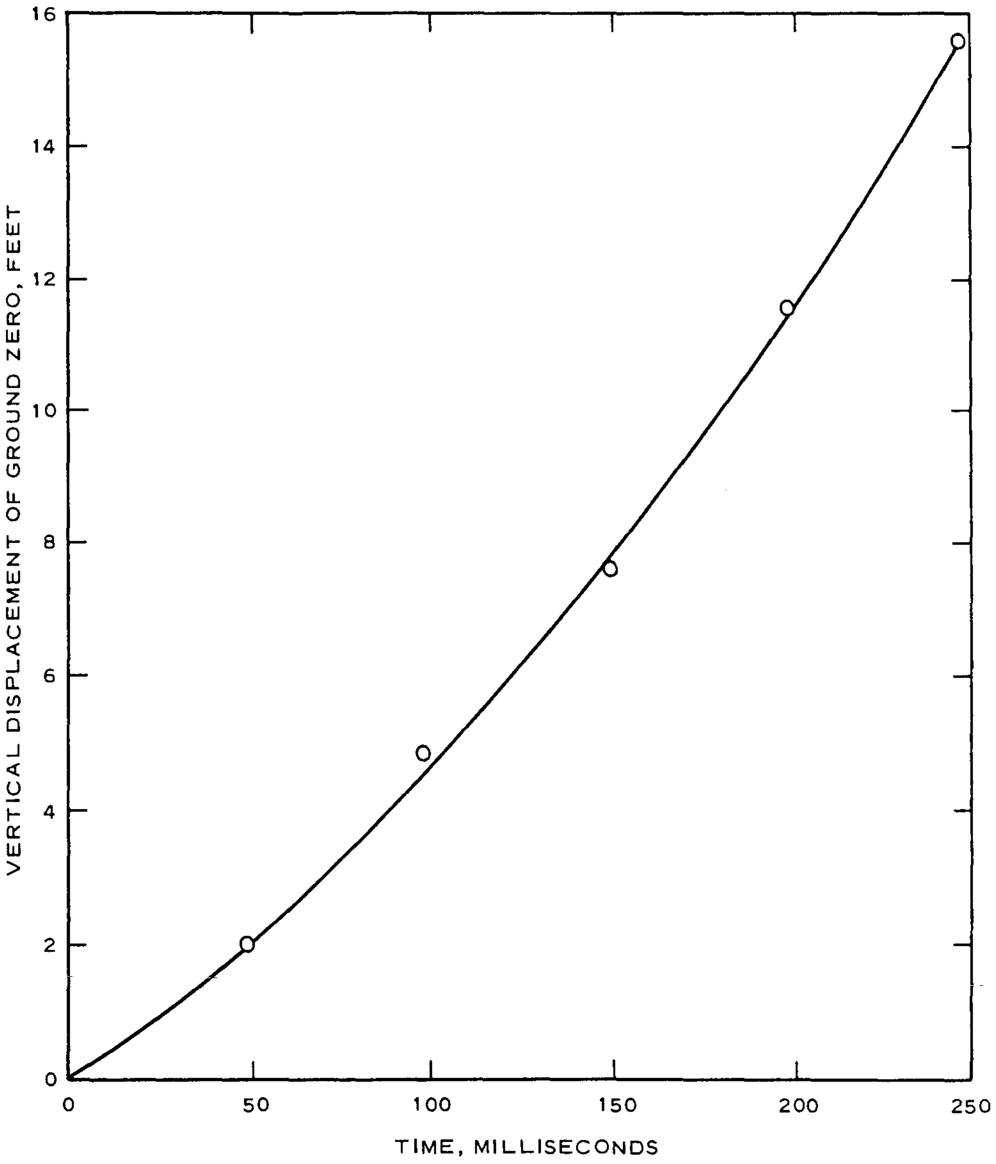


Figure 3.2 Vertical displacement of ground zero as a function of time after detonation.

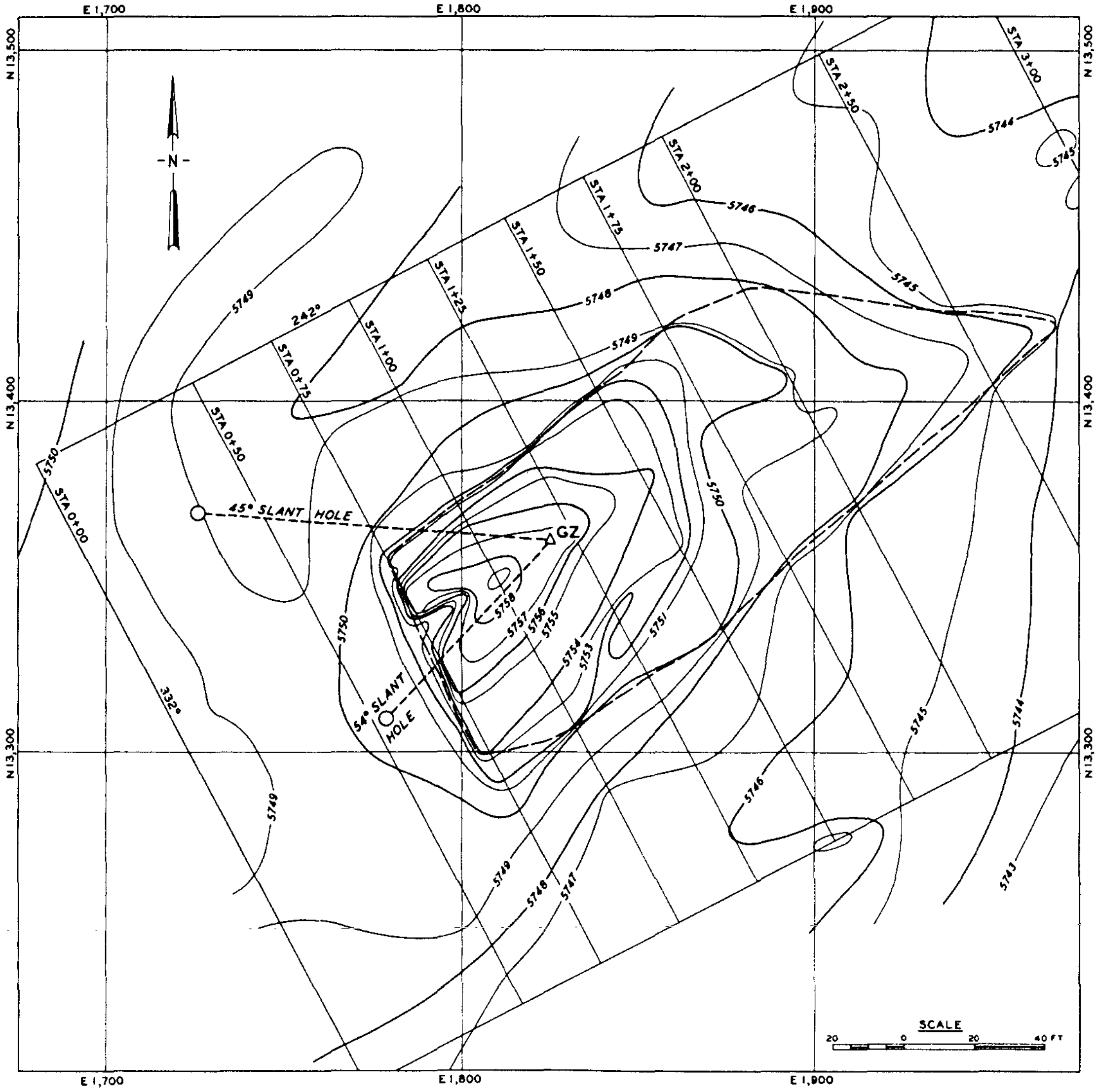


Figure 3.3 Postshot contour map of GZ area, MINERAL LODE Event.

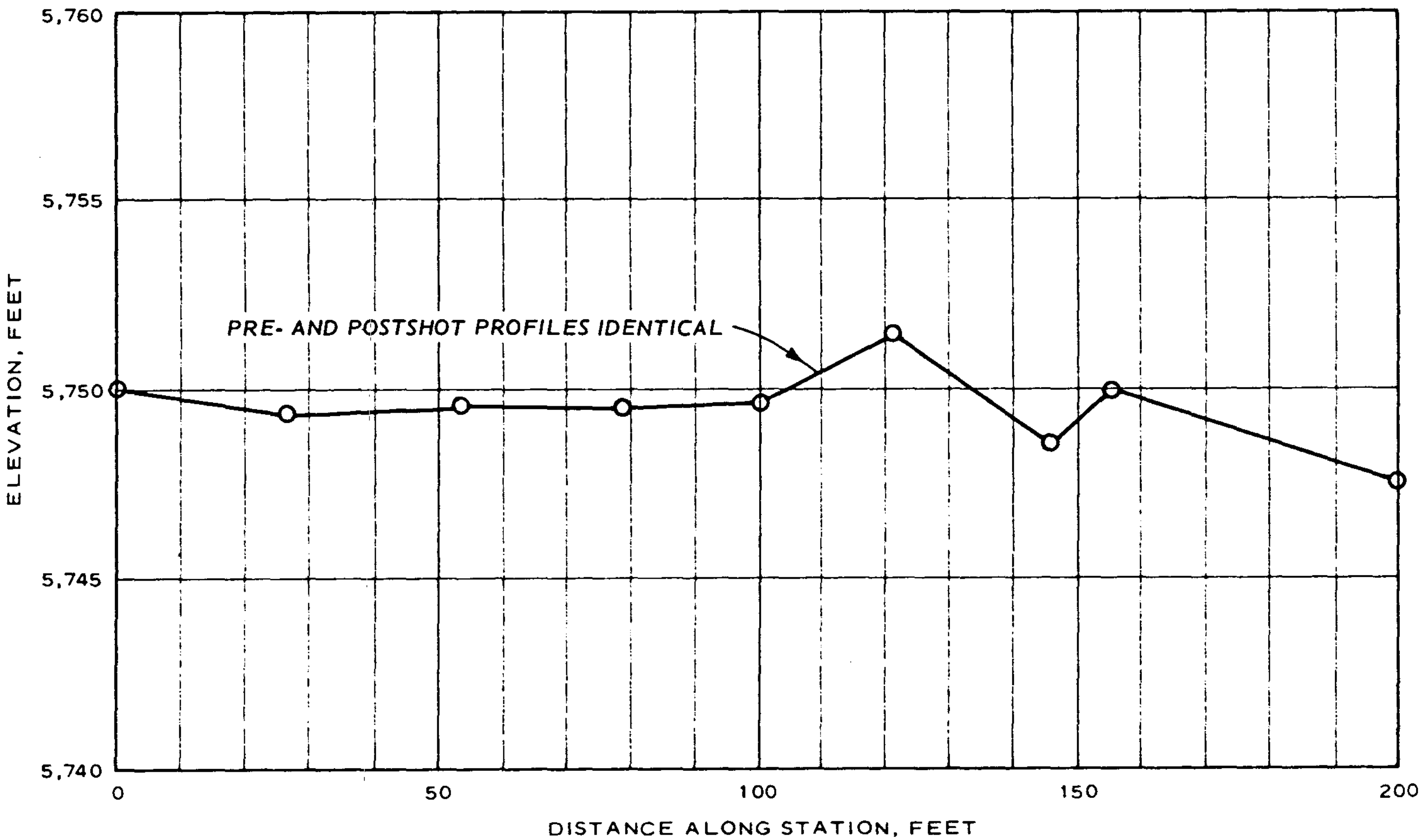


Figure 3.4 Pre- and postshot profiles along station 0+00.

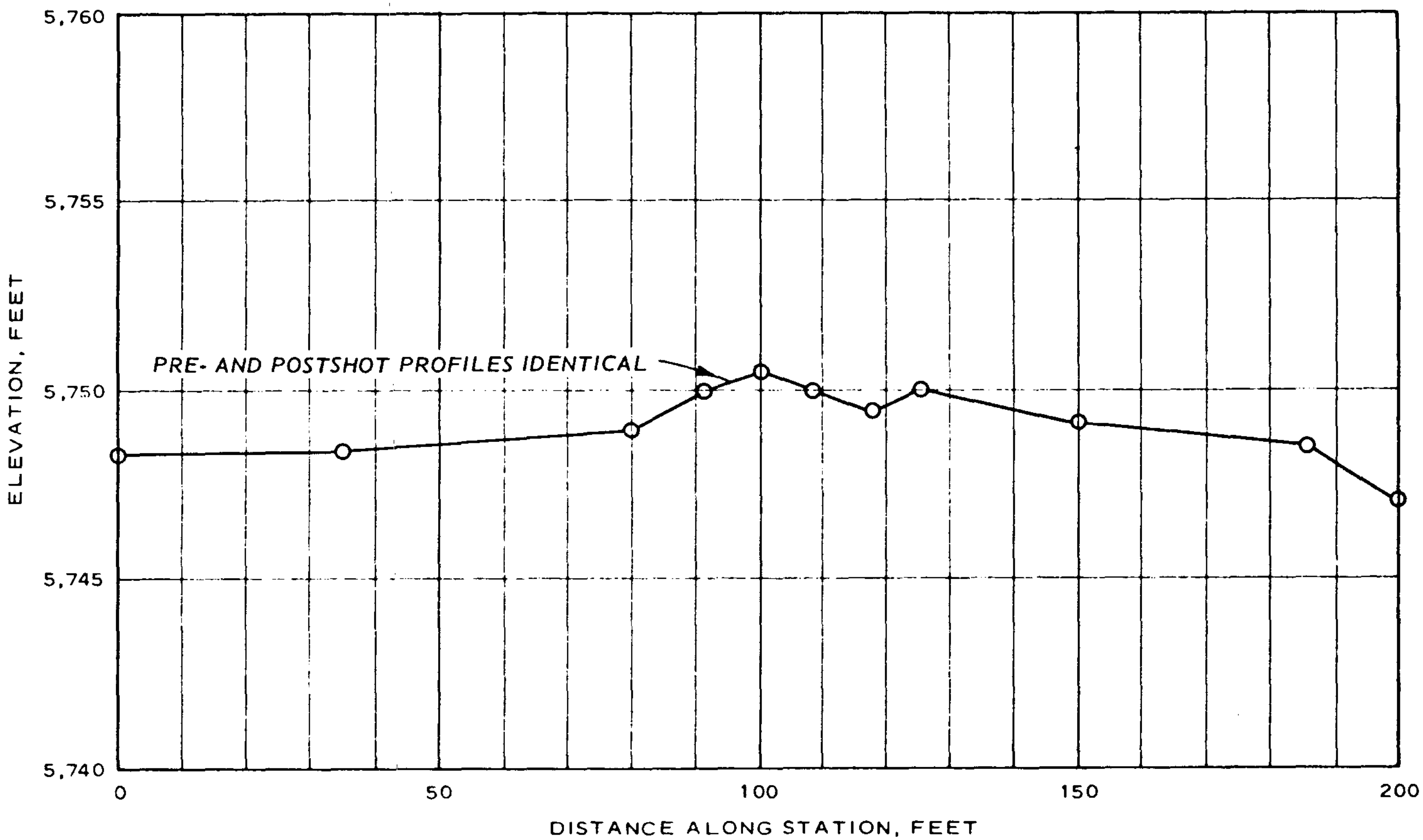


Figure 3.5 Pre- and postshot profiles along station 0+50.

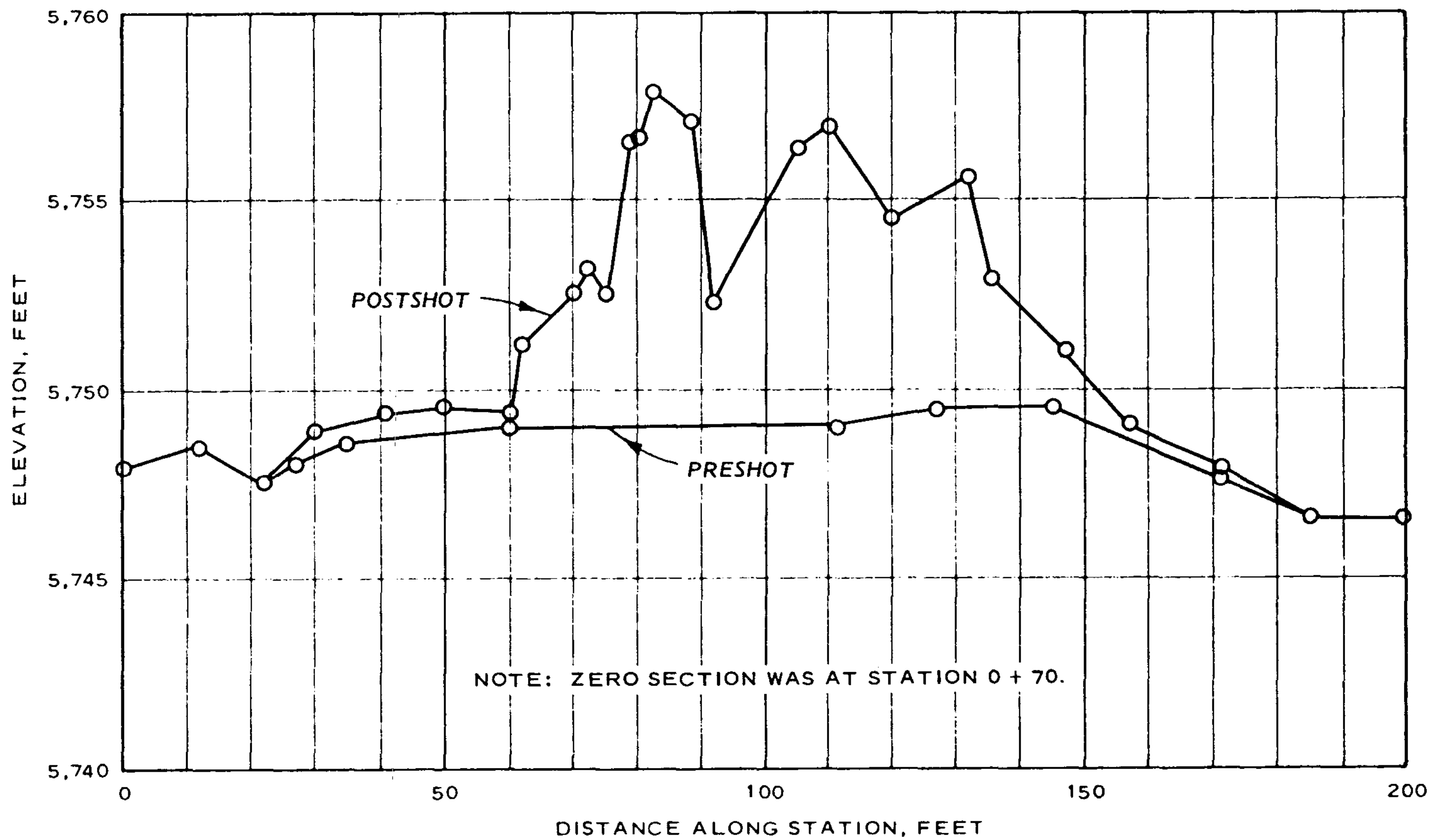


Figure 3.6 Pre- and postshot profiles along station 0+75.

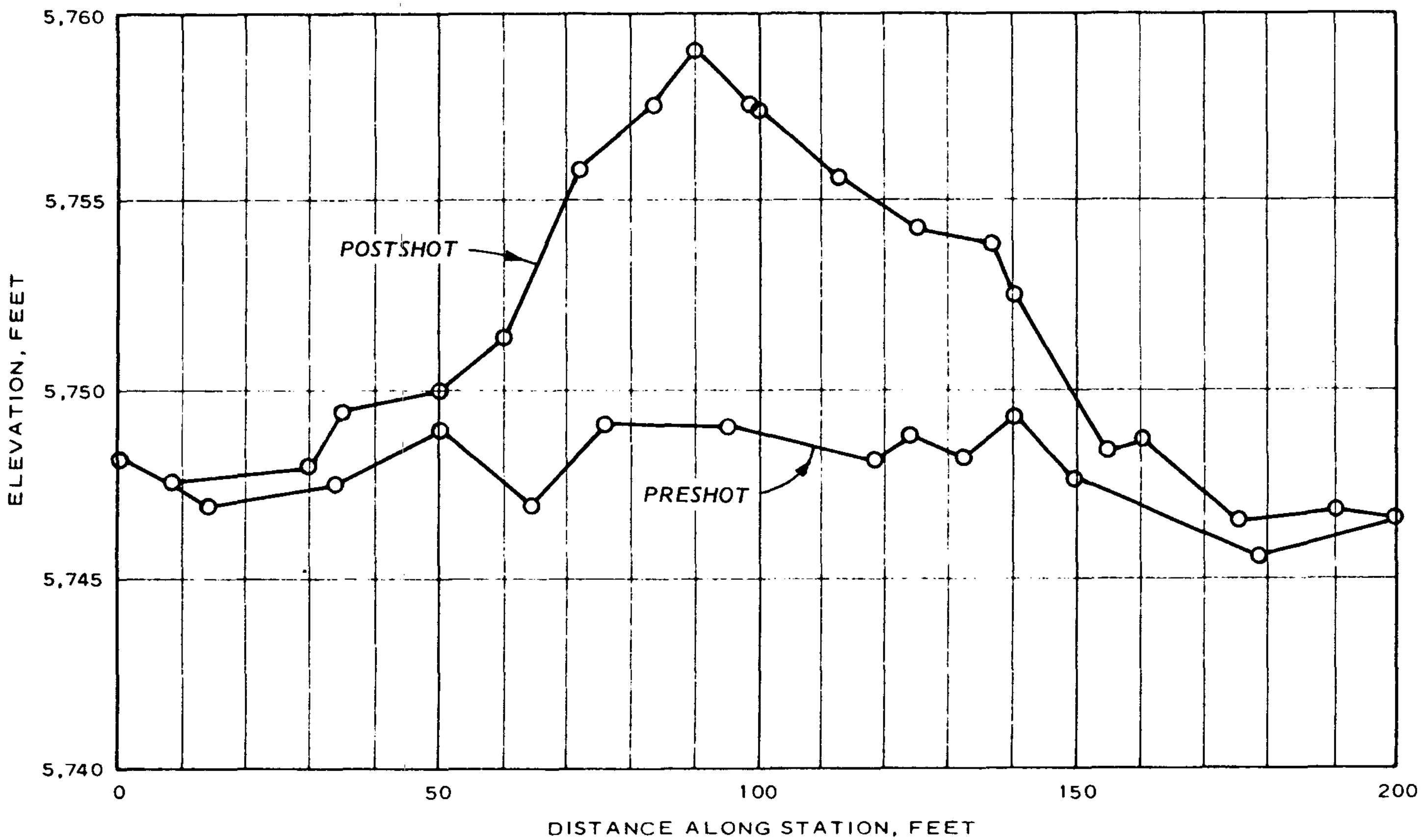


Figure 3.7 Pre- and postshot profiles along station 1+00.

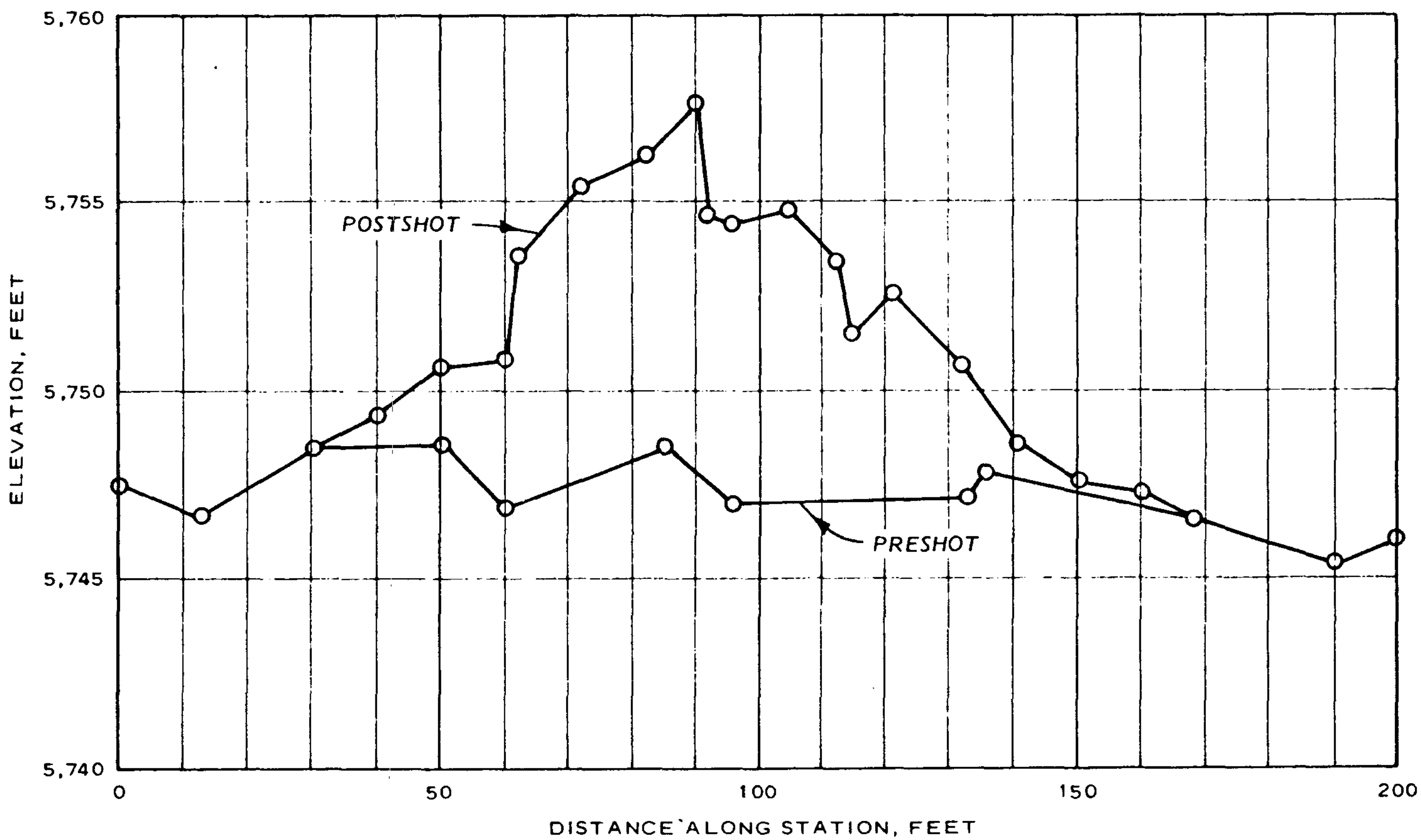


Figure 3.8 Pre- and postshot profiles along station 1+25.

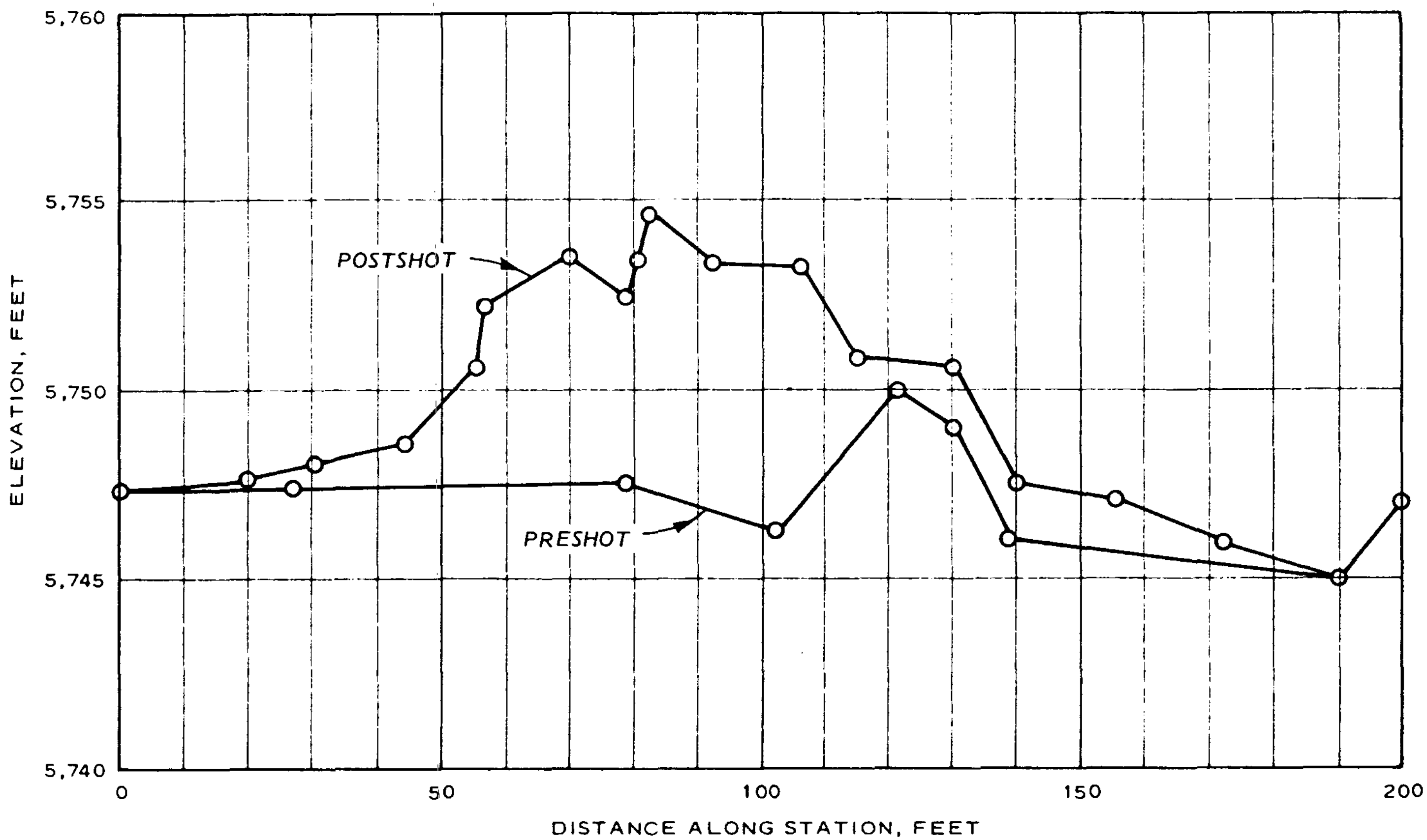


Figure 3.9 Pre- and postshot profiles along station 1+50.

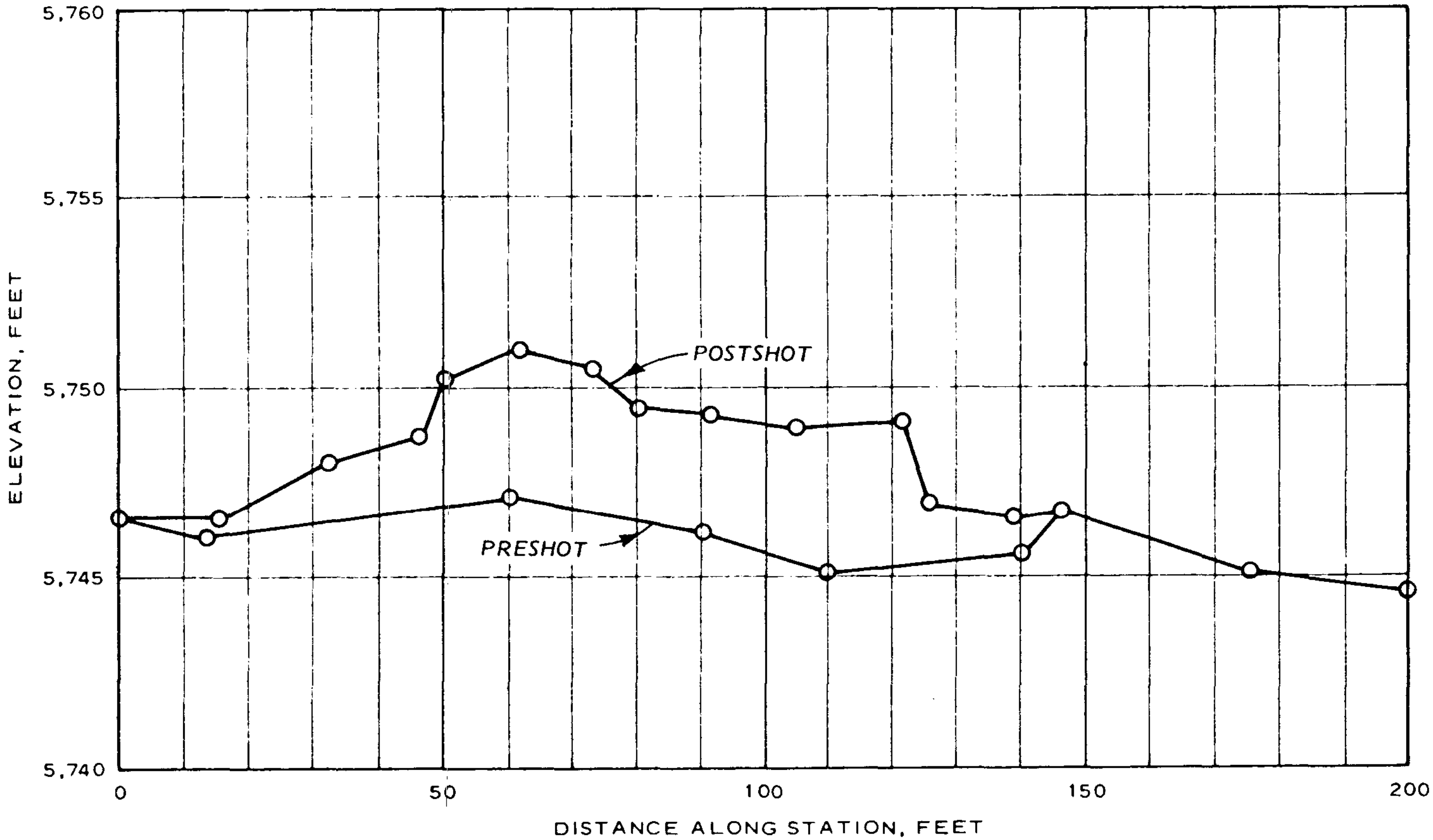


Figure 3.10 Pre- and postshot profiles along station 1+75.

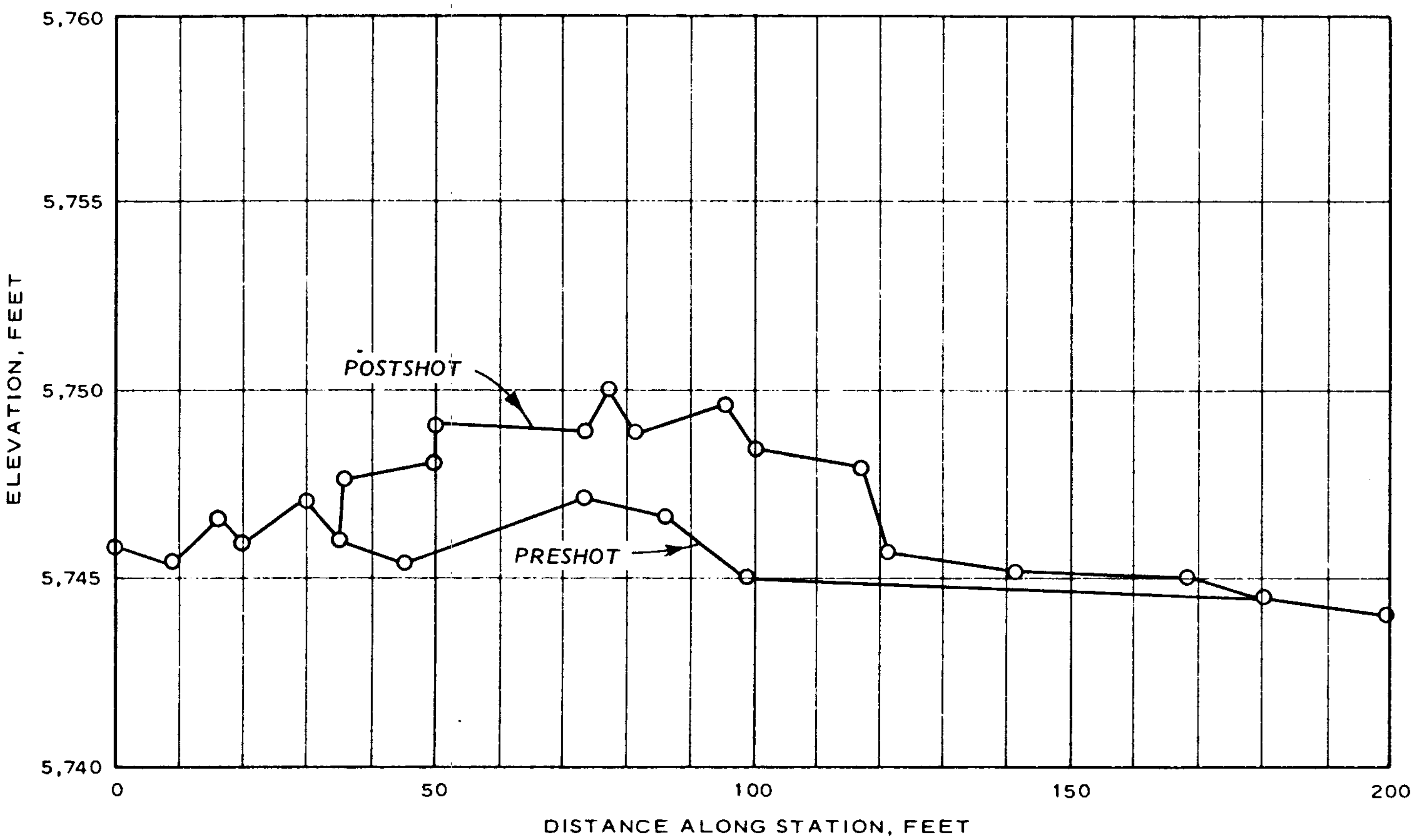


Figure 3.11 Pre- and postshot profiles along station 2+00.

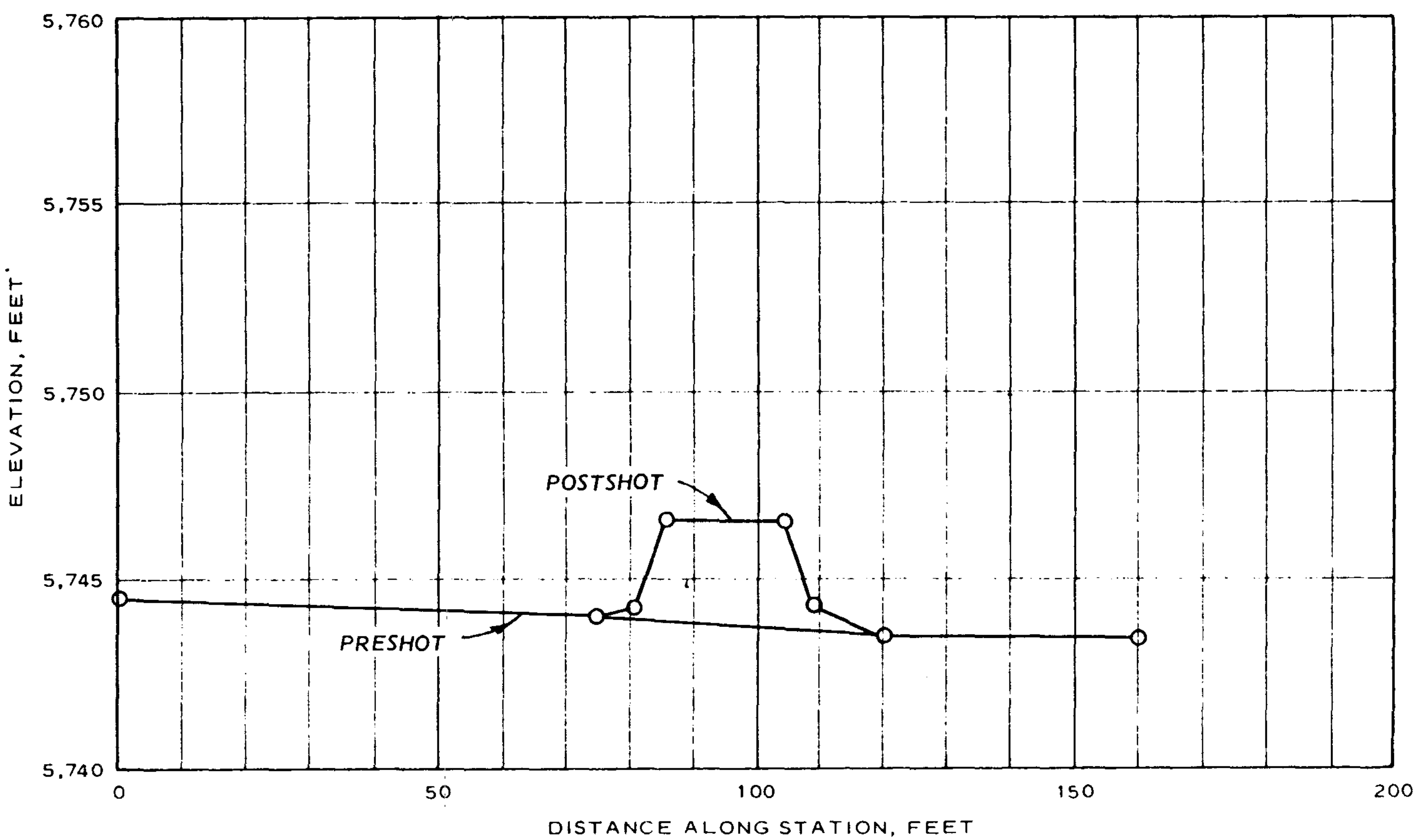


Figure 3.12 Pre- and postshot profiles along station 2+50.

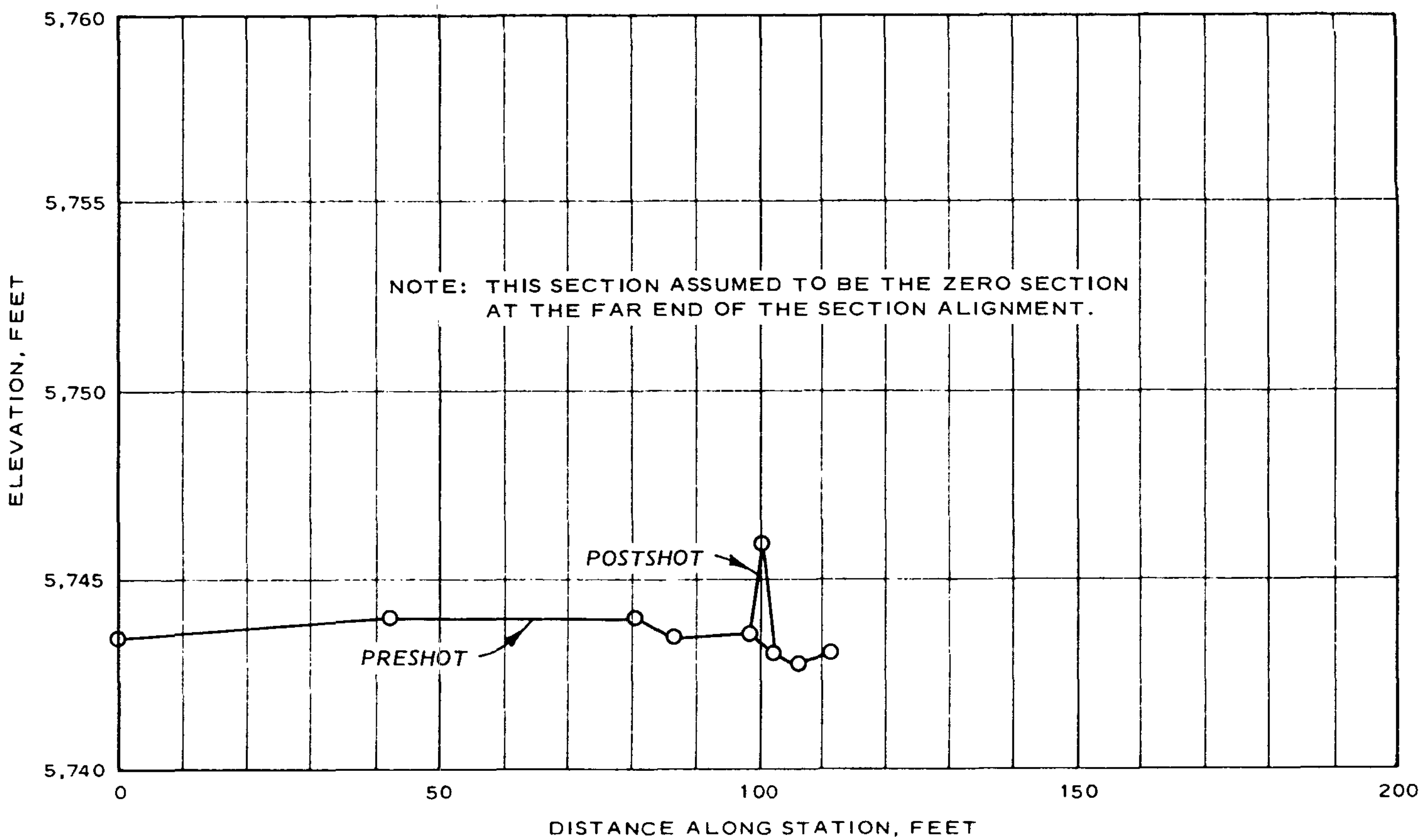


Figure 3.13 Pre- and postshot profiles along station 2+74.

Figure 3.14 Oblique aerial view of MINERAL LODE mound.

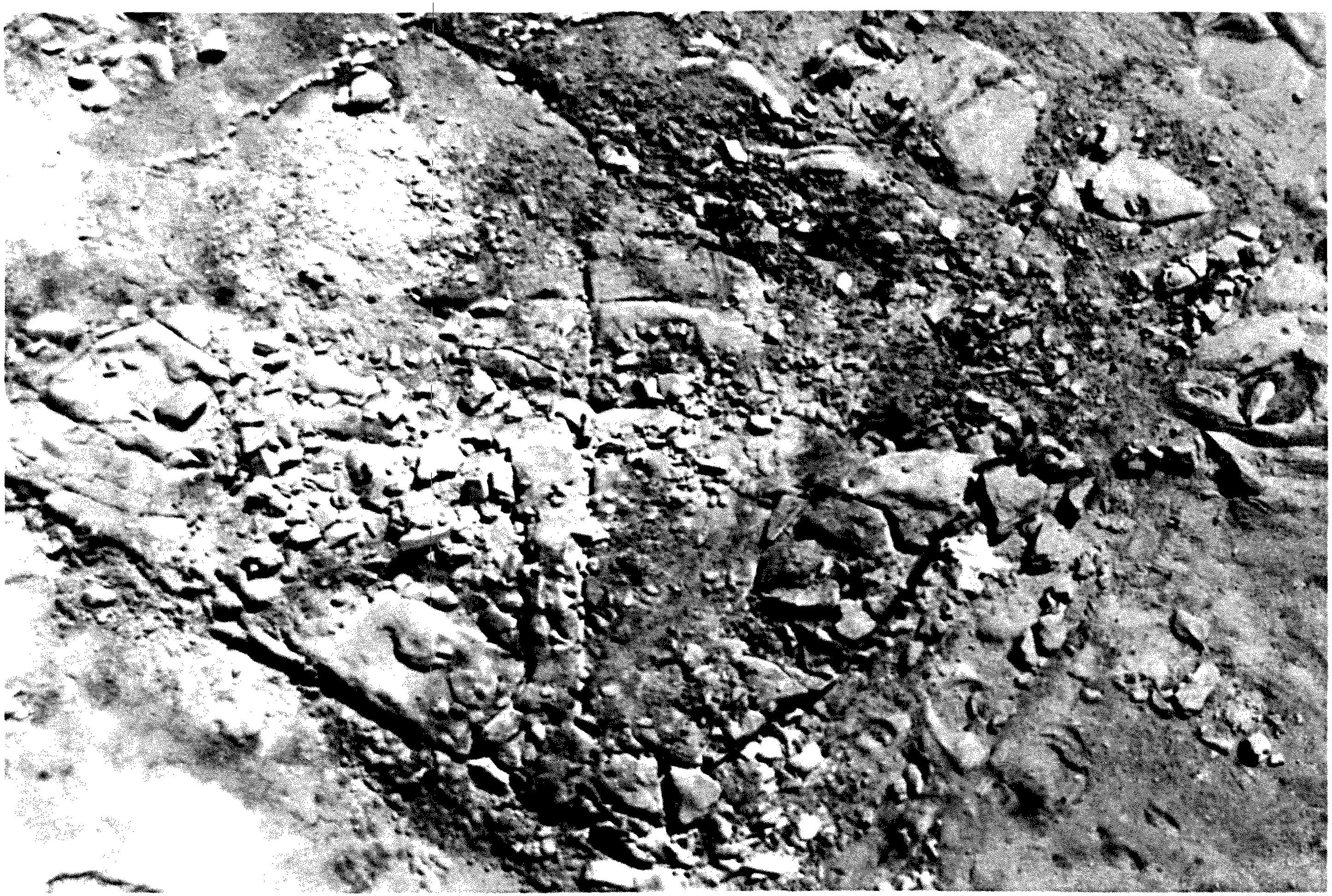
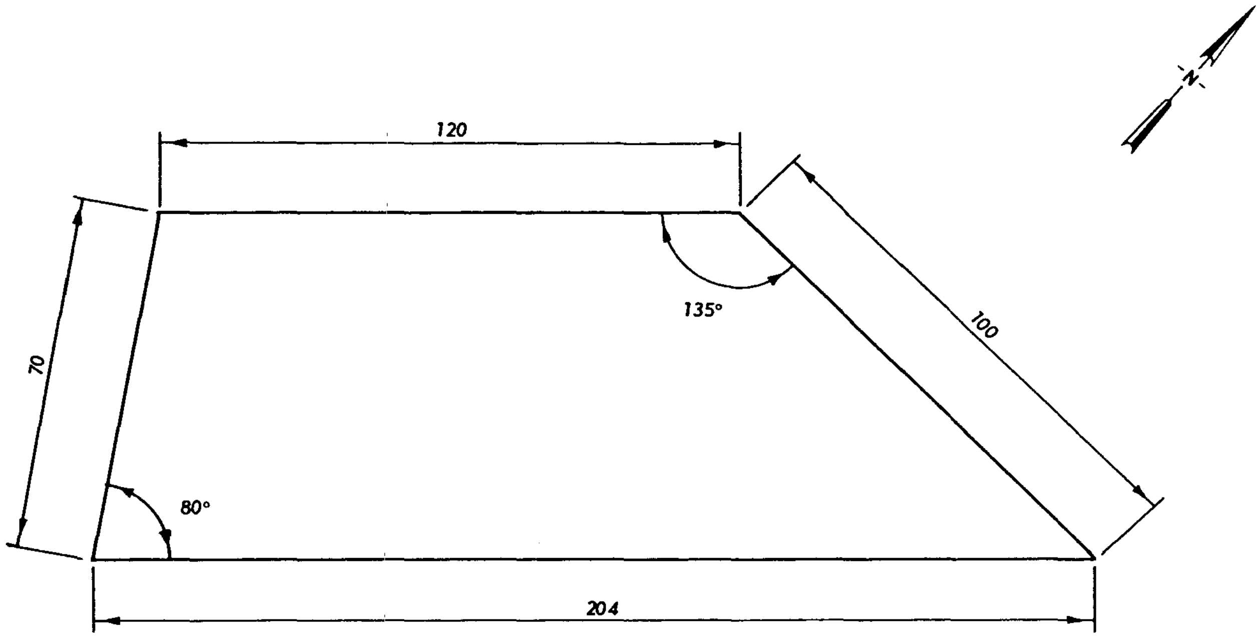


Figure 3.15 Overhead aerial view of MINERAL LODE mound.

Figure 3.16 Southerly view of MINERAL LODE mound.

Figure 3.17 Southeasterly view of MINERAL LODE mound.

Figure 3.18 Westerly view of MINERAL LODE mound.



NOTE: ALL LINEAR DIMENSIONS ARE IN FEET.

Figure 3.19 Approximate geometry and dimensions of rubble mound, MINERAL LODE Event, MINE SHAFT Series.

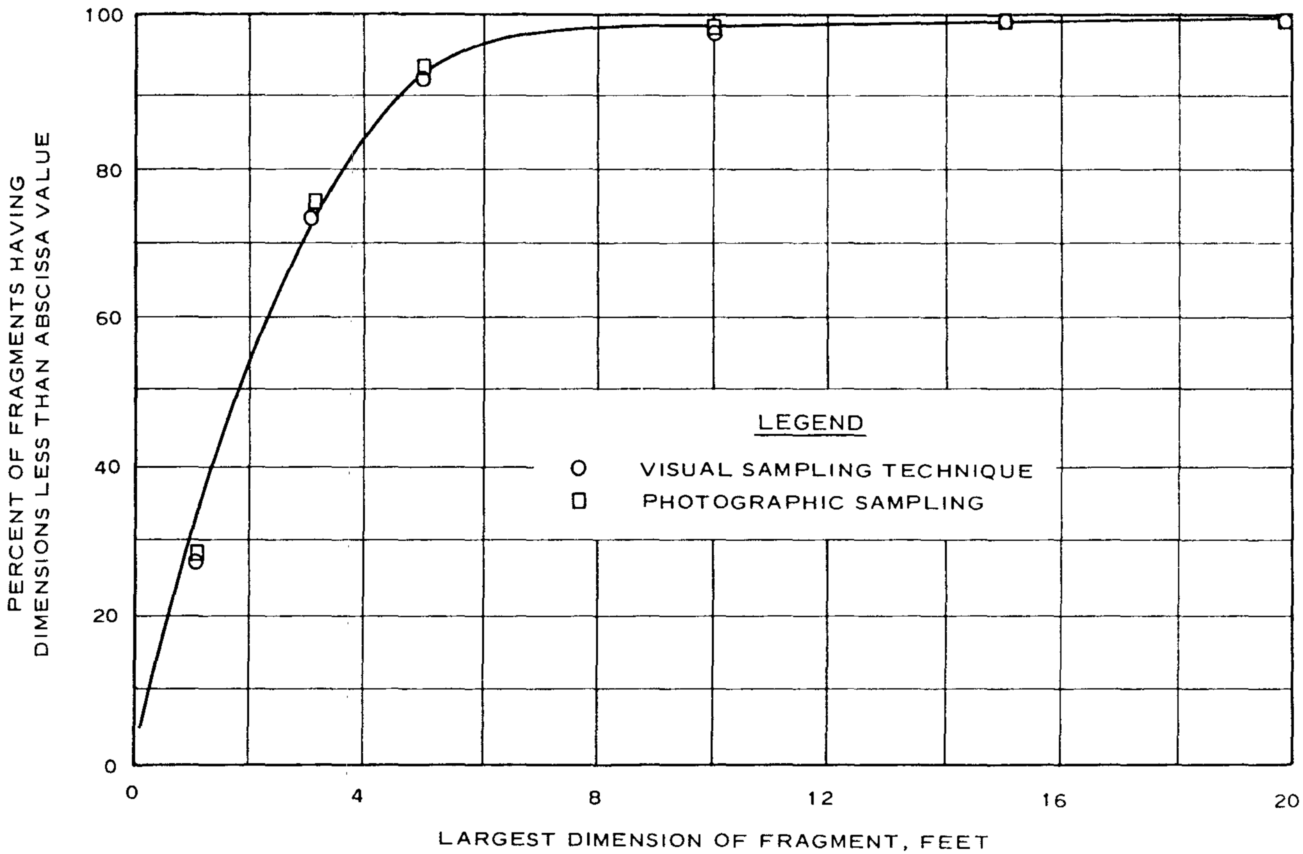


Figure 3.20 Less-than ogive portraying fragmentation statistics.

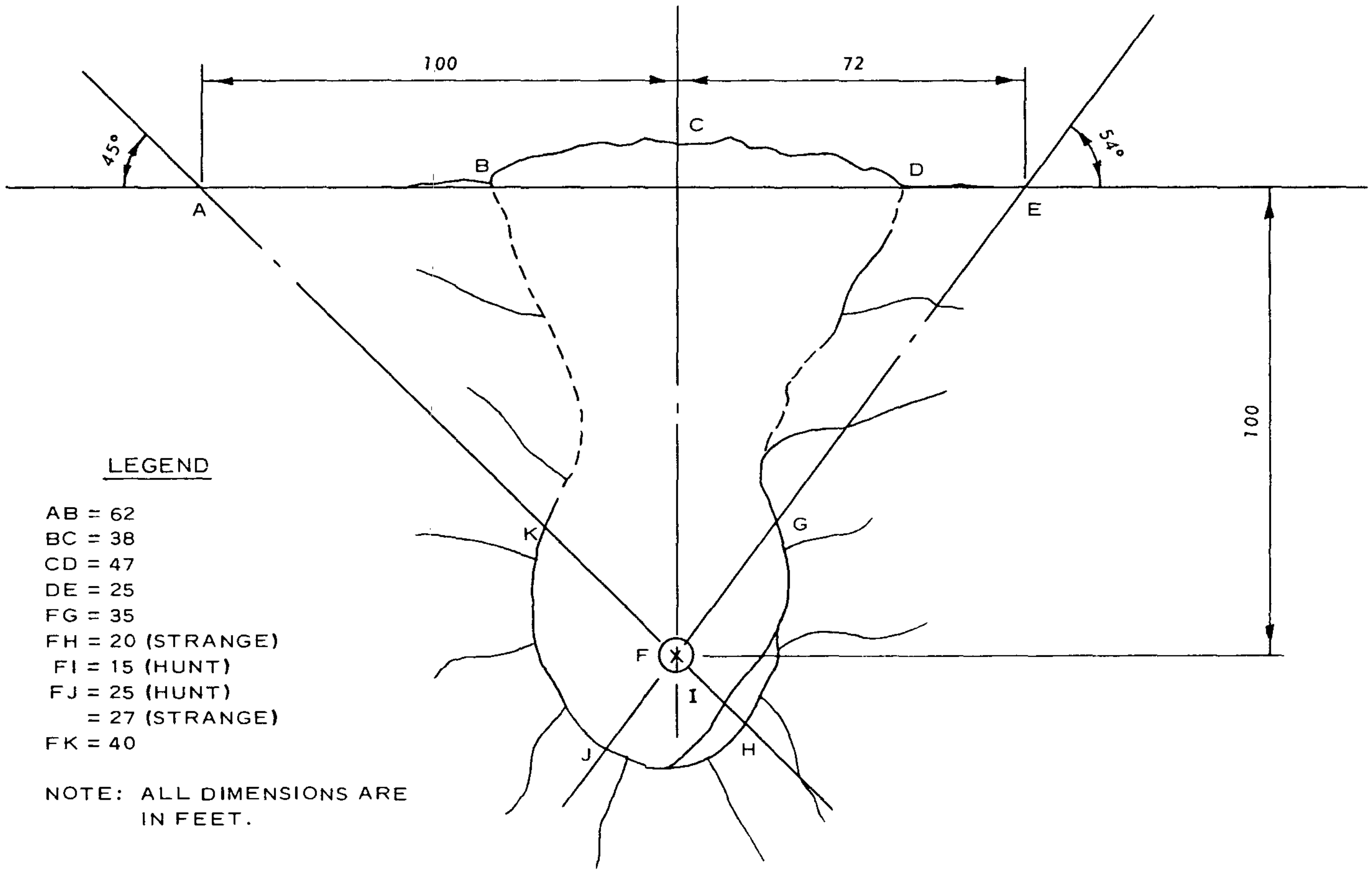


Figure 3.21 Postshot cavity dimensions for the MINERAL LODE Event as inferred from slant hole borings.

CHAPTER 4

DISCUSSION OF TEST RESULTS

4.1 SURFACE EFFECTS

4.1.1 Ground Rise. The uplifted area was bounded by nearly vertical faults. The initial ground rise appeared to be the uplift of a large, monolithic rock mass separating from the surrounding rock along previously existing joints. Very shortly, however, fissures developed along other joints in the overall mass and the rate and magnitude of rise varied widely over the mound. The uplift phenomenon was thus dominated by failure and slippage along preexisting joints in the parent medium. Venting occurred as free paths developed to the free surface.

Apparently the concrete stemming was not significantly displaced relative to the borehole. A small residual vertical displacement of the top of the stemming with respect to the borehole was noted, and the stemming lay in the hole at a slight angle. This suggested that at least the upper portion of the stem spalled off and rose higher than the top of the borehole and then fell back.

A 3-inch gap between stemming and borehole on the east side revealed that bonding between the concrete and rock was minimal. Separation was smooth with no observable particles of one material adhering to the other.

Results from the surface accelerometer mounted at GZ are shown in Figure 4.1. The accelerations after integration show a velocity of 27 feet per second for the first 50 milliseconds. This is reasonably confirmed by film measurements that indicate an initial velocity of 30 feet per second. Analysis of the film, however, reveals that after 50 milliseconds additional acceleration had increased the velocity to about 40 feet per second.

4.1.2 Venting. The jets of smoke and dust caused by the venting of the explosion gases were visible for only a short time on the high-speed film as they appeared above the dust cloud and quickly passed out of the field of view. Computations based on measurements during this interval permitted approximate estimation of times of origin and maximum heights achieved by the jets. On the basis of these computations it is also estimated that the initial jet velocities varied from 90 to 110 feet per second. The determination of the jet's height and time of maximum development was verified by the slower speed film taken from the VOP.

In the high-speed film, the third venting jet appeared to be black, but examination of the slower film indicated that this was the result of the shadow cast by the first jet. The actual color of all jets was a light smoky gray.

The location of probable venting positions in the east-west plane was accomplished by extending the path of the jet tip (as determined by film analysis) back to ground level. This positioning was checked and the location in the north-south plane was obtained by inspecting the mound for openings and smoke traces.

4.1.3 Dust Cloud and Ejecta. The fully developed dust cloud expanded outside the high-speed cameras' field of view within a few seconds after detonation and thus prevented adequate film analysis of ejecta range and velocities.

One missile of less than a foot in diameter was observed for most of its flight. It was among the ejecta thrown out by the original surface uplift and attained a maximum height of about 34 feet. On the basis of rough trajectory calculations it is estimated that it had a horizontal range of about 120 feet.

4.1.4 Mound Size and Shape. The mound size and shape were determined by the size and internal pressure of the explosion bubble prior to venting and by the preshot joint/fault patterns in the parent rock. In all probability, venting occurred at an earlier time than if the rock mass had been free of jointing; thus mound size was believed to be smaller than would have resulted from an identical detonation in a homogeneous, unjointed rock of the same type (tonalite).

4.1.5 Fragmentation. The fragmentation statistics (particularly as regards fragmentation size) for any underground explosion event are determined primarily by the yield level, the physical properties of the parent rock, and the jointing definition of the rock mass. In most cases, it is to be expected that the jointing and physical properties of the rock will have the dominant effect. Thus fragmentation size is not a scalable parameter.

In like manner, the height and range of ejected fragments are not in the strictest sense scalable parameters. The spall velocity of a surface fragment is theoretically twice the particle velocity behind the incident shock front. The particle velocity is in turn defined by the peak pressure of the shock wave. Thus a 1-kt explosion at a depth of burial of 150 feet causes surface spall velocities of a given magnitude. A 1-Mt explosion at a depth of 1500 feet, which is at the same scaled depth as the 1-kt charge (assuming cube root scaling to be valid), causes the same magnitudes of surface spall velocities.

The main source of fragment acceleration however comes from the explosion bubble. The venting conditions of the explosion bubble at the free surface are similar for the 1-kt and 1-Mt shots assumed; thus fragment acceleration levels will be comparable. In the case of the 1-kt charge, the fragments ejected may have sufficient velocities to escape the boundaries of the crater, while the fragments associated with the 1-Mt charge, having almost identical ballistic paths, may not escape the boundaries of the crater because of its larger size. This assumes that final rest locations of the dissociated fragments are mainly determined by the ejection velocities and the exiting angles; no consideration is given as to secondary influences such as negative phase winds.

4.2 SUBSURFACE EFFECTS

It is evident that the yield of the MINERAL LODE Event (~16 Tons Slurry = ~11 Tons TNT) was too small to override the influence of joint/fault patterns in the parent rock in dictating the shape of the explosion cavity. Venting of the explosion bubble through expanded joint/fault paths to the free surface probably terminated bubble growth prematurely.

The assumed average cavity radius for MINERAL LODE (between 20 and 25 feet) agrees reasonably well with the calculated values obtained from empirical equations recently developed by Strange for HE detonations in a variety of earth materials (work scheduled for publication during CY 1970). For rock, the equation is

$$r_c = 0.65 \, (Z_c)^{0.1} \, (W)^{0.3} \qquad (4.1)$$

where r_c is the cavity radius, feet

Z_c is the charge depth of burial, feet

W is the charge weight, pounds (TNT)

Equation 4.1 gives a cavity radius of 20 feet when Z_c equals 100 feet and W equals 22,250 pounds.

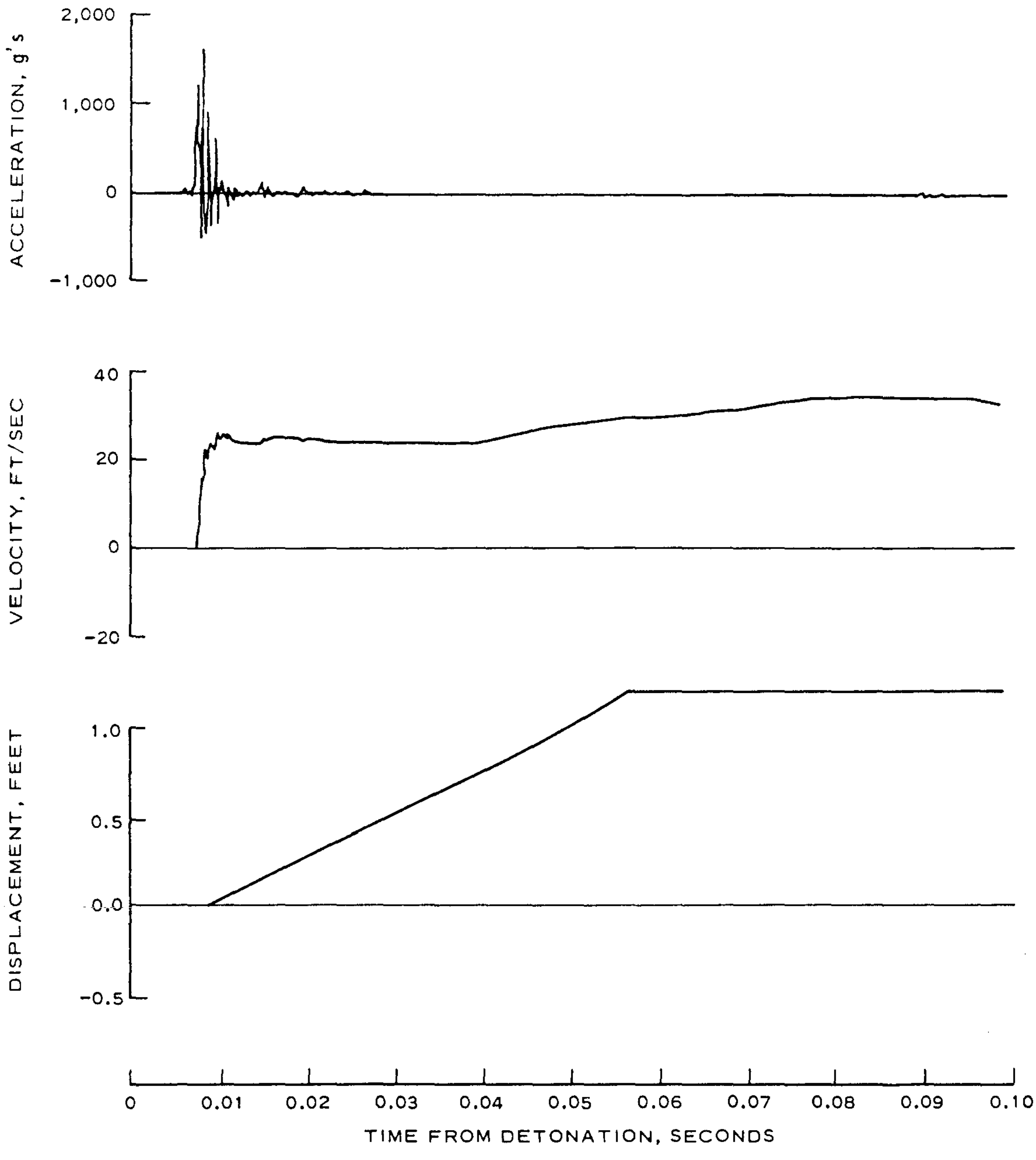


Figure 4.1 Accelerometer record and derived displacement curves for surface ground zero (from Murrell, MS-2159, in preparation).

CHAPTER 5

SUMMARY OF RESULTS

A succinct summary of MINERAL LODE results, particularly of the quantitative measurements obtained, is presented under individual listings below.

(a) Jointing patterns in the rock significantly affected the mound shape. The total volume of the mound was calculated to be 2700 ± 50 cubic yards.

(b) The initial rise velocity of the ground surface immediately above the charge (GZ) was approximately 30 feet per second. After 250 milliseconds, the rise velocity was about 85 feet per second.

(c) Ejecta heights and ranges were probably less than 150 feet for both. Ejecta sampling showed that 75 percent of the visible (surface lying) fragments were smaller than 3.5 feet, 50 percent were smaller than 2 feet, and 25 percent were smaller than 1 foot.

(d) The mean radius of the below-surface explosion cavity was established as 20 to 25 feet.

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13. ABSTRACT

This report describes the time history of the above-surface phenomena associated with the MINERAL LODE Event of the MINE SHAFT Series, 1969. The report also documents the subsurface cavity as inferred from postshot slant holes that had as an aiming point the original center of detonation. MINERAL LODE involved detonation of a 16-ton ammonium nitrate slurry at a depth of burial of 100 feet in granite at the MINE SHAFT test area near Cedar City, Utah. A summary of the MINERAL LODE results, particularly of the quantitative measurements obtained, is as follows: (a) Jointing patterns in the rock significantly affected the mound shape. The total volume of the mound was calculated to be 2700 ± 50 cubic yards. (b) The initial rise velocity of the ground surface immediately above the charge (GZ) was approximately 30 feet per second. After 250 milliseconds, the rise velocity was about 85 feet per second. (c) Ejecta heights and ranges were probably less than 150 feet for both. Ejecta sampling showed that 75 percent of the visible (surface lying) fragments were smaller than 3.5 feet, 50 percent were smaller than 2 feet, and 25 percent were smaller than 1 foot. (d) The mean radius of the below-surface explosion cavity was established as 20 to 25 feet.

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