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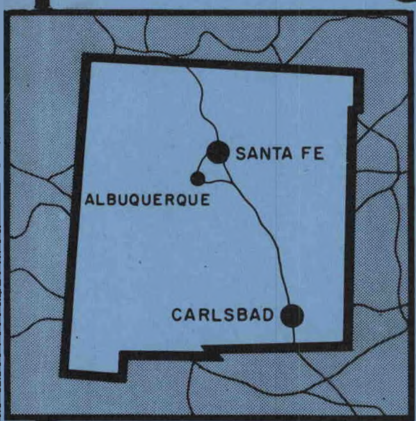
PNE-109F

U.S. ATOMIC ENERGY COMMISSION PLOWSHARE PROGRAM

Project GNOME

CARLSBAD, NEW MEXICO
DECEMBER 10, 1961



Final Report

EARTH DEFORMATION FROM A NUCLEAR DETONATION IN SALT

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R. M. Foose

STANFORD RESEARCH INSTITUTE

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NUCLEAR EXPLOSIONS—PEACEFUL APPLICATIONS

Project Gnome

EARTH DEFORMATION FROM A NUCLEAR DETONATION IN SALT

R. B. Hoy, Project Officer
R. M. Foose

Stanford Research Institute
Menlo Park, California

May 23, 1962

/ (Supersedes PNE-109P).

ABSTRACT

Measurement of rock deformation caused by the Gnome explosion revealed that maximum permanent surface displacement was confined to an area within 100 meters of surface ground zero. The surface above ground zero remained permanently raised 0.3 to 0.6 meter after an initial transient displacement estimated to be 1.5 meters. The permanent deformation was characterized by fractures with offsets up to 0.2 meter. Abundant hair-line fractures were observed out to 300 meters. Occasional small fractures were noted as far as 1000 meters from surface ground zero.

Underground, fractures were observed in the shaft lining at 23, 27, 49, and 146 meters, with a slight water seep at 146 meters.

In the shaft station a cone-shaped pile of debris which caved from the ceiling reached a maximum height of 1.2 meters. The old drift was also partially filled by debris but was open all the way to the explosion cavity. Aside from spalling and slabbing, the old drift had also been contracted to approximately two-thirds its original size, the amount of contraction being greater near the shot point.

Apparently the pressure of the explosion spread the salt layers apart and thrust wedges from the cavity into the spaces between the layers.

The cavity itself appears to be a stable sphere approximately 27 meters in radius, which should be a useful size for underground storage of natural gas or petroleum or as a site for solution mining.

12 references. /end

PREFACE

The authors wish to acknowledge the cooperation of Mr. Ernest Wyncoop, Atomic Energy Commission Support Director, Lt. Colonel Raul Nunez of the Air Force Technical Applications Center (AFTAC), Lt. Colonel W. L. Carss and Major E. B. Nelson of Field Command, Defense Atomic Support Agency, Dr. P. L. Randolph, Deputy Technical Test Director, and Dr. R. G. Preston, both of Lawrence Radiation Laboratory (LRL), all of whom were most helpful in coordinating the rock deformation investigations.

Dr. D. E. Rawson, LRL geologist, provided information on rock deformation in the material around the shot cavity.

Also acknowledged is the cooperation of Mr. R. H. Jaeger and Mr. K. E. Hall, both of LRL, in providing close-in aerial photograph of the surface ground zero area immediately following the shot.

The high altitude aerial photographic work was performed for AFTAC by the 1370th Photo Mapping Group, Turner Air Force Base, Albany, Georgia.

Personnel from Stanford Research Institute (SRI) who participated in the project included R. B. Hoy, senior geologist, and R. M. Foose, chairman of the Earth Sciences Department, who conducted the field work and analyzed its results. C. J. Moore, senior photographer, took photographs from a helicopter and also on the surface and underground. A list of the negative numbers of SRI photos is included as Appendix A of this report.

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FIGURES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Stanford Research Institute (SRI) has determined by geological studies the extent and degree of rock deformation caused by nuclear explosions in tuff (References 1, 2) and in alluvium (Reference 3), and by high explosive detonations in salt (Reference 4).

The Gnome explosion at a depth of approximately 366 meters in salt, 40 km southeast of Carlsbad, provided an excellent opportunity to determine the nature and extent of rock deformation in a different geographical, geological, and topographical environment. Consequently, the Atomic Energy Commission (AEC) requested SRI to investigate the geologic aspects of rock deformation (Project PD-3771) for Gnome.

The Gnome test was fired at 1200 hours MST on December 10, 1961, and produced a yield (preliminary estimate)of 3±1 kt. The test was conducted to investigate the peaceful applications of nuclear energy. The investigation of the extent and degree of rock deformation was expected to provide valuable information regarding the applicability of nuclear explosions in salt for constructing underground chambers, for assisting in salt mining, and for developing and containing heat for power generation. Also tentative conclusions were anticipated on the applicability of explosions in other media for engineering and mining purposes.

1.2 OBJECTIVES

The broad purpose of the research was to measure the extent, form, and degree of deformation caused by the Gnome explosion to provide basic information that would be valuable for application of nuclear energy to peaceful uses.

The specific objectives were to:

1. Map in detail the extent, degree, and form of surface and underground deformation;

2. Compare the deformation due to this shot with that of explosions in Nevada Test Site tuff;

3. Evaluate the significance of this information for peaceful uses of nuclear energy.

1.3 THEORY

Theoretical calculations indicated that the effects of the Gnome nuclear explosion would result in a cavity 17 meters in radius and total tunnel collapse to a point 125 meters from the blast. Essentially no permanent displacement was expected in the shaft. Damage was not expected in the Shell gas well, 9.3 km distant; the potash mines, the nearest 13 km distant; nor in Carlsbad Caverns, 55 km distant.

The theoretical maximum limit of displacement of a free particle at the surface was 3.035 meters (Reference 5). This was expected to develop fractures and visible permanent displacements.

CHAPTER 2

DESCRIPTION OF THE GNOME AREA

2.1 LOCATION

Gnome, an underground test of a nuclear device, was located at a point 303 meters on a bearing N49°43'11"E from the center of Section 34, Township 23 South, Range 30 East, New Mexico Principal Meridian, at an elevation of about 674 meters referred to mean sea level or at a depth from the surface of 361 meters (Figures 2.1 and 2.2).

This site is about 40 km southeast of Carlsbad, New Mexico, in salt beds of the Salado formation in the Delaware Basin.

2.2 TOPOGRAPHY

The surface at Gnome site is at an elevation of about 1036 meters above sea level (Figure 2.2). The topography is very gently rolling with a general slope to the northeast of about 92 meters in 46 km. The area drains into Nash Draw, thence westerly into the Pecos River. Surface sand dunes with up to about 6 meters of relief are elongated in an east-west direction (30 to 90 meters long and about 15 meters wide).

2.3 GEOLOGY

2.3.1 Stratigraphy. The Gnome area is underlain by gently dipping sedimentary rocks of the Salado (Permian), Rustler (Permian), Dewey Lake (Permian), and Gatuña (Pleistocene) formations (Reference 6, 7, 8). Figure 2.3 shows a section through the Gnome shaft and tunnel. At the shaft-site the surface sand (Mescalero) and caliche extend from the surface to 13 meters. The Gatuña sandstones extend from 13 to 28 meters. The Dewey Lake red sands and shales extend from 28 to 90 meters. The Rustler formation consisting largely of anhydrite and gypsum extends from 90 to 198 meters with the Culebra member, a water-bearing dolomite, between 151 and 159 meters. The Salado formation, consisting mainly of halite with minor beds of shale, anhydrite, and polyhalite, extends from 198 meters to a depth of about 686 meters at the Gnome shaft site (References 9, 10).

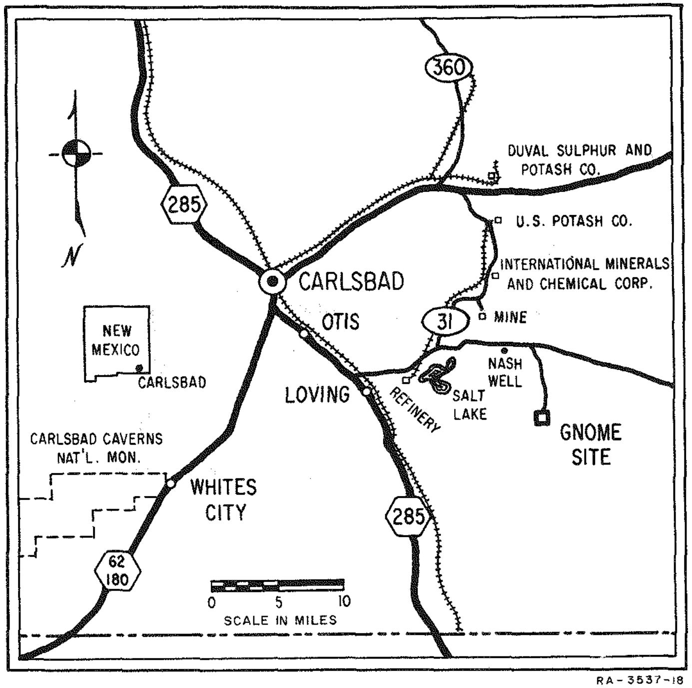

Figure 2.1 Index Map Showing Locations of Gnome Site

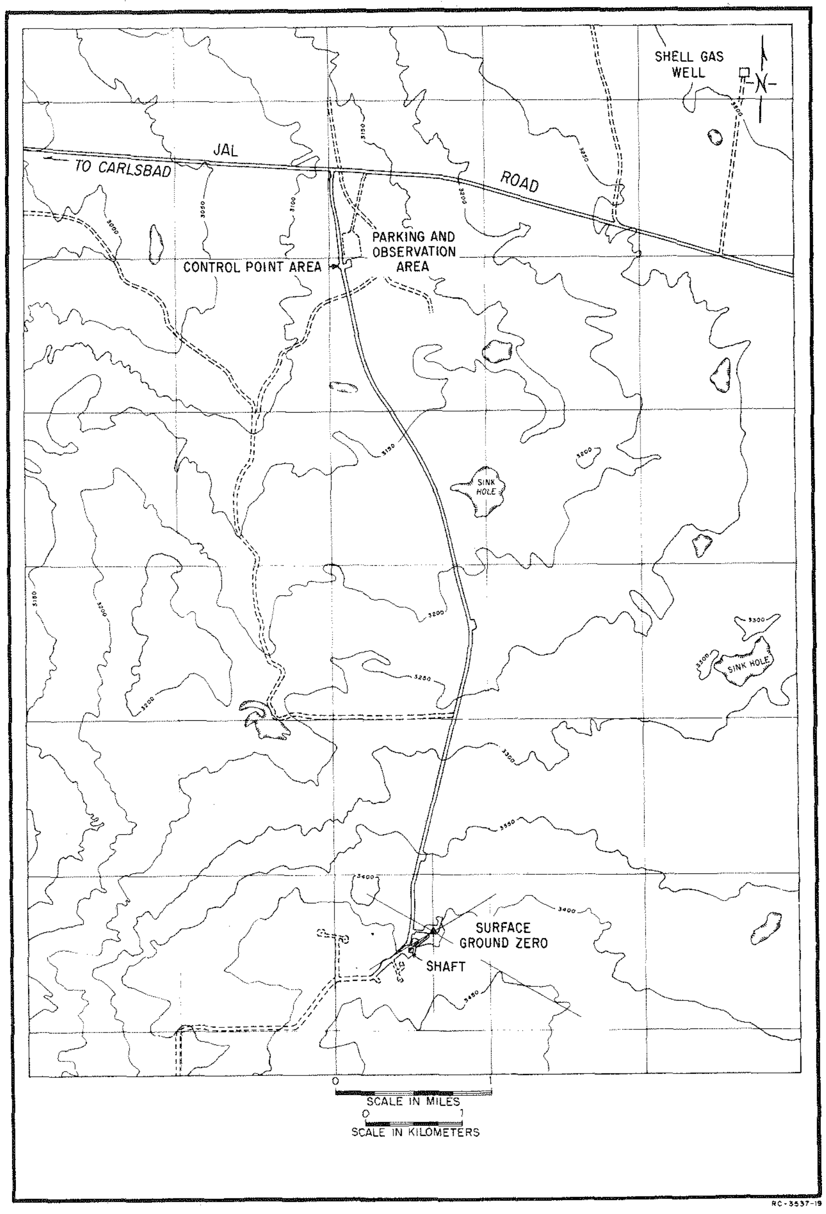

Figure 2.2 Topographic Map of Gnome Shot Area

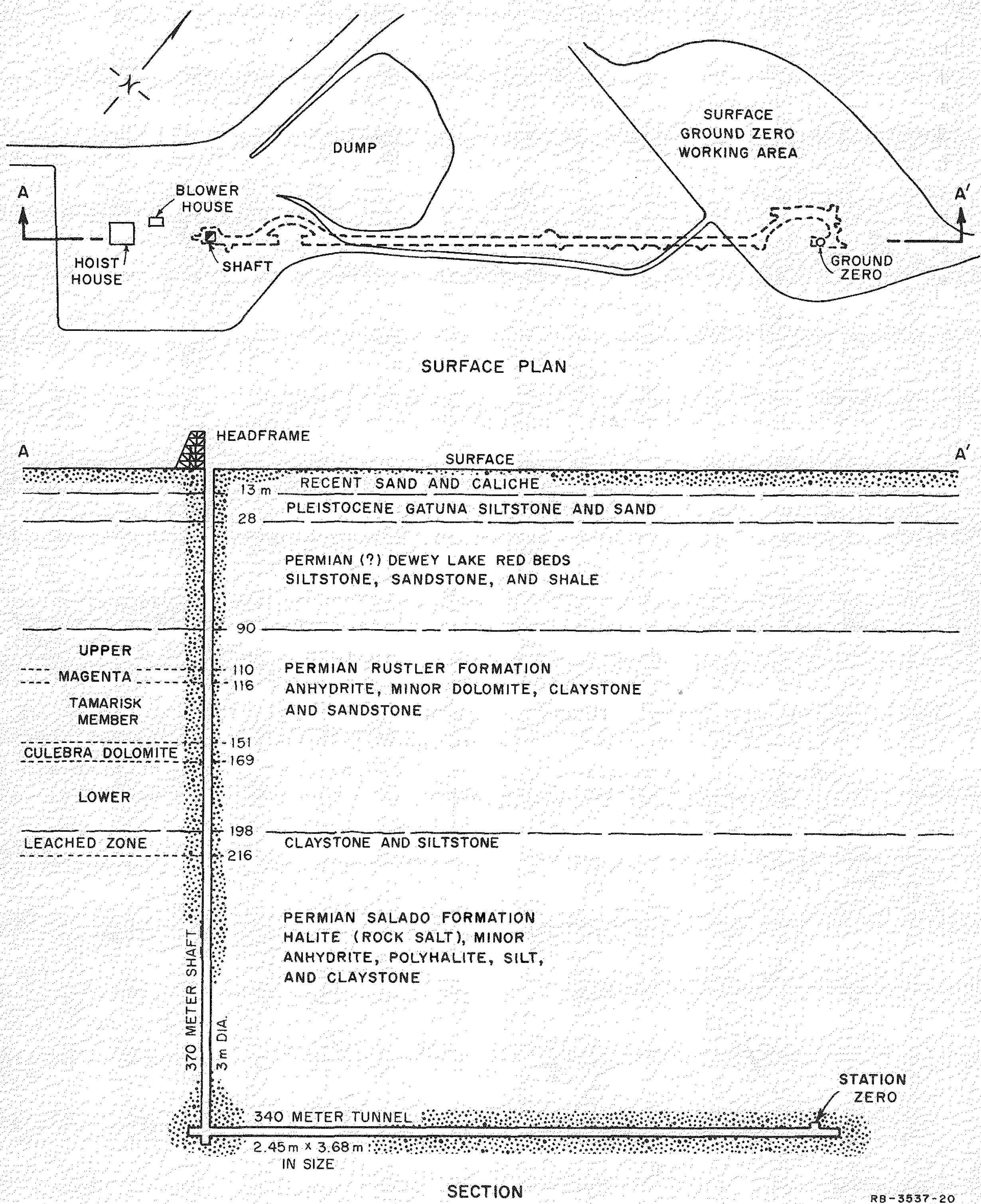

Figure 2.3 Geologic Section Through the Gnome Shaft and Tunnel

The stratigraphic section exposed throughout the length of the tunnel from the foot of the shaft to the Gnome detonation point consists dominantly of horizontally bedded crystalline halite colored white, pink, and orange. A prominent bed of dense, dark red polyhalite, 15-cm to 30-cm thick, is exposed low on the tunnel walls throughout the first half of the tunnel length. A few centimeters below the polyhalite bed there is a moist, slick, gray clay seam ranging up to 2.5-cm thick. Upon exposure, the clay swells. Near the top of the section throughout most of the tunnel there is a 30- to 60-cm thick bed of mottled white and brown or dark gray rock which is halite mixed with varying amounts of clay that occupies intercrystalline space. This rock is weak; it crumbles and slabs easily. Slickensided displacement planes were observed in this rock. Near the Gnome detonation point the top of the tunnel is occupied by 30 to 60 cm of clear white and pink halite situated above the dark-colored crumbly halite (Reference 11).

The Gnome detonation point is essentially at the same stratigraphic depth at which potash is produced in the International Minerals and Chemical Company mine 13 km to the north; however, potash minerals are very sparse in the Gnome area.

2.3.2 Structure. The main structural features of the Gnome area are northeasterly-trending broad anticlines within a depth of 458 meters from the surface. The deeper formations (the lower part of the Salado formation and the Castile formation below the Salado) dip easterly at an angle of less than 5 degrees. Sink holes, developed by solution of the soluble members of the Rustler formation, are present 3 km northwest and 4 km northeast of surface ground zero.

CHAPTER 3

PROCEDURE

The procedures used in this project include interpretation of aerial photographs, and surface and underground field investigations.

3.1 AERIAL PHOTOGRAPHY

Aerial photographs were taken from an RC-130 photo-reconnaissance aircraft from the 1370th Photo Mapping Wing, Turner Air Force Base, Albany, Georgia. The pre-event aerial mission was flown on December 9, 1961, the day preceding the Gnome shot. The postshot mission was flown December 12, 1961. Both pre- and post-shot photos were taken with black and white film at scales of 1:11,500 and 1:2800 feet.

The conventional aerial photography was supplemented by pre- and postshot photographs taken with Speed Graphic cameras from helicopters. These latter photos were particularly helpful in detailed mapping of the fractures in the area of surface ground zero.

3.2 SURFACE EXAMINATIONS

Surface examinations were made of all areas which might reveal effects from the Gnome explosion. The pre-event examinations included detailed visual observations of the area of surface ground zero and of fractures, dunes,vegetation, animal activity, and other special features along six radial lines, five of them extending 850 meters from surface ground zero and one line (120° azimuth) extending 1750 meters from surface ground zero. These lines were at azimuths of 0°, 60°, 120°, 180°, 240°, and 300°. Each line had marked stations at 30, 60, 100, 150, 250, 300, 350, 450, 550, 650, 750, and 850 meters. Photographs were taken from each station facing away from surface ground zero. Photographs were also taken from each of the 30-meter stations toward surface ground zero.

On previous tests the movement of rock fragments proved to be an excellent clue as to surface disturbance and the direction of surface motion. For example, statistical analysis of the movement of rock fragments on the surface around an underground explosion at the Nevada Test Site (NTS) (Reference 2) proved that the majority of rock fragments were flipped away from the surface ground zero point. Rock fragments are so sparse in the area of Gnome surface ground zero that rocks were placed along each of the radial survey lines. This was done at 30, 60, 75, 90, 106, 121, and 136 meters.

Field examination after the test included mapping of faults and fractures, measuring displacement of rock fragments, observation of vegetation disruption and effect upon animal activity, and other effects of the test. Photographs were taken both of the ground surface and of man-made structures to illustrate significant effects.

3.3 UNDERGROUND EXAMINATION

Pre-event underground examinations were conducted and photographs were taken. The northwest wall of the tunnel was marked with black paint lines from the shaft to 7+00 (feet). Horizontal lines were painted at 3-foot (0.9-meter) and 5-foot (1.5-meter) heights above the floor, and vertical lines at 5-foot (1.5-meter) intervals measured along the center line of the shaft. This gridded wall was photographed. Roof bolts were placed in the roof and in the northwest wall of the tunnel at 15-meter intervals from the shaft to 8+00 (feet). The roof bolts were marked with numbers 1 through 34 stamped in the heads (odd numbers in roof and even numbers in wall), and the coordinates and elevation of each bolt were determined (see Appendix B). Photographs were also taken of the roof, rock bolts, and pipes, and other places where the possibility of deformation was anticipated.

Reentry for photography and preliminary observation was permitted on January 10, 1962, one month after the blast. Reentry for additional photography and further observation was again permitted on May 9, 1962. By this time a parallel recovery drift had been driven on a centerline 25 feet southeast of the centerline of the original drift to a point within about 27 meters of the shot point. Access to the old drift was gained at the blast door, at cross-cuts from the new drift at stations 2+09.5 and 6+53.

The 70-foot section of drift from the blast door to the 2x2-foot manway was examined in considerable detail. However, safety restrictions limited access at the other two points. At 209.5 feet permission was granted only to look at the drift from the crawl-hole and at 653 feet entrance was limited to a 10-foot section of the old drift on both sides of the crawl-hole.

CHAPTER 4

RESULTS

Gnome shot was detonated at noon on December 10, 1961. Preliminary analyses indicate that the yield was 3±1 kt (predicted 5 kt).

4.1 AERIAL PHOTOGRAPHS

The 1:11,500-scale aerial photographs were of aid in mapping rock deformation, primarily in locating points where surface effects were observed on the ground.

The 1:2800-scale photographs likewise were of value as mapping bases for locating features observed on the ground. The area around surface zero was so badly fractured that immediately after the preliminary surface examination, new material was dumped on the ground and leveled off to provide a smooth level working area. Numerous trucks, drill rigs, graders, bulldozers, and automobiles were brought into the area to begin the post-shot experiments; consequently, most evidence of surface fracturing was soon wiped out.

Photographs taken from a helicopter at an elevation of about 500 feet above the terrain, Figure 4.1, were valuable for mapping the surface zero fracture pattern.

4.2 SURFACE EXAMINATION

4.2.1 Fractures. The surface fractures were primarily concentric about and radial from surface ground zero (see Figures 4.1 and 4.2). The pattern is not circular but is elliptical with the long axis in approximately a N60°W-S60°E orientation. Some of the fractures that do not fit into the concentric and radial systems have been controlled by man-made features. For example, fractures formed (1) along trenches that had been dug for pipes and cables, (2) around the well head, the containment storage tank, and the spray pond, and (3) along tracks made by heavy equipment.

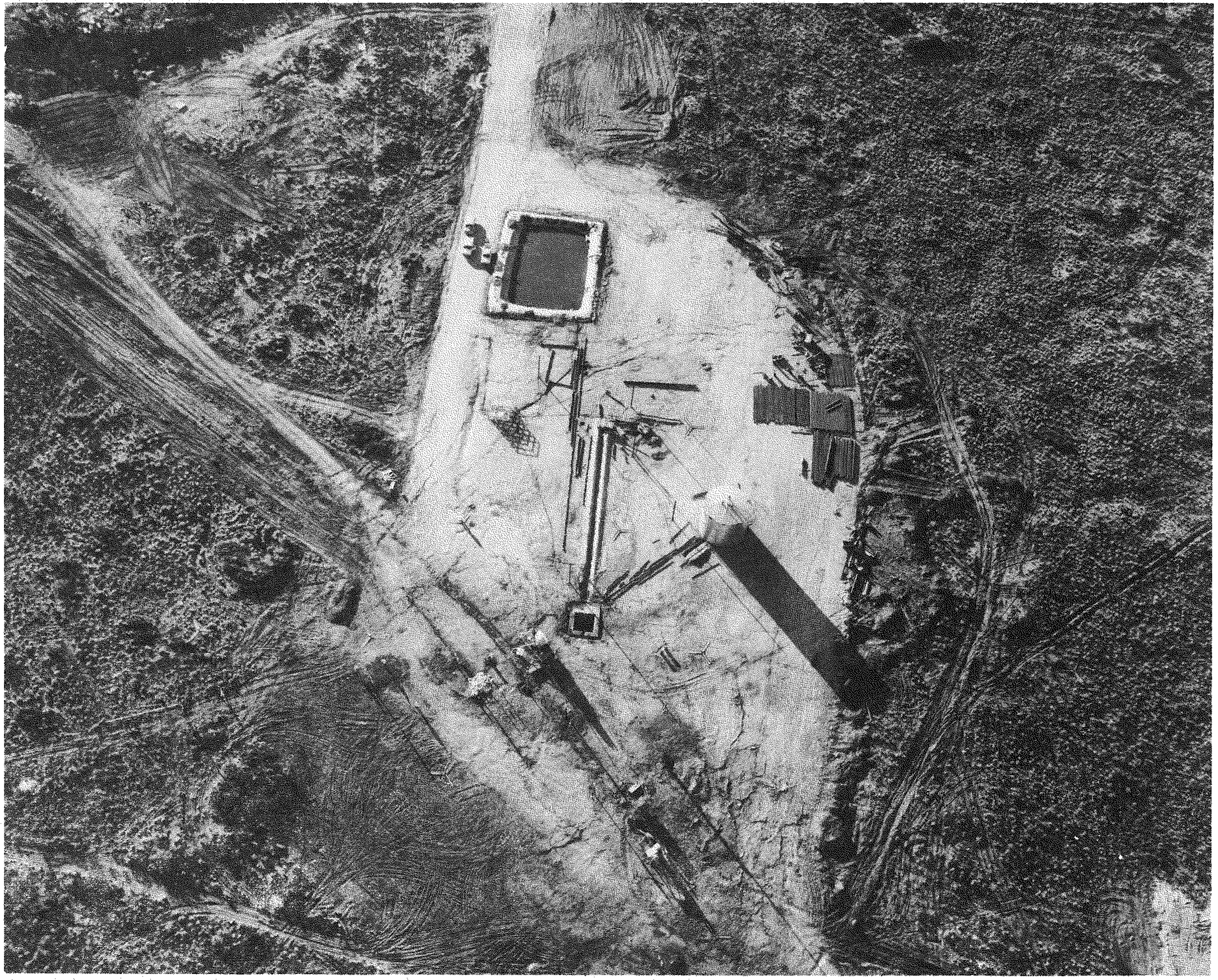

Figure 4.1 Fractures Around Surface Ground Zero

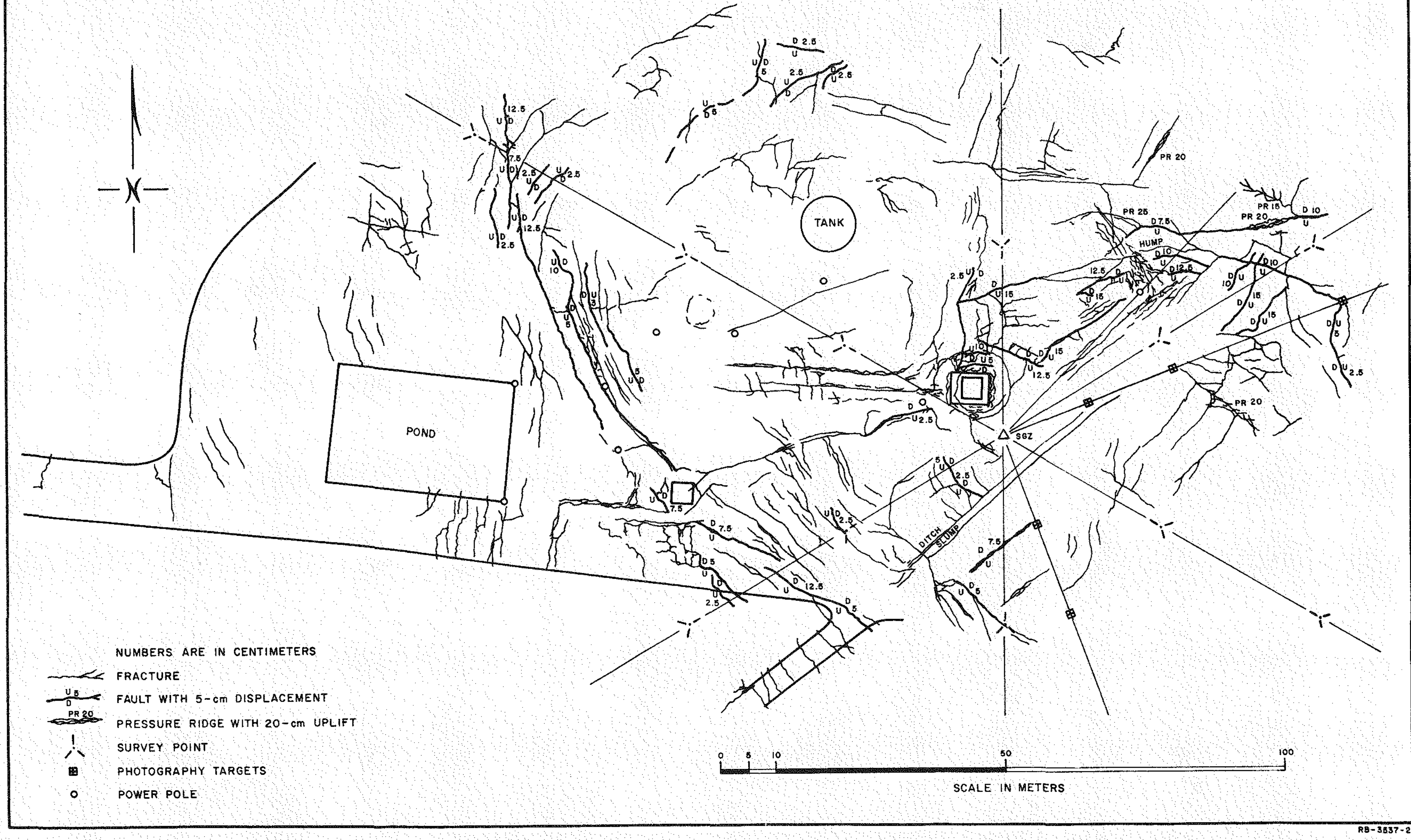

Figure 4.2 Map of Fractures Around Surface Ground Zero

Profiles surveyed the day following the event compared with pre-event profiles indicated that the surface above ground zero was permanently raised from 0.3 to 0.6 meter (Figure 4.3)*. Apparently the initial transient displacement was much larger than this (an estimated 1.5 meters). As the surface settled, concentric fractures developed with a permanent displacement of up to 0.2 meter. This displacement was almost always down on the side of the fracture toward surface ground zero, revealing tilting of individual blocks. Figure 4.4 shows a concentric fracture located 40 meters southwest of surface ground zero.

In some areas, particularly to the northeast of ground zero, pressure ridges were formed when the surface readjusted (Figure 4.5). The platform supporting the gas sampling apparatus at surface ground zero was tilted at an angle of 20 degrees after the shot because the basal concrete slab came to rest on the sheared casing (Figure 4.6).

All of the fractures with displacement were confined to an area within 100 meters of surface ground zero. However, abundant small and hair-line fractures without displacement were mapped outward to approximately 300 meters. Figure 4.7 shows the extent of abundant fracturing. Some hair-line fractures occurred at distances up to 1000 meters from surface ground zero (see Figures 4.8 and 4.9).

Detailed analysis of three Holmes and Narver, Inc. pre- and post-shot profiles surveyed across the Gnome area (north-south line, 1 N60°W line, and 1 N60°E line) indicates that the surface was permanently lifted as much as 0.5 meter. The maximum displacement was measured at a point 30 meters northeast of surface zero. Both shot-time photography (by E.G.&G.) and the comparative pre- and post-shot surveys indicate that a plug about 150 meters in diameter moved upward much more than the surrounding terraine, with a permanent displacement of about a foot out to radii of 80 meters but only a few tenths of a foot beyond this point. Don E. Rawson**, LRL geologist in charge of post-shot drilling, has reported faults with offsets of 8 to 10 feet immediately above the cavity as indicated by study of exploratory holes. The same cylindrical fault system apparently extends to the surface, but with much lesser displacement at successively higher levels.

The individual surface trace of this fault or system of faults was not observed. However, its effects could be dispersed in the numerous fractures observed in the alluvium within 75 to 100 meters of surface zero.

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* Profiles surveyed by Holmes and Narver, Inc.

** Personal communication.

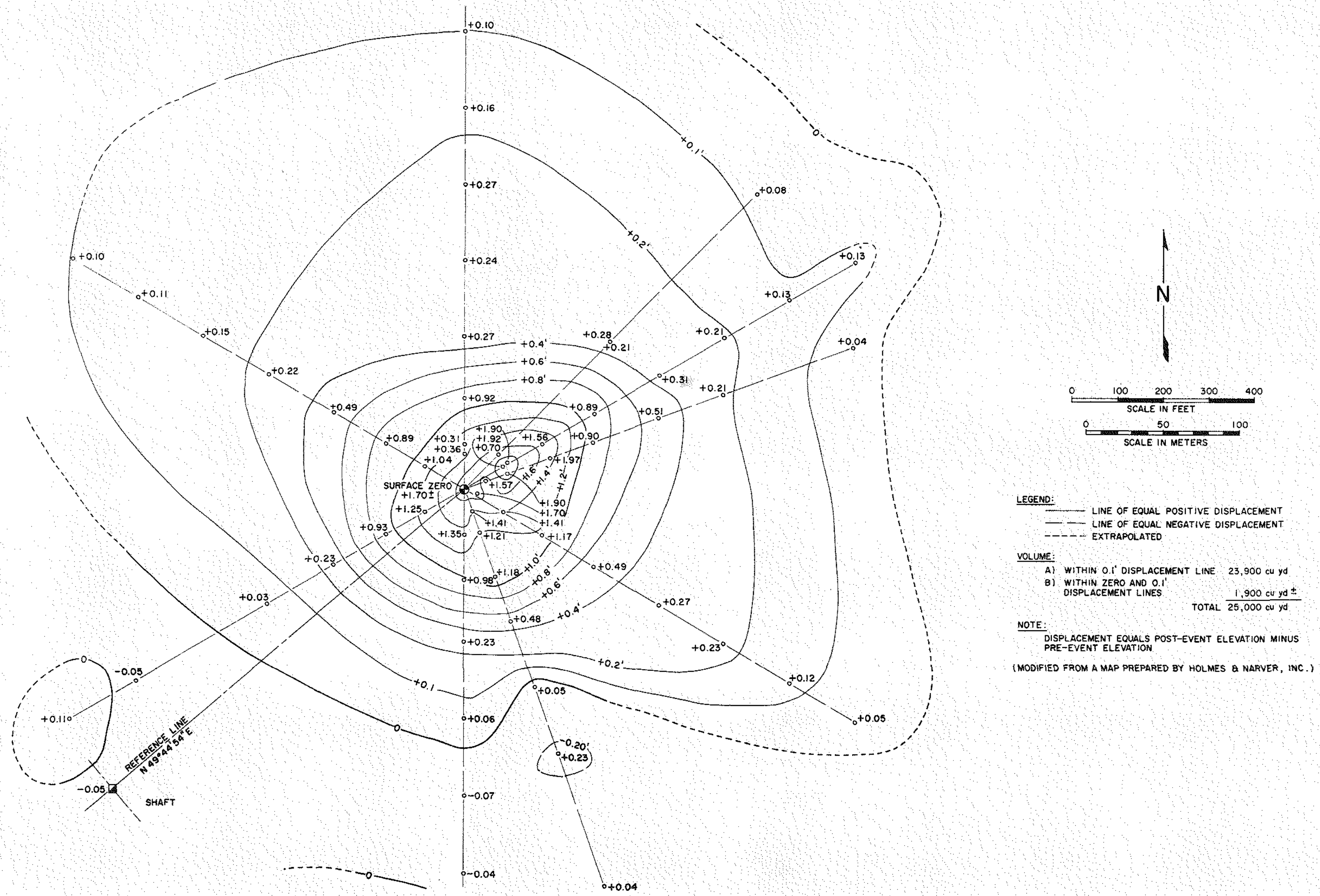


Figure 4.3 Map Showing Permanent Displacement Measured by Comparing Pre- and Post-Shot Elevations

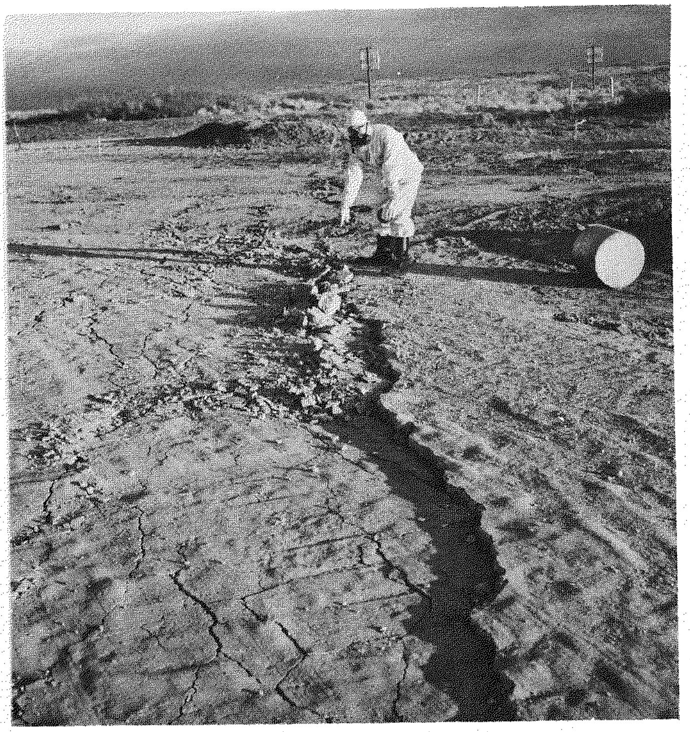
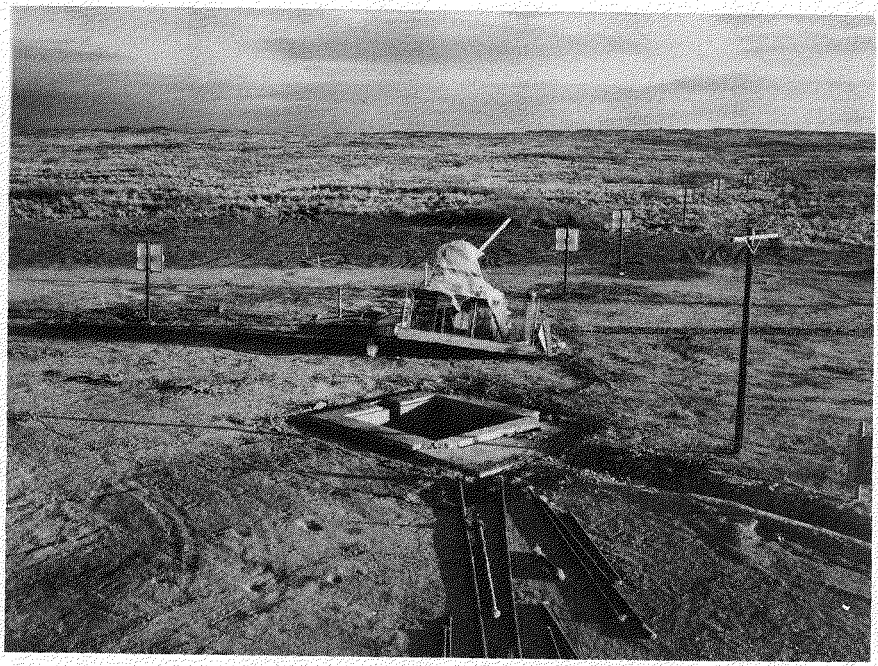


Figure 4.4 Concentric Fault Located 40 Meters Southwest of Surface Ground Zero.

Figure 4.5 Pressure Ridge Located 40 Meters Northeast of Surface Ground Zero

(a) before event



(b) after event

Figure 4.6 Surface Ground Zero Looking Southeast

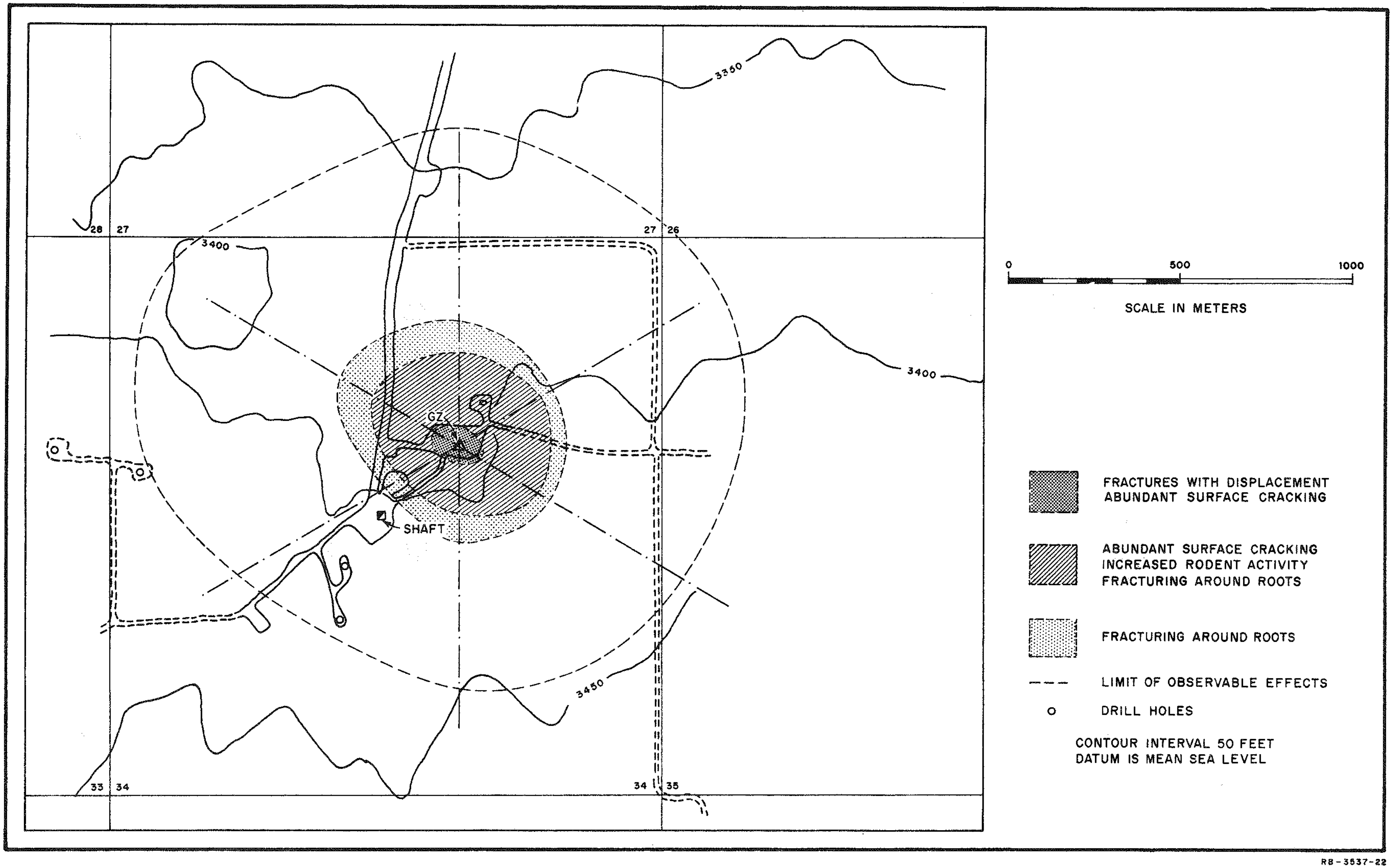


Figure 4.7 Map Showing the Extent of Surface Effects

Figure 4.8 Fractures 750 Meters N60°E of Surface Ground Zero

Figure 4.9 Fractures 830 Meters N60°E of Surface Ground Zero

In the northeast quadrant from surface ground zero, observations were made regarding the orientation of surface fractures and the relationship of these fractures to topography. Forty-four percent of the fractures were concentric, 31 percent were radial, and 20 percent were oriented between E-W and S75°E. In 68 percent of the fractures--on sand dunes, animal tracks, ditches, and embankments beside roadways--most fracturing was observed on the slopes away from ground zero.

One of the most widespread effects of the Gnome event was the fracturing of soil around the bases of bushes. This effect was noted in some instances as far as 900 meters from surface ground zero. It was noted particularly around mesquite and Yucca plants (Figure 4.10). As can be seen in Figure 4.7, the area of abundant root fractures extends to about 300 meters on all lines and is most severe near surface ground zero.

4.2.2 Movement of Rock Fragments. All of the rocks planted at the 30- and 60-meter stations exhibited movement ranging from 0.025 to 1.5 meters. Figure 4.11 indicates the positioning and displacement of the rocks at two 30-meter stations. Half of the rocks flipped over. The direction of movement was random. At the remaining stations most of the rocks were covered with sand but were not moved. On the north line two rocks had been moved; one at 121 meters moved 5 cm north, and one at 136 meters moved 2.5 cm north. The rock at 106 meters on the 60-degree line moved 5 cm north.

4.2.3 Animal Burrows. The presence of animal burrows was helpful in evaluation of the effects of the test in two ways: (1) the shock effects collapsed burrows (Figure 4.12), and (2) the animals dug many new burrows (Figure 4.13) or were forced to clean out the sand that collapsed into old burrows. Prior to the shot, careful search had revealed no evidence of new burrows. However, following the shot a count of burrows on six radial lines indicated that new excavations had been made at more than 7000 points within 300 meters of surface ground zero.

4.2.4 Soil Dispersal. In many areas, particularly in sandy roadways, the soil was loosened and dispersed by the shot, appearing as though it had been passed through a flour sifter. This is a characteristic effect of underground shots and is well illustrated in Figure 4.14.

4.2.5 Water-Level Observations. (Reference 12). U.S. Geological Survey water-level observations were recorded at four wells in the Gnome area. The nearest well (No. 1) was 600 meters southwest of surface

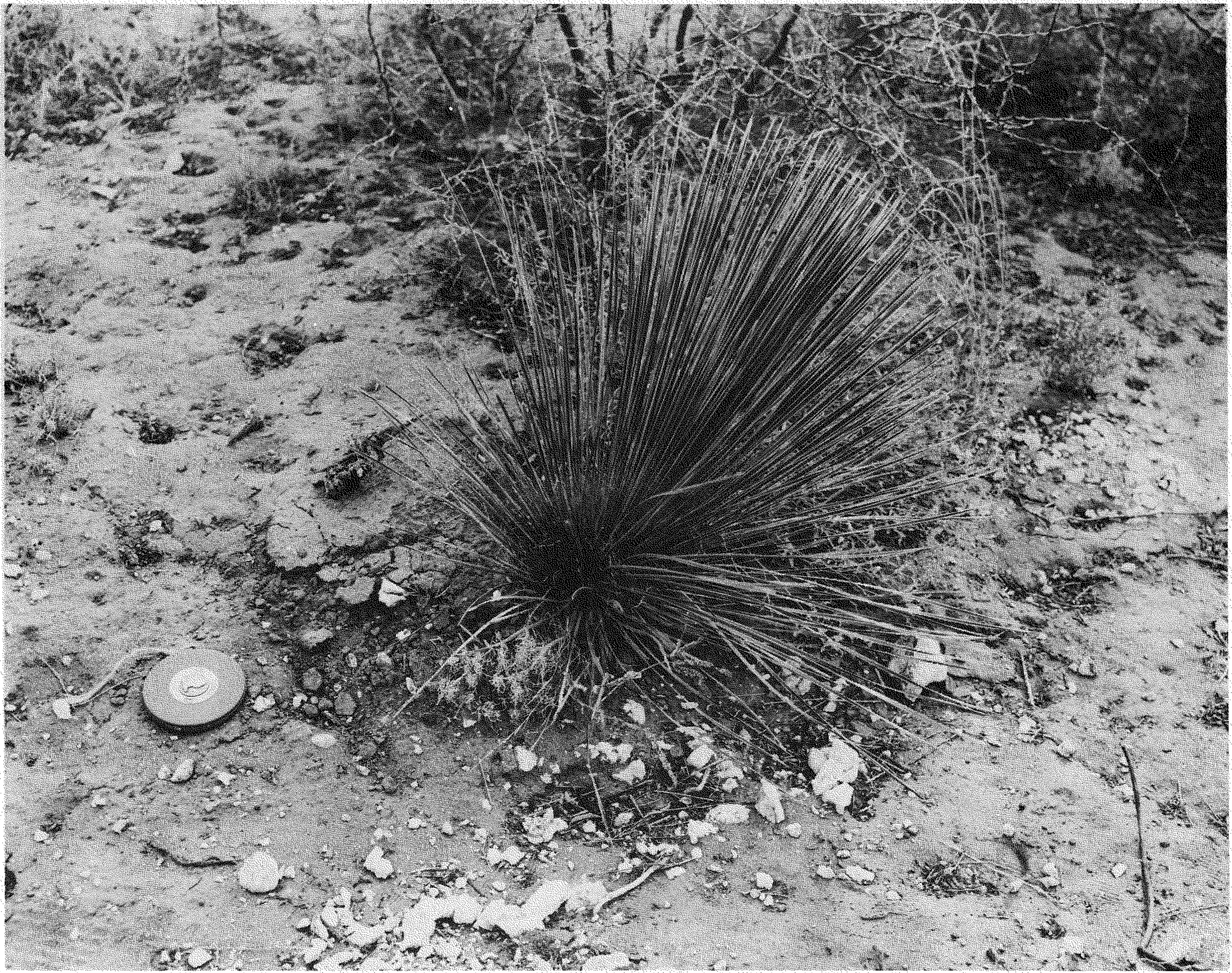
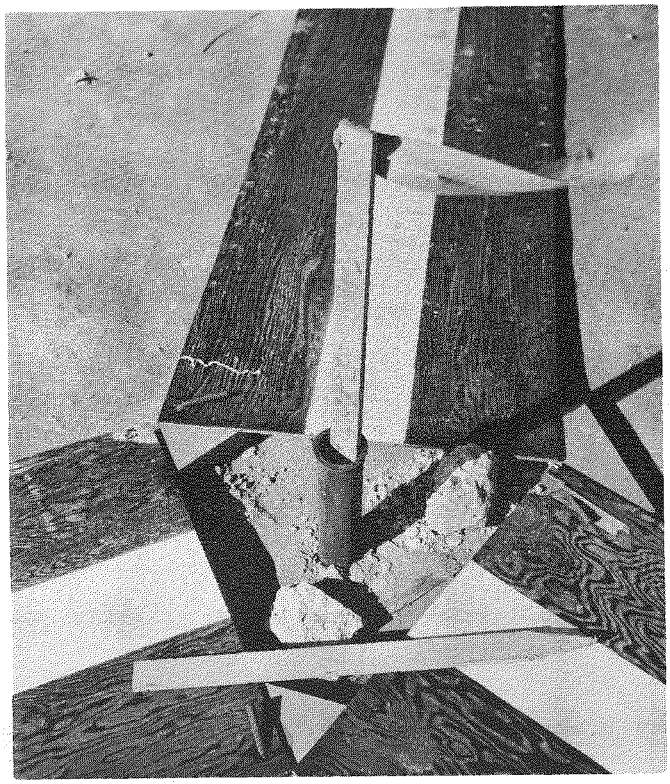


Figure 4.10 Fractures Around Yucca Roots



(a) before event

(b) after event

Figure 4.11 Rocks Planted at Two 30-Meter Stations

Figure 4.12 Collapsed Burrow Entrance

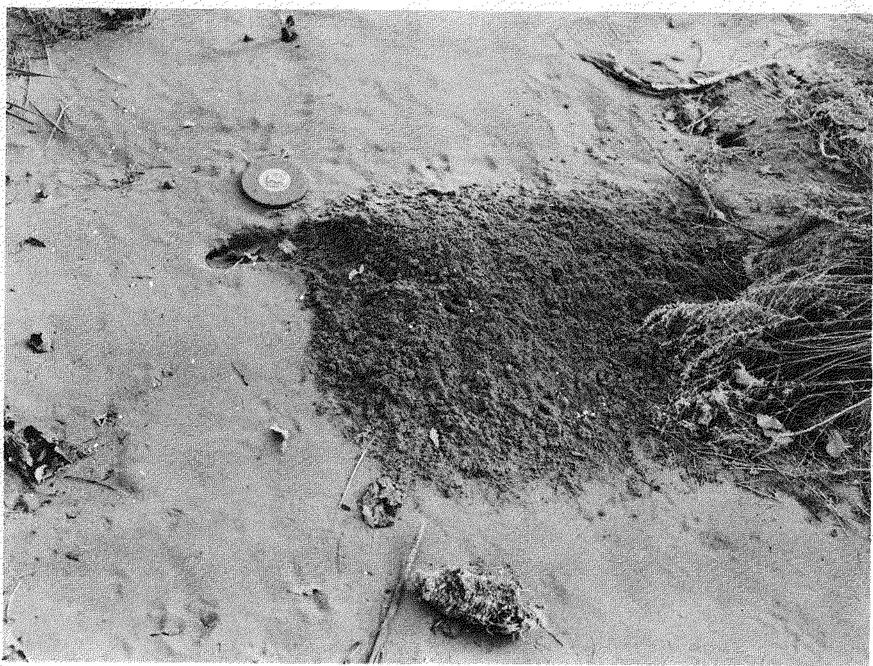


Figure 4.13 New Burrow Excavation

(a) before event

(b) after event

Figure 4.14 Loose Dirt 30 to 60 Meters S60°E of Surface Ground Zero

zero and the farthest (No. 2) was about 3 kilometers in the same direction. Wells No. 4 and No. 5 were 955 meters and 1200 meters, respectively, west of surface zero.

Recording gages in these wells indicated -- even though the recorders were pretty badly shaken and not functioning properly -- that the following changes took place immediately after the shot.

Hole No.	Rise in Water Level ft	Distance from Surface Zero
1	3.97	600 m SW
2	0.50	3 km SW
4	2.20	960 m W
5	0.40	1200 m W

The water levels were measured again on December 12, 1961, revealing water levels to be essentially the same as they were prior to the shot.

Records of many other wells in the surrounding area were examined. In only two of these, near the bend of the Pecos River, 9 miles west of Gnome site, was any effect of the shot recorded. These records showed fluctuations of 0.06 feet for a few seconds after the Gnome shot.

4.3 UNDERGROUND EXAMINATION

The shaft station, 340 meters from the shot point, is an irregularly shaped room, 23 meters long and a maximum of 9 meters wide. Extensive slabbing from the roof in the center of the 9-meter section resulted from the shot. The slabbed rock made up a pile of debris a maximum of 1.2 meters in depth at the center of the room (see Figure 4.15). A few slabs also fell from the walls, and the walls had been spalled extensively so that few of the grid lines remained. The fallen rock pushed the shaft guides out of alignment thus preventing the cage from descending the last 1.5 meters to the bottom.

The shaft itself received practically no damage. Fractures in the concrete walls were noted at depths of about 23 and 27 meters which revealed offsets of 0.6 cm, the upper side having moved away from the shot point. A fracture at about 49 meters was not displaced and another at

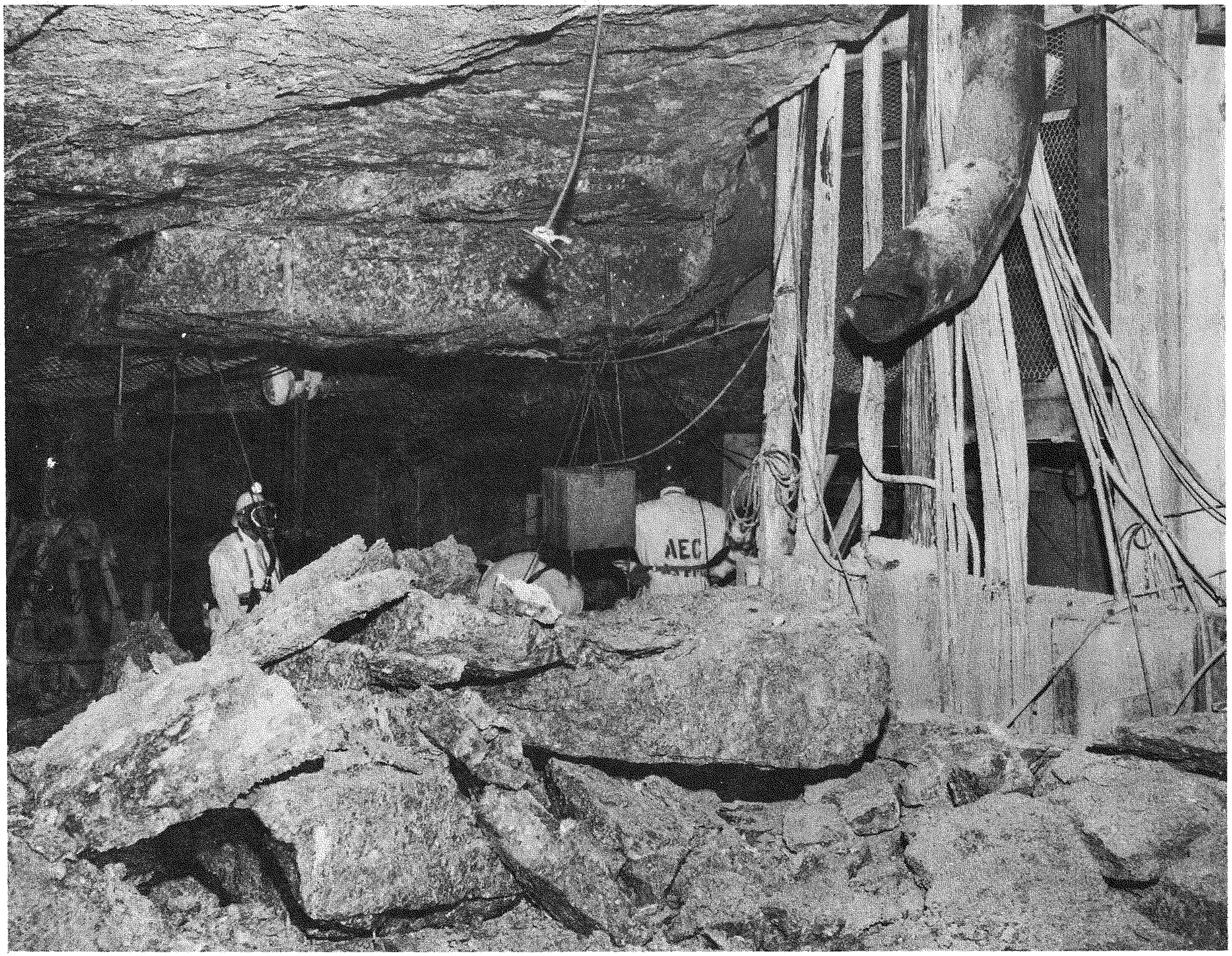


Figure 4.15 Rock Slabbed from the Tunnel Ceiling Near the Bottom of the Shaft

approximately 146 meters permitted water to seep into the shaft. Below that depth several small fragments had fallen from the walls, but these were of the same sort that might be expected to fall in a normal mining operation.

There was some slight separation but no measurable displacement either in the lower part of the shaft or the shaft station along the slick clay seams of variable thickness that are occasionally interbedded with the halite and polyhalite. The drift roof parted at a mud seam at 1 to 1.2 meters above the original drift roof; however, the rock bolts held it in place.

Examination of the 70-foot section between the blast door and the barricade revealed that considerable material had slabbed from the back and some from the walls. A few remnants of the black grid lines remained just inside the blast door. However, most of the lines were removed by spalling from the walls and by the dissolving action of the steam that escaped from the cavity. Salt had dissolved and recrystallized on the walls.

Ventilation of the shaft and drift was by sucking 2000 cubic feet of air per minute from holes drilled from the surface into the cavity. In the drift the air could be heard escaping around the I-beam stemming at the cinder block barricade. Most of the air was leaking at the top of the left-hand side (facing away from the shaft) with lesser leaks along the top of the right side. No leaks could be detected around the line-of-sight pipe nor through the 2x2-foot crawl-hole.

The next section of drift, examined from the crawl-hole opening at 2+09.5 feet, was partially filled with slabs that broke from the back. The salt has broken to the mudseam in the back and the drift is so filled with slabs and debris that it would be impossible to walk upright in most places. The drift is open as far as the 653-foot crawl-hole because a light could be seen from one point to the other.

The section of drift at 653 feet appeared to be open as far as the light would reach toward the cavity. However, a light placed in the drift at 880 feet could not be seen at 653 feet.

The drift was about half full of debris that had broken from the back. The steam melted the salt which formed salt stalactites in the back and crystalline stalagmites on the floor. The cross-section appeared to be smaller than it was pre-shot; however, this may just appear so because only the upper part of the drift is visible. Directly opposite the crawl-hole, the vent pipe was flattened and pressed into the wall. Toward the shot point, the drift appeared to be open as far as the light would carry for a distance of at least 150 feet (Figure 4.16).

The end of the exploratory drift was at 912 feet. A drill station was established, and the first drill hole was nearing the cavity the night of May 9, 1962. Drill hole 3 was partially excavated and many of the samples had been recovered from it. Surveys show that this hole was permanently displaced from up to 5 meters away from the zero point. A branch drift had located the sandbags that were in the drilling alcove for drill hole No. 25. This alcove was moved away from surface zero point 9 meters.

Two lines of evidence indicate that the force of the blast spread the bedding planes: (1) High levels of radioactivity (900 mr/hr) were found in the clay seam in the drill hole No. 3 cross-cut fifteen feet from the original drift, and (2) wedges of rock appear to have been thrust between the bedding planes when they were spread apart. Rawson* has mapped polyhalite thrust over polyhalite. As of May 9, excavation was not extensive enough to show clearly the extent of thrusting. However, definite evidence of thrusting was visible.

A hole that was punched into the original drift from the end of the exploratory drift appeared to have encountered a partially-open cavity. This may be connected to the shot cavity and may indicate that the original drift was not completely blocked at any point.

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* Rawson, D. E. LRL, personal communication

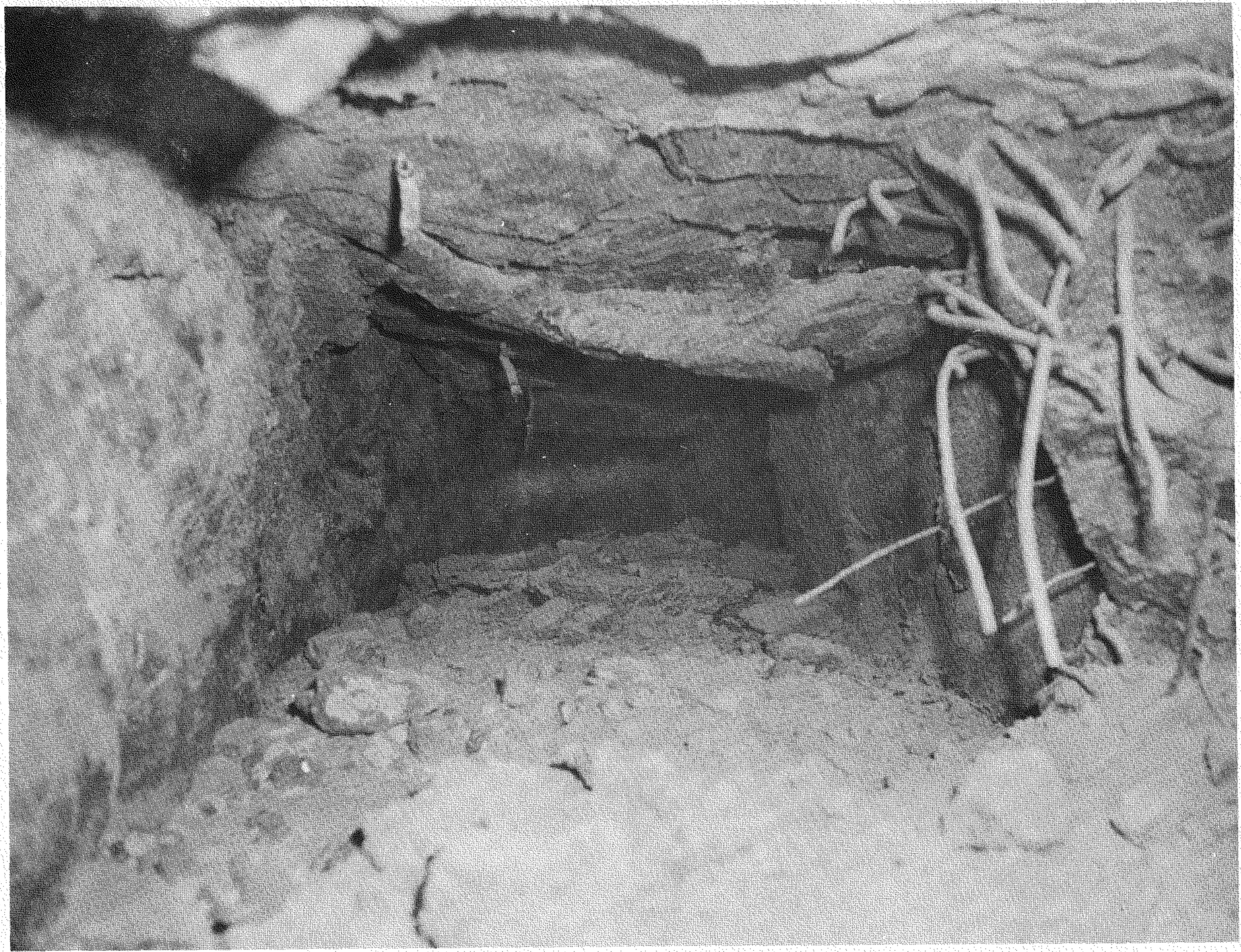

Figure 4.16 Looking Toward the Shot Point from Station 6+53

CHAPTER 5

DISCUSSION

5.1 SURFACE DEFORMATION

Fractures with measurable displacement were limited to an area within 100 meters of surface ground zero. Permanent uplift of the surface was limited to a radius of 360 meters. Noticeable surface fracturing was limited to a radius of 1000 meters. No damage was experienced at the shaft collar nor to the buildings or trailers around the shaft 350 meters from surface ground zero.

The most nearly comparable nuclear explosion in tuff was Logan shot at the Nevada Test Site in 1958 (Reference 1), which was essentially the same yield, but at a depth of only 284 meters. Direct comparisons are difficult because topography, lithology, geologic structure, and depth of burial are so different for the two shots.

Because of these differences, Logan surface effects were much more severe. In the vicinity of surface ground zero, displacement of bedding plane faults of as much as 3 meters was measured and faults along the mesa rim were offset 0.6 meter and had openings 0.3-meter wide extending to depths of more than 6 meters.

It is important to note, however, that in a westerly direction--the direction in which Logan topography and geology are most nearly comparable to those of the Gnome site--fractures were observed out to a radius of only 500 meters compared to 1000 meters for those caused by the Gnome explosion.

The causes for the differences in effects are important when considering the use of underground nuclear explosions for peaceful purposes. If bedding planes or other planes of weakness, such as joints or faults, extend from the shot point toward nearby surface points, as they do at NTS, a more localized but greater linear displacement will result. The displacement will consist of movement of large blocks between faults that form along the planes of weakness. This has been true of shots in tuff at the Nevada Test Site. Rainier, Logan, and Blanca explosions all caused bedding plane faulting.

5.2 UNDERGROUND DEFORMATION

The underground deformation observed at the station around the bottom of the Gnome shaft is materially less than the effects at the same distance for Logan event at NTS. In the U12e tunnel at NTS, damage was extensive at 400 meters from Logan shot. At this point a bedding plane fault had a permanent offset of 0.6 meter. In the Gnome shaft and tunnel station no permanent offset of bedding planes was detected; only slabbing from the roof and walls.

Close in to the shot point, Rawson--as was described in the previous chapter--has mapped thrust faults which repeat a polyhalite layer. This suggests that wedges of material from the borders of the cavity have been thrust outward between the salt layers as they were separated by the force of the explosion.

This observation supports the explanation above concerning the significant differences between the effects of Gnome and Logan shots created by the differing topographic, lithologic, and structural environments between the two sites. Clearly the Gnome site has much greater physical homogeneity and stress stability than the Logan site.

The significance of the major differences between Gnome and Logan events to a Plowshare program oriented toward underground mining or excavation is that materially different results must be expected from the use of nuclear explosives in environments that differ topographically, lithologically, and structurally. There may even be important differences that result from more subdued and subtle geographic effects such as climate and vegetation. Until there is a greater body of factual data collected from experiments in differing environments, particularly in different rock types, interpolation of results may be poor at best.

The most prevalent form of deformation in the drift was slabbing from the ceiling and from the floor, similar to that which occurred at the bottom of the shaft. This was caused by clay seams which form unusually weak bedding planes between the halite and polyhalite layers. Even during excavation, the halite layers below these seams frequently separated from the clay and either had to be barred down or roof-bolted in place. The effects of the shock and the swelling of the clay caused by the steam has caused considerably more slabbing, most from the ceiling and some from the floor.

At the Gnome site, however, the bedding planes are practically horizontal and very nearly parallel to the surface. Furthermore, there are no strong vertical faults or fractures that cut across the bedding. Consequently, no planes of weakness existed that permitted easy block displacement toward the surface. Instead, the maximum displacement was close to the surface ground zero point and decreased in all directions away from that point. As was mentioned in the previous section, a cylindrical fault plug of more than one million cubic meters was permanently displaced a minimum of 0.3 meter. Since the rock structures at Gnome provided no easy relief of the stress, it seems probable that the shot was relatively better coupled and that seismic expressions would be stronger for greater distances than they were for comparable shots in tuff at NTS.

In addition, the lithologic environment of Gnome shot was much more homogeneous than that of Logan. The physical characteristics of the salt in the Salado formation are homogeneous, while the differences between the welded tuff and unwelded tuff units of the Oak Springs formation at NTS are considerable. Considering the differences in topography, structure, and lithology, it is not surprising that there was better containment of the shot at Gnome with consequent better coupling and manifestly fewer effects. The detailed results close in to the shot, of course, still remain to be observed and measured.

No radiation was detected coming from any of the fractures around the surface ground zero area. Some radiation did escape from the shaft, through the stemming, probably because the bedding planes were separated by the explosion and the drift did not close off by collapse as was anticipated. If the device had been placed in a drill hole without a shaft and drift, probably no radioactivity would have escaped.

The Culebra dolomite member of the Rustler formation is water-bearing throughout the area surrounding the Gnome site. It is the source of water for ranches in the area and was found to contain free-flowing water when penetrated by the Gnome shaft and by all the test drill holes in the area. The effects of the shot did not breach the lining of the shaft in this formation to permit any appreciable leakage, nor did the fracturing above the shot point permit water to leak from the Culebra dolomite into the cavity. Radiation surveys made by the U.S. Geological Survey in four monitor drill holes since the shot have revealed no ground water contamination. These holes range in distance from 600 meters to 3 kilometers from surface ground zero.

Furthermore, at the station 6+53 crawl-hole, the cross-sectional area of the drift will probably prove to be measurably decreased.

5.3 THE CAVITY

The exploratory drift broke into the cavity on May 22. The cavity was examined, photographed, and surveyed by LRL scientists the week of May 13th. The top of the cavity appears to be stable with little likelihood of major collapse. It opens directly into the original drift; so it would be possible to open the blast door and walk--or in some places crawl--to the cavity.

The diameter of the cavity at the equator is 54 meters. It is nearly spherical in shape. Therefore, indications are that a cavity has been formed that should be excellent for waste storage or storage of petroleum or natural gas.

CHAPTER 6

CONCLUSIONS

At the Gnome shot point a relatively stable cavity about 40 meters high was formed that could be used for underground storage of gas, petroleum, or waste products or to assist in mineral extraction. Surface effects from the explosion were minor, because the lithology, geologic structures, and topography were favorable for minimizing effects. The only potentially-dangerous effect of the deformation was the escape of radiation, and this could probably be prevented by additional stemming in the tunnel or by firing the shot in a vertical drill hole.

It would be desirable to test a similar device in a drill hole to determine if, in fact, venting could be prevented.

Nuclear detonations of 3±1-kt yield can be fired in horizontally-layered salt without damaging shafts at distances of 400 or more meters.

A drift near a nuclear detonation in salt does not suffer total collapse as it does in tuff and granite and as it was theorized would happen to a point 125 meters from the shot point.

It is also concluded that a 5-kt nuclear explosion can be detonated in halite 200 meters under a water-bearing formation (aquifer) without so seriously fracturing both the upper part of the halite and the aquifer that water would penetrate downward to the cavity or to any part of the mine.

The significantly different results between Gnome and Logan events--both having a yield of approximately 5-kt (Gnome 3±1-kt)--demonstrate that different environmental characteristics will almost certainly cause differing effects from nuclear explosions. There is a critical need to reduce the necessity for interpolation by increasing both empirical and theoretical knowledge by other experiments in different environments.

The transient displacement at the surface, reported to be 1.5 meters, was just half the theoretical maximum limit of 3 meters estimated for displacement of a free particle at the surface.

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APPENDIX A

NEGATIVE NUMBERS OF PHOTOS TAKEN BY STANFORD RESEARCH INSTITUTE

Negative numbers of the photographs appearing in this report are as follows:

Figure 4.1 - C43142	Figure 4.11a - C43089
Figure 4.3 - A17128	Figure 4.11b - C43126
Figure 4.4 - C43117	Figure 4.12 - C43119
Figure 4.5 - C43114	Figure 4.13 - C43111
Figure 4.6a - C43085	Figure 4.14a - C43462
Figure 4.6b - C43125	Figure 4.14b - C43159
Figure 4.8 - C43113	Figure 4.15 - C43668
Figure 4.9 - C43122	Figure 4.16 - C46424
Figure 4.10 - C43130	

NEGATIVE NUMBERS OF PHOTOS TAKEN BY STANFORD RESEARCH INSTITUTE

Surface photos taken before the shot.

C43400 through C43408
C43087 through C43089
C43094

Underground photos taken before the shot.

C43144 through C43149
C43409 through C43431

Aerial photos taken one day before the shot.

C43104
C43217 through C43219
C43221 through C43229

At the control point on shot day before the shot.

C43092
C43097
C43102
C43105

At the control point about 45 minutes after the shot.

C43093
C43096
C43100
C43101
C43106

Aerial photos of ground zero about 3 hours after the shot.

C43138 through C43142
C43216

NEGATIVE NUMBERS OF PHOTOS TAKEN BY STANFORD RESEARCH INSTITUTE

Ground zero 3-1/2 to 4 hours after the shot.

C43107 through C43109
C43114 through C43117
C43123 and C43124
C43126 through C43128
C43131 and C43132
C43671 and C43672

Before and after photos.

C43068
C43084 and C43085
C43090 and C43091
C43110
C43118
C43125
C43133
C43135 through C43137
C43432
C43679

Aerial photos taken the day after the shot.

C43150 through C43156

Surface photos taken the day after the shot.

C43111 through C43113
C43119 through C43122
C43129 and C43130

Photos taken along the azimuth lines.

Photos looking away from ground zero were taken at every station on all the azimuth lines before the shot and at all the stations up to 100 meters distance after the shot. After the shot, photos were taken at each 30-meter station looking toward ground zero. Negative numbers for photos at the various positions are as follows:

NEGATIVE NUMBERS OF PHOTOS TAKEN BY STANFORD RESEARCH INSTITUTE

	0°	60°	120°	180°	240°	300°
GZ	C43433 C43172	C43447 C43178	C43461 C43179	C43475	C43489 C43157	C43502 C43161
30 meters	C43434 C43169	C43448	C43462 C43159 C43680	C43476 C43165	C43490 C43158	C43503 C43166
30 meters	C43173	C43183 C43681	C43177	C43174	C43171	C43163
60 meters	C43435 C43160	C43449 C43167	C43463 C43180	C43477 C43175	C43491 C43184	C43504 C43162
100 meters	C43436 C43176	C43450 C43182	C43464 C43170	C43478 C43168	C43492 C43181	C43505 C43164
150 meters	C43437	C43451	C43465	C43479	C43493	C43506
200 meters	C43438	C43452	C43466	C43480	C43494	C43507
250 meters	C43430	C43453	C43467	C43481	C43495	C43508
300 meters	C43440	C43454	C43468	C43482	C43496	C43509
350 meters	C43441	C43455	C43469	C43483	C43497	C43510
450 meters	C43442	C43456	C43470	C43484		C43511
550 meters	C43443	C43457	C43471	C43485	C43498	C43512
650 meters	C43444	C43458	C43472	C43486	C43499	C43513
750 meters	C43445	C43459	C43473	C43487	C43500	C43514
850 meters	C43446	C43460	C43474	C43488	C43501	C43515

NEGATIVE NUMBERS OF PHOTOS TAKEN BY STANFORD RESEARCH INSTITUTE

In the shaft before the shot.

C43516 through C43520

At the bottom of the shaft on January 10, 1962

C43549 through C43551
C43664 and C43665
C43667 through C43669
C43673 through C43678

APPENDIX B

LOCATIONS OF ROOF BOLTS PLACED IN GNOME DRIFT

No.	Station	Coordinates North	Coordinates East	Elevations
1	0+00-B	100,008.57	99,993.06	2216.52
2	-0+06-R	100,015.88	99,980.10	2211.60
3	0+50-B	100,035.93	100,036.09	2217.57
4	0+50-R	100,042.68	100,030.69	2211.71
5	1+00-B	100,077.56	100,061.33	2216.70
6	1+00-R	100,079.37	100,052.57	2211.42
7	1+50-B	100,118.50	100,081.70	2217.29
8	1+50-R	100,124.22	100,082.62	2211.58
9	2+00-B	100,129.01	100,131.66	2216.58
10	2+00-R	100,134.73	100,131.21	2211.63
11	2+50-B	100,152.71	100,175.09	2216.48
12	2+50-R	100,158.66	100,169.52	2211.73
13	3+00-B	100,184.86	100,212.86	2216.86
14	3+00-R	100,190.78	100,208.21	2211.51
15	3+50-B	100,216.84	100,251.63	2216.82
16	3+50-R	100,222.99	100,246.11	2211.33
17	4+00-B	100,249.99	100,289.07	2217.33
18	4+00-R	100,255.28	100,284.28	2211.63
19	4+50-B	100,282.33	100,327.42	2216.68
20	4+50-R	100,287.20	100,322.93	2211.49
21	5+00-B	100,314.93	100,365.47	2217.65
22	5+00-R	100,319.76	100,361.78	2211.57
23	5+50-B	100,347.37	100,403.71	2217.12
24	5+50-R	100,351.47	100,399.08	2211.60
25	6+00-B	100,379.34	100,441.61	2216.69
26	6+00-R	100,386.68	100,434.46	2211.62
27	6+50-B	100,411.79	100,479.79	2216.80
28	6+50-R	100,416.20	100,476.49	2211.79

		Coordinates		
No.	Station	North	East	Elevations
29	7+00-B	100,443.54	100,518.24	2216.13
30	7+00-R	100,447.94	100,514.44	2211.43
31	7+50-B	100,475.33	100,556.35	2217.45
32	7+50-R	100,478.98	100,553.49	2211.39
33	8+00-B	100,507.78	100,594.88	2216.28
34	8+00-R	100,511.84	100,591.53	2211.32

Center of Back = B

Left Rib = R

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ERDL	Reflectance Studies of Vegetation Damage
SRI	Visual and Photographic On-Site Inspection
SRI	Seismic Noise Monitoring
ERDL	Soil Density Studies
TI	Geochemical and Radiation Surveys
USGS	Solid State Changes in Rock
EG&G	Radon Studies
C&GS	Intermediate Range Seismic Measurements
GeoTech	Long Range Seismic Measurements
USGS	Aeromagnetic and Aeroradiometric Surveys
ARA	On-Site Resistivity and Self Potential Measurements

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ARA	Allied Research Associates Inc., Boston
EG&G	Edgerton, Germeshausen, and Grier, Inc., Boston, Las Vegas, and Santa Barbara
ERDL	USA C of E Engineer Research and Development Laboratories, Ft. Belvoir
GeoTech	The Geotechnical Corporation, Garland
LASL	Los Alamos Scientific Laboratories, Los Alamos
LRL	Lawrence Radiation Laboratory, Livermore
SC	Sandia Corporation, Albuquerque
SGC	Space-General Corporation, Glendale
SRI	Stanford Research Institute, Menlo Park
STL	Space Technology Laboratories, Inc., Redondo Beach
TI	Texas Instruments, Inc., Dallas
USC&GS	Coast and Geodetic Survey, Washington, D.C. and Las Vegas
USGS	Geological Survey, Denver
WES	USA C of E Waterways Experiment Station, Jackson

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USPHS	132	Off-Site Radiological Safety Report
REECo	133	On-Site Radiological Safety Report
USBM	134	Pre and Post-Shot Mine Examination

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