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GEOLOGICAL SURVEY INVESTIGATIONS IN THE U12b.01 TUNNEL, NEVADA TEST SITE

By W. H. Diment, V. R. Wilmarth, F. A. McKeown,
D. D. Dickey, T. Botinelly, E. N. Hinrichs,
C. H. Roach, F. M. Byers, G. A. Izett, and
G. R. Johnson

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Trace Elements Memorandum Report 998

UNITED STATES 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.01 TUNNEL, NEVADA TEST SITE

PART I - INTRODUCTION

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

The U12b.01 tunnel is part of the U12b (Rainier) tunnel system driven northwestward from the east slope of Rainier Mesa (figs. 1 and 2). Geologic and geophysical studies in this tunnel were conducted by the U. S. Geological Survey on behalf of the Albuquerque Operations Office of the Atomic Energy Commission. This report includes a brief description of the stratigraphy and structure, and data on petrology, mineralogy, and chemical and physical properties of the rocks that are exposed in the tunnel.

The U12b.01 tunnel trends N. 10° W., and connects with the U12b tunnel at about 500 feet from the portal (fig. 2). The U12b.01 tunnel is about 250 feet long and contains an alcove 40 feet long and 20 feet wide, and a shot chamber 17 by 20 feet. The tunnel is irregular and ranges from 6 to 15 feet in width and averages 7 feet in height. Much of the tunnel has been supported using 6-foot steel sets and wood planks for lagging. Vertical and minimum cover over the shot chamber at west end of the tunnel are approximately the same, about 295 feet.

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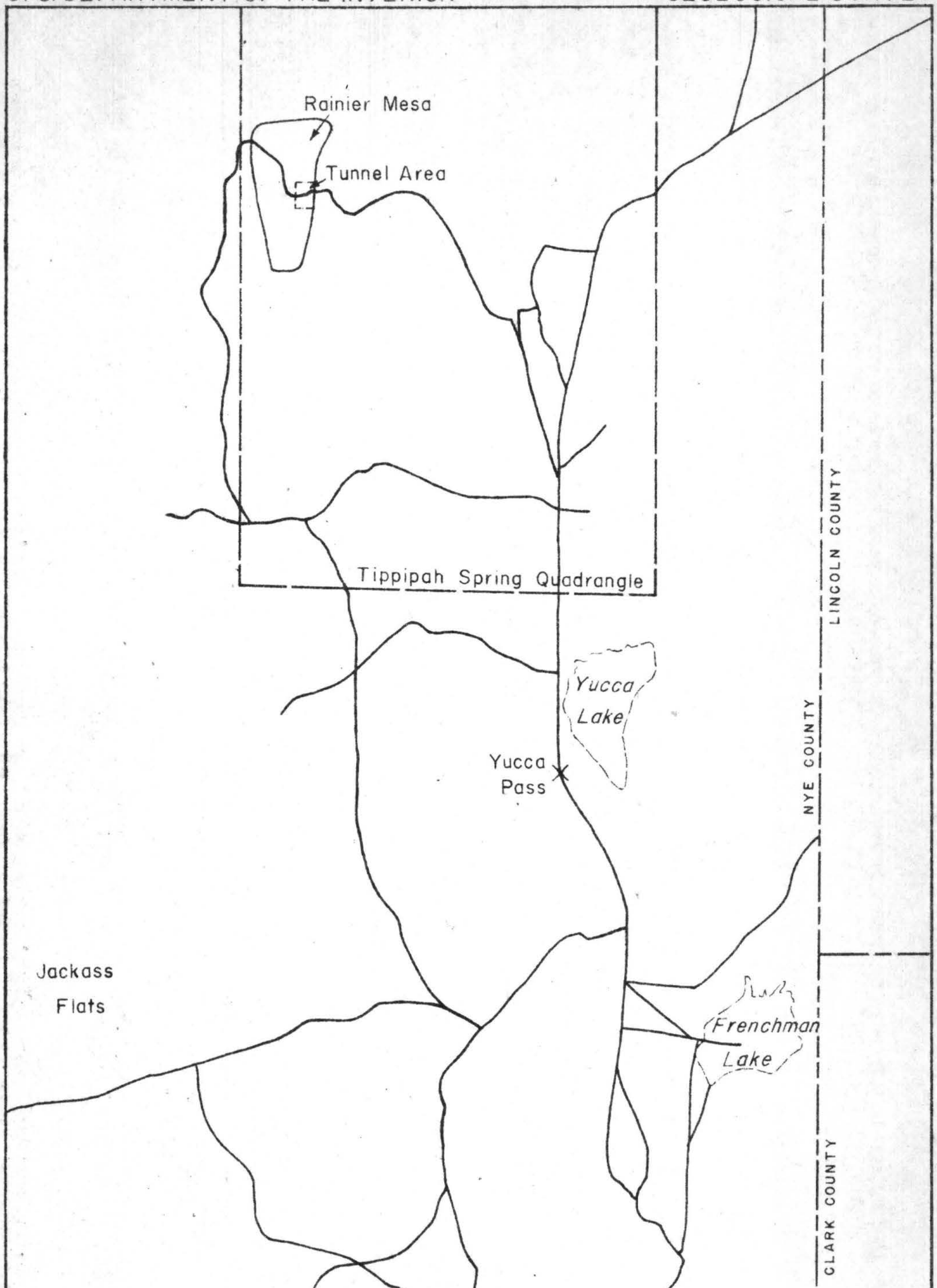

FIGURE 1—INDEX MAP SHOWING LOCATION OF TUNNEL AREA, RAINIER MESA, TIPPIPAH SPRING QUADRANGLE, NYE COUNTY, NEVADA

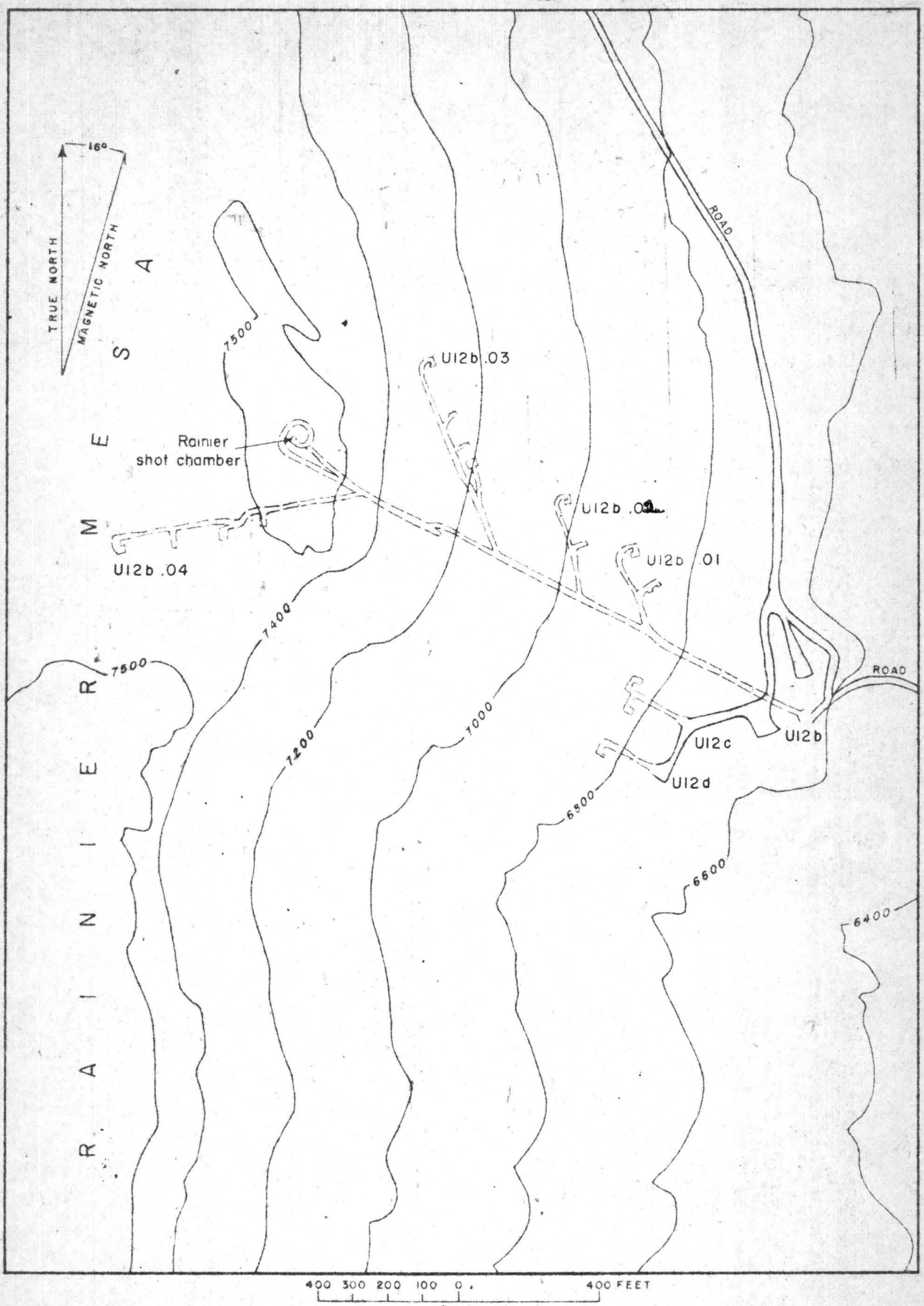

FIGURE 2-INDEX MAP SHOWING LOCATION OF U12B, C, D TUNNELS, RAINIER MESA, TIPPIPAH SPRING QUADRANGLE, NYE COUNTY, NEVADA

PART II - STRATIGRAPHY AND STRUCTURE

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

The rocks penetrated by the U12b tunnel system consist of varicolored nonwelded and welded tuffs that form the upper part of the Oak Spring formation of Tertiary age. Similar rocks comprise the lower part of this formation and rest unconformably on limestone, dolomite, quartzite, and siliceous shale of Paleozoic age. Near the portal of U12b tunnel the contact between the Paleozoic and Tertiary rocks strikes N. 11° E. to N. 65° E., and dips 12° to 22° SE.; there is relief of at least 20 feet on this contact. The Paleozoic rocks have been complexly faulted, trend north, and dip 10° to 70° W. The tuffaceous rocks strike N. 10° W. to N. 60° E., dip 5° SW. to 36° NW., and have been broken by north- to northwest-trending faults of small vertical displacement.

Stratigraphy

The Oak Spring formation in the vicinity of Rainier Mesa has been divided into eight lithologic units designated in ascending order Tos_1 to Tos_8 (Hansen and Lemke, 1957), (table 1). The U12b tunnel begins in Tos_4 (fig. 3), penetrates successively younger units, and ends in the Rainier shot chamber in the lower part of Tos_7.

The rocks which comprise these units are welded and nonwelded tuffs. Generally they are grayish tan, white, or reddish brown and range from relatively soft and friable rock to very hard rock. Most of the tuffaceous rocks are distinctly bedded; the beds range from less than an inch to about 4 feet in thickness.

Units Tos_4 to Tos_7 were further subdivided during geologic mapping of the U12b tunnel into 17 units designated by letters J to Z (A. B. Gibbons, written communication, 1958). The units exposed in the U12b.01 tunnel (fig. 4) include L (Tos_5), M, N, and O (Tos_6) and P, Q, and R (Tos_7). These rocks are briefly described as follows:

Unit L.--Unit L of Tos_5 is about 50 feet thick. Only the upper 15 feet is exposed in the tunnel. The rocks are yellowish-gray fine-grained well-bedded tuffs that consist of pumice and lithic fragments, generally less than one-half inch across, in a tuff matrix. Beds range from a few inches to 1 foot in thickness.

Table 1--Generalized stratigraphic section of Oak Spring formation, Rainier Mesa, Nye County, Nevada

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 (cont.)

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 porcelaneous beds up to several feet thick form 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	

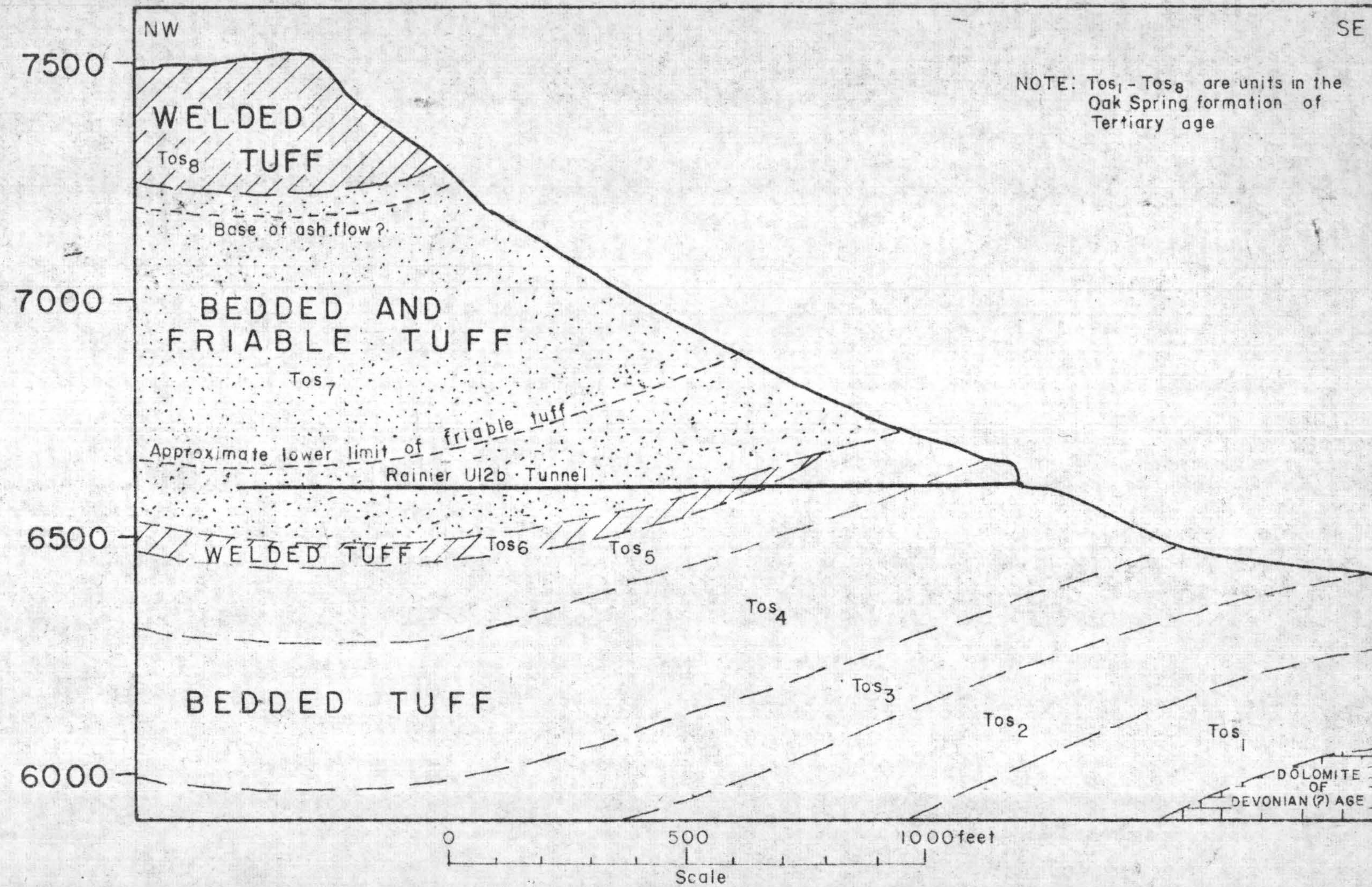

FIGURE 3 - GENERALIZED GEOLOGIC CROSS SECTION ALONG U 12 b TUNNEL, RAINIER MESA, NYE COUNTY, NEVADA

Unit M.--Unit M is a volcanic breccia that makes up the lower part of Tos_6: the breccia is composed of rounded to angular fragments 0.12 inch to as much as 1.5 feet across of volcanic rocks and a few metamorphic rocks. The upper 1 to 2 feet is finer grained and composed of fragments 0.12 to 0.5 inch across. Unit M is about 5 feet thick where exposed in the U12b.01 tunnel, but as it fills scours and channels in unit L the thickness is very irregular.

Unit N.--Unit N forms the middle part of Tos_6 and is a welded red and gray tuff. It has an exposed thickness of about 40 feet in the U12b.01 tunnel. The tuff is rhyolitic in composition and is dominantly a very hard dense rock. About 8 feet from the base is a 3-foot thick layer of dark green glassy perlitic tuff. Flattened pumice fragments are abundant. Vesicles are rare.

Unit O-P.--Unit O forms the upper part of Tos_6 and unit P the basal unit of Tos_7 where mapped in the U12 b tunnel. These units, however, could not be differentiated in the U12b.01 tunnel and are mapped as one unit. Their total thickness is about 7 feet and bedding is indistinct or lacking. The rock is a sandy, soft light reddish to purplish-brown slightly welded tuff. Flattened greenish-brown pumice fragments and relicts(?) of pumice fragments are common. In hand specimens feldspar is the chief mineral observed and much of it is partly altered to white clayey material.

Unit Q.--Unit Q of Tos_7, where observed in the tunnel, is about 4 feet thick. The rock of unit Q consists predominantly of olive-tan sandy tuff with abundant dark olive-green pumiceous lapilli. Minor constituents disseminated in the rock are feldspar, lithic fragments, and rare dark-brown glass. The unit has no distinct bedding.

Unit R.--Unit R of Tos_7 is about 50 feet thick. It consists predominantly of grayish-cream to tan fine- to medium-grained tuff. A distinguishing characteristic of the tuff is its sandy texture. It is laminated to thin bedded and rarely has thin sets of low-angle cross lamination. Minor variations of lithology, subunits R_1 and R_2, were mapped in the shot chamber of the U12b.01 tunnel (fig. 4). Subunits R_1 and R_2 are probably of local extent as they are not present in the U12b.02 and U12b tunnels. R_1 is a silicified zone about 1 foot thick that transects bedding at low angles. This rock is dark tannish-gray whereas the enclosing tuff is light tan; limonite-stained laminae, 1 to 2 inches thick are common. The rock of R_1 contains feldspar, an unidentified hard orange mineral, dark lithic grains and a matrix of a soft greenish-white claylike mineral. Subunit R_2 is dark tannish-gray coarse tuff and characteristically contains abundant black, soft, fine-grained aggregates of rice-sized material, which may be manganese oxide; the material has not been identified. Limonite stain is common. Under a low power microscope the rocks of R_2 are seen to be similar to those of subunit R_1.

Structure

The structure of the rocks in the U12b.01 tunnel is relatively simple (fig. 4). Beds strike N. 55° to 70° E., and dip 21° to 34° NW. An exception to the general northeast strike is the contact between units M and L. This contact which strikes N. 70° W., and dips 30° NE. is an erosional surface on unit L and may be expected to vary widely in strike and dip.

Two faults cut the tuffs exposed in the U12b.01 tunnel. The principal fault strikes N. 50° W., dips 75° to the northeast and has a vertical displacement of 2 feet down on the northeast side. This fault is an extension of the fault mapped by Gibbons and Eckel (A. B. Gibbons, written communication, 1958, fig. 3) in the Rainier tunnel near entrance to the U12b.01 tunnel. A small thrust fault with about 0.5 foot vertical displacement was mapped 3 feet northeast of the principal fault and is probably subsidiary to it.

Joints are common in the rocks cut by the U12b.01 tunnel especially in the vicinity of the shot chamber. The joints strike predominantly N. 30° to 60° W., and N. 15° to 30° E. (fig. 5). About 70 percent of the joints that strike northwest are vertical or dip northeast more than 60°; the other 30 percent dip 60° to 85° SW. Nearly all of the joints that strike northeast dip southeast more than 60°.

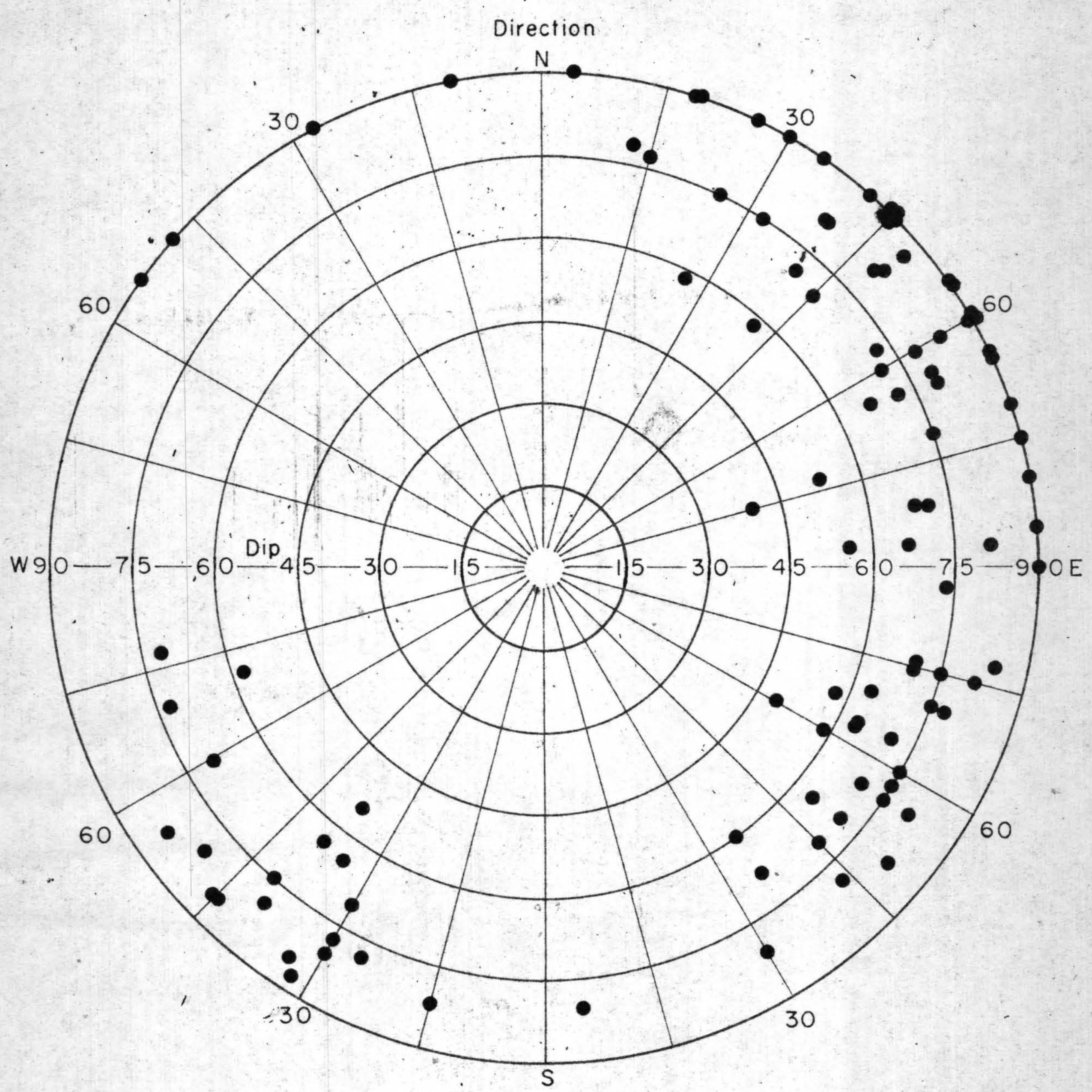

FIGURE 5—DIAGRAM SHOWING POLES OF 107 JOINTS MEASURED IN THE U12b. 01 TUNNEL. POLES OF PERPENDICULARS TO THE JOINT PLANES ARE PROJECTED TO THE UPPER HEMISPHERE.

PART III - PETROLOGY

By T. Botinelly and E. N. Hinrichs

Samples of the tuff from mapped units O-P, Q, R, R_1, and R_2 exposed in the U12b.01 tunnel were analyzed by microscopic, X-ray, and chemical methods. The sample locations are shown on figure 4 and sample descriptions are given in table 2. The mineral constituents of the tuff were determined by X-ray diffractometer analyses, from study of thin sections, and from examination under a binocular microscope of specimens that had been etched with hydrofluoric acid and stained with sodium cobaltinitrite. Modal analysis of the tuff was made by a point-count method (table 3).

The tuff consists of phenocrysts and xenoliths in a fine-grained claylike to glassy matrix (table 3). Irregular vesicles are common and average 15.8 percent by volume of the tuffs. Matrix makes up from 18 to 70 percent by volume of the tuffs.

Phenocrysts make up 15 to 33 percent by volume of the tuffs in all but units O-P and Q, which contain 5.3 and 6.5 percent respectively. Potassian feldspar and plagioclase are the principal phenocrysts, and quartz, magnetite, and mica, usually biotite, occur in minor quantities. Most of the phenocrysts are subrounded to angular and are as much as 0.8 mm across.

Table 2--Description of samples from the U12b.01 tunnel, Rainier Mesa, Nye County, Nevada

Sample number	Lithologic unit	Description
B15	O-P	Tuff, light purplish-gray to light reddish-brown, fine to coarse, slightly welded, scattered lapilli of white pumice(?) fragments.
B16	Q	Tuff, light greenish-yellow mottled with dark greenish-yellow, fine to medium, few relict pumice(?) and lithic fragments.
B13, B17, B19	R	Tuff, grayish-cream, fine- to medium-grained, well bedded, laminated, friable.
B11	R_1	Tuff, tannish-gray, fine- to medium-grained, laminated; silicified.
B12, B18	R_2	Tuff, yellowish-gray, fine to coarse, laminated, partly indurated.

Table 3--Modal analyses of tuff from the U12b.01 tunnel, Nevada Test Site, Nye County, Nevada 1/

Sample nos. 2/	B15	B16	B13	B17	B19	B11	B12	B18	Mean	Size maxima (mm)	Remarks
Lithologic unit	O-P	Q	R	R	R	R_1	R_2	R_2			
Phenocrysts	5.3	6.5	15.2	16.5	33.1	22.8	15.8	18.4	16.7		
Potassian feldspar	3.7	3.2	4.4	11.1	14.1	8.1	5.4	7.1	7.1	.8-4.	A few grains of included magnetite
Plagioclase	1.0	2.7	9.1	3.8	14.3	11.0	5.2	8.5	7.0	.5-3.	
Quartz	0.5	0.6	0.5	0.8	4.1	2.2	3.9	2.0	1.8	.3-2.	
Magnetite	0.1	0	1.2	0.8	0.2	0.1	1.1	0.7	0.6	.3-.5	A few grains are coated with red oxides
Mica	0	0	0	0	0.4	1.4	0.2	0.1	.3	.2-.5	Brown, gray, and black
Xenoliths	7.0	7.6	6.5	7.8	20.9	11.2	6.4	13.3	10.1	2-15	Mainly volcanic rocks; some brown argillite present; other fragments not identified
Vesicles	28.9	20.0	10.5	16.2	27.8	4.4	8.4	10.0	15.8	.5-5.	
Area measured (mm^2)	1,100	873	355	500	422	600	441	1,300	699		

Table 3--Modal analyses of tuff from the U12b.01 tunnel, Nevada Test Site, Nye County, Nevada (cont.)

Sample nos. 2/	B15	B16	B13	B17	B19	B11	B12	B18	Mean	Size maxima (mm)	Remarks
Lithologic unit	O-P	Q	R	R	R	R_1	R_2	R_2			
Matrix 3/	58.8	65.9	67.8	59.5	18.2	61.6	69.4	58.3	57.4	.5-4.	Chiefly sand-sized fragments
Heulandite	5	40	35	25	8	20	20	25			
Clay	15	-- 4/	10	10	2	5	30	10			
Beta-cristobalite	--	--	--	--	--	10	--	--			
Other	30 6/	10 6/				5/					
Remainder 7/	10	15	25	25	10	25	20	25			

1/ Modal analyses by E. N. Hinrichs; X-ray analyses of finely crystalline and amorphous fragments by T. Botinelly.

2/ See table 2 for sample description.

3/ The minerals present in the matrix were estimated from X-ray diffractometer patterns.

4/ Not detected.

5/ Feldspar, amount not estimated.

6/ Quartz

7/ 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.

The xenoliths in the tuffs are principally volcanic rocks, though some argillite fragments are present. The xenoliths range from 2 to 15 mm across and by volume make up 6.4 to 20.9 percent of the tuffs. Vesicles, 0.5 to 5 mm across, are irregular and are most abundant in the tuff of unit O-P where they make up 28.9 percent by volume of the rock.

Matrix is the most abundant constituent of the tuffs. It is a soft grayish-white fine to very fine grained part of the rock which by X-ray diffractometer anlysis contains heulandite, beta-cristobalite, and clay minerals. Heulandite is present in all samples analyzed and in one comprises about 40 percent by volume of the matrix. Clay minerals, mainly montmorillonite, are present in all but one sample whereas beta-cristobalite was detected in only the silicified unit R_1. The material not identified by X-ray diffractometer analysis is indicated in table 3 as the remainder and is part amorphous.

Thin sections of samples from units R, R_1, and R_2 show that the groundmass is finely blocky, vesicular, and that flow structures outlined by very fine grained heulandite are common around the phenocrysts and xenoliths. Groundmass in specimens from units O-P and Q as seen in thin sections is a dense structureless submicroscopic material; fine-grained crystals of heulandite are scattered through the groundmass.

Chemical analyses were made of samples from units Q, R, R_1 and R_2, and with the exception of R_1, which contains more SiO_2 and correspondingly less Al_2O_3, all of the rocks are chemically similar (table 4). Radiometric analyses of these samples indicate the equivalent uranium ranges from less than 0.001 to 0.007 percent. The uranium content is less than 0.001 percent.

Minor elements in units R, R_1, and R_2 were determined by semiquantitative spectrographic analysis (table 5). The spectrographic analyses show samples B11, B12, and B13 are remarkably uniform in trace element content. The differences shown are insignificant. The tuffs are higher than normal felsic rock in Sc, La, Ce, Nd, and Yb. Comparison with spectrographic analyses of other samples of Oak Spring formation from the Nevada Test Site shows similar trace element content.

Table 4--Chemical analyses of tuff from U12b.01 tunnel, Nevada Test Site, Nye County, Nevada 1/

Sample number	B16	B13	B19	B11	B12	B18
Laboratory number	267308	267307	267310	267305	267306	267309
Lithologic unit	Q	R	R	R_1	R_2	R_2
SiO_2	64.7	63.1	62.2	68.6	61.5	61.9
Al_2O_3	12.7	14.6	15.0	12.0	15.5	14.9
Fe_2O_3	3.6	3.4	3.4	2.6	3.5	3.4
FeO	.04	.09	.03	.07	.22	.09
MgO	.90	.79	.88	.82	.84	1.0
CaO	2.3	2.4	2.4	2.1	2.5	2.5
Na_2O	1.3	2.4	2.5	1.9	2.6	2.3
K_2O	4.6	4.4	4.4	3.3	3.2	3.1
H_2O+	5.9	4.9	4.7	4.6	4.4	4.6
H_2O-	4.1	3.2	3.7	3.7	5.2	5.5
TiO_2	.42	.66	.60	.47	.70	.62
P_2O_5	.07	.15	.16	.10	.20	.16
MnO	.18	.16	.16	.14	.16	.15
CO_2	.11	.16	.14	.13	.12	.12
Sum	101	100	100	101	101	100
Equiv. U 2/	0.002	$<$0.001	0.002	0.007	0.002	0.001
U 2/	--	--	--	$<$0.001	--	--

Table 4--Chemical analyses of tuff from U12b.01 tunnel, Nevada Test Site, Nye County, Nevada 1/ (cont.)

1/ Rapid rock analysis by P. L. D. Elmore, S. D. Botts, M. D. Mack, and H. H. Thomas, USGS, using methods similar to those described in USGS Bulletin 1036-C. Report No. IRC-330, November 4, 1958.

2/ Equivalent uranium and uranium analyses by L. M. Lee and E. J. Fennelly, Report No. TDC 9595, September 30, 1958. Uranium was analyzed by the fluorimetric method.

Table 5--Semiquantitative spectrographic analyses of tuff from the shot chamber and tunnel of U12b.01, Nevada Test Site, Nye County, Nevada [1]

Sample No.	B11[2]	B12	B13	Standard spectrographic sensitivity
Lab. No.	267305	267306	267307	
Lithologic unit	R_1	R_2	R	
Ba	.15	.3	.3	.0002
Be	.0003	.00015	.00015	.0001
Ce	d [3]	.03	.03	.02
Cr	.00015	.00015	.00015	.0001
Cu	.0007	.0007	.0003	.0001
Ga	.003	.003	.003	.0002
La	.015	.015	.015	.002
Nb	.0015	.003	.003	.001
Nd	.015	.015	.015	.01
Pb	.0015	.0015	.0015	.001
Sc	.0015	.003	.003	.0005
Sr	.03	.03	.03	.0002
V	.0015	.003	.0015	.001
Y	.003	.003	.003	.001
Yb	.0007	.0007	.0007	.0005
Zr	.03	.07	.03	.001

Table 5--Semiquantitative spectrographic analyses of tuff from the shot chamber and tunnel of U12b.01, Nevada Test Site, Nye County, Nevada [1] (cont.)

1/ Analyses by N. M. Conklin

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

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. Comparisons of this type of semi-quantitative result with data obtained by quantitative methods, either chemical or spectrographic, show that 60 percent of the quantitative values fall within the assigned semiquantitative groups.

2/ For sample descriptions see table 2.

3/ d - barely detected; concentration unknown.

PART IV - POROSITY, WATER CONTENT, AND DENSITY

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

Measurements were made of porosity, water content, grain density, and rock or bulk density of samples from five units exposed in the U12b.01 tunnel. These data were obtained to assist in the evaluation of the yield and determining the geologic effects of a proposed detonation in the shot chamber.

The samples obtained represent as closely as possible the natural-state condition of the rocks and in this report are designated natural-state samples. All rock types exposed in the tunnel were sampled and their descriptions are given in parts II and III of this report. The location of samples discussed in this section is plotted on figure 6 (in pocket).

Natural-state 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, indicated by asterisk in table 6, were by necessity collected in the tunnel after the rock had been exposed several weeks. These samples were treated in the same manner as were the natural-state samples. The water content and bulk density of these samples may not be representative of the rocks in their natural state. Measurements of porosity, dry bulk density, and grain density, which do not depend on water content, are considered to be representative.

The laboratory procedure used to determine the physical properties is as follows: The natural-state samples were opened 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 heated in an electric oven from 16 to 24 hours at 105°C. The fragments were allowed to cool in a desiccator and again weighed to obtain the dry weight of the rock, or the quantity, M_{1f}.

Table 6.--Porosity, density, and water content data for individual samples of the Oak Spring formation in the U12b.01 tunnel, Nevada Test Site, Nye County, Nevada

Sample number	Rock unit	Distance from entrance of U12b.01 (feet)	Porosity (P) (percent)	Dry bulk density (D_{bd}) (g/cc)	Grain density (D_g) (g/cc)	Percent water content (by weight)	Natural-state bulk density (D_{bn}) (g/cc)	Water content (by volume) (g/cc)
10	Q	143	39.7	1.57	2.61	5.9	1.66	0.097
14	Q	167	36.4	1.43	2.24	12.1	1.63	0.198
15	R	167	25.2	1.71	2.28	11.8	1.93	0.228
16	R	167	30.7	1.63	2.35	9.3	1.79	0.167
17	R	180	32.3	1.68	2.48	7.7	1.83	0.140
18	R	180	30.4	1.62	2.32	9.7	1.62	0.156
*19	N	50	10.8	2.16	2.42	4.5	2.27	0.103
*20A	M	50	2.3	2.50	2.56	1.1	2.53	0.029
*20B	M	50	11.4	1.98	2.24	4.4	2.08	0.092
*21	N	75	10.7	2.32	2.61	3.1	2.39	0.074
*22	N	75	16.2	2.01	2.40	6.2	2.15	0.134
23	R	184	32.2	1.59	2.34	10.7	1.78	0.191
26	N	Alcove-rm 2	30.6	1.65	2.37	9.8	1.83	0.179
27	N	Alcove-rm 2	37.4	1.62	2.58	10.3	1.80	0.185

Table 6.--Porosity, density, and water content data for individual samples of the Oak Spring formation in the U12b.01 tunnel, Nevada Test Site, Nye County, Nevada -- Continued

Sample number	Rock unit	Distance from entrance of U12b.01 (feet)	Porosity (P) (percent)	Dry bulk density (D_{bd}) (g/cc)	Grain density (D_g) (g/cc)	Percent water content (by weight)	Natural-state bulk density (D_{bn}) (g/cc)	Water content (by volume) (g/cc)
*44	R	205	33.1	1.61	2.41	9.5	1.77	0.168
*45	R	205	32.6	1.62	2.40	9.3	1.78	0.165
48	R	Shot chamber	37.4	1.47	2.35	10.3	1.65	0.170
*49	N	Alcove- rm 2	31.5	1.79	2.61	12.7	2.06	0.262
*50	N	Alcove- rm 2	26.9	1.91	2.61	9.8	2.12	0.207
*51	N	Alcove - rm 2	27.9	1.88	2.61	10.2	2.09	0.214
*52	N	Alcove- rm 2	10.1	2.37	2.64	2.1	2.42	0.052
*53	N	Alcove - rm 2	32.8	1.76	2.62	10.3	1.95	0.200
*54	N	Alcove- rm 2	31.4	1.78	2.59	10.1	1.98	0.200
*55	N	Alcove-rm 1	30.9	1.80	2.61	10.6	2.02	0.215
*56	N	Alcove- rm 1	18.1	2.13	2.60	6.8	2.28	0.156
*57	N	Alcove - rm 1	18.7	2.13	2.62	7.7	2.30	0.177
*58	N	Alcove - rm 1	18.8	2.12	2.62	7.0	2.29	0.161
*59	N	Alcove - rm 1	18.6	2.13	2.61	7.3	2.30	0.170

Table 6.--Porosity, density, and water content data for individual samples of the Oak Spring formation in the U12b.01 tunnel, Nevada Test Site, Nye County, Nevada--Continued

Sample number	Rock unit	Distance from entrance of U12b.01 (feet)	Porosity (P) (percent)	Dry bulk density (D_{bd}) (g/cc)	Grain density (D_g) (g/cc)	Percent water content (by weight)	Natural-state bulk density (D_{bn}) (g/cc)	Water content (by volume) (g/cc)
*60	N	Alcove-rm 1	40.4	1.57	2.63	9.3	1.73	0.161
*61	N	Alcove-rm 2	41.0	1.55	2.63	12.4	1.77	0.219
*62	R	Shot chamber	31.5	1.68	2.45	7.6	1.81	0.137
63	R_1	Shot chamber	8.4	2.15	2.35	4.0	2.24	0.089
64	R_1	Shot chamber	22.1	1.87	2.40	6.9	2.00	0.138
65	R_2	Shot chamber	27.7	1.73	2.39	12.0	1.97	0.237
66	R	Shot chamber	28.2	1.72	2.39	13.3	1.98	0.263
70	R_2	266	30.7	1.65	2.37	15.4	1.95	0.300
71	R	Shot chamber	25.0	1.84	2.45	6.0	1.95	0.116
72	R	Shot chamber	24.1	1.84	2.43	6.5	1.97	0.128
73	R	Shot chamber	33.2	1.67	2.50	8.4	1.82	0.152
74	R	Shot chamber	33.4	1.66	2.50	8.9	1.83	0.162
75	R_2	Shot chamber	29.2	1.77	2.50	6.9	1.89	0.130
76	R	Shot chamber	34.0	1.63	2.48	9.0	1.79	0.161

Table 6.--Porosity, density, and water content data for individual samples of the Oak Spring formation in the U12b.01 tunnel, Rainier Mesa, Nye County, Nevada--Continued

Sample number	Rock unit	Distance from entrance of U12b.01 (feet)	Porosity (P) (percent)	Dry bulk density (D_{bd}) (g/cc)	Grain density (D_g) (g/cc)	Percent water content (by weight)	Natural-state bulk density (D_b) (g/cc)	Water content (by volume) (g/cc)
77	R	Shot chamber	24.5	1.79	2.36	12.0	2.04	0.244
78	R_2	Shot chamber	26.9	1.76	2.41	12.2	2.01	0.244
79	R	Shot chamber	33.7	1.65	2.49	8.8	1.82	0.159

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

After the dry weights of the fragments were obtained, a cylindrical plug about 1 inch in length and 1 inch in diameter was cored from each rock fragment. These plugs were heated at 105°C in an electric oven for 16 hours at 105°C to drive off moisture introduced during coring. After the plugs were allowed to cool in the desiccator, the dry weights were obtained and recorded as M_{1c}. The plugs 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 cover the evacuated 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 weights 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 6 and 7:

(1) Porosity (P) (percent) $= \frac{M_{2c} - M_{1c}}{M_{2c} - M_{3c}} \times 100$

(2) Dry bulk density (D_{bd}) (g/cc) $= \frac{M_{1c}}{M_{2c} - M_{3c}}$

(3) Grain density (D_g) (g/cc) $= \frac{M_{1c}}{M_{1c} - M_{3c}}$

(4) Water content (by weight) $= \frac{M_{0f} - M_{1f}}{M_{0f}} \times 100$

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

(6) Water content (by volume) (g/cc) = Water content by weight x "Natural-state" bulk density

The physical properties were determined from 57 of 59 samples collected in the U12b.01 tunnel. The data for individual samples are tabulated in table 6. Two 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 of all samples of each rock unit is given in table 7. Standard deviations and confidence limits were not computed for rock units that are represented by fewer than 10 samples. Data on water content by weight, natural-state bulk density, and water content by volume for samples marked with an asterisk in table 6 were not used in the statistical summary in table 7.

Table 7.--Statistical summary of porosity, dry bulk density, grain density, natural-state bulk density, and water content measurements on samples of the Oak Spring formation in the U12b.01 tunnel, Nevada Test Site, Nye County, Nevada

	Rock unit M	Rock unit N	Rock unit Q	Rock unit R	Rock unit R_1	Rock unit R_2
Percent porosity (P) (arithmetic mean)	6.9	23.7	38.1	29.0	13.6	25.1
1 Standard deviation 1/		±10.8		±5.9		
Confidence limit 2/		±4.6		±2.5		
Number of samples	2	21	2	21	3	8
Dry bulk density (D_{bd}) (arithmetic mean)	2.24	1.97	1.50	1.69	2.04	1.75
1 Standard deviation		±0.28		±0.16		
Confidence limit		±0.12		±0.07		
Number of samples	2	21	2	21	3	8
Grain density (D_g) (arithmetic mean)	2.40	2.58	2.43	2.39	2.37	2.33
1 Standard deviation		±0.08		±0.07		
Confidence limit		±0.03		±0.03		
Number of samples	2	21	2	21	3	8
Percent water content by weight of natural state rock (arithmetic mean)		6.6	9.0	10.3	5.0	11.6
1 Standard deviation				±3.3		
Confidence limit				±1.5		
Number of samples		5	2	20	3	8
Natural-state bulk density (D_{bn}) (arithmetic mean)		3.13	1.65	1.87	2.14	1.97
1 Standard deviation				±0.19		
Confidence limit				±0.10		
Number of samples		5	2	18	3	8

Table 7.--Statistical summary of porosity, dry bulk density, grain density, natural-state bulk density, and water content measurements on samples of the Oak Spring formation in the U12b.01 tunnel, Nevada Test Site, Nye County, Nevada--Continued

	Rock unit M	Rock unit N	Rock Unit Q	Rock unit R	Rock unit R_1	Rock unit R_2
Water content in grams per cc of natural-state rock (arithmetic mean)		0.128	0.098	0.179	0.106	0.228
1 Standard deviation				±0.053		
Confidence limit				±0.027		
Number of samples		5	2	18	3	8

1/ Standard deviation assuming a normal distribution.

2/ Confidence limit (95 percent level of the arithmetic mean)

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