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POROSITY, DENSITY, AND WATER
CONTENT DATA ON TUFF OF THE OAK
SPRING FORMATION FROM THE U12e
TUNNEL SYSTEM, NEVADA TEST SITE,
NYE COUNTY, NEVADA

By F. M. Byers, Jr.

Trace Elements Investigations Report 811

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ABSTRACT

This report summarizes the porosity, density, and water content data on about 200 tuff specimens from the Tunnel Beds which compose the lower member of the Oak Spring Formation of Miocene(?) or younger age at the U12e tunnel, Rainier Mesa, Nevada Test Site. The U12e tunnel penetrated from oldest to youngest: Tunnel Bed 1, Tunnel Bed 2, Tunnel Bed 3, and about the lower third of Tunnel Bed 4 of the tunnel beds. Average porosity of the tuff ranges from about 25 to 40 percent and generally increases stratigraphically upward. The natural-state bulk density ranges from about 2.10 grams per cubic centimeter (g/cc) in the oldest part to 1.85 g/cc in the youngest part, and varies inversely to the porosity. Average grain or mineral density mostly ranges from 2.3 to 2.5 g/cc, but the red tuff strata in Tunnel Bed 1 and in subunit A, Tunnel Bed 3, average about 2.6 g/cc. Average water content of saturated tuff units that are more than 1,000 feet in from the tunnel portal ranges from 14 to 21 percent by weight.

The data are pooled within nine stratigraphic groupings in table 2 and statistically significant differences are discussed, using the arithmetic mean, standard deviation, and two standard errors of the mean in table 3. Percent error of the mean within

two standard errors of the mean is also given in table 3 as an indication of the reliability of mean values for substitution in equations of state. Frequency distributions and the statistical parameters are shown graphically for each property and stratigraphic grouping in figures 3 to 5. Tables containing the statistically grouped data are appended in tables 4 to 12.

INTRODUCTION

Since July 1957, the U. S. Geological Survey has been measuring some of the physical properties of the tuffs from the Oak Spring Formation of Tertiary (Miocene(?) or younger) age that underlies U12e in Rainier Mesa, Nevada Test Site, Nye County, Nev. This report summarizes the porosity, density, and water content data obtained on tuff specimens from the U12e tunnel system (figs. 1 and 2) during the period May 1958 to March 1959. Part of these data were collected during the Hardtack test series in 1958 and were transmitted in preliminary reports (Diment and others, 1958 and 1959). Because some of these reports are no longer readily available for distribution and also contained errors, the corrected porosity, density, and water content data are included in this report.

The Nevada Test Site is in southeastern Nye County in the southern part of Nevada. (See inset, fig. 1.) The U12e tunnel area is in the northwestern part of the Test Site and can be reached by 45 miles of hard surface road from Mercury, the main headquarters, in the southern part of the Test Site (fig. 1).

116°00'

Figure 1.—Index map showing the tunnel area, Nevada Test Site, Nye County, Nevada.

FIGURE 2.--INDEX MAP SHOWING THE U12e TUNNEL SYSTEM, RAINIER MESA,
NEVADA TEST SITE, NYE COUNTY, NEVADA

1000 0 1000 FEET
Contour interval 200 feet, except 7600-foot contour also shown
Datum is mean sea level

The portal of the U12e tunnel is at an altitude of 6,115 feet on the east flank of Rainier Mesa (fig. 2). The porosity, density, and water content measurements were made in the Geological Survey laboratories, Denver, Colo., by R. N. Babcock, C. C. Hawley, G. R. Johnson, J. G. McGrath, F. H. Spence, and the author.

GENERAL GEOLOGIC SETTING

The geology of the U12e tunnel system and surrounding area has been described by Hansen and Lemke (1957), by Wilmarth, Houser, and Dickey (in Diment and others, 1959, p. 11-18), and by McKeown and Dickey (1960).

The rocks consist of dolomite of Paleozoic age and tuffs of the Tunnel Beds that constitute the lower member of the Oak Spring Formation of Tertiary (Miocene(?) or younger) age (Hinrichs and Orkild, 1961, p. 99) at the U12e tunnel. The Tunnel Beds consist of Tunnel Beds 1 through 4. Each Tunnel Bed is named in a formal stratigraphic sense to replace the old informal terminology but may actually be composed of as many as 50 beds or strata. The following table lists the symbols used informally in previous reports and correlates them with the present nomenclature:

Source	Designation			
TE Reports prior to TEI-772---	Tos ₁	Tos ₂	Tos ₃	Tos ₄
TEI-772-----	tr ₁	tr ₂	tr ₃	tr ₄
This report-----	Tunnel Bed 1	Tunnel Bed 2	Tunnel Bed 3	Tunnel Bed 4

The Tunnel Beds were further subdivided into lettered subunits during mapping of the U12e tunnels by McKeown and Dickey (1960, fig. 1). Some of the subunits are a single stratum; others may contain several strata. Thicknesses of the Tunnel Beds and subunits of the Tunnel Beds are given in table 1.

The Tunnel Beds dip 6° to 32° westerly to northwesterly so that the main U12e tunnel, which trends S. 65° W., intersects the strike at angles varying from 25° to 60° . The steep dips are in basal Tunnel Bed 1 near the tunnel portal and probably reflect in part the dip of the erosion surface on the dolomite that crops out at the portal. The low-angle dips are found in the strata that are exposed from about station 30400 and inward (McKeown and Dickey, 1960, fig. 1). From about station 38400 and inward the U12e tunnel crosses a succession of open folds with gentle dips.

COLLECTING AND PROCESSING SPECIMENS

Field sampling

The collection of a representative sample for average mass physical properties measurements is beset with a special sampling problem in addition to those normally encountered in sampling for chemical assay. A channel sample cut across the entire thickness of a stratum cannot be used to obtain average properties, because one fragment or one core must be processed in one piece and cannot be ground for quartering as is done in other analytical methods to obtain average values. Therefore, the term "specimen," rather than "sample," is used in this report for the small portion of the

Table 1.--Thicknesses of Tunnel Beds and subunits, lower member of
Oak Spring Formation, exposed in the U12e tunnel system,
Rainier Mesa, Nye County, Nev.

Unit	Subunit	Thickness (feet)
Tunnel Bed 4-----	G	30+
Do-----	F	30
Do-----	E	30
Do-----	D	12
Do-----	C	14
Do-----	B	7
Do-----	A	15
Subtotal-----		138+
Tunnel Bed 3-----	D	35
Do-----	C	75
Do-----	B	23
Do-----	A	38
Subtotal-----		171
Tunnel Bed 2-----	E	10
Do-----	D	5
Do-----	C	35
Do-----	B	40
Do-----	A	85
Subtotal-----		175
Tunnel Bed 1-----	K	15
Do-----	J	35
Do-----	I	20
Do-----	H	8
Do-----	G	35
Do-----	F	15
Do-----	E	7
Do-----	D	30
Do-----	C	15
Do-----	B	25
Do-----	A	85
Subtotal-----		290
Total thickness-----		774+

stratum taken for analysis. The term "sample" in this report conforms to the statistician's usage, which defines a group of specimens processed together in order to obtain common statistical parameters.

The method of sample collection, except for ten specimens, was uniform and preserved the natural-state water within the specimen. Grab specimens, weighing 1 to 5 kilograms, were wrapped in aluminum foil and placed in a polyethylene bag. The specimens were later sealed off from the air by melted paraffin. Ten specimens were taken from subunit F, Tunnel Bed 4, with a short-barrel, portable core drill (designed by C. R. Roach and J. G. McGrath, Physical Properties Laboratory, U. S. Geological Survey, Denver, Colo.), utilizing water. This procedure could have introduced water into partly saturated rock but other independent data had previously shown that the part of the tunnel wall from which these specimens came was saturated with natural-state water. Therefore, all data included here are comparable. Moreover the results of other experiments, data for which are not included in this report, have shown that grain or mineral densities obtained by the water-saturation method agree closely with the mineral densities obtained by such conventional means as pycnometer or mineral counts. The porosities measured on grab specimens, however, will be somewhat lower than those measured from well logging or in situ geophysical methods, inasmuch as open fractures, in addition to intergranular porosity, are determined by such measurements.

Laboratory procedure

A good review of several methods for determining porosity, density, and water content is given by Fancher, Lewis, and Barnes (1933, p. 67-80, 101-121). In general the water-saturation method gives the best reproducible values, although a few of the tuff specimens completely disaggregated within a few hours after being saturated with water.

The procedures used for making the physical properties measurements contained in this report differ in only minor details from those described in earlier reports. (See Diment and others, 1959, p. 33-37.) In brief, the procedures are as follows. Two hundred to 500 grams of a "natural-state" unfractured specimen, in one fragment if possible, is weighed. This wet or "natural-state" weight is designated M_{0f} . The specimen is then dried for at least 60 hours at 105°C and weighed again; the dry weight is designated M_{1f} . Water loss, in weight percent, at 105°C is calculated from the formula:

$$\text{Percent H}_2\text{O(wt)} = \frac{M_{0f} - M_{1f}}{M_{0f}} \times 100$$

This is the same value as H_2O- in a standard chemical analysis of a rock.

A core cylinder, 1 inch in diameter by 1 inch in length, was cut from each of the weighed fragments. The cores are redried to constant weight in about 16 hours at 105°C. The dry weight of the cores is designated M_{1c} . The cores are then saturated with water under a differential pressure of 1 atmosphere,

following which the saturated core is weighed in air and again suspended on a stirrup in water.

The three weighings, dry weight, M_{1c} , saturated weight, M_{2c} , and suspended weight, M_{3c} , are used to calculate the porosity, dry-bulk density, and grain density. The following formulae are used:

Volume of pores in core:

$$V_{pc} = M_{2c} - M_{1c}$$

Bulk volume of core:

$$V_{bc} = M_{2c} - M_{3c}$$

Volume of grains in core:

$$\begin{aligned} V_{gc} &= V_{bc} - V_{pc} \\ &= (M_{2c} - M_{3c}) - (M_{2c} - M_{1c}) \\ &= M_{1c} - M_{3c} \end{aligned}$$

Percent (by volume) porosity:

$$P = \frac{V_{pc}}{V_{bc}} = \frac{M_{2c} - M_{1c}}{M_{2c} - M_{3c}} (X 100)$$

Dry-bulk density:

$$D_{bd} = \frac{M_{1c}}{V_{bc}} = \frac{M_{1c}}{M_{2c} - M_{3c}}$$

Grain density:

$$D_g = \frac{M_{1c}}{V_{gc}} = \frac{M_{1c}}{M_{1c} - M_{3c}}$$

Natural-state bulk density, D_{bn} , is computed by a formula which relates the dry-bulk density, D_{bd} , to the original ("natural state") weight (M_{Of}) and the dry weight (M_{lf}) of the fragment,

$$D_{bn} = D_{bd} \times \frac{M_{Of}}{M_{lf}}$$

In order to compute the percent saturation of the pores, S , the percent of water by weight, $H_2O(wt)$, must first be converted to volume percent of water, $H_2O(V)$,

$$H_2O(V) = H_2O(wt) \times D_{bn}$$

whence,

$$S = \frac{H_2O(V)}{P} \times 100.$$

Data obtained by water-saturation method

The porosity, density, and water content data are individually presented in tables 4 through 12, appended to this report, under the following five headings:

Porosity, P , in volume percent.

Natural-state bulk density, D_{bn} , in g/cc.

Grain density, D_g , in g/cc.

Percent water content by weight, $H_2O(wt)$.

Percent saturation of the pores, S .

In order to convert percent water content by weight to water content by volume in centimeter-gram-second units, the following transformation may be used:

$$H_2O(V) \text{ (g/cc)} = \frac{H_2O(wt) \times D_{bn}}{100}$$

Dry-bulk density may also be obtained by the formula,

$$D_{bd} = D_{bn} - H_2O(V) \text{ (all in g/cc)}$$

Locations from which the specimens were collected are indicated in the tables. The sampling design was based on the stratigraphic position represented by the specimen or specimens rather than on precise tunnel locations, which mostly were determined by ease of accessibility and engineering restrictions at the time of sampling. From the descriptions given in the tables, it is possible, if desired, to plot specimen locations on the map of the U12e tunnel system contained in Trace Elements Investigations Report 772 (McKeown and Dickey, 1960, fig. 1).

STATISTICAL SUMMARY

Frequency distributions of grouped data

Porosity, density, and water content data of specimens from the Tunnel Beds of the Oak Spring Formation exposed in the U12e tunnel system are grouped according to stratigraphic position as shown in table 2.

No specimens were taken of subunits D and E, Tunnel Bed 2, representing a stratigraphic thickness of 15 feet. The greater

Table 2.--Summary of sample data, U12e tunnel, Rainier Mesa,
Nye County, Nev.

Stratigraphic grouping		Tunnel locations	Thickness (feet)	No. of porosity, density analyses	No. of water content analyses	Table numbers (appendix)
Tunnel Bed	Subunits					
4	F	U12e, U12e.04, and U12e.04p	30	21	21	11 and 12
4	E	U12e	30	8	8	10
4	A-D	U12e	48	14	14	10
3	D	U12e	35	24	30	9
3	D	U12e.05	35(?)	31	34	8
3	B-C	U12e.05	98	34	34	7
3	A	U12e.02 and U12e.05	38	20	22	6
2	A-C	U12e	160	13	15	5
1	A-K	U12e	290	31	41	4

Total no. of analyses-----196

219

number of specimens analyzed for water content, $H_2O(wt)$, is due to the fact that some of the cores, on which porosity and density are measured, disaggregated during water-saturation procedure. The more refined stratigraphic groupings within Tunnel Beds 3 and 4 are made because the nuclear detonations in the U12e.02 and U12e.05 tunnels affected these units. Tunnel Beds 1 and 2 were not sampled as extensively; hence they are not further subdivided for comparisons between the physical properties.

Frequency distributions of the data within the pooled stratigraphic groupings given in table 2 are shown by means of histograms on figure 3 (in pocket). In general, most of the data fall in about 5 classes, but small samples with narrow ranges are contained in as few as 2 classes. The larger class interval of 10 percent, for percent saturation of pores, is used in those histograms of Tunnel Beds 1 and 2 because of their generally lower and wider range of saturation as compared with the narrow range and essentially saturated condition of Tunnel Beds 3 and 4.

Statistical parameters used to generalize data

The statistical parameters used in this report to summarize the data within the chosen stratigraphic groupings are the arithmetic mean, $\bar{X}$, the standard deviation, s , and two standard errors of the mean, $2s_{\bar{X}}$. The data are summarized statistically in figure 3 and in table 3. The percent error or variation of the mean within two standard errors is also given in table 3; it

Table 3.--Statistical summary of porosity, density, and water content, Tunnel Beds, lower member of Oak Spring Formation, U12e tunnel complex, Rainier Mesa, Nye County, Nev.

$\bar{n}$ = number of specimens in sample; number of specimens analyzed for water content are greater in some samples owing to disintegration of cores following the determination of water content.

To obtain dry bulk density, multiply weight percent of water (H_2O_{wt}) by natural-state bulk density (D_{bn}), divide by 100, and subtract from natural-state bulk density (D_{bn}). To obtain water content by volume, multiply weight percent of water (H_2O_{wt}) by natural-state bulk density (D_{bn}) and divide by 100 to convert to grams per cubic centimeter (g/cc).

Two standard errors of the mean, given by the formula $2s_{\bar{x}} = 2s/\sqrt{n}$. It is approximately equal to confidence limits at the 95 percent level. Percent error of mean = $2s_{\bar{x}}/\bar{x} \times 100$; percent error or percent variation of two standard errors of the mean with respect to the mean. This is the percent error of the mean at approximately the 95 percent level of confidence.

Stratigraphic grouping (see figs. 3, 4, and 5)	Porosity (P) (volume percent)	Grain density (D_g) (g/cc)	Natural-state bulk density (D_{bn}) (g/cc)	Water content (H_2O) (weight percent)	Percent saturation of pores (S)
Subunit F, Tunnel Bed 4 (n = 21)					
Arithmetic mean, $\bar{x}$	38.6	2.39	1.86	21.4	103.2
Standard deviation, s	± 4.5	± 0.05	± 0.06	± 2.7	± 6.5
Two standard errors, $2s_{\bar{x}}$	± 2.0	± 0.022	± 0.026	± 1.2	± 2.8
Percent error of mean	± 5.2	± 0.9	± 1.4	± 5.6	± 2.1
Subunit E, Tunnel Bed 4 (n = 8)					
Arithmetic mean, $\bar{x}$	31.4	2.38	1.96	16.8	105.3
Standard deviation, s	± 2.2	± 0.06	± 0.03	± 0.7	± 10.1
Two standard errors, $2s_{\bar{x}}$	± 1.6	± 0.044	± 0.020	± 0.5	± 7.8
Percent error of mean	± 5.1	± 1.8	± 1.0	± 3.0	± 7.4
Subunits A to D, Tunnel Bed 4 (n = 14)					
Arithmetic mean, $\bar{x}$	37.0	2.42	1.89	19.5	99.1
Standard deviation, s	± 3.7	± 0.04	± 0.07	± 2.9	± 8.6
Two standard errors, $2s_{\bar{x}}$	± 1.7	± 0.024	± 0.04	± 1.6	± 4.8
Percent error of mean	± 4.7	± 1.0	± 2.1	± 8.2	± 4.8
Subunit D, Tunnel Bed 3 (n = 24)				(n = 30)	(n = 24)
Arithmetic mean, $\bar{x}$	32.3	2.48	1.98	15.2	92.9
Standard deviation, s	± 2.9	± 0.06	± 0.08	± 1.5	± 6.8
Two standard errors, $2s_{\bar{x}}$	± 1.4	± 0.028	± 0.032	± 0.6	± 2.8
Percent error of mean	± 4.7	± 1.1	± 1.6	± 3.9	± 3.0
Subunit D, Tunnel Bed 3 (n = 31)				(n = 34)	(n = 31)
Arithmetic mean, $\bar{x}$	33.4	2.45	1.96	16.8	98.4
Standard deviation, s	± 1.8	± 0.04	± 0.04	± 1.8	± 3.3
Two standard errors, $2s_{\bar{x}}$	± 0.6	± 0.014	± 0.014	± 0.6	± 1.2
Percent error of mean	± 1.8	± 0.6	± 0.7	± 3.6	± 1.2
Subunits B and C, Tunnel Bed 3 (n = 34)					
Arithmetic mean, $\bar{x}$	33.6	2.31	1.86	18.6	103.2
Standard deviation, s	± 5.0	± 0.09	± 0.09	± 2.9	± 7.5
Two standard errors, $2s_{\bar{x}}$	± 1.8	± 0.030	± 0.03	± 1.0	± 2.6
Percent error of mean	± 5.4	± 1.3	± 1.6	± 5.3	± 2.5
Subunit A, Tunnel Bed 3 (n = 20)				(n = 22)	(n = 20)
Arithmetic mean, $\bar{x}$	30.6	2.60	2.11	14.3	97.1
Standard deviation, s	± 7.1	± 0.037	± 0.13	± 3.8	± 6.9
Two standard errors, $2s_{\bar{x}}$	± 3.2	± 0.016	± 0.06	± 1.6	± 3.0
Percent error of mean	± 10.5	± 0.6	± 2.8	± 11.2	± 3.2
Tunnel Bed 2 (n = 13)				(n = 15)	(n = 13)
Arithmetic mean, $\bar{x}$	32.3	2.45	1.94	14.9	87.8
Standard deviation, s	± 3.7	± 0.06	± 0.07	± 3.4	± 19.2
Two standard errors, $2s_{\bar{x}}$	± 2.1	± 0.032	± 0.04	± 1.8	± 10.8
Percent error of mean	± 6.5	± 1.3	± 2.1	± 12.1	± 12.3
Tunnel Bed 1 (n = 31)				(n = 41)	(n = 31)
Arithmetic mean, $\bar{x}$	24.8	2.57	2.10	8.4	69.9
Standard deviation, s	± 4.6	± 0.07	± 0.14	± 3.6	± 28.3
Two standard errors, $2s_{\bar{x}}$	± 1.6	± 0.024	± 0.05	± 1.2	± 10.2
Percent error of mean	± 6.5	± 0.9	± 2.4	± 14.3	± 14.6

should be noted that this percent error or variation for grain density is nearly an order of magnitude lower than that for porosity. These "errors" are used in the statistician's sense; replication studies and analysis of variance of the data have demonstrated that, with the exception of grain density, the errors summarized in table 3 are largely the result of actual variation of the properties measured within the tuff. Sampling and laboratory "errors" contribute only a small fraction to the total variation, except for grain density, whose actual between specimen variance is so low, as shown by replicate analyses, that laboratory errors may form a significant amount of the total variance.

Two standard errors of the mean, rather than confidence interval of the mean at the 95 percent level, are used to define the reliability interval of the arithmetic mean. However, for any number, n , of specimens in the sample suite greater than about 12, two standard errors of the mean will approach or approximate the confidence interval at the 95 percent level for population distributions that do not depart markedly from normal. (See discussion in Croxton and Cowden, 1939, p. 307-317; Waugh, 1952, p. 256-261). For any number of specimens fewer than 12 the approximation of the two standard errors formula (headnote, table 3) falls somewhat short of a 95 percent confidence interval. If the number, n , is as small as 8, the number of specimens taken of subunit E, Tunnel Bed 4, two standard

errors of the mean would include a confidence interval at about the 92 percent level. (See R. A. Fisher's table of t, in Arkin and Colton, 1950, p. 116).

Discussion of results

The means and their two standard errors for the porosity, density, and water content of the selected stratigraphic groupings in the U12e tunnel system are directly comparable in figures 4 and 5. Significant differences between means at about the 95 percent level or slightly less are inferred if the horizontal arrows showing the spread of two standard errors, $2s_x$, do not overlap.

Several significant differences are at once apparent in figures 4 and 5 between the physical property means of the stratigraphic groupings. For example, the average porosity tends to increase with increasing height in the stratigraphic column (fig. 4), although the low porosity of subunit E, Tunnel Bed 4, stands out against this general trend. Both the grain density and the natural-state bulk densities of Tunnel Bed 1 and subunit A, Tunnel Bed 3, are significantly higher than those of any of the other stratigraphic groupings. The water content and percent saturation of Tunnel Bed 1 are significantly lower than those of stratigraphically higher units penetrated farther from the ground surface and suggests that the lower water content of Tunnel Bed 1 may be related to nearness of the surface. Finally, two special features of the water content variation of the tuffs in the interior

Figure 4.--Plots of arithmetic means and ranges of two standard errors of the means for porosity and density in lower part of Oak Spring Formation, U12e tunnel system, Rainier Mesa, Nye County, Nevada.

Figure 5.—Plots of arithmetic means and ranges of two standard errors of the means for water content in lower part of Oak Spring Formation, U12e tunnel system, Rainier Mesa, Nye County, New Mexico.

of Rainier Mesa should be noted; namely, the apparent supersaturation of the pores of some specimens and the possible drying out of the tuffs as a result of the Blanca nuclear explosion. These two features will be discussed briefly.

The water content should be directly related to percent porosity (compare graphs in figs. 4 and 5), if the pores are saturated. The pores of tuff strata of Tunnel Beds 3 and 4 are about 100 percent saturated. Some specimens, however, have an apparent supersaturation of as much as 125 percent. One interpretation of supersaturation of the pores is that the excess water comes from the mineral grains, such as the zeolites. Apparent supersaturation, however, may result from the fact that in a fully saturated fragment, the core cylinder for porosity determination may have been cut from the most indurated part having lowest porosity. Studies of a series of two replicate cores cut from each specimen have demonstrated that the porosity may vary considerably, even within a single specimen. This wide variation of porosity in some specimens would more than account for the apparent supersaturation indicated, particularly in Tunnel Beds 3 and 4. Possibly part of the porosity being measured by the water-saturation method is within the zeolite crystal structure.

The percent saturation mean of subunit D, Tunnel Bed 3, in the main U12e tunnel is significantly lower than the mean of the same subunit, based on specimens from U12e.05 tunnel (fig. 5). The specimens of subunit D, Tunnel Bed 3, in U12e.05 were

collected as the tunnel advanced; those in the U12e tunnel were collected 2 to 3 months after the Blanca explosion and 1 to 20 days after the U12e tunnel had been advanced past the specimen sites. Specimens U12e-2865, -2875, -2885, and -2895 (table 9), however, were collected within 24 hours after the round had been shot, and the percent saturation of these specimens is as follows: 93.1, 89.2, 89.4, and 90.4, which are slightly below the mean of other specimens from this subunit in the U12e tunnel. One possible interpretation of the lower saturation of the post-Blanca suite is that intergranular water drained through fractures opened at the time of the Blanca explosion. Better experimental design is needed, however, before this hypothesis could be proved.

Nonstatistical summary and conclusions

In nonstatistical terms, the following conclusions are reached from porosity, density, and water content data obtained on about 200 specimens of tuff from the Tunnel Beds of the Oak Spring Formation (tables 3 through 12).

1. Average porosities of nine stratigraphic groupings within the Tunnel Beds of Oak Spring Formation generally increase stratigraphically upward with one or two reversals to this general trend; the porosities range from about 25 percent for the lowest grouping (Tunnel Bed 1) to nearly 40 percent for the highest (subunit F, Tunnel Bed 4).

2. Average natural-state bulk densities, in general, show a trend opposite to that for porosity because the more porous beds tend to be lower in bulk density. The beds ranging from 25 to 30 percent porosity have natural-state bulk densities of about 2.10 g/cc; those ranging from 30 to 40 percent porosity in general have natural-state bulk densities ranging from 1.85 to 2.00 g/cc. The effect of the grain density on natural-state bulk density is minor compared to that of porosity. The natural-state bulk densities were determined mainly on water-saturated tuff.

3. Grain density shows no trend with respect to stratigraphic position. Red strata have a higher grain density (2.57 to 2.64 g/cc) than the lighter colored strata which range from 2.30 to 2.48 g/cc. The higher grain density of the red strata may be due to greater proportion of quartz and feldspar and less clay and zeolite minerals, which have a low density.

4. The percentage of water ranges from 8 to 21 percent by weight and, like porosity, generally increases in the younger stratigraphic groupings. The low values associated with Tunnel Bed 1 is due not only to its low porosity but also to the fact that it is not completely saturated.

5. The percent saturation of the pores is close to 100 percent for all stratigraphic units except the lowermost (Tunnel Bed 1), which is only 70 percent saturated. This lower degree of saturation is also associated with the group of specimens taken

nearest the U12e tunnel portal. At depth it is expected that Tunnel Bed 1 would be saturated like the other units.

6. One stratum, subunit D, Tunnel Bed 3, has a relatively narrow range of physical properties compared to other subunits and would provide an excellent control stratum for studying the effects of nuclear blasts on tuffs. Water-content data on two suites of specimens from this stratum--one taken before the Blanca explosion and the other taken after the explosion--suggest that the explosion may have caused a slight or partial dessication of the pores at distances ranging from 400 to 600 feet from the shot point. Pre-shot or original lateral variation in water saturation, however, cannot be ruled out, but seems less likely, in view of the pre-shot saturated condition of the rocks at that depth.

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Table 4.--Porosity, density, and water content of specimens from Tunnel Bed 1, Oak Spring Formation, U12e tunnel, Rainier Mesa, Nye County, Nev.

The specimen number following U12e- is numerically equal to the distance in feet from the U12e tunnel portal. Specimens ending in R (right wall of tunnel facing inward) or L (left wall) collected by G. A. Izett, July 23-24, 1958, on even 50-foot intervals. Other specimens collected by A. B. Gibbons, May 22 to June 17, 1958.

Subunits after McKeown and Dickey (1960, fig. 1). Thicknesses scaled from their map and given in table 1, this report.

To convert weight percent of water (H_2O_{wt}) to weight/volume ratio (g/cc) multiply by natural-state bulk density (D_{bn}) and divide by 100.

Lithologic descriptions largely from specimens; bedding descriptions from U. S. Geological Survey notebook of G. A. Izett.

Abbreviations: VF, very fine; F, fine; M, medium; C, coarse; VC, very coarse.

Asterisk (*) indicates disaggregated during water-saturation procedure.

Specimen number U12e-	Subunit	Date collected (1958)	Porosity (P) (volume percent)	Natural-state bulk density (D_{bn}) (g/cc)	Grain density (D_g) (g/cc)	Water content (H_2O) (weight percent)	Percent saturation of pores (S)	Lithologic description (color is of dry specimen)
1050R	K	7/24	24.6	2.12	2.63	6.6	57.3	Reddish-orange M to C sandy tuff; bedded.
1000R	K	7/24	23.1	2.16	2.50	11.0	103.0	Light-red, F to M tuff, less sandy than above; massive.
950R	J	7/24	22.4	2.22	2.55	10.8	107.1	Light pinkish-gray, M to C sandy tuff; poorly bedded.
900R	J	7/24	*	*	*	8.6	*	Light pinkish-gray, M to VC, sandy friable tuff; poorly bedded.
880	J	6/17	*	*	*	14.5	*	Similar to above.
850L	J	7/24	28.1	2.14	2.61	12.3	93.2	Red, F, hard tuff.
843	J	6/16	23.1	2.19	2.52	11.6	110.4	Similar to specimen above.
830	J	6/14	18.1	2.26	2.54	8.3	114.2	Red, F, hard tuff, less sandy than specimen 850L above.
804	J	6/13	27.2	2.09	2.57	10.4	79.9	Pale-red, F to M, hard tuff.
800R	J	7/24	25.2	2.15	2.55	11.7	99.2	Red, F to M, tuff; water seeps from fractures.
771	J	6/12	20.7	2.25	2.59	8.9	97.0	Pale-red, M to VC, hard tuff.
750R	J	7/24	24.7	2.21	2.63	10.4	93.1	Grayish-red, granular tuff.
738	I	6/11	*	*	*	7.0	*	Mottled pale-red and red, F, friable tuff; well-bedded.
700R	I	7/24	25.1	2.12	2.57	8.8	74.5	Reddish-orange, M to VC, friable tuff; well-bedded.
650R	I	7/24	18.9	2.17	2.60	3.0	34.4	Pale reddish-brown, M to VC tuff; sparse lithic fragments up to 7 mm; poorly bedded.
600R	H	7/24	23.0	2.11	2.54	6.9	63.5	Pale reddish-brown, F to M, friable tuff; bedded.
561	G	6/3	*	*	*	13.6	*	Finely mottled pale reddish-brown and pink clayey tuff.
550R	G	7/24	27.4	2.11	2.63	9.5	73.0	Similar to specimen above.
533	G	6/2	15.5	2.40	2.66	8.9	94.5	Finely mottled reddish-brown and orange, F to C tuff, sparse pink altered pumice fragments.
508	G	6/2	*	*	*	9.8	*	Finely streaked reddish-brown and pink, M tuff.
500R	G	7/24	22.5	2.09	2.45	9.3	86.2	Reddish-orange, M to C, sandy friable tuff.
450R	G	7/24	23.0	2.15	2.64	5.0	51.3	Finely mottled reddish-brown and orange, M to C tuff, sparse white pumice fragments.
434	G	5/29	*	*	*	10.2	*	Pale reddish-brown, F, sandy friable tuff.
418	G	5/28	*	*	*	13.7	*	Similar to above.
410	G	5/28	25.7	1.93	2.49	6.8	51.0	Banded pale purplish-red and pink VF, hard tuff.
400	G	5/26	36.4	1.68	2.49	4.1	18.7	Pale-red tuff; abundant white pumice; rare lithic and crystal fragments.
400R	G	7/24	31.1	1.95	2.62	7.9	49.5	Pale reddish-brown, F to M tuff; common white pumice; sparse sandy fragments.
380	F	5/27	24.8	2.19	2.64	9.5	84.4	Reddish-orange, VF to F, tuff.
363	F	5/26	30.3	1.98	2.48	12.6	82.5	Pink, F to M, tuff; rare white pumice; common sandy fragments.
350R	F	7/24	28.2	1.99	2.62	5.4	37.9	Reddish-brown, M to C tuff; common white pumice and sandy fragments; well-bedded.
340	E	5/24	27.6	1.99	2.57	6.9	50.3	Grayish-red, M to C tuff.
326	D	5/24	28.6	1.94	2.34	13.7	93.0	Pink, M to C tuff, sparse biotite flakes.
323	D	5/23	*	*	*	7.6	*	Light-red, M to C tuff, sparse biotite flakes.
320	D	5/22	28.0	2.00	2.49	9.7	69.8	Pink, VF to F hard tuff, sparse biotite flakes.
300R	D	7/23	*	*	*	5.3	*	Pink, M to C, tuff, sparse biotite flakes.
288	D	5/22	28.3	2.02	2.61	7.3	53.0	Mottled pale-red and pale reddish-brown granular tuff; abundant lithic fragments.
250R	D	7/23	*	*	*	8.6	*	Pale red-brown, friable tuff, abundant white pumice fragments.
200R	C	7/23	22.7	2.18	2.63	7.1	67.8	Reddish-brown hard tuff, M to VC, sparse lithic and pumice fragments.
150R	B	7/23	13.7	2.32	2.65	1.4	24.1	Grayish-red, F to C, very hard tuff.
100R	A	7/23	28.7	2.00	2.62	6.7	47.0	Light reddish-brown, F, well-sorted tuff; well-bedded.
50R	A	7/23	23.3	1.95	2.52	0.9	7.3	Pale purplish-red, hard scoriaceous tuff.
Arithmetic mean, $\bar{x}$			24.8	2.10	2.57	8.4	69.9	
One standard deviation, s			± 4.6	± 0.14	± 0.07	± 3.6	± 28.3	
Two standard errors of the mean, $2s_{\bar{x}}$			± 1.6	± 0.05	± 0.024	± 1.2	± 10.2	
Probable means of saturated rock at depth			24.8	2.18	2.57	12.9	100.0	

Subunits after McKeown and Dickey (1960, fig. 1). Thicknesses scaled from their map and given in table 1, this report.

Table 5.--Porosity, density, and water content of specimens from Tunnel Bed 2, Oak Spring Formation, U12e tunnel, Rainier Mesa, Nye County, Nev.

The specimen number following U12e- is numerically equal to the distance in feet from the U12e tunnel portal. R, right wall of tunnel; L, left wall. Specimens collected by G. A. Izett, U. S. Geological Survey. Subunits after McKeown and Dickey (1960, fig. 1). Thickness scaled from their map and given in table 1, this report. Lithologic descriptions largely from specimens; bedding descriptions from U. S. Geological Survey notebook of G. A. Izett. Abbreviations: VF, very fine; F, fine; M, medium; C, coarse; VC, very coarse. Asterisk (*) indicates disaggregated during water-saturation procedure. To convert weight percent of water to weight-volume ratio (g/cc) multiply by natural-state bulk density (D_{bn}) and divide by 100.7

Specimen number U12e-	Subunit	Porosity (P) (volume percent)	Natural-state bulk density (D_{bn}) (g/cc)	Grain density (D_g) (g/cc)	Water content (H_2O) (weight percent)	Percent saturation of pores (S)	Lithologic description (color is of dry specimen)
1755R	C	28.9	1.99	2.37	15.5	106.2	Light yellowish-gray, M to VC tuff.
1708L	C	28.1	2.04	2.43	14.3	103.9	Light yellowish-brown granular tuff with white pumice fragments.
1675R	B	34.2	1.99	2.54	15.9	92.7	White, M to C, salt and pepper tuff.
1600R	B	34.5	1.93	2.48	16.0	89.6	Light purplish-gray, M to VC tuff; abundant lithic fragments.
1550R	B	37.4	1.87	2.43	18.8	94.1	Light purplish-gray, F to M tuff; purplish volcanic and quartzite fragments.
1500R	B	25.4	1.99	2.51	6.0	46.9	Purple and gray-streaked pisolitic marker tuff.
1450R	A	29.2	1.98	2.37	15.1	102.4	White, hard, M to C tuff, sparse lithic fragments.
1435R	A	*	*	*	17.6	*	White, VF to F, friable salt and pepper tuff.
1400R	A	33.8	1.95	2.43	17.3	99.7	Purplish-gray tuff with pumice and lithic fragments as much as 1 cm.
1350R	A	29.8	2.04	2.49	14.7	100.3	Purplish-gray, M to C, pumiceous tuff; rare lithic fragments.
1300R	A	*	*	*	14.8	*	Purplish-white, M to C, friable pumiceous tuff.
1250R	A	35.5	1.88	2.38	18.2	96.6	Light reddish-purple, M to VC, pumiceous tuff.
1200R	A	35.3	1.79	2.37	14.8	74.8	Light-purple tuff; abundant pumice as much as 7 mm rare lithic fragments.
1150R	A	36.3	1.89	2.49	15.9	82.9	Light-purple tuff, abundant pumice as much as 2 mm sparse lithic fragments.
1100R	A	31.5	1.88	2.52	8.6	51.4	Purple tuff, speckled with abundant white pumice as much as 4 mm.
Arithmetic mean, $\bar{X}$ ---		32.3	1.94	2.45	14.9	87.8	
One standard deviation, s-----		± 3.7	± 0.07	± 0.06	± 3.4	± 19.2	
Two standard errors of the mean, $2s$ --- $\bar{X}$		± 2.1	± 0.04	± 0.032	± 1.8	± 10.8	

Table 6.--Porosity, density, and water content of specimens of subunit A, Tunnel Bed 3, Oak Spring Formation, U12e.02 (pre-Logan) and U12e.05 (pre-Blanca) tunnels, Rainier Mesa, Nye County, Nev.

The number following the tunnel designation is numerically equal to the distance in feet from the tunnel entrance. R, right; L, left. To convert weight percent of water (H_2O_{wt}) to weight-volume ratio (g/cc) multiply by natural-state bulk density (D_{bn}) and divide by 100. Asterisk (*) indicates disaggregated during water-saturation procedure.

Specimen number	Porosity (P) (volume percent)	Natural-state bulk density (D_{bn}) (g/cc)	Grain density (D_g) (g/cc)	Water content (H_2O) (weight percent)	Percent saturation of pores (S)
U12e.02-0	14.3	2.37	2.62	5.4	89.7
-50	*	*	*	16.3	*
-100	35.8	1.98	2.63	14.3	79.1
-150	35.0	2.02	2.63	15.4	88.7
-200	33.7	2.09	2.64	16.0	99.2
-250	28.9	2.16	2.64	13.0	97.3
-300	30.2	2.14	2.63	14.2	100.6
-350	28.7	2.17	2.63	13.4	101.6
-400	33.9	2.06	2.57	17.2	104.4
-450	34.5	2.04	2.61	16.3	96.8
-500	25.5	2.18	2.61	10.7	91.2
-525	25.7	2.22	2.62	12.5	107.7
-550	38.1	2.01	2.63	18.8	98.9
-575	34.2	2.00	2.58	15.1	88.3
-600	33.8	2.03	2.57	16.3	97.5
-625	33.7	2.04	2.58	16.3	98.4
-652	35.2	2.01	2.58	16.7	95.0
-673L	18.4	2.31	2.61	8.0	100.0
-673R	39.2	1.95	2.57	19.9	98.8
U12e.05-25	*	*	*	12.7	*
-50	16.3	2.36	2.62	7.2	104.7
-100	35.9	1.96	2.48	19.1	104.2
Arithmetic mean, $\bar{X}$ -----	30.6	2.11	2.60	14.3	97.1
One standard deviation, s---	± 7.1	± 0.13	± 0.037	± 3.8	± 6.9
Two standard errors of the mean, $2s_{\bar{X}}$ -----	± 3.2	± 0.06	± 0.016	± 1.6	± 3.0

Table 7.--Porosity, density, and water content of specimens of subunits B and C, Tunnel Bed 3, Oak Spring Formation, U12e.05 tunnel, Rainier Mesa, Nye County, Nev.

The specimen number is numerically equivalent to the distance from the entrance to U12e.05 tunnel. The letter "R" preceding sample number indicates oriented sample for permeability measurement.

Letters of subunits and detailed thicknesses of strata are taken from the stratigraphic section of F. N. Houser and V. R. Wilmarth (in Diment et al, 1959, p. 56-70). See also McKeown and Dickey (1960, fig. 1). Lithologic descriptions modified to fit individual specimens selected for the above analyses.

To convert weight percent of water (H_2O_{wt}) to weight-volume ratio (g/cc) multiply by natural-state bulk density and divide by 100.

Specimen number U12e.05-	Subunit	Thickness of stratum (feet)	Porosity (P) (volume percent)	Grain density (D_g) (g/cc)	Natural-state bulk density (D_{bn}) (g/cc)	Water content (H_2O) (weight percent)	Percent saturation of pores (S)	Lithologic description (color is of dry specimen)
-698	C	3.5	30.7	2.21	1.86	17.5	106.1	Pinkish-gray tuff.
-688	C	1.0	32.5	2.31	1.87	16.8	97.0	Fine soft tuff, pinkish-gray.
-R689	C	6.5	28.8	2.13	1.82	16.8	106.2	Fine tuff.
-661			33.8	2.33	1.86	17.0	93.2	Coarse tuff.
-660	C	2.5	28.5	2.18	1.87	16.7	109.4	Fine to coarse light-gray tuff.
-R616	C		26.4	2.28	1.96	14.6	108.1	Fine and coarse tuff.
-605	*	7.5	32.2	2.15	1.75	16.6	90.0	Fine even-textured tuff.
-583			40.9	2.41	1.81	21.1	93.5	Coarse granular tuff.
-534	C		39.5	2.32	1.78	21.1	95.0	Light-gray coarse tuff.
-525		9.5	25.0	2.23	1.93	13.1	100.5	Hard red bed.
-518			36.9	2.32	1.80	18.6	90.5	Indistinctly laminated tuff.
-520			31.5	2.28	1.89	17.4	104.3	Greenish-gray medium-grained tuff.
-492	C		25.4	2.41	2.07	12.9	104.5	Hard red tuff, 0.8 foot thick.
-487		8.5	24.8	2.32	2.03	14.1	115.2	Reddish-gray tuff.
-477			33.6	2.23	1.87	20.7	115.1	Greenish-gray tuff.
-465			37.6	2.23	1.79	22.4	106.3	Gray coarse tuff.
-445	C		32.3	2.30	1.87	16.9	98.2	Gray tuff mottled with red.
-435		5.5	36.6	2.39	1.88	19.4	99.5	Red pumiceous tuff.
-425			33.1	2.32	1.90	18.6	107.0	Gray tuff streaked with red.
-415	C		34.4	2.34	1.86	17.7	96.0	Coarse reddish tuff with pumice fragments.
-390		8.5	39.6	2.38	1.86	22.9	107.5	Fine tuff with few coarse subangular quartzite grains.
-380	C	1.4	38.9	2.28	1.79	22.0	101.0	Coarse tuff, moderately hard.
-370	C		39.6	2.37	1.82	21.4	98.8	Coarse tuff.
-365		4.0	36.8	2.34	1.86	20.2	102.0	Coarse banded tuff.
-315	C	5.0	41.8	2.34	1.75	22.4	93.6	Fine tuff.
-305	C	5.8	36.7	2.20	1.80	22.6	110.9	Coarse tuff, red mottled with gray.
-271	C		36.3	2.24	1.82	21.3	106.7	Coarse tuff, gray mottled with red.
-272		5.0	29.8	2.31	1.97	17.5	115.1	Fine tuff, gray and red.
-254	B	5.0	32.4	2.33	1.93	18.6	111.1	Coarse tuff, gray and red mottled.
-242	B	2.0	36.1	2.26	1.84	21.5	109.4	Coarse tuff, gray.
-235	B	5.0	23.0	2.52	2.18	11.1	105.2	Red, hard, fine tuff, mottled with coarse purple tuff.
-210	B	3.5	33.3	2.27	1.89	20.2	115.3	Coarse purplish tuff, common pumice fragments.
-200	B	8.0	37.8	2.42	1.85	18.9	92.6	Fine and coarse banded tuff, light-gray and red.
-130	B	11.1	37.4	2.46	1.93	20.2	104.6	Coarse tuff, purplish-red, with common pumice fragments.
Arithmetic mean, $\bar{X}$ -----			33.6	2.31	1.86	18.6	103.2	
One standard deviation, s-----			± 5.0	± 0.09	± 0.09	± 2.9	± 7.5	
Two standard errors of the mean, $2s$ -----			± 1.8	± 0.03	± 0.03	± 1.0	± 2.6	

*This sample is from unit in Blanca shot chamber; original shot chamber at end of tunnel was abandoned and moved to point 600 feet from entrance of U12e.05 tunnel.

Table 8.--Porosity, density, and water content of specimens from subunit D, Tunnel Bed 3, Oak Spring Formation, U12e.05 tunnel, Rainier Mesa, Nye County, Nev.

$\bar{R}$, 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 indicates oriented sample collected for permeability measurements.

Sample numbers in original shot chamber at end of tunnel are equal to distances in feet from right-angle turnoff station. This chamber was abandoned and Blanca was detonated at a point 600 feet from entrance of U12e.05 tunnel. The physical properties for the rocks enclosing the Blanca shotpoint are given in table 7, samples U12e.05-583 to -R616.

To convert weight percent of water (H_2O_{wt}) to weight-volume ratio (g/cc) multiply by natural-state bulk density (D_{bn}) and divide by 100./

Specimen number	Location (distance from entrance of U12e.05) (feet)	Porosity (P) (volume percent)	Grain density (D_g) (g/cc)	Natural-state bulk density (D_{bn}) (g/cc)	Water content (H_2O) (weight percent)	Percent saturation of pores (S)
05-800	Alcove (800)	35.5	2.48	1.95	17.9	98.5
05-826	Alcove (826)	36.7	2.48	1.93	18.6	97.8
05L-50R	817(R)	34.3	2.48	1.99	18.0	104.2
05L-100R	867(R)	34.2	2.45	1.95	17.3	98.6
05L-116L	883(L)	32.2	2.49	2.01	15.8	99.0
05L-142R	909(R)	35.0	2.44	1.91	16.5	89.9
05L-163R	930(R)	30.3	2.50	2.03	14.2	95.2
05L-168L	935(L)	31.4	2.41	1.97	16.0	100.4
05L-170L	937(L)	32.9	2.48	1.97	15.6	93.0
05L-171C	938(C)	*	*	*	12.8	*
05L-R171C	938(C)	32.7	2.44	1.96	16.3	97.6
05L-R179L	946(L)	35.9	2.47	1.92	17.8	95.6
05L-180R	947(R)	33.2	2.46	1.96	16.2	95.2
05L-198R	965(R)	31.0	2.46	1.98	14.4	92.0
05L-198C	965(C)	32.6	2.50	2.01	16.1	99.6
05L-198L	965(L)	33.7	2.48	1.97	16.8	98.5
05L-R198	965(L)	32.3	2.46	1.97	15.8	96.8
05L-220R	987(R)	*	*	*	22.6	*
05L-220L	987(R)	31.6	2.47	2.01	15.8	100.6
05L-234C	1001(C)	32.5	2.47	2.00	16.8	103.5
05S-12L	Original chamber	35.3	2.43	1.92	18.2	99.0
05S-13R	do	33.9	2.34	1.87	17.4	96.0
05S-16R	do	32.1	2.47	2.00	16.2	101.3
05S-21L	do	35.0	2.39	1.92	18.9	103.6
05S-22R	do	32.3	2.40	1.97	17.3	105.5
05S-22L	do	32.6	2.41	1.95	16.7	100.1
05S-R23R	do	37.8	2.42	1.88	20.0	99.8
05S-25R	do	34.2	2.41	1.92	17.6	98.6
05S-28L	do	30.6	2.41	1.99	15.5	100.7
05S-29R	do	34.7	2.44	1.94	18.0	100.4
05S-34L-1	do	*	*	*	14.8	*
05S-34L-2	do	31.8	2.45	1.98	15.7	98.0
05S-R34C	do	35.6	2.43	1.91	18.0	96.6
05S-34R-1	do	31.9	2.43	1.96	15.6	96.4
Arithmetic mean, $\bar{X}$ -----		33.4	2.45	1.96	16.8	98.4
One standard deviation, s -----		± 1.8	$\pm .04$	$\pm .04$	± 1.8	± 3.3
Two standard errors of the mean, $2s$ --		± 0.6	$\pm .014$	$\pm .014$	± 0.6	± 1.2
		$\bar{X}$				

*Asterisk indicates disaggregated during water absorption.

Table 9.--Porosity, density, and water content of specimens, subunit D, Tunnel Bed 3,
Oak Spring Formation, U12e tunnel, Rainier Mesa, Nye County, Nev.

The number following U12e- is numerically equal to the distance in feet from the U12e tunnel portal; all specimens taken on the right side of tunnel; R, red; B, black. Asterisk (*) indicates disintegrated during water saturation. To convert weight percent of water (H_2O_w) to weight-volume ratio (g/cc) multiply by natural-state bulk density (D_{bn}) and divide by 100.

Specimen number U12e-	Porosity (P) (volume percent)	Natural-state bulk density (D_{bn}) (g/cc)	Grain density (D_g) (g/cc)	Water content (H_2O) (weight percent)	Percent saturation of pores (S)
2765	33.0	2.01	2.54	15.6	95.4
2775	33.6	1.95	2.51	14.6	84.6
2785	31.3	2.02	2.53	13.8	88.9
2795	*	*	*	17.2	*
2805	34.6	1.93	2.47	16.0	89.3
2815	37.4	1.90	2.49	18.3	98.3
2825	33.7	1.94	2.45	16.5	95.2
2835	*	*	*	16.8	*
2835-R	*	*	*	14.5	*
2845	36.6	1.89	2.44	17.8	91.5
2845-R	30.0	2.05	2.49	14.3	97.1
2855	35.7	1.90	2.51	15.4	82.4
2855-R	*	*	*	13.9	*
2865	33.2	1.94	2.45	15.9	93.1
2875	32.7	1.97	2.50	14.8	89.2
2875-B	*	*	*	13.9	*
2885	33.8	1.94	2.45	15.6	89.4
2885-B	*	*	*	15.1	*
2895	30.7	2.00	2.48	13.9	90.4
2895-R	28.2	2.06	2.50	13.1	96.2
2915	28.8	1.94	2.34	13.8	93.0
2935	33.3	1.89	2.39	16.3	92.8
2955	33.8	1.88	2.38	16.3	91.1
2975	32.7	1.94	2.44	15.3	91.0
2995	29.4	2.02	2.46	13.9	95.3
3015	31.3	1.96	2.50	12.7	79.7
3035	25.2	2.20	2.55	13.0	114.6
3045	35.0	2.00	2.54	17.3	98.6
3055	28.2	2.16	2.59	13.5	104.0
3065	33.9	2.00	2.54	16.1	95.0
Arithmetic mean, $\bar{X}$ -----	32.3	1.98	2.48	15.2	92.9
One standard deviation, s-----	± 2.9	± 0.08	± 0.06	± 1.5	± 6.8
Two standard errors of the mean, 2s ----- $\bar{X}$	± 1.4	± 0.032	± 0.028	± 0.6	± 2.8

Table 10.--Porosity, density, and water content of specimens, subunits A to E, Tunnel Bed 4, Oak Spring Formation, U12e tunnel, Rainier Mesa, Nye County, Nev.

The number following U12e- is numerically equal to the distance in feet from the portal of the U12e tunnel portal; L, left; all other specimens taken on right side of drift.

Lithologic data after McKeown and Dickey (1960, TEI-772, fig. 1). Descriptions in part from F. A. McKeown's field notes. Abbreviations: F, fine (grained); M, medium; C, coarse; VC, very coarse.

To convert weight percent of water (H_2O_{wt}) to weight-volume ratio (g/cc) multiply by natural-state bulk density (D_{bn}) and divide by 100.

Specimen number U12e-	Subunit	Porosity (P) (volume percent)	Natural-state bulk density (D_{bn}) (g/cc)	Grain density (D_g) (g/cc)	Water content (H_2O) (weight percent)	Percent saturation of pores (S)	Lithologic description (color is of dry specimen)
-3560	E	27.2	1.98	2.27	16.5	120.0	Red, F to M tuff.
-3550	E	30.3	2.00	2.40	16.6	110.5	Gray-red mottled M to C tuff.
-3548	E	30.5	1.96	2.34	16.9	108.6	Pinkish-gray, M to C tuff.
-3514	E	31.1	1.97	2.36	17.8	113.1	Pinkish-gray, M to VC tuff.
-3493	E	31.4	1.94	2.33	17.4	106.6	Light-yellow, M to C tuff.
-3460	E	33.8	1.96	2.45	17.2	100.0	Purplish-red granular tuff.
-3427	E	33.4	1.91	2.42	15.9	91.3	Purplish-red, M to C pumiceous tuff.
-3403L	E	33.3	1.94	2.44	15.9	92.2	Same as above.
Arithmetic mean, $\bar{X}$ --		31.4	1.96	2.38	16.8	105.3	
One standard deviation, s-----		± 2.2	± 0.03	± 0.06	± 0.7	± 10.1	
Two standard errors of the mean, $2s$ -- $\bar{X}$		± 1.6	± 0.020	± 0.044	± 0.5	± 7.8	
-3358	D	35.9	1.93	2.45	18.6	100.0	Light yellowish-gray, F to M tuff.
-3336	D	35.7	1.95	2.35	22.7	124.6	White hard salt and pepper tuff.
-3321	D	38.0	1.86	2.40	19.7	91.1	White hard granular tuff.
-3294	D	39.6	1.83	2.41	20.4	94.5	Light-purple granular tuff.
-3273	C	34.1	1.98	2.48	17.1	99.0	Purplish-red granular tuff.
-3237	C	36.1	1.95	2.46	19.6	106.1	Similar to above but less hard.
-3213	C	40.9	1.82	2.43	21.2	94.7	Light-purple granular pumice lapilli tuff.
-3192	B	28.2	2.04	2.50	12.5	90.4	Reddish-purple hard C tuff.
-3185	B	38.4	1.87	2.41	20.4	98.8	Light greenish-gray C pumiceous tuff.
-3178	B	43.3	1.80	2.39	24.9	103.8	Light greenish-gray C pumice lithic tuff.
-3173	A	35.5	1.89	2.41	17.6	93.4	Light-brown hard C lapilli tuff.
-3150	A	36.1	1.87	2.39	18.7	97.0	Light yellowish-gray C pumice lithic tuff.
-3121	A	35.0	1.87	2.36	18.6	100.0	As above.
-3088	A	40.7	1.79	2.39	21.2	93.4	Light-gray C pumice lapilli tuff.
Arithmetic mean, $\bar{X}$ --		37.0	1.89	2.42	19.5	99.1	
One standard deviation, s-----		± 3.7	± 0.07	± 0.04	± 2.9	± 8.6	
Two standard errors of the mean, $2s$ -- $\bar{X}$		± 1.7	± 0.04	± 0.024	± 1.6	± 4.8	

Table 11.--Porosity, density, and water content of specimens mainly obtained by core drilling with water, subunit F, Tunnel Bed 4, Oak Spring Formation, U12e tunnel, Rainier Mesa, Nye County, Nev.

The number following U12e- is numerically equal to the distance in feet from the U12e portal; R, L, right, left; the number following the plus sign is numerically equal to the height above the track. Descriptions in part from F. A. McKeown's field notes. Abbreviations: F, fine (grained); M, medium; C, coarse; VC, very coarse. Specimens marked with asterisk (*) were obtained with a portable core drill, utilizing water. To convert weight percent of water (H_2O_{wt}) to weight-volume ratio (g/cc) multiply by natural-state bulk density (D_{bn}) and divide by 100.⁷

Specimen number U12e-	Porosity (P) (volume percent)	Natural-state bulk density (D_{bn}) (g/cc)	Grain density (D_g) (g/cc)	Water content (H_2O) (weight percent)	Percent saturation of pores (S)	Lithologic description (color is of dry specimen)
3800L +6.0	44.2	1.77	2.40	24.4	98.4	Yellowish-gray, F to M tuff.
*3784R +6.0	38.8	1.86	2.40	20.7	99.6	Light yellowish-gray, F to M tuff.
*3784R +3.5	45.3	1.82	2.41	24.6	95.0	Salt and pepper, VC tuff.
*3784R +3.0	38.0	1.90	2.41	21.4	107.0	Pink C pumiceous tuff.
*3784R +1.0	41.5	1.82	2.40	23.3	102.6	Light yellowish-gray C pumiceous tuff.
*3732R +3.5	41.1	1.86	2.44	22.6	102.8	Yellowish-gray M to C tuff.
*3732R +2.5	35.0	1.97	2.46	19.0	107.3	Vermilion marker tuff.
3639L +6.5	32.0	1.92	2.28	19.5	117.3	Yellowish-gray and pink, M to C tuff.
*3639L +3.5	36.8	1.91	2.39	21.2	110.2	Yellowish-gray M to C tuff.
*3639L +3.0	31.8	1.89	2.28	18.2	109.2	Red marker tuff.
*3623L +6.5	36.1	1.86	2.34	20.0	103.3	Light yellowish-gray C tuff.
*3623L +3.5	40.3	1.90	2.41	24.4	115.3	Light yellowish-gray, VC tuff.
3562	42.8	1.78	2.35	24.9	103.8	White granular tuff.
Arithmetic mean, $\bar{X}$ -----	38.7	1.87	2.38	21.9	105.5	
One standard deviation, s-	± 4.3	± 0.05	± 0.05	± 2.3	± 6.7	
Two standard errors of the mean, $2s$ ---- $\bar{X}$	± 2.4	± 0.03	± 0.03	± 1.3	± 3.8	

Table 12.--Porosity, density, and water content of specimens of subunit F, Tunnel Bed 4, Oak Spring Formation, U12e.04 and U12e.04p tunnels, Rainier Mesa, Nye County, Nev.

The number following the hyphen is numerically equal to the distance in feet from the entrance of U12e.04 or U12e.04p tunnels, except -E41 and -E42, which were collected at the blast percussion pocket about 450 feet from the entrance of U12e.04. Descriptions in part from F. A. McKeown's field notes. Abbreviations: F, fine (grained); M, medium; C, coarse. Specimens 04p-190 and 04-E42 are averaged and treated as one sample in statistical summary. To convert weight percent of water (H_2O_{wt}) to weight-volume ratio (g/cc) multiply by natural-state bulk density (D_{bn}) and divide by 100.

Specimen number U12e-	Porosity (P) (volume percent)	Natural-state bulk density (D_{bn}) (g/cc)	Grain density (D_g) (g/cc)	Water content (H_2O) (weight percent)	Percent saturation of pores (S)	Lithologic description (color is of dry specimen)
04-890	46.7	1.73	2.42	25.7	95.5	Light-gray, M, salt and pepper tuff.
04-889	44.1	1.81	2.45	24.6	101.2	Light-gray, M, salt and pepper tuff.
04-894	35.5	1.93	2.42	19.5	106.5	Vermilion marker tuff.
04-903	41.1	1.85	2.45	22.3	101.0	Light-gray, M to C, salt and pepper tuff.
04p-186	34.4	1.91	2.37	18.3	101.8	Light yellowish-gray, C, salt and pepper tuff.
04p-189	35.1	1.89	2.38	18.2	98.6	Light yellowish-gray, C, pumice lapilli tuff.
04p-190	(38.1)	(1.87)	(2.42)	(19.8)	(97.2)	Red marker bed.
04-E42	(34.8)	(1.96)	(2.44)	(19.0)	(106.9)	Red marker bed.
04-E41	34.1	1.86	2.37	16.6	89.6	White C tuff.
Arithmetic mean, $\bar{X}$ -----	38.4	1.86	2.41	20.6	99.5	
One standard deviation, s---±	4.9	±.07	±.02	±3.3	±5.1	
Two standard errors of the mean, $2s_{\bar{X}}$ -----±	3.4	±.05	±.014	±2.4	±3.6	

STRATIGRAPHIC
GROUPING AND
TUNNEL LOCATION

Subunit F,
Tunnel Bed 4
UI2e, UI2e.04
and UI2e.04p

POROSITY

GRAIN DENSITY

NATURAL STATE BULK DENSITY

WATER CONTENT

WATER SATURATION OF PORES

Subunit E,
Tunnel Bed 4
UI2e (main
tunnel)

Subunits A-D,
Tunnel Bed 4
UI2e

Subunit D
Tunnel Bed 3
UI2e

Subunit D
Tunnel Bed 3
UI2e.05

Subunits B & C
Tunnel Bed 3
UI2e.05

Subunit A,
Tunnel Bed 3
UI2e.0
UI2e.05

Tunnel Bed 2
UI2e

Tunnel Bed 1
UI2e

Explanation of symbols: n, number of specimens in histogram; $\bar{X}$, arithmetic mean; $2s_{\bar{x}}$, two standard errors of the mean; s, one standard deviation; $2s$, two standard deviations

Figure 3. Histograms and related statistical parameters of porosity, density and water content in the lower part of the Oak Spring Formation, UI2e tunnel system, Rainier Mesa, Nye County, Nevada