LA-7900-PR
Progress Report

Research and Development Related to the Nevada Nuclear Waste Storage Investigations

January 1—March 31, 1979

MASTER

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
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This report was prepared by the Los Alamos Scientific Laboratory as part of the Nevada Nuclear Waste Storage Investigations managed by the Nevada Operations Office of the US Department of Energy. Based upon their applicability to the investigation, some results from the Radionuclide Migration Project, managed by the Nevada Operations Office of the US Department of Energy, are included in this report.

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Compiled by

Bruce M. Crowe

RESEARCH AND DEVELOPMENT RELATED TO THE NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS

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ABSTRACT

The results of research and program development related to the Nevada Nuclear Waste Storage Investigations is presented for Subtasks 3, 2, and 5. Batch sorption measurements have been completed for selected core samples obtained from exploration drill hole UE25A#1. In general, sorptive properties of the cores are highly favorable for the isotopes studied. Work with tuff is continuing in the areas of crushed rock column studies, sorption ratio studies of U(VI), batch measurements of sorption of ^{241}Am and ^{239}Pu, and microautoradiographic work. Petrologic characterization of core samples from drill hole UE25A#1 is completed; x-ray diffraction analyses are in progress. Field investigations of the basalts of Crater Flat are in progress. Areas of investigation include determination of the eruptive history and structural setting of volcanic centers, determination of magnetic polarity and basalt petrology (petrography and microprobe studies of mineral phases). Quality assurance procedures and work plans were processed for G-6 and CNC-11 programs. Requirements for a quality assurance program for the U.S. Geological Survey are being evaluated.

I. YUCCA MOUNTAIN INVESTIGATIONS: (Subtask 3.2.2)

A. Geochemical Studies (CNC-11)

Batch sorption measurements on Yucca Mountain cores YM22, YM38, YM45, YM49, and YM54, described in LA-7647-PR, have been completed. Preliminary results are given in the attached report (Appendix A). In general, the sorptive properties of the six Yucca Mountain cores were highly favorable for the isotopes studied: ^{85}Sr, ^{137}Cs, ^{133}Ce, and ^{152}Eu, with a "low" Sr value (50-83% sorbed) obtained for YM22 and YM54. A comparison of calculated R_d values for 20- and 40-day sorption times showed an average increase in R_d at 40 days (for all isotopes studied) of 45% for YM49, 15% for YM22, and 70% for YM48. YM45 and YM54 showed no change, and YM38 decreased 28%, although sorption ratios for YM38 remained in the very high (for Sr, Cs, and Ba) and high (for Ce and Eu) categories.

Preliminary results indicate that there is little variation in R_d between the two size fractions studied (<106 and 106-500μm) except for cores YM48 and YM38, where values for Sr, Cs, and Ba decreased an average of 60% and 40% respectively. Perhaps a major sorbing component in these two fractions was particularly fine grained (devitrification products?) and therefore was not ground and separated with the smaller fraction. Petrographic analysis of the ground samples may provide an explanation.

Desorption experiments of 20 and 40 days have been completed. Counting data however, for the samples is still being obtained and preliminary results are not yet available. Samples from 40-day sorption measurements of ^{99}Tc and/or ^{95m}Tc in concentrations ranged from 10^{-3}M to 10^{-12}M on YM22, YM48, and YM49 are also being counted.

Crushed rock (∿36 + 0104μm) column studies with JA32, YM38, YM54, and YM22 are in progress. ^{85}Sr was added to columns of YM38 and JA32 and ^{85}Sr, ^{137}Cs, and ^{133}Ba were added to YM54 and YM22. The columns are 0.5-cm diameter and 2- to 4.5-cm long. After 70 days no activity has been eluted from YM38, while >96% ^{85}Sr was eluted from JA32 in ∿30 days. Two additional JA32 columns were prepared for comparison. In one, ^{85}Sr was added in a 10 μl spike, as for the first JA32 column, but the activity was eluted at a slower flow rate (0.083 ml/h compared with 0.131 ml/h used for the first column) in an upward flow path. With the third JA32 column, ^{85}Sr was added to 100 ml of pre-equilibrated JA32 water and, by gravity flow, was eluted through the column. Data comparing the three types of columns are being analyzed. Column volumes have been determined by elution with both ^{131}I and HTO. YM54 and YM22 columns are being analyzed. Column volumes have been determined by elution with both ^{131}I and HTO. YM54 and YM22 columns are still running and the eluants are being counted with a GE(Li) detector.

Cation exchange capacities for Sr and Cs on Yucca Mountain cores were run. The devitrified tuffs have low values; those containing zeolites have high values.

Surface area measurements using the glycol method are complete. The 106-500 μm fractions of the Yucca Mountain tuffs were measured. No correlation of surface area with mineralogy has yet been determined.

Sorption ratio studies of U(VI) on Jackass Flats tuffs at 70°C are in progress. Calculations are not complete, but indications are that the ratios are higher at 70°C than at ambient temperature.

Work has continued on the batch measurements of the sorption of ^{241}Am and ^{239}Pu on three lithologic types of tuff from hole J-13 in Jackass Flats. Crushed tuff samples which had sorbed activity were dissolved so that ^{239}Pu analyses could be performed; analyses are in progress on these solutions and on the corresponding aqueous phases. Preliminary results for ^{239}Pu indicate sorption ratios (R_d) between 100 and 300 ml/g at ambient temperatures. Four-week desorptions have been completed for 14 crushed tuff samples from the sorption experiments. Counting of the ^{241}Am is in progress; the rock fractions will be dissolved for ^{239}Pu analyses.

Batch experiments to investigate the effect of large changes in the Pu concentration have been completed. Three portions of tuff JA-18 using the 106-150 μm particle size were contacted with pre-equilibrated J-13 water which had been tagged with ^{237}Pu. The Pu concentration was $\sim 2 \times 10^{-13}$ $\underline{M}$, contrasted to $\sim 1 \times 10^{-6}$ $\underline{M}$ for the experiments with ^{239}Pu. Samples were analyzed after contact periods of two, four, and eight weeks. Samples were subjected to desorption for two weeks. The average R_d for sorption was ~150 ml/g, while for desorption it was ~400 ml/g. The preliminary results for ^{239}Pu on tuff sample JA-18 give a sorption ratio of ~140 ml/g. The $\sim 10^7$ change in Pu concentration appears to have caused no recognizable change in the measured R_d value.

Earlier results indicated a difference in sorption when the traced feed solution was prepared by pH readjustment (for a single solution). Consequently, rather than drying the tracer, another set of batch experiments using ^{237}Pu and ^{241}Am feed solutions prepared by pH readjustment has been started. There is evidence for the presence of particulates in both Pu and Am solutions, so some experiments examining the effect of filtering the solutions after contact are being performed. Early results indicate that filtering through a 0.4-μm polycarbonate membrane removes activity from such solutions even after they have been centrifuged four times for one hour at 12 000 rpm, so that sorption ratios for Am and Pu calculated from after-filtering data are significantly higher than from before-filtering data.

Equipment for use in the study of solid- and cracked-rock core columns has been assembled and tested. Cores are 5/8-inch high by 1-inch in diameter. A preliminary study using a cracked granite core (porous flow ∿0) and ^{85}Sr tracer is in progress. The effective porosity (free column volume) of a J-13 tuff core (JA-35) was measured using this apparatus. Three separate measurements gave values of 23.3, 24.7, and 23.9% for an average of 24.0%.

Earlier microautoradiographic work suggested that removal of ^{241}Am from solution may be influenced by parameters other than those normally monitored in the laboratory (pH, ionic composition, etc.). Sorption of ^{241}Am on thin sections of tuff, granite, and argillite was investigated in atmospheres of CO_2, O_2, and N_2. For sorption times of 2.5 hours no effects attributable to the different atmosphere were observed.

B. Mineralogical-Petrological Studies (G-6)

Petrologic characterization of core samples from the Yucca Mountain exploratory drill hole (UE25A#1) is completed. The samples have been characterized by using techniques of petrographic description, modal point counts, and electron microprobe analysis of glass and mineral phases. X-ray diffraction analyses, primarily of authigenic mineral phases, are currently in progress. The analyzed samples include welded and nonwelded ash-flow deposits of the Paintbrush and Crater Flat Tuffs and bedded and reworked tuff (Fig. 1). No lavas or soils were noted in the drill hole section. Brief sample descriptions are given in the attached tables (Appendix B). Authigenic mineral phases present in the core samples include feldspar and silica minerals (cristobolite, tridymite and quartz). Zeolite mineral phases include heulandite(?) which occurs as fracture filling in the vitrophyric zone of dense welding of the Topopah Spring Member and heulandite and clinoptilolite present in core samples from the tuffaceous beds of Calico Hills and Crater Flat Tuff.

II. VOLCANIC HAZARD INVESTIGATIONS: Activity 2.5.1 (G-6)

Field investigations of the basalts of Crater Flat, a series of late Pliocene and Quaternary age basalt cinder cones present within and adjacent to Crater Flat, is progressing. The distribution of vent areas define two structural settings: (1) a northeast trending arc within central Crater Flat and (2) north-south trending vents that appear to follow basin-range fault trends. Individual basaltic centers consist of one to several coalesced cinder cones

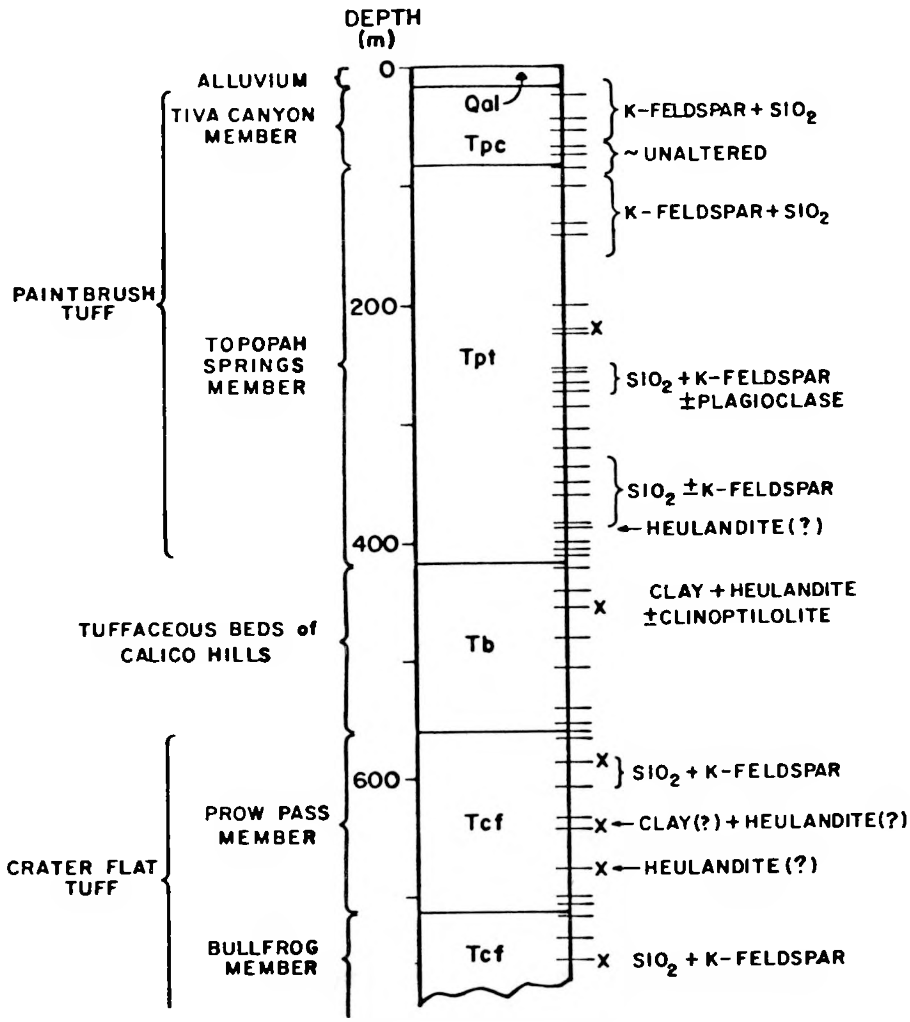

Fig. 1.

Predominant Alteration Phases in Yucca Mountain Tuff.

flanked and generally surrounded by associated lava flows. The north-south trending basalt centers, with the exception of the Lathrop Wells cone, are deeply dissected by erosion and feeder dike systems are exposed.

Magnetic polarity, using a fluxgate magnetometer, has been determined for all the basalt centers to supplement K-Ar age dating. The volcanic centers are all reversely magnetized with the exception of the Lathrop Wells center (normal) and a lava flow exposed in the basal section of the volcanic section exposed east of Red Cone (normal).

The basaltic volcanic cones comprise two petrographic types: (1) Aphyric olivine basalt containing olivine phenocrysts and rare plagioclase phenocrysts and (2) Porphyritic pyroxene-olivine basalt with phenocrysts of olivine (altered to iddingsite), plagioclase and glomeroporphyritic clots containing augite and lesser amounts of hypersthene. Electron microprobe studies of the basalts are in progress.

III. QUALITY ASSURANCE: (CMB-QA)

Six quality assurance procedures and work plans were developed, issued, and implemented: (1) NTS Core Petrography, (2) X-ray Diffraction Analysis, (3) Sample Preparation Laboratory Procedures, (4) Tuff Experiments-Mineralogy and Petrography Studies by G-6, (5) Geologic Investigations, and (6) Volcanic-Tectonic Investigations. Two procedures were revised, issued, and implemented: "Tuff Experiments-Sorption Coefficients and Migration Measurements, Group CNC-11," and "Document Control." Implementation of the quality assurance program and surveillance activities continue.

LASL QA personnel met with USGS personnel on January 29, 30, and 31 to discuss requirements for a quality assurance program for USGS. LASL QA personnel completed a rough draft of the USGS Quality Assurance Program and discussed the draft with USGS personnel in Denver on March 1, 1979. Unit Task Procedure drafts are to be prepared by USGS and will be discussed on April 2 in Denver. Target date for a preliminary Quality Assurance Program Plan for USGS is May 22, 1979. Target date for final issuance is September 15, 1979.

IV. PUBLICATIONS

1. G. H. Heiken and M. L. Bevier, "Petrology of Tuff Units from the J-13 Drill Site, Jackass Flats, Nevada," Los Alamos Scientific Laboratory report LA-7563-MS (February, 1979).

2. B. R. Erdal, R. D. Aguilar, B. P. Bayhurst, W. R. Daniels, C. J. Duffy, F. O. Lawrence, S. Maestas, P. Q. Oliver, and K. Wolfsberg, "Sorption-Desorption Studies on Granite," Los Alamos Scientific Laboratory report LA-7456-MS (February, 1979).

3. A. R. Lappin and B. R. Crowe, "Status of Evaluation of Tuffs in Southern Nevada for Waste Disposal," in the proceedings of 19th Annual ASME Symposium on Geological Disposal of Nuclear Waste, March 16-19, 1979, University of New Mexico.

4. B. M. Crowe and K. Sargent, "Major-Element Geochemistry of the Silent Canyon-Black Mountain Peralkaline Volcanic Centers: Applications to Volcanic Hazard Assessment of the NTS Region": to be published as a U.S. Geological Survey Technical Report.

V. ACKNOWLEDGMENTS

The following people contributed to this report:

B. P. Bayhurst, S. DeVilliers, W. R. Daniels, F. O. Lawrence, E. N. Vine, K. Wolfsberg, B. R. Erdal, L. Lanham, J. R. Smyth, M. Sykes, G. H. Heiken, B. M. Crowe, F. Goff, P. L. Bussolini, and R. J. Romero.

APPENDIX A

STATUS REPORT - SORPTIVE PROPERTIES OF YUCCA MOUNTAIN TUFF

by

E. N. Vine, S. J. DeVilliers, B. P. Bayhurst, and K. Wolfsberg

Sorption ratios are being determined for five tuff samples from hole UE25A#1 on Yucca Mountain. Our assessment of the sorptive properties of tuff based on earlier work and the preliminary results of this work continues to be very favorable. However, the relationship between sorption ratios and mineralogy is not as clear as had been thought.

The experimental methods are similar to those used for the determination of sorption ratios for tuff from hole J-13.[1] Because particle size effects were small in that study, a larger particle size range, 106 to 500 μm, was used in this work. Contact times for sorption at ambient temperature were 20 and 40 days. Descriptions of the Yucca Mountain hole samples (YM) are given in Table A-I. The descriptions and results from the earlier work with Jackass Flats hole J-13 samples (JA) are included. The descriptions and comments are from Sykes and Heiken.[2] The average sorption ratios for Sr, Cs, Ba, Ce, and Eu are given in Table A-II. In general, sorption ratios for the YM samples increase with increasing contact times as they do for the JA samples. For simplification, sorption ratios are classified from very low to very high according to Table A-III, and the sorption ratios are expressed in terms of the classification in Table A-IV. Cation exchange capacities are given in Table A-V.

Since sorption ratios are good for some samples that are not highly zeolitized, alteration to zeolites or clays may not be a necessary condition for high sorption ratios of tuff. Likewise, devitrified tuffs have high sorption ratios. Sample YM-38 contains only a small amount of zeolites and no glass, but exhibits very good sorptive properties.

On the basis of work with sample JA-32 it had been thought that microgranite-like tuff samples would exhibit generally low sorption ratios. This seems to be true for Sr, Cs, and Ba which probably sorb by ion-exchange mechanisms. However, the microgranite-like tuffs from Yucca Mountain exhibit significantly higher sorption ratios for Ce and Eu than JA-32. All of this type of samples have low cation exchange capacities.

The relationship between mineralogy of tuff and sorption ratios will be examined in more detail when the characterization of the samples is completed.

REFERENCES

1. M. L. Sykes and G. H. Heiken, "Status Report - Yucca Mountain Core Analysis," March 1979.

2. K. Wolfsberg, B. P. Bayhurst, B. M. Crowe, W. R. Daniels, B. R. Erdal, F. O. Lawrence, A. E. Norris, and J. R. Smyth, "Sorption-Desorption Studies on Tuff. I. Initial Studies with Samples from the J-13 Drill Site, Jackass Flats, Nevada," Los Alamos Scientific Laboratory Report LA-7480-MS, in preparation.

TABLE A-I

DESCRIPTION OF TUFF SAMPLES

SAMPLE[A]	MEMBER	DESCRIPTION	COMMENTS
YM-22	Topopah Springs	Denseley welded, devitrified ash flow tuff; depth, 259 m.	Completely devitrified; mineralogically similar to microgranite.
YM-38	Tuffaceous Beads of Calico Hills	Non-welded, devitrified bedded tuff; depth, 459 m.	Completely devitrified; some zeolite.
YM-45	Prow Pass	Welded, devitrified ash flow tuff; depth, 588 m.	Like YM-22.
YM-48	Prow Pass	Slightly welded, vitric ash flow tuff, depth, 644 m.	Partly devitrified; some zeolite.
YM-49	Prow Pass	Non-welded devitrified tuff; depth, 677 m.	Completely devitrified; high zeolite.
YM-54	Bullfrog	Welded, devitrified ash flow tuff; depth, 759 m.	Like YM-22; no zeolite.
JA-18	Topopah Springs	Densely welded, vitric ash flow tuff; depth, 433 m.	Fresh glass; some zeolite.
JA-32	Bullfrog	Partially welded, devitrified ash flow tuff; depth, 772 m.	Like YM-22.
JA-37	Unknown	Partially welded, zeolitized ash flow tuff; depth, 1066 m.	No glass; high zeolite.

[A] YM samples from hole UE25A#1; JA samples from hole J-13.

TABLE A-II

AVERAGE SORPTION RATIOS (ML/G)

SAMPLE	CLASSIFICATION	Sr	Cs	Ba	Ce	Eu
YM-22	Microgranite	50	290	950	1 090	1 320
YM-38	Devitrified	14 200	10 000	79 100	770	2 060
YM-45	Microgranite	104	250	860	535	1 300
YM-48	Some zeolite	2 150	18 600	17 500	1 380	1 910
YM-49	High zeolite	3 240	32 600	42 400	685	1 260
YM-54	Microgranite	84	240	670	135	410
JA-18	Vitric	13 000	6 000	5 000	40	30
JA-32	Microgranite	55	150	440	80	90
JA-37	High zeolite	300	740	850	--	6 000

TABLE A-III

CLASSIFICATION OF SORPTION RATIOS

CLASSIFICATION	R_D (ML/G)	% SORBED[A]
Very low	0-20	0-50
Low	20-100	50-83
Intermediate	100-600	83-97
High	600-10 000	97-99.8
Very high	>10 000	>99.8

[A]On 1 G solid from 20 ML solution.

TABLE A-IV

SORPTIVE PROPERTIES OF TUFF

		Sr	Cs	Ba	Ce	Eu
YM-22	Microgranite	Low	Inter.	High	High	High
YM-38	Devitrified	V. High	V. High	V. High	High	High
YM-45	Microgranite	Inter.	Inter.	High	Inter.	High
YM-48	Some zeolite	High	V. High	V. High	High	High
YM-49	High zeolite	High	V. High	V. High	High	High
YM-54	Microgranite	Low	Inter.	High	Inter.	Inter.
JA-18	Vitric	V. High	High	High	Low	Low
JA-32	Microgranite	Low	Inter.	Inter.	Low	Low
JA-37	High zeolite	Inter.	High	High	---	High

TABLE A-V

CATION EXCHANGE CAPACITIES

SAMPLE	CLASSIFICATION	Meq/100 G Sr	Meq/100 G Cs
YM-22	Microgranite	3	2
YM-38	Devitrified	54	109
YM-45	Microgranite	6	6
YM-48	Some zeolite	21	51
YM-49	High zeolite	27	107
YM-54	Microgranite	4	4
JA-18	Vitric	16	77
JA-32	Microgranite	2	2
JA-37	High zeolite	45	18

APPENDIX B

Petrography of Yucca Mountain Drill Hole UE25A#1 (Preliminary)*

SAMPLE NUMBER	UNIT	DEPTH (m)	BRIEF PETROGRAPHIC DESCRIPTION	HABIT AND SIZE OF PREDOMINANT AUTHIGENIC[a] PHASES	COMPOSITIONS[b] OF PREDOMINANT AUTHIGENIC PHASES	COMMENTS
YM-1	Tiva Canyon member, Paintbrush Tuff	25.5	Densely welded[c] vitric[d] tuff. 3.3%[e] phenocrysts (AF, Fe-oxide). 60% matrix[f]. Completely altered; devitrification and minor vapor phase crystallization.	Fibrous 1-2 μm (matrix). Euhedral tabular 50-400 μm (vugs).	AF + SiO_2	none
YM-2	"	48.0	Welded vitric tuff. 3.6% phenocrysts (AF, PL, SPH, HB, Fe-oxide). 43.0% matrix. Completely altered; devitrification and vapor phase crystallization.	Fibrous 1-2 μm (matrix). Euhedral tabular 50-400 μm (vugs).	AF + SiO_2	none
YM-3	"	57.0	Partly welded vitric tuff. 4.6% phenocrysts (AF, SPH). 63.0% matrix. Altered; devitrification.	Fibrous 1-2 μm (matrix). Fibrous 500 μm (pumice)	AF + SiO_2	none
YM-4	"	69.0	Nonwelded crystal vitric tuff. 13.9% phenocrysts (PL, BT, Fe-oxide, AF, HB). 36.9% matrix. Partly altered (large shards glassy); devitrification.	Hydrated glass (?) (shards). Fibrous <1-2 μm (shard boundaries).	N. A.	none
YM-5	"Bedded tuff"	76.5	Nonwelded vitric crystal tuff. 10.9% phenocrysts (PL,BT,AF,Fe-oxide). 4.3% lithic fragments. Partly altered, devitrification.	N. A.	N. A.	Pumice-rich (36%)
YM-6	Topopah Springs member, Paintbrush Tuff	84.3	Densely welded crystal vitric tuff. 16.8% phenocrysts (AF,PL,OPX,BT, Fe-oxide). 56.0% matrix; unaltered.	N. A.	N. A.	none
YM-7	"	102.0	Densely welded vitric crystal tuff. 17.2% phenocrysts (AF,Fe-oxide,CPX, BT). 46.6% matrix. Completely altered; devitrification and vapor phase crystallization.	Fibrous to granular 1-2 μm (matrix). Fibrous <250 μm (vugs).	AF + SiO_2	none
YM-8	"	137.2	Densely welded vitric tuff. 3.1% phenocrysts (AF,Fe-oxide,BT). 81.4% matrix. Completely altered; devitrification, minor vapor phase crystallization, incipient lithophysae.	Fibrous 1-2 μm (matrix).	N. D.	irregular rounded patches of authigenic SiO_2
YM-9	"	143.0	Densely welded vitric tuff. 2.0% phenocrysts (AF,PL,Fe-oxide)/65.0% matrix. Completely altered, devitrification, lithophysae, minor vapor phase crystallization.	Fibrous 1-2 μm (matrix). Tabular euhedral 100-200 μm (vugs).	AF + SiO_2	none
YM-20	"	206.4	Partly welded vitric lithic tuff. 1.4% phenocrysts (PL,AF,Q,BT). 71.8% matrix. Completely altered, devitrification, minor vapor phase crystallization, incipient lithophysae.	Fibrous 1-2 μm (matrix). Tabular euhedral 100-200 μm (vugs)	N. D.	none

YM-21	Topopah Springs member, Paintbrush Tuff	223.3	Moderately welded vitric tuff. 2.0% phenocrysts (PL,Fe-oxide,BT,Q). 82.7% matrix. Completely altered; devitrification, lithophysae, minor vapor phase crystallization.	Fibrous 70-100 µm (matrix). Granular 50-100 µm (mosaics).	N.D.	pumice bounded by spherulites
YM-17	"	226.8	Moderately welded vitric tuff. 2.0% phenocrysts (PL,BT,AF), 67.7% matrix. Completely altered, devitrification and minor vapor phase crystallization.	Fibrous to granular 2-100 µm (matrix). Tabular euhedral <100 µm (vugs).	N.D.	pumice-rich (37%)
YM-18	"	254.8	Densely welded vitric tuff. 1.6% phenocrysts (PL, AF, Fe-oxide). 65.5% matrix. Completely altered; devitrification and vapor phase crystallization.	Fibrous to granular 2-100 µm (matrix). Tabular euhedral <100 µm (vugs).	SiO_2 + AF + PL	en echelon fractures parallel to fabric filled with SiO_2
YM-22	"	258.5	Densely welded vitric tuff. 1.0% phenocrysts (PL, AMP). 59.5% matrix. Completely altered; devitrification and vapor phase crystallization.	Fibrous 1-3 µm (matrix). Granular <300 µm (vugs).	N.D.	en echelon fractures parallel to fabric filled with SiO_2
YM-19	"	267.9	Densely welded vitric tuff. 2.7% phenocrysts (AF, Fe-oxide, PL). 72.2% matrix. Completely altered; devitrification, minor vapor phase crystallization, incipient lithophysae	Fibrous 2-6 µm (matrix). Fibrous to spherulitic 10-50 µm (pumice). Tabular euhedral 70 µm (vugs).	AF + SiO_2	none
YM-23	"	272.5	Densely welded vitric tuff. 0.8% phenocrysts (PL, AF, Fe-oxide, Q, BT). 52.6% matrix. Completely altered; devitrification, vapor phase crystallization, incipient lithophysae.	Fibrous 1 µm (matrix). Tabular euhedral 100 µm (vugs).	N.D.	none
YM-27	"	339.1	Densely welded vitric tuff. 1.0% phenocrysts (PL, AF, Q). 67.3% matrix. Completely altered. Devitrification and vapor phase crystallization.	Granular 5-20 µm (matrix). Anhedral <200 µm (mosaics). Spherulites.	SiO_2	en echelon fractures parallel to fabric filled with SiO_2
YM-28	"	351.3	Densely welded vitric tuff. 1.7% phenocrysts (PL, Q, AF). 65.2% matrix. Completely altered; devitrification and vapor phase crystallization.	Granular 5-20 µm (matrix). Anhedral equant 200 µm (mosaics). Spherulites (around mosaics).	SiO_2 + AF	en echelon fractures parallel to fabric filled with SiO_2
YM-29	"	364.3	Densely welded vitric lithic tuff. 1.0% phenocrysts (AF, PL, HB, Fe-oxide) 61.2% matrix. Completely altered; devitrification and vapor phase crystallization.	Fibrous to granular 5-10 µm (matrix). Fibrous to spherulitic <300 µm (around mosaics)	AF + SiO_2	en echelon fractures parallel to fabric filled with SiO_2

APPENDIX B (Cont'd.)

YM-30	Topopah Springs member, Paintbrush Tuff	385.4	Densely welded vitric lithic tuff. (vitrophyre) 2.1% phenocrysts (Q, PL, AF, BT). 60.7% matrix. Completely altered, devitrification and minor vapor phase crystallization.	Spherulites 150 μm (pumice). Fibrous orange (shards).	AF (matrix)	branching fractures cross cutting fabric filled with a zeolite (?) (heulandite ?)
YM-31	"	389.9	Densely welded vitric tuff (perlitic vitrophyre). 0.6% phenocrysts (PL, AF, Fe-oxide). Altered, incipient devitrification and hydration (?).	Granular high b.f. <1 μm (perlitic fractures).	N.D.	none
YM-36	'Bedded tuff' of Calico Hills	422.0	Nonwelded vitric tuff. Nonvesicular glass clasts and pumice. Altered, incipient devitrification and hydration (?).	Fibrous high b.f. <6 μm (vug rims). Euhedral tabular <80 μm (vugs).	N.D.	glass clasts have perlitic cracks
YM-37	"	446.7	Slightly welded vitric tuff. 2.4% phenocrysts (PL, AF, Q, BT). 44% matrix. Completely altered, devitrification and secondary (?) mineralization.	Hydrated glass. Wedge-shaped 10-30 μm (vugs). Fibrous high b.f. <1 μm (vug rims).	N.D.	Lithic fragments (5.6%) consist of older welded tuffs.
YM-38	"	458.7	Nonwelded lithic crystal tuff. Perlitic clasts and numerous lithic fragments. Phenocrysts: PL, AF, Q. Completely altered; devitrification and secondary (?) mineralization.	Fibrous high b.f. <1 μm (cement). Granular 4-8 μm (cement). Granular 3-6 μm (clasts). Fibrous medium b.f. 1-3 μm (clasts). Tabular euhedral <80 μm (vugs).	Clay (?) (matrix)	the euhedral phase occurring in vugs may be a zeolite (??) (heulandite??).
YM-40	"	508.1	Nonwelded vitric tuff. 1.4% phenocrysts (PL,AF,Q). 43% matrix. Altered, incipient devitrification and minor vapor phase crystallization.	Fibrous <1-5 μm (matrix). Tabular euhedral 5-25 μm (vugs).	N.D.	none
YM-45	Prow Pass member, Crater Flat Tuff	588.4	Welded vitric crystal tuff. 13.5% phenocrysts (AF,PL,BT). 64.4% matrix. Completely altered, devitrification and vapor phase (?) crystallization.	Granular 1-25 μm (matrix and pumice). Fibrous 5-10 μm and 20-50 μm (matrix and pumice). Tabular euhedral <200 μm (pumice).	SiO_2 + AF	none
YM-48	"	644.3	Slightly welded vitric tuff. 8.0% phenocrysts (PL,AF,Q,PX,AMP,Fe-oxide). 39.1% matrix. Partly altered (shards are glassy); devitrification.	Granular <1-8 μm (matrix). Fibrous 3-5 μm (shard rims).	zeolite (heulandite?) in fractures	randomly oriented fractures occasionally filled with low b.f. phase or medium b.f. phase

APPENDIX B (Cont'd.)

YM-49	Prow Pass member, Crater Flat Tuff	676.8	Nonwelded vitric tuff. 7.4% phenocrysts (PL,AF,Q,Fe-oxide,BT). Completely altered. Incipient devitrification, vapor phase crystallization (?) and secondary mineralization (?).	Granular <1-5 μm (matrix). Granular medium b.f. <1 μm (shard rims). Fibrous 10-15 μm (shards). Tabular euhedral 15-25 μm (vugs).	zeolite (heulandite?) in both vugs and matrix	none
YM-54	Bull Frog member, Crater Flat Tuff	759.3	Welded crystal vitric tuff. 17.8% phenocrysts (AF,Q,PL,BT,Fe-oxide). 80.5% matrix. Completely altered; coarse grained devitrification and vapor phase (?) crystallization.	Granular 2-20 μm (matrix). Granular <150-200 μm (mosaics). Fibrous <5 μm (vug rims).	SiO_2 + AF	occasional clots of former mafic pheno/glomerocrysts now altered to a high b.f. micaceous phase and Fe-oxides.

*Notes to APPENDIX B

Abbreviations:

AF	alkali feldspar	PX	pyroxene
AMP	amphibole	Q	quartz
BT	biotite	SPH	sphene
CPX	clinopyroxene	b.f.	birefringence
OPX	orthopyroxene	N.A.	not applicable
PL	plagioclase	N.D.	not yet determined

a. 'Authigenic' is used to describe phases which may be a result of vapor phase crystallization, devitrification, and/or ground-water alteration.

b. Compositions of authigenic phases are obtained from microprobe analyses. The tentative identification of zeolites in YM-30, 38, 48, and 49 is based on low analytical totals, and appropriate Si/(Al + Fe) ratios and cation compositions. This identification will not be considered positive until verified by X-ray diffraction analysis.

c. Degree of welding is based on visual estimates of shard/pumice compaction and deformation.

d. The modifiers 'vitric,' 'crystal,' and 'lithic' are used according to the classification scheme of Cook (1965).

e. Percents given are volume percents based on modal analyses of more than 300 points. Phenocrysts and authigenic phases are listed in order of decreasing abundance.

f. 'Matrix' is used for the finer grained fraction of the sample, generally shards and fine ash or their alteration products.