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OPERATION SUN BEAM, SHOTS LITTLE FELLER I AND II

Project Officers Report--Project 1.9

Crater Size and Shape

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The Little Feller II experiment ~~utilized~~ used colored sand columns, vertically embedded in the vicinity of ground zero, to enable postshot measurement of permanent earth deformation below the apparent crater. In this report, postshot excavation and mapping of these columns is discussed, the results are evaluated, and correlation is made with previous cratering data.

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FOREWORD

Classified material has been removed in order to make the information available on an unclassified, open publication basis, to any interested parties. The effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is either currently classified as Restricted Data or Formerly Restricted Data under the provisions of the Atomic Energy Act of 1954 (as amended), or is National Security Information, or has been determined to be critical military information which could reveal system or equipment vulnerabilities and is, therefore, not appropriate for open publication.

The Defense Nuclear Agency (DNA) believes that though all classified material has been deleted, the report accurately portrays the contents of the original. DNA also believes that the deleted material is of little or no significance to studies into the amounts, or types, of radiation received by any individuals during the atmospheric nuclear test program.

OPERATION SUN BEAM

SHOTS LITTLE FELLER I AND II

PROJECT OFFICERS REPORT—PROJECT 1.9

CRATER SIZE AND SHAPE

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ABSTRACT

Early measurement of craters formed by low airbursts over a surface of desert alluvium was accomplished by means of aerial stereophotography. The first shot (Little Feller II) was statically fired above ground surface; the second (Little Feller I) was fired at an estimated height of also. When radioactivity levels permitted, the stereophotographically obtained crater measurements were refined by conventional surveys which established apparent crater dimensions as follows:

The Little Feller II experiment utilized colored sand columns, vertically embedded in the vicinity of ground zero, to enable postshot measurement of permanent earth deformation below the apparent crater. In this report, postshot excavation and mapping of these columns are discussed, the results are evaluated, and correlation is made with previous cratering data.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES

The original objectives of Project 1.9 were to obtain the dimensions of the apparent and true craters formed in desert alluvium by the Little Feller II event, low airburst, and to measure the permanent earth deformation occurring within the plastic response zone. A later requirement was the measurement of the apparent crater formed by Little Feller I, fired 10 days after Little Feller II.

1.2 BACKGROUND

Figure 1.1 shows a profile of a typical land crater formed by an explosion. The study of explosively formed craters has both military and civil significance, i.e. a large apparent crater may represent a tactical obstacle or it may be the result of a planned program of excavation. The true crater, which usually encompasses a larger volume than the apparent crater, is an indicator of the quantity of explosive energy which actually contributed to crater formation. The zones underlying the true crater, which exhibit varying degrees of deformation, are primarily of importance in the prediction of damage to underground targets. Excellent discussions of cratering mechanics and phenomena are contained in References 1 through 3.

Several methods have been employed to define and measure the various regions of earth disturbance in land craters. The apparent crater ordinarily presents no measurement problems; however, the zones and boundaries of a crater (Figure 1.1) are often difficult to locate and evaluate. One of the most successful methods for measurement of these subsurface regions, which was first employed by the Ballistics Research Laboratories (Reference 4), involves the use of colored columns of sand, vertically embedded in the earth near ground zero (GZ) and designed to match closely the density and strength properties of the medium. These columns reflect permanent deformation which occurs beyond the true crater boundary and permit such deformation to be measured by a carefully planned postshot excavation program.

Despite intensified research in the field of cratering during the past decade, no completely general, quantitative explanation of the phenomenon of crater formation has yet been published, due largely to the multitude of variables involved in the problem, as well as to a lack of data in some areas. Thus, crater prediction, especially for large yields, remains an inexact science based principally upon empirical approaches. The Little Feller events were expected to supplement the data plotted in existing cratering curves by more clearly defining the potential of nuclear weapons set off at very low altitudes.

1.3 THEORY

Dimensional analysis suggests that linear dimensions associated with craters should scale in proportion to the cube root of the explosive yield, a relation which has long been the basis for practical and theoretical work in the explosives field. However, consideration of various requirements for similitude shows that cube-root scaling, often called Hopkinson's Law, conflicts with another scaling law (Froude's) when the effects of gravity become important (Reference 5). These requirements cannot be simultaneously satisfied; neither can they be ignored in all cases.

Recent experimentation has indeed shown significant departures from cube-root scaling, although the reasons for such departures are still subject to argument. An informative, critical review of various proposed scaling laws can be found in Reference 6. $Y^{1/3.4}$-scaling, where Y represents the nuclear explosive yield in terms of its equivalence to the recognized high explosive (HE) standard, trinitrotoluene (TNT), seems to agree more closely with experimental results obtained in the range of yields corresponding to the Little Feller events and thus has been adopted for the development of data in this report.

Reference 7 describes the development of a computer program for a theoretical hydrodynamic model of a 2-Mt surface burst, with certain assumptions being made and with the effects of gravity, viscosity, and heat conduction being neglected. Pressure and velocity field vectors were developed, and the two-dimensional model thus established was found to be in reasonable agreement with experimental observations. The pressures surrounding the model charge were of sufficient magnitude to cause appreciable plastic flowage of the medium, a phenomenon which probably accounts for much of the crater volume (Reference 8). Throwout of crater ejecta, of course, accounts for the major portion of the crater volume of a surface or subsurface burst, with possible minor contributions from vaporization and gross compression of the medium.

Reference 7 also considers the case of a low airburst, concluding that the crater created thereby is probably very sensitive to height of burst (HOB), and that when the burst occurs at a height that precludes ground motion induced by impact of fragments of the device casing itself, little cratering action should be expected.

A theoretical examination of an explosion at the earth-air interface (spherical charge or point energy source resting on ground surface) is contained in Reference 9. For a nuclear detonation, the energy actually coupled into the medium is postulated to approximate only 2 percent of the total energy. Both References 7 and 9 indicate large differences in the cratering capabilities of HE and nuclear energy (NE) in unconfined and partially confined configurations.

The problem of crater prediction is approached through a detailed consideration of the properties and characteristics of the cratered medium in Reference 10. Although airbursts are excluded from the study, the formation of craters by surface and near-surface explosions is found to result from plastic deformation and fracturing of the soil medium by shock waves and scouring action of the expanding gases. It is interesting to note that this reference also lends theoretical support to the 1/3.4-scaling exponent. Differences in cratering capabilities of HE and NE are thought to be dependent primarily upon properties of the medium cratered.

A review of literature on the theory of cratering, coupled with a comparison with observed results (as in Reference 1), reveals at once the many areas of uncertainty concerning this phenomenon. Probably nowhere are these uncertainties more pronounced than in the regime of airbursts, where the effects of energy coupling and the behavior of the cratered medium are only partially understood.

1.4 CRATER PREDICTION, LITTLE FELLER II

To insure an experimental array that would be sufficiently extensive to reflect all required data, the following prediction of apparent crater dimensions was made for Little Feller II:

Little difference was anticipated between true and apparent crater dimensions, and no discernible crater lip was expected. Insufficient information was available for predicting the extent of plastic deformation beneath the true crater, but a sand-column depth of 15 feet (4.6 meters) near GZ and radial distance of 60 feet (18.3 meters) from GZ were considered sufficient.

No crater measurements were originally planned for Little Feller I, since it was believed that the scheduled 42-foot HOB for this event would preclude the formation of an identifiable crater.

1.5 SHOT GEOMETRIES

Figure 1.2 illustrates the shot geometry (both planned and actual) for Little Feller I, and Figure 1.3 illustrates the shot geometry and predicted crater for Little Feller II.

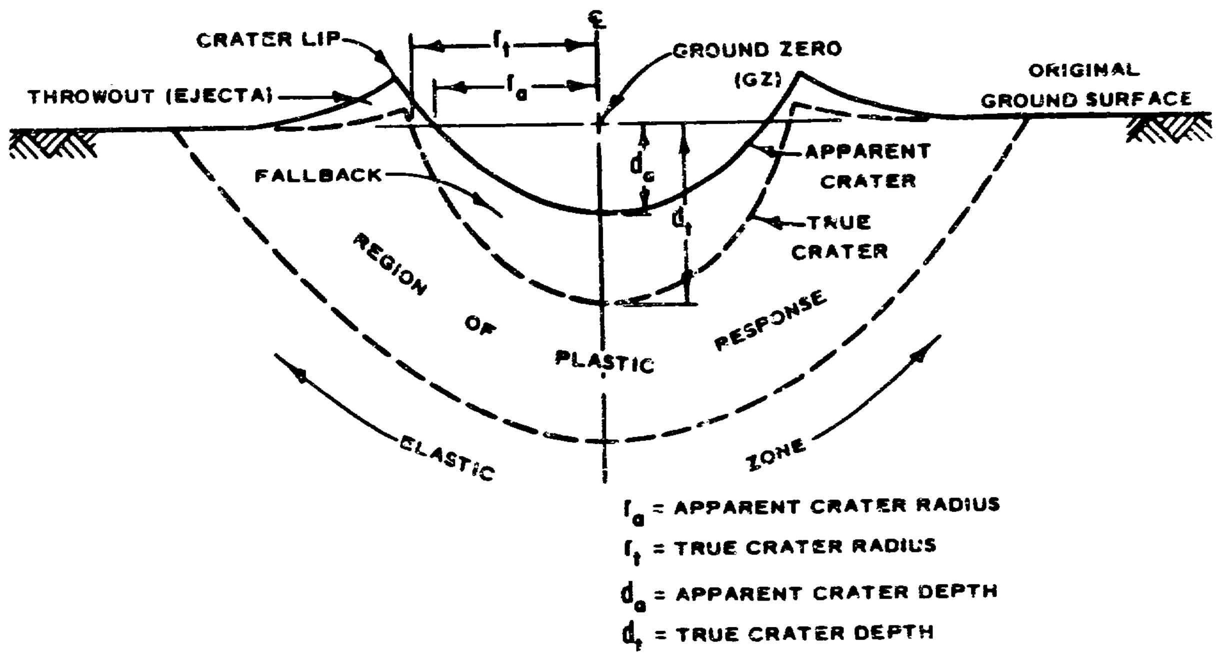

Figure 1.1 Idealized profile of a typical, explosion-formed crater.

CHAPTER 2

PROCEDURE

2.1 SHOT LOCATIONS AND ENVIRONMENTAL CONDITIONS

The Little Feller events were located in the vicinity of Area 18 of the U. S. Atomic Energy Commission Nevada Test Site (NTS). Figure 2.1 shows both shot locations. Nevada State coordinates for each GZ were:

Little Feller I	N859,076 E601,880
Little Feller II	N862,569 E606,067

The terrain in the area of the tests was typical of the relatively barren desert region of the southwest U. S. Little Feller I was fired at a target near the topographical crest of a low hill, while the immediate GZ area of Little Feller II was fairly flat. The soil in the test area consisted of poorly sorted desert alluvium. In the case of Little Feller II, for which sand columns were emplaced (see Paragraph 2.2), no variation in the soil was apparent to a depth of at least 15 feet, the depth of the deepest borehole. Cobbles up to about 8 inches in size were present in the soil; for the most part, the medium consisted of sand-size particles and contained practically no binder. Soil conditions in the Little Feller I area appeared about the same.

2.2 EXPERIMENTAL ARRAY, LITTLE FELLER II

2.2.1 Geometry. The experimental array consisted of eight colored-sand columns, each about 7 inches in diameter, varying in depth from 5 to 15 feet, and extending to a radial distance of 60 feet from GZ (Figure 2.2). It was originally intended that the columns be spaced across a crater diameter, but drilling problems and an accelerated construction schedule forced a change to only a single crater radius.

2.2.2 Preparation of Sand Columns. Survey for the sand-column layout was accomplished by Holmes and Narver, Inc., on-site architect-engineers. The boreholes were drilled by Reynolds Electrical and Engineering Co., on-site contractors. Absence of cementation in the soil made drilling difficult, and the drilling method finally adopted included the use of drilling mud in conjunction with a Portadrill rig using a 6-1/4-inch steel bit (see Figure 2.3). When the desired depth was reached, compressed air was used to blow the mud from the hole (Figure 2.4). The resulting boreholes were somewhat irregular in shape (due mostly to the cobbles) but were well plumbed and of satisfactory diameter. Backfilling was accomplished with a mixture of vegetable dye, lime, washed sand, and water in approximate proportions of 1 pound, 2 sacks, 0.8 cubic yard, and 3 gallons, respectively. This mixture was intended to give a readily identifiable column in the earth while closely approximating the density and strength characteristics of the surrounding medium. As the mixture for a particular column was prepared (Figure 2.5), it was introduced into the borehole and tamped (Figure 2.6). At predetermined vertical intervals, which varied from about 1 to 5 feet, a layer of cold-mix asphalt was added in amounts necessary to give a tamped thickness of about 0.1 foot. Depths to these asphalt layers were determined by level readings taken on a graduated tamp. The layered columns were emplaced thusly to show vertical, as well as horizontal, movement.

2.3 AERIAL STEREOPHOTOGRAPHY

Preshot and postshot mapping of Little Feller II and postshot mapping of Little Feller I were accomplished by means of aerial stereophotography performed by American Aerial Surveys, Inc., through an arrangement with Holmes and Narver. For this purpose, a Park camera with a 6-inch focal length and a distortion-free lens was mounted in a Cessna 180 aircraft. Overlap obtained was about 60 percent. Processing of negatives was accomplished in Department of Defense facilities at Mercury, Nevada, thus permitting early estimates of crater radii. The photography missions were flown during the morning hours at altitudes of 1,200 and 1,500 feet above ground and with an aircraft ground speed of about 80 mph. These rather high altitudes were necessary to avoid the turbulence of thermal updrafts which are common in this area in summer. For

Little Feller II, ground reference stations needed for the establishment of horizontal and vertical survey control were provided by a pattern of 16-foot by 18.5-foot crosses formed by sections of roof-shaped, concrete parking curbs. In the case of Little Feller I, the reference stations were placed after the shot and since there was no danger of their being destroyed by the blast, cloth panels were used. The preshot and postshot photography missions for Little Feller II were flown on D-2 and D+1 days, respectively; postshot photography for Little Feller I was accomplished a little more than one month after the shot. The aerial contour maps of both sites were prepared by Michael Baker, Jr., Inc., consulting engineers, Jackson, Mississippi.

2.4 CRATER MEASUREMENTS

Early crater measurements of both Little Feller events were made by means of aerial photography (Paragraph 2.3), as residual radioactivity in both cases made extended stay-time near GZ hazardous. Since participation in Little Feller I was not planned until after the shot, the crater measurements for this event were made without the benefit of preshot photography. Profile surveys were run on both craters about four months after the shots. Excavation and mapping of the sand columns for Little Feller II were accomplished eight months after the event. Control for this survey was obtained by use of preshot hubs placed on either end of the sand-column array at distances sufficient to preclude movement by blast or shock. Residual alpha contamination made necessary the observance of rather strict safety measures during the sand-column excavation. The area was sprayed with water to control the dust, and the top of the soil was bladed off before work began. Unfortunately, the blading operation resulted in accidental loss of some very valuable data when the blading was carried too deep (see Figure 3.15). A trench was excavated alongside the sand-column array by means of a 1-1/2-cubic-yard backhoe, and the columns were uncovered by hand. Figures 2.7 and 2.8 show the results of this excavation.

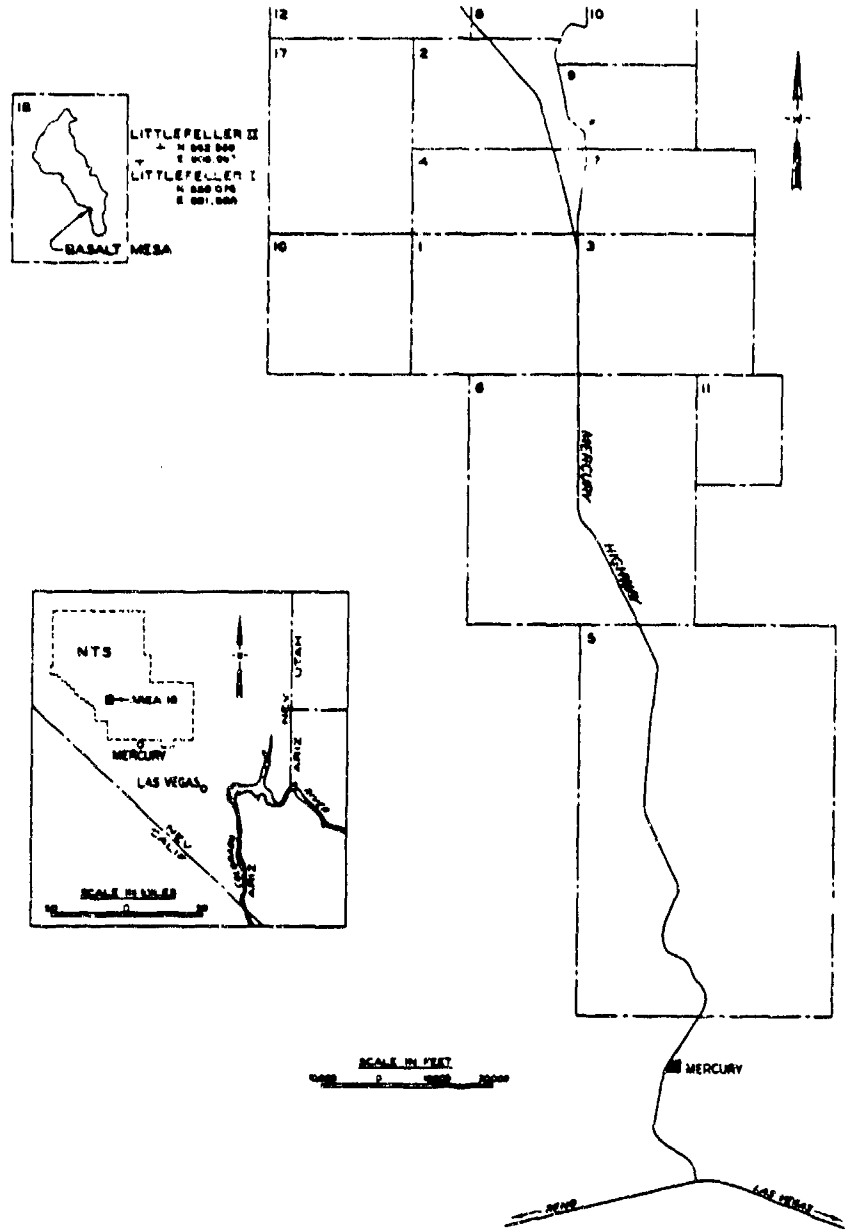

Figure 2.1 Vicinity map of Nevada Test Site (NTS), showing locations of Little Feller events. Numerals denote NTS area numbers.

Figure 2.2 Sand-column array. The true bearing of the array was south 70 degrees west from GZ.

Figure 2.3 Portadrill rig in operation near GZ. Note use of drilling mud. (WES photo)

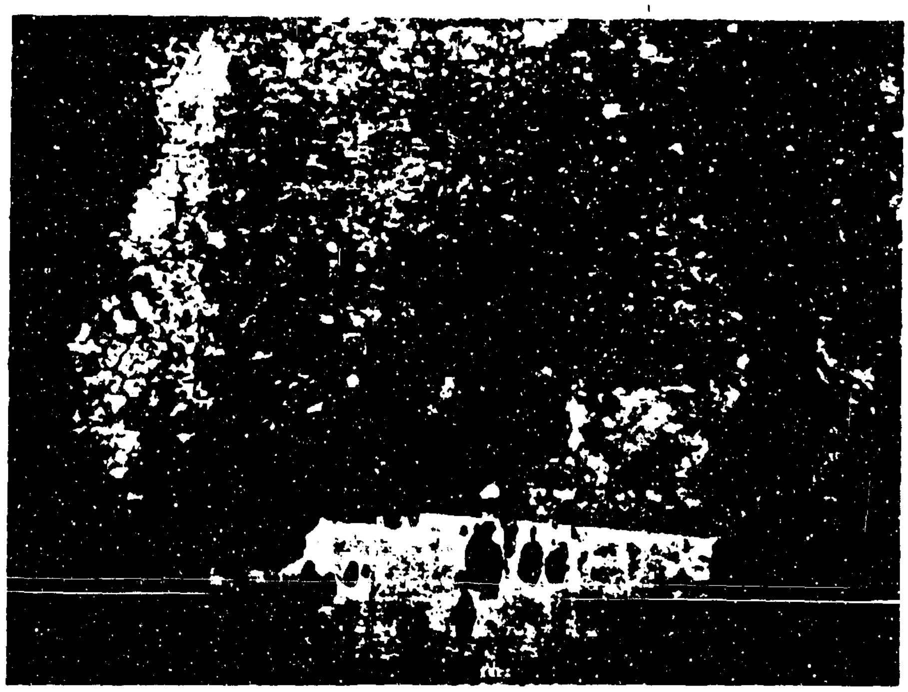

Figure 2.4 Finished borehole prior to backfilling. Drilling mud has been blown out by compressed air. (WES photo)

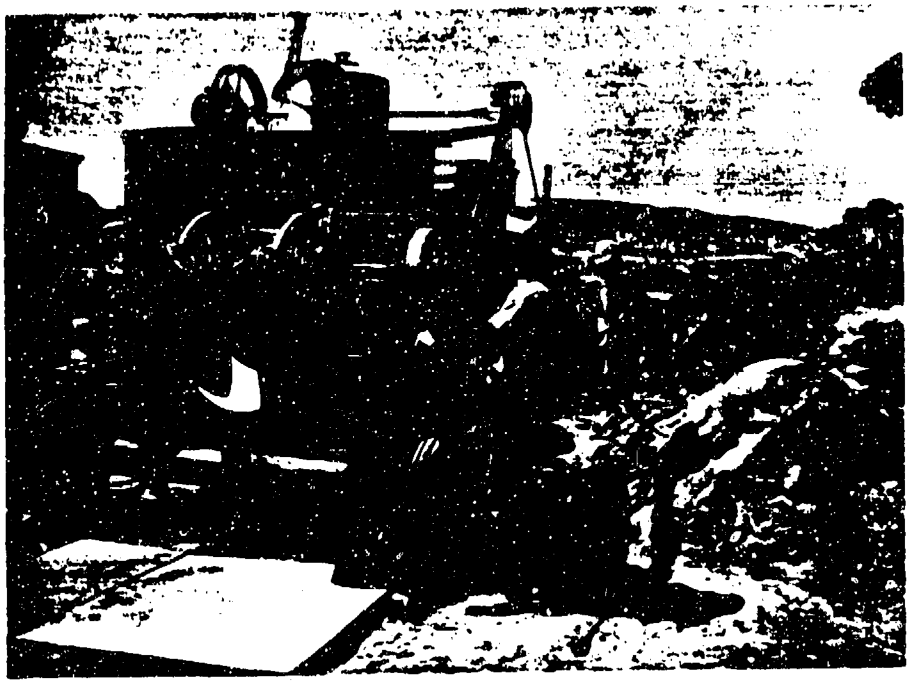

Figure 2.5 Mixing of colored sand for backfilling. (WES photo)

Figure 2.6 Backfilling and tamping of sand columns. (WES photo)

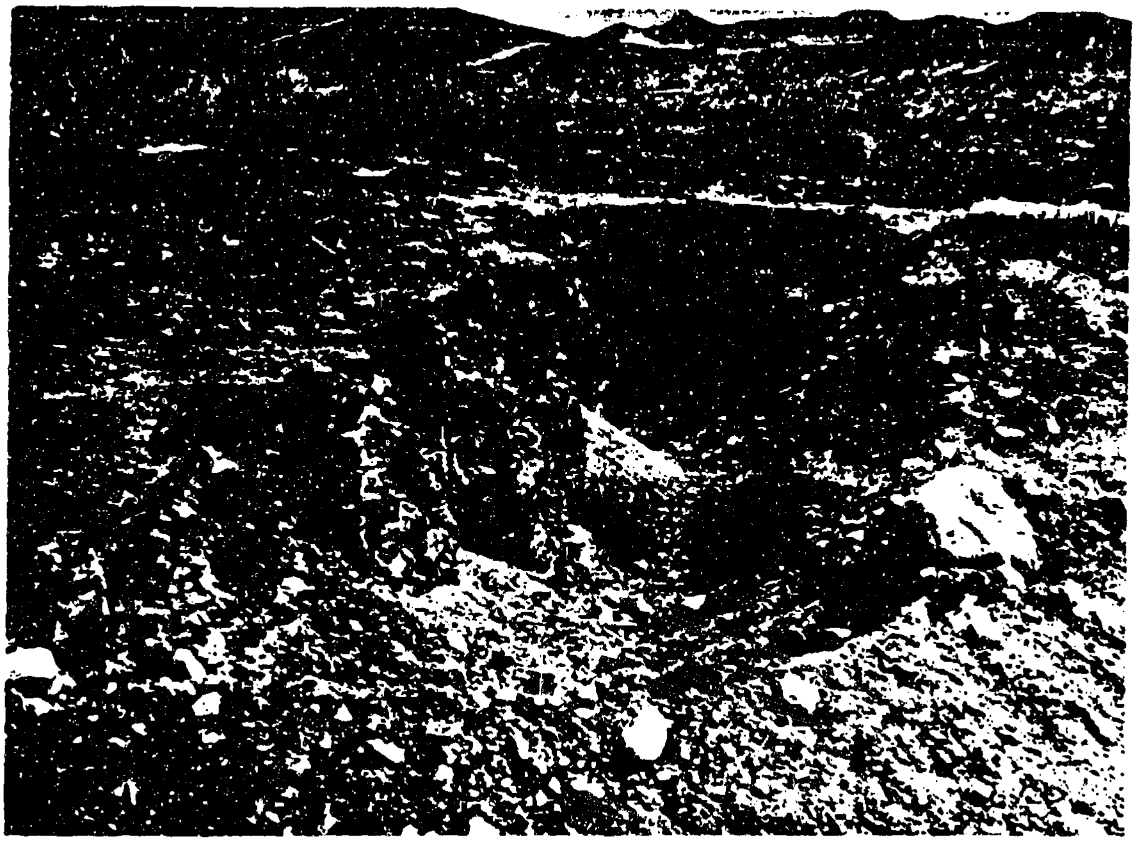

Figure 2.7 Sand-column excavation trench, looking toward GZ. (WES photo)

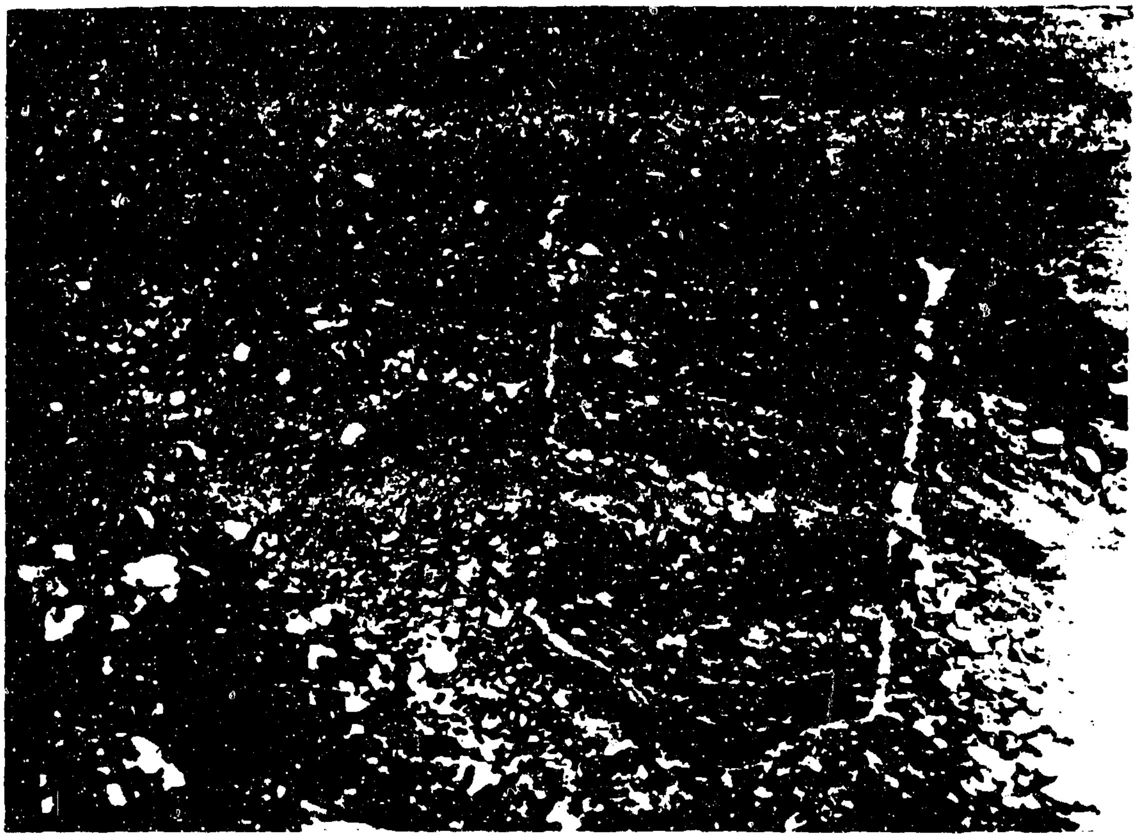

Figure 2.8 Sand-column excavation, showing columns 25 through 60 feet from GZ. View is toward the northwest. Note asphalt layers in columns. (WES photo)

CHAPTER 3

RESULTS

3.1 TEST CONDITIONS

Little Feller II was detonated at 1200 hours on 7 July 1962. Little Feller I was fired in conjunction with a troop exercise at 1000 hours, 17 July 1962.

3.2 CRATER MEASUREMENTS

3.2.1 Aerial Photography. Figure 3.1 is an aerial close-up of the Little Feller I crater, while Figure 3.2 is a stereopair of the same general area. Figure 3.3 is a contour map of this crater, and Figure 3.4 is a contour overprint of a photograph showing the same area. Figures 3.5 through 3.11 show corresponding preshot and postshot views of Little Feller II. Figure 3.12 is a map of the Little Feller II crater area in which only the differences between preshot and postshot aerial photography have been contoured, thus showing the topographical changes effected by the explosion.

Apparent crater dimensions, obtained by means of aerial photography, were as follows:

In both cases an elliptical crater was noted, and the apparent radii were found by averaging the minor and major axes.

3.2.2 On-the-Ground Surveys. Results of conventional profile surveys of the two craters are shown in Figures 3.13 and 3.14. Apparent crater dimensions obtained in this fashion (by averaging major and minor axes) were:

Dimensions of the crater axes were as follows:

3.2.3 Subsurface Crater Measurements, Little Feller II. Figure 3.15 is a centerline section (profile) of the Little Feller II crater, illustrating the results of the sand-column excavation (see also Figures 2.7 and 2.8).

Dimensions of the identifiable subsurface zones were as follows:

Plastic Response Zone	
Depth (feet)	Radius (feet)
Undetermined	22 (Estimated)

The rupture zone was virtually undetectable in this medium, and no reliable measurements of it are available.

3.2.4 Summary of Crater Data, Little Feller Events. Table 3.1 summarizes the data on both Little Feller craters, showing both actual and scaled values.

Figure 3.1 Aerial close-up of Little Feller I crater showing intended and actual GZ's. Dark spot immediately south of crater is an oily patch on ground. (WES photo)

Figure 3.2 Aerial stereopair showing Little Feller I crater. (Use standard stereoscopic instrument to obtain three-dimensional effect.) (WES photo)

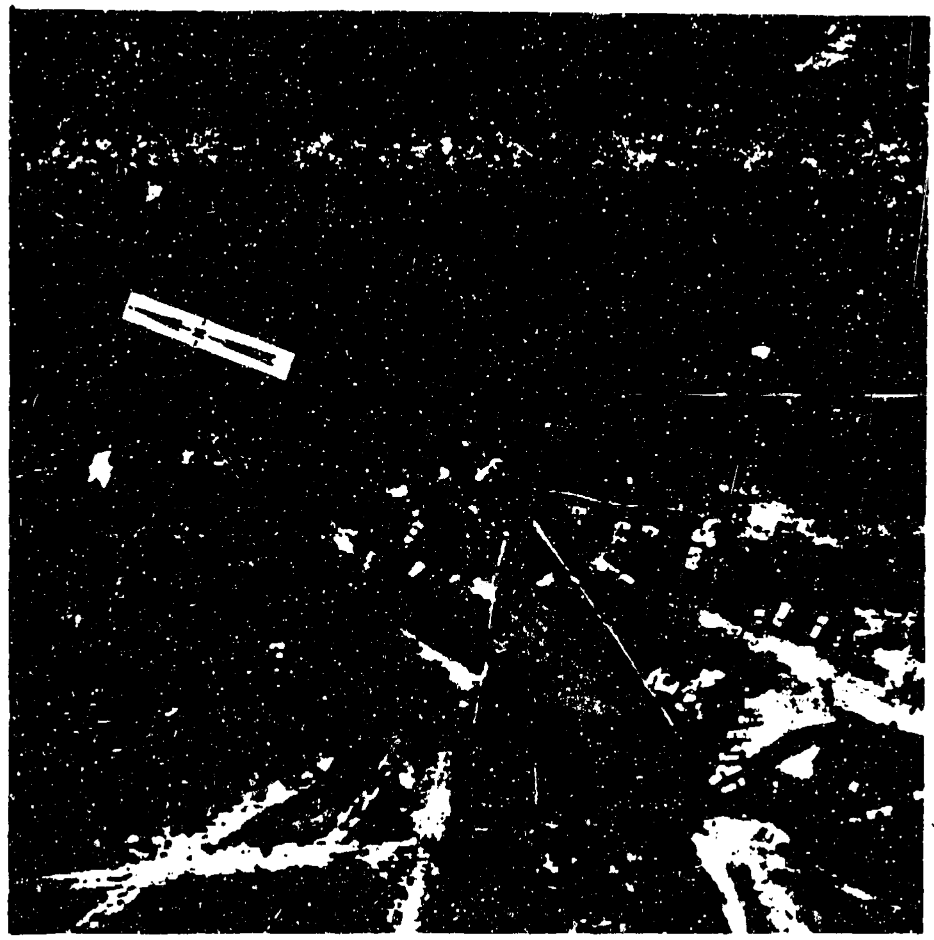

Figure 3.5 Preshot aerial close-up of Little Feller II test site. (WES photo)

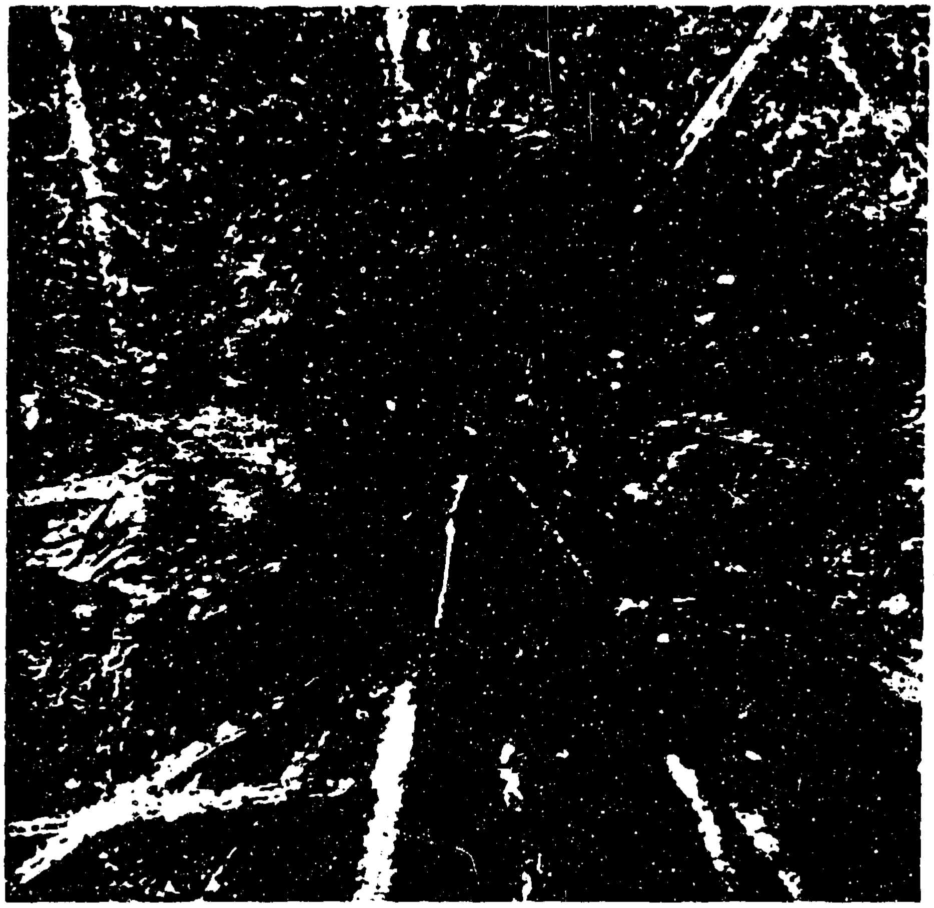

Figure 3.6 Postshot aerial close-up of Little Feller II crater. The object immediately south of the crater is a tracked vehicle with a boom extending over the crater. This device was used for early monitoring of the radiation in the crater. (WES photo)

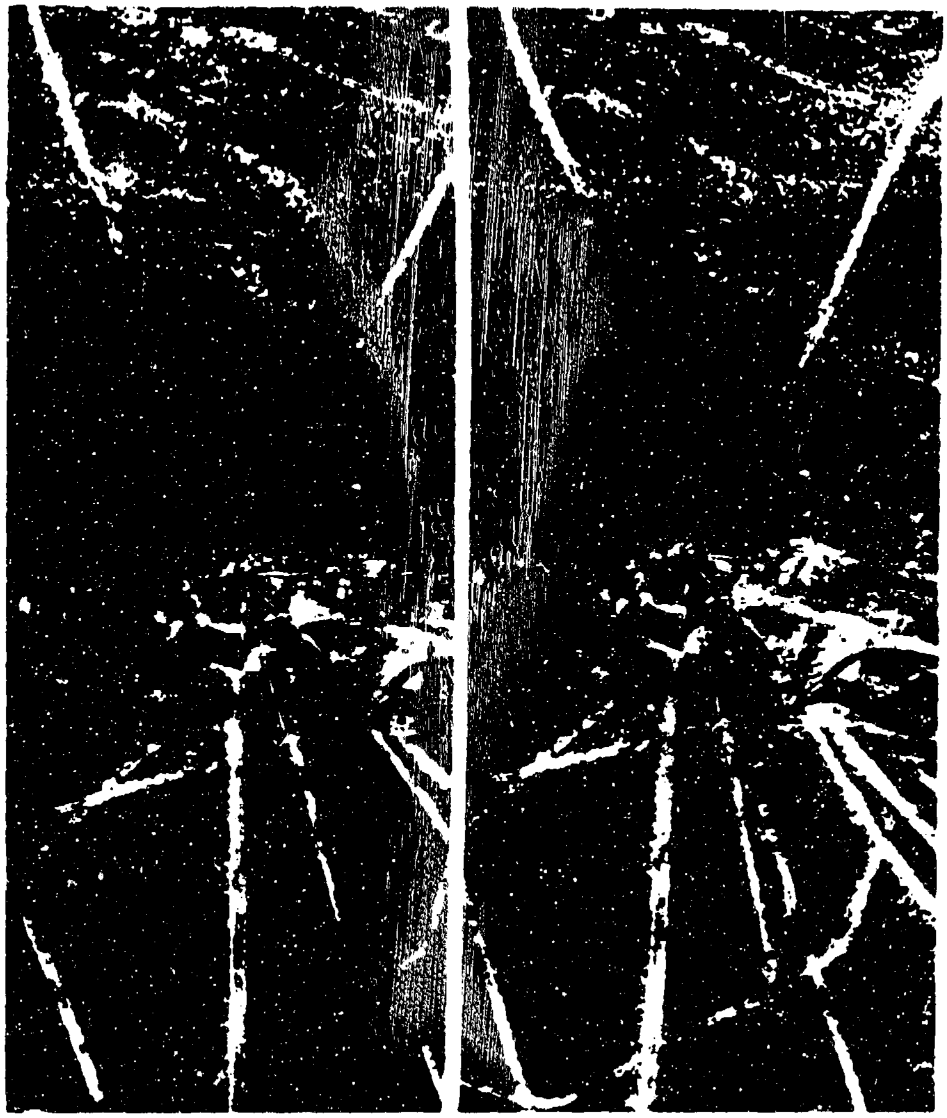

Figure 3.7 Aerial stereopair showing Little Feller II test site prior to the shot. Dark spots are oily patches on ground. (WES photo)

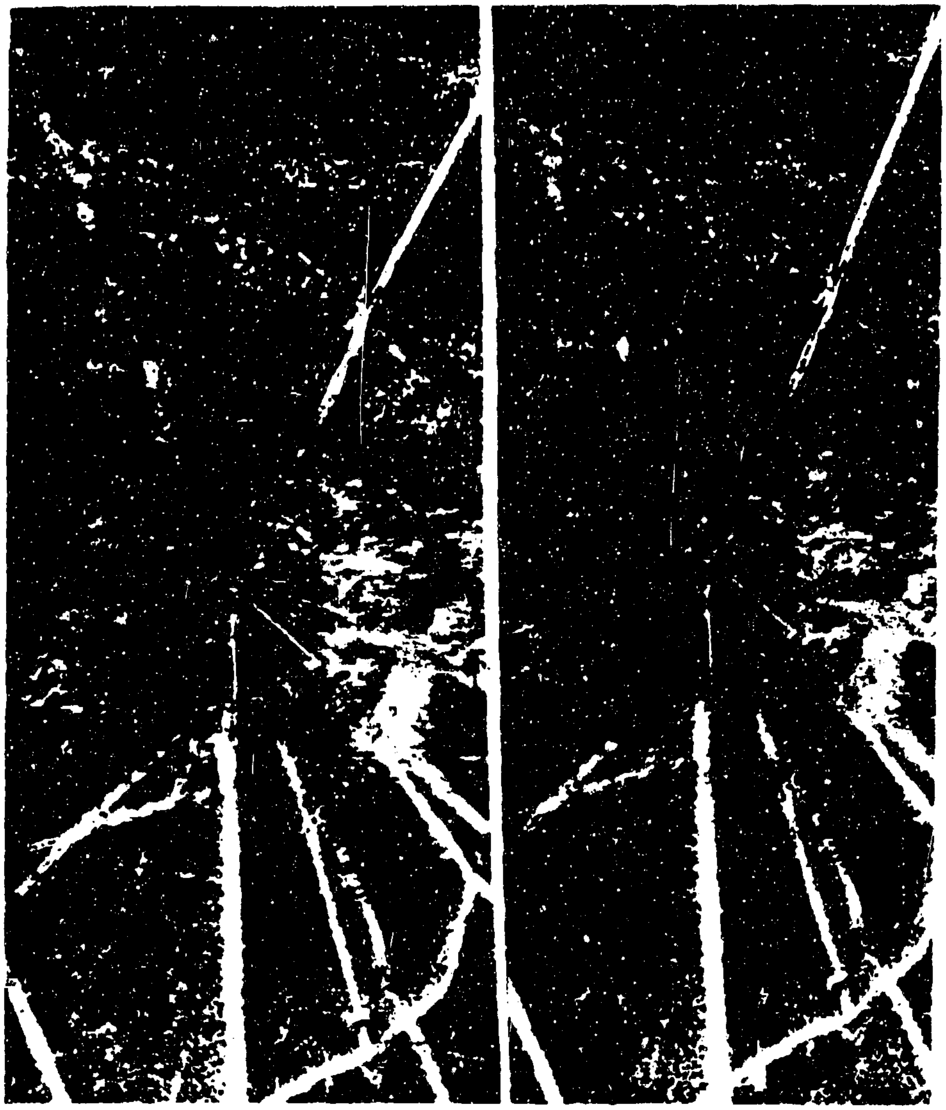

Figure 3.8 Postshot aerial stereopair of Little Feller II crater. (WES photo)

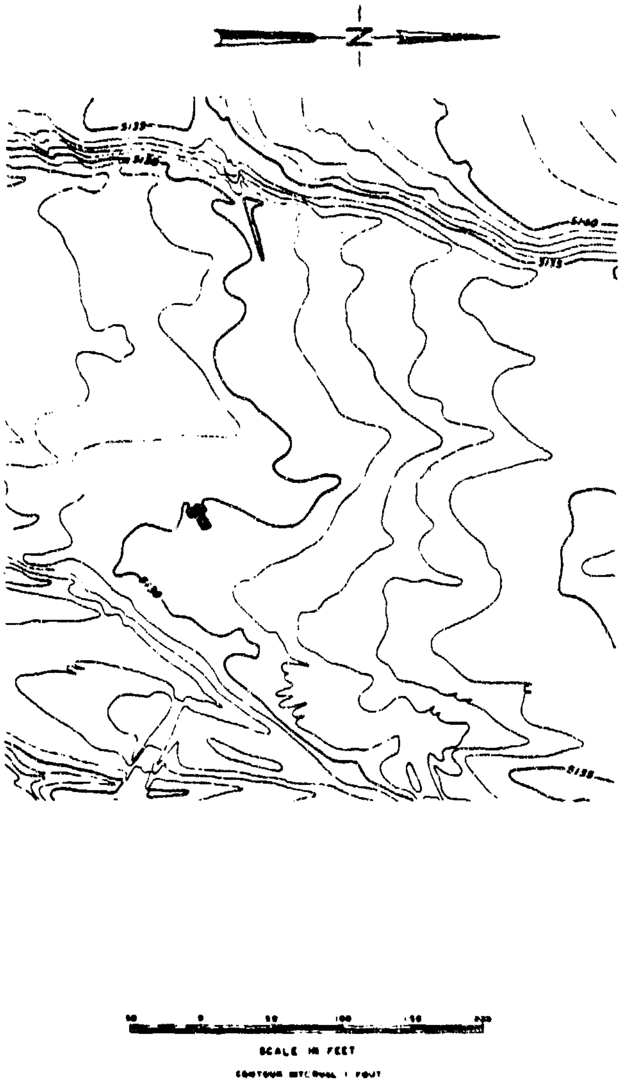

Figure 3.9 Preshot aerial contour map of Little Feller II crater area.

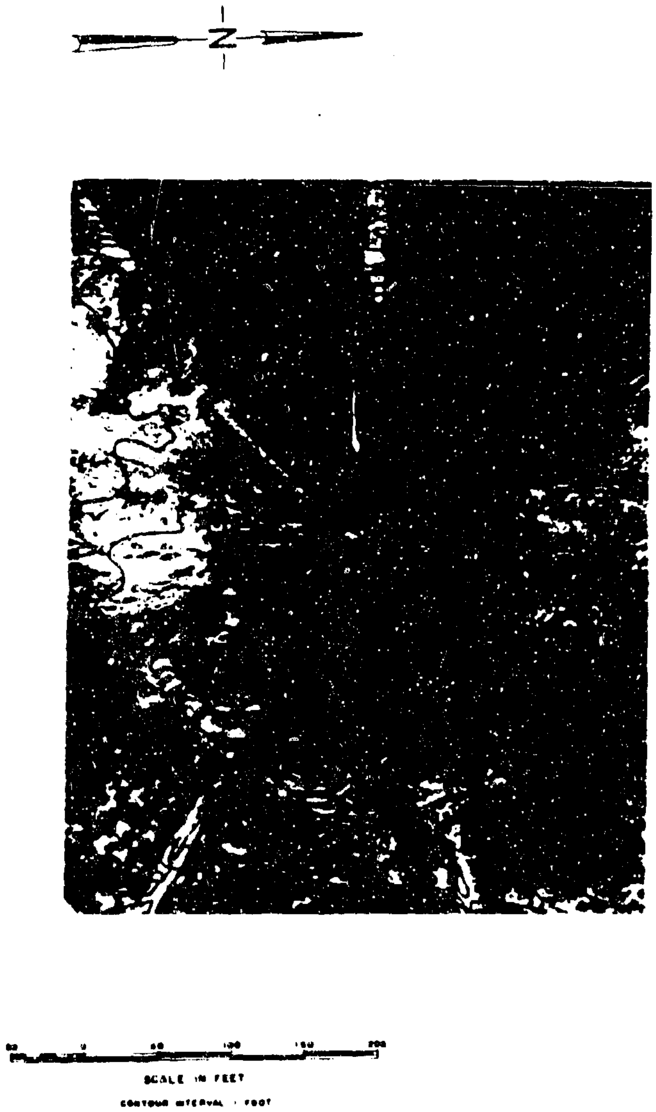

Figure 3.11 Postshot contour overprint of Little Feller II crater. (WES photo)

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CHAPTER 4

DISCUSSION

4.1 DATA RELIABILITY

The wrinkled appearance of the ground surface surrounding both craters made precise determination of the crater radii difficult. Thus, the radii measurements are averages of the major and minor axes and are considered accurate only to the nearest foot. They have been checked by computations involving the areas encompassed by the uppermost contours on both craters and have been found to be in reasonable agreement with these planimetric measurements.

Hubs for the postshot survey were emplaced during preshot operations for Little Feller II, and the postshot horizontal and vertical locations of the sand columns were determined quite satisfactorily during postshot excavation. With only a few exceptions, error between preshot and postshot surveys probably did not exceed 0.2 foot. The exceptions occurred in the vertical location of the asphalt layers in some of the columns near the extremity of the array, where sloughing had been noticed during backfilling. Figure 3.15 shows where sloughing occurred.

The accidental loss of much near-surface sand-column data prevented accurate appraisals of either the true crater or plastic zone radii for Little Feller II. Estimates of these boundaries included in Figure 3.15 are probably reliable only to approximately the nearest foot. All other dimensions and volumes for both of the Little Feller events (and other events listed in this report) are shown to the nearest figure considered significant.

Little Feller I was fired

its HOB was considerably lower than planned, and the HOB reported herein is merely a best estimate. Therefore, in the plotting of scaled dimensions, greater reliance has been placed upon the statically fired Little Feller II event.

4.2 CHARACTERISTICS OF THE CRATERS

Examination of the crater profiles from both shots indicates the occurrence of plastic flowage in the media near the GZ's (see Figures 3.13 through 3.15), a phenomenon which probably accounted for virtually all of the apparent crater volumes except for the amounts carried aloft by thermal currents. No conventional crater lip or throwout (ejecta) was apparent for either event.

The only evidence of a distinction between the boundaries of the apparent and true craters was found in the GZ sand column in Little Feller II, which showed a definite dissociation of the medium to a depth of more than twice that of the apparent crater. The graunlar, unconsolidated soil in the crater area made visual distinction between fallback and the true crater boundary practically impossible, although the former tended to slough somewhat more readily upon excavation. In view of the compressive and scouring actions which must have occurred beneath the expanding fireball, as well as the high temperatures in this region, it seems likely that most of the fallback was the result of dissociation caused by extreme fracturing and flowage, rather than by the normal uplifting action common to explosions of buried charges.

Both Little Feller craters had approximately an elliptical shape (as viewed from above) with major:minor axes ratios of ~1.3 for Little Feller I and ~1.8 for Little Feller II.

4.3 CORRELATION WITH PREVIOUS TEST DATA

Figures 4.1 and 4.2 are scaled plots of available data on NTS alluvium shots (References 2 and 12). On both the apparent crater depth and radius graphs, the Little Feller events fall on or near extensions of existing curves constructed to favor the larger yields. Little difference between NE and HE data is noticeable on the depth curve, but some difference is evident in scaled radius, particularly between about depth of burst (DOB) 25 $ft/kt^{1/3.4}$ and HOB 10 $ft/kt^{1/3.4}$.

Table 4.1 is a compilation of cratering data for large yields (> 5 tons) in desert alluvium and similar media, representing all information known to be available at this time. Based upon these data, the Little Feller shots are graphically compared as to depth, radius, and volume in Figures 4.3 through 4.5, respectively. Available true crater data have been included, and true crater depth is shown by a dashed line in Figure 4.3; however, the scatter of the few true crater data points in Figure 4.4 precludes construction of a reliable curve. In Figure 4.5, apparent and true crater volume curves appear almost coincident in the range for which data for the latter are available. In the construction of Figure 4.4, the radial dimensions for Neptune (point 9), a nuclear shot in tuff located on a hillside, have been averaged so as to approximate the dimensions which would have been realized if the shot had been located on level ground.

With few exceptions, the apparent crater data points in Figures 4.3 through 4.5 lend themselves to construction of smooth curves for crater dimensions and volumes, despite minor differences in cratered media. The general configuration of both depth and radius curves resembles that of their counterparts for alluvium only in Figures 4.1 and 4.2. The departure exhibited by the White Tribe data (point 1) in Figure 4.4 may be attributed to the charge configuration and position (a hemisphere resting on ground surface);

however, the failure of ERA 115 (point 3), a dry-sand shot, to compare favorably with the other data cannot readily be explained.

Figure 4.4 illustrates the sharp upward trend (with increasing HOB) which is characteristic of the radius curve and which occurs at a minimum point near a scaled

At about this same location, the downward slope of the depth curve decreases, and the net result is an increase in crater volume beginning at a low HOB and continuing through an undetermined range of increasing charge elevations. These observations are in general agreement with those of Reference 1. The general profile of this type crater is suggested by a diagram of the shock front in Reference 9.

The porous, unconsolidated nature of the cratered medium may partially account for the early dissipation of shock energy, and it appears probable that impacting fragments of the device casing contributed to crater depth directly below the charge.

In summary, the cratering effects of the Little Feller shots were much as would be expected from empirical data, although the exact mechanics of the crater formations are not fully understood. Both craters appear to have resulted from high-velocity impact of casing fragments, plastic flowage of the soil under the conditions of shock, temperature and pressure accompanying the explosions, scouring and thermal uplift of the explosion gases, and perhaps to a small extent, direct compression of the media. The true crater was surprisingly deep but appeared to have been formed by gross compression/flowage of the medium.

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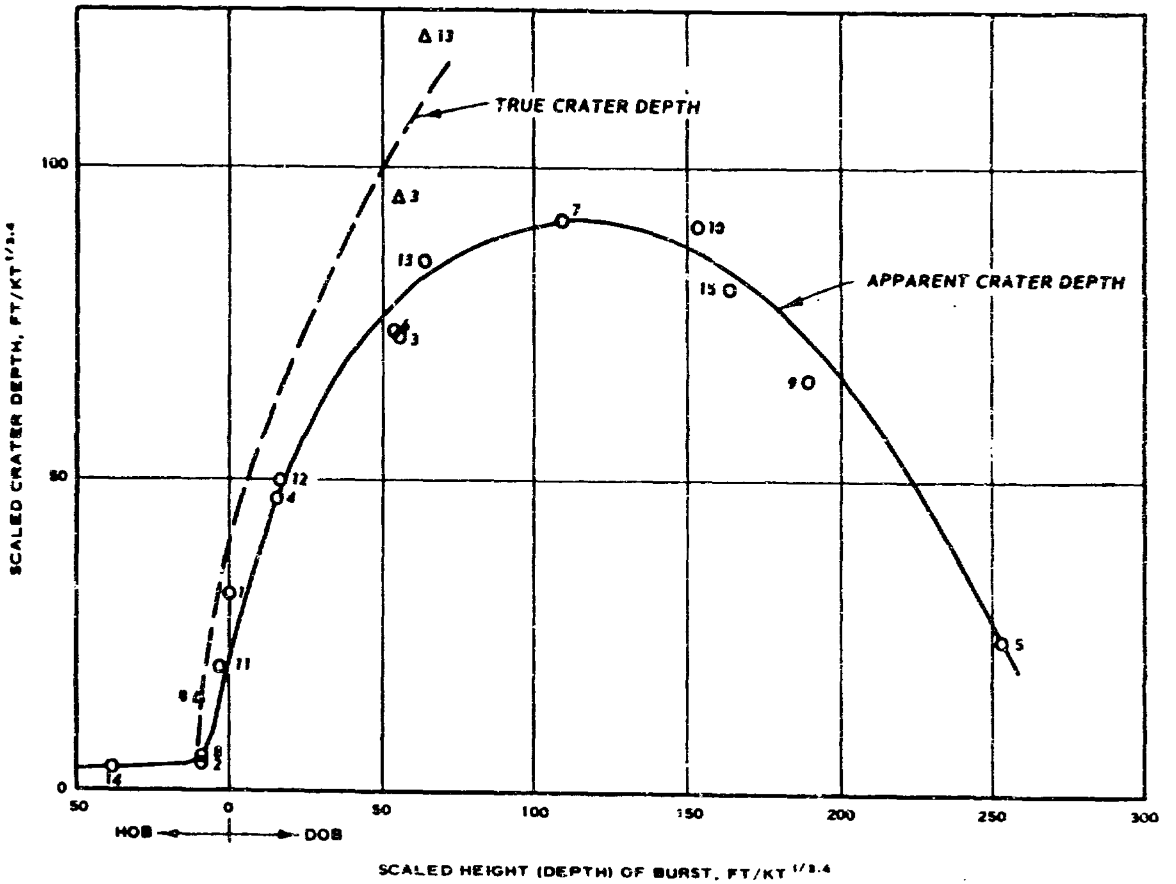

Figure 4.3 Scaled crater depth versus HOB (DOB) for large explosions in desert alluvium and similar media. Numbers by points refer to events listed in Table 4.1.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In the crater measurements of Little Feller I and II, a relatively simple and inexpensive experiment yielded valuable information on crater parameters for low airbursts. Both craters exhibited asymmetrical tendencies and both appeared to have been formed largely by plastic flowage of the medium in the high heat and pressure fields surrounding the detonation.

Both Little Feller shots plot reasonably well as extensions of existing desert-alluvium cratering curves, and together they approximate the first minimum point to the left of the surface burst on the radius and volume curves. A height of burst which would be more favorable from a tactical standpoint would also yield a larger crater, in terms of displaced volume of soil, but in order to form a crater which would represent a significant obstacle, a much larger yield would be required. With weapons

the denial of an area or defile will probably be more effectively accomplished by residual radiation than by their cratering capability.

5.2 RECOMMENDATIONS

Further experimentation in crater formation by low air-bursts is very desirable whenever the opportunity is presented. Not only should more be known about HE and NE cratering curves for airbursts over different types of soil, but the reproducibility of results already obtained should be further examined.

On future cratering experiments, especially those involving unconfined or partially confined charge positions, a preplanned exchange of technical information is recommended, wherein results of high-speed fireball photography, ground-motion investigations, and pressure and temperature data at and below ground surface would be made available in the study of the crater. The availability of such data should make it possible to explain with a greater degree of confidence the mechanics of crater formation for above-surface bursts.

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