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Gèology and physical properties of the near-surface rocks at Mesita de los Alamos, Los Alamos County, New Mexico

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Abstract

The surface of Mesita de los Alamos is formed by units 2b and 3 of the Tshirege Member of the Bandelier Tuff. These units dip gently east-southeastward at 3 to 6 degrees. The units are faulted near the center of the mesa by a north-south trending normal strike slip fault, that is downthrown about 14 feet to the east. The units east of the fault have moved about 14 feet south relative to the units on the west side of the fault.

Units 2b and 3 have bulk density values ranging from 80 to 120 pounds per cubic foot. The moisture content of the tuff below the soil zone and near surface tuff was less than 5 percent by volume in five of the 25 test holes drilled during a foundation investigation for the Meson Facility. The temperature of the tuff in the bottom of three test holes (depth 16 to 43 feet) varied from 50°F to 54°F. Temperature variations were a function of density and amount of solar radiation.

Introduction

The U.S. Geological Survey was requested by Engineering 1 of the Los Alamos Scientific Laboratory and the U.S. Atomic Energy Commission to make a geologic investigation of a part of Mesita de los Alamos, which, in turn, is a part of the Pajarito Plateau in Los Alamos County, New Mexico (fig. 1).

The Pajarito Plateau, formed by a series of ashflow and ashfalls of rhyolite tuff, is dissected into a number of "finger-like" mesas by eastward flowing intermittent streams that are tributary to the Rio Grande. Mesita de los Alamos is one of these finger-like mesas that is bounded on the north by Los Alamos Canyon and on the south by Sandia Canyon. The canyon floors are 200 to 400 feet below the surface of the mesa. There is a small east-west ridge along the northern edge of the mesa and the surface of the mesa slopes southward from the ridge at an altitude of about 7,035 feet to an altitude of about 6,920 feet along the southeastern edge of the mesa.

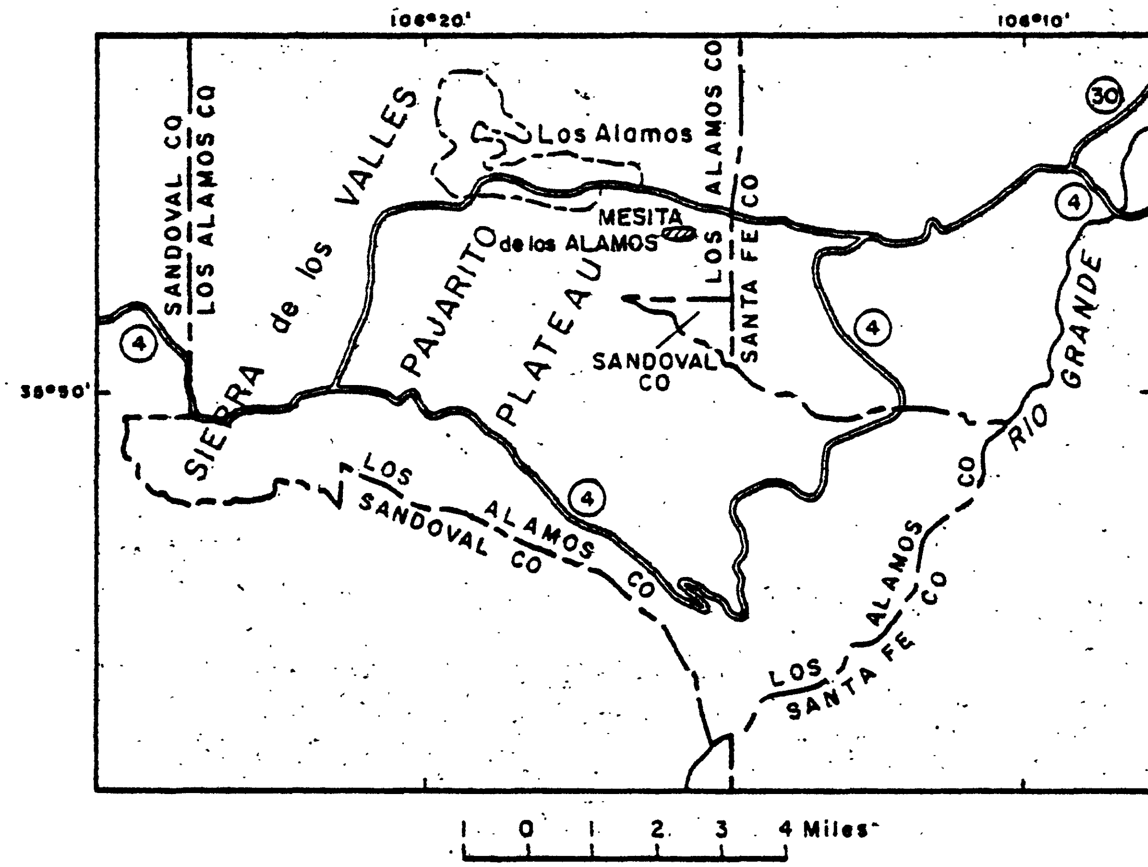

Figure 1.--Map of the Los Alamos area showing location of Mesita de los Alamos, Los Alamos County, New Mexico, and area of investigation.

The geologic investigation was to be made in conjunction with the drilling of 25 test holes by Albuquerque Testing Laboratory to determine the bearing capacities of the tuff. These data are necessary for the design of foundations for buildings of the Meson Facility which is to be constructed on the mesa. The major structure of the facility is the injector building to be built near test holes TH-1 and TH-2 (fig. 2). A tunnel formed of concrete and covered with crushed tuff will extend from near test hole TH-2 to TH-12 to the experimental building located between TH-12 and TH-14. The foundation of these structures is at an altitude of 6,970 feet above mean sea level. Most of the test holes in a line with these structures were drilled and tested to an altitude of 6,960 feet. In the eastern area of the proposed tunnel and experimental building area core recovery was poor or penetration tests indicated low bearing capacities; hence, the holes were bored to greater depths.

A geologic map and cross sections of the upper surface of the mesa were compiled. Temperature measurements were made in three of the test holes and continuous temperature recordings were made to a depth of 3 feet in two types of soil and in one type of the tuff. Moisture and density measurements were made along the walls of the test holes. Gamma ray and caliper logs were run in the test holes to aid in the stratigraphic correlation of the tuff.

Geology

Mesita de los Alamos is composed of the Bandelier Tuff of Pleistocene age. Underlying the Bandelier Tuff are rocks of the Santa Fe Group of middle(?) Miocene to Pleistocene(?) age. In this area the rocks of the Santa Fe Group are in ascending order the Tesuque Formation, the Puye Conglomerate and the basaltic rocks of Chino Mesa.

The Tesuque Formation is composed of siltstone and sandstones with some conglomerate and clay lenses. The formation exceeds a total thickness of 2,400 feet in the area. The Puye Conglomerate is composed of the Totavi Lentil a poorly consolidated channel fill deposit and an overlying fanglomerate member that is composed of volcanic debris. The fanglomerate member is interbedded with the basaltic rocks of Chino Mesa. The total thickness of the Puye Conglomerate and the basaltic rocks of Chino Mesa at well T-3 in Los Alamos Canyon immediately north of Mesita de los Alamos exceeds 640 feet. Detailed description of the geology of the Los Alamos area is presented by R. L. Griggs (1964).

Bandelier Tuff

The Bandelier Tuff overlies the fanglomerate member of the Puye Conglomerate and consists of ashfall and ashflow rocks that are draped over older rocks, filling the lows and initially forming a smoother surface than that on the older rocks. The Bandelier Tuff is composed of three members. In ascending order they are: the Guaje Member, an ashfall pumice about 35 feet thick, found in the subsurface at Mesita de los Alamos; the Otowi Member, a friable ashflow that is about 235 feet thick and that is partly exposed in the lower wall of Los Alamos Canyon adjacent to Mesita de los Alamos; and the Tshirege Member, a series of ashflow tuffs which cap Mesita de los Alamos. Only units of the Tshirege Member were studied in this investigation.

Tshirege Member

The Tshirege Member is composed of a series of ashflows of rhyolite tuff which contain quartz and sanidine crystals and crystal fragments, some mafic minerals and rock fragments of pumice, rhyolite, and latite in a fine ash matrix. The ashflows vary from a nonwelded to a welded tuff (Purtymun and Koopman, 1965). The Tshirege Member is about 300 feet thick under the ridge at Mesita de los Alamos. Five units of the Tshirege Member described by Baltz and others (1963) are present at Mesita de los Alamos. They are units 1a, 1b, 2a, 2b, and 3. Brief descriptions are given of these five units.

Units 1a and 1b- The lower part of the Tshirege Member consistsof two ledge-forming layers of pumiceous tuff breccia that are similar in lithology, but are slightly different in color and weathering characteristics. The lower layer is unit 1a which is a massive orange-weathering pumiceous tuff breccia forming a near vertical cliff above the alluvium in Sandia Canyon. It contains pumice fragments ranging from ½ inch to 6 inches in longest dimension with small fragments of obsidian and rhyolite in a fine glassy ash matrix. The weathered outer 1 to 3 inches of tuff is cased hardened which protects the unweathered rock from erosion. The thickness of unit 1a varies because of the irregular erosion surface at the top of the Otowi Member on which it rests; it may be as much as 80 feet thick near the center of the mesa, based on log of well T-3.

Unit 1b rests conformably on unit 1a and weathers to a dull grayish-brown. It is a tuff breccia with a fine-grained pink ash matrix similar to the underlying unit 1a; however, the pumice fragments are smaller and 15 to 20 percent of the material consists of granule-sized quartz-crystal fragments and fragments of dense volcanic rocks. Unit 1b is slightly less resistant to erosion than the unit 1a and forms a ledge set back from the lower unit. At some places both layers form a near vertical cliff. At these places the units can be distinguished by a soft bed of pumice at the base of the upper unit which weathers to a persistent notch in the cliffs. The thickness is fairly uniform ranging from 21 to 23 feet along the southern edge of Mesita de los Alamos (fig. 3).

Units 2a and 2b- The lower unit 2a is a light-gray pumiceous tuff. It consists of moderately welded pumiceous ash containing fragments of pumice, dense rhyolite, and latite fragments as much as 3 inches in length. The unit weathers to a dull gray with rind of case hardening several inches thick at the surface. It forms a steep smooth slope set back from unit 1 and is separated from the overlying unit 2b by an erosional unconformity. The thickness ranges from 47 to 51 feet along the southern edge of the mesa (fig. 3).

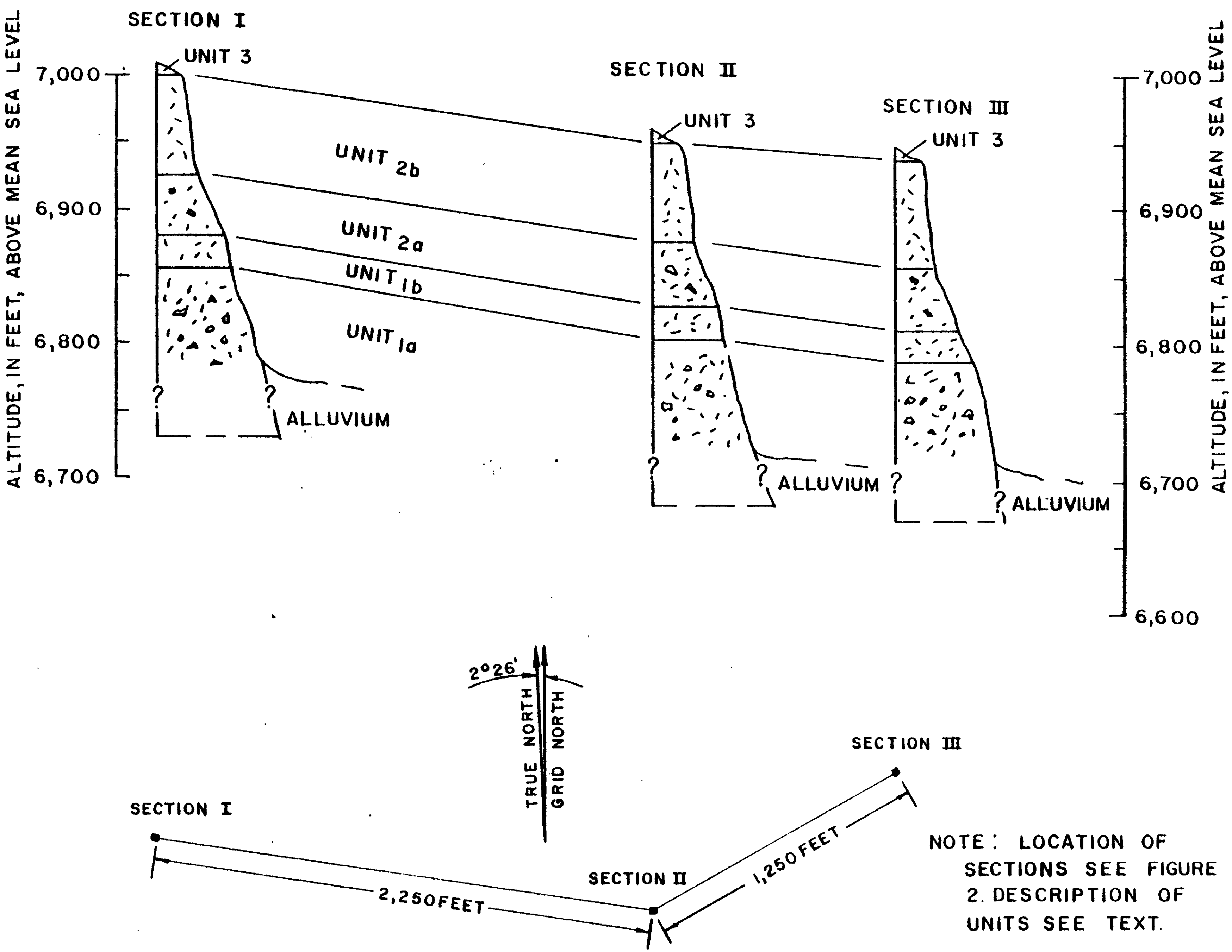

FIGURE 3.- STRATIGRAPHIC SECTIONS OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF AT MESITA DE LOS ALAMOS.

The overlying unit 2b is a light pink to brown-weathering moderately welded tuff composed of quartz and sanidine crystals and fragments in a matrix of light-pinkish fine-grained ash. Some rock fragments of pumice and latite are as much as ½-inch in length. The unit is resistant to erosion and forms ledges and benches above the steep rounded slopes of basal unit 2a. The unit ranges from 76 to 83 feet thick along the southern edge of the mesa where it forms the uppermost rim of Sandia Canyon. Along Los Alamos Canyon unit 2b forms a bench along the Canyon wall. Unit 2b underlies the proposed foundation of the Injector building and tunnel in the western part of the mesa.

Unit 3.—The upper unit 3 rests conformably on unit 2b and grades downward into it. Unit 3 consists mainly of light-gray, light-tan, and white nonwelded to moderately welded pumiceous tuff breccia. The rock is composed of fine pumice fragments and glassy shards, and contains numerous layers of pebble- and cobble-sized pumice fragments and some gray dense rhyolite. Most of the unit is relatively soft and has eroded to form smooth round slopes with a rind of case hardened material several inches thick at the weathered surface.

The unit has eroded away along the southern and extreme eastern edges of the mesa (fig. 2). The thickest section of unit 3 occurs near the center of the east-west trending ridge along the northern edge of the mesa where it is about 75 feet thick. This unit forms the foundation of the tunnel and experimental building in the eastern part of the area.

Structure

The units of the Tshirege Member of the Bandelier Tuff dip gently eastward at Mesita de los Alamos. Units 2b and 3 form the upper part of the mesa dipping 4 to 6 degrees toward the east-southeast.

Unit 2b outcrops at TH-1 and TH-2. The dip of the unit causes the contact between unit 2b and 3 to cross the foundation elevation between TH-7 and TH-8. Thus, due to the dip of the two units, west of TH-7 the foundation of the buildings and tunnel will be in unit 2b while east of TH-7 the foundation will be in unit 3 (fig. 2).

The units 2b and 3 are broken by a normal strike slip fault between TH-8 and TH-9 (fig. 2). The units on the east have moved down about 14 feet relative to the units west of the fault. Slickensides gouge in the fault zone indicate the units on the east have moved about 14 feet south relative to the units west of the fault. Surface expression of the fault is a gouge zone 6 to 18 inches wide that stands 2 to 3 feet above the land surface for a distance of about 20 feet along the southern flank of the east-west trending ridge. The gouge zone consists of a reddish tuff that has been welded by the movement, thus forming a more competent rock than unit 3 which forms the ridge. Along the crest of the ridge the gouge zone narrows and is eroded level with the land surface. The attitude of the fault plane is near vertical as indicated by the remnants of the gouge zone in Los Alamos Canyon.

The cause of the fault is unknown. It may be due to compaction of the underlying members of the Bandelier Tuff as the upper units of the Tshirege Member were laid down or it may be related to the tectonic forces that formed the Rio Grande depression.

The numerous joints in units 2b and 3 probably are tension joints formed during the cooling of the ashflows. The most prominent and numerous joints are nearly vertical and are either slightly open or closed. Near surface joints are filled with clay and weathering products of the tuff.

Physical characteristics of the Tshirege Member

Physical characteristics of units 2b and 3 were investigated by geophysical methods as these units will support the foundation of the structures of the Meson Facility. The physical characteristics of these units differ in the degree of welding and in amount and size of the rock fragment inclusions. Unit 2b is a moderately welded tuff (porosity range from 30 to 50 percent by volume) with rock inclusions of latite and pumice that are generally less than ½ inch in length. Unit 3 is a nonwelded to moderately welded tuff (porosity range from 30 to 60 percent by volume) with rock inclusions of latite that are generally less than 1 inch in length; pumice fragments may be as much as 2½ inches in length. In the nonwelded parts of unit 3 the tuff is quite soft and friable. Welding of the tuff of unit 2b has resulted in less pore space in the matrix and a denser tuff than in unit 3 which contains numerous large porous pumice fragments.

Density of the tuff

The density measurements of the units 2b and 3 were made by a density gauge manufactured by Nuclear Chicago. A probe emitting gamma rays was lowered into the test holes. Electric pulses from the probe were counted by a scaler at 5-foot depth intervals and were converted to densities.

The bulk density of the tuff of unit 2b as determined by density logging ranged from 100 to 120 lbs per cu ft (pounds per cubic foot) while the density of unit 3 ranged from 80 to 110 lbs per cu ft. Differential cooling of an ashflow unit will result in density changes of the unit in a vertical section (table 1). Rapid cooling of an ashflow or unit after emplacement will result in a more porous and pumiceous tuff at the upper and lower contacts.

Penetration test and bearing capacities determined from cores indicate that as the density of the tuff increases the bearing capacities increase (Purtymun and Koopman, 1965).

Table 1.--Density of the tuff in test holes TH-1, TH-7, and TH-11 as determined by density logging.

TH-1			TH-7			TH-11		
Depth (feet)	Unit of Tshirege Member	Density (lbs per cu ft)	Depth (feet)	Unit of Tshirege Member	Density (lbs per cu ft)	Depth (feet)	Unit of Tshirege Member	Density (lbs per cu ft)
3	2b	114	5	3	94	5	3	80
6	2b	112	10	3	105	10	3	97
9	2b	115	15	3	107	15	3	105
12	2b	113	20	3	105	20	3	105
15	2b	110	25	3	110	25	3	105
-	-	-	30	3	102	30	3	108
-	-	-	34	2b	110	35	3	105
-	-	-	39	2b	109	40	3	105
-	-	-	-	-	-	45	3	90
-	-	-	-	-	-	49	3	103

Moisture contents of tuff

The moisture contents of the bore walls of some test holes were determined with a neutron-scattering moisture probe manufactured by Nuclear Chicago Co. Pulses from the probe were counted with a portable scaler and converted to moisture content.

The moisture content of the tuff beneath the soil zone or near surface tuff in TH-1, TH-2, TH-3, TH-4, and TH-5 was below 5 percent by volume. The moisture content of the other holes was not determined because water was added during drilling. Measurements in 6 test holes drilled in January 1964 indicate that the moisture content of the tuff below foundation altitude was less than 5 percent by volume (written communication to C. R. Wherritt, Eng. 1, from W. D. Purtymun, USGS, February 5, 1964). Other studies in the distribution of moisture in the soil and tuff in the Los Alamos area indicate that the natural moisture content of the tuff beneath the mesas is generally less than 5 percent by volume in areas where the natural soil cover and drainage have not been disturbed (Abrahams and others, 1961).

Temperature

Test holes drilled into the tuff inhale and exhale air in response to atmospheric pressure changes. Plastic inflatable packers were implaced in the test holes to eliminate the effect of transient air movement during the measurement of temperatures of the borewalls. Standard laboratory thermometers were placed between the packers and borewalls at selected depth intervals. The thermometers were calibrated and placed in carriers which provided an oil reservoir around the bulbs with sufficient heat capacity to maintain constant temperature while they were being removed from the test holes. The temperatures of three test holes given in table 2 were measured by this technique.

The lower temperatures measured in TH-1 are due in part to the physical characteristics of the tuff. TH-1 is completed in unit 2b which is more dense and less permeable to air than unit 3 in TH-7 and TH-11. The tuff at TH-7 and TH-11 also receives more solar heat as they are on the south facing slope of the east-west ridge. The combination of higher permeability and higher solar radiation probably accounts for the slightly higher temperatures of the tuff. The cause of the 1 to 2 degree temperature increase of the tuff at depth in TH-7 and TH-11 is unknown.

Temperatures were recorded at 2-hour intervals at depths of 0.5 foot, 1 foot, 2 feet and 3 feet on the surface of the mesa in a sandy soil overlying the light gray pumice tuff of unit 3 (table 3), a clayey soil (table 4), and in the light gray pumice tuff of unit 3 (table 5). Concurrent air temperatures are also shown on each table. Daily temperature changes appear to affect the soil or tuff only to a depth of a foot. Daily temperature extremes in the fall and early spring probably extend slightly deeper.

Table 2.--Temperature gradients in the tuff in test holes TH-1, TH-7, and TH-11. (June, 1966)

TH-1		TH-7		TH-11	
Depth (feet)	Temperature (°F)	Depth (feet)	Temperature (°F)	Depth (feet)	Temperature (°F)
3	60	3	62	3	63
8	53	8	61	8	56
13	50	18	52	13	53
16	50	28	52	23	53
-	-	38	54	33	54
-	-	-	-	43	54

Table 3.--Air temperature and temperature at depth in a sandy soil and a pumiceous tuff (unit 3). (June 1-7, 1966)

Time	Air Temp. (°F)	Soil Temp. at 0.5 ft (°F)	Air Temp. (°F)	Soil Temp. at 1.0 ft (°F)	Air Temp. (°F)	Tuff Temp. at 2.0 ft (°F)	Air Temp. (°F)	Tuff Temp. at 3.0 ft (°F)
00:00	58	72	50	63	60	63	60	61
02:00	57	71	50	62	50	63	58	61
4:00	51	68	50	62	54	63	54	61
6:00	50	68	50	62	54	63	54	61
8:00	74	65	54	62	70	63	70	61
10:00	75	64	65	62	73	63	77	61
12:00	76	68	70	62	78	63	76	61
14:00	77	72	64	62	78	63	76	61
16:00	72	74	57	62	-	-	74	61
18:00	74	75	57	62	75	63	72	61
20:00	66	74	50	62	64	63	62	61
22:00	61	74	50	62	62	63	57	61

Table 4.--Air temperature and temperature at depth in a clay soil. (June 13-20, 1966)

Time	Air Temp. (°F)	Soil Temp. at 0.5 ft (°F)	Air Temp. (°F)	Soil Temp. at 1.0 ft (°F)	Air Temp. (°F)	Soil Temp. at 2.0 ft (°F)	Air Temp. (°F)	Soil Temp. at 3.0 ft (°F)
00:00	59	72	60	70	60	66	53	64
02:00	58	71	54	70	53	66	50	64
4:00	54	70	52	70	53	66	50	64
6:00	60	68	52	69	56	66	50	64
8:00	76	68	74	68	80	66	65	64
10:00	80	68	81	68	80	66	74	64
12:00	81	69	82	68	80	66	74	64
14:00	85	71	80	68	80	66	72	64
16:00	90	74	80	68	78	66	68	64
18:00	82	75	84	70	76	66	68	64
20:00	62	75	68	70	70	66	62	64
22:00	60	74	60	70	64	66	52	64

Table 5.--Air temperature and temperature at depth in a pumiceous tuff (unit 3). (June 7-13, 1966)

Time	Air Temp. (°F)	Tuff Temp. at 0.5 ft (°F)	Air Temp. (°F)	Tuff Temp. at 1.0 ft (°F)	Air Temp. (°F)	Tuff Temp. at 2.0 ft (°F)	Air Temp. (°F)	Tuff Temp. at 3.0 ft (°F)
00:00	60	67	56	66	44	61	58	60
02:00	54	65	54	66	44	61	59	60
4:00	51	62	53	65	44	61	58	60
6:00	48	60	50	64	45	61	52	60
8:00	53	60	54	64	48	61	58	60
10:00	64	60	62	62	54	61	68	60
12:00	72	61	66	62	58	61	76	60
14:00	80	62	72	62	66	61	78	60
16:00	85	68	-	-	73	62	88	60
18:00	84	70	79	64	66	62	84	60
20:00	72	71	72	65	61	62	74	60
22:00	64	70	58	66	52	62	64	60

Conclusions

The two geologic units 2b and 3 of the Tshirege Member of the Bandelier Tuff form the surface of the mesa at Mesita de los Alamos. The two units differ in physical characteristics due to different degrees of welding and the amount and size of pumice inclusions. Unit 2b is a more densely welded tuff than unit 3 and contains smaller particles and lesser amounts of pumice. Thus, unit 2b generally is a more competent tuff than unit 3.

The two units dip gently east-southeastward from 3 to 6 degrees so that unit 2b occurs below the foundation elevation (altitude 6,970 feet) west of a point between test hole TH-7 and TH-8 and unit 3 occurs below the foundation elevation to the east. The competent tuff of unit 2b occurs at greater depth eastward due to the eastward dip of the units and due to a north-south trending fault that is located between test holes TH-8 and TH-9. Movement on the fault has downthrown the units about 14 feet along the eastern side of the fault.

Density logging indicates that the density of unit 2b ranges from 100 to 120 lbs per cu ft and the density of unit 3 ranges from 80 to 110 lbs per cu ft. The variations in density are due to the degree of welding and differences of lithology and occur through a vertical section of the units.

The moisture content of the tuff below the weathered or soil zone is generally less than 5 percent by volume.

Seasonal changes in temperature affect the upper 8 to 13 feet of tuff. Below these depths the temperature of the tuff ranges from 50 to 54 degrees with the higher 2 to 4 degrees occurring in unit 3.

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