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ZONAL FEATURES OF AN ASH-FLOW SHEET IN THE PIAPI CANYON FORMATION, SOUTHERN NEVADA

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Abstract.—Chemical analyses from devitrified, lithophysal, and vapor-phase zones of an ash-flow sheet in southern Nevada, newly named the Yucca Mountain Member, indicate limited compositional variation. Nonwelded vitric tuff at the edges of the ash-flow sheet differs appreciably in composition from crystallized tuff because of incipient secondary alteration of metastable glass shards.

In the vicinity of the southwestern part of the Nevada Test Site (fig. 1) a previously undescribed sheet of nonwelded to densely welded ash-flow tuff wedges into the Piapi Canyon Formation. The Piapi Canyon Formation has been dated by the potassium-argon method as about 13 million years old, near the Miocene-Pliocene boundary (R. Kistler, written communication, 1963). As originally described the Piapi Canyon Formation comprises 5 members, of which 4 are ash-flow sheets—in ascending order, the Stockade Wash, Topopah Spring, Tiva Canyon, and Rainier Mesa Members (Poole and McKeown, 1962). The fifth member, the Survey Butte, consists of lithologically distinctive ash-fall tuffs into which the three lower ash-flow sheets wedge out. The newly recognized sheet occurs immediately below the Tiva Canyon Member and conformably overlies a thick sequence of bedded tuffs correlative with the Survey Butte Member. In accordance with previous designation of major ash-flow sheets of the Piapi Canyon Formation as members, the newly described sheet is here named the Yucca Mountain Member. The northwest end of the mesalike part of Yucca Mountain in the Topopah Spring 15-minute quadrangle is designated the type locality because the member is best exposed there and because all its zones are represented.

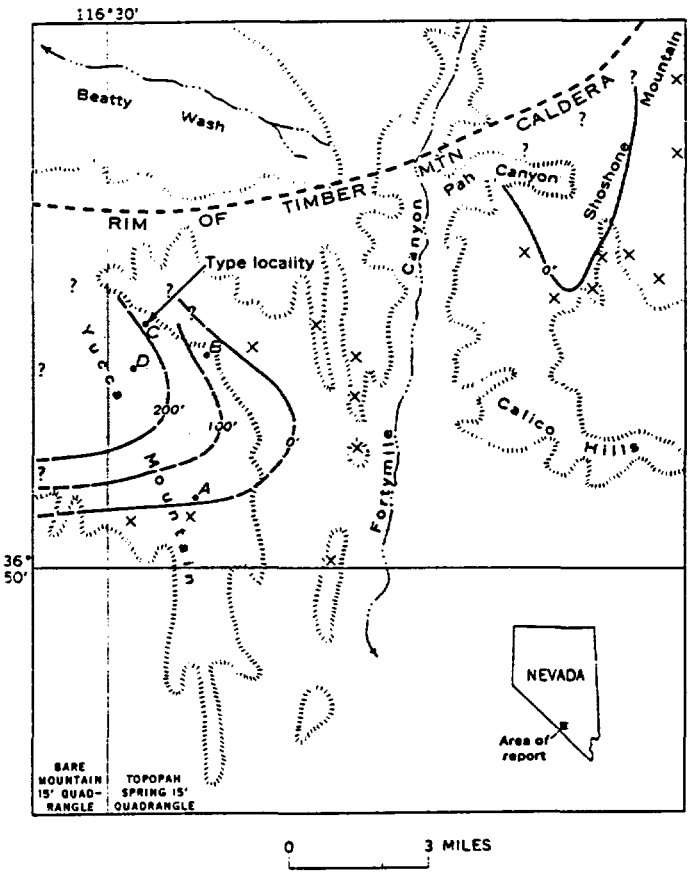

FIGURE 1.—Map of the southwestern part of the Nevada Test Site and vicinity, showing areal extent (stippled), thickness, and type locality of the Yucca Mountain Member of the Piapi Canyon Formation. Isopachs show approximate thickness; contour interval is 100 feet. ×, outcrop at which Yucca Mountain Member is absent. *A*, *B*, *C*, *D*, locations of measured sections that are shown on figure 2.

Outcrops of the Yucca Mountain Member are confined to about 20 square miles near the type locality and 5 square miles near Pah Canyon; the unit appears to have a more limited areal extent than other members of the Piapi Canyon Formation. From a maximum thickness of 250 feet near the type locality the sheet thins to the east and south. It underlies the entire west-central part of the Topopah Spring 15-minute quadrangle, and its depositional edge can be located almost continuously around the east and south sides of Yucca Mountain (fig. 1). The original distribution of the sheet has not been satisfactorily reconstructed to the north or west because of erosion, faulting, and cover by younger rocks. About 100 feet of the unit is present east of Fortymile Canyon, at Pah Canyon, and the depositional edge of the sheet has been mapped 2½ miles south of that locality. Adequate exposures demonstrate that the sheet was not deposited between Yucca Mountain and Pah Canyon, and that the two outcrop areas apparently represent the southeastern ends of separate lobes of an ash-flow sheet which originated to the north and northwest.

PETROLOGIC DESCRIPTION

The Yucca Mountain Member before welding and crystallization was a distinctively uniform shard tuff containing only very small amounts of pumice, phenocrysts, and lithic inclusions. The original character of the tuff can be determined by examination of the nonwelded glassy margins of the ash-flow sheet. Refractive indices of unaltered glass shards average about 1.50. The phenocryst content of the tuff, mainly alkali feldspar and some oligoclase, is constant at about 1 percent. Quartz and mafic minerals are scarce. Pumice typically makes up 3 to 4 percent of the tuff but increases in abundance toward the edges of the ash-flow sheet, where it locally makes up as much as 10 percent. A few small grayish-red aphanitic lithic inclusions are present. The abundance of these constituents does not vary significantly in vertical sections of the sheet. This uniformity contrasts with other major ash-flow sheets of the Piapi Canyon Formation, especially the Topopah Spring and Tiva Canyon Members, in which pumice and phenocrysts increase in abundance upward in vertical sections. Tuffs of the Yucca Mountain Member closely resemble crystal-poor pumice-poor lower parts of the Topopah Spring and Tiva Canyon Members.

Although relict shard textures and the proportions of pumice, phenocrysts, and lithic inclusions demonstrate initial vertical and lateral uniformity of the Yucca Mountain Member, differential welding and crystallization during cooling produced a variety of rocks that differ in color, density, crystallinity, and other physical properties. These variations are zonal in character and show a consistent pattern throughout the exposed part of the ash-flow sheet. Such zonal variations in welded ash flows have been discussed recently by Smith (1960). Smith's concepts of welding and crystallization zones, although based on extensive field observations, were presented as hypothetical models. The Yucca Mountain Member provides a particularly fine example to illustrate Smith's concepts because of its uniform simple composition, its uncomplicated cooling history, and because the distal end of the sheet, rarely preserved in prehistoric ash flows (Smith, 1960, p. 150), is well exposed in several places.

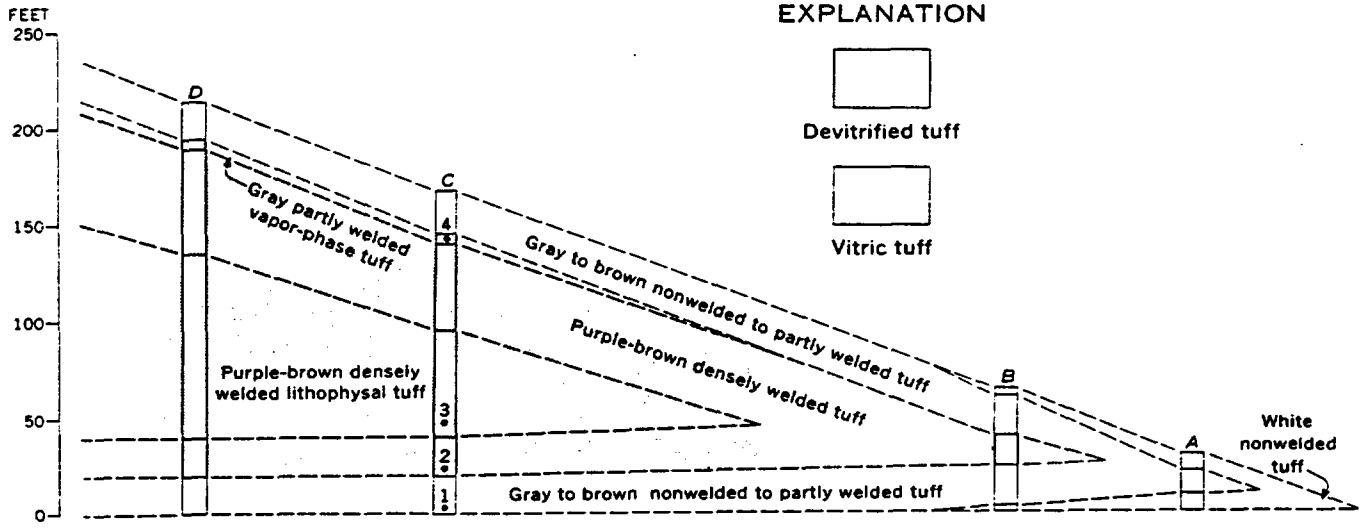

FIGURE 2.—Diagrammatic longitudinal cross section showing measured sections of the Yucca Mountain Member and schematic zonal variations of the ash-flow sheet. Numbers in section C indicate positions of analyzed samples (tables 1 and 2). Locations of sections shown on figure 1. The sections are plotted in order of decreasing distance from the distal edge of the sheet in such a manner as to emphasize the wedgelike character of the separate zones.

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In Smith's terminology, the Yucca Mountain Member is a simple cooling unit. The sheet is wedge shaped in cross section (fig. 2) and on a large scale can be divided into a nonwelded to welded glassy envelope enclosing a welded devitrified core. Where the devitrified core is thickest and most densely welded, it contains an inner zone characterized by lithophysal cavities (see Smith, 1960, pl. 21L).

Most of the glassy part of the Yucca Mountain Member is nonwelded. Where the sheet is less than about 50 feet thick, the outermost part of the nonwelded zone is white to pink tuff that grades inward into gray tuff with the inception of welding. The gray tuff owes its color to magnetite crystallites, and the pink color of the peripheral tuff probably resulted from oxidation of magnetite to hematite where the outer part of the ash-flow sheet was in contact with air during cooling. Where the sheet is thicker, either nonwelded or incipiently welded gray tuff extends to the base of the sheet, and underlying ash-fall and reworked tuffs are reddened to a depth of 6 to 10 inches indicating baking by the overlying ash-flow sheet. The nonwelded vitric shard tuffs of the Yucca Mountain Member appear unaltered in hand specimen, and the shards are transparent in thin section. Fine-grained dusty material is present around the edges of the shards, however, and X-ray analysis indicates that this material is a calcic montmorillonitic clay constituting 5 to 10 percent of the glassy tuffs.

The transition from nonwelded to partly welded tuff, marked by the first recognizable deformation of shards or compaction of pumice (Smith, 1960, p. 151), is approximately coincident with a change in color from gray to orange brown or red brown. The partly welded rock commonly forms bluffs and has imperfect columnar jointing. In the area studied, devitrification extended into the zone of partial welding, and no vitrophyre zone was formed. In most places the boundary between glassy and devitrified tuff is abrupt and can be located within a few inches. The boundary between zones of partial and dense welding, being within the zone of devitrification, cannot be precisely located because the primary porosity has been obscured by crystallization. The devitrified zone typically is composed of dense purple-brown welded tuff with closely spaced platy or semiconchoidal fractures subparallel to the eutaxitic foliation. X-ray examination shows that the devitrified rock consists mainly of alkali feldspar and cristobalite.

Where the Yucca Mountain Member is thickest, the devitrified zone contains in its center a distinctive subzone characterized by lithophysal crystallization in roughly spherical to lenticular gas cavities. These cavities are as much as 5 cm in diameter and may produce as much as 25 percent bulk porosity. The lithophysal minerals are mainly alkali feldspar and tridymite.

The zone of partial welding near the top of the sheet is thin and shows evidence of vapor-phase crystallization. This vapor-phase zone is inconspicuous, mainly because drusy crystallization of alkali feldspar and tridymite in the cavities of pumice fragments, the most distinctive feature of the zone (Smith, 1960, p. 156), was limited by the scarcity of pumice in the Yucca Mountain Member. Tuff of the vapor-phase zone is pale gray, in contrast to the brownish colors of welded tuff from the main part of the devitrified zone.

CHEMICAL AND SPECTROGRAPHIC ANALYSES

Some writers (for example, Smith, 1960, p. 156) have suggested that different crystallization zones which have developed in an initially homogeneous tuff might have chemical variations as a result of volatile transfer during crystallization. The possibility of such chemical variation in the Yucca Mountain Member resulting from devitrification, formation of lithophysae, or vapor-phase crystallization was tested by a series of chemical and semiquantitative spectrographic analyses. The Yucca Mountain ash-flow sheet is in certain respects a nearly ideal unit for such a study; it is quite homogeneous in composition and has a very low content of crystals and lithic inclusions throughout. A bulk analysis approximates the composition of the glass shards. Analyses were made of samples of four lithologic zones collected from a single vertical section of the Yucca Mountain Member, as follows: (1) the basal nonwelded glassy gray shard zone, (2) the densely welded devitrified zone, (3) the lithophysal zone, and (4) the vapor-phase zone. Positions of the analyzed samples are shown in figure 2. Chemical and semiquantitative spectrographic analyses are given in table 1. For direct comparison of the cationic constituents of the four zones, the chemical analyses have been recalculated free of water and calcite and are presented in table 2 as cation percentages.

The cation percentages of the four zones sampled indicate, for the most part, strikingly little variation. Silicon averages 71.4 percent of the cations with a max-

TABLE 1.—*Chemical and spectrographic analyses of ash-flow tuffs of the Yucca Mountain Member*

[Analyses given in weight percent; numbers in boxheads refer to locations shown on fig. 2; sample numbers in parentheses]

Component	1 Nonwelded vitric zone (62L-50o)[1]	2 Densely welded devitrified zone (62L-50q)	3 Lithophysal zone (62L-50qq)	4 Vapor-phase zone (62L-50y)
Chemical analyses:[2]				
SiO_2	71.5	76.0	75.4	76.4
TiO_2	.14	.13	.14	.15
Al_2O_3	12.6	13.0	12.3	12.7
Fe_2O_3	.80	.81	.82	.94
FeO	.14	.17	.16	.03
MnO	.10	.12	.12	.10
MgO	.86	.20	.30	.07
CaO	.41	.12	.32	.18
Na_2O	2.8	4.3	4.0	4.2
K_2O	4.8	4.7	4.6	4.6
H_2O_{total}	5.6	.68	.93	.40
CO_2	.10	<.05	.19	<.05
P_2O_5	.02	.02	.02	.03
Total	99.9	100.3	99.3	99.9
Spectrographic analyses:[3 4]				
Ba	0.01	0.01	0.01	0.01
Be	.0005	.0007	.0007	.0005
Cu	.0003	.0003	.0003	.0005
Ga	.003	.003	.003	.003
La	.003	.003	.003	.003
Mo	.001	.001	.001	.001
Nb	.002	.003	.003	.002
Pb	.005	.005	.003	.005
Sr	.005	.003	.003	.002
V	.001	.001	.002	0
Y	.003	.003	.003	.003
Yb	.0003	.0003	.0003	.0003
Zr	.02	.02	.02	.02
Powder density	2.39	2.45	2.54	2.51

[1] Refractive index of glass from the nonwelded vitric zone = 1.498±0.001.
[2] By rapid methods (Shapiro and Brannock, 1962) by P. Elmore, S. Botts, G. Chloe, L. Artis, and H. Smith.
[3] By J. C. Hamilton. Results reported to the nearest number in the series 0.02, 0.015, 0.01, 0.007, 0.005, 0.003, 0.002, 0.0015, 0.001, 0.0007, 0.0005, 0.0003, which represent approximate midpoints of group data on a geometric scale. Assigned group for semiquantitative results will include the quantitative value about 30 percent of the time.
[4] Other elements looked for but not found in any specimen: Ag, As, Au, B, Bi, Cd, Ce, Co, Cr, Eu, Ge, Hf, Hg, In, Li, Ni, Pd, Pr, Pt, Re, Sb, Sc, Sm, Sn, Ta, Te, Th, Tl, U, W, Zn.

imum deviation of only 0.6 percent of that value. Total iron is virtually constant within a range of 2.5 percent of the mean value of 0.70 cation percent. The minor constituents titanium, manganese, and phosphorus are practically constant for all four zones, and the trace constituents have no major variations. The Fe^{+2}/Fe_{total} ratio is almost constant in all except the sample from the vapor-phase zone, a relation which indicates considerable oxidation in that zone.

Of the remaining cations, all except possibly magnesium are constant within the limits of determinative error for the three crystallized zones, but they vary significantly between the glassy and crystalline rocks. It is notable that crystallization from a vapor phase, either in primary pore spaces of partly welded tuff or in the formation of lithophysae, has no measureable effect on the bulk composition of the rocks; only the local redistribution of major elements and the oxidation of iron in the vapor-phase zone appear to have been involved.

TABLE 2.—*Cation weight-percentage compositions of ash-flow tuffs of the Yucca Mountain Member*

[Numbers in boxheads refer to locations shown on fig. 2; sample numbers in parentheses]

Cation	1 Nonwelded vitric zone (62L-50o)	2 Densely welded devitrified zone (62L-50q)	3 Lithophysal zone (62L-50qq)	4 Vapor-phase zone (62L-50y)
Si	71.2	71.0	71.8	71.7
Ti	.10	.09	.10	.10
Al	14.8	14.3	13.8	14.0
Fe^{+3}	.60	.57	.58	.66
Fe^{+2}	.11	.13	.12	.02
Mn	.08	.09	.09	.08
Mg	1.27	.25	.42	.10
Ca	.33	.12	.13	.18
Na	5.4	7.8	7.4	7.6
K	6.0	5.6	5.6	5.5
P	.01	.01	.01	.02
Total	100.0	100.0	100.0	100.0
Fe_{total}	.71	.70	.70	.68
Fe^{+2}/Fe_{total}	.16	.18	.17	.03

The glassy tuff is higher in aluminum, magnesium, calcium, and potassium content and is much lower in sodium content than the crystallized rocks. Similar variations in several other paired analyses of glassy and devitrified ash-flow tuffs from the Piapi Canyon Formation indicate that these differences are not fortuitous (analyses 5 and 6 of Cornwall, 1962, table 2, are from the Tiva Canyon Member: other such analyses made by the U.S. Geological Survey and still unpublished have a similar pattern). The higher aluminum, magnesium, and calcium content of glassy tuff of the Yucca Mountain Member is explained by the presence of 5 to 10 percent calcic montmorillonitic clay coating glass shards as indicated by X-ray determination and optical estimates. The significance of the excess potassium in the glass is not entirely clear: possibly potassium has been added by base exchange within the glass. Although low sodium and high calcium content might indicate some base exchange between the clay mineral or the glass and ground water, only a small part of the sodium deficiency can be explained in this way. Considerable additional sodium would appear to have been leached from the metastable glass by percolating fluids. The noted presence of similar chemical patterns for other paired analyses indicates that leaching of sodium and formation of montmorillonitic clays may be common alteration features of rhyolitic glasses. Analyses

of even apparently fresh glasses should be regarded with some caution as representatives of an original magma.

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