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GEOLOGICAL SURVEY INVESTIGATIONS IN THE U12b.03 AND U12b.04 TUNNELS, NEVADA TEST SITE

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Trace Elements Memorandum Report 996

DEPARTMENT OF THE INTERIOR

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

*This report concerns work done on behalf of Albuquerque Operations Office, U. S. Atomic Energy Commission.

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GEOLOGICAL SURVEY INVESTIGATIONS IN THE U12b.03 AND U12b.04 TUNNELS, NEVADA TEST SITE

PART I - INTRODUCTION

By W. H. Diment and V. R. Wilmarth

The papers comprising the various parts of this report contain preliminary results of the U. S. Geological Survey investigations in the U12b.03 and U12b.04 tunnels at the Nevada Test Site, Nye County, Nevada (fig. 1). The geologic studies were undertaken to define the structural, chemical, mineralogic, and some of the physical properties of the tuffaceous rocks that enclose the explosion chambers at the end of each tunnel.

The U12b.03 and .04 tunnels are part of the U12b (Rainier) tunnel complex that was driven northwestward from the steep east slope of Rainier Mesa (a prominent topographic feature in the northwest part of the Test Site (fig. 2)).

The U12b.03 tunnel trends north from a point about 980 feet from the portal of the U12b tunnel (fig. 3). The U12b.03 tunnel consists of 620 feet of tunnel, two alcoves, and a shot chamber. The tunnel is irregular, ranging from 6 to 10 feet in width, and 6 to 9 feet in height. The shot chamber at the north end of the tunnel is 22 feet on each side. The vertical and minimum cover over the shot chamber are 610 and 510 feet, respectively.

U. S. DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY

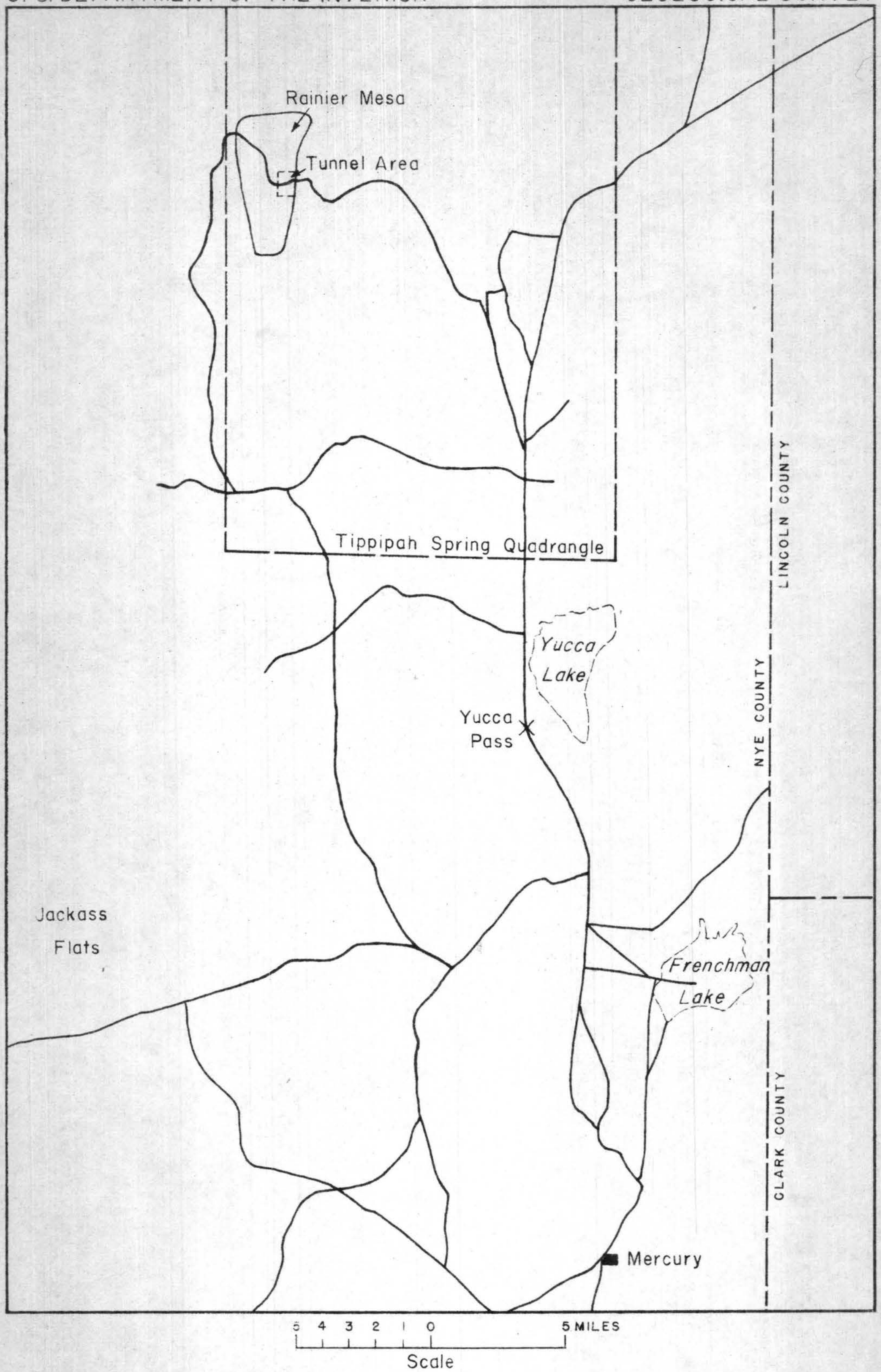

FIGURE 1—INDEX MAP SHOWING LOCATION OF TUNNEL AREA, RAINIER MESA, TIPPIPAH SPRING QUADRANGLE, NYE COUNTY, NEVADA

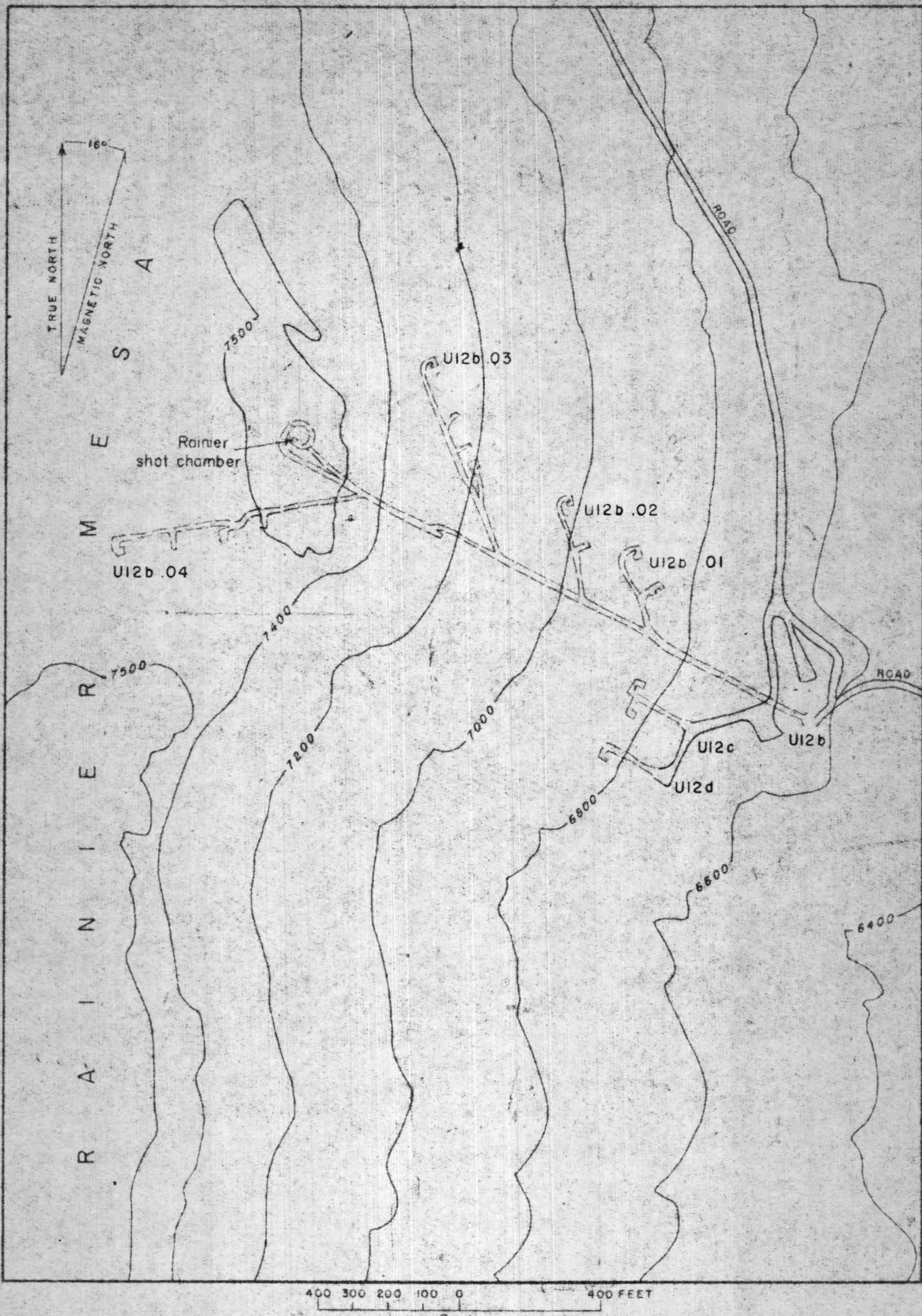

FIGURE 2-INDEX MAP SHOWING LOCATION OF U12b, c, d TUNNELS, RAINIER MESA, TIPPIPAH SPRING QUADRANGLE, NYE COUNTY, NEVADA

The U12b.04 tunnel trends west and from a point about 1,400 feet from the portal of the U12b tunnel (fig. 4). The U12b.04 tunnel consists of 775 feet of tunnel, three alcoves, and a shot chamber. The tunnel ranges from about 6 to 13 feet in width and averages about 7 feet in height. The shot chamber is at the west end of the tunnel and is about 20 feet on each side. The vertical and minimum cover over the shot chamber are both about 860 feet.

The rocks penetrated by the U12b tunnel complex are part of the Oak Spring formation of Tertiary age and are predominantly tuffs and tuffaceous sandstones. The Oak Spring formation in vicinity of the tunnel is about 1,900 feet thick and unconformably overlies limestones, dolomites, quartzites, and siliceous shales of late Paleozoic age. The contact between the Tertiary and Paleozoic rocks strikes N. 11° W. to N. 65° E. and dips 12° to 22° NW. to SW. The contact is highly irregular and locally relief is as much as 30 feet. The Paleozoic rocks trend north to northeast, dip 10° to 70° W. to NW., and have been cut by many northwest- to northeast-trending steeply dipping normal and reverse faults. Several folds of small amplitude and north- to northwest-trending faults with vertical displacement of as much as 50 feet have been mapped in the Tertiary rocks. These rocks strike N. 10° W. to N. 60° E., and dip 5° to 36° SW. to NW.

The Oak Spring formation in Rainier Mesa and contiguous areas has been divided into eight lithologic units designated in ascending order, Tos_1 to Tos_8 (Hansen and Lemke, fig. 2, 1958). The rocks comprising the formation consist of fine to coarse welded and non-welded tuff, tuffaceous sandstone, tuff breccia, and agglomerate. Pumice fragments are abundant in all of the rocks. Quartzite and volcanic rock fragments are sparse to common in most of the tuffs. A stratigraphic section of the Oak Spring formation on Rainier Mesa, generalized from Hansen and Lemke (1958), is given in table 1 and shown on figure 5.

The work reported herein was done on behalf of the Albuquerque Operations Office, U. S. Atomic Energy Commission.

Table 1.--Generalized stratigraphic section of Oak Spring formation, Rainier Mesa, Nye County, Nevada (from Hansen and Lemke, 1958)

Lithologic unit	Thickness (feet)	Description
Tos_8	270	Two ash flows of welded tuff. The lower 130 to 140 feet is quartz latitic tuff; dark gray to gray purple; grades downward into coarse pumiceous nonwelded tuff of Tos_7. The upper part is rhyolitic welded tuff; pale red purple; caps Rainier Mesa. The welded tuffs are resistant to erosion and crop out as cliffs. Near-vertical joints are abundant.
Tos_7	720	Tos_7 has been divided into 3 subunits designated from youngest to oldest as a, b, and c. Subunit a is about 50 feet thick; a light brown-gray to orange-brown poorly sorted, massive fine to coarse indurated pumiceous tuff. Subunit b is about 490 feet thick; white, gray, tan to red-brown granular tuff and interbedded gray tuffaceous sandstones; pumice fragments are abundant. The rocks are soft, friable and poor to well bedded; outcrops sparse along the east slope of Rainier Mesa. Subunit c is about 180 feet thick; white-gray locally brown, granular, fine to coarse, indurated tuff. The Rainier explosion chamber and U12b.02, .03 and .04 tunnels are in subunit c.
Tos_6	0-75	Olive-brown to purplish-red fine to coarse, well-bedded welded rhyolitic tuff; stands in near vertical ledges; unconformably underlies Tos_7.
Tos_5	98-125	Greenish-gray to yellowish-gray fine to coarse, well-bedded pumiceous tuff; forms ledges; unconformably underlies Tos_6.

Table 1.--Generalized stratigraphic section of Oak Spring formation, Rainier Mesa, Nye County, Nevada (from Hansen and Lemke, 1958)--Continued

Lithologic unit	Thickness (feet)	Description
Tos_4	285	Light gray to green, pale brown to white, in part mottled, fine to medium nonwelded pumiceous tuff in beds from 2 to 15 feet thick; yellow porcelanic beds up to several feet thick forms ledges.
Tos_3	100	Pink, red, purple, light gray to buff nonwelded pumiceous tuff with some tuffaceous sandstones; basal bed is dark red, and forms a blocky outcrop. Most beds are 12 to 35 feet thick. Locally Tos_3 is as much as 170 feet thick.
Tos_2	120	Light gray to buff, locally red to purple, fine to coarse, bedded to massive, nonwelded tuffs; a thick bedded tuffaceous sandstone forms at top of unit.
Tos_1	210	Purplish to pink, fine, nonwelded tuff, conglomerate as much as 5 feet thick, locally forms base of the unit.
Total thickness	1,803 to 1,905	

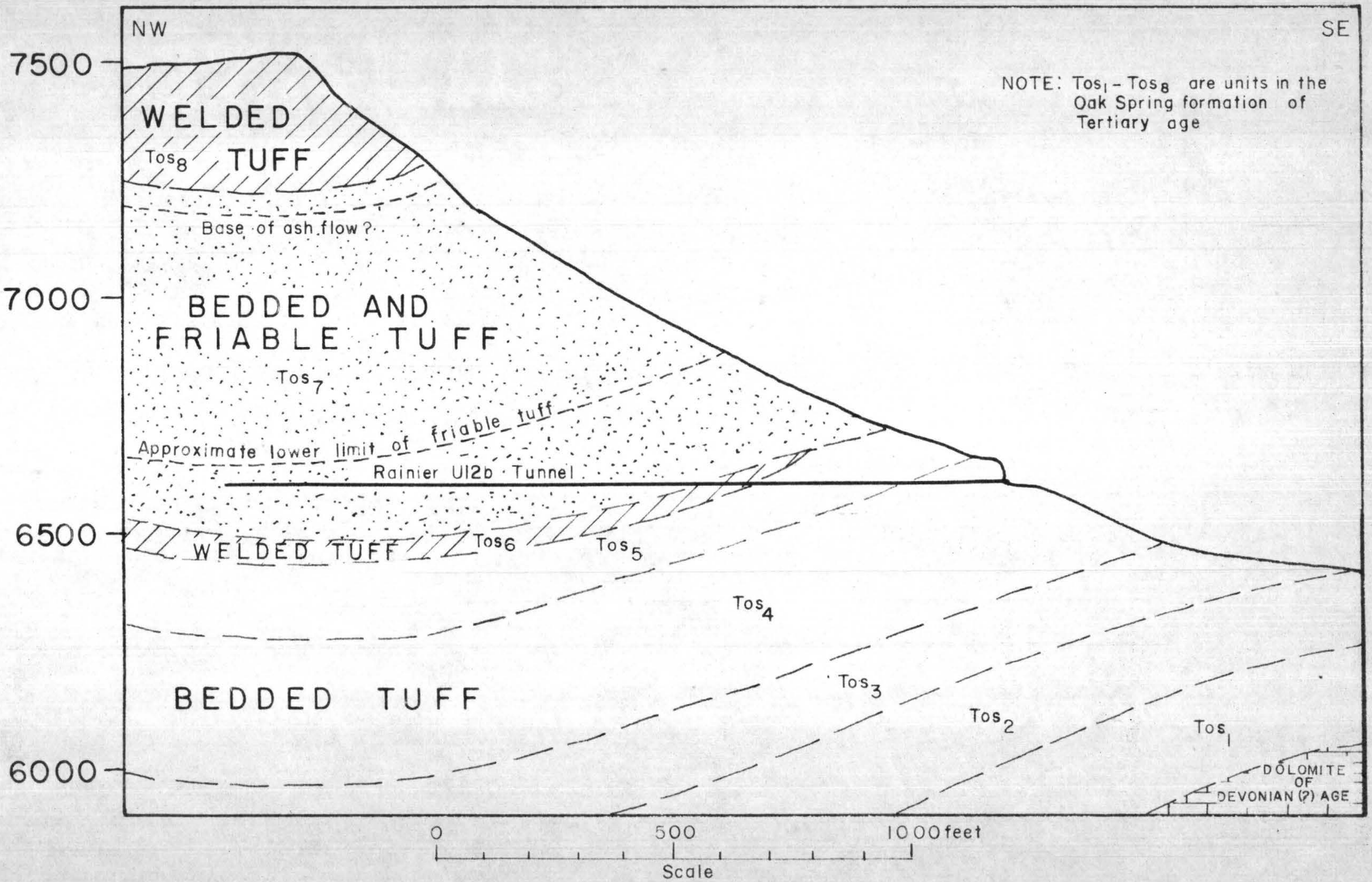

FIGURE 5-GENERALIZED GEOLOGIC CROSS SECTION ALONG U 12b TUNNEL, RAINIER MESA, NYE COUNTY, NEVADA

PART II - STRATIGRAPHY AND STRUCTURE

By F. A. McKeown and D. D. Dickey

The U12b.03 and U12b.04 tunnels are in the lower part of unit Tos_7 of Hansen and Lemke (1958). The entrance to tunnel U12b.03 is approximately 70 feet stratigraphically above the contact with the underlying unit Tos_6; the entrance to tunnel U12b.04 is stratigraphically about 115 feet above Tos_6. During mapping of the U12b tunnel that part of unit Tos_7 exposed in the tunnel was divided into 11 lithologic units designated from oldest to youngest P to Z (Gibbons, A. B., 1958, written communication, fig. 3). Units R through Z are exposed in the U12b.03 tunnel (fig. 3), and of these units, W to Z are correlative with the rocks exposed in the Rainier shot chamber. The rocks exposed in these tunnels have an average strike of N. 80° E., and throughout most of the tunnels dip 8° to 10° NW. except in the northwestern part of U12b.03 tunnel where they dip 3° to 4° SE.

Stratigraphy

The rocks exposed in the U12b.03 and U12b.04 tunnels consist of tuffaceous sandstone and reddish-brown to white fine to coarse lapilli tuff[1]. The sandstone is laminated to thin bedded; the tuffs are

[1] Volcanic terminology from Wentworth, C. K. and Williams, Howell, 1932, The classification and terminology of the pyroclastic rocks: National Research Council Bull. No. 89, Report on the Committee on Sedimentation. The rocks are designated as follows according to size of fragments: Tuff breccia, > 32 mm; lapilli tuff, 4 to 32 mm; coarse tuff, ¼ to 4 mm; and fine tuff, < ¼ mm.

poorly bedded, soft, friable, and locally vary laterally and vertically within short distances in color, texture, and hardness.

The lithologic units exposed in the tunnels (figs. 3 and 4) are described briefly.

Unit R--Unit R is about 50 feet thick but only the upper 6 feet is exposed in the entrance to U12b.03 tunnel (fig. 3). The rocks of unit R are predominantly grayish-cream to light reddish-tan fine to medium tuffs. The tuff is laminated to thin bedded and locally has thin sets of low angle cross laminae. White streaks 1 to 2 inches thick of altered(?) pumice are common in the tuff and occur parallel to the bedding; some are contorted. Less common are streaks of limonite-stained tuff that have a similar mode of occurrence. In the tunnel U12b.03 the rocks of unit R are reddish tan with sparse pumice fragments; near the contact with the overlying unit S pumice fragments increase in abundance. The upper 2 to 4 feet of unit R are gradational to the tuff of unit S. Under the binocular microscope the tuff is seen to consist of feldspar, quartz, zeolite(?), and biotite phenocrysts, and a variety of lithic fragments in a white claylike groundmass. A yellow-green mineral that is common in the groundmass appears to be present only in the tuffs of unit R.

Unit S--Unit S is 5 feet thick and is only exposed in the U12b.03 tunnel (fig. 3). The rocks of unit S are chiefly reddish-brown and white tuff with many disseminated white and greenish-yellow pumice fragments. Some of the white pumice fragments are tinged with pink. The contacts between the red-brown and white tuff are very irregular and both lateral and vertical gradations in color are common. A zone about 1 foot thick at the base of the unit contains many scalloped nodules of light reddish-brown porcelaneous material. Pumice fragments ranging from silt to pebble size are common in the tuff; some of the pumice seems comminuted. Feldspar and lithic fragments are the most common sand and granule size material in the rock. Rare dark reddish-brown glass and a greenish-yellow mineral are the most conspicuous fine-grained material.

Unit T--Unit T is about 8 feet thick and is only exposed in the U12b.03 tunnel (fig. 3). This unit consists of white, chalky tuff with conspicuous lithic fragments. The lithic fragments are dark red or gray quartzite(?) and volcanic rocks, and are as much as much as 0.5 inch across. The matrix is white silt and clay-sized material. A greenish-yellow claylike mineral fills or forms a thin layer on walls of some small (less than 0.12 inch) cavities.

Unit U--Unit U is about 10 feet thick and is exposed in the U12b.03 tunnel (fig. 3); about 8 feet is exposed in alcove 3 in the U12b.04 tunnel (fig. 4). The unit consists of interbedded reddish-brown and greenish-white tuff. The reddish-brown tuff is generally a little harder than the greenish-white tuff, though both rocks are moderately friable. The tuffs consist of poorly sorted lapilli (lithic fragments and altered pumice) disseminated in fine to coarse tuff. Some of the pumice fragments are yellowish green. The fine-grained material consists of light-brown mica, clear, white, and reddish-orange feldspar(?), and claylike unidentified minerals.

Unit V--Unit V is exposed in the U12b.03 and U12b.04 tunnels (figs. 3 and 4). The U12b.03 tunnel transects unit V and exposes a total thickness of about 30 feet. The U12b.04 tunnel was driven along strike of the unit and does not expose the total thickness of the unit. Unit V is mostly a reddish-brown lapilli tuff. The base is marked by a persistent bed about 0.5 foot thick of very coarse lithic tuff with an olive-green porcelaneous matrix. Above this bed is a zone about 3 feet thick of white lapilli tuff that grades upward to a reddish-brown lapilli tuff which is the most abundant rock in unit V.

The lapilli tuff consists of feldspar, coarse white altered pumice fragments and other lapilli, granule-size lithic fragments, biotite, rare magnetite and hornblende in a matrix of light reddish-brown claylike material.

The tuffs that are exposed in the shot chamber and adjacent curved part of the U12b.04 tunnel are in a downthrown block on the southwest side of a fault that intersects the tunnel about 120 feet from the chamber (fig. 4). These rocks though similar cannot be correlated with certainty with the rocks that form the lithologic units in the U12b tunnel. Nine lithologic subunits, from oldest to youngest V_1 to V_9, are exposed in the tunnel and shot chamber (fig. 4).

Subunit V_1 is reddish-brown lapilli tuff. About 2 feet of this tuff is exposed in the shot chamber; the total thickness is not known. The tuff is fairly soft and friable and contains abundant white and greenish-white lapilli, most of which are probably altered pumice fragments. The green color of some of the fragments is due to included biotite that has altered to a soft greenish claylike mineral. Coarse lithic fragments are common though not conspicuous. Other components are biotite, feldspar, amber-colored mica, rare dark reddish-brown glass and an unidentified black, metallic soft nonmagnetic mineral. The matrix of the tuff is soft light reddish-brown claylike material.

Subunit V_2 is 2 to 2.5 feet thick and is a white lapilli tuff that has a sharp contact with the underlying tuff and a gradational contact with overlying tuff. Altered pumice and other lapilli and tuff make up a large part of the rock. Some of the pumice and lapilli seem macerated. Lithic fragments are common. Biotite, some of which is altered to a yellowish-green mineral, feldspar, and quartz(?) are the chief phenocrysts. The high plagioclase and mica content shown in the modal analyses of unit W (sample B36, B37, and B313, table 2) and unit V_2 (sample B410, table 3) indicates the units may be correlative. Lack of mineralogic similarities between adjacent units, however, precludes reliable correlation.

Subunit V_3 is 3 to 4 feet thick and is a reddish-brown lapilli tuff similar in appearance to subunit V_1, though more indurated. Large white altered pumice fragments, some of which include biotite, are abundant in the tuff; sand- and granule-size lithic fragments are much less conspicuous. Phenocrysts include sand-size grains of feldspar, quartz(?), biotite, pyroxene(?), and hornblende.

Subunit V_4 is about 2.5 feet thick and is a fairly hard white lithic tuff. The tuff contains abundant granules of dark-gray, black, and red lithic fragments; altered pumice fragments are common and some are tinged with pink or green. The principal sand-size particles are biotite, feldspar, orange claylike material some of which is vesicular, and yellowish-green claylike mineral.

Subunit V_5 ranges from 0.5 to 1.5 feet thick and is a reddish-brown lapilli tuff. On the northeast, northwest, and southwest walls in the shot chamber the tuff contains many irregular layers and nodules of porcelaneous rock. The porcelaneous rock is tough light reddish-brown, scratches easily, and contains minor amounts of feldspar, mica, magnetite, and hornblende. The lapilli tuff is megascopically very similar to the lapilli tuffs of subunits V_1 and V_3. White lapilli of altered pumice fragments and reddish-brown tuff are the most prominent constituents. Lithic fragments, feldspar, and biotite are the principal minor constituents.

Subunit V_6 is white lapilli tuff and about 3.5 feet of it is exposed in the shot chamber. The tuff is fairly soft and composed of white pumice fragments and other lapilli, and some lithic fragments. Fine-grained biotite, feldspar, quartz(?), montmorillonite(?), and some reddish-brown claylike material are common in the matrix.

Subunit V_7 is about 2 feet thick and is exposed on the northwest wall of the shot chamber and in the small alcove about 45 feet north of the shot chamber. The rock is principally a reddish-brown tuff that contains layers 0.5 to 2 inches thick of reddish-white tuff. Red-brown masses, 0.12 to 0.75 inch across, are present in these layers. Lapilli of tuff and pumice fragments are abundant and lithic fragments are common.

Subunit V_8 is exposed only in the small alcove about 45 feet north of the shot chamber. It is 1.2 feet thick and consists of white tuff with common lithic fragments; greenish-white opalized nodules of tuff are sparse. Subunit V_8 has a gradational contact with overlying subunit but appears to truncate part of underlying subunit.

Subunit V_9 has an exposed thickness of 2 feet near the back of the small alcove about 45 feet north of the shot chamber. The total thickness is unknown. The rock is dark tannish-gray fine tuff.

Unit W--Unit W is only exposed in the U12b.03 tunnel where it is 1.5 to 2.5 feet thick (fig. 3). The rock is a grayish-white lapilli tuff. It is very poorly bedded and has a fairly sharp contact with underlying unit V and a gradational contact with overlying unit X. The rock of unit W consists of lapilli and abundant granules of lithic fragments in a matrix of micaceous claylike material.

Unit X--Unit X is exposed in the U12b.03 tunnel and is about 5 feet thick. The contact between units X and Y is sharp. The rock of unit X is fairly hard massive reddish-brown lapilli tuff. It is composed of abundant white altered pumice fragments and other lapilli in a matrix of light reddish-brown silt- to clay-size material with biotite, orange-white feldspar(?), and pyroxene. Lithic fragments 0.12 to 0.5 inch across are common.

Unit Y--Unit Y is about 1 foot thick and is exposed near the back of Alcove No. 1 in the U12b.03 tunnel (fig. 3). It is a bed of white lapilli tuff that makes a sharp contact with underlying unit X and has an erosional contact with overlying unit Z. Just north of where the synclinal axis crosses the U12b.03 tunnel (fig. 3), rocks of unit Y have been removed by erosion and the scour filled with rocks similar to those of unit Z.

The rocks of unit Y contain granules of lithic material and soft white lapilli fragments, some of which were probably pumice. A preponderance of red lithic fragments may be a diagnostic feature.

of the rock. Feldspar, biotite, amber mica, and aggregates about 0.06 inch across of chocolate-brown soft porous material are disseminated in the white claylike matrix.

Unit Z--Unit Z is pinkish-white coarse lapilli tuff with a discontinuous light purplish-brown fine- to coarse-grained tuffaceous sandstone at the base. The thickness of unit Z is unknown. Unit Z is exposed at two places in the U12b.03 tunnel 1) at the top of the north wall of Alcove No. 1 where the lower 2 feet are exposed and 2) about 1 foot is exposed near the synclinal axis just north of Alcove No. 1. According to A. B. Gibbons (1958, written communication, fig. 3) about 6 feet of unit Z was exposed in the Rainier shot chamber.

The tuffaceous sandstone at the base of unit Z is generally less than 1 foot thick. The sandstone is poorly sorted, in part conglomeratic and consists of feldspar, quartz(?), biotite, light-brown mica, a soft greenish-yellow mineral that may be montmorillonite, and traces of an unidentified light-green hard mineral. Discontinuous layers about 0.5 inch thick heavily stained with limonite occur at the base and rarely several inches above the base of the sandstone. The tuffaceous sandstone grades into the lapilli tuff of the upper part of unit Z. Most of the lapilli are white or light green and are probably altered pumice. The tuff contains abundant biotite and feldspar, some coarse-grained dark-gray lithic fragments, and a minor amount of light-brown mica and yellowish-green mineral which may be montmorillonite.

Structure

The structure of the rocks exposed in U12b.03 and U12b.04 tunnels is relatively simple. The general westerly dip of the beds of the Oak Spring formation as observed inward from the portal of U12b tunnel is interrupted by a shallow northeast-trending syncline whose axis intersects U12b.03 tunnel near Alcove No. 1 (fig. 3). The syncline is broad, has an amplitude of at least 15 feet and plunges about 2° SW. The axis of the syncline is sinuous as indicated by the abrupt change in strike from N. 88° E. in the tunnel to N. 67° E. just north of Alcove No. 1 (fig. 3). South of Alcove No. 2 (fig. 3) the beds strike N. 59° to 84° E. and dip 8° to 13° NW., whereas near Alcove No. 1 the beds are more nearly parallel and strike N. 83° E., dip 9° NW. With the exception of the rocks adjacent to the synclinal axis, the rocks in the north part of the tunnel strike N. 65° to 71° E. and dip southeast, some as much as 7°. As shown in section A-A' (fig. 3) the average dip of the beds north of the syncline is about 5° SE.

In the U12b.04 tunnel the strike and dip of bedding can be measured at only a few places. In the shot chamber and nearby tunnel the beds strike N. 35° to 52° E. and dip 4° to 8° to the northwest, whereas in Alcove No. 3 they strike N. 75° E. and dip 5° to the northwest (fig. 4). The northwest trend in Alcove No. 3 is probably representative of the attitude of the rocks throughout most of the U12b.04 tunnel.

Ten faults are exposed in the U12b.04 tunnel, three of which are in or near the shot chamber; they strike N. 3° to 21° E. and dip 70° to 80° NW. (fig. 4). The other seven are in the tunnel and alcoves; six of these faults strike N. 41° to 62° W. and dip 37° to 69° SW.; the other strikes N. 41° W. and dips 60° NE. The rocks have been displaced along most of the faults from less than 1 to about 4 feet. However, one fault, which intersects the tunnel 115 feet west of the entrance to Alcove No. 1, has a vertical displacement of at least 10 feet; the exact displacement cannot be determined. This fault possibly could be the continuation of a fault exposed at the surface about 300 feet southwest of Point Mabel (Hansen and Lemke, fig. 2). None of the other faults in the U12b.04 tunnel are believed to extend to the surface.

Joints are conspicuous in most rock units in the U12b.03 tunnel (fig. 3) but are more abundant in unit S near the entrance to the tunnel, in unit X near the syncline axis, and in unit V near the shot chamber. The concentration of joints is apparently related to the syncline and type of lithology. As shown on figure 6, there are two prominent joint sets which trend north and northwest. The joints in the former set strike N. 15° W. to N. 60° E.; about 32 percent of these strike N. to N. 15° E. The joints in the northwest-trending set range from N. 30° W. to W.; the dominant strike is N. 45° to 60° W.

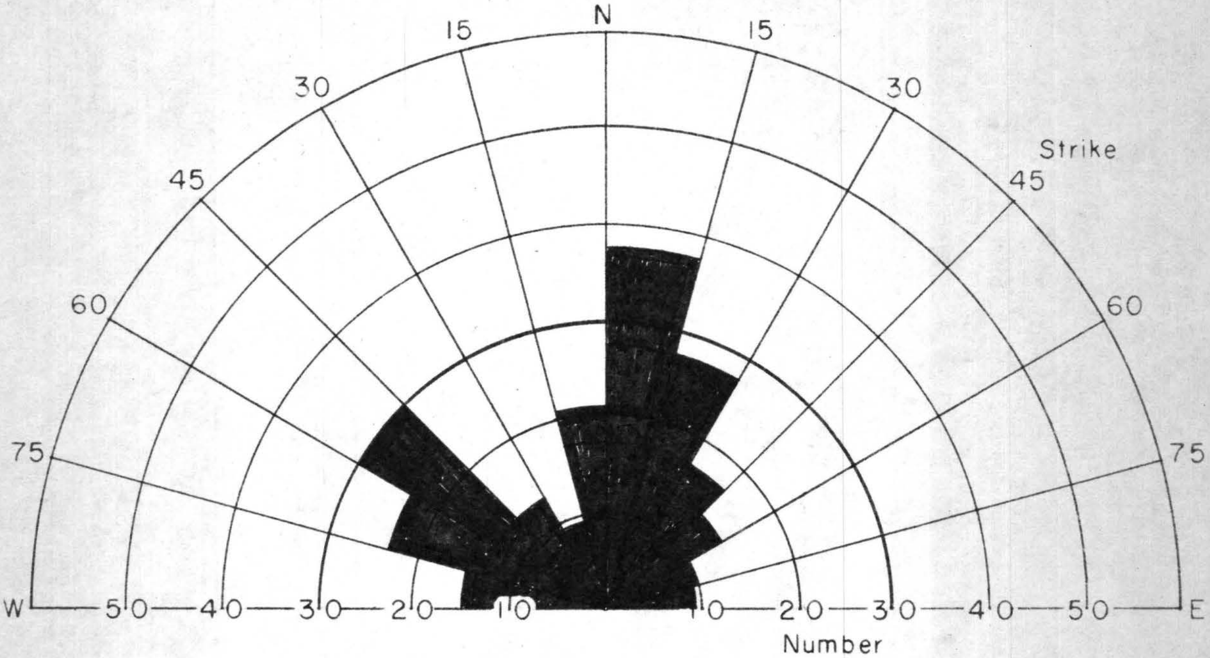

FIGURE 6-PLOT OF STRIKE OF 227 JOINTS, U12b-03 TUNNEL, NEVADA TEST SITE, NYE COUNTY, NEVADA

Dip of joints measured in U12b.03 tunnel is shown on figure 7. About 27 percent of the joints are vertical. Most of the remainder dip more than 60° NE. and SE., or 75° SW. and NW.

Joints are generally not conspicuous in the rocks exposed from the entrance of the U12b.04 to Alcove No. 1. From Alcove No. 1 to and including the shot chamber, joints are abundant and well developed. The increased number of joints in the vicinity of the shot chamber may be genetically related to the faults that are exposed in the tunnel and shot chamber. Two sets of joints predominate in the U12b.04 tunnel. One set strikes N. 45° to 60° W. and another set strikes N. 15° to 30° E. (fig. 8). The northwest set of joints are vertical or dip steeply to the northeast or southwest (fig. 9). Most of the northeast set of joints dip steeply to the northwest or are vertical; a few dip to the southeast.

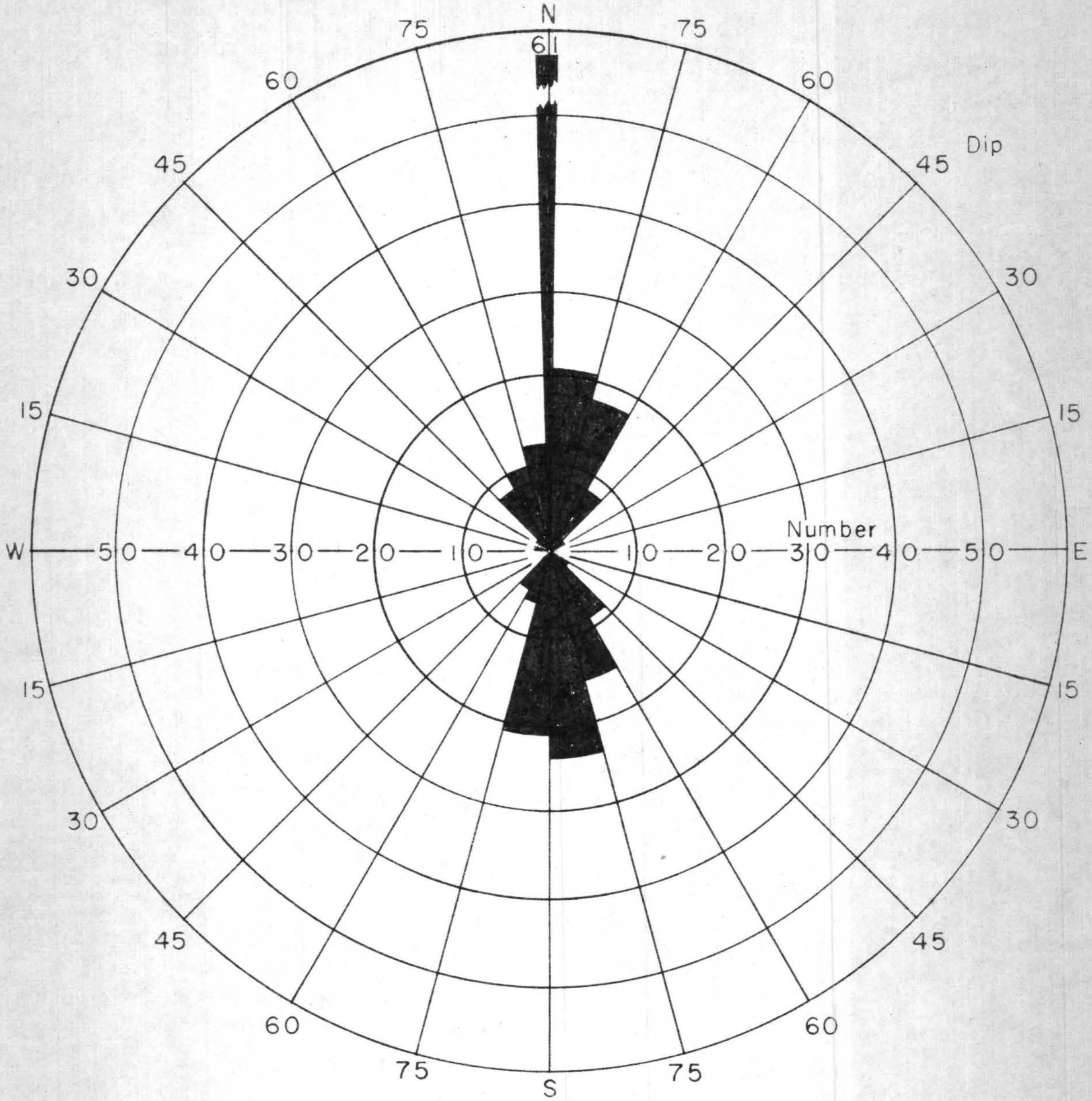

FIGURE 7—PLOT OF DIP OF 227 JOINTS, U12b-03 TUNNEL, NEVADA TEST SITE, NYE COUNTY, NEVADA

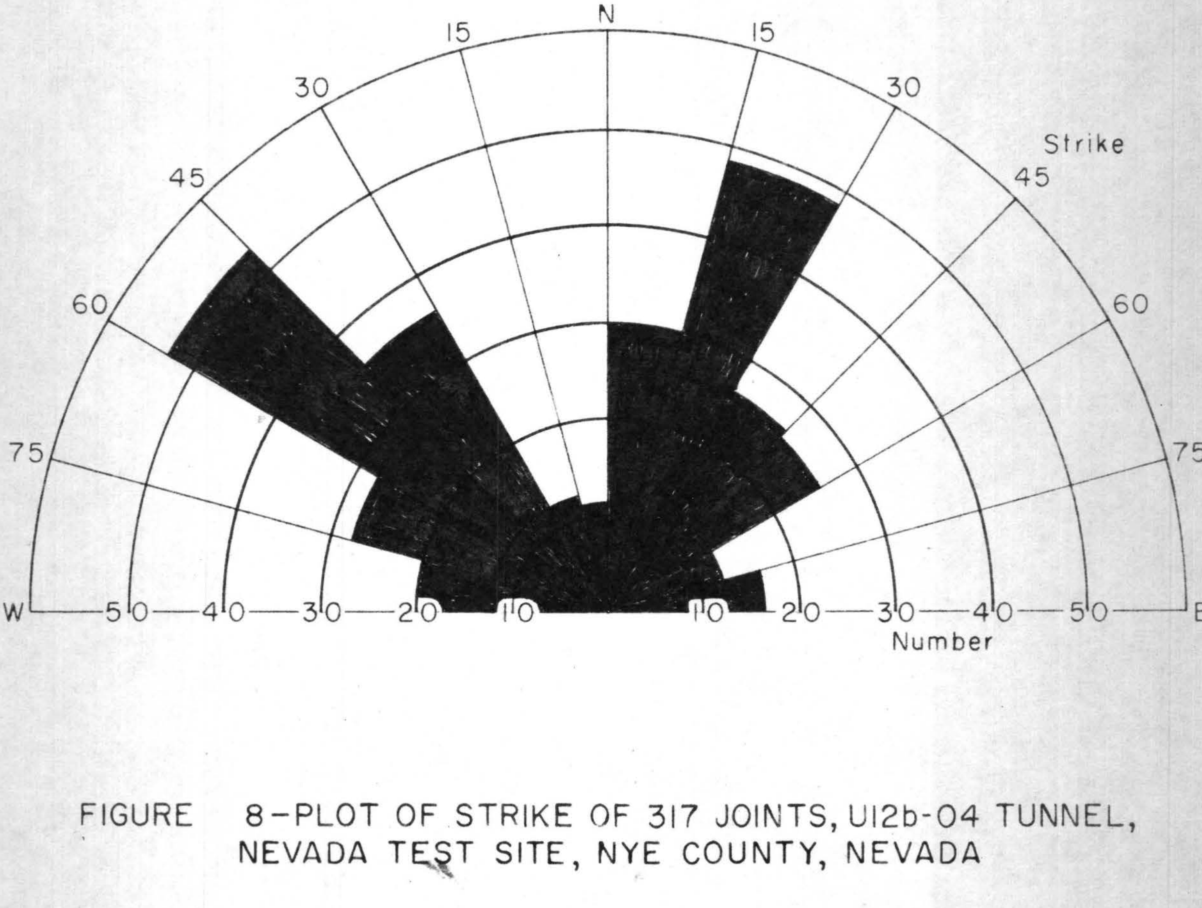

FIGURE 8-PLOT OF STRIKE OF 317 JOINTS, U12b-04 TUNNEL, NEVADA TEST SITE, NYE COUNTY, NEVADA

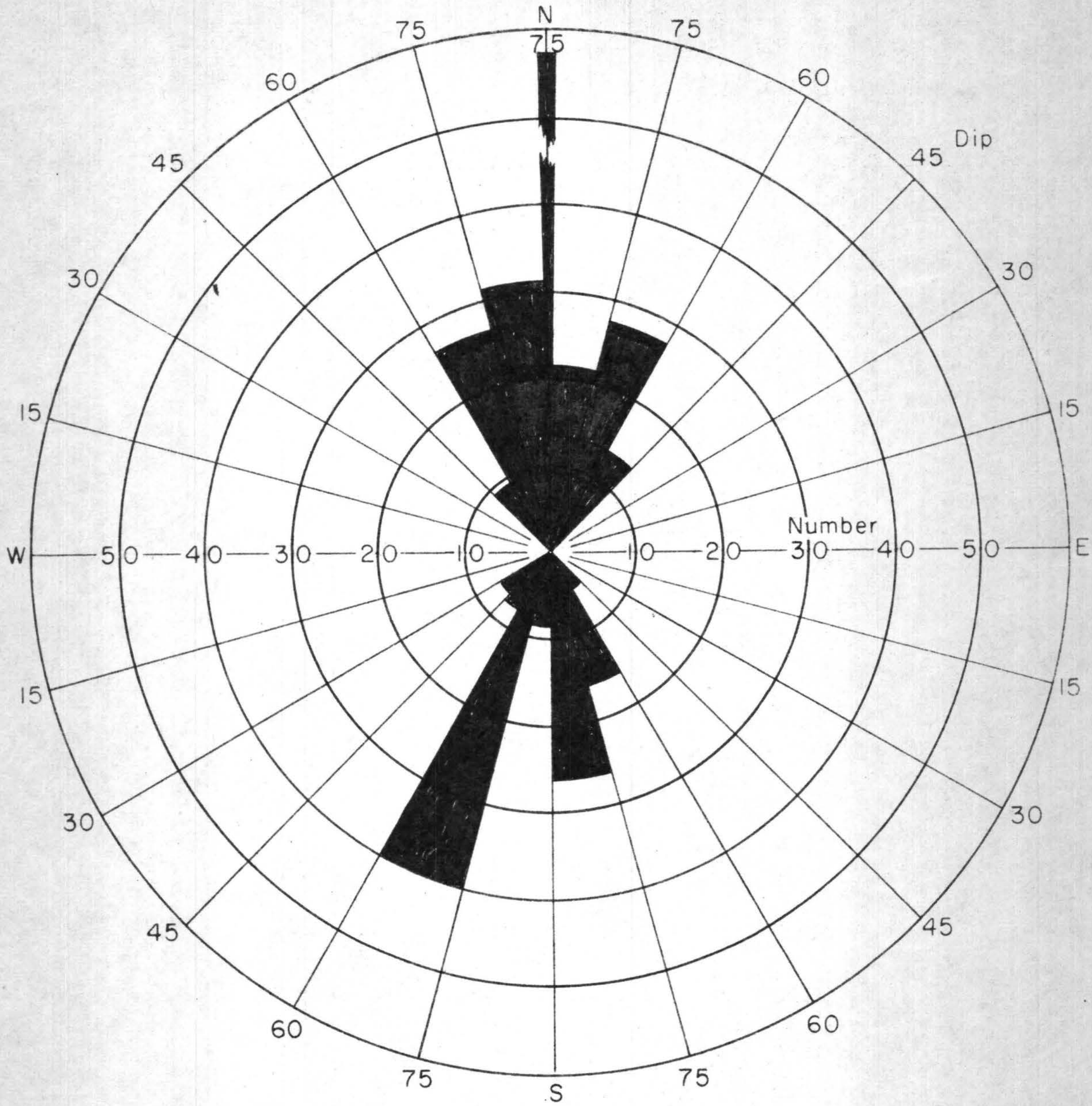

FIGURE 9 — PLOT OF DIP OF 317 JOINTS, U12b-04 TUNNEL, NEVADA TEST SITE, NYE COUNTY, NEVADA

PART III - PETROLOGY

By E. N. Hinrichs, T. Botinelly, and F. A. McKeown

Samples of the lithologic units exposed in the shot chambers and other workings of U12b.03 and U12b.04 tunnels were analyzed by microscopic, X-ray, and chemical methods. The mineralogic constituents of the tuff were determined by X-ray analysis, study of thin sections with a petrographic microscope, and examination under a binocular microscope of sawed specimens of tuff which had been etched with hydrofluoric acid and stained with sodium cobaltinitrite. Modal analyses of the tuff specimens were made by a point count method (tables 2 and 3).

In thin sections the tuffaceous rocks are seen to consist of zeolitized lapilli, xenoliths, and phenocrysts in a matrix of indurated zeolitized ash. The lapilli and ash which constitute 60 to 90 percent of the rock contain heulandite, clay, and intergrowths of cryptocrystalline quartz(?) and feldspar(?).

Some of the lapilli, which were probably fragments of pumice, contain many globular vesicles; some of the walls of the vesicles are lined with colloform heulandite(?). Other lapilli are structureless solid masses and others contain spherulites which are probably intergrowths of cryptocrystalline quartz and feldspar. The matrix is foliated, fibrous, orbicular, and reticulated. Flowage is indicated in some samples by swirls in parts of the matrix and by contorted schlieren of fine particles around phenocrysts and xenoliths.

Table 2.--Volume percent of minerals in tuff from the U12b.03 tunnel, Nevada Test Site, Nye County, Nevada

Sample number 1/	B31	B32	B34	B38	B36	B37	B313	B312	B314	B315	B39	B316	B310	B311
Lithologic unit	S	T	V	V	W	W	W	X	X	X	Y	Y	Z	Z
Phenocrysts 2/	6	3	2	21	31	25	31	22	9	20	25	22	24	22
Potassian feldspar	63	86	74	21	11	7	16	17	17	26	50	46	38	42
Plagioclase	27	7	9	48	54	65	57	58	61	48	34	17	34	31
Quartz	3	7	17	11	12	7	3	8	5	14	1	0	18	23
Mica	3	0	0	9	20	15	21	12	13	8	12	32	6	2
Magnetite	3	0	0	2	4	5	5	2	5	4	2	5	3	1
Pyroxene and amphibole	0	0	0	8	0	1	0	2	0	0	1	0	2	0
Xenoliths	7	2	5	2	1	4	5	6	5	3	9	3	14	6
Vesicles	6	12	7	2	5	4	4	3	7	8	3	7	8	15
Finely crystalline and amorphous fragments	81	84	85	75	63	67	60	70	80	68	63	68	55	57
Heulandite 3/	24	33	26	15	19	17	12	21	20	14	22	20	19	23
Clay	12	13	21	11	16	37	36	14	44	44	13	37	0	0
Beta-cristobalite	12	8	13	15	ND	7	6	7	8	7	9	ND	8	11
Mica	ND	ND	ND	4	9	7	6	4	ND	3	3	3	0	2
Remainder 4/	32	4	26	30	19	0	0	24	8	0	16	7	27	21

Table 2.--Volume percent of minerals in tuff from the U12b.03 tunnel, Nevada Test Site, Nye County, Nevada--Continued

1/ See table 4 for descriptions of samples.

2/ Modal analyses by E. N. Hinrichs.

3/ X-ray analyses of finely crystalline and amorphous fragments by T. Botinelly.

4/ Calculated by difference. This remainder is in part due to errors in estimating mineral percentage, in part to amorphous material, and in part to crystalline material too small in amount to show by X-ray analysis.

ND--not detected.

Table 3.--Volume percent of minerals in tuff from the U12b.04 tunnel, Nevada Test Site, Nye County, Nevada

Sample numbers 1/	B41	B42	B43	B44	B46	B49	B410	B412	B414	B411	B48	B47	B413	B418	B417	B416	B415
Lithologic units	V	V	V	V	V	V_1	V_2	V_3	V_4	V_5	V_5	V_6	V_6	V_6	V_7	V_8	V_9
Phenocrysts 2/	9	8	4	6	5	15	28	14	9	4	13	13	20	18	29	16	26
Potassian feldspar	63	52	100	37	60	15	18	23	42	43	35	35	47	26	28	48	30
Plagioclase	4	13	0	46	8	60	57	65	44	41	41	57	36	48	49	32	51
Quartz	28	28	0	8	23	8	2	3	2	0	3	2	2	4	1	4	5
Mica	4	3	0	0	9	15	18	7	9	14	11	8	12	20	21	16	13
Magnetite	0	5	0	8	0	2	4	2	2	0	5	0	3	2	1	0	1
Pyroxenes and amphiboles	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Xenoliths	6	6	9	6	9	3	3	4	3	2	2	7	6	12	2	4	5
Vesicles	7	6	4	23	5	2	7	4	9	1	3	6	10	10	6	7	4
Finely crystalline and amorphous fragments 3/	78	81	83	65	81	80	62	79	79	94	82	74	64	60	63	74	65
Heulandite	-4/	-	-	-	20	24	22	24	-	32	-	26	22	18	22	19	26
Clay	-	-	-	-	57	20	12	16	-	9	-	11	6	ND	ND	7	ND
Beta-cristobalite	-	-	-	-	ND	8	ND	8	-	9	-	ND	13	6	6	19	7
Mica	-	-	-	-	ND	4	6	4	-	-	-	ND	3	6	6	-	7
Remainder 5/	-	-	-	-	4	24	22	28	-	42	-	37	19	30	29	30	26

Table 3.--Volume percent of minerals in tuff from the U12b.04 tunnel, Nevada Test Site, Nye County, Nevada--
Continued

1/ See table 5 for description of samples.

2/ Modal analyses by E. N. Hinrichs.

3/ X-ray analyses of finely crystalline and amorphous fragments by T. Botinelly.

4/ Not analyzed.

5/ Calculated by difference. This remainder is in part due to errors in estimating mineral percentage, in part to amorphous material, and in part to crystalline material too small in amount to show by X-ray analysis.

ND--not detected.

Table 4.-- Description of samples taken from U12b.03 tunnel, Nevada Test Site, Nye County, Nevada 1/

Sample No.	Lithologic unit	Description
B31	S	White to light brownish-red pumiceous tuff.
B32	T	Chalky white tuff with coarse lithic fragments.
B34	V	Light reddish-brown pumiceous tuff.
B36	W	Grayish-white, coarse, lapilli tuff.
B37	W	" " " " "
B38	V	Reddish-brown, pumiceous tuff.
B39	Y	White, coarse lapilli tuff.
B310	Z	Grayish-white to purplish-brown, tuffaceous sandstone.
B311	Z	Grayish-white sandy tuff.
B312	X	Reddish-brown pumiceous tuff.
B313	W	Grayish-white, coarse, lapilli tuff.
B314	X	Reddish-brown pumiceous tuff.
B315	X	" " " "
B316	Y	White, coarse lapilli tuff.

1/ See figure 3 for location of samples.

Table 5.--Description of samples taken from U12b.04 tunnel, Nevada Test Site, Nye County, Nevada 1/

Sample No.	Lithologic unit	Description
B41	V	Reddish-brown lapilli tuff.
B42	V	Reddish-brown lapilli tuff.
B44	V	White lithic tuff.
B46	V	Reddish-brown lapilli tuff.
B47	V_6	White lapilli tuff.
B48	V_5	Reddish-brown lapilli tuff and porcelaneous tuff.
B49	V_1	Reddish-brown lapilli tuff.
B410	V_2	White lapilli tuff.
B411	V_5	Reddish-brown lapilli tuff and porcelaneous tuff.
B412	V_3	Reddish-brown lapilli tuff.
B413	V_6	White lapilli tuff.
B414	V_4	White lithic tuff.
B415	V_9	Dark reddish-brown lapilli tuff.
B416	V_8	Greenish-tan pumiceous tuff.
B417	V_7	Reddish-brown and white lapilli tuff.
B418	V_6	White lithic tuff.

1/ See figure 4 for location of samples.

Phenocrysts make up from 2 to 31 percent by volume of the tuffs exposed in the U12b.03 and .04 tunnels. They are most abundant in the tuffs of units W, X, Y, Z, and part of unit V. The rocks of unit V are well exposed in the tunnels and their modal analysis (tables 2 and 3) indicates the variable phenocryst content of the tuffs. In these rocks, especially U12b.04 tunnel (table 3), 4 to 29 percent of the volume of the tuff is made up of phenocrysts.

The phenocrysts range from 0.5 to 3.5 mm across and named in order of abundance are potassian feldspar, plagioclase, quartz, and mica (biotite). Magnetite and the minerals of pyroxene and amphibole groups are present but rarely account for as much as 10 percent of the phenocrysts. Much of the feldspar is subhedral to euhedral; twinned and zoned crystals are very common. Corroded crystals, due to partial remelting, of plagioclase are common.

Though too few samples have been analyzed for conclusive results, comparison of ratio of potassian feldspar to plagioclase may be useful in the correlation of some of the stratigraphic units. The average ratio for units S through Z exposed in the tunnels is given below.

Unit		Average potassian feldspar/plagioclase
S		2.5
T		12
V	(range .31 to 15.0)	2.5
W		.2
X		.37
Y		2.0
Z		1.2

These values indicate that for all units except W and X, potassian feldspar phenocrysts are as abundant or several times more abundant than the plagioclase phenocrysts.

Mica may also be a diagnostic mineral. It is appreciably more abundant in unit W.

The volume of xenoliths present in the tuffaceous rocks ranges from 2 to 14 percent. Many of them are rounded, as much as 1 inch across and are predominantly dark metavolcanic rocks. Some quartzite and argillite fragments are present.

The vesicles in the rocks are irregular, rarely more than a few tenths of an inch across, and make up as much as 15 percent by volume of the rocks.

X-ray analyses were made of the matrix of the samples from the U12b.03 and .04 tunnels (tables 2 and 3). Estimates of the percentages of each mineral were made from the relative heights of critical peaks of each mineral on the X-ray diffractometer chart; the estimates are only rough approximations.

The minerals identified in the matrix named in relative order of abundance include heulandite, clay minerals, beta-cristobalite, and mica. Heulandite averages about 22 percent by volume of the matrix in the rocks of units S through Z, but in units W and X the content is somewhat less. The clay minerals, principally montmorillonitic, make up as much as 57 percent by volume of the matrix. They apparently are more abundant in the tuffs of unit X and parts of unit V. Beta-cristobalite though present in many of the samples analyzed rarely forms over 10 percent by volume of the matrix. The mica in the matrix, dominantly biotite, averages about 5 percent of the volume.

In addition to the identified minerals the matrix contains amorphous material, indicated as remainder in tables 2 and 3. Some of the remainder is undoubtedly glass, but further work is necessary to determine the complete mineralogic composition.

Semiquantitative spectrographic analyses of samples from the units exposed in the U12b.03 and .04 tunnels are given in tables 6 and 7. The rocks of these units are characterized by the presence of the rare-earth metals--Ce, La, Nd--in amounts greater than normal acidic rocks. Niobium is present in amounts ranging from 0.0015 to 0.007 percent which is comparable to the alkalic complex at Magnet Cove, Arkansas.

Chemical analyses were made of 14 samples from units V through Z in the U12b.03 tunnel (table 8) and 12 samples from unit V and sub-units in the U12b.04 tunnel (table 9). The six samples--B37, B38, B313, B314, B315, and B316--are from the shot chamber of the U12b.03 tunnel and the five samples--B49, B410, B411, B412, and B413--are from the shot chamber of the U12b.04 tunnel.

Table 6.--Semiquantiative spectrographic analyses of tuff from the shot chamber and tunnel of U12b.03, Rainier Mesa, Nye County, Nevada 1/

Sample number	B31 2/	B32	B34	B38	B316	B36	B37	B313	B312	B314	B315	B39	B310	B311
Laboratory number	267321	267322	267323	267326	267873	267324	267325	267870	267898	267871	267872	267895	267896	267897
Lithologic unit	S	T	V	V	V	W	W	W	X	X	X	Y	Z	Z
Ba	.03	.015	.015	.07	.15	.07	.07	.15	.15	.15	.15	.15	.15	.15
Be	.0003	.0007	.0007	.0007	.0003	.0003	.00015	.0003	.0003	.0003	.0003	.00015	.0003	.0003
Ce	d	.03	d	d	.03	d	d	.03	.03	.03	.03	.03	.03	.03
Co	0	0	0	d	d	d	d	.0007	.0007	.0007	.0007	0	0	0
Cr	.0007	0	.0003	.0015	.0007	.0007	.0007	.0007	.0007	.0015	.0007	.0003	.0003	.0003
Cu	.0015	.0007	.0007	.0015	.0015	.0007	.0007	.0007	.003	.007	.0015	.0007	.0007	.0007
Ga	.003	.003	.0015	.0015	.0015	.0015	.0015	.003	.003	.003	.003	.003	.0015	.0015
La	.015	.015	.007	.007	.03	.007	.007	.015	.015	.015	.015	.015	.015	.015
Nb	.003	.007	.003	.0015	.003	.0015	.0015	.003	.0015	.003	.003	.003	.003	.003
Nd	.015	d	d	d	.015	d	d	.015	0	d	d	.015	d	0
Ni	0	0	0	.0003	.0007	.0003	.0007	0	.0007	0	.0007	0	0	0
Pb	.003	.003	.003	.0015	.003	.0015	.0015	.003	.003	.003	.003	.003	.003	.003
Sc	.0015	0	0	.0007	d	.0015	.0007	.0007	.0015	.0007	.0007	.0007	0	0

Table 6.--Semiquantiative spectrographic analyses of tuff from the shot chamber and tunnel of U12b.03, Rainier Mesa, Nye County, Nevada--Continued

Sample number	B31 2/	B32	B34	B38	B316	B36	B37	B313	B312	B314	B315	B39	B310	B311
Laboratory number	267321	267322	267323	267326	267873	267324	267325	267870	267898	267871	267872	267895	267896	267897
Lithologic unit	S	T	V	V	V	W	W	W	X	X	X	Y	Z	Z
Sr	.03	.015	.015	.07	.07	.07	.07	.15	.07	.07	.07	.03	.03	.03
V	.0015	d	.0015	.003	.003	.003	.007	.007	.003	.007	.007	.003	.003	.003
Y	.007	.003	.003	.0015	.003	.0015	.0015	.003	.007	.003	.003	.003	.003	.007
Yb	.015	.0007	.0003	.00015	.0007	.00015	.00015	.0007	.0007	.0007	.0007	.0007	.0003	.0007
Zr	.03	.15	.03	.03	.15	.03	.03	.15	.0007	.07	.03	.03	.03	.015

Looked for but not found: Ag, As, Au, B, Bi, Cd, Dy, Er, Eu, Gd, Ge, Hf, Hg, Ho, In, Ir, Li, Lu, Mo, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sn, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn.

The number 0 also indicates looked for but not found.

The letter d indicates barely detectable, concentration unknown.

1/ Analysts: Nancy M. Conklin, USGS, Reports Nos. TDS-9595, TDS-9622, and TDS-9618, and John C. Hamilton, USGS, Report No. TDS-9595, pt. II. Figures are reported to the nearest number in the series 7, 3, 1.5, 0.7, 0.3, 0.15, etc., in percent. These numbers represent midpoints of group data on a geometric scale.

2/ See table 4 for descriptions of samples.

Table 7.--Semiquantiative spectrographic analyses of tuff from the shot chamber and tunnel of U12b.04, Rainier Mesa, Nye County, Nevada 1/

Sample No.	B46 2/	B49	B410	B412	B414	B411	B413	B47	
Lab. No.	267327	267329	267891	267893	268407	267892	267894	267328	Standard spectrographic sensitivity
Lithologic unit	V	V_1	V_2	V_3	V_4	V_5	V_6	V_6	
Ba	.03	.07	.15	.15	.07	.15	.15	.07	.0002
Be	.0003	.0003	.0003	.00015	0	.0003	.00015	.00015	.0001
Ce	.03	d	.03	.03	0	.03	.03	0	.02
Co	0	.0007	.0007	d	0	d	0	0	.0005
Cr	.0015	.0007	.0007	.0007	.0003	.0003	.0003	.0003	.0001
Cu	.003	.003	.0007	.0015	.0007	.0015	.0007	.003	.0001
Ga	.003	.003	.003	.003	.003	.003	.003	.0015	.0002
La	.015	.015	.03	.015	.007	.015	.015	.007	.002
Nb	.007	.003	.003	.003	.0015	.0015	.003	.0015	.001
Nd	.015	d	.015	d	0	0	d	0	.01
Ni	.0015	.0007	.0007	.0007	0	.0007	0	.0007	.0003
Pb	.003	.0015	.0015	.0015	.003	.003	.003	.003	.001
Sc	.0007	.0015	.0015	.0015	0	.0015	.0007	0	.0005
Sn	0	0	0	0	.003	0	0	0	.001
Sr	.03	.15	.15	.15	.07	.15	.15	.07	.0002
V	.003	.007	.007	.007	.003	.0015	.0015	.0015	.001
Y	.003	.003	.003	.003	.003	.003	.003	.003	.001
Yb	.0007	.0007	.0007	.0007	.0005	.0007	.0007	.0007	.0005
Zr	.15	.07	.07	.07	.015	.07	.07	.03	.001

Table 7.--Semiquantiative spectrographic analyses of tuff from the shot chamber and tunnel of U12b.04, Rainier Mesa, Nye County, Nevada--Continued

Looked for but not found: Ag, As, Au, B, Bi, Cd, Dy, Er, Eu, Gd, Ge, Hf, Hg, Ho, In, Ir, Li, Lu, Mo, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn.

The number 0 also indicates looked for but not found.

The letter d indicates barely detectable, concentration unknown.

1/ Analysts: Nancy M. Conklin and John C. Hamilton, USGS, Reports Nos. TDS-9622, TDS-9595, and TDS-9663. Figures are reported to the nearest number in the series 7, 3, 1.5, 0.7, 0.3, 0.15, etc., in percent. These numbers represent midpoints of group data on a geometric scale.

2/ See table 5 for descriptions of samples.

Table 8.--Chemical and equivalent uranium analyses of tuff from tunnel [illegible], Nevada Test Site, Nye County, Nevada 1/

Sample No. 2/	B31	B32	B34	B38	B36	B37	B313	B312	B314	B315	B39	B316	B310	B311
Lab. No.	267321	267322	267323	267326	267324	267325	267870	153640	267871	267872	153637	267873	153638	153639
Lithologic unit	S	T	V	V	W	W	W	X	X	X	Y	Y	Z	Z
SiO_2	65.6	67.5	67.4	64.5	59.7	58.9	57.0	62.7	62.4	62.1	68.0	66.4	69.0	70.2
Al_2O_3	12.7	10.9	11.3	14.3	15.6	17.2	16.4	14.0	14.1	14.5	11.8	13.2	12.3	11.7
Fe_2O_3	2.7	2.2	2.5	3.5	3.8	3.9	4.3	3.4	3.4	3.4	2.3	2.3	1.6	1.5
FeO	.06	.03	.06	.44	.59	.66	.66	.24	.39	.39	.30	.53	.18	.12
MgO	.75	.81	.82	1.3	1.4	1.4	1.5	1.4	1.4	1.6	.88	1.0	1.0	1.0
CaO	2.2	2.4	1.9	3.1	3.7	3.9	4.0	3.0	3.0	2.8	2.6	2.4	2.4	2.3
Na_2O	1.1	.46	.86	2.1	2.2	2.6	2.0	1.4	1.5	1.5	1.3	1.5	1.2	1.0
K_2O	3.0	2.9	2.6	2.4	1.9	2.0	1.9	2.6	2.2	2.2	2.4	2.4	2.5	2.2
H_2O+	5.6	6.7	5.9	3.8	5.4	3.9	4.6	5.5	4.8	4.6	5.4	4.3	5.3	5.3
H_2O-	5.4	6.4	6.2	3.6	4.9	4.3	6.5	5.5	6.1	6.7	4.9	6.0	4.5	5.0
TiO_2	.34	.12	.18	.52	.54	.63	.64	.48	.48	.50	.34	.32	.21	.18
P_2O_5	.08	.00	.01	.09	.20	.18	.23	.11	.12	.08	.23	.06	.05	.06
MnO	.11	.09	.10	.13	.14	.16	.13	.11	.14	.11	.10	.10	.10	.08
CO_2	.14	.16	.15	.09	.13	.14	.55	.18	.21	.14	.16	.18	.13	.12
Sum	100	101	100	100	100	100	100	101	100	101	101	101	100	101
Equivalent uranium	0.002	0.002	0.002	<0.001	0.001	<0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002

Table 8.--Chemical and equivalent uranium analyses of tuff from tunnel U12b.03, Nevada Test Site, Nye County, Nevada--Continued

1/ Chemical analyses by Samuel D. Botts, Paul L. D. Elmore, Marvin D. Mack, and Herman H. Thomas; equivalent uranium analyses by Edward J. Fennelly, Lorraine M. Lee, and William W. Niles.

2/ See table 4 for description of samples.

Table 9.--Chemical and equivalent uranium analyses of tuff from tunnel U12b.04, Nevada Test Site, Nye County, Nevada [1]

Sample No.[2]	B46	B49	B410	B412	B414	B411	B413	B418	B47	B417	B416	B415
Laboratory No.	267327	267329	153633	153635	153744	153634	153636	153979	267327	153978	153977	153976
Lithologic unit	V	V_1	V_2	V_3	V_4	V_5	V_6	V_6	V_7	V_7	V_8	V_9
SiO_2	59.5	64.2	62.0	63.9	68.1	66.4	68.3	69.0	69.0	63.3	71.2	69.6
Al_2O_3	15.0	13.5	14.5	13.7	12.0	11.6	12.2	12.3	11.2	15.3	11.7	12.5
Fe_2O_3	3.6	3.2	3.3	3.2	1.7	2.9	2.1	1.5	1.5	2.5	1.1	1.5
FeO	.07	.44	.56	.33	.24	.07	.33	.17	.38	.29	.35	.44
MgO	1.7	1.3	1.2	1.3	1.1	1.2	.84	.68	.78	1.0	.63	.57
CaO	2.4	2.9	3.8	3.0	2.6	2.6	2.4	2.6	2.4	3.2	2.1	2.3
Na_2O	.98	1.6	2.0	1.5	1.0	1.0	1.5	1.3	1.5	2.0	1.6	1.8
K_2O	1.9	2.2	2.0	2.2	2.0	2.2	2.3	2.4	2.1	2.4	2.7	2.9
H_2O+	6.7	4.9	5.3	5.4	5.7	5.5	4.8	9.2[3]	5.9	9.0[3]	7.7[3]	7.8[3]
H_2O-	8.4	4.9	4.5	5.2	4.7	6.1	4.8	--	5.5	--		
TiO_2	.32	.49	.50	.48	.28	.44	.34	.21	.19	.38	.17	.25
P_2O_5	.02	.06	.20	.09	.03	.11	.07	.04	.03	.10	.04	.04
MnO	.11	.10	.14	.12	.06	.10	.10	.07	.08	.09	.07	.08
CO_2	.16	.14	.38	.17	.14	.19	.16	.06	.14	.06	.07	.07
Sum	101	101	100	101	100	100	100	100	101	100	99	100
Equivalent uranium	0.002	0.001	$<$.001	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.002

Table 9.--Chemical and equivalent uranium analyses of tuff from tunnel U12b.04, Nevada Test Site, Nye County, Nevada--Continued

1/ Chemical analyses by Paul L. D. Elmore, Ivan H. Barlow, Samuel D. Botts, Marvin D. Mack, and Herman H. Thomas.

Equivalent uranium analyses by Edward J. Fennelly, Lorraine M. Lee, and William W. Niles.

2/ See table 5 for description of samples.

3/ Total water content.

The tuffaceous rocks are characterized by high silica (57.0 to 71.2 percent), a high alumina content in respect to the sum of alkali and lime, and significantly more alkali than lime. The water content ranges from 7.4 to 13.1 percent. The high potassian feldspar and heulandite content correlates with the high alkali content indicated in bulk analysis of the rock. Most of the lime is contained in the plagioclase phenocrysts though some is present in the clay minerals.

Comparisions of the chemical analysis of samples from the same lithologic unit suggest some of the units have distinctive compositions. For example the rocks of unit W contain 57 to 59.7 percent SiO_2 (table 8) whereas the rocks of the other units rarely contain less than 62 percent SiO_2. Corresponding with the decreased SiO_2 content of the rocks in unit W is the noted increase in Al_2O_3 and TiO_2 content.

The equivalent uranium content of the rocks ranges from less than 0.001 to 0.002 percent. No chemical analyses for uranium were made.

PART IV - POROSITY, WATER CONTENT, AND DENSITY OF THE TUFF

By C. H. Roach, F. M. Byers, Jr., C. C. Hawley, and G. A. Izett

Measurements were made of porosity, water content, grain density, and rock or bulk density of specimens of tuff from the U12b.03 and U12b.04 tunnels. These data were obtained to assist in the evaluation of the yield and determination of the effects of proposed nuclear detonations in the U12b.03 and U12b.04 shot chambers.

Sampling was done to obtain specimens that represent as closely as possible the natural-state condition of the rocks. Such samples are designated natural-state samples. All rock types in the U12b.03 and U12b.04 tunnels were sampled. Descriptions of the various rock units are given in part II of this report. The location of all samples discussed in this section is plotted on figures 10 and 11.

Bulk samples were obtained from the tunnel face and walls as soon as possible after exposure by blasting. The samples when collected were labeled, wrapped tightly in aluminum foil, sealed in polyethylene bags, and placed in canvas sample bags for transportation to the field laboratory. At the field laboratory, the foil-wrapped samples were immersed in melted paraffin to obtain a thick protective coat, which would serve to protect the samples while they were in temporary storage.

Some samples were, by necessity, collected from the walls of the tunnel after the rocks had been exposed for several weeks. These samples were treated in the same manner as the others, even though the water content and bulk density might not be representative of these rocks in the natural state. Measurements of porosity and grain density, however, are considered to be representative.

The following laboratory procedure was adopted for analyzing the rock samples. The coatings on the natural-state samples were removed and an equidimensional fragment of approximately 200 grams was broken from each sample. These fragments were immediately weighed on an analytical balance to an accuracy of 0.005 gram to obtain the quantity, M_{0f}. The fragments were then labeled and dried in an electric oven from 16 to 24 hours at 105°C. After cooling in a desiccator, the fragments were again weighed to obtain the dry weight of the rock, or the quantity M_{1f}.

After the dry weights of the fragments were obtained, a cylindrical plug about 1 inch long and 1 inch in diameter was cored from each rock fragment. These cylindrical plugs were dried in an electric oven for 16 hours at 105°C to drive off moisture introduced during cutting of the cores. After the specimens were cooled in the desiccator, the dry weights were obtained and recorded as M_{1c}. The core specimens were then placed in a desiccator under a vacuum of 1 mm of mercury for about 12 hours. Sufficient deaerated tap water was then introduced into the desiccator to completely cover the evacuated cylindrical plugs. The plugs remained under water for approximately 36 hours at atmospheric pressure.

After saturation the excess water was wiped from the surface of the plugs with moist absorbent paper and the weight of the saturated plugs were recorded as M_{2c}. The saturated specimens were then suspended on a wire stirrup and weighed in water to obtain the quantity M_{3c}.

The following equations were used to compute the values of the physical properties in tables 10, 11, 12, and 13:

(1) Percent porosity (P) $= \dfrac{M_{2c} - M_{1c}}{M_{2c} - M_{3c}} \times 100$

(2) Dry bulk density (D_{bd}) $= \dfrac{M_{1c}}{M_{2c} - M_{3c}}$

(3) Grain density (D_g) $= \dfrac{M_{1c}}{M_{1c} - M_{3c}}$

(4) Percent water content (by weight) $= \dfrac{M_{0f} - M_{1f}}{M_{0f}} \times 100$

(5) Natural-state bulk density (D_{bn}) $= \dfrac{M_{0f} \times M_{1c}}{M_{1f}\,(M_{2c} - M_{3c})}$

(6) Water content (by volume) = Water content by weight x Natural state bulk density

Table 10.--Statistical summary of some physical properties of natural-state samples from the U12b.03 tunnel, Nevada Test Site, Nye County, Nevada

	Total No. of samples		No. samples of unit V	
Percent porosity, P (arithmetic mean)	50	27.1	32	27.0
1 Standard deviation 1/		±7.1		±6.5
Confidence limit (95 percent level) of the mean		±2.0		±2.3
Dry bulk density, D_{bd} (arithmetic mean)	50	1.73 g/cm^3	32	1.76 g/cm^3
1 Standard deviation		±0.19		±0.15
Confidence limit (95 percent level) of the mean		±0.05		±0.05
Grain density, D_g (arithmetic mean)	50	2.39 g/cm^3	32	2.41 g/cm^3
1 Standard deviation		±0.11		±0.16
Confidence limit (95 percent level) of the mean		±0.03		±0.06
Percent water content by weight of natural-state rock (arithmetic mean)	45	14.0 percent	26	13.0 percent
1 Standard deviation		±2.5		±2.1
Confidence limit (95 percent level) of the mean		±0.8		±0.8

Table 10.--Statistical summary of some physical properties of natural-state samples from the U12b.03 tunnel, Nevada Test Site, Nye County, Nevada--Continued.

	Total No. of samples		No. samples of unit V	
Natural-state bulk density, D_{bn} (arithmetic mean)	37	2.01 g/cm^3	24	2.02 g/cm^3
1 Standard deviation		±0.11		±0.14
Confidence limit (95 percent level) of the mean		± .04		±0.06
Water content in grams per cc of natural-state rock (arithmetic mean)	37	0.270 g/cm^3	24	0.257 g/cm^3
1 Standard deviation		±0.039		±0.041
Confidence limit (95 percent level) of the mean		±0.013		±0.016

1/ Standard deviation assuming a normal distribution.

Table 11.--Some physical properties for individual samples of tuff from the U12b.03 tunnel, Nevada Test Site, Nye County, Nevada

Sample number	Rock unit	Distance from entrance of U12b.03 (feet)	Porosity (percent) (P)	Dry bulk density (D_{bd})	Grain density (D_g)	Percent water content (by weight)	Natural-state bulk density (D_{bn}) g/cc	Water content (by volume) g/cc
* 8	V	300	30.5	1.60 g/cc	2.30 g/cc	18.2	1.89	0.344
13	X	500	24.5	1.77	2.35	15.5	2.05	.318
14	X	500	27.1	1.78	2.44	13.7	2.02	.277
* 15	V	550	16.3	2.01	2.40	9.5	2.20	.209
* 16	W	550	Disintegrated		during	15.3	saturation	
19	V	615	19.5	1.97	2.45	8.5	2.14	.182
20	V	615	16.5	1.98	2.38	14.4	2.27	.327
21	V	630	27.9	1.73	2.40	13.9	1.97	.274
22	V	630	Disintegrated		during	18.2	saturation	
23	V	630	28.5	1.74	2.43	13.7	1.98	.271
* 24	S	50	Disintegrated		during	9.9	saturation	
* 25	S	50	39.8	1.41	2.34	22.5	1.73	.389
* 26	U	150	45.6	1.29	2.38	25.2	1.62	.408
* 27	U	150	32.5	1.57	2.32	19.0	1.86	.353

Table 11.--Some physical properties for individual samples of tuff from the U12b.03 tunnel, Nevada Test Site, Nye County, Nevada--Continued

Sample number	Rock unit	Distance from entrance of U12b.03 (feet)	Porosity (percent) (P)	Dry bulk density (D_{bd})	Grain density (D_g)	Percent water content (by weight)	Natural-state bulk density (D_{bn}) g/cc	Water content (by volume) g/cc
* 28	V	250	40.4	1.40	2.34	23.8	1.73	0.412
* 29	V	250	36.5	1.50	2.36	19.4	1.79	.347
* 30	V	350	31.7	1.54	2.26	18.4	1.83	.337
* 31	V	350	43.4	1.55	2.74	13.3	1.76	.234
* 32	X	450	27.3	1.71	2.36	14.4	1.96	.282
* 33	X	450	24.0	1.76	2.32	13.9	2.01	.279
* 34	V	625	23.3	1.87	2.44	10.1	2.06	.208
* 35	V	625	27.8	1.74	2.41	12.4	1.96	.243
36	V	639	27.6	1.75	2.42	14.8	2.01	.297
37	V	639	30.3	1.72	2.47	13.5	1.95	.263
38	V	shot chamber				12.8		
40	V	do	27.2	1.74	2.39	12.9	1.96	.253
41	V	do	23.0	1.85	2.40	11.0	2.05	.226

Table 11.--Some physical properties for individual samples of tuff from the U12b.03 tunnel, Nevada Test Site, Nye County, Nevada -- Continued

Sample number	Rock unit	Distance from entrance of U12b.03 (feet)	Porosity (percent) (P)	Dry bulk density (D_{bd})	Grain density (D_g)	Percent water content (by weight)	Natural-state bulk density (D_{bn}) g/cc	Water content (by volume) g/cc
44	V	shot chamber	24.6	1.85	2.46	12.0	2.07	0.248
45	V	do	23.8	1.85	2.43	10.8	2.05	.221
46	V	do	22.8	1.85	2.40	11.3	2.06	.233
47	V	do	20.6	1.84	2.32	9.9	2.03	.201
48	W	do		Disintegrated	during	14.9	saturation	
49	V	do	25.5	1.80	2.42	13.6	2.04	.277
50	W	do		Disintegrated	during	18.8	saturation	
51	V	do	29.6	1.69	2.40	15.4	1.95	.300
52	V	do	29.6	1.74	2.46	12.8	1.96	.251
53	V	do	24.7	1.74	2.30	9.4	1.90	.179
55	V	do	22.1	1.89	2.43	12.0	2.12	.254
56	V	do	35.4	1.58	2.45	17.5	1.86	.326
57	V	do	31.0	1.66	2.40	16.0	1.92	.307

Table 11.--Some physical properties for individual samples of tuff from the U12b.03 tunnel, Nevada Test Site, Nye County, Nevada--Continued

Sample number	Rock unit	Distance from entrance of U12b.03 (feet)	Porosity (percent) (P)	Dry bulk density (D_{bd})	Grain density (D_g)	Percent water content (by weight)	Natural-state bulk density (D_{bn}) g/cc	Water content (by volume) g/cc
58	V	shot chamber	24.4	1.85	2.44	12.3	2.07	0.255
59	V	do	22.9	1.89	2.45	11.3	2.10	.237
60	V	do	17.4	1.97	2.39	9.6	2.16	.207
61	W	do		Disintegrated during		17.7	saturation	
62	W	do		Disintegrated during		14.7	saturation	
63	V	do	33.2	1.67	2.49	15.6	1.92	.300
64	V	do	27.3	1.76	2.42	13.6	2.00	.272
69	W	do		Disintegrated during		18.2	saturation	
70	W	do	16.6	1.83	2.20	14.6	2.10	.307
71	W	do	30.6	1.69	2.43	14.9	1.94	.289
72	X	alcove #1	16.0	1.90	2.66	12.1	2.13	.258
73	W	do		Disintegrated during		15.6	saturation	
74	Y	do	35.0	1.55	2.38	17.3	1.82	.315

Table 11.--Some physical properties for individual samples of tuff from the U12b.03 tunnel, Nevada Test Site, Nye County, Nevada -- Continued

Sample number	Rock unit	Distance from entrance of U12b.03 (feet)	Porosity (percent) (P)	Dry bulk density (D_{bd})	Grain density (D_g)	Percent water content (by weight)	Natural-state bulk density (D_{bn}) g/cc	Water content (by volume) g/cc
75	X	shot chamber	21.8	1.82	2.32	14.7	2.08	0.306
76	W	do	33.9	1.60	2.42	16.5	1.86	.307
77	X	do	26.0	1.74	2.35	13.8	1.98	.273
78	Z	do	15.0	1.95	2.29	12.5	2.18	.273
79	Z	do	23.3	1.71	2.22	15.0	1.96	.294
450Y	Y	450	29.6	1.62	2.30	17.2	1.90	.327
450Z	Z	450	23.5	1.68	2.20	14.7	1.93	.284

* Denotes sample that was collected after mining operations had passed the location of the sample. These samples are not considered natural-state samples and have not been used in the statistical computations.

Table 12.--Statistical summary of some physical properties of natural-state samples from the U12b.04 tunnel, Nevada Test Site, Nye County, Nevada

Physical property	No. of samples	Arithmetic mean	1 Standard deviation	95 percent confidence limit of arithmetic mean
Porosity (P) percent	30	29.1	±5.0	±1.8
Dry bulk density (D_{bd}) gm/cc	30	1.67	±0.10	±0.03
Grain density (D_g) gm/cc	30	2.35	±0.08	±0.03
Water content, by weight percent	26	16.5	±3.7	±1.5
Natural-state bulk density (D_{bn}) gm/cc	23	1.90	±0.08	±0.03
Water content, by volume g/cc	23	0.296	±0.044	±0.02

Table 13.--Some physical properties of individual samples of tuff from the U12b.04 tunnel, Nevada Test Site, Nye County, Nevada

Sample number	Rock unit (Tos_7)	Distance from entrance of U12b.04	Porosity (percent) (P)	Dry bulk density (D_{bd})	Grain density (D_g)	Percent water content (by weight)	Natural-state bulk density (D_{bn}) g/cc	Water content (by volume) g/cc
1	V_4	710	21.9	1.75	2.25	12.3	1.97	0.242
2	V_5	710	19.8	1.82	2.27	12.1	2.01	0.243
4	V_6	763	33.7	1.50	2.27	18.9	1.79	0.338
5	V_6	771	29.2	1.63	2.30	15.1	1.88	0.284
6	V_6	771		1.72	2.29	12.4	1.93	0.239
* 11	V 1/	300	Disintegrated		during	15.6	saturation	
* 13	V	400	Disintegrated		during	17.6	saturation	
* 15	V	500	Disintegrated		during	26.4	saturation	
* 16	V	500	Disintegrated		during	26.9	saturation	
* 17	V	600	35.1	1.64	2.53	15.0	1.89	0.284
* 19	V	625	30.5	1.78	2.56	13.8	2.03	0.280
* 20	V	625	34.2	1.64	2.50	16.1	1.91	0.308
* 21	V	650	28.7	1.73	2.43	15.4	2.00	0.308

Table 13.--Some physical properties of individual samples of tuff from the U12b.04 tunnel, Nevada Test Site, Nye County, Nevada--Continued

Sample number	Rock unit (Tos_7)	Distance from entrance of U12b.04	Porosity (percent) (P)	Dry bulk density (D_{bd})	Grain density (D_g)	Percent water content (by weight)	Natural-state bulk density (D_{bn}) g/cc	Water content (by volume) g/cc
* 23	V	675	22.3	1.83	2.35	12.6	2.05	0.258
* 25	V_4	700	26.4	1.70	2.31	13.9	1.94	0.270
* 26	V_5	700	26.1	1.72	2.33	15.4	1.99	0.306
27	V_6	725	34.7	1.54	2.36	18.0	1.82	0.328
29	V_7	750	29.9	1.63	2.33	14.5	1.87	0.271
34	V	Alcove #1	Disintegrated		during	27.9	saturation	
* 36	V	do	Disintegrated		during	24.9	saturation	
* 40	V	450	Disintegrated		during	27.3	saturation	
* 42	V	150	Disintegrated		during	20.0	saturation	
* 43	V	250	Disintegrated		during	16.5	saturation	
50	V	Alcove #2	Disintegrated		during	19.4	saturation	
51	V	do	Disintegrated		during	21.4	saturation	
* 52	V	50	Disintegrated		during	17.9	saturation	
54	V_6	786	40.1	1.40	2.33	22.7	1.71	0.388

Table 13.--Some physical properties of individual samples of tuff from the U12b.04 tunnel, Nevada Test Site, Nye County, Nevada--Continued

Sample number	Rock unit (Tos_7)	Distance from entrance of U12b.04	Porosity (percent) (P)	Dry bulk density (D_{bd})	Grain density (D_g)	Percent water content (by weight)	Natural-state bulk density (D_{bn}) g/cc	Water content (by volume) g/cc
57	V_5	790	27.9	1.72	2.39	14.0	1.97	0.276
59	V_7	790	21.5	1.82	2.32	11.4	2.03	0.231
62	V_6	790	27.3	1.67	2.30	15.1	1.93	0.291
63	V_7	790	25.8	1.67	2.23	15.0	1.92	0.288
65	V_2	Chamber	32.3	1.61	2.38	16.9	1.89	0.319
66	V_1	do	33.2	1.60	2.40	18.6	1.90	0.353
81	V	Alcove #1	36.2	1.56	2.45	17.0	1.83	0.311
83	V	do	29.8	1.64	2.34	15.2	1.89	0.287
525	V	525	35.0	1.56	2.40	21.0	1.88	0.395
R4-2	V_3	Chamber	32.1	1.60	2.36	17.5	1.88	0.329
R4-5	V_4	do	27.6	1.65	2.28	15.7	1.91	0.300
R4-12	V_6	do	23.4	1.73	2.26	12.7	1.95	0.248
R4-16	V_3	do	27.1	1.73	2.37	15.1	1.99	0.300
R4-18	V_5	do	32.9	1.52	2.26	16.4	1.77	0.290
R4-20	V_3	do	22.3	1.83	2.36	12.9	2.07	0.267

Table 13.--Some physical properties of individual samples of tuff from the U12b.04 tunnel, Nevada Test Site, Nye County, Nevada--Continued

* Denotes samples that were collected from places far removed from current mining activities. These samples may not represent the natural-state condition of the rocks in place.

1/ Those samples designated unit V without subscript were collected east of the fault that crosses the tunnel at 694 feet (fig. 11), east of which unit V is not divided into subunits.

These properties were determined for as many samples as possible from a total of 60 samples collected from the U12b.03 tunnel and 42 samples collected from the U12b.04 tunnel. The data for individual samples are tabulated in tables 11 and 13. Some core specimens disintegrated during saturation and the percent water by weight was the only property determined for those samples. A statistical summary of the physical properties for all natural-state samples from the U12b.03 tunnel and all samples of rock unit V are listed separately in table 10. A statistical summary of the physical properties for all natural-state samples from the U12b.04 tunnel is listed in table 12.

The statistical data summarized in tables 10 and 12 are for only those samples that are considered to approximate natural-state conditions. A comparison of the properties of the natural-state and the nonnatural-state samples from the U12b.03 tunnel has shown that the water content for both types of samples is about the same. However, this similarity in water content is misleading as water is believed to have been added to the nonnatural-state samples from ground water moving into the tunnel. Further study of the properties of natural- and nonnatural-state samples will be undertaken to investigate these effects.

The statistical summary of the properties for rocks from the U12b.03 tunnel includes only those from unit V, because the numbers of samples of the other rock units were insufficient for statistical analysis.

PART V - GROUND WATER

By Alfred Clebsch, Jr.

Occurrence

In contrast to the dry condition of the main U12b tunnel and tunnels U12b.01 and U12b.02, the U12b.03 and U12b.04 tunnels showed evidence of circulating ground water. In the U12b.03 tunnel, free water was observed between 298 and 501 feet from the junction with the main U12b tunnel. In the U12b.04 tunnel, water discharged from the rock in the stretch between 161 and 561 feet from the junction with the main tunnel. Virtually all the water discharged from fractures, faults, and joints; there was no evidence of discharge from intergranular pores. In the tuffaceous sandstones stratigraphically above the rocks exposed by these two tunnels (table 1), there may be some ground water that moves predominantly through intergranular pores, but the volume of such water is undoubtedly small and the details of occurrence are unknown. Although water moves predominantly through secondary openings, there probably is some indirect stratigraphic control of the movement of water through the tuff because of stratigraphic and lithologic influences on the distribution, continuity, attitude, and width of fractures and joints.

Most of the tunnel footage is in subunit V, unit Tos_7, but subunits R through Z are exposed also (figs. 3 and 4).

U12b.03 tunnel

According to reports of miners working in this drift, the section that produced water was dry at the time it was driven and the water appeared several days later. This might possibly suggest that the water is transient and that the time (mid-July) indicates the time lag between the occurrence of snow melt on the mesa surface and the appearance of water in the tunnel which is about 500 feet vertically beneath the surface. The time lag could also be one year or more longer than the few months indicated between the time of snow melt and mid-July. On the other hand it is possible that the process of excavating the tunnel may have merely resulted in the opening of water-filled fractures so that they drained into the tunnel.

Total discharge of ground water from this tunnel probably was less than a gallon a minute at its peak.

On July 22, 1958, the maximum discharge of water was near 370 feet from the junction with U12b, where the contact of units V and W (fig. 3) intersects the back. This suggests that unit V acts as a perching bed for water moving down-dip in unit W, but from outward appearances there is little difference in the permeability of the two units. This question can be resolved only when laboratory determinations of permeability are available.

The thin sandstone at the base of unit Z, exposed in the U12b.03 tunnel, appears capable of transmitting some water through its intergranular spaces. It could be fortuitous that the most prominent seep in the drift occurred at the contact of units V and W. It may be that unit Z, or another unit higher in the stratigraphic section, transmits water laterally and that joints cutting across units W, X, and Y drain water from unit Z and into the tunnel.

No discharging water was observed in the tunnel beyond about 501 feet from the junction. This probably is related to the higher concentration of joints, many of them near vertical, in the vicinity of the shot chamber (fig. 3). These would tend to transmit water downward readily and prevent its accumulation on possible perching beds.

U12b.04 tunnel

Seven zones in the U12b.04 tunnel from which water was dripping were observed on July 22, 1958, between 162 and 561 feet from the junction with U12b tunnel. Four of these were at or near fault zones, two were along joints, and one was obscured by lagging. All the water discharged from subunit V, unit Tos_7 (fig. 4). A cursory examination of the tunnel on October 25, 1958, indicated that water still discharged from these zones and from the faults exposed in the Number 2 alcove, which had not been excavated in July. The total discharge into the drift was no more than a few gallons per day at the times of observation, but the discharge appeared to be less in October than in July.

Chemical characteristics

Chemical analyses of water samples from the seeps in tunnels U12b.03 and U12b.04 are shown in table 14. For comparison, the analysis of a water sample collected from station 14+65 of the U12b Exploratory tunnel is included also.

The low concentration of dissolved solids suggests one or more of the following: 1) the water has not moved far from the recharge area; 2) it has moved relatively rapidly through the rock; and 3) the rock itself does not contain highly soluble constituents. The principal dissolved constituents are sodium and bicarbonate ions and silica.

Table 14.--Chemical analyses of ground water from the U12b tunnel system 1/

Analysis No.	2819	2893 2/	2589
Location	U12b.03 sta 3+70	U12b.04 sta 3+26	U12b Exploratory sta 14+65
Date of collection	8/22/58	9/29-10/1/58	6/6/58
Chemical components (ppm)			
Silica (SiO_2)	67	--	68
Aluminum (Al)	.5	--	.4
Iron (Fe) (total)	.40	--	.14
Manganese (Mn)	.00	--	.00
Calcium (Ca)	9.6	8.0	13
Magnesium (Mg)	1.5	8.3	1.0
Sodium (Na)	15	22	18
Potassium (K)	2.8	--	2.8
Bicarbonate (HCO_3)	48	60	74
Carbonate (CO_3)	0	0	0
Sulfate (SO_4)	8.2	--	12
Chloride (Cl)	7.5	12	5.0
Fluoride (F)	.2	--	.1
Nitrate (NO_3)	7.4	--	2.1
Phosphate (PO_4)	.15	--	.05

Table 14.--Chemical analyses of ground water from the U12b tunnel system--Continued.

Analysis No.	2819	2893 2/	2589
Location	U12b.03 sta 3+70	U12b.04 sta 3+26	U12b Exploratory sta 14+65
Date of collection	8/22/58	9/29-10/1/58	6/6/58
Physical characteristics and computed values			
Dissolved solids (ppm)			
Res. on evap. at 180°C --	151	162	134
Sum --------------------	143	--	159
Hardness as $CaCO_3$ (ppm)----	30	54	40
Specific conductance (micromhos per cm. at 25°C) ----------------	144	169	164
pH ----------------------	6.9	7.5	7.6
Radiochemical data			
Beta-gamma activity (micro-microcuries per liter)---------------	<12 3/	<8 4/	10
Radium (Ra) (micro-microcuries per liter)-	<.1	--	.2
Uranium (U) (micrograms per liter) -----------	0.7±0.1	--	1.1
Extractible alpha -------	1.2±1.2 5/	--	0.8±0.6 6/
Uranium equivalent (gross alpha) (micrograms per liter) ------	--	--	<3
Strontium 90 (micro-microcuries per liter)-	--	--	< 5

Table 14.--Chemical analyses of ground water from the U12b tunnel system--Continued

1/ Analysis by U. S. Geological Survey, Quality of Water Branch, Denver Laboratory.

2/ Volume of sample too small for a more complete analysis.

3/ As of 9/22-23/58.

4/ As of 10/16/58.

5/ Micrograms per liter.

6/ Micro microcuries per liter.