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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGICAL SURVEY INVESTIGATIONS IN THE U12e.05 TUNNEL, NEVADA TEST SITE*

By

W. H. Diment, V. R. Wilmarth, F. N. Houser, D. D. Dickey,
E. N. Hinrichs, T. Botinelly, R. E. Wilcox, and F. M. Byers, Jr.

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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 U12e.05 TUNNEL, NEVADA TEST SITE

PART I - INTRODUCTION

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

The papers comprising the various parts of this report contain the preliminary results of the U. S. Geological Survey investigations in the U12e.05 tunnel at the Atomic Energy Commission's Nevada Test Site, Nye County, Nevada (fig. 1). Reports on electrical resistivity, natural radioactivity, and heat required to raise the rocks to 100°C will be issued later. A preliminary report on the geologic effects of the Blanca event is being prepared.

The U12e.05 tunnel, one of two laterals from the main U12e tunnel, trends west and connects with the main tunnel about 1,960 feet from the portal (fig. 2). The U12e.05 tunnel was driven for the nuclear test, code name Blanca, which took place on October 30, 1958. Before the explosion, the tunnel was 8 feet high and 8 to 9 feet wide and consisted of 990 feet of workings, a shot chamber, and an alcove (fig. 2). The original shot chamber, at the west end of the tunnel, was 19 feet long, 10 feet wide, and 15 feet high. The vertical and minimum cover over the original shot chamber are 1,150 and 950 feet, respectively. After detonation of the nuclear device in the test, code named Logan, in the U12e.02 tunnel on October 15, 1958, the U12e.05 tunnel, locally, was damaged severely (W. H. Diment, V. R. Wilmarth, F. A. McKeown, F. N. Houser, and others, 1958, written communication, p. 8 and 27) and a new

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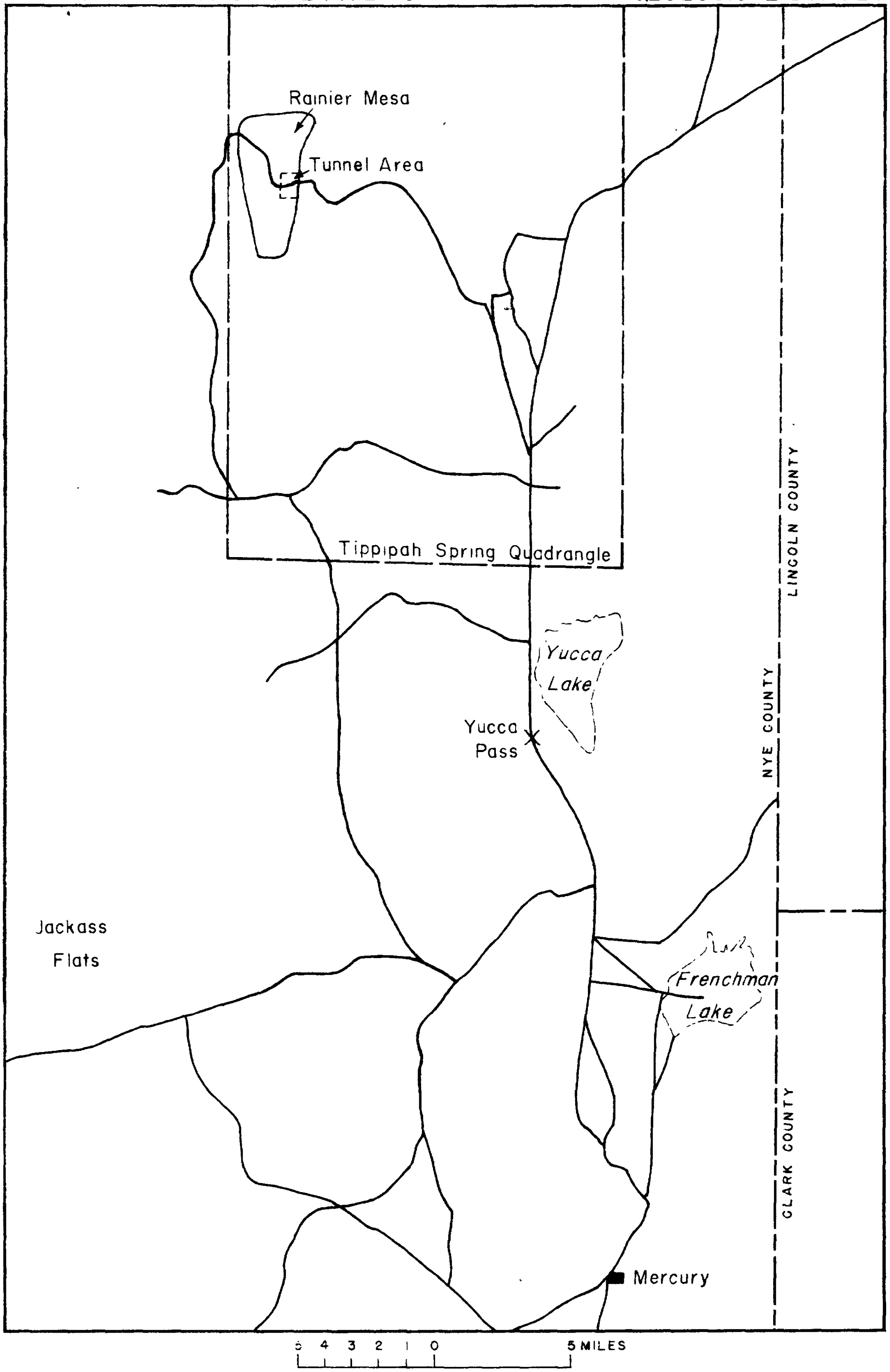

FIGURE 1—INDEX MAP SHOWING LOCATION OF TUNNEL AREA, RAINIER MESA, TIPPIPAH SPRING QUADRANGLE, NYE COUNTY, NEVADA

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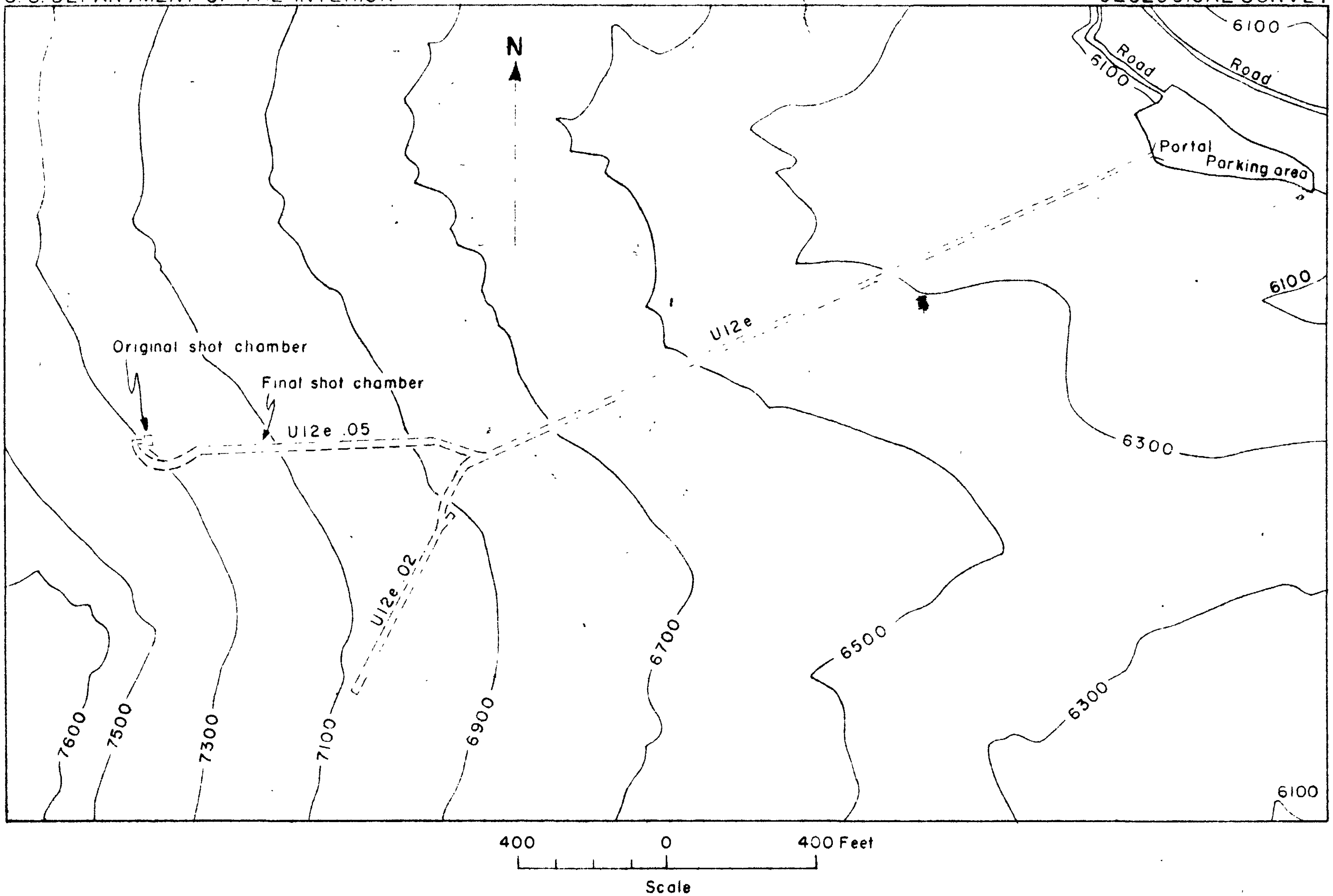

FIGURE 2—INDEX MAP SHOWING THE U12e TUNNEL SYSTEM, RAINER MESA, NYE COUNTY, NEVADA

shot chamber was constructed at a point about 600 feet from entrance to the tunnel (fig. 2). The new chamber, about 10 feet square and 8 feet high, had a vertical and minimum cover of 1,020 and 880 feet, respectively.

Although the overall effects of the Logan underground test on the U12e tunnel system are described in the written communication just cited some of the details of the damage to the U12e.05 tunnel are summarized briefly in this report.

The force of the Logan U12e.02 shot damaged much of the lagging and filled many parts of the U12e.05 tunnel with rock. Most of the U12e.05 tunnel from the entrance to 6+00 and from about 8+00 to 9+00 was lagged before the Logan event. The original shot chamber was lagged with heavy timber. After the Logan event, the U12e.05 tunnel, from the entrance to 2+00 and from about 4+00 to 6+00, was partly filled with rock to a depth of 4 feet. Both these tunnel segments are about 700 feet from the Logan shot chamber. From 6+00 to about 7+50, the tunnel was not lagged; the back failed and the muck pile was as high as 15 feet. Beyond 7+50, the tunnel, the alcove, and the original shot chamber reportedly were affected lightly even though much of the tunnel was not lagged. Only one of the heavy timbers in the original shot chamber was broken.

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

Geologic setting

The U12e tunnel extends beneath Rainier Mesa, a prominent topographic feature in the northwest part of the Nevada Test Site. The rocks exposed in the tunnel are part of the Oak Spring formation of Tertiary age and are predominantly tuff and tuffaceous sandstones (fig. 3). The Oak Spring formation is about 1,900 feet thick and unconformably overlies limestone, dolomite, quartzite, and siliceous shale of late Paleozoic age. The contact between the Tertiary and Paleozoic rocks has an average strike of N. 30° E., dips northwest at a low angle, and is highly irregular; local relief is as much as 50 feet. The Paleozoic rocks strike N. to N. 20° E., dip 10° to 70° W., or NW., and have been cut by northwest- to northeast-trending, steeply dipping, normal and reverse faults. Northeast and east-northeast folds with amplitudes of 50 to 100 feet and north- to northwest-trending faults with vertical displacements of as much as 50 feet have been mapped in the Tertiary rocks (Hansen and Lemke, 1957, fig. 5). The tuffaceous rocks at the portal of the U12e tunnel strike N. 5° to 30° E. and dip 5° to 35° W.

The Oak Spring formation in Rainier Mesa and nearby areas has been divided into eight lithologic units, designated in ascending order, Tos_1 to Tos_8, respectively (Hansen and Lemke, 1957). The rocks comprising these units consist of fine- to coarse-grained welded and nonwelded tuff, tuffaceous sandstone, tuff breccia, and agglomerate. Pumice fragments are abundant in all of the rocks. Clastic quartzite and volcanic rock fragments are rare to common in most of the tuff.

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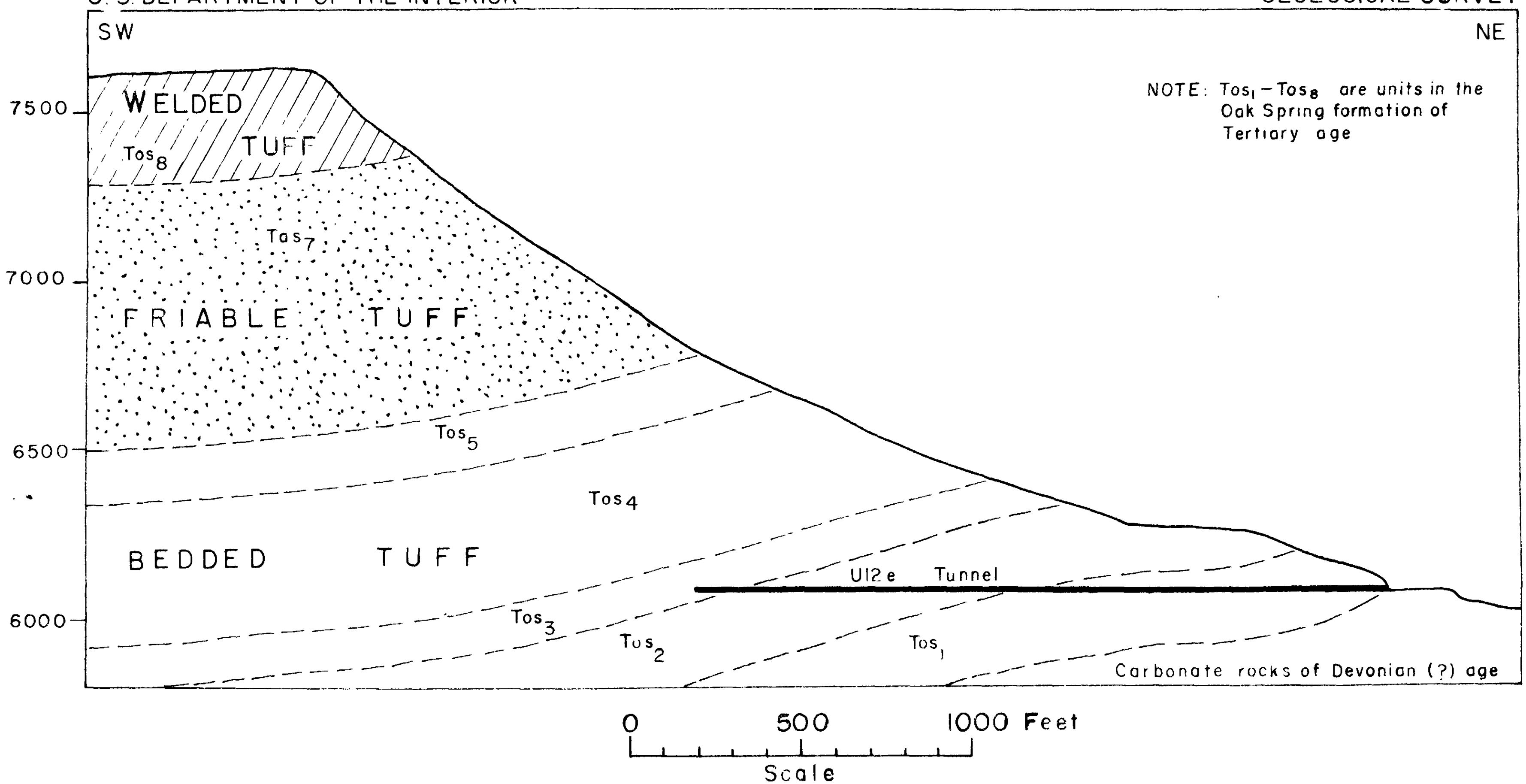

FIGURE 3. GENERALIZED GEOLOGIC CROSS SECTION ALONG U12e TUNNEL, RAINIER MESA, NYE COUNTY, NEVADA

PART II - STRATIGRAPHY AND STRUCTURE

By F. N. Houser and D. D. Dickey

Stratigraphy

The U12e.05 tunnel was driven in tuff of unit Tos_3 of the Oak Spring formation and penetrated nearly the entire stratigraphic sequence of this unit from its base at the entrance (U12e.05) to near its top in the original shot chamber at the western end of the tunnel (fig. 4). The tuff of unit Tos_3 (fig. 4) is a minimum of 170 feet thick and divided lithologically into four subunits, A through D. The basal lithologic subunit A correlates with Bed 24 of Hansen and Lemke (1957, p. 68); the upper lithologic subunit D probably correlates with Bed 27 (upper bed of Tos_3) of the same authors (p. 67-68). The final shot chamber at 6+00 is stratigraphically about 25 feet below the top of subunit C. Detailed descriptions of the subunits are given in the appendix. Fragments that make up the tuffs of the four subunits are indicated as: lapilli (4 to 32 mm), coarse (0.25 to 4 mm), and fine (less than ¼ mm). The bedding character of the tuff is described according to the nomenclature of McKee and Weir (1953, p. 383).

Subunit A is about 38 feet thick and is exposed in the U12e.05 tunnel from its entrance to 1+79 (right wall) (fig. 4). Megascopically, the unit is predominantly coarse, dense, well-cemented to moderately well cemented medium-red to dark-red tuff, which contains from a trace to 10 percent lapilli of slightly to well-decomposed pumice. The coarse component of the tuff is mostly pumice that has been slightly to well decomposed, and angular to subangular phenocrysts of clear feldspar, biotite, quartz, and black opaque grains (probably largely magnetite). The fine component locally makes up about 50 percent of the rock in a few zones in the middle part of Tos_3 and is a red, red-brown, dark-pink, and pink-gray decomposed mass of glass(?) shards and pumice, and sparse mica and black opaque grains.

Subunit B is about 23 feet thick and consists of indistinctly to fairly well-bedded coarse tuff. The beds range from laminae to as much as 5 feet thick. The subunit is exposed in the tunnel from 1+79 to 2+62 (right wall) (fig. 4). The tuff is dense, moderately well cemented, light-gray mottled and banded with red and purplish red. The tuff of subunit B is distinguished from that of subunit C by the absence of quartzite and volcanic(?) rock fragments. Sparse to moderate amounts of lapilli consist of moderately to well-decomposed pumice. The coarse component of the tuff is predominantly well-decomposed white to light-gray pumice and subordinately subangular to angular quartz, feldspar, and biotite. The fine component is white, light-gray, and red devitrified glass(?) shards and decomposed pumice.

Subunit C, about 75 feet thick, is an indistinctly to distinctly thin bedded to laminated fine to coarse tuff. Fine tuff constitutes about one-third of this subunit. In the tunnel the base and top of subunit C are at 2+62 and 7+36 (right wall), respectively (fig. 4). The tuff is friable to well cemented, dense and ranges from very light gray to light-gray, greenish-gray, within thin pale-yellow, red, and red-purple bands. Lapilli, a light-gray to white well-decomposed pumice, range in abundance from sparse to 5 percent of the rocks. They are generally small (4-8 mm) except for some in the upper bed. Coarse components are very light gray to white decomposed pumice and sparse common angular to subangular quartz and feldspar. The fine tuff component of most beds is light gray, white, and light pinkish gray. Clastic fragments are quartzite and volcanic(?) rock.

The uppermost subunit, subunit D, is at least 33 feet thick and is exposed in the alcove, shot chamber, and in the tunnel beyond point 7+36 (right wall) (fig. 4). It is a dense, moderately well to well-cemented red to medium-red coarse tuff with some lapilli. The tuff is thin bedded and laminated near the base but within a few feet above the base becomes thick bedded to massive. The lapilli and coarse component consist mainly of moderate to well-decomposed light-gray to white pumice; quartz, feldspar, and biotite are common to abundant as angular to subangular phenocrysts. The fine component is light red to pink and consists probably of decomposed glass shards and pumice. Subangular to subrounded quartzite(?) and volcanic rock fragments are common to abundant.

Structure

In the U12e.05 tunnel, the beds of Tos_3 unit strike N. 35° E. to N. 10° W., and dip 5° to 18° NW. and SW. (fig. 4). The trend of the tunnel, which is westerly, is thus generally perpendicular to the strike of the beds. At the tunnel entrance the beds strike N. 35° E. and dip 15° NW. whereas at 1+65 they strike N. 20° E., and dip 18° NW. From 3+60 feet to the original shot chamber, the beds strike N. 19° W. to N. 11° E., and dip 5° to 12° westerly. Such local changes of attitude are common in the tuff of the Oak Spring formation throughout the tunnel area on the east slope of Rainier Mesa.

Joints are numerous and strike from W. to N. 75° E.; two sets are prominent (fig. 5). One set near the tunnel entrance strikes mostly N. 30° to 60° W., and is vertical or dips steeply northeast. A second set exposed from about 4+00 to original shot chamber strikes N. 15° to 45° E., and dips steeply to the southeast (fig. 6).

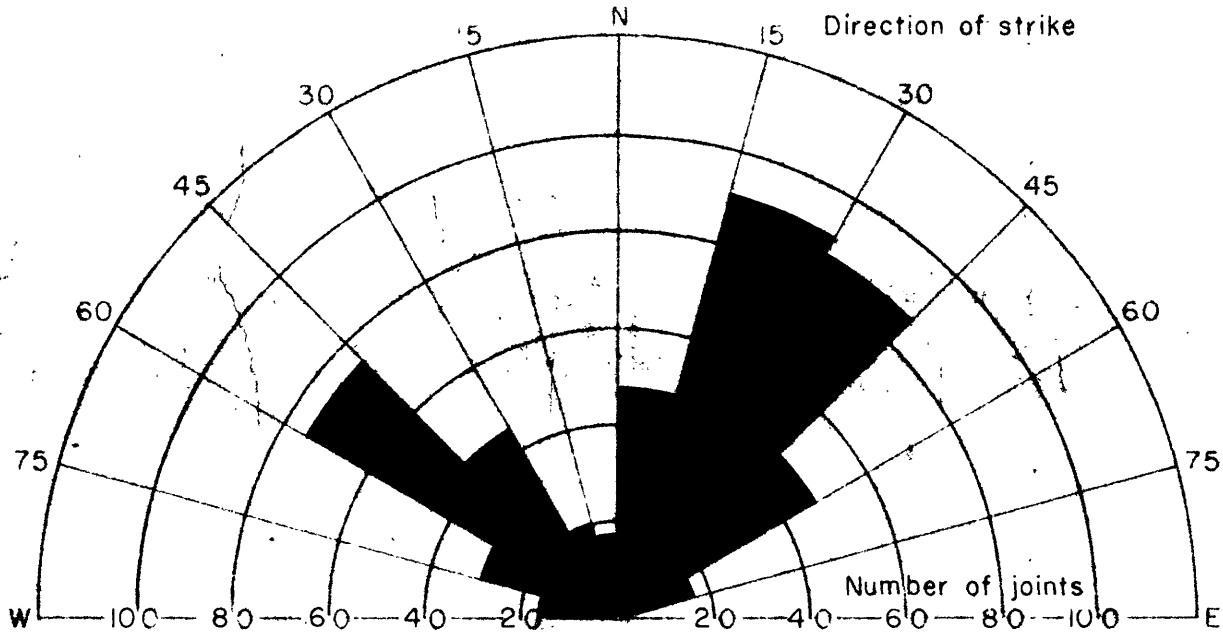

FIGURE 5. —PLOT OF STRIKE OF 492 JOINTS, U12e .05 TUNNEL, RAINIER MESA, TIPPIPAH SPRING QUADRANGLE, NYE COUNTY, NEVADA

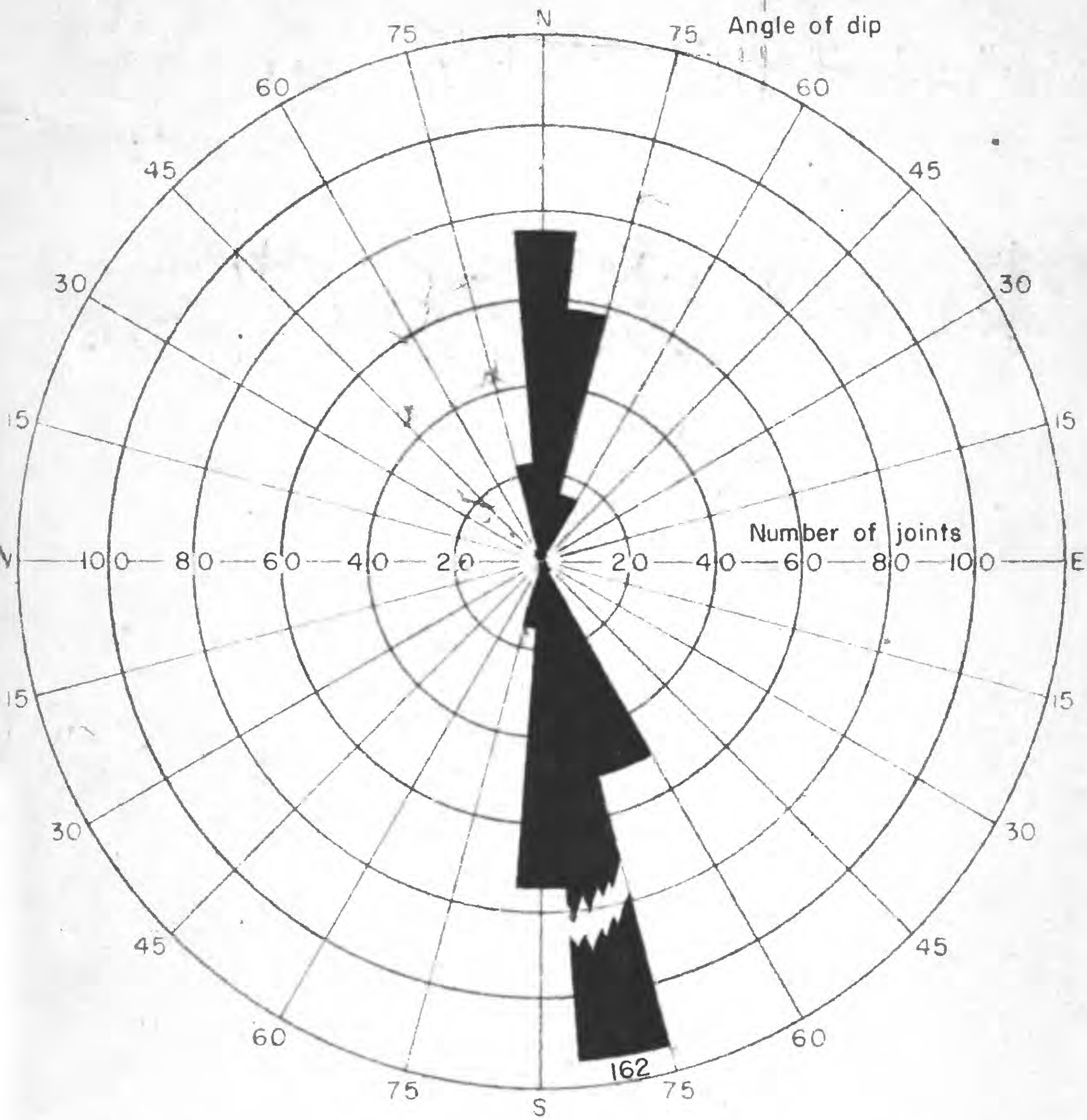

FIGURE 6. –PLOT OF DIP OF 492 JOINTS, U12e .05 TUNNEL, RAINIER MESA, TIPPIPAH SPRING QUADRANGLE, NYE COUNTY, NEVADA

Twenty-four faults were mapped in U12b.05 tunnel. Stratigraphic displacement is commonly less than 1 foot but some of the faults have no determinable vertical offset although horizontal slickensides indicate lateral movement. With a few exceptions, the faults strike north to northeast and average about N. 20° E.; most dip 75° to 85° SE. or E. Many faults, therefore, generally parallel the northeast set of joints, and are probably related genetically to the joint set. One fault was penecontemporaneous with deposition of the beds as demonstrated by its truncation at a bedding plane.

PART III - PETROLOGY

By E. N. Hinrichs, T. Botinelly, and R. E. Wilcox

Samples of the red tuff that constitute subunit D in the original shot chamber and of the varicolored tuff of subunit C in the final shot chamber (fig. 4) 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,and examination under a binocular microscope of specimens of tuff which had been etched with hydrofluoric acid and stained with cobaltinitrite. Modal analyses were made by a point-count method (table 1). The modal analyses of the tuff from the U12e.02 shot chamber are also shown for purposes of comparison.

The tuff of subunit D consists of lapilli, phenocrysts, and xenoliths in a very fine to coarse-grained tuffaceous matrix (table 1, E5CA to E5CE). Open vesicles are common and constitute as much as 13.7 percent and average 7.4 percent of the volume of the rock. The phenocrysts, listed in order of abundance, are potassian feldspar, plagioclase, quartz, opaque oxides, and biotite. They are angular to subrounded, and constitute from 5.8 to 8.6 percent of the rock volume. The xenoliths, which consist of volcanic rock fragments, form as much as 9.8 percent and average 6.4 percent of the volume of the rock. The groundmass including aphanitic fragments constitutes

Table 1.--Volume percent of minerals in tuff from the shot chamber of U12e.05 and U12e.02 tunnels, Rainier Mesa, Nye County, Nevada 1/

Sample number 2/	E02-3	E02-4	E5V-1	E5V-2	E5CA	E5CB	E5CC	E5CE
Thickness			2.5	5.8	6	2.6	7	2
Subunit and shot chamber	A-e.02		C-e.05 (final)		D-e.05 (original)			
Phenocrysts	23.6	15.2	3.2	6.1	8.6	5.8	7.0	7.4
Potassian feldspar	7.0	4.1	1.7	2.7	2.9	2.1	3.2	3.1
Plagioclase	7.4	4.6	1.3	1.3	2.0	2.4	1.9	1.8
Quartz	7.9	5.9	0.2	2.1	3.1	1.2	1.8	1.6
Magnetite	0.5	0.3	0	0	0.5	0.1	0.1	0.6
Mica	0.8	0.3	0	0	0.1	0	0	0.3
Volcanic rock	1.8	1.4	0	0	5.0	5.8	9.8	5.2
Xenoliths	0	0	3.0	4.5	0	0	0.1	0
Unknown	0.1	0.1			0.2	0.2	0	0
Total	25.5	16.7	6.2	10.6	13.8	11.8	16.9	12.6
Vesicles	7.2	8.4	15.4	14.1	5.4	4.3	13.7	6.3
Aphanitic material (shards and lapilli)	66.3	75.1	78.5	75.3	80.8	83.9	69.4	81.1

Table 1.--Volume percent of minerals in tuff from the shot chambers of U12e.05 and U12e.02 tunnels, Rainier Mesa, Nye County, Nevada--Continued

Sample number 2/	E02-3	E02-4	E5V-1	E5V-2	E5CA	E5CB	E5CC	E5CE
Thickness			2.5	5.8	6	2.6	7	2
Subunit and shot chamber	A-e.02		C-e.05 (final)		D-e.05 (original)			
Heulandite 3/			35	35	30	40	30	35
Beta-cristobalite 3/			25	35	30	30	25	25
Clay 3/			20		20	10	15	10
Size maxima (mm)	6.	3.			5.	5.	5.	4.
Area measured (mm^2)	1800	1600			900	1084	777	879

1/ Modal analyses by E. N. Hinrichs, Oct. 1958; X-ray analyses by T. Botinelly.

2/ See table 3 for sample descriptions.

3/ Percents of heulandite, beta-cristobalite, and clay were estimated from X-ray diffractometer patterns; they have been adjusted to the percent aphanitic material reported above but are at best only rough approximations.

from 70 to 84 percent of the volume of the rock and consists of lapilli and shards altered in part to cryptocrystalline quartz, alkali feldspar(?), and zeolite[1]. Hematite is abundant and

_/ The zeolite corresponds in X-ray pattern to heulandite; it is, however, stable above 260°C, corresponding to clinoptilolite as redefined by Mumpton (1958). However, to avoid confusion with older definitions of clinoptilolite and because of its general similarity, it is here referred to as heulandite.

accounts for the red color of the tuff. It occurs as a stain on the lapilli and shards and apparently as a cementing material. Silica may also be an important cementing agent. The aphanitic material of the samples averages less than 2 microns in diameter and thus modal analyses are impractical. X-ray analyses of this material show that heulandite and beta-cristobalite are major components; clay (montmorillonitic) is also present (table 1).

The tuff of subunit C consists of lapilli(?), phenocrysts, and xenoliths in a coarse tuff matrix (table 1, E5V1 and 2). Vesicles constitute about 15 percent by volume of the rock. The phenocrysts are, in order of abundance, potassian feldspar, plagioclase, and quartz. These average about 4 percent of the rock by volume. The groundmass constitutes about 75 percent of the rock. X-ray analyses of these samples show the heulandite and beta-cristobalite make up most of the aphanitic material. About 20 percent clay is present in E5V-1 sample.

X-ray analyses of bulk samples from Tos_3 unit are given in table 2. Heulandite, beta-cristobalite, and quartz are the major constituents; montmorillonitic clay is present in some beds. Heulandite and quartz are present in all lithologic units and range from 10 to 45 and 10 to 35 percent of the volume of the rock, respectively. Beta-cristobalite is confined mainly to subunits C and D and makes up from 15 to 30 percent of the rock's volume. Comparison of the analyses of subunit D given in table 2 (E5III-AD through HK) and the analyses in table 1 (E5CA to E5CE) emphasizes the consistent mineralogic composition of this subunit. As the X-ray analyses of table 2 are of bulk samples and those of table 1 are of the aphanitic material, the quartz in samples AD through HK (table 2) probably occurs as phenocrysts and rock fragments (perhaps quartzite as reported in Appendix A).

The division of the middle part of Tos_3 into subunits B and C on megascopic character (Part II and Appendix A) is supported apparently by the X-ray analyses (table 2). The remainder shown in table 2 consists of feldspar, mica, other crystalline components and amorphous material, and shows a marked decrease from an average of about 45 percent in subunit B to about 25 percent of the volume in subunit C. Quartz is apparently more abundant in the upper part of subunit B. Beta-cristobalite was not detected in subunit B whereas in subunit C it makes up as much as 30 percent by volume of the rock. Heulandite is nearly as common in both subunits.

Table 2.--X-ray analyses of bulk samples from Tos_3 unit, U12e.05 tunnel, Rainier Mesa, Nye County, Nevada 1/

Tos_3 subunit	A				B					C															D		
Sample No.	E5-I-				E5-II-					E5-II-															E5-III-		
	1	2a	2b	3	1	2	3	4	5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	AD	EG	HK
Lithologic unit 2/	24	23	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1		
Heulandite 3/	20	10	25	30	30	35	35	35	30		40	45	40	30	45	40	30	30	40	35	35	40	40	30	30	35	30
Beta-cristobalite	5	- 4/	5	-	-	-	-	-	20		25	30	25	25	15	25	20	15	25	15	25	20	20	20	25	25	25
Clay	50	-	-	-	10	-	-	-	-		10	-	-	-	-	-	10	15	-	-	-	10	25	-	10	-15-	25
Quartz	20	35	25	30	30	20	20	10	15		10	15	5	10	10	10	10	10	10	10	5	15	10	5	10	5	10
Remainder	5	55	45	40	30	45	45	55	35		15	10	30	35	30	15	30	30	25	40	35	15	5	45	25	35	10

1/ X-ray analyses by T. Botinelly. The percentages given were estimated from peak heights of X-ray diffractometer patterns and should be considered at best as rough approximations. Remainder derived by difference and is subject to larger errors than other figures; it includes feldspar, mica, and crystalline components in small amounts and amorphous material.

2/ Lithologic units represented by samples analysed are described in appendix.

3/ "Clinoptilolite"

4/ Not present.

Study of thin sections shows the tuffs of subunits A, C, and D vary in relative zeolite-feldspar content of the groundmass. Feldspar in the groundmass of subunit A is abundant, but in the groundmass of subunit C the feldspar is less abundant and is rarely present in the groundmass of subunit D. Heulandite is most abundant in the groundmass of subunit D, somewhat less abundant in C, and much less abundant in subunit A.

The rocks represented by samples E5V-1 and 2 are tuffs with only a few scattered phenocrysts and crystal fragments of alkali feldspar and plagioclase. Some xenolithic fragments of spherulitic rock and aphanitic volcanics are present. Part of the groundmass of sample E5V-1 shows a slightly higher birefringence and contains many isolated zeolitized shards, and a few large feldspar crystals and xenoliths. X-ray analyses of this "altered" material shows considerably less heulandite than in unaltered material.

Results of chemical analyses of channel samples of tuff from the original U12e.05 shot chamber and from the final shot chamber at 6+00 are given in tables 3 and 4. Although the original shot chamber was not used in the Blanca test, the chemical analyses of tuffs exposed in this chamber are included because these rocks are about 25 feet stratigraphically above the final shot chamber. Chemically, the tuff in the original chamber is very similar to the tuff (subunit A, Tos_3) exposed in the U12e.02 shot chamber (W. H. Diment, V. R. Wilmarth, F. N. Houser, F. A. McKeown, and others,

Table 3.--Chemical analyses of tuff from U12e.05 original shot chamber (9+80), Rainier Mesa, Nye County, Nevada 1/ (percent by weight)

Sample 2/ Lab. No. 3/ Thickness	E5CA 153775 6 ft	E5CB 153776 2.6 ft	E5CC 153777 7 ft	E5CE 153778 2 ft	Weighted average
SiO_2	67.4	69.1	68.5	67.9	68.1
Al_2O_3	13.3	12.3	12.3	13.2	12.7
Fe_2O_3	1.6	1.3	1.5	1.9	1.6
FeO	.03	.04	.05	.04	0.04
MgO	.24	.22	.28	.39	0.27
CaO	1.1	1.1	1.1	1.2	1.1
Na_2O	2.6	2.7	2.4	2.3	2.5
K_2O	3.4	3.1	3.1	3.4	3.2
H_2O+	4.9	5.0	5.0	4.8	5.0
H_2O-	5.7	5.8	5.8	5.6	5.8
TiO_2	.23	.17	.21	.24	.21
P_2O_5	.02	.02	.03	.02	.02
MnO	.05	.05	.08	.08	.07
CO_2	.13	.13	.19	.20	.17
Sum	101	101	101	101	

1/ Rapid rock analyses by P. Elmore, S. Botts, M. Mack, and H. Thomas using methods similar to those described in USGS Bull. 1036-C. Report No. IRC-334.

2/ Samples E5CA and E5CC are red pumiceous tuff, and samples E5CB and E5CE are of white and red tuff.

3/ Lot No. 5026, Job No. 4036.

Table 4.--Chemical analyses of tuff from U12e.05 final shot chamber (6+00) and nearby tunnel, Rainier Mesa, Nye County, Nevada 1/ (percent by weight)

Sample No.[2/] Lab. No.[3/]	E5V-1 153853	E5V-2 153854	E5II-14 153864	E5II-15 153865	E5II-16 153866	E5II-17 153867	Weighted average
Thickness (in ft)	2.5	5.8	9.5	7.5	2.5	6.5	
SiO_2	70.6	70.0	70.1	69.8	70.9	69.9	70.1
Al_2O_3	12.3	12.3	11.8	12.4	11.7	12.8	12.2
Fe_2O_3	.9	.9	.94	1.2	1.0	.92	0.9
FeO	.08	.08	<.05	<.05	<.05	<.05	0.06
MgO	.55	.54	.50	.46	.43	.43	0.48
CaO	1.8	1.8	2.1	1.7	1.7	1.9	1.9
Na_2O	.95	.89	.89	.97	.76	.92	0.91
K_2O	4.5	4.5	3.6	4.6	4.7	4.4	4.2
H_2O+	5.0	5.2	5.8	5.1	5.1	5.1	5.3
H_2O-	3.9	4.1	4.2	4.0	3.6	4.1	4.0
TiO_2	.12	.11	.12	.15	.13	.12	.13
P_2O_5	.00	.00	.00	.00	.00	.00	0
MnO	.06	.06	.10	.04	.05	.05	0.6
CO_2	.06	.07	.07	.07	.06	.06	0.07
Sum	101	101	100	100	100	100	

1/ Rapid rock analyses by P. Elmore, S. Botts, I. Barlow, and M. Mack using methods similar to those described in USGS Bulletin 1036-C. Report Nos. IRC=341 and 342.

Table 4.--Chemical analyses of tuff from U12e.05 final shot chamber (6+00) and nearby tunnel, Rainier Mesa, Nye County, Nevada 1/ (percent by weight)--Continued

2/ Samples E5V-1 and E5V-2 are of very light gray coarse tuff taken after the detonation, code name Logan, in U12e.02 tunnel. They represent the same lithologic unit (No. 6, Appendix A) as the composite sample E5II-15.

Samples E5II-14 through 17 are of composite samples of lithologic units 7, 6, 5, and 4, respectively (Appendix A), and were taken prior to the detonation in U12e.02.

3/ Lot No. 5026, Job Nos. 4061 and 4065.

1958, written communication, p. 21) but differs from it only in containing more lime, less soda, and much less potash. Tuff of subunit A is stratigraphically about 115 feet below the final U12e.05 shot chamber.

The tuff of the original chamber is slightly different chemically from that of the final chamber. The tuff of the original chamber has less SiO_2, MgO, CaO, and K_2O and more Al_2O_3, Fe_2O_3, H_2O, TiO_2, P_2O_5, and CO_2 (tables 3 and 4).

On table 4, a direct comparison between the pre-Logan (E5II-15) and the post-Logan (E5V-1 and 2) samples can be made. The only noteworthy differences are that MgO is greater and total iron is less in the samples taken after the Logan event. These differences are not considered necessarily significant as they are within the limits of analytical error.

Semiquantitative spectrographic analyses of the tuffs exposed in the two shot chambers are given in table 5. Of the 16 elements determined, Ba shows significant variation in subunit D (compare samples E5CB and C with E5CE) and Cr and Cu show significant variation in subunit C (compare E5V-2 and E5II-16 with E5II-17). The samples analyzed contain less Ce, La, Nd, and Zr than samples of tuff of Tos_7 (W. H. Diment, V. R. Wilmarth, F. A. McKeown, D. D. Dickey, and others, 1958, written communication, table 3). No significant changes can be noted in minor element content between the samples taken in the final shot chamber (6+00) area before and after the Logan explosion, samples E5II-15 and E5V-1 to 2, respectively.

Table 5.--Semiquantitative spectrographic analyses of tuff from the original and final shot chambers and tunnel of U12e.05, Rainier Mesa, Nye County, Nevada 1/

Sample No. Lab. No. Lithologic unit	E5CA 2/ 268408 D	E5CB 268409 D	E5CC 268410 D	E5CE 268411 D	E5V-1 153853 C	E5V-2 153854 C	E5II-14 153864 C	E5II-15 153865 C	E5II-16 153866 C	E5II-17 153867 C	Standard spectrographic sensitivity 4/
Ba	.03	.015	.015	.07	.015	.015	.015	.015	.015	.03	0.0002
Be	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	0.0001
Ce	0 3/	0	0	.03	0	0	0	0	0	0	0.02
Cr	.0007	.0003	.0003	.0007	.0003	.0003	.0003	.0003	.0007	.00015	0.0001
Cu	.0003	.0003	.0003	.0007	.0003	.0007	.0003	.0003	.003	.00015	0.0001
Ga	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	0.0002
La	.007	.003	0	.007	.003	.003	.003	.003	.003	.003	0.002
Nb	.003	.003	.003	.003	.003	.003	.003	.003	.003	.003	0.001
Nd	0	0	0	.015	0	0	0	0	0	0	0.01
Pb	.007	.003	.003	.007	.0015	.003	.003	.003	.003	.0015	0.001
Sc	.0007	0	0	.0007	0	0	0	0	0	0	0.0005
Sr	.015	.007	.007	.015	.007	.007	.007	.007	.007	.007	0.0002
V	.0015	.0015	.0015	.0015	0	0	0	0	0	0	0.001
Y	.003	.003	.003	.007	.003	.003	.003	.003	.003	.0015	0.001
Yb	.0003	.0003	.0003	.0007	.0003	.0003	.0003	.0003	.0003	.0003	0.0005
Zr	.015	.015	.015	.03	.015	.015	.007	.015	.015	.015	0.001

Table 5.--Semiquantitative spectrographic analyses of tuff from the original and final shot chambers and tunnel of U12e.05, Rainier Mesa, Nye County, Nevada--Continued

1/Analyst: J. C. Hamilton, USGS, Report Nos. TDS-9664, TDS-9717, and TDS-9718. 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 tables 3 and 4 for descriptions of samples. Samples E5CA through E5CE from Tos_3, subunit D (original shot chamber); E5V-1, E5V-2, and E5II-14 through E5II-17 from Tos_3, subunit C (final shot chamber).

3/ Looked for but not found.

4/ Some combinations of elements affect the detectabilities. Approximate values are given. In unusually favorable materials, concentrations somewhat lower than the values given may be detected. In unfavorable materials the given detectabilities may not be detected. In unfavorable materials the given detectabilities may not be attained for some of the elements.

Comparison of the spectrographic analyses of the tuffs for subunits C and D given on table 5 with analyses for subunit A (W. H. Diment, V. R. Wilmarth, F. N. Houser, F. A. McKeown, and others, 1958, written communication, table 4) shows significant differences for four elements: silver was not detected in subunits C and D, but gallium, niobium, and yttrium are more abundant in subunits C and D than in subunit A.

PART IV - POROSITY, DENSITY, AND WATER CONTENT OF TUFFS FROM U12e.05 TUNNEL

By F. M. Byers, Jr.

Data on the porosity; dry bulk, grain, and natural-state density; and water content of the tuffaceous rocks exposed in the U12e.05 tunnel were obtained for evaluating yield and determining the effects of the nuclear device detonated in this tunnel. The rocks were sampled according to the lithologic units described by Houser and Wilmarth (Appendix A); their physical properties are summarized in table 6. The new shot chamber at 6+00 is in a 7.5-foot thick tuff bed (lithologic unit 6). Three samples (583, 605, and R 616, table 9) of the tuff from this lithologic unit indicate its variable properties.

Table 6.--Statistical summary of physical properties of samples of Tos_3 from U12e.05 tunnel, Rainier Mesa, Nye County, Nevada

Property	Lithologic unit No. 1 1/ thickness 33.3 feet 32 samples			Lithologic units 2 to 23 1/ thickness 126.5 feet 36 samples		
	Arithmetic mean	Standard deviation	Confidence limits (.95) of the mean	Arithmetic mean	Standard deviation	Confidence limits (.95) of the mean
Porosity (P) percent	33.4	±1.8	±0.6	33.0	±6.0	±2.1
Grain density (D_g) g/cc	2.45	±0.04	±0.02	2.31	±0.12	±0.04
Dry bulk density (D_{bd}) g/cc	1.63	±0.05	±0.02	1.55	±0.18	±0.05
Natural-state rock density (D_{bn}) g/cc	1.96	±0.04	±0.02	1.89	±0.14	±0.04
Water content Wt.-percent	16.8	±1.3	±0.5	18.3	±3.5	±1.2
Water content g/cc	.328	±0.022	±0.008	0.341	±0.053	±0.018
Water lost + Water absorbed percent	98.4	±3.3	±1.2	104.5	±10.8	±3.2

1/ Stratigraphic units of Tos_3 after F. N. Houser and V. R. Wilmarth. Lithologic unit No. 1 is the highest unit and contained the old U12e.05 shot chamber at end of tunnel. The samples from units 2 to 23 were collected 2 to 5 weeks after the tunnel was driven, and therefore are not strictly natural state with respect to water content and natural-state rock density.

The samples were collected during the first 10 days of October 1958 by F. M. Byers, Jr., C. C. Hawley, and G. R. Johnson. All samples from U12e.05 tunnel were wrapped in aluminum foil and sealed in polyethylene bags to preserve the moisture content of the sample at the time of sampling. Nearly all 35 samples of lithologic unit No. 1, Tos_3 (Appendix A), were collected at or near working faces as the tunnel was advanced from about 8+00 feet to the end of the tunnel. These samples should, therefore, form a useful control group, because they were collected as natural-state samples from this rock unit. More samples were taken of lithologic unit No. 1 than from any other unit of Tos_3, because the shot chamber originally was in this unit. Samples of lithologic units Nos. 2 through 23 (tables 6, 8, and Appendix A) are from tuff layers, whose individual properties differ from one another more widely than samples from lithologic unit No. 1. The sample from lithologic unit 24 disaggregated during the procedure, and is therefore not included in the statistical summary shown in table 6. Samples from units 2 to 24 are not strictly in the natural state with respect to water content, inasmuch as they were collected 2 to 5 weeks after the tunnel heading had been advanced past their sample locations. However, their high water content indicates that they changed but slightly between the times of driving the tunnel and sampling.

The laboratory procedure that was used to determine porosity, densities, and water content of the tuffs is as follows: the samples were unsealed and a chip of approximately 200 grams was broken from each sample. These chips were immediately weighed on an analytical balance to an accuracy of 0.01 gram to obtain the quantity, M_{0f}. The chips were then heated in an electric oven for 48 hours at 105°C, allowed to cool in a desiccator, and were again weighed to obtain the dry weight of the chip, M_{1f}. A cylindrical plug about 1 inch long and and 1 inch in diameter was cored from each rock chip. These cylindrical plugs were heated in the electric oven for 16 hours at 105°C to drive off moisture introduced during cutting of the cores. The dry weights of the cores furnished the quantity M_{1c}. The core specimens were then placed in a clean glass vacuum desiccator under a pressure of less than 1 mm of mercury for 8 hours, after which the stopcock to the vacuum pump was closed. The hose connection was immediately opened under deaerated distilled water, which was sucked by the vacuum into the desiccator and completely covered the evacuated plugs. The plugs remained under water for approximately 36 hours at atmospheric pressure to insure optimum water absorption. It was found that some fine-grained tuffs do not absorb as much water at one atmospheric pressure gradient as they lose in the oven at 105°C.

After absorption the excess water was wiped from the surface of the plugs with moist absorbent paper and the weight of the water-logged plugs gave the quantity M_{2c}. They 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 7 and 8.

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

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

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

(7) Percentage of water lost (at 105°C) with respect to water absorbed (at 1 atm gradient) $= \dfrac{\dfrac{M_{0f} - M_{1f}}{M_{1f}} \times 100}{\dfrac{M_{2c} - M_{1c}}{M_{1c}}}$

Table 7.--Porosity, density, water content, and water absorption data for individual samples of lithologic unit No. 1, Tos_3, Oak Spring formation in the U12e.05 tunnel, Rainier Mesa, Nye County, Nevada.

Sample Number	Location (distance from entrance of U12e.05) (feet)	Porosity (percent) (P)	Dry bulk density (D_{bd})	Grain density (D_g)	Natural-state rock density (D_{bn})	Percent water content (by weight)	Water content (by volume) g/cc	Water lost ÷ water absorbed (percent)
*05-800	Alcove (800)	35.5	1.60	2.48	1.95	17.9	.349	98.5
*05-826	Alcove (826)	36.7	1.57	2.48	1.93	18.6	.359	97.8
*05L-50R1/	817(R)1/	34.3	1.63	2.48	1.99	18.0	.357	104.2
05L-100R	867(R)	34.2	1.61	2.45	1.95	17.3	.337	98.6
05L-116L	883(L)	32.2	1.69	2.49	2.01	15.8	.318	99.0
05L-142R	909(R)	35.0	1.59	2.44	1.91	16.5	.316	89.9
05L-163R	930(R)	30.3	1.75	2.50	2.03	14.2	.288	95.2
05L-168L	935(L)	31.4	1.65	2.41	1.97	16.0	.315	100.4
05L-170L	937(L)	32.9	1.66	2.48	1.97	15.6	.306	93.0
05L-171C	938(C)	disaggregated during water absorption procedure				12.8		
05L-R171C	938(C)	32.7	1.64	2.44	1.96	16.3	.319	97.6
05L-R179L	946(L)	35.9	1.58	2.47	1.92	17.8	.343	95.6
05L-180R	947(R)	33.2	1.64	2.46	1.96	16.2	.316	95.2

Table 7.--Porosity, density, water content, and water absorption data for individual samples of lithologic unit No. 1, Tos_3, Oak Spring formation in the U12e.05 tunnel, Rainier Mesa, Nye County, Nevada.--Continued.

Sample Number	Location (distance from entrance of U12e.05) (feet)	Porosity (percent) (P)	Dry bulk density (D_{bd})	Grain density (D_g)	Natural-state rock density (D_{bn})	Percent water content (by weight)	Water content (by volume) g/cc	Water lost ÷ water absorbed (percent)
05L-198R	965(R)	31.0	1.70	2.46	1.98	14.4	.286	92.0
05L-198C	965(C)	32.6	1.69	2.50	2.01	16.1	.325	99.6
05L-198L	965(L)	33.7	1.64	2.48	1.97	16.8	.332	98.5
05L-R198	965(L)	32.3	1.66	2.46	1.97	15.8	.313	96.8
05L-R198N	965(L)	31.8	1.69	2.47	1.99	15.4	.308	97.0
05L-220R	987(R)	disaggregated during water absorption procedure				22.6		
05L-220L	987(R)	31.6	1.69	2.47	2.01	15.8	.318	100.6
05L-234C	1001(C)	32.5	1.67	2.47	2.00	16.8	.337	103.5
05S-12L	Chamber2/	35.3	1.57	2.43	1.92	18.2	.349	99.0
05S-13R	Chamber	33.9	1.55	2.34	1.87	17.4	.325	96.0
05S-16R	Chamber	32.1	1.68	2.47	2.00	16.2	.325	101.3
05S-21L	Chamber	35.0	1.55	2.39	1.92	18.9	.363	103.6
05S-22R	Chamber	32.3	1.63	2.40	1.97	17.3	.341	105.5

Table 7.--Porosity, density, water content, and water absorption data for individual samples of lithologic unit No. 1, Tos_3, Oak Spring formation in the U12e.05 tunnel, Rainier Mesa, Nye County, Nevada.--Continued

Sample Number	Location (distance from entrance of U12e.05) (feet)	Porosity (percent) (P)	Dry bulk density (D_{bd})	Grain density (D_g)	Natural-state rock density (D_{bn})	Percent water content (by weight)	Water content (by volume) g/cc	Water lost ÷ water absorbed (percent)
05S-22L	Chamber 2/	32.6	1.63	2.41	1.95	16.7	.326	100.1
05S-R23R	Chamber	37.8	1.51	2.42	1.88	20.0	.377	99.8
05S-25R	Chamber	34.2	1.58	2.41	1.92	17.6	.337	98.6
05S-28L	Chamber	30.6	1.68	2.41	1.99	15.5	.308	100.7
05S-29R	Chamber	34.7	1.59	2.44	1.94	18.0	.348	100.4
05S-34L-1	Chamber	disaggregated during water absorption procedure				14.8		
05S-34L-2	Chamber	31.8	1.67	2.45	1.98	15.7	.312	98.0
05S-R34C	Chamber	35.6	1.57	2.43	1.91	18.0	.344	96.6
05S-34R-1	Chamber	31.9	1.66	2.43	1.96	15.6	.307	96.4

* Wall samples collected 3 to 10 days after tunnel was advanced past their locations; however, their properties fall close to the arithmetic means and are therefore not too far removed from the natural state.

1/ R, right side of tunnel or working face; L, left side of tunnel or working face; C, center of working face. The letter R preceding sample number, R 171 C and others, indicates oriented sample collected for directional permeability measurements. The letter N following sample R 198 N indicates control subsample split of sample R 198.

Table 7-.-- Porosity, density, water content, and water absorption data for individual samples of lithologic unit No. 1, Tos_3. Oak Spring formation in the U12e.05 tunnel, Rainier Mesa, Nye County, Nevada--. Continued.

2/ Original shot chamber at end of tunnel was abandoned and moved to point 600 feet from entrance of U12e.05 tunnel. The physical properties for the rocks enclosing this new chamber are given in table 8, samples U12e.05-583 to -R616.

The above physical properties were determined for 32 samples of lithologic unit No. 1 and 36 samples from unit Nos. 2 through 23, all of Tos_3, in U12e.05 tunnel (tables 7 and 8). Because of disaggregation during the water-absorption procedure, only water content by weight could be determined for 3 samples of lithologic unit No. 1 or for the one sample of unit No. 24. Unit 17, a thin layer, was not sampled. Physical-properties data shown in table 8 are for units 2 through 24, and are arranged to present the data from the youngest to oldest beds following the same order as the stratigraphic section given in Appendix A.

The physical properties of 32 samples of lithologic unit No. 1, presented in table 7, are summarized statistically in table 6. The lower 5 to 10 feet is exposed from 700 to 800 feet from the entrance of the U12e.05 tunnel and was not sampled. The lithology of this part of unit No. 1 appeared fairly uniform, and the physical properties of these tuffs are probably about the same as the tuffs for which data are available. The standard deviation and confidence limits of the mean of unit 1 (table 6) are low, which may be expected from samples of one rock type.

Table 8.--Porosity, density, wates3, Oak Spring formation,

Sample No. Location 1/ U12e.05-	Lithologic unit 2/ No.	Thickness 2/ feet	Description of unit or subunit sampled 2/
-698	2	3.5	Pinkish gray tuff in middle part
-688	3	1.0	Fine soft tuff, pinkish gray
-R689	4	6.5	Fine tuff in upper-two-thirds
-661	4		Coarse tuff in lower one-third
-660	5	2.5	Fine to coarse light gray tuff
-R616	6	7.5	Fine and coarse tuff, 2 feet from top
-605	6		Fine even-textured tuff in middle
-583	6		Coarse granular tuff, 1 foot above base
-534	7	9.5	Light gray coarse tuff, 1.5 feet from top
-525	7		Hard red bed, 4 feet from top
-518	7		Indistinctly laminated tuff, 3 feet above base
-520	7		Greenish gray medium-grained tuff, 1 foot above base
-492	8	8.5	Hard red tuff, 0.8 foot thick, at top
-487	8		Reddish gray tuff in upper part
-477	8		Greenish gray tuff in middle part
-465	8		Gray coarse tuff in lower part

Table 8.--Poro 24, Tos_3, Oak Spring formation,

Sample No. Location 1/ U12e.05-	ater ost ÷ ater bsorbed percent)	Description of unit or subunit sampled 2/
-445	98.2	Gray tuff mottled with red in upper part
-435	99.5	Red pumiceous tuff in middle part
-425	107.0	Gray tuff streaked with red in lower part
-415	96.0	Coarse reddish tuff with pumice fragments
-390	107.5	Fine tuff with few coarse sub-angular quartzite grains
-380	101.0	Coarse tuff, moderately hard
-370	98.8	Coarse tuff in upper 1/4 of unit
-365	102.0	Coarse banded tuff in lower 3/4
-315	93.6	Fine tuff in upper half of unit
-305	110.9	Coarse tuff, red mottled with gray
-271	106.7	Coarse tuff, gray mottled with red
-272	115.1	Fine tuff gray and red near middle of unit
-254	111.1	Coarse tuff, gray and red mottled
-242	109.4	Coarse tuff, gray
-235	150.1	Red hard fine tuff mottled with coarse purple tuff

Table 9.--Porosity, densit 24, Tos$_3$, Oak Spring formation,

Sample No. Location 1/ U12e.05-	Lithologic u 2/ No.	Thi nes fee	Water lost ÷ water absorbed (percent)	Description of unit or subunit sampled 2/
-210	20	3.	115.3	Coarse purplish tuff, common pumice fragments
-200	21	8.	92.6	Fine and coarse banded tuff, light gray and red
-130	22	11.	104.6	Coarse tuff, purplish red, with common pumice fragments
-100	23)	17.	104.2	Coarse tuff, medium red
- 50	23)		104.7	Coarse hard tuff, dark red
- 25	24	10.		Coarse tuff, light red with decomposed pumice fragments

1/ The sample number is num ng sample number indicates oriented sample for directional p

2/ Numbers and thicknesses Lithologic descriptions modified to fit individual sample

3/ No physical properties s

The statistical summary of the physical properties of 36 samples from lithologic unit Nos. 2 through 23 is also given in table 6. The standard deviation about the mean and the confidence limits of the mean at the 95 percent level are 2 to 4 times greater than the corresponding statistical parameters for the physical properties of lithologic unit No. 1. This difference is due to the varied lithology represented by samples of these units. More samples would have been desirable in order to arrive at reasonable averages for individual tuff layers. For example, unit 6, the tuff bed which contained the final shot chamber, is represented by only 3 samples, 1 from each of the 3 principal types of tuff of unit 6 observed in the tunnel and shot chamber. Each lithology is represented only by a core cylinder 1 inch in diameter and height; because of this limitation, no channel sample that would represent the full width of a layered unit can be analyzed as a single sample. Hence, all samples are given equal weight in calculating the arithmetic mean.

PART V - NATURE OF THE ROCK SURROUNDING THE FINAL SHOT CHAMBER FOR BLANCA EVENT

By F. N. Houser

The final shot chamber was in tuff characterized by variable physical and chemical features. To obtain some indication of the nature of part of the rock affected by the Blanca test, the weighted averages were calculated for the physical properties, mineralogy, and the chemical composition for the rock contained in a sphere having a diameter of 100 feet and centered at the shot chamber. Weighted averages for the rocks of the Tos_3 section that were represented in this sphere before the test were calculated using the measured thicknesses (Appendix A) and adjusting for structure setting. The original sphere of rock would contain by volume 17.7 percent of subunit D and 82.3 percent of subunit C.

No correction was made in the average composition of the sphere of rock for the void due to the tunnel nor for the steel, wood, and other constituents that were added in preparing the tunnel for use. The rock removed by construction of the tunnel was approximately 7,200 cubic feet, or about 1.4 percent of the rock in the sphere. Detailed geochemical studies of the rocks in the sphere should take into account the volume, density, and composition of the nine steel sets, approximately 180 cubic feet of timber and the air pipes, ducts, electrical cords, rails, and ties. The greater density of the metals used would contribute more significantly to the composition of the various products of the blast than might be indicated by their relatively small volume. The timber would contribute hydrogen and carbon as well as other minor constituents.

The weighted averages for the following physical properties of the rock in the original sphere were calculated from tables 6, 7, and 8.

Percent water content (by weight)	18.0
Water content (by volume) g/cc	0.34
Grain density, g/cc	2.3
Natural-state bulk density, g/cc	1.9
Dry bulk density, g/cc	1.5
Porosity (percent)	33.4

The original sphere of tuffaceous rocks has the following weighted average mineralogic composition. The averages were determined from data given in tables 1 and 2, Part III; the X-ray analyses of aphanitic material have been rounded to the nearest 5 percent.

	Percent (by volume)	
Phenocrysts	5.8	
Potassian feldspar		2.6
Plagioclase		1.5
Quartz		1.6
Magnetite		0.05
Mica		0.05
Xenoliths	4.5	
Vesicles	13.4	
Aphanitic material	76.3	
Heulandite		30
Beta-cristobalite		15
Clay		5
Quartz		5
Remainder		20
Total	100.0	

The weighted average chemical composition was determined using the analyses in tables 3 and 4 for those parts of the sphere composed of tuff of subunit D and C, respectively. The chemical analyses in these tables were first weighted according to the thickness represented by each sample. The resultant weighted averages for each of the two subunits were used for the proportional amount of rock of both subunits composing the sphere. The weighted average chemical composition for the original sphere is as follows:

	Percent (by weight)
SiO_2	69.7
Al_2O_3	12.3
Fe_2O_3	1.02
FeO	.06
MgO	.44
CaO	1.8
Na_2O	1.2
K_2O	4.0
H_2O+	5.2
H_2O-	4.3
TiO_2	0.14
P_2O_5	0.04
MnO	0.5
CO_2	0.09
Sum	101

The above weighted chemical average is based on the assumption that the compositions of subunit C and D are individually consistent throughout. The chemical composition assumed for subunit C, particularly, may not be entirely representative. Analyses for samples E5II-14, -16, and -17 (table 4) vary (in percent) up to 1.2 for SiO_2; 0.6 for Al_2O_3, 0.12 for total iron, 0.08 for MgO, 0.3 for CaO, 0.3 for Na_2O, and 1.1 for K_2O from the weighted average composition of E5V-1, -2, and E5II-15. This is more variation for most of the oxides (with the exception of MgO and total Fe) than the variation among E5V-1, -2, and E5II-15, and might be greater for other lithologic units within the subunit C in the sphere.

Chemical analyses in table 3 represent the 17.5 feet in the upper part of the subunit D exposed in the original shot chamber and may not be representative of the lower half of the subunit. The petrographic and physical consistency of this subunit, however, suggests that it probably is chemically homogeneous.

One alternative interpretation that might enable estimation of a more representative chemical composition of Tos_3, or of any given part thereof, is made possible by figure 7, a diagram of major oxide variations. This interpretation assumes continual variation of the units within Tos_3 from the oldest to youngest rocks. Not enough analyses are available, however, to warrant the use of such an interpretation in calculating the composition of the sphere of rock described above. In fact, it is doubtful that the curves are everywhere as smooth as shown; more fluctuation in composition is probably present. It is hoped additional analyses of subunit D, and of subunits C and B will substantiate or modify this interpretation.

As shown in figure 7, SiO_2 and K_2O decline markedly from the base to the top of the Tos_3 unit; Al_2O_3, FeO, and TiO_2 decline, then rise; MgO and CaO rise, then abruptly decline; and Na_2O declines, then rises very abruptly. These differences in chemical composition may be related to mineralogic composition, particularly to differences in relative amounts of zeolite (heulandite) and feldspar. Thin-section studies indicate a higher feldspar content in the groundmass in samples from subunit A and relatively higher zeolite content in subunit D. The same variation in relative content is indicated by the X-ray analyses (table 2) that show heulandite composing an average 20 percent of subunit A and an average of 35 and 30 percent for subunits C and D.

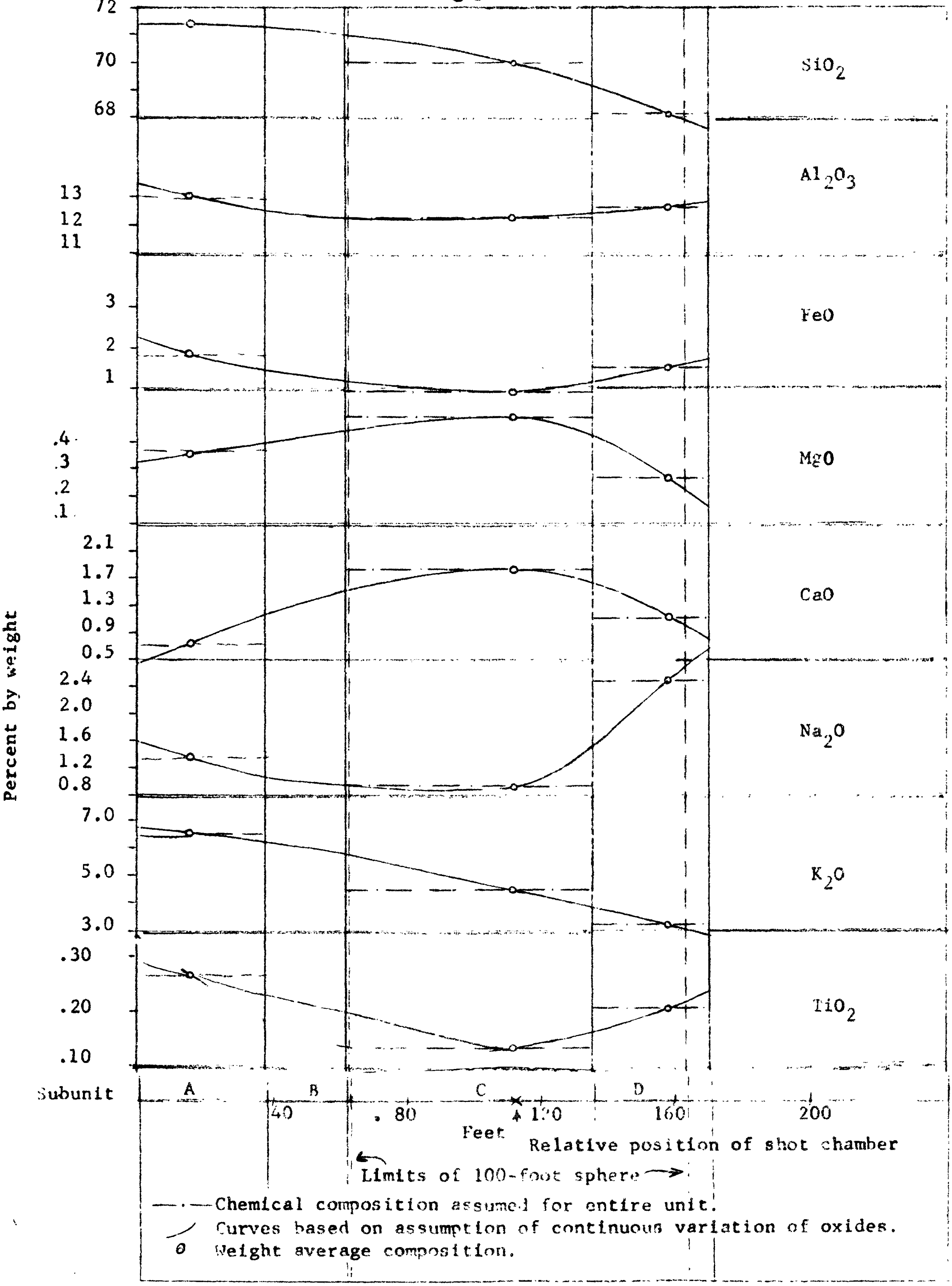

Figure 7.--Variation diagram for unit 3, Tos_3, Oak Spring formation, U12e tunnel, Rainier Mesa, Nye County, Nevada.

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Appendix A

Detailed megascopic description of the Oak Spring formation exposed in the U12e.05 tunnel, Rainier Mesa, Nye County, Nevada.

Measured by F. N. Houser and V. R. Wilmarth

October 1 and 6, 1958

Top of section

Top of exposure is at the ceiling at the west end of the U12e.05 shot chamber

Oak Spring formation (incomplete):

Tos_3 unit (incomplete--highest stratigraphic exposure is in top lithologic unit of Tos_3):

Lithologic unit no.	Description	Thickness (in feet)
Tos_3 subunit D:		
1	Tuff, coarse, with small (4-8 mm) lapilli, dense, well-cemented, dark green-gray mottled and streaked with red in lower part, grades upward within a few feet to red pink and medium red; thin beds and laminae near base, grades upward to indistinct, massive, thick beds. Lapilli: moderately to well-decomposed very light gray to white pumice (up to 30 percent in a few thin layers in the middle part, but in general ranges between sparse and 3	

Lithologic unit no.	Description	Thickness (in feet)
	percent). Coarse tuff fragments; very abundant light-gray to white decomposed pumice; common quartz, feldspar, and biotite; composes generally about 60 percent. Fine tuff (matrix): light red to pink, decomposed volcanic fragments (generally <30 percent). Clastics: common to abundant, quartzite subangular to subrounded and volcanic(?) fragments. Probably equivalent to bed 27 of Hansen and Lemke (1957, p. 67-68). Samples E5III-1A-K (lower 20 feet), EC5A-C, E-G (upper 15 feet). Base is at 736 feet (right wall). .	33.3+
	Total of Tos_3 subunit D.	33.3+
Tos_3 subunit C:		
2	Tuff, coarse, with small (4-8 mm) and large (8-32 mm) lapilli, friable to well-cemented green-gray in lower part, pinkish-gray in middle part, and brownish-red to pinkish-gray in upper part; distinct, thin even beds; top is pink, soft, gougelike material, 1-2 inches thick, along possible bedding plane fault. Lapilli: light-gray to white decomposed pumice as much	

Lithologic unit no.	Description	Thickness (in feet)
	as 20 mm long in some layers. Coarse tuff: moderately to well-decomposed pumice; quartz, feldspar, and biotite. Fine tuff (matrix): very light gray and very light pinkish gray. Clastics: subangular to subrounded, dark-brown quartzite and volcanic(?) fragments. Sample E5II-19. Base is at 706 (right wall) and at 700 feet (left wall).	3.5
3	Tuff, fine, soft, very light pinkish gray; consists of one bed. Lapilli: sparse decomposed light-gray pumice. Coarse tuff: decomposed light-gray to white pumice; sparse to common quartz, feldspar, and biotite. Fine tuff: very light pinkish gray. Clastics: dark brown fine to medium grains of quartzite and volcanic(?) rocks. Sample E5II-18. Base located at 700 feet (right wall)	0.8-1.0
4	Tuff, coarse in lower one-third, fine in upper two-thirds, friable to well cemented, very light gray to white; thick-bedded; upper contact sharp. Coarse tuff: decomposed pumice; quartz and feldspar, little or no	

Lithologic unit no.	Description	Thickness (in feet)
	biotite. Fine tuff: white. Clastics: medium to very coarse grains and granules of dark-brown to black quartzite and volcanic(?) rocks. Sample E5II-17. Base at 700 feet (right wall)	6.5
5	Tuff, coarse to fine, even-textured; greenish-gray; friable; indistinctly bedded. Coarse tuff: moderately to well-decomposed white and pale greenish-gray pumice. Fine tuff: light gray. Clastics: subangular to subrounded, fine to coarse grains of dark-brown quartzite and volcanic(?) rock. Sample E5II-16. Base located at 644 feet (right wall). . . .	2.5
6	Tuff, coarse, moderately well cemented to well cemented, very light gray, laminated to thick-bedded; top is a well-cemented red even-grained, fine tuff. Coarse tuff: moderately to well-decomposed pumice. Fine tuff: very light gray to white. Clastics: subangular to subrounded, medium to coarse grains of dark-brown quartzite and volcanic(?) rock. Includes	

Lithologic unit no.	Description	Thickness (in feet)
	a few beds in middle of unit of fine, uniform-textured greenish-gray tuff with sparse lapilli. Sample E5II-15. Base is at 567 feet (right wall), 570 feet (left wall).	7.5
7	Tuff, coarse, lapilli in some beds, moderately hard, light-gray and light greenish-gray, reddish-brown and orange-brown laminae; distinctly laminated to indistinctly, thinly bedded; upper contact sharp. Lapilli: moderately to well-decomposed, very light gray to white pumice. Coarse tuff: slightly to well-decomposed light greenish-gray to pale yellowish-white pumice; quartz and feldspar, sparse at base increasing to common in the middle, little, if any, in upper part. Fine tuff: light gray and light pink. Extremely friable bluish-white hydrated opal(?) abundant in certain of lower and upper beds. Clastics: dark-brown, subangular to subrounded fine to coarse grains of quartzite and volcanic(?) rock. In the	

Lithologic unit no.	Description	Thickness (in feet)
	middle of unit is a fine tuff, very light gray, porous with not over 10 percent of coarse decomposed pumice fragments. Three well-cemented red fine tuff layers, 0.5 to 0.8 foot thick, are at top and 4 and 2 feet below top. Sample E5II-14. Base located at 507 feet (right wall)	9.5
8	Tuff, coarse, friable to well-cemented, light gray near base, grades to greenish-gray in middle, and reddish-gray in upper part; indistinctly bedded; top contact is sharp. Coarse tuff: slightly to well-decomposed pumice; sparse quartz and feldspar, little or no biotite in most beds. Fine tuff: light gray to light reddish gray. Some extremely friable bluish-white hydrated opal(?). Clastics: dark brown, subangular to subrounded, fine to coarse grains of quartzite, volcanic(?) rocks and trace of chert. At top is fine tuff, red, pumiceous, well-indurated, 0.8 foot thick. Sample E5II-13. Base is at 463 feet (right wall)	8.5

Lithologic unit no.	Description	Thickness (in feet)
9	Tuff, fine, with traces to 5 percent lapilli, moderately hard, gray streaked with red in lower part grades to reddish-gray and red in middle and to gray mottled with red in upper part; indistinct thick bedding; upper contact sharp. Lapilli and coarse tuff: slightly to well-decomposed very light gray to white pumice; traces of quartz and feldspar. Fine tuff: light gray, light pinkish gray, and reddish-gray. Some extremely soft, bluish-white hydrated opal(?). Clastics: sparse, subangular to subrounded, fine to coarse grains of dark-brown very fine quartzite and volcanic(?) rocks. Sample E5II-12. Base is at 428 feet (right wall)	5.5
10	Tuff, fine, moderately hard, light gray to light reddish gray, laminated to thin-bedded, upper contact fairly sharp. Coarse tuff: decomposed pumice with light yellow, microcrystalline alteration mineral. Fine tuff: very light gray and light pink. Clastics: sparse subangular to subrounded, medium to coarse grains of dark-	

Lithologic unit no.	Description	Thickness (in feet)
	brown very fine quartzite and volcanic(?) rocks. Sample E5II-11. Base is at 393 feet (right wall), 390 (left wall).	8.5
11	Tuff, coarse, moderately hard, light greenish gray in lower part that grades to pale red gray in upper part; indistinct bedding; upper contact fairly sharp, wavy. Coarse tuff: moderately to well-decomposed pumice and common pale yellow microcrystalline alteration mineral (montmorillonite?) in lower part of unit, some slightly decomposed pumice; sparse, coarsely crystalline quartz and feldspar. Fine tuff: very light gray in lower part to pale red gray in upper. Clastics: subangular to subrounded, medium to very coarse grains of dark-brown very fine quartzite and volcanic(?) rock. Sample E5II-10. Base is at 382 feet (right wall).	1.4
12	Tuff, coarse, with granules and pebbles of quartzite, moderately hard, light gray discontinuously banded with red in the lower	

Lithologic unit no.	Description	Thickness (in feet)
	three-quarters, not banded in upper one-quarter, banding may or may not be parallel to very thick bedding. Coarse tuff: slightly to well-decomposed pumice; quartz and feldspar common, evenly distributed. Fine tuff: light red to orange white. Clastics: common, subangular to subrounded, medium to very coarse grains, granules and pebbles of dark-brown to black quartzite and volcanic(?) rock distributed throughout; any given thin zone contains generally a narrow size range of these fragments. Sample E5II-9. Base is at 343 feet (right wall)	4.0
13	Tuff, coarse in lower half, fine in upper half, with up to 5 percent lapilli, moderately hard, gray mottled with red and purple; very thick to thick bedding. Coarse tuff: very light gray to white decomposed pumice; quartz, feldspar, and biotite common. Fine tuff: white to light red and purple. Clastics: abundant, subangular to subrounded, fine (in the fine tuff) to very coarse grains (in the coarse tuff) of dark-brown	

Lithologic unit no.	Description	Thickness (in feet)
	quartzite and volcanic(?) rock. The fine tuff of the upper half is generally harder than the lower half, is more obviously porous, and contains as little as 10 percent coarse fraction. Some extremely friable, bluish-white hydrated opal(?). Sample E5II-8. Base is at 308 feet (right wall).	5.0
14	Tuff, fine with some coarse tuff beds, moderately well cemented, gray and red banding in basal 1 foot, remainder of unit is red mottled with gray; the lower banded part is gradational in color with unit 15 below but is in sharp contact on the basis of texture. Coarse tuff: white and pale yellow, slightly to well-decomposed pumice with thin red borders where fine tuff matrix is highly hematitic; light-red and light-gray aphanitic volcanic fragments; sparse quartz, feldspar, and biotite crystals. Fine tuff: medium red, light red, and light pink red. Traces of extremely soft, bluish-white, hydrated opal(?). Clastics: subangular to subrounded, fine to	

Lithologic unit no.	Description	Thickness (in feet)
	coarse grains, of dark-brown quartzite and volcanic(?) rock. Sample E5II-7. Base is at 282 feet (right wall).	5.8
15	Tuff, coarse except fine tuff in middle of unit and lapilli tuff in thin beds in lower part; well-cemented, light gray and red, thinly banded in basal 0.8 to 1.0 foot, predominantly gray mottled with red at top; thinly laminated to very thin bedded; upper and lower contacts sharp. Lapilli, small (4-8 mm), moderately to well-decomposed very light gray to white pumice. Coarse tuff: slightly to well-decomposed very light gray and white pumice; quartz, feldspar, biotite, and iron opaques, sparse to abundant in different layers. Fine tuff: white, very light gray, medium red to red. Clastics: common to abundant (as much as 5 percent), subrounded, medium to very coarse grains of dark-brown quartzite and volcanic(?) rock. Sample E5II-6. Base 2 feet above track at 265 (right wall).	5.0

Lithologic unit no.	Description	Thickness (in feet)
16	Tuff, coarse with lapilli, moderately hard, gray mottled and banded (particularly in lower 1 foot) with red and purplish red; very thin bedded. Coarse tuff: slightly decomposed (and slightly deformed) to well-decomposed white pumice; some black vesicular wad (MnO_2)(?). Fine tuff: light reddish. Subrounded, dark brown, very fine grains of quartzite and volcanic(?) rock. Sample E5II-5E. Base is about 262 feet (right wall).	0.5
	Total of Tos_3 subunit C (lithologic units 2-16).	74.7

Tos_3 subunit B:

17	Tuff, coarse, with sparse to moderate lapilli in some beds, moderately hard to hard,gray and red thin bands in lower part thick (1- and 2-foot) banding and mottling in the remainder of the unit; laminated and very thin bedded in lower part, thin-bedded in upper part. Lapilli: moderately well decomposed pumice; trace of quartz and feldspar crystals. Coarse tuff: moderately decomposed white to very light gray	

Lithologic unit no.	Description	Thickness (in feet)
	pumice, some vesicular; angular to subangular quartz, feldspar and biotite, pumice fragments commonly have thin red border in the red parts of unit. Fine tuff: light gray and red. Sample E5II-5A-D. Base is 2 feet above track at 266 feet (right wall).	5.0
18	Tuff, coarse, with trace (<1 percent) lapilli, moderately hard, gray partly banded and mottled with red; fairly well bedded, very thin beds; sharp color contact at base, sharp textural contact at top. Lapilli: small (4-8 mm), white, well-decomposed pumice; angular to subangular quartz, feldspar, and biotite. Fine tuff: white and red. Sample E5II-4. Base is at 240 feet (right wall). . .	2.0
19	Tuff, coarse, with trace of lapilli, pink, red, purple mottled with gray. Lapilli: (< 1 percent) fine, soft, brown tuff fragments. Coarse tuff: well-decomposed pumice; trace subangular quartz, feldspar, and biotite.	

Lithologic unit no.	Description	Thickness (in feet)
	Fine tuff: red. Sample E5II-3. Base is at 214 feet (right wall)	5.0
20	Tuff, coarse with rare lapilli, moderately well-cemented; massive, light gray mottled in part with purple; indistinct bedding. Lapilli: rare decomposed pumice. Coarse tuff: white decomposed pumice; common angular to subangular quartz, feldspar, mica, and black opaques. Fine tuff: very light gray. Sample E5II-2. Base is at 206 feet (right wall).	3.5
21	Tuff, coarse, moderately hard, light gray and red banded; bedding indistinct to distinct. Coarse tuff: white and light gray, decomposed pumice with pale yellow microcrystalline material (montmorillonite?), sparse to common angular to subangular quartz, feldspar, biotite, and black opaques; much of the biotite lies parallel to beds. Fine tuff: very light gray and red. Sample E5II-1. Base is at 179 feet (right wall)	8.0
	Total of Tos$_3$ subunit B (lithologic units 17-21)	23.5

Lithologic unit no.	Description	Thickness (in feet)
Tos$_3$ subunit A		
22	Tuff, coarse, with lapilli moderately hard, light pinkish gray, light purplish red and medium red; bedding indistinct or structureless. Lapilli: from traces to 10 percent, slightly to well-decomposed white and light-gray pumice. Coarse tuff: decomposed pumice; angular to subangular clear feldspar, quartz, brown to black biotite, and black opaque grains. Fine tuff: pink and red. Samples E5I-3A to 3B. Base is at 132 feet (right wall)	11.1
23	Tuff, fine and coarse, hard to moderately hard, dark red in the lower part that grades to medium red in the upper; indistinct bedding, upper contact sharp. Coarse tuff: undeformed pumice, angular to rounded clear feldspar, biotite, and black opaques. Fine tuff: pink, gray, red-brown, and dark-red, vesicular, some biotite; unit contains sparse canary yellow, finely crystalline material (montmorillonite?). Samples E5I-2A to 2B. Base is at 42 ft (right wall).	17.2

Lithologic unit no.	Description	Thickness (in feet)
24	Tuff, coarse, as much as 3 percent lapilli, light red to dark red, hard; indistinct bedding. Lapilli: (< 1 to 3 percent) white, light gray, tan, red, slightly to well-decomposed pumice and traces of indurated red tuff fragments. Coarse tuff: slightly to well-decomposed pumice, common biotite, sparse to common, angular to subangular clear feldspar and accessory lithic fragments. Fine tuff: dark pink and red, glass(?) shards and decomposed pumice, mica, and black opaque grains. Samples E5I-1A to D. Units 22 through 24 are equivalent to bed 24 of Tos_3 of Hansen and Lemke (1957, p. 68).	10.2
	Total of Tos_3 subunit A (lithologic units 22-24) . . .	38.5
	Total of incomplete Tos_3 unit. .	170.0