TEI-756

NUCLEAR EXPLOSIONS—PEACEFUL APPLICATIONS

U. S. DEPARTMENT OF THE INTERIOR

SOME EFFECTS OF UNDERGOUND NUCLEAR EXPLOSIONS ON TUFF

By
Verl R. Wilmarth

December 1959

This report is preliminary and has not been edited for conformity with Geological Survey format and nomenclature.

Geological Survey
Washington, D. C.

Prepared by Geological Survey for the
UNITED STATES ATOMIC ENERGY COMMISSION
Technical Information Service

Printed in USA. Price $0.75. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

AEC Technical Information Service Extension
Oak Ridge, Tennessee

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

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Trace Elements Investigations Report 756

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SOME EFFECTS OF UNDERGROUND NUCLEAR EXPLOSIONS ON TUFF

By Verl R. Wilmarth

(Read at the Geological Society of America annual meeting, Pittsburgh, Pa., November 2, 1959)

ABSTRACT

The effects of the Rainier (1.7 kt. at a scaled depth of 690 ft), Logan (5 at 482), and Blanca (19 at 319) explosions on tuff were determined from observations and measurements on the surface and in drill holes and tunnels.

Rock slides above the explosion points were the most obvious surface effects. Movement took place mainly along preexplosion fractures. Displacements were observed at distances up to 3,000 feet on the surface and up to 2,500 feet in tunnels.

Below the Rainier chamber a hemispherical breccia zone about 75 feet in radius was found. The breccia contains angular blocks of tuff in a pulverized matrix which contains droplets and fragments of radioactive glass. The glass contains the bulk of the fission products and seems to be restricted to the breccia zone. Beyond the breccia for a radial distance of at least 110 feet from the chamber, the tuff is minutely fractured and is characterized by low compressive strength, low velocity, and high permeability. One year after the explosion temperatures greater than 2°C above normal extended 120 feet horizontally and

80 feet vertically from the chamber. Integration of anomalous temperature data indicates that over half the energy in the explosion was in the form of heat. The temperatures probably dropped below the boiling point of water a few hours or days after the explosion because of the rapid transfer of heat by steam through explosion-produced and natural fractures.

INTRODUCTION

This talk will summarize briefly some results obtained from the Geological Survey's investigations of the effects of Rainier, Logan, and Blanca underground nuclear explosions on the tuffaceous rocks that surround the shot chambers. Reports on some of these investigations have been written by Gibbons (1958), McKeown and others (1958), and Diment and others (1959). The effects of these shots will be described in the following order: Those observed on the surface, in the underground workings and core holes, and, finally, the preliminary results from laboratory investigations of the affected tuffs.

The energy released, vertical and minimum cover, and minimum scaled depth for the Rainier, Logan, and Blanca tests are shown on figure 1. Scaled depth is a method of relating the depth of an explosion to the energy released and is defined as the ratio of depth of burial to the cube root of the energy released measured in kilotons of TNT equivalent.

EFFECTS ON SURFACE

On the surface of Rainier Mesa (fig. 2), the area affected by the Rainier explosion extends along the mesa rim about 2,000 feet north and about 3,500 feet south of ground zero.

Figure 2 shows the fractures caused by the explosion. Some of them are traceable along outcrops for 300 feet. It is clear that the dominant north- and northwest-trending tectonic fractures controlled the orientation of the post-Rainier fractures and as shown on figures 3 and 4, this is also characteristic of the fractures formed by the Logan and Blanca tests. The one fault visible on the surface after the explosion is a thrust fault about 1,400 feet east of ground zero; the upper plate moved eastward about 2 inches.

The surface effects of the Logan test, shown in figure 3, were considerably more evident than those of Rainier, although the minimum and vertical distance below ground level were approximately the same. However, for the Logan test the scaled depth was 482 feet as compared to 690 feet for Rainier.

Nearly all fractures produced by the Logan explosion are within the 2,600-foot isodistan line--a line on the surface connecting points of equal distance from the explosion chamber. The welded tuff capping the mesa is considerably more fractured than the bedded tuffs east of the epicenter--here considered to be the point on the surface nearest to the explosion. The fractures are most abundant within

200 feet of the rim and many parallel pretest fractures. Those fractures trending parallel to the mesa rim are the result of eastward displacement of the tuff.

Post-Logan fractures in the bedded tuff east of the epicenter dip steeply and many are as much as 300 feet in length. Within 1,000 feet of the shot chamber, the fractures trend predominantly northwest and northeast. Commonly they are open as much as 1 foot in width and to depths of 20 feet below the surface. Between the 1,000- and 2,000-foot isodistan lines, the dominant northeast-trending sets have openings generally less than 2 inches.

Low- and high-angle thrust faults due to the Logan blast were mapped as far as 2,300 feet from the epicenter. The hanging wall on each of these faults has moved upward and eastward away from the explosion chamber. The maximum horizontal displacement is 3 feet.

The largest underground nuclear explosion at the Nevada Test Site, code-name Blanca, was detonated at a minimum scaled depth of 319 feet and had an energy release of 19 kilotons. The surface over the shot chamber was vented and a dust cloud containing highly radioactive material was ejected. In January 1959, some two months after the explosion, all of the pinon and juniper trees within the area enclosed within the dotted line (fig. 4) were dead. Within this area radioactivity was a minimum of 1 milliroentgen per hour. Since January the outer limit of dead trees has expanded.

As a result of the explosion much rock was spalled from the mesa rim, and the pyramidal slump block (fig. 4) containing an estimated 125,000 cubic yards moved downslope about 65 feet. The tuffs were extensively fractured for a distance of 3,400 feet from the shot chamber. As in the Rainier and Logan tests, most fractures are concentrated in the welded tuff to the west and in the bedded tuffs east of the epicenter. On the mesa the Blanca test further opened and extended the northwest-, north-, and northeast-trending fractures. As shown on figure 4, the fractures in the bedded tuffs trend northeast, east, and southeast away from the explosion. They are as much as 400 feet in length and are open a maximum of 2 feet.

Many thrust and high-angle normal faults resulted from the explosion. Thrust faults parallel to bedding planes are a distinctive feature in the tuffs east of the epicenter. They occur only beyond the 1,800-foot isodistan line where the bedding planes are nearly parallel to radii from the shot chamber. The faults strike north and are traceable along outcrop for as much as 2,000 feet. The upper plate has moved eastward locally as much as 4 feet.

All normal faults are near vertical and some are open to a depth of 50 feet. On top of Rainier Mesa, most faults trend northwest and generally the southwest side is displaced downward as much as 3 feet. In the bedded tuff east of the mesa the normal faults are diversely oriented, are traceable on outcrop as much as 3,000 feet, and have displaced the tuffs a maximum of 60 feet vertically and 5 feet horizontally. The largest faults bound a northwest-trending graben formed mainly south and west of the vent (fig. 4). The graben resulted from collapse of the explosion-produced cavity, but it was probably somewhat exaggerated due to fractures formed by the earlier Logan test. Figure 5 is a cross section through the graben showing the relative displacement of the rocks and the brecciated zone above the chamber. The vent is just above the fault forming the lower edge of the graben.

East of the epicenter, the normal faults trend northeast to southeast and have vertical displacements of 1 to 5 feet. Figures 6 and 7 are typical of the faults mapped in this area. The fault shown on figure 6 has a vertical displacement of about 5 feet; the lateral movement is downslope about 1 foot. The fault shown on figure 7 is open to depth of 25 feet.

EFFECTS IN UNDERGROUND WORKINGS

Damage to the underground workings was similar for all three nuclear explosions. From the portal inward the amount of rocks spalled from the tunnel walls increased to a point where the tunnel was completely collapsed. The radial distance from the shot chamber to this point for the Rainier test was 205 feet and for the Logan and Blanca tests 820 and 870 feet, respectively.

Portalward from the collapsed tunnel areas, the explosion deformed the tunnels, opened and extended pretest joints and faults, and formed new faults. Near the explosion chambers the backs of the tunnels were arched owing to spalling of the tuff from along shear planes that are parallel to but dip away from the tunnel.

In the tunnels most new faults are bedding plane thrust faults that dip west at low angles. The principal thrust faults developed by the Logan test are shown on figure 8. The most distant fault, about 1,900 feet from the shot chamber, displaced the beds horizontally 3 feet. The principal effect of the later Blanca test was to increase the amount of displacement along faults formed by earlier tests. In general, the amount of horizontal displacement along the thrust faults is not a function of distance from the shot chambers but is more closely related to character of the tuffs. Thrusting occurred generally where a soft wet clayey material separated competent tuff beds.

Permanent rock displacement after the Rainier and Blanca tests was determined from precision surveys made by Holmes and Narver, Inc., of Los Angeles in the tunnels and on the surface above. The amount of radial displacement of surveyed stations for the Rainier event is shown on figure 9. Portalward from 200 feet, where the tunnel was caved, to 400 feet, the amount of displacement decreased from 2.5 to 1 foot. Flatness of the curve beyond 400 feet suggests this point represents the approximate outer limit of significant rock deformation in the tunnel. From these data, it is interpreted that the rock between 400 and 1,100 feet moved as a unit and was displaced radially about 1 foot. A thrust fault at 1,100 feet has a 0.3-foot vertical displacement and accounts for part of this movement. Beyond 1,100 feet the radial displacement of the rocks averaged about 0.6 foot. A precision survey in the tunnel after the Blanca test indicates that at a radial distance of 1,100 feet from the shot chamber the amount of radial displacement is about 4 feet or about four times that of Rainier.

EFFECTS ZONE ABOUT RAINIER CHAMBER

Exploration of the disturbed zones about Rainier chamber has been carried on by the 2 tunnels and 20 core holes shown on figure 10. The Rainier chamber is surrounded by an explosion breccia, the outer limits of which are shown by the dotted outline of an ellipsoid (fig. 10). At the level of the chamber the major axis is 160 feet and the minor axis is 130 feet.

Breccia zone

Configuration of the breccia zone in a vertical plane normal to the Exploratory tunnel is shown on figure 11. Above the 100-foot level the size and shape of the breccia zone are not known. A vertical section parallel to the tunnel is shown on figure 12. The breccia zone extends below the explosion chamber for about 80 feet and is roughly ellipsoidal. The breccia zone 100 feet above the chamber has a maximum width of 170 feet and minimum estimated width of about 150 feet.

A vertical hole drilled from the surface near ground zero entered a cavity 385 feet above the explosion chamber. This cavity is considered to be the upper limit of the collapsed zone. Assuming the breccia mass is egg shaped and has a vertical length of 465 feet, the total volume of crushed rock is about 244,000 cubic yards or 143,500 cubic yards per kiloton.

The explosion breccia in the Exploratory tunnel is composed of angular to subrounded fragments of white to brown tuff and radioactive glass in a fine-grained matrix of brown-gray tuff. Near the outer edge of the breccia zone, the fragments range from a few inches to 3 feet across, whereas in the central part they are larger, some measuring 12 feet long and 3 feet wide. In the 100-foot level, the breccia contains no glass, is not abnormally radioactive, and is less well compacted. Cavities several feet across were intersected in the drift.

Character of explosion-produced glass

The explosion-produced glass shown in black on figure 12 is concentrated in two poorly defined zones separated by as much as 15 feet of breccia containing low radioactivity. All of the glass is radioactive and most of it is in the breccia below the level of the explosion chamber. The upper zone is considered to have formed by collapse of the cavity produced by the explosion.

The glass shown in black on figure 13 occurs (1) as disseminated rounded to subrounded masses as much as 5 inches across within the breccia matrix which is shown blank, (2) as thin coatings on breccia fragments--stippled, and (3) along fractures and shear planes. The contact between the glass and adjacent rocks is sharp. The volume percent of glass within the breccia as determined from drill hole and Exploratory tunnel ranges from about 0.5 to 3 percent.

The glass is black to gray, red, or clear. Most black and red glass has a vitreous luster whereas the gray glass is dull. Texture is variable. Some of it is dense, some is frothy with discrete lenticular masses of dense glass, and some consists of a core of red glass and brown clay surrounded by black opaque glass. Index of refraction of the glass ranges from 1.495 to 1.530 which is within the range of silicic to intermediate natural glass.

Radioactive zones

In general the anomalous radioactive zones correspond closely with the distribution of the explosion-produced glass within the breccia. The highest radioactivity is present in those portions containing megascopic glass; however, values considerably above background were found where no glass was visible without microscopic examination. The radioactivity of selected specimens of glass measured one year after the explosion was more than 400 milliroentgens per hour and in general the black and red varieties are the most radioactive. The unaffected tuffaceous rocks have a natural radioactivity of about 0.02 milliroentgen per hour.

Temperature distribution

Figure 14 shows the anomalous temperatures measured one year after the Rainier explosion and projected to a vertical plane through the shot chamber. The outer edge of the temperature perturbations corresponds closely to the outer edge of the breccia zones that contain most of the explosion-produced glass. The maximum temperature, 94°C, was measured in breccia containing abundant glass about 40 feet below the chamber. Assuming the temperature distribution is symmetrical about the vertical axis, it is estimated that over half the energy in the explosion was in the form of heat.

Textural features of breccia

Another characteristic feature of the breccia is the presence of irregular veins as much as 2 inches wide of finely comminuted dark-gray and dark-brown tuff formed in the breccia matrix and in some of the fragments (fig. 15). They are not abnormally radioactive and have sharp but irregular contacts. By X-ray diffractometer analysis, the veins are shown to contain more noncrystalline material than the enclosing tuff. They are considered to have formed by shearing during brecciation of the tuff.

In the Exploratory tunnel, the rocks adjacent to the breccia zone are highly fractured for as mucn as 140 feet from the chamber. The postshot fractures have attitudes similar to the preexplosion fractures. Thin sections of the tuff from near the breccia have revealed the presence of many hairlike veinlets composed of opaque nonradioactive material. Figure 16 shows in black the incipient veinlets formed in the tuff at about 70 feet radially from the explosion. In figure 17 the veinlets are well developed, and the comminuted character of the tuff is obvious. This specimen was obtained at a distance of 65 feet below the chamber.

Physical and chemical changes in tuff

Preliminary study suggests that the physical changes in the tuffs brought about by the Rainier explosion were _inter_granular rather than _intra_granular. Measurements made on samples of tuff from the Exploratory tunnel show that the porosity of the fractured tuff at 70 feet to 230 feet from the shot chamber as compared to the breccia decreased 30 percent; the compressive strength increased more than 1,200 percent; the acoustical velocity increased about 150 percent and in general the permeability decreased (fig. 18). Chemical and spectrographic analyses of bulk samples and X-ray diffractometer patterns and thermoluminescent curves of the mineral separates showed no change in the tuff from the breccia outward to a distance of 60 feet.

EFFECTS ZONES ABOUT LOGAN AND BLANCA CHAMBERS

The chief difference in the breccia zones about Rainier and Logan is that about Rainier the zone is 20 percent larger though the yield of Rainier was about 60 percent less than for Logan. Vertical sections A-A' and B-B' through the Logan shot chamber show that the breccia zone approximates a prolate spheroid with the major axis 290 feet long inclined about 25° from vertical (fig. 19). The minor axes average about 180 feet in length. The breccia zone has an estimated volume of 190,000 cubic yards as compared to 244,000 for the Rainier blast. Preliminary sections C-C' and D-D' from near the Blanca chamber indicate the crushed zone at the level of the chamber is at least 165 feet in radius (fig. 19). The same zone appears to extend more than 50 feet below and at least 300 feet and possibly 900 feet above the shot point.

CONCLUSION

In conclusion, the gross geologic effects of underground nuclear explosions on the tuffaceous rocks were determined to a large degree by the structural and physical-chemical properties of the tuffs and to a lesser degree by the yield of the explosion. The almost total absence of fractures caused by the explosions in the soft friable tuffs and their concentration in the welded tuff on Rainier Mesa and in the indurated tuffs east of the epicenters suggest that the inherent rock properties were the controlling factors. Likewise, thrust faults were formed by the three explosions but only at places where attitudes of the beds were nearly parallel to radii from the shot chambers. Most thrust faults occurred where competent beds were separated by soft beds of tuff containing abundant water. The upper thrust plate of every fault moved upward and away from the explosion; the amount of horizontal movement being closely related to character of the thrust plane and only indirectly to distance from and size of explosion.

The properties of the tuffs were also the critical factors in determining the amount of crushed rock and to some extent the shape of the crushed zone formed by the explosion. Over Rainier the tuffs are soft and friable whereas over Logan and Blanca they are indurated and tough. Consequently in the Rainier test an estimated 143,000 cubic yards of rock were crushed per kiloton; whereas in the Logan test only 42,000 cubic yards were crushed per kiloton. Comparative data are not yet available for the Blanca test.

Above Rainier, the unconsolidated tuffs were easily collapsed as a result of the explosion thereby further extending vertically the breccia zone. Over Logan the compact tuffs were more stable and self supporting; consequently, the vertical length of the breccia zone was much less than for Rainier.

The breccia varies significantly with distance from the explosion. In the upper parts it is less compact, contains no fused material, and is not radioactive. The reverse is true of the breccia near the explosion.

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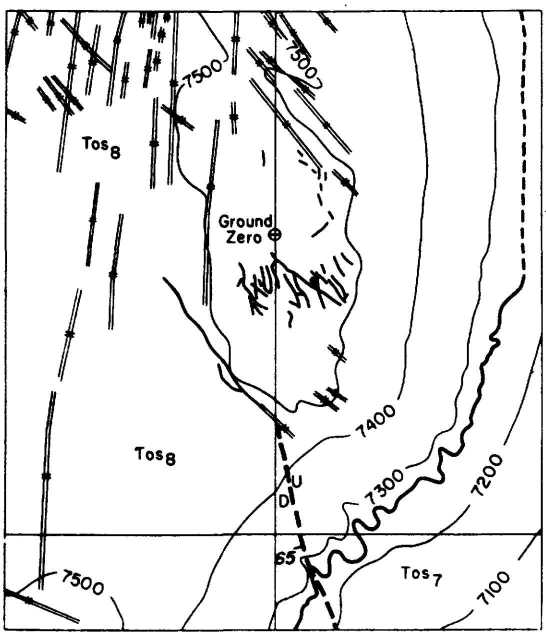
Diment, W. H., Wilmarth, V. R., and others, 1959, Geologic effects of the Rainier underground nuclear explosion: U. S. Geol. Survey TEI-355, 134 p. Open-file report.

Gibbons, A. B., 1958, Geologic effects of the Rainier underground test--Preliminary report: U. S. Geol. Survey TEI-718, 35 p. Open-file report.

McKeown, F. A., Houser, F. N., Dickey, D. D., Poole, F. G., Stewart, S. W., and Clebsch, A., 1958, Preliminary report on the geologic effects of Logan underground test, U12e.02 tunnel, Rainier Mesa, Nye County, Nevada: U. S. Geol. Survey TEM-986, 30 p. Open-file report.

	Rainier	Logan	Blanca
Explosion date	September 19, 1957	October 15, 1958	October 30, 1958
Yield (Kilotons)	1.7	5	19
Vertical distance to surface (feet)	900	930	988
Minimum distance to surface (feet)	820	830	835
Minimum scaled depth (feet)	690	482	319

FIGURE 1--PHYSICAL FACTS ON RAINIER, LOGAN, AND BLANCA EXPLOSIONS



EXPLANATION

Contact
Dashed where approximately located

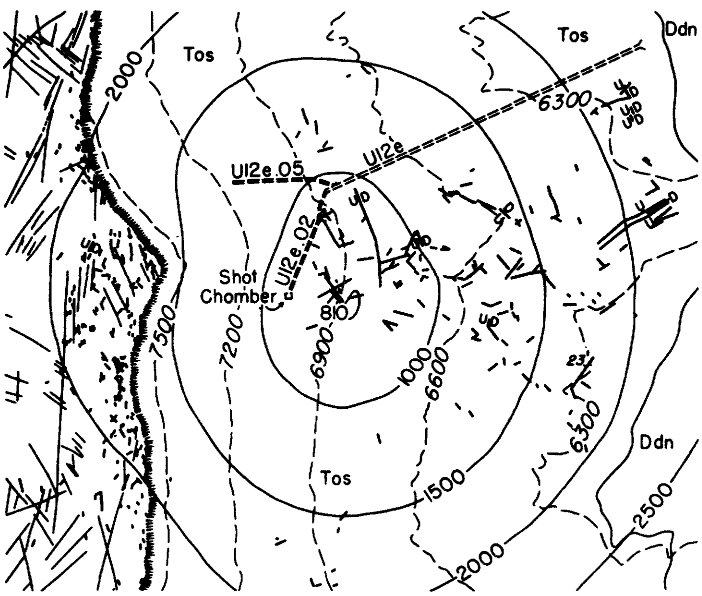
U
65 D
Pre-test fault

Pre-test lineaments

Post test fractures

FIGURE 2 MAP SHOWING FRACTURES FORMED BY THE RANIER EXPLOSION, NEVADA TEST SITE, NYE COUNTY, NEVADA

200 0 200
SCALE



EXPLANATION

Tos
Oak Spring formation

Ddn
Devils Gate(?) limestone and Nevada formation

Contact

U
D
Fault resulting from explosion
U, *upthrown side;*
D, *downthrown side*

Fractures resulting from explosion

Pre-shot lineaments

Strike and dip of beds

Lines of equal distance in feet from shot chamber

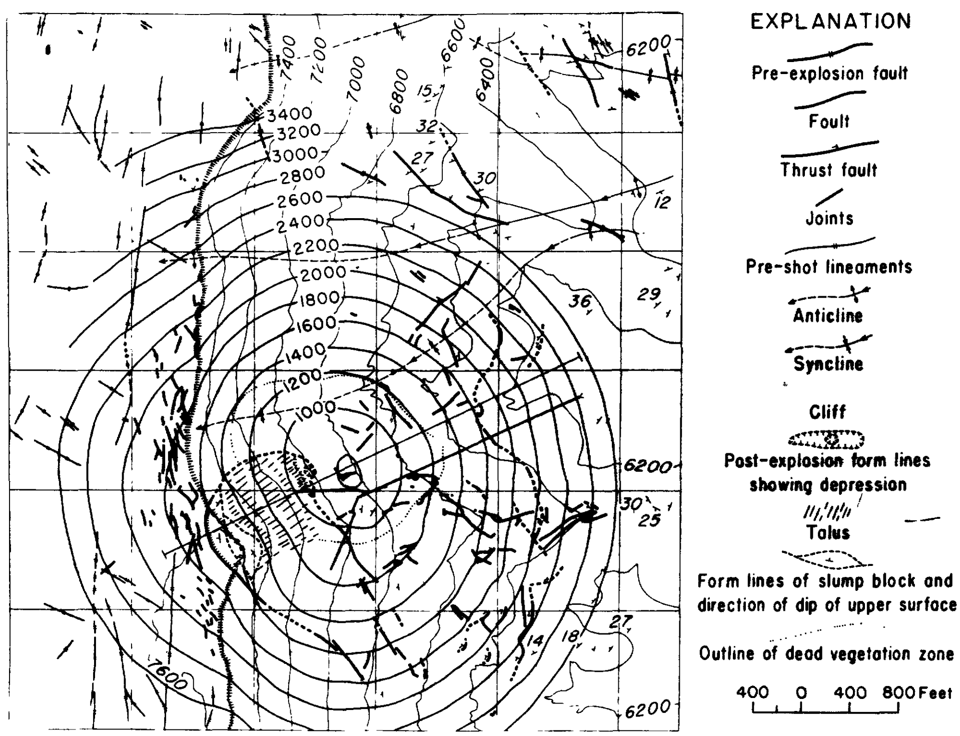
N

Cliff

200 0 200 600 Feet
Scale

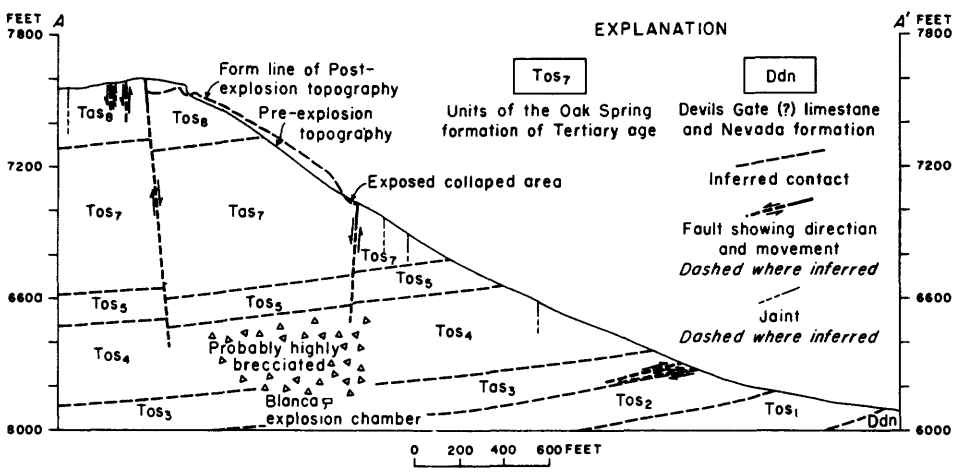
GEOLOGIC MAP OF THE U12e TUNNEL AREA SHOWING FRACTURES AND FAULTS RESULTING FROM THE LOGAN EXPLOSION, NEVADA TEST SITE, NYE COUNTY, NEVADA

FIGURE 3



GEOLOGIC MAP U12e TUNNEL AREA SHOWING JOINTS AND FAULTS RESULTING FROM BLANCA EXPLOSION

FIGURE 4

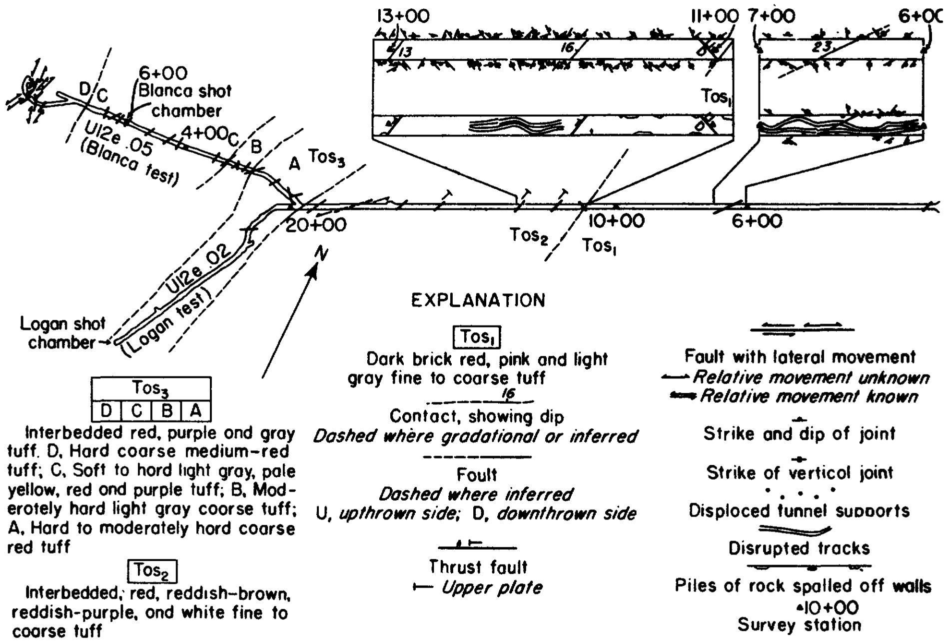


SECTION THROUGH A-A' SHOWING POST-BLANCA EXPLOSION GEOLOGIC EFFECTS

FIGURE 5

FIGURE 6--PHOTOGRAPH OF FAULT HAVING VERTICAL DISPLACEMENT OF 5 FEET

FIGURE 7--PHOTOGRAPH LOOKING ALONG FAULT HAVING HORIZONTAL DISPLACEMENT OF 2 FEET AND OPEN TO DEPTH OF 25 FEET



GEOLOGIC MAP OF THE U12e TUNNEL SYSTEM AND LOGAN SHOT EFFECTS

FIGURE 8

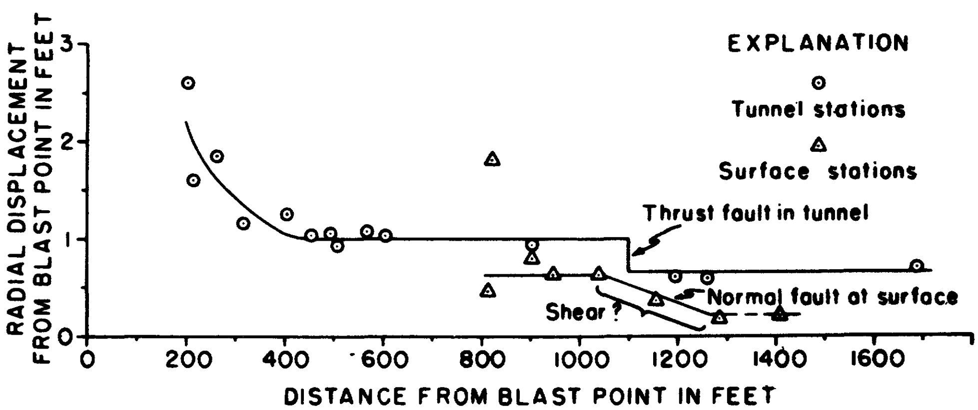
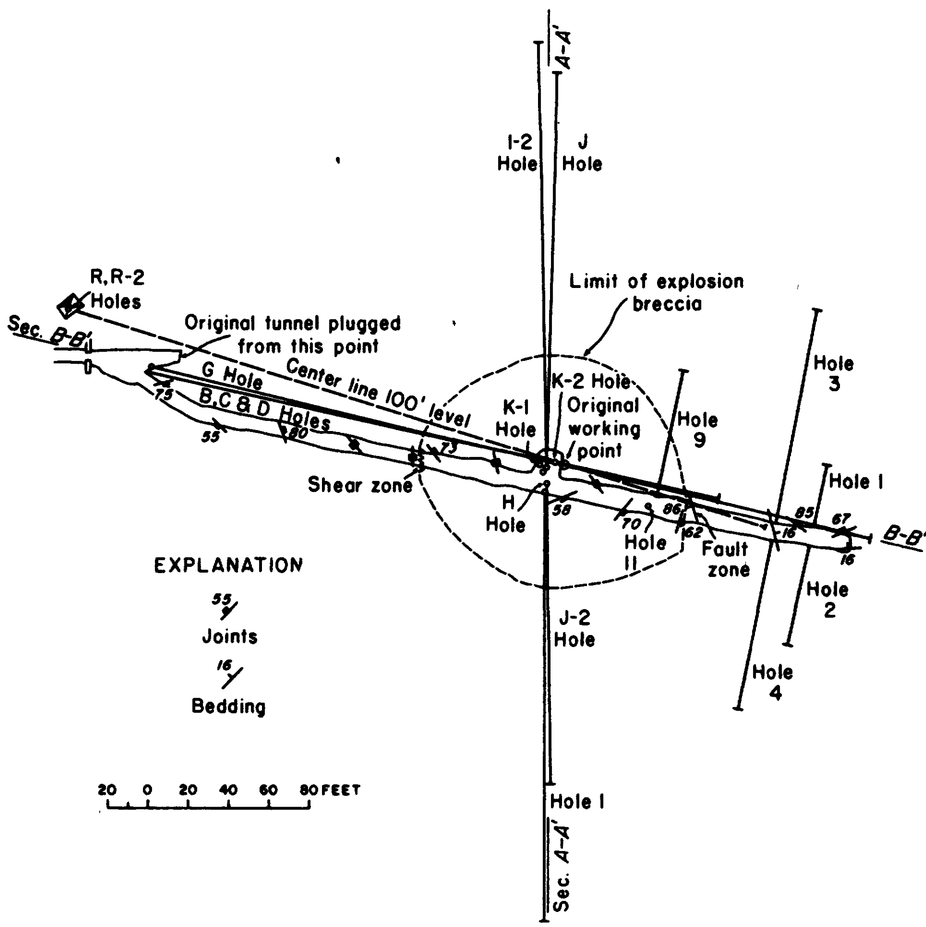


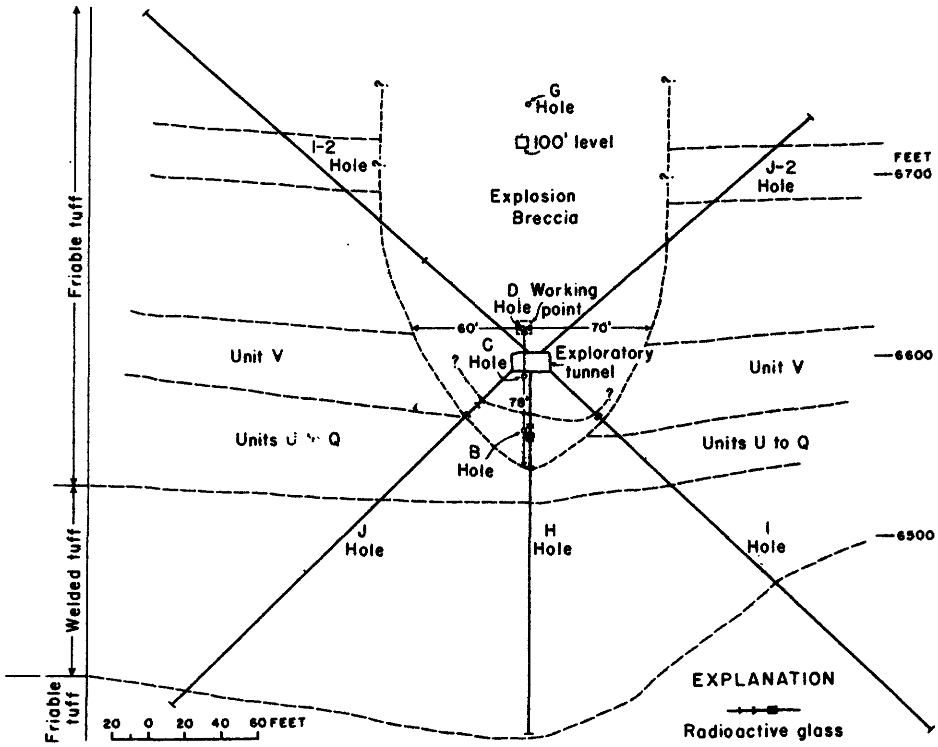
FIGURE 9 —COMPONENT OF RADIAL DISPLACEMENT OF SURVEY STATIONS FROM BLAST POINT, RAINIER MESA, NYE COUNTY, NEVADA

(Based on survey data by Holmes and Narver, Inc.)



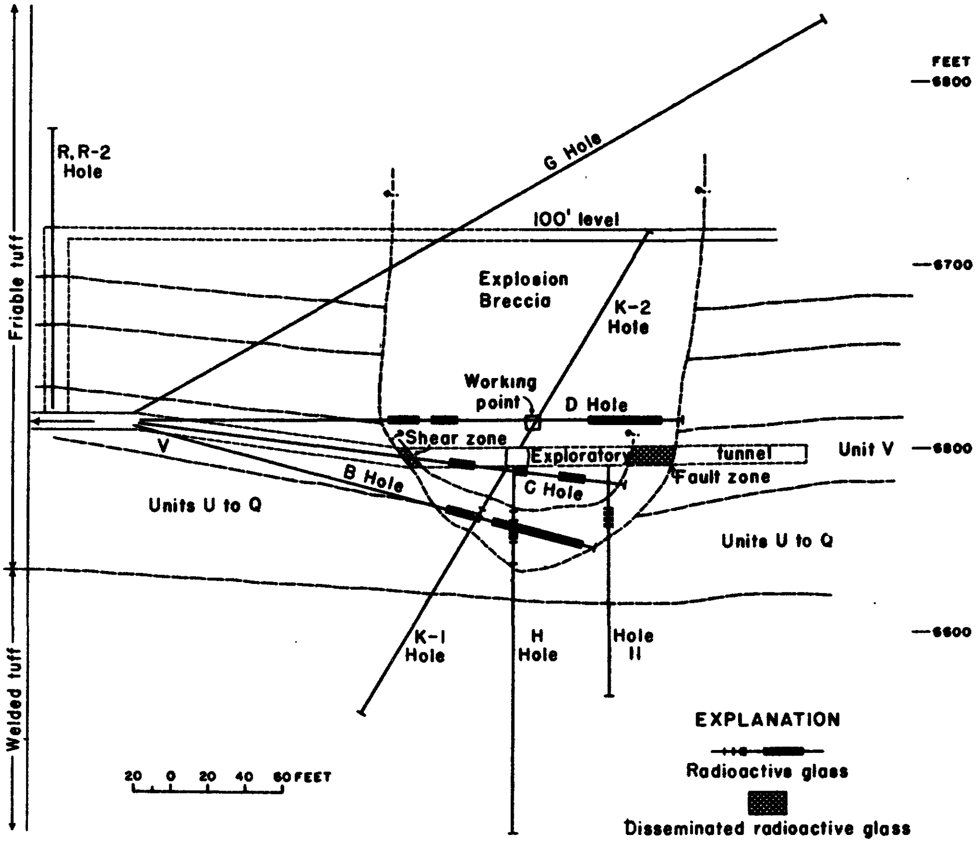
GEOLOGIC MAP OF RAINIER EXPLORATORY TUNNEL SHOWING DRILL HOLE LOCATIONS

FIGURE 10



SECTION A-A' RAINIER EFFECTS ZONE

FIGURE 11



SECTION B-B' RAINIER EFFECTS ZONE

FIGURE 12

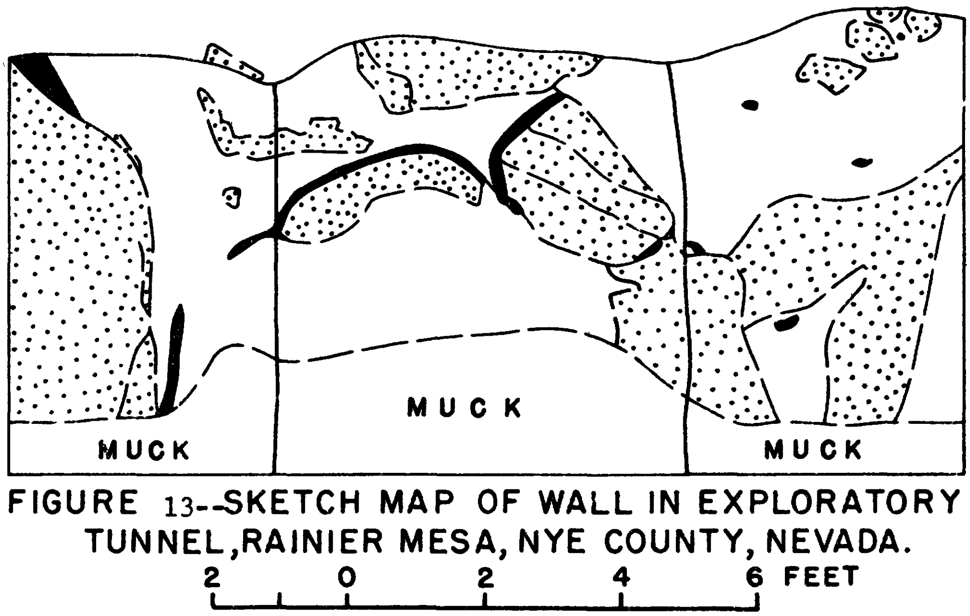
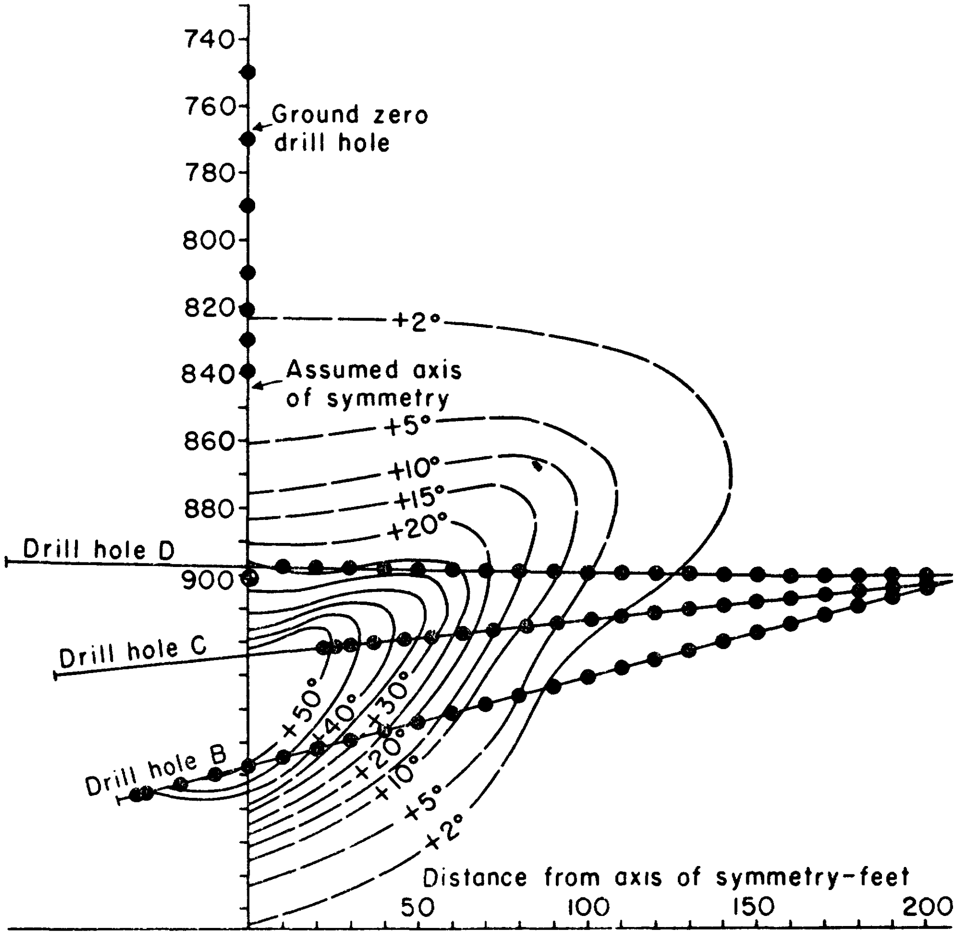


FIGURE 13--SKETCH MAP OF WALL IN EXPLORATORY TUNNEL, RAINIER MESA, NYE COUNTY, NEVADA.



ANOMALOUS TEMPERATURES IN VERTICAL PLANE
THROUGH RAINIER EXPLOSION POINT

FIGURE 14

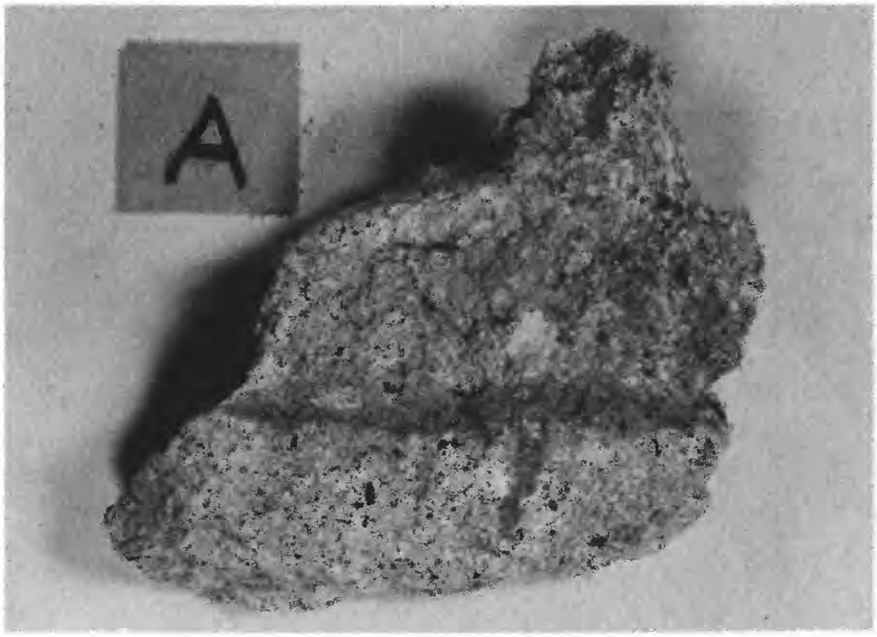


FIGURE 15--PHOTOGRAPH OF TUFF CONTAINING
BLAST-PRODUCED VEINLET (DARK GRAY)
NATURAL SIZE

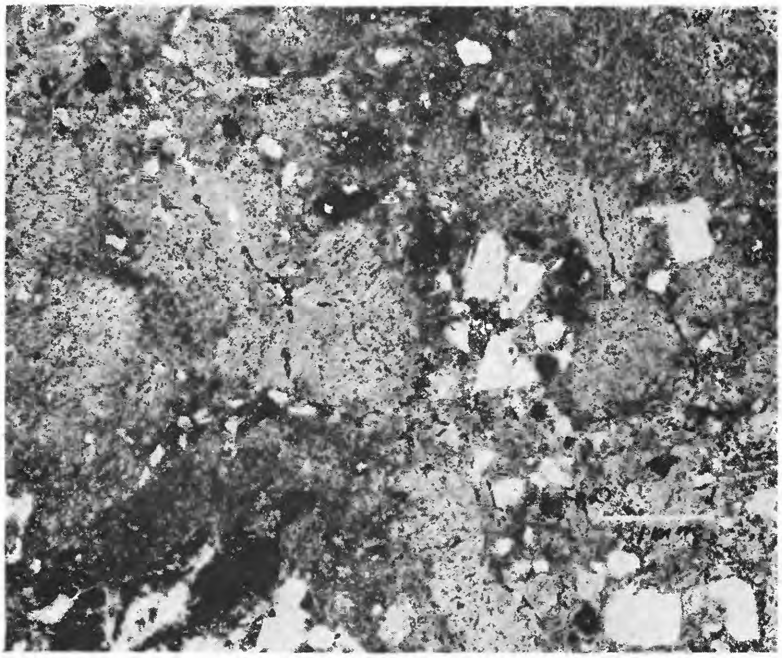


FIGURE 16--PHOTOMICROGRAPH OF TUFF SHOWING VEINLETS (BLACK) FORMED BY NUCLEAR EXPLOSION

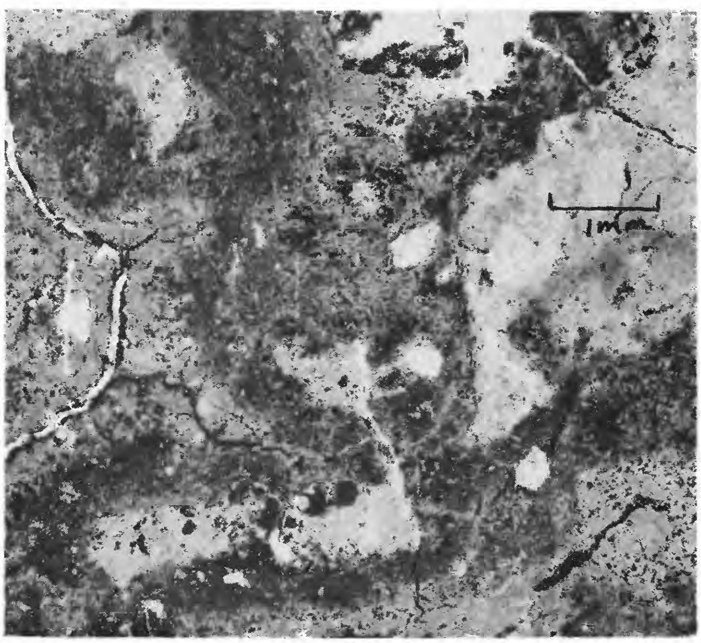
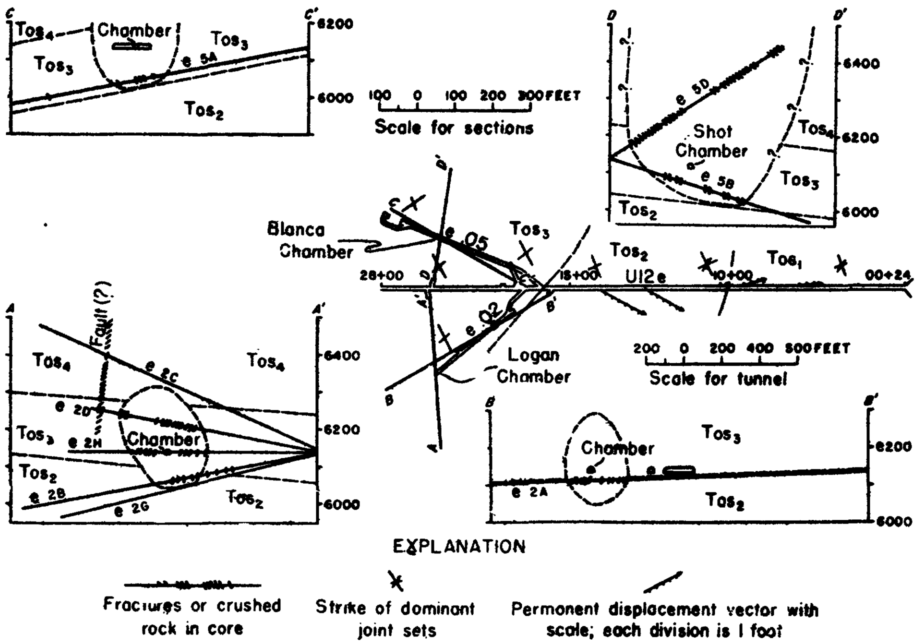


FIGURE 17--PHOTOMICROGRAPH OF TUFF SHOWING VEINLETS (BLACK) FORMED BY NUCLEAR EXPLOSION. WHERE VEINLETS ARE WHITE, MATERIAL REMOVED DURING SECTIONING

PROPERTIES OF ROCKS IN
EXPLORATORY TUNNEL

	Breccia zone	Highly fractured tuffs	Relatively unfractured tuff
Radial distance (ft) from shot chamber	60-70	70-140	140-230
Porosity (percent)	38	25	28
Compressive str. (psi)	<100	400	1300
Velocity (ft/sec)	3000	5000	7500
Perm. (md)	--	4	2

FIGURE 18



GEOLOGIC MAP AND SECTIONS OF PART OF U12e TUNNEL COMPLEX SHOWING EXPLORATORY DRILL HOLES AND SOME EFFECTS OF THE LOGAN AND BLANCA EXPLOSIONS

FIGURE 19